Modal Shift Comparative Analysis Technical Report

Comprehensive Truck Size and Weight Limits Study

June 2015

U.S. Department of Transportation

Federal Highway Administration

EXECUTIVE SUMMARY

Background

This report documents analyses conducted as part of the U.S. Department of Transportation (USDOT) *2014 Comprehensive Truck Size and Weight Limits Study* (2014 CTSW Study). As required by Section 32801 of MAP-21 [Moving Ahead for Progress in the 21st Century Act (P.L. 112-141)], Volumes I and II of the 2014 CTSW Study have been designed to meet the following legislative requirements:

- Subsection 32801 (a)(1): Analyze accident frequency and evaluate factors related to accident risk of vehicles to conduct a crash-based analyses, using data from states and limited data from fleets;
- Subsection 32801 (a)(2): Evaluate the impacts to the infrastructure in each State including the cost and benefits of the impacts in dollars; the percentage of trucks operating in excess of the Federal size and weight limits; and the ability of each state to recover impact costs;
- Subsection 32801 (a)(3): Evaluate the frequency of violations in excess of the Federal size and weight law and regulations, the cost of the enforcement of the law and regulations, and the effectiveness of the enforcement methods; Delivery of effective enforcement programs;
- Subsection 32801 (a)(4): Assess the impacts that vehicles have on bridges, including the impacts resulting from the number of bridge loadings; and
- Subsections 32801 (a)(5) and (6): Compare and contrast the potential safety and infrastructure impacts of the current Federal law and regulations regarding truck size and weight limits in relation to six-axle and other alternative configurations of tractor-trailers; and where available, safety records of foreign nations with truck size and weight limits and tractor-trailer configurations that differ from the Federal law and regulations. As part of this component of the study, estimate:

  (A) the extent to which freight would likely be diverted from other surface transportation modes to principal arterial routes and National Highway System intermodal connectors if alternative truck configuration is allowed to operate and the effect that any such diversion would have on other modes of transportation;

  (B) the effect that any such diversion would have on public safety, infrastructure, cost responsibilities, fuel efficiency, freight transportation costs, and the environment;

  (C) the effect on the transportation network of the United States that allowing alternative truck configuration to operate would have; and

  (D) the extent to which allowing alternative truck configuration to operate would result in an increase or decrease in the total number of trucks operating on principal arterial routes and National Highway System intermodal connectors.

To conduct the study, the USDOT, in conjunction with a group of independent stakeholders, identified six different vehicle configurations involving six-axle and other alternative configurations of tractor-trailer as specified in Subsection 32801 (a)(5), to assess the likely results of allowing widespread alternative truck configurations to operate on different highway networks. The six vehicle configurations were then used to develop the analytical scenarios for each of the five comparative analyses mandated by MAP-21. The use of these scenarios for each of the analyses in turn enabled the consistent comparison of analytical results for each of the six vehicle configurations identified for the overall study.

The results of this *2014 Comprehensive Truck Size and Weight Limits Study* (2014 CTSW Study) are presented in a series of technical reports. These include:

- *Volume I: Comprehensive Truck Size and Weight Limits Study – Technical Summary Report.* This document gives an overview of the legislation and the study project itself, provides background on the scenarios selected, explains the scope and general methodology used to obtain the results, and gives a summary of the findings.
- *Volume II: Comprehensive Truck Size and Weight Limits Study.* This volume comprises a set of the five comparative assessment documents that meet the technical requirements of the legislation as noted:
  - *Modal Shift Comparative Analysis* (Subsections 32801 (a)(5) and (6)).
  - *Pavement Comparative Analysis* (Section 32801 (a)(2)).
  - *Highway Safety and Truck Crash Comparative Analysis* (Subsection 32801 (a)(1)).
  - *Compliance Comparative Analysis* (Subsection 32801 (a)3)).
  - *Bridge Structure Comparative Analysis* (Subsection 32801 (a)(4)).

Purpose of the Modal Shift Analysis

The purpose of this *Volume II: Modal Shift Comparative Analysis* is to present the analysis of six truck size and weight policy options (scenarios) and to describe in detail the approach, data, models, limitations, and assumptions underlying estimates of potential modal shifts associated with the six scenarios analyzed in the US Department of Transportation (USDOT) *Comprehensive Truck Size and Weight Limits Study* (2014 CTSW Study). For this study, the term modal shift includes both shifts between truck and rail modes and shifts between vehicles and operating weights within the truck mode.

This *Volume II: Modal Shift Comparative Analysis* provides the foundation for assessing the full range of potential impacts associated with the truck size and weight scenarios analyzed in the 2014 CTSW Study. Changes in allowable vehicle weights and dimensions will influence the payloads that can be carried on different truck configurations, which in turn will affect:

- The total number of trips and miles of travel required to haul a given quantity of freight,
- The transportation mode chosen to haul different types of freight between different origins and destinations,
- The truck configurations and weights used to haul different types of commodities,
- The axle loadings to which pavements and bridges are subjected,
- Potential highway safety risks,
- The costs of enforcing Federal truck size and weight limits,

- Energy requirements to haul the Nation's freight,
- Emissions harmful to the environment and to public health,
- Traffic operations on different parts of the highway system,
- Total transportation and logistics costs to move freight by surface transportation modes,
- The productivity of different industries, and
- The competitiveness of different segments of the surface transportation industry.

Impacts are quantified to the greatest extent possible, but where data are unavailable to reliably quantify potential nationwide impacts, qualitative assessments of the impacts of changes in truck size and weight limits are discussed.

Approach

The USDOT study team began this modal shift analysis effort by conducting a desk scan to identify and evaluate potential analytical tools and data sources. A copy of the desk scan is included in **Appendix A** of this report. Researchers then developed a detailed project plan describing how the analysis would be conducted using analytical tools and data identified in the desk scan. This included estimating truck traffic currently operating within and above existing Federal truck size and weight regulations and specifying truck size and weight scenarios for analysis in the 2014 CTSW Study. USDOT, with stakeholder input, identified the basic vehicle configurations to be analyzed and developed the specifications for those vehicles and how they would operate. The team then developed a set of assumptions necessary for the modal shift analysis, including identifying limitations in the data and analytical methods that might affect the analysis. Finally, researchers estimated the modal shifts associated with each scenario using the analytical tools and data chosen for the analysis.

Current Truck Operations Within and Above Federal Weight Limits

Table ES-1 summarizes current truck traffic operating at weights within and above the 80,000 pound Federal gross vehicle weight (GVW) limit on the Interstate System, other National Highway System (NHS) routes, and highways off the NHS. For purposes of this 2014 CTSW Study, truck configurations are defined in terms of the number of trailers and the number of axles on the vehicle.

Table ES-1: Vehicle Miles of Travel by Vehicle Configuration and Highway System

Operating weight (thousand pounds)	2011 Vehicle Miles of Travel (millions)								
	Single semitrailers			Twin trailers			Triple trailers		
	Interstate	Other NHS	Non-NHS	Interstate	Other NHS	Non-NHS	Interstate	Other NHS	Non-NHS
< = 60	44,821	23,212	21,193	2,625	1,200	1,090	9	5	10
61-70	11,720	5,667	4,520	1433	540	484	9	4	10
71-80	15,522	7,483	5,978	813	419	388	15	8	17
81-90	4,540	2,199	1,848	327	213	249	19	10	22
91-100	867	430	405	171	130	184	13	7	15
101-110	314	161	162	151	124	171	7	3	8
111-120	149	75	75	111	92	114	3	2	4
121-130	72	37	36	91	71	86	1	1	2
>130	63	35	32	239	162	196	0	0	1
Total	78,068	39,299	34,248	5,961	2,951	2,962	76	39	88

There clearly is significant travel above the 80,000 pound Federal GVW limit that applies to Interstate Highways. Much of this travel is off the Interstate System, where State weight limits apply, but much also is on the Interstate System. Some such overweight Interstate System travel occurs in States with "grandfathered" weight limits over 80,000 pounds,[1] some is under non-divisible load permits, and some reflects illegal overloads.

Truck Size and Weight Scenarios

This report analyzes the potential modal shifts associated with six different truck size and weight policy options (scenarios). Each scenario involved estimating the impacts of variations in vehicle configurations and GVWs above the current 80,000 pound Federal weight limit. **Table ES-2** shows the vehicles assessed under each scenario as well as the current vehicle configuration from which most freight traffic would likely shift (the control vehicle).

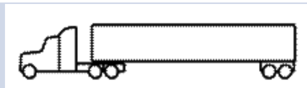
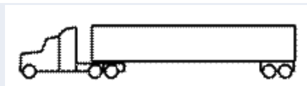
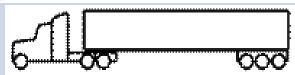
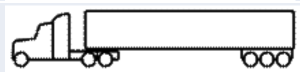
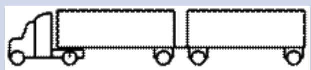
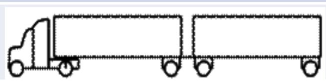
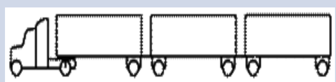
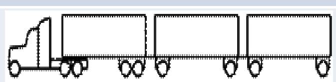
The first three scenarios assess tractor semitrailers that are heavier than generally allowed under currently Federal law. Scenario 1 assesses a five-axle (3-S2) tractor-semitrailer operating at a GVW of 88,000 pound, while Scenarios 2 and 3 assess six-axle (3-S3) tractor semitrailers operating at GVWs of 91,000 and 97,000 pounds, respectively. The control vehicle for these scenario vehicles is the five-axle tractor-semitrailer with a maximum GVW of 80,000 pounds. This is the most common vehicle configuration used in long-haul over-the-road operations and carries the same kinds of commodities expected to be carried in the scenario vehicles.

Scenarios 4, 5, and 6 examine vehicles that would serve primarily less-than-truckload (LTL) traffic that currently is carried predominantly in five-axle (3-S2) tractor-semitrailers and five - axle (2-S1-2) twin trailer combinations with 28 or 28.5-foot trailers and a maximum GVW of 80,000 pounds. Scenario 4 examines a five-axle (2-S1-2) double trailer combination with 33-foot trailers with a maximum GVW of 80,000 pounds. Scenarios 5 and 6 examine triple trailer combinations with 28.5-foot trailer lengths and maximum GVWs of 105,500 (2-S1-2-2) and 129,000 (3-S2-2-2) pounds, respectively. The five-axle twin trailer with 28.5-foot trailers (2-S1-2) is the control vehicle for Scenarios 4, 5, and 6 since it operates in much the same way as the scenario vehicles are expected to operate.

At this point it is important to note that while the control double has an approved GVW of 80,000 pounds, the GVW used for the control double in the study is 71,700 pounds based on data collected from weigh-in motion (WIM)-equipped weight and inspection facilities and is a more accurate representation of actual vehicle weights than the STAA authorized GVW. Using the WIM-derived GVW also allows for a more accurate representation of the impacts generated through the six scenarios.

[1] The Federal government began regulating truck size and weight in 1956 when the National Interstate and Defense Highways Act (Public Law 84-627), establishing the Interstate Highway System, was enacted. A state wishing to allow trucks with sizes and weights greater than the Federal limits was permitted to establish "grandfather" rights by submitting requests for exemption to the FHWA. During the 1960s and 1970s, most grandfather issues related to interpreting State laws in effect in 1956 were addressed, and so most grandfather rights have been in place for many decades. See USDOT *Comprehensive Truck Size and Weight Study, Volume 2*, "Chapter 2: Truck Size and Weight Limits – Evolution and Context," FHWA-PL-00-029 (Washington, DC: FHWA, 2000), p. II-9.

Table ES-2: Truck Configuration and Weight Scenarios Analyzed in the 2014 CTSW Study

Scenario	Configuration	Depiction of Vehicle	# Trailers or Semi-trailers	# Axles	Gross Vehicle Weight (pounds)	Roadway Networks
Control Single	5-axle vehicle tractor, 53 foot semitrailer (3-S2)		1	5	80,000	STAA[1] vehicle; has broad mobility rights on entire Interstate System and National Network including a significant portion of the NHS
1	5-axle vehicle tractor, 53 foot semitrailer (3-S2)		1	5	88,000	Same as Above
2	6-axle vehicle tractor, 53 foot semitrailer (3-S3)		1	6	91,000	Same as Above
3	6-axle vehicle tractor, 53 foot semitrailer (3-S3)		1	6	97,000	Same as Above
Control Double	Tractor plus two 28 or 28 ½ foot trailers (2-S1-2)		2	5	80,000 maximum allowable weight 71,700 actual weight used for analysis[2]	Same as Above
4	Tractor plus twin 33 foot trailers (2-S1-2)		2	5	80,000	Same as Above
5	Tractor plus three 28 or 28 ½ foot trailers (2-S1-2-2)		3	7	105,500	74,500 mile roadway system made up of the Interstate System, approved routes in 17 western states allowing triples under ISTEA Freeze and certain four-lane PAS roads on east coast[3]
6	Tractor plus three 28 or 28 ½ foot trailers (3-S2-2-2)		3	9	129,000	Same as Scenario 5[3]

[1] The STAA network is the National Network (NN) for the 3-S2 semitrailer (53') with an 80,000-lb. maximum GVW and the 2-S1-2 semitrailer/trailer (28.5') also with an 80,000 lbs. maximum GVW vehicles. The alternative truck configurations have the same access off the network as its control vehicle.
[2] The 80,000 pound weight reflects the applicable Federal gross vehicle weight limit; a 71,700 gross vehicle weight was used in the study based on empirical findings generated through an inspection of the weigh-in-motion data used in the study.
[3] The triple network is 74,454 miles, which includes the Interstate System, current Western States' triple network, and some four-lane highways (non-Interstate System) in the East. This network starts with the 2000 CTSW Study Triple Network and overlays the 2004 Western Uniformity Scenario Analysis, Triple Network in the Western States. There had been substantial stakeholder input on networks used in these previous USDOT studies and use of those provides a degree of consistency with the earlier studies. The triple configurations would have very limited access off this 74,454 mile network to reach terminals that are immediately adjacent to the triple network. It is assumed that the triple configurations would be used in LTL line-haul operations (terminal to terminal). The triple configurations would not have the same off network access as its control vehicle–2-S1-2, semitrailer/trailer (28.5'), 80,000 lbs. GVW. The 74,454 mile triple network includes: 23,993 mile network in the Western States (per the 2004 Western Uniformity Scenario Analysis, Triple Network), 50,461 miles in the Eastern States, and mileage in Western States that was not on the 2004 Western Uniformity Scenario Analysis, Triple Network but was in the 2000 CTSW Study, Triple Network (per the 2000 CTSW Study, Triple Network).

With the exception of the triple trailer combinations, the study parameters assume the scenario vehicles are able to travel wherever their control vehicles could operate. For analytical purposes triple trailer combinations are assumed to be restricted to a 74,500 mile network of Interstate and other principal arterial highways. Access off this network to terminals and facilities for food, fuel, rest, and repairs is assumed to be restricted to a maximum of 2 miles. These restrictions recognize that the length and stability and control properties of triples may not make them suitable for travel on roads with narrow lanes or restrictive geometry.

Summary of Modal Shift Methodology

Figure ES-1 on the following page summarizes data and methods used in the modal shift analysis. The analysis begins with an estimation of current (base case) truck traffic by vehicle configuration (number of trailers, number and types of axles, etc.), operating weight, and highway functional class. Data sources for base case traffic estimates include the volumes of truck traffic by highway functional class from the Federal Highway Administration's (FHWA) Highway Performance Monitoring System (HPMS), the distribution of trucks by vehicle configuration from vehicle classification data collected by the States, and the distribution of vehicle operating weights from weigh-in-motion (WIM) data reported by the States. Data are primarily from 2011, the analysis year for the 2014 CTSW Study, although in some cases weigh-in-motion data were supplemented by data from 2010 and 2012 to provide a more robust distribution of operating weights on different highway functional classes. A summary of base case traffic is presented in the body of this technical report.

Following a review of available commodity flow databases, the FHWA's Freight Analysis Framework (FAF) was selected as the commodity flow database for this 2014 CTSW Study. As discussed in the body of this report, the FAF is an amalgamation of data from several different sources. One limitation of the FAF for the modal shift analysis is the fact that origins and destinations in the database are reported for only 123 regions generally representing the largest markets in the country. This level of detail was too coarse for purposes of the modal shift analysis since it would not allow a detailed assessment of the potential impacts of restricting the highway networks available for certain scenario vehicles. The Oak Ridge National Laboratory, FHWA's developer of the FAF origin and destination matrix, disaggregated the FAF and provided commodity flows for origins and destinations at the county level.

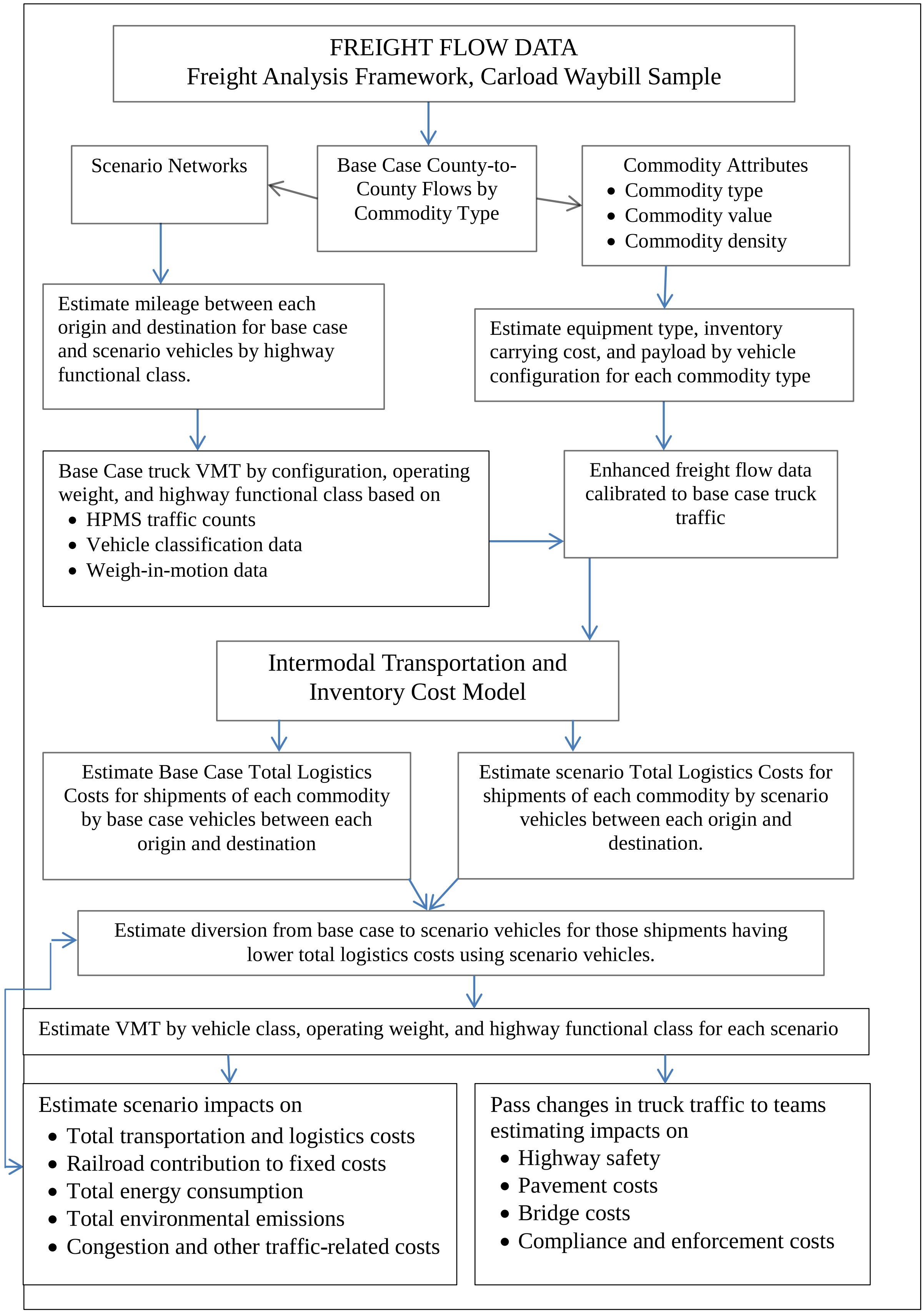


Figure ES-1: Mode Shift Methodology

The analytical tool used for the modal shift analysis itself was the Intermodal Transportation and Inventory Cost Model (ITIC). This model was developed by USDOT during the course of and immediately following the USDOT's *Comprehensive Truck Size and Weight Study 2000* (2000 CTSW Study) and was used for subsequent studies by both FHWA and the Federal Railroad Administration (FRA). The ITIC model is described in detail in **Appendix C**.

In general the model estimates transportation and non-transportation logistics costs for shipments of different commodities by different vehicle configurations and transportation modes between various origins and destinations.

Specific costs considered in the ITIC model include vehicle operating costs, shipping rates that vary by market, and inventory carrying costs such as safety stock, cycle costs, and in-transit costs. If costs for moves by scenario vehicles at scenario size and weight limits are lower than costs for the same move in existing vehicle configurations at current size and weight limits, the move would be assumed to shift to the heavier scenario vehicle. Likewise if shipments by scenario vehicles cost less than shipments by rail, freight traffic would be assumed to shift from rail to truck.

In the ITIC model, railroads are assumed to respond to increased competition from more productive trucks by lowering their rates to the point where rates equal variable cost. If lowering the rates reduces total transportation and logistics costs for rail below rates for the scenario vehicles, freight traffic will remain on the railroads, but the contribution of those shipments to covering railroad fixed costs will be reduced.

Analytical Assumptions and Limitations

In conducting the modal shift analysis, data and methodological limitations required that a number of assumptions be made. Those assumptions include:

- Cargo weighing less than 75,000 pounds GVW will not divert to six-axle (3-S3) semitrailers.
- Traffic currently moving in five-axle semitrailers that cannot benefit from the added weight allowed on a six-axle tractor-semitrailer will not shift to the six-axle vehicle. Carriers would not shift their entire fleets over to six-axle vehicles simply to increase the flexibility of their fleets.
- All scenario vehicles except triples have the same access to cargo origins and destinations as base case vehicles. In the short run, bridge or other highway improvements would need to be made before scenario vehicles could use the same routes as base case vehicles, but in the long run it is assumed that such improvements would be made. The modal shift analysis is based on this long-run state.
- Triple configurations operate in LTL line haul (terminal to terminal) operations. In actuality there may be a few markets where heavy triples could be used for truckload shipments under the network and access restrictions placed on triples operations, but based on discussions with industry experts those are believed to be localized and would have very little impact nationally.
- Equipment currently being hauled in specialized configurations such as truck-trailer combinations will not shift to scenario vehicles. Specialized configurations are used

because of unique commodity characteristics that would not be met by the scenario vehicles.
- Some 90 percent of short line carloads interline with Class 1 railroads and thus are reflected in the Surface Transportation Board's Carload Waybill Sample.
- The analysis year for the 2014 CTSW Study is 2011. To the maximum extent possible, all data used for the study are from 2011 or have been adjusted to reflect 2011 values.
- The analysis assumes Federal and State highway user fees on the scenario vehicles are unchanged.

In addition to these assumptions, several other data limitations affect the analysis, including:

- The precise origins and destinations of shipments are unknown from the FAF. Origins and destinations are assumed to be county centroids[2] for inter-county shipments.
- The precise routes used to ship commodities between origin and destination are not known. Shortest path routes between each origin and destination pair are calculated for purposes of estimating transportation costs.
- Characteristics of specific commodities within broad commodity groups may vary significantly.
- Shipment sizes and annual usage rates for freight flows between individual origins and destinations cannot be discerned from the FAF and must be estimated from the Vehicle Inventory and Use Survey (VIUS) and other sources. This affects non-transportation logistics costs.
- Rail carload and truck/rail intermodal origins and destinations are unavailable from the Carload Waybill Sample and have been estimated using the same assumptions as were used in the 2000 CTSW Study.
- Multi-stop truck moves to accumulate and/or distribute freight from/to multiple establishments are not captured in the FAF.

These limitations are unavoidable in a nationwide study such as this. They were also confronted in USDOT's 2000 CTSW Study and in other national studies. They are not believed to affect overall study conclusions, but they must be borne in mind when considering study implications.

Summary of Scenario Impacts on Modal Shifts

Table ES-3 summarizes impacts of each scenario on total truck vehicle miles traveled (VMT) required to haul freight included in the 2011 FAF, the cost of moving that freight, and the impact of shifts from rail to truck on railroad profitability. As would be expected, impacts on VMT generally vary with the allowable GVW assumed in each scenario. Percentage changes in VMT reflect changes in VMT from the base case to the scenario size and weight limits for those vehicle configurations affected by each scenario. They do not reflect percentage changes in total VMT or total truck VMT, both of which would be much smaller than the percentage changes in VMT for just those truck configurations affected by the scenario size and weight limits.

[2] A county centroid is the latitudinal and longitudinal (i.e., geographic) center of a county. See http://opengeocode.org/tutorials/USCensus.php for more information.

In terms of the tons of cargo that shifts from base case configurations to the scenario configurations, the vast majority shifts from truck rather than rail. Scenarios 1-3 affect more tonnage than Scenarios 4-6 because they primarily affect movements of bulk commodities whereas Scenarios 4-6 only affect LTL shipments.

Table ES-3: Scenario Impacts on VMT, Total Logistics Costs, and Railroad Revenue

	Change in VMT (millions)	Quantity of Freight Shifted (000s of tons)		Change in Total Logistics Costs ($ millions)	Change in Railroad Contribution ($ millions)
		From Truck	From Rail		
Scenario 1	-861 (-0.6%)	2,658,873	2,345	-5,749 (-1.4%)	-197 (-1.1%)
Scenario 2	-1,200 (-1%)	2,622,091	2,311	-5,655 (-1.4%)	-196 (-1.1%)
Scenario 3	-2,878 (-2%)	3,197,815	4,910	-13,193 (-3.2%)	-562 (-3.1%)
Scenario 4	-2,953 (-2.2%)	578,464	1,473	-2,326 (-6.3%)	-22 (-0.1%)
Scenario 5	-1,896 (-1.4%)	716,838	2,374	-1,901 (-5.1%)	-17 (-0.1%)
Scenario 6	-1,944 (-1.4%)	716,838	2,363	-1,971 (-5.3%)	-15 (-0.1%)

Changes in total logistics costs and railroad contribution were much higher for Scenarios 1-3 than for Scenarios 4-6. Transportation costs are relatively higher for the bulk commodities most affected by Scenarios 1-3 and there are few if any savings in non-transport logistics costs associated with changes in the sizes of vehicles used to haul less-than-truckload freight. The greatest reduction in total logistics costs was associated with Scenario 3 where costs decreased by over $13 billion. The percentage change in total logistics costs (transportation and non-transport logistics costs) for Scenarios 1-3 is based on a comparison of total logistics costs associated with moving all freight traffic in the configurations affected by each scenario to total transportation and non-transport logistics costs associated with hauling the same traffic at the size and weight limits for each scenario. Changes in total logistics costs for Scenarios 4-6 are calculated differently because those scenarios are assumed to apply only to LTL traffic. Total logistics costs associated with moving all LTL traffic both by truck and by rail in the base case are compared with total logistics costs associated with moving the same freight traffic under the size and weight limits assumed for each scenario. For all scenarios, the percentage change in railroad contribution reflects changes in total net operating revenues compared to total net operating expenses for the railroads. The negative values indicate that net revenues fell more than net expenses.

Variations in truck size and weight limits under the study scenarios may also have an impact on short line railroads. Short lines provide regional/intrastate rail service, 90 percent of which connects to the larger Class 1 railroads. Data on short line operations in the Carload Waybill Sample are limited, but most commodities hauled by short lines are moved in carload quantities that would only be affected by the truck size and weight changes analyzed in Scenarios 1, 2, and 3. Using the same general methods as were used to analyze rail impacts for Class 1 railroads, short line railroads were estimated to lose from 1 to 4 percent of total revenue under each of Scenarios 1, 2, and 3. Revenue losses under Scenario 3 would be somewhat greater than losses under Scenarios 1 and 2. Losses for some individual short line railroads could be greater.

In **Table ES-4**, changes in fuel consumption and emissions reflect the reduced VMT shown in **Table ES-3.** Percentage changes in fuel consumption, CO2, and NOx are calculated the same way that changes in VMT were calculated – changes in base case fuel consumption and emissions for the vehicle configurations affected by each scenario compared to fuel consumption and emissions for those same vehicles under the assumed size and weight limits for each scenario. Congestion costs went down in all scenarios reflecting changes in the relative VMT for each scenario. Congestion cost savings ranged from $256 million in Scenario 1 to $875 million for Scenario 4. The percentage change in congestion cost is estimated by comparing congestion costs **for all vehicles operating on the highway** under base case size and weight limits to congestion costs for all vehicles assuming the scenario size and weight limits. Impacts on congestion are not limited just to the vehicles whose VMT is affected by each scenario, but accrue to all vehicles in the traffic stream.

Table ES-4: Scenario Impacts on Energy Consumption, Emissions, and Traffic Operations (millions)

	Change in Fuel Consumption (gallons)	Change in CO2 Emissions (kilograms)	Change in NOx Emissions (grams)	Change in Congestion Costs (dollars)
Scenario 1	-107 (-0.5%)	-1,086 (-0.5%)	-406 (-0.5%)	-256 (-0.02%)
Scenario 2	-109 (-0.5%)	-1,107 (-0.5%)	-414 (-0.5%)	-358 (-0.03%)
Scenario 3	-309 (-1.4%)	-3,138 (-1.4%)	-1,175 (-1.4%)	-857 (-0.08%)
Scenario 4	-244 (-1.1%)	-2,483 (-1.1%)	-929 (-1.1%)	-875 (-0.08%)
Scenario 5	-233 (-1.1%)	-2,366 (-1.1%)	-886 (-1.1%)	-505 (-0.05%)
Scenario 6	-230 (-1.1%)	-2,343 (-1.1%)	-877 (-1.1%)	-525 (-0.05%)

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LIST OF ACRONYMS

Acronym	Definition
CTSW	Comprehensive Truck Size and Weight Limits Study
CARB	California Air Resources Board
FAF	Freight Analysis Framework
FHWA	Federal Highway Administration
FRA	Federal Railroad Administration
GCW	Gross combined weight
GVW	Gross vehicle weight
HPMS	Highway Performance Monitoring System
ITIC	Intermodal Transportation and Inventory Cost Model
LCV	longer combination vehicles
LTL	Less than truckload
MATLAB	Matrix Laboratory
NATS	National Truck Stop Survey
NESCCAF	Northeast States Center for a Clean Air Future
NHTSA	National Highway Traffic Safety Administration
NREL	National Renewable Energy Lab
ORNL	Oak Ridge National Laboratories
PCE	passenger car equivalents
STB	Surface Transportation Board
STAA	Surface Transportation Authorization Act
STCC	Standard Transportation Commodity Code
SwRI	Southwest Research Institute
USDOT	US Department of Transportation
VMT	vehicle miles traveled
VIUS	Vehicle Inventory and Use Survey
WHVC	World Harmonized Vehicle Cycle
WIM	weigh-in-motion

CHAPTER 1 – INTRODUCTION

1.1 Background

Truck size and weight regulations in the United States represent a patchwork of Federal and State regulations that provides very little uniformity to shippers and carriers engaged in interstate commerce. Federal weight limits cover gross vehicle weight (GVW), permissible loads on single and tandem axles, and permissible loads on groups of axles intended to protect bridges. Current limits are 80,000 pounds GVW, 20,000 pounds on single axles, 34,000 pounds on tandem axles, and a complex formula (Bridge Formula B) that limits loads on groups of axles at different spacings.

Federal weight limits apply only to the Interstate System, although States cannot apply lower limits on the 200,000 mile National Network established in the Surface Transportation Assistance Act of 1982. **Figure 1** is a map showing relationships between the Interstate System, the National Network, and the National Highway System.

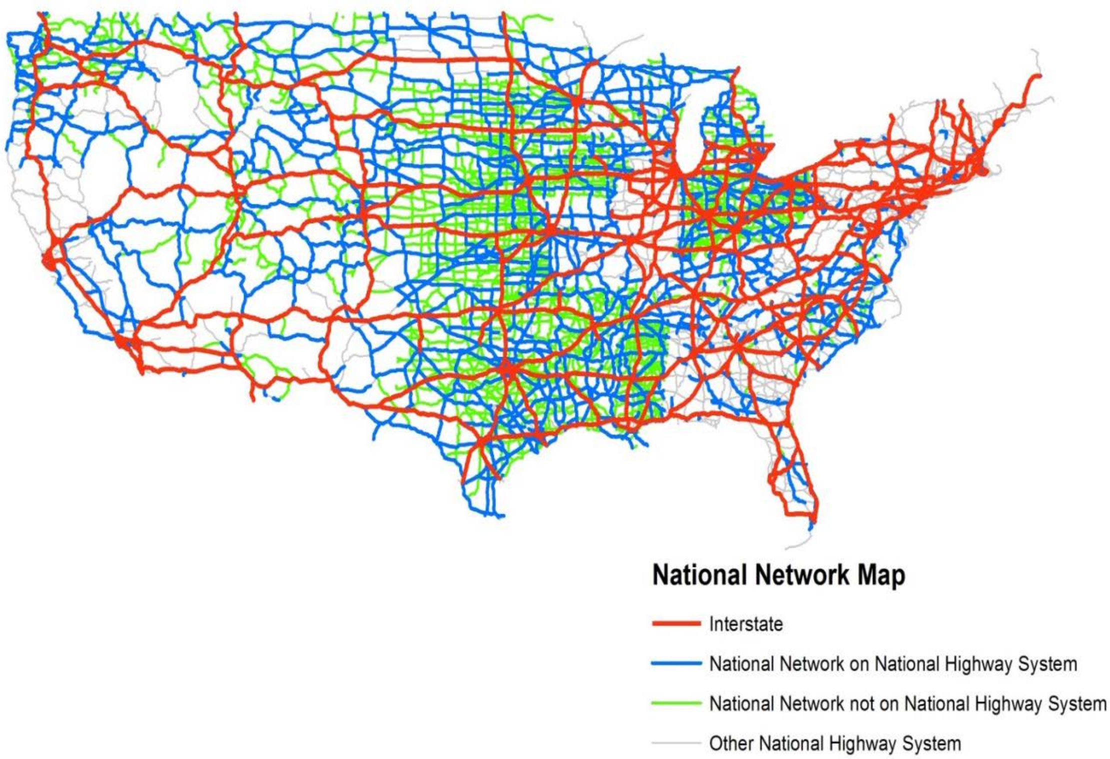

Figure 1: National Network Map

Federal truck size and weight limits do not apply uniformly to Interstate Highways in all States, however. States that had higher weight limits when Federal weight limits were first enacted in

1956 were allowed to retain those higher limits under a "grandfather clause." [3] Furthermore, until 1991 States had the authority to reinterpret their grandfathered weight limits, which led to a gradual increase of weight limits in some States. The so-called ISTEA Freeze instituted in the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 froze the weights and trailer lengths of longer combination vehicles at levels determined to be in effect in a particular State in 1991. This still left a set of divergent weight limits applying to longer combination vehicles in States where those vehicles were allowed.

Each State has its own set of truck size and weight limits that apply to highways off the Interstate System. In some States, Federal and State limits correspond closely, while in others higher GVW or axle load limits are allowed off the Interstate System than are allowed under Federal law on the Interstate System. Further complicating State size and weight limits is the fact that some States have higher limits only for particular commodities, and some States have seasonal variations in weight limits as well.

An often-expressed concern is that higher State weight limits off the Interstate System cause truck traffic to use non-Interstate routes that may be less safe and may not have pavements and bridges designed to the same standards as those on the Interstate System. Studies have recently been conducted in Maine and Vermont to examine this issue in greater detail. Those studies examined the safety impacts of allowing some of the same vehicles as are being analyzed at a national level in this 2014 CTSW Study. Also, see the companion *Volume II: Pavement Comparative Analysis* document for additional information on this topic.

The most recent USDOT truck size and weight studies have focused primarily on the effects of allowing more widespread use of longer combination vehicles (LCV) (USDOT 2000, USDOT 2004). Those vehicles have substantially higher weights and higher cubic capacities than typical over-the-road tractor-semitrailers and could potentially draw freight from a wide variety of other types of vehicle as well.

Potential modal shifts to the tractor-semitrailers being examined in the current 2014 CTSW Study would be expected to be considerably less than diversion to the LCVs examined in the previous USDOT studies because fewer commodities would be able to benefit from the weight increases being examined. Most commodities shipped by truck in the United States fill the cubic capacity or floor area of the trailer before the vehicle's maximum GVW is reached (in other words, they "cube out" before they "weigh out"). These commodities would realize no benefit from the increased tractor-semitrailer weights examined in this 2014 CTSW Study.

[3] The Federal government began regulating truck size and weight in 1956 when the National Interstate and Defense Highways Act (Public Law 84-627), establishing the Interstate Highway System, was enacted. A state wishing to allow trucks with sizes and weights greater than the Federal limits was permitted to establish "grandfather" rights by submitting requests for exemption to the FHWA. Claims that were not legally defensible were rejected. During the 1960s and 1970s, most grandfather issues related to interpreting State laws in effect in 1956 were addressed, and so most grandfather rights have been in place for many decades. See USDOT *Comprehensive Truck Size and Weight Study, Volume 2*, "Chapter 2: Truck Size and Weight Limits – Evolution and Context," FHWA-PL-00-029 (Washington, DC: FHWA, 2000), p. II-9.

1.2 Purpose and Scope

The purpose of this analysis is to estimate modal shifts associated with truck size and weight policy scenarios being analyzed by the U.S. Department of Transportation (USDOT) in the *Comprehensive Truck Size and Weight Limits* (2014 CTSW) *Study* called for in Section 32081 of the Moving Ahead for Progress in the 21st Century Act (MAP-21). Section 32081specifically requires an assessment of potential freight diversion associated with variations in truck size and weight limits. This report presents the estimated potential diversion associated with six truck size and weight policy options.

Within the context of this 2014 CTSW Study, freight diversion includes both the shift of freight traffic from railroads to trucks as well as the shift of truck traffic from one vehicle configuration to another and from one operating weight distribution that reflects Federal truck size and weight limits to another distribution reflecting higher weight limits.

The freight transportation system has grown increasingly complex as shippers and carriers continuously strive for greater efficiency in the face of high fuel costs, pressures to reduce greenhouse gas and other environmental emissions, difficulty recruiting drivers, and competition from a global marketplace. Even relationships between competing surface transportation modes have become more complex; trucking companies now are one of the railroads' biggest customers. All of these factors present challenges to estimating how truck size and weight limits in excess of Federal maximums might affect nationwide freight transportation patterns.

Numerous truck size and weight policy studies have been conducted over the years at the Federal and State level. They have used a variety of analytical tools and data to estimate potential impacts of changes in truck size and weight limits on modal diversion. The desk scan conducted as part of this 2014 CTSW Study revealed that data and analytical tools have improved markedly over the past 20 years. This is especially true with respect to commodity flow data. Whereas the USDOT's 2000 CTSW Study relied primarily on limited survey data collected at truck stops, the Federal Highway Administration's (FHWA) Freight Analysis Framework (FAF) provides a much more robust picture of current commodity flows across the country.

Even with improved data there are many challenges in translating annual commodity flows between various origins and destinations (the exact locations of which are unknown) into annual truck volumes on different highway networks with weight distributions that match observed weight distributions. Vehicle weight distributions are particularly important since several of the truck size and weight options examined in this study only increase allowable weights with no increase in the cubic capacity of the vehicle. Thus only those shipments that reach the maximum payload of current vehicles before they fill the cubic capacity of the vehicle would be able to take advantage of the additional weight provided under several of the alternative federal truck size and weight limits examined in this 2014 CTSW Study.

Estimating potential adverse impacts on the railroads from truck size and weight limits greater than those outlined by Federal regulation is particularly important. While truck and rail are partners in some transportation markets, they are strong competitors in other markets. Considerable concern has been expressed, especially by short-line railroads, that increasing the productivity of trucks could have serious economic consequences not only on the railroads themselves, but on the communities they serve.

In addition to estimating modal shifts associated with variations in truck size and weight configurations, this task also requires estimates of how those shifts would affect energy consumption, environmental emissions, and highway traffic operations. The general state-of-the-art in energy, environmental, and traffic modeling has improved rapidly in recent years, and analyses in this 2014 CTSW Study reflect the latest understanding of factors that affect energy, environmental, and traffic impacts associated with the use of alternative truck configurations.

CHAPTER 2 - SCENARIO DEFINITIONS

The only explicit direction provided in Section 32801 of MAP-21 regarding vehicles to be studied in the 2014 CTSW Study was that the study should consider “six-axle and other alternative configurations of tractor-trailers.”

USDOT determined that up to six alternative truck configurations could be examined as part of this comparative analysis in the timeframe established in MAP-21. Also, to be selected for study, USDOT stipulated that an alternative truck configuration needed to be currently in use in the United States, Canada, or elsewhere, and practical for use in the United States. USDOT then proposed three specific truck configurations and solicited input from stakeholders regarding the selection of the additional configurations to include in the mix.

After extensive public and stakeholder input, USDOT identified the six alternative truck configurations to compare with control or baseline vehicles meeting current federal size and weight limitations. In addition, two truck configurations that now meet Federal size and weight limitations were selected to serve as “baseline” or “control” vehicles. The comparisons would be conducted over six illustrative network scenarios, using data analysis, modeling, and other state of the art methods to derive technical results in each of the five study focus areas. All but one of the vehicles selected for analysis are currently in use on some highways in the United States so that there is some experience with these vehicles in this country. The box on the following page shows the reasons why each alternative configuration was selected for inclusion in this Study. **Table 1** describes key attributes of each configuration.

USDOT developed details of analytical scenarios based on these vehicles to serve as the basis for estimating potential impacts associated with widespread use of each vehicle configuration.

First, each scenario assumes an increase in size and weight for only one of the vehicle types identified above. In other words, none of the scenarios involve increases in weight for more than a single vehicle configuration. The impacts presented in this study cannot be added or subtracted from each other – for example one cannot add the impact of the higher gross vehicle weight five-axle tractor semitrailer to that of the 6-axle tractor semitrailer. To understand the impact of multiple changes to truck size and weight, a new analysis would be necessary.

Second, maximum weight limits for the scenario vehicles are assumed to extend beyond the Interstate System. Except for the triple trailer combinations, States are assumed to allow the scenario vehicles to operate on the same networks on which tractor-semitrailers and twin trailer combinations with 28.5-foot trailing units currently operate and to have the same access to terminals and facilities for food, fuel, rest, and repairs. Wherever tractor-semitrailers currently operate, the scenario tractor-semitrailers would also operate. Wherever twins with 28.5-foot trailers operate, the scenario twin-trailer combination with 33-foot trailers would operate. Triple trailer combinations are assumed for analytical purposes to be limited to a much more restricted network of 74,500 miles of Interstate and other principal arterial highways. **Figure 2** shows the network assumed to be available for triples in the modal shift analysis. Because of their length and challenge in maneuvering, access by triples to points of loading and unloading off the network is assumed to be limited to 2 miles.

Alternative Truck Configurations and Control Truck Configurations

Control Vehicle for Comparison with One Trailer Combinations

- Five-axle, tractor-semitrailer combination (3-S2), 80,000 lbs.: This is the "standard" configuration of a three-axle tractor with a 53-foot long, two-axle semitrailer and a GVW of 80,000 pounds that operates on U.S. Interstates and other National Highways. This combination is used in the study to compare with alternative truck configurations 1 through 3 below. It is a STAA vehicle meeting current Federal size and weight limitations.

Alternative Truck Configurations with One 53-Foot Semitrailer

- Five-Axle, Tractor-Semitrailer Combination (3-S2), 88,000 pounds: The same vehicle as the Control but loaded to the Gross Manufacturers Weight Rating (GMWR) of 88,000 lbs. This configuration was identified for inclusion at the outset of the 2014 CTSW Study to understand the performance implications of trucks operating at the manufacturers' gross vehicle weight rating.
- Six-axle, Tractor-Semitrailer Combination (3-S3), 91,000 pounds: This six-axle, 91,000 lb. configuration was selected to evaluate a six-axle truck that complies with the Federal Bridge Formula.*
- Six axle, Tractor-Semitrailer Combination (3-S3), 97,000 lbs.: A tractor-semitrailer configuration with a 3-axle tractor and a 3-axle semitrailer (hence 3-S3) and a GVW of 97,000 lbs. This configuration was selected because of the reference to analyzing the impacts of a six-axle truck in Section 32801 and the weight of 97,000 lbs. was identified due to Congressional interest (HR 612, as introduced in the 113th Congress in 2013).

Control Vehicle for Combinations with More Than One Trailer

- Twin 28.5-foot, 80,000 lbs.: This "standard" configuration is in wide use. Like the Control Vehicle for One Trailer Combinations above, this vehicle is used to provide "baseline" data in the comparative analyses, and is defined as a STAA vehicle that meets current Federal size and weight limitations. (Note: While the control double has an authorized GVW of 80,000 lbs., the actual study is based on a GVW of 71,700 lbs. This GVW is based on actual data collected from weigh-in motion (WIM) equipped weight and inspection facilities and is a more accurate representation of actual vehicle weights than the STAA authorized GVW.)

Alternative Configurations with More than One Semitrailer/Trailer

- Twin 33 foot, 80,000 lbs. (2-S1-2): A configuration with two twin trailers, each 33-foot long and a GVW of 80,000 lbs. This combination was selected because of the strong interest expressed by carriers specializing in Less-Than-Truckload (LTL) shipments. This is the only alternative configuration not currently used in the United States.
- Triple 28.5-foot, 105,000 lbs. (2-S1-2-2): A triple-trailer configuration with three 28.5-foot trailers, seven axles, and a GVW of 105,000 lbs. This combination was selected because of the high level of interest from diverse Stakeholders.
- Triple 28.5-foot, 129,000 lbs. (3-S2-2-2): The triple-trailer configuration with three 28.5-foot trailers and a GVW of 129,000 lbs. It was selected to evaluate the upper GVW limit allowed to operate under the ISTEA Freeze .

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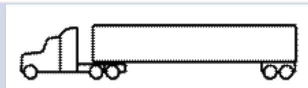
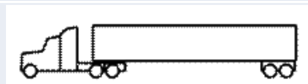
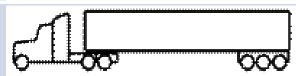
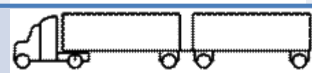
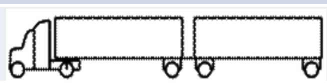
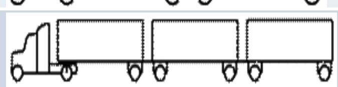
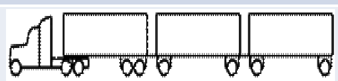
* The Bridge Formula established weight limits on vehicle axle groups for different distances between axles and set a maximum GVW of 80,000 pounds. Congress enacted the Bridge Formula to limit the weight-to-length ratio of a vehicle crossing a bridge. This is accomplished either by spreading weight over additional axles or by increasing the distance between axles.

Table 1: Truck Configuration and Weight Scenarios Analyzed in the 2014 CTSW Study

Scenario	Configuration	Depiction of Vehicle	# Trailers or Semi-trailers	# Axles	Gross Vehicle Weight (pounds)	Roadway Networks
Control Single	5-axle vehicle tractor, 53 foot semitrailer (3-S2)		1	5	80,000	STAA[1] vehicle; has broad mobility rights on entire Interstate System and National Network including a significant portion of the NHS
1	5-axle vehicle tractor, 53 foot semitrailer (3-S2)		1	5	88,000	Same as Above
2	6-axle vehicle tractor, 53 foot semitrailer (3-S3)		1	6	91,000	Same as Above
3	6-axle vehicle tractor, 53 foot semitrailer (3-S3)		1	6	97,000	Same as Above
Control Double	Tractor plus two 28 or 28 ½ foot trailers (2-S1-2)		2	5	80,000 maximum allowable weight 71,700 actual weight used for analysis[2]	Same as Above
4	Tractor plus twin 33 foot trailers (2-S1-2)		2	5	80,000	Same as Above
5	Tractor plus three 28 or 28 ½ foot trailers (2-S1-2-2)		3	7	105,500	74,500 mile roadway system made up of the Interstate System, approved routes in 17 western states allowing triples under ISTEA Freeze and certain four-lane PAS roads on east coast[3]
6	Tractor plus three 28 or 28 ½ foot trailers (3-S2-2-2)		3	9	129,000	Same as Scenario 5[3]

[1] The STAA network is the National Network (NN) for the 3-S2 semitrailer (53') with an 80,000-lb. maximum GVW and the 2-S1-2 semitrailer/trailer (28.5') also with an 80,000 lbs. maximum GVW vehicles. The alternative truck configurations have the same access off the network as its control vehicle.

[2] The 80,000 pound weight reflects the applicable Federal gross vehicle weight limit; a 71,700 gross vehicle weight was used in the study based on empirical findings generated through an inspection of the weigh-in-motion data used in the study.

[3] The triple network is 74,454 miles, which includes the Interstate System, current Western States' triple network, and some four-lane highways (non-Interstate System) in the East. This network starts with the 2000 CTSW Study Triple Network and overlays the 2004 Western Uniformity Scenario Analysis, Triple Network in the Western States. There had been substantial stakeholder input on networks used in these previous USDOT studies and use of those provides a degree of consistency with the earlier studies. The triple configurations would have very limited access off this 74,454 mile network to reach terminals that are immediately adjacent to the triple network. It is assumed that the triple configurations would be used in LTL line-haul operations (terminal to terminal). The triple configurations would not have the same off network access as its control vehicle–2-S1-2, semitrailer/trailer (28.5'), 80,000 lbs. GVW. The 74,454 mile triple network includes: 23,993 mile network in the Western States (per the 2004 Western Uniformity Scenario Analysis, Triple Network), 50,461 miles in the Eastern States, and mileage in Western States that was not on the 2004 Western Uniformity Scenario Analysis, Triple Network but was in the 2000 CTSW Study, Triple Network (per the 2000 CTSW Study, Triple Network).

Third, it is assumed that current typical weight/horsepower ratios would be maintained so long as tractors are widely available with sufficient horsepower to maintain the weight/horsepower ratio. A typical over-the-road tractor currently has about 485 horsepower, which results in a weight/horsepower ratio of about 165 for an 80,000 pound vehicle. The largest tractors commonly available have approximately 588 horsepower. Thus weight/horsepower ratios can be maintained or nearly maintained for all scenario vehicles except the triple trailer combinations. The weight/horsepower ratio for a 129,000 pound triple with a 588 horsepower tractor is 219. This could adversely affect triples' performance relative to the standard twin trailer combinations and is one reason that triples are assumed to be limited to a smaller network of roads than the other scenario vehicles.

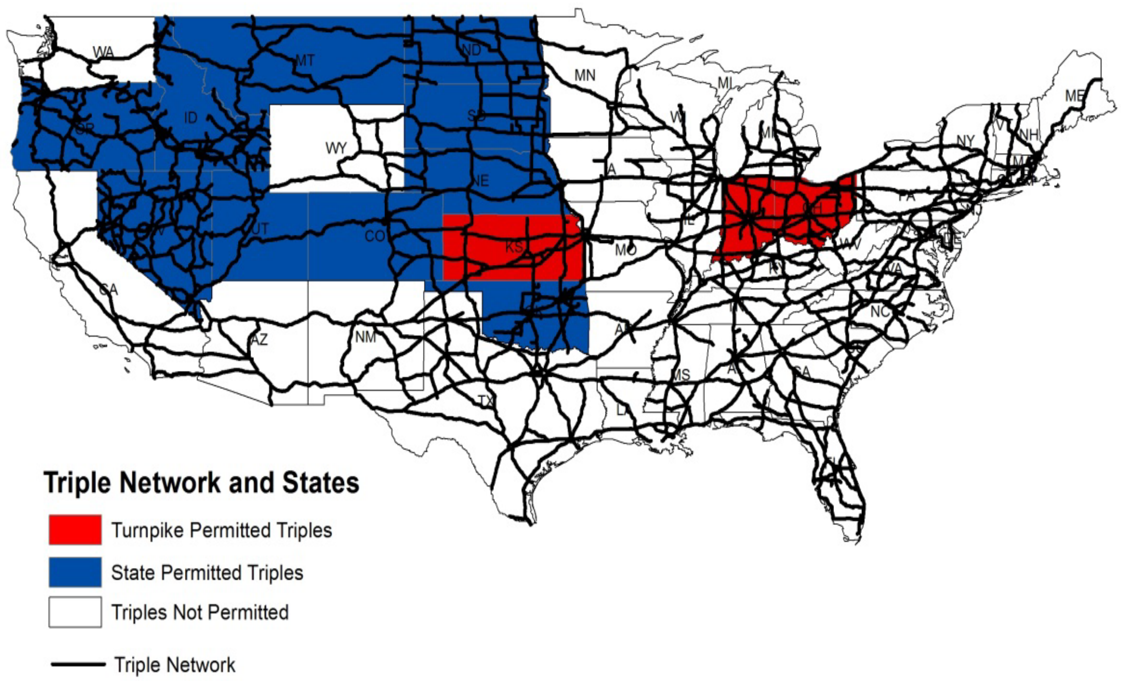


Figure 2: Analytical Network for Triples Operation

Fourth, diversion of freight traffic from one truck configuration to another or from one operating weight to another will be limited for the various scenario vehicles. It is assumed that the tractor-semitrailers analyzed in Scenarios 1-3 will attract freight traffic only from five- and six-axle tractor semitrailers. Numerous other truck configurations, including tractor-semitrailers with seven axles or more and various truck-trailer combinations (a straight truck pulling a full trailer behind it), operate within the weight range that might shift to one of the heavier scenario tractor-semitrailers, but many of those vehicles already operate above 80,000 pounds under special permits, and the cargo they carry in those specialized vehicle configurations generally would not be suitable for loading on one of the scenario configurations—otherwise they would have been using that equipment in the first place.

Cargo shifting to one of the multi-trailer combinations analyzed in Scenarios 4-6 is limited to less-than-truckload traffic currently being hauled in five- or six-axle twin trailer combinations or in a five-axle tractor semitrailer. While the additional cubic capacity of the twin 33-foot trailers and the triple trailer combination would be attractive to many carriers, logistical issues with loading, unloading, and maneuvering multi-trailer combinations at origins and destinations are difficult for most shippers to manage and more than offset the benefits of increased cubic capacity. There certainly could be exceptions for certain types of shippers and carriers, but these exceptions are believed to represent a small share of freight that otherwise might be attracted to the multi-trailer combinations.

CHAPTER 3 – MODAL SHIFT ANALYSIS AND RESULTS

This chapter summarizes data and methods included in the modal shift analysis and presents results of the analysis for each scenario. The discussion is organized around the various activities undertaken in conducting the modal shift analysis.

Figure 3 summarizes the overall modal shift analysis methodology. Basic elements of the methodology include the base case commodity flow data from the Freight Analysis Framework (FAF) and the Surface Transportation Board's Carload Waybill Sample; the base case truck traffic volumes by vehicle class, highway functional class, and operating weight from the Highway Performance Monitoring System, state vehicle classification data, and state weigh-in-motion (WIM) data; commodity attributes from the latest (2002) Vehicle Inventory and Use Survey (VIUS) and other sources that affect the kind of equipment required to haul each commodity; the highway networks on which base case and scenario vehicles can travel; and the Intermodal Transportation and Inventory Cost (ITIC) model. Each of these elements is discussed in greater detail later in this Chapter.

From these data, transport and non-transport logistics costs for shipments of each of the 43 commodities included in the FAF between each origin and destination (approximately 3,000 counties in the United States) are calculated for applicable base case truck configurations, the scenario configuration, and for railroads. The model assumes that shippers choose the mode with the lowest total cost.

For a nationwide analysis such as this, it is impossible to include all factors that might affect mode choice decisions for individual moves, and the transport and non-transport cost factors included in ITIC can only be representative of actual costs for individual moves. However, these factors are believed to reflect the considerations that would affect long-term decisions on the choice of equipment for particular moves— especially for tradeoffs among the truck configurations—under the assumptions about each truck size and weight scenario.

Once the mode choice for each shipment has been estimated, overall changes in truck VMT and vehicle weight distributions can be estimated, as can changes in total transportation and logistics costs. Changes in overall energy consumption, environmental emissions, and traffic operations associated with changes in freight mode choice are also estimated in this study.

Impacts on pavements, safety, enforcement and compliance requirements, and bridge structures are estimated in the other studies within this volume:

- *Pavement Comparative Analysis,*
- *Highway Safety and Truck Crash Comparative Analysis,*
- *Compliance Comparative Analysis, and*
- *Bridge Structure Comparative Analysis*

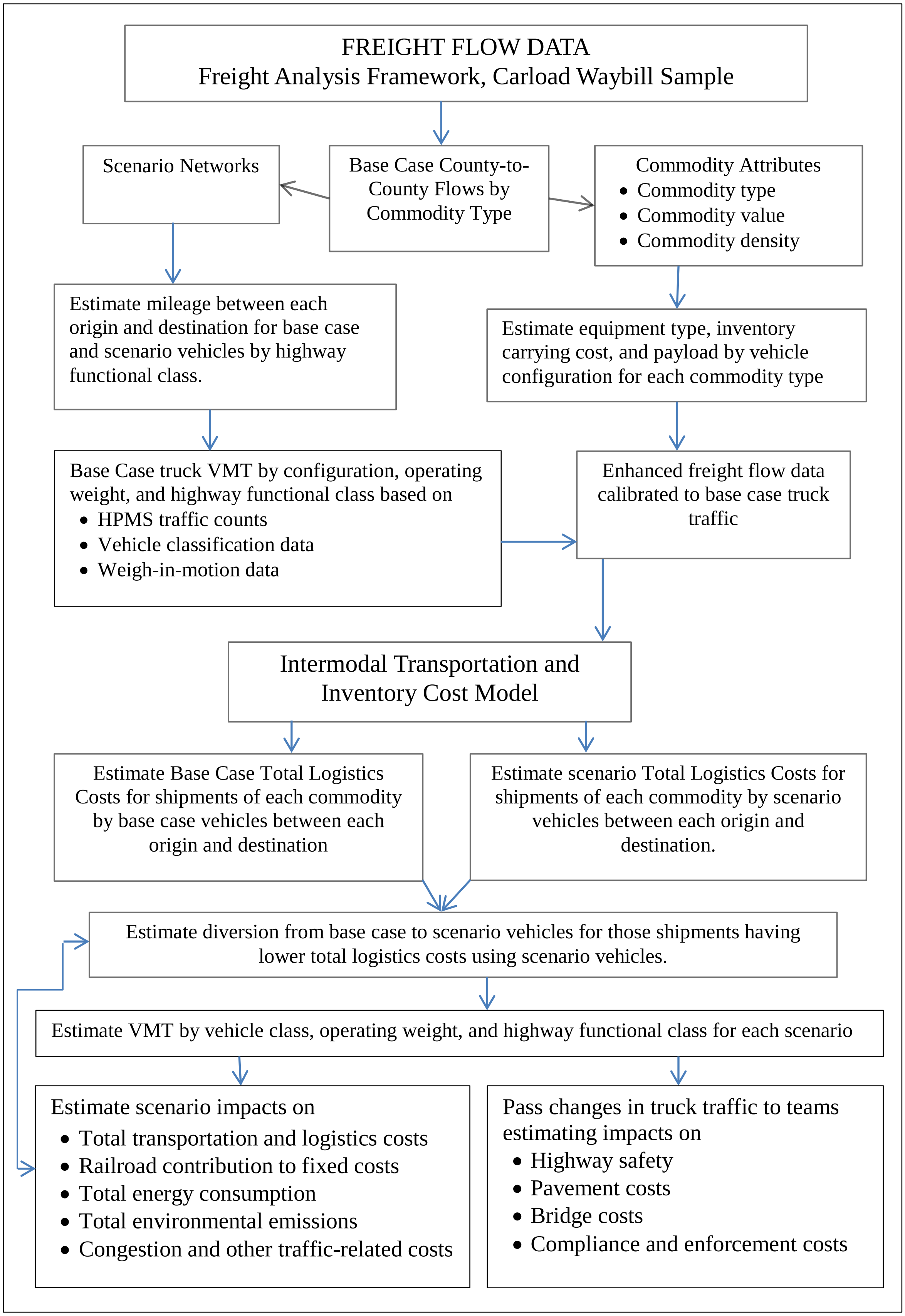


Figure 3: Mode Shift Methodology

Analytical Assumptions and Limitations

In conducting the modal shift analysis, data and methodological limitations required the USDOT study team to make a number of assumptions:

- Cargo weighing less than 75,000 pounds GVW will not divert to six-axle (3-S3) tractor-semitrailers.
- Traffic currently moving in five-axle (3-S2) tractor-semitrailers that cannot benefit from the added weight allowed on a six-axle (3-S3) tractor-semitrailer will not shift to the six-axle vehicle. Simply put, carriers would not shift their entire fleets over to six-axle vehicles simply to increase the flexibility of their fleets.
- All scenario vehicles except triples have the same access to cargo origins and destinations as base case vehicles. This study assumes that, in the longer term, State and Federal agencies would make any necessary improvements to roads and bridges to enable these facilities to handle all scenario vehicles. The modal shift analysis is based on this long-term assumption.
- Triple configurations operate in LTL line haul (terminal to terminal) operations. In actuality there may be a few markets where heavy triples could be used for truckload shipments under the network and access restrictions placed on triples operations, but based on discussions with industry experts those are believed to be localized and would have very little impact nationally.
- Equipment currently being hauled in specialized configurations such as truck-trailer combinations will not shift to scenario vehicles. Specialized configurations are used because of unique commodity characteristics that would not be met by the scenario vehicles.
- Some 90 percent of short-line carloads interline with Class 1 railroads and thus are reflected in the Surface Transportation Board's Carload Waybill Sample.
- The analysis year for the 2014 CTSW Study is 2011. To the maximum extent possible all data used for the study are from 2011 or have been adjusted to reflect 2011 values.
- The analysis assumes Federal and State highway user fees on the scenario vehicles are unchanged.

In addition to these assumptions, several other data limitations affect the analysis including:

- The precise origins and destinations of shipments are unknown from the FAF. Origins and destinations are assumed to be county centroids for inter-county shipments.
- The precise routes used to ship commodities between origin and destination are unknown. Shortest path routes between each origin and destination pair are calculated for purposes of estimating transportation costs.
- Physical characteristics of specific commodities within broad commodity groups may vary significantly.

- Shipment sizes and annual usage rates for freight flows between individual origins and destinations cannot be discerned from the FAF and must be estimated from VIUS and other sources. This affects non-transportation logistics costs.
- Rail carload and truck/rail intermodal origins and destinations are unavailable from the Carload Waybill Sample and have been estimated using the same assumptions as were used in the 2000 CTSW Study.
- Multi-stop truck moves to accumulate and distribute freight from and to multiple establishments are not captured in the FAF.

3.1 Freight Flow Data by Commodity, Origin-Destination, and Mode

Scope

Freight flow data are essential for estimating potential mode shifts associated with the truck size and weight variations studied under scenarios 1 through 6. Transportation characteristics and the requirements of different commodities vary significantly, but the coverage of all major commodities and all major transportation flows was an important criterion in choosing the commodity flow database to be used in this 2014 CTSW Study.

Another important consideration was the geographic detail of the origins and destinations. Some scenario vehicles cannot use all parts of the highway system, so the origin and destination granularity must be fine enough that differences in the networks available to scenario and base-case vehicles can be discerned. Finally public availability of both the data and any methods utilized to refine the data was an important element in scoping the study.

Methodology

As described in detail in the desk scan (**Appendix A**), the first step in this effort was to identify candidate commodity flow databases for use in this analysis. Four potential databases were identified: the FHWA's FAF, the Commodity Flow Survey conducted by the Bureau of the Census, the Transearch database developed by IHS Global Insight, and the Surface Transportation Board's Carload Waybill Sample for railroads.

Off the shelf, none of these databases met all the scoping considerations noted above, but the FAF came closest with respect to truck commodity flow data. The main weakness of the FAF data was that the geographic granularity was too coarse to allow differences in network availability for the different scenario vehicles to be evaluated. This issue was resolved for this study, with some loss of fidelity, when FHWA commissioned the Oak Ridge National Laboratory (ORNL) to disaggregate the FAF from its 123 regions to a county level of detail. Thus origins and destinations of commodity shipments between each of the approximately 3,000 counties in the country could be analyzed, creating a matrix of 9 million potential origin-destination pairs. The methodology used by ORNL to disaggregate the FAF data is included in **Appendix A**.

The commodity flow data for truck shipments in this 2014 CTSW Study is superior to the truck database used in USDOT's 2000 CTSW Study. The FAF was not available when the 2000

CTSW Study was underway. At that time the only available database that met the study's needs was the National Truck Stop Survey (NATS) conducted by the Association of American Railroads. The NATS had other weaknesses as compared to the FAF, including the fact that it had many fewer observations and it was limited to long-haul shipments where drivers stopped at truck stops while traveling to their destinations and were willing to participate in the survey.

Results

The outputs of this effort are matrices of freight flows by commodity, origin and destination, and mode. The USDOT study team used data from the Surface Transportation's Carload Waybill Sample to analyze potential shifts from rail to truck rather than the rail data in the FAF because the Carload Waybill Sample data include more detailed origin, destination, and other shipment characteristics than rail data in the FAF. The Carload Waybill Sample data also include information as to the rates paid for each move.

Forty-three Standard Classification of Transported Goods (SCTG) groups are included in the FAF. The Census Bureau defines SCTG Codes at a 5-digit level of detail, but also groups commodities into two-digit groups as well. The two-digit level of detail is used in the FAF. **Table 2** shows the ton-miles of each commodity group shipped in five-axle tractor-semitrailers in 2011 as estimated from the FAF. The five-axle tractor-semitrailer is the base vehicle for scenarios 1-3 and also accounts for a significant share of LTL traffic analyzed in scenarios 4-6.

Table 2: Estimated 2011 Ton-Miles Hauled by 5-Axle Tractor-Semitrailers by Standard Classification of Transported Goods (SCTG) Code

SCTG Code	**Commodity Name**	**Ton-Miles (millions)**
SCTG1	Live animals/fish	32,245
SCTG2	Cereal grains	183,376
SCTG3	Other ag prods.	105,601
SCTG4	Animal feed	53,348
SCTG5	Meat/seafood	39,800
SCTG6	Milled grain prods.	11,957
SCTG7	Other foodstuffs	139,099
SCTG8	Alcoholic beverages	28,854
SCTG9	Tobacco prods.	431
SCTG10	Building stone	5,913
SCTG11	Natural sands	40,360
SCTG12	Gravel	143,280
SCTG13	Nonmetallic minerals	36,342
SCTG14	Metallic ores	8,474
SCTG15	Coal	38,109
SCTG16	Crude petroleum	2,380
SCTG17	Gasoline	49,261
SCTG18	Fuel oils	41,439
SCTG19	Coal-n.e.c.	74,093

SCTG Code	Commodity Name	Ton-Miles (millions)
SCTG20	Basic chemicals	65,108
SCTG21	Pharmaceuticals	4,002
SCTG22	Fertilizers	33,681
SCTG23	Chemical products	45,343
SCTG24	Plastics/rubber	69,842
SCTG25	Logs	45,833
SCTG26	Wood products	55,870
SCTG27	Newsprint/paper	40,329
SCTG28	Paper articles	25,982
SCTG29	Printed products	13,913
SCTG30	Textiles/leather	28,255
SCTG31	Nonmetal mineral products	111,751
SCTG32	Base metals	87,929
SCTG33	Articles of base metal	50,149
SCTG34	Machinery	56,414
SCTG35	Electronics	29,645
SCTG36	Motorized vehicles	48,878
SCTG37	Transport equipment	2,565
SCTG38	Precision instruments	2,540
SCTG39	Furniture	18,302
SCTG40	Misc. mfg. products	33,106
SCTG41	Waste/scrap	128,272
SCTG43	Mixed freight	54,581

Source: Freight Analysis Framework

Table 3 shows the distribution of highway shipments by length of haul. Almost one-third of shipments contained in the FAF are 50 miles or less in length. Fewer than 10 percent of shipments are greater than 500 miles. The length of haul affects costs associated with using different modes and different types of equipment.

Table 3: Distribution of Lengths of Haul for Highway Shipments

Length of Haul (miles)	Percent of Trips
0-50	30
51-100	18
101-250	28
251-500	15
501-1,000	6
>1,000	3

Source: Based on 2011 Freight Analysis Framework

3.2 Estimation of Shipment Size for Each Shipping Alternative

Scope

The FAF contains annual flows of commodities between various origin-destination (O-D) pairs. These annual flows must be translated into the number of individual truck or rail shipments that would be required to haul these annual flows using different types of equipment.

Methodology

The VIUS provides information on the payload for each vehicle configuration. Likewise, information is available on the maximum payload that can be carried in different types of rail equipment. Dividing the annual tons of each commodity going between each O-D pair for each equipment type provides the total number of trips that would be required to haul the freight for each type of equipment.

Results

The output of this task is incorporated into ITIC to provide the ability to estimate the total number of loads required to move the annual tonnage of each commodity hauled between each O-D pair by each type of truck and railroad equipment.

3.3 Freight Assignment to Highway Equipment, Including: Body Type, Configuration and Payload

Scope

Commodity characteristics are important determinants of the types of equipment that would be used and the payloads for shipments of each commodity. Among the most important commodity characteristics for the mode shift analysis are density, physical characteristics of the commodity, value, and the origin and destination of the shipment.

Commodity density measured in pounds per cubic foot directly influences whether a commodity will fill the cubic capacity of a trailer or container before the maximum payload is reached (a “cube-out” commodity) or whether the maximum payload will be reached before the trailer or container is physically filled (a “weigh-out” commodity). This, in turn, determines the extent to which a commodity could take advantage of potential changes in truck size and weight limits. Cube-out commodities generally would not benefit from increases in the allowable weight of a vehicle if the vehicle’s cubic capacity were not increased. Likewise, weigh-out commodities would not benefit by increases in the cubic capacity of a vehicle if the maximum gross vehicle weight were not also increased.

For many commodities, physical characteristics dictate the types of equipment that could be used to carry the commodities. Bulk commodities are almost always shipped in vehicles with specialized body types designed to accommodate their size. For example, construction equipment, building materials, lumber, large spools of wire and other similar commodities that cannot easily be loaded in a dry van typically are moved on flatbed or other specialized trailer.

This analysis estimated the vehicle configurations and body types that could be used to transport various commodities. It also estimated the tare weights of each vehicle configuration and body type of interest from which maximum payloads were estimated.

Methodology

The primary source of information on the vehicle configurations and body types used to haul various commodities is the VIUS. As noted above, the last VIUS was conducted in 2002, but the basic types of equipment used to haul various types of commodities have not changed significantly since that survey. The VIUS asked specific questions concerning the vehicle configurations and body types used to haul different commodities. It also asked the percentage of miles a vehicle was fully loaded and empty. Based on responses to these questions and estimates of commodity density, a payload distribution was developed for each commodity and vehicle configuration.

As noted above, the commodity groups contained in the FAF are not homogeneous. Within each group there may be a range of different commodities with different densities and different physical characteristics that affect the body type used to haul those commodities. For each commodity group within the FAF the distribution of vehicle configurations, body types, and payloads was estimated based on information from the VIUS.

During the process of disaggregating FAF to the county level a number of O-D pairs had annual tonnage volumes for specific commodities below 25 tons. It is unclear whether such small shipments of individual commodities actually occurred, but it is highly unlikely that they were hauled in truckload lots. Rather than discard these observations, the moves were treated as LTL shipments regardless of the commodity. The average volume handled in this manner was 4 tons.

Tonnage for each commodity group was assigned to configurations (single unit trucks, truck trailer combinations, and single, double, and triple trailer combinations), number of axles, and equipment type (dry, bulk, open, refrigerated body types) based on the ton-mile weighted distribution of the commodity group reported in the 2002 VIUS. Likewise, VIUS data were used to estimate length-of-haul distributions (less than 100 miles, 100 to 200 miles, over 200 miles) for each commodity group.

Results

Figure 4 shows the estimated distribution of shipments in 2011 by body type for the two most prevalent tractor-semitrailer configurations, the 3-S2 (five-axle tractor semitrailer) and 3-S3 (six-axle tractor semitrailer). More than ten times as many shipments were made in the five-axle tractor-semitrailer than in the six-axle vehicle. The primary reason is that the five axle vehicle can carry the maximum Federal GVW limit on Interstate highways within current axle load limits and within the Federal Bridge Formula. There is no need for the additional axle that adds weight to the vehicle and increases fuel consumption as well. Within the 3-S2 configuration, bulk body types account for about half of all shipments, followed by dry vans (28 percent), flatbeds (14 percent), and refrigerated trailers (7 percent). This is not the same as the portion of registered trucks by body type. Because **Figure 4** shows the rankings by number of shipments, it is skewed towards those body types that carry heavier commodities. Among the 3-S3 configurations, bulk trailers account for an even larger share of all loads (64 percent) followed by dry vans (22 percent) flatbeds (11 percent) and refrigerated units (3 percent). The large share of bulk trailers among 3-S3 configurations is consistent with the use of these vehicles to haul cargo at weights greater than typically are allowed on 5-axle vehicles. Many of these loads are hauled under special permit.

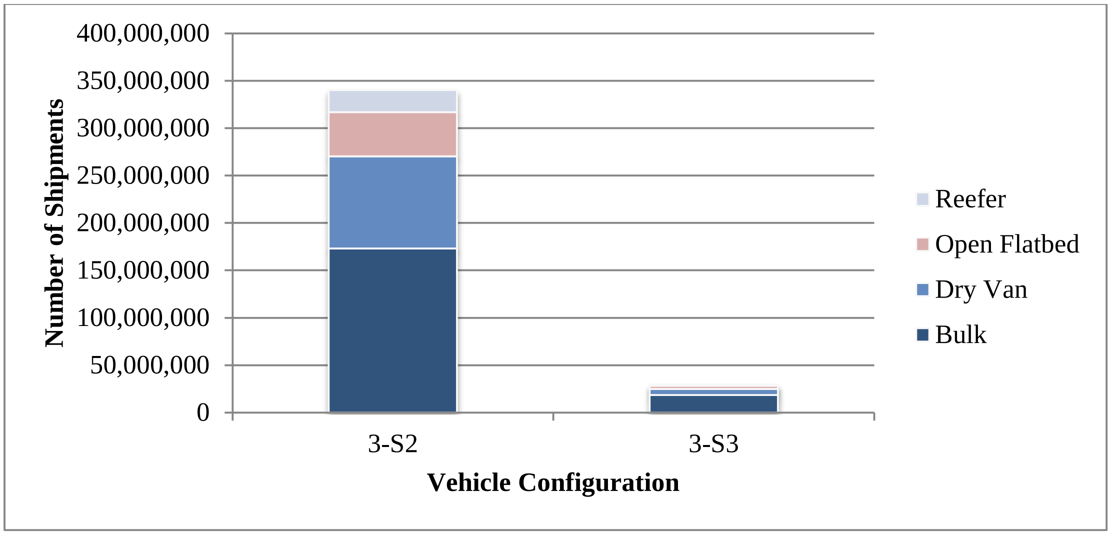


Figure 4: Current Distribution of Shipments by Body Type for Five- and Six-axle Tractor Semitrailers

Table 4 shows the estimated tare (empty) weights of the vehicles analyzed in this 2014 CTSW Study. Many factors can affect a vehicle's tare weight including where it operates (flat versus mountainous terrain), the construction of the trailer, whether the tractor has a sleeper and the dimensions of the sleeper, whether the vehicle has an auxiliary power unit to provide power when parked without having to run the engine, and whether the vehicle is equipped with dual or "super-single" tires. Thus the tare weights shown should be viewed as representative; weights of individual vehicles could vary.

Table 4: Assumed Tare Weights of Control and Scenario Vehicles (pounds)

Scenario	Configuration (Gross Vehicle Weight (pounds))	Tare Weight			
		Dry Van	Flatbed	Reefer	Bulk
control vehicle	5-axle vehicle (3-S2) (80,000)	30,800	26,180	32,650	32,960
1	5-axle vehicle (3-S2) (88,000)	30,800	26,180	32,650	32,960
2	6-axle vehicle (3-S3) (91,000)	32,854	27,920	34,825	35,150
3	6-axle vehicle (3-S3) (97,000)	32,854	27,920	34,825	35,150
control vehicle	Tractor plus two 28-ft trailers (2-S1-2) (80,000)	30,350	NA	NA	NA
4	Tractor plus two 33-foot trailers (2-S1-2) (80,000)	32,300	NA	NA	NA
5	Tractor plus three 28-foot trailers (2-S1-2-2) (105,500)	39,275	NA	NA	NA
6	Tractor plus three 28-foot trailers (3-S2-2-2) (129,000)	42,622	NA	NA	NA

NA=Not Applicable

(Scenarios 4, 5, 6 assume a non-sleeper cab-over-engine in dry van LTL operation – 3,000 pounds less weight than a conventional sleeper cab)

Tare, or unloaded, weights of different body types can vary significantly as shown in **Table 4**. On average, flatbed trailers are approximately 15 percent lighter than dry vans while refrigerated trailers and bulk trailers are estimated to be 6 percent and 7 percent heavier, respectively, than dry vans on average. Within these broad classifications, there may be additional variation; for example, bulk trailers include dumps, tanks, transit mixers, etc., each of which has a unique design and tare weight.

Table 5 shows the assumed payloads that can be carried by each of the scenario and base-case vehicles based on the tare weights. The maximum payload is simply the maximum gross vehicle weight minus the vehicle's tare weight.

Table 5: Maximum Assumed Payloads of Control and Scenario Vehicles (pounds)

Scenario	Configuration	Maximum Payload			
		Dry Van	**Flatbed**	**Reefer**	**Bulk**
	5-axle vehicle (3-S2) [control vehicle]	49,200	53,820	47,350	47,040
1	5-axle vehicle (3-S2)	57,200	61,820	55,350	55,040
2	6-axle vehicle (3-S3)	58,146	63,080	56,175	55,850
3	6-axle vehicle (3-S3)	64,146	69,080	62,175	61,850
	Tractor plus two 28-ft trailers (2-S1-2) [control vehicle]	49,650	NA	NA	NA
4	Tractor plus two 33-foot trailers (2-S1-2)	47,700	NA	NA	NA
5	Tractor plus three 28-foot trailers (2-S1-2-2)	66,225	NA	NA	NA
6	Tractor plus three 28-foot trailers (3-S2-2-2)	86,378	NA	NA	NA

NA=Not Applicable

3.4 Calculation of Total Highway Travel by Configuration, Highway Network and Vehicle Operating Weight

Scope

An important input to the modal shift analysis is the base case distribution of travel by vehicle configuration, highway network, and operating weight. These data are needed not just for the modal shift analysis, but for all other tasks in this project. For the modal shift analysis the focus is on those vehicle configurations and weight groups from which freight traffic might divert to the scenario vehicles. Many truck configurations other than those selected for use in this study's scenarios are in use today, but as previously noted, these generally have specialized uses, and traffic would not be likely to divert from those configurations to the scenario vehicles. Among the configurations not subject to significant diversion are tractor-semitrailers that already operate with more than six axles, truck-trailer combinations that have specialized uses, and twin trailers with more than five axles that would not be economical for LTL operations. This 2014 CTSW Study does not analyze the potential diversion of double-trailer dump construction vehicles. While some diversion might occur, it would have a small impact on national VMT because these are principally short-haul vehicles. Methods used to estimate base-case travel are described in detail in the *Volume II: Data Acquisition and Technical Analysis Report.*

Results

Table 6 shows VMT by vehicle configuration and operating weight. Data are shown only for the control vehicles for this study (five-axle semitrailers and twin 28' trailers) and the scenario vehicle classes (six-axle tractor-semitrailer, seven-axle triple, and nine-axle triple). The Oth-CS5 designation represents a five-axle tractor-semitrailer with axles at the rear of trailer split by at least 8 feet. Note that for the purposes of this study, specifically for modelling impacts on pavement infrastructure, these split-axle sets were treated as a separate and different truck configuration. The Oth-CS5 variation appears in Tables 6-18 as a standalone configuration. No travel is shown for the twins with 33-foot trailers since that vehicle currently is not in wide use around the country.

Table 6: Base Case Distribution of VMT by Vehicle Configuration and Operating Weight 2011

Operating Weight (lb., 000)	Tractor-Semitrailers			Twin Trailers	Triple Trailers	
	3-S2	Oth-CS5	3-S3	2-S1-2	2-S1-2-2	3-S2-2-2
<60	63,090,911,956	7,934,351,711	1,129,801,222	2,665,558,717	19,228,582	144,555
60-65	8,436,004,234	1,270,276,441	139,393,766	765,561,904	8,272,858	3,380
65-70	9,755,202,047	1,722,396,820	149,081,933	593,116,217	11,024,906	3,774
70-75	12,131,995,576	2,335,314,116	160,519,434	388,882,880	14,540,758	6,233
75-80	11,721,521,062	2,206,146,822	184,806,915	251,194,098	18,270,645	5,001
80-85	5,048,658,924	919,406,936	153,875,149	95,045,506	20,507,241	6,365
85-90	1,857,437,727	336,038,655	126,847,310	30,948,103	19,939,742	4,675
90-95	762,855,262	135,304,741	92,368,197	13,206,028	15,470,712	5,082
95-100	404,661,066	69,550,675	71,514,248	7,876,063	11,734,620	9,919
100-105	230,153,662	38,811,758	51,721,979	5,204,639	8,628,988	8,006
105-110	155,206,191	25,542,732	36,267,245	4,099,634	6,739,153	12,071
110-115	103,776,929	16,591,831	20,802,860	2,948,539	4,639,560	16,141
115-120	78,073,942	12,411,907	12,759,868	2,241,939	3,074,466	55,325
120-125	53,257,796	8,595,469	7,471,538	1,766,691	1,807,628	48,569
125-130	35,349,508	5,866,926	4,833,108	1,293,027	905,692	17,832
>130	87,050,434	13,795,643	8,819,656	3,144,877	785,979	33,967
Total	113,952,116,312	17,050,403,179	2,350,884,425	4,832,088,859	165,571,527	380,891

The five-axle semitrailers have by far the greatest VMT of these vehicle classes. The split axles on the Oth-CS5 are considered single axles for weight enforcement purposes, allowing them to carry 20,000 pounds each under Federal axle load limits, compared to a total of 34,000 pounds that can be carried on the tandem axle of the 3-S2. Together the 3-S2 and the other CS5 traveled over 130 billion miles in 2011 compared with 2.4 billion for the six-axle tractor-semitrailer, 4.8 billion for twin 28-trailer combinations, and 222 million for triple trailer combinations. Among the triples, the seven-axle configuration dominates. That is the vehicle most frequently used in LTL operations. Triple-trailer configurations with nine or more axles account for less than

400,000 miles of total truck travel. Most of that travel is for the transportation of bulk commodities in the several States that allow those vehicles to operate at high weights.

Each configuration has considerable travel at weights above the Federal weight limit of 80,000 pounds on the Interstate System. Some of this occurs under special permit, some is allowed without special permit off the Interstate System in States where weight limits are higher than the Federal limits on the Interstate System. Some of the travel observed at weights above 80,000 pounds also represents illegal overloads. Shipping that uses by five- and six-axle semitrailers above 80,000 pounds would particularly benefit from the availability of the higher maximum vehicle sizes and weights being analyzed in this study, but LTL cargo that could use triples would also benefit.

Table 7 shows highway travel by vehicle configuration and functional highway system. The majority of travel by five-axle tractor-semitrailers (3-S2) and twin trailer combinations is on the Interstate System, but this is not true for other vehicle classes. More travel by six-axle tractor-semitrailers (3-S3) is off the Interstate System because they generally haul bulk commodities, and State weight limits often are higher off the Interstate System.

Table 7: 2011 Base Case VMT by Vehicle Class and Highway Functional Class 2011

Highway Functional Class	Tractor Semitrailers			Twin Trailers	Triple Trailers	
	3-S2	Oth-CS5	3-S3	2-S1-2	2-S1-2-2	3-S2-2-2
Rural Interstate	36,143,310,663	5,201,712,388	463,281,220	1,922,687,499	39,856,969	102,166
Rural Other Principal Arterial	15,239,993,256	3,019,396,594	354,089,469	525,095,591	19,466,596	11,442
Rural Minor Arterial	5,225,254,321	837,428,775	219,492,618	138,743,046	14,034,412	5,746
Rural Major Collector	7,134,100,148	1,079,311,991	285,362,621	177,331,422	12,480,319	15,614
Rural Minor Collector	1,260,535,340	178,344,977	42,259,751	23,703,464	1,144,720	769
Rural Local	915,647,145	145,671,982	46,976,361	27,963,951	1,181,205	1,460
Urban Interstate	25,961,477,627	3,556,978,703	346,701,822	1,018,607,874	23,205,416	19,559
Urban Freeway / Expressway	5,708,394,628	813,851,633	76,570,075	372,128,620	1,760,676	6,148
Urban Other Principal Arterial	7,891,868,092	1,078,434,245	246,637,664	258,000,227	11,555,662	28,775
Urban Minor Arterial	4,893,550,947	663,522,956	127,724,532	161,324,996	7,338,514	3,534
Urban Collector	2,012,794,735	272,084,381	73,129,166	76,591,096	21,034,714	99,666
Urban Local	1,565,189,410	203,664,554	68,659,126	129,911,073	12,512,324	86,012
Total	113,952,116,312	17,050,403,179	2,350,884,425	4,832,088,859	165,571,527	380,891

Data for the seven-axle and nine-axle triple trailers show considerable travel on lower order systems in both rural and urban areas, but those distributions are significantly affected by the limited operations of triple-trailer combinations. Several Western States allow triples to run widely off the Interstate System, but only a few Eastern States allow triples, and then only on turnpikes. Triples must assemble and disassemble immediately adjacent to the turnpike in those Eastern States.

Figure 5 shows the base case operating weight distribution for five- and six-axle semitrailers in 2011. The two five-axle combinations have peaks between 75,000 and 80,000 pounds, but the six-axle tractor-semitrailer has a much less pronounced peak at those weights. That vehicle travels substantial distances at weights above the 80,000 pound Federal limit.

Figure 6 shows the base case operating weight distributions for multi-trailer combinations. The twin trailer combination does not have a peak at the upper end of its weight distribution. Over half of its loaded travel is at weights at or below 60,000 pounds.

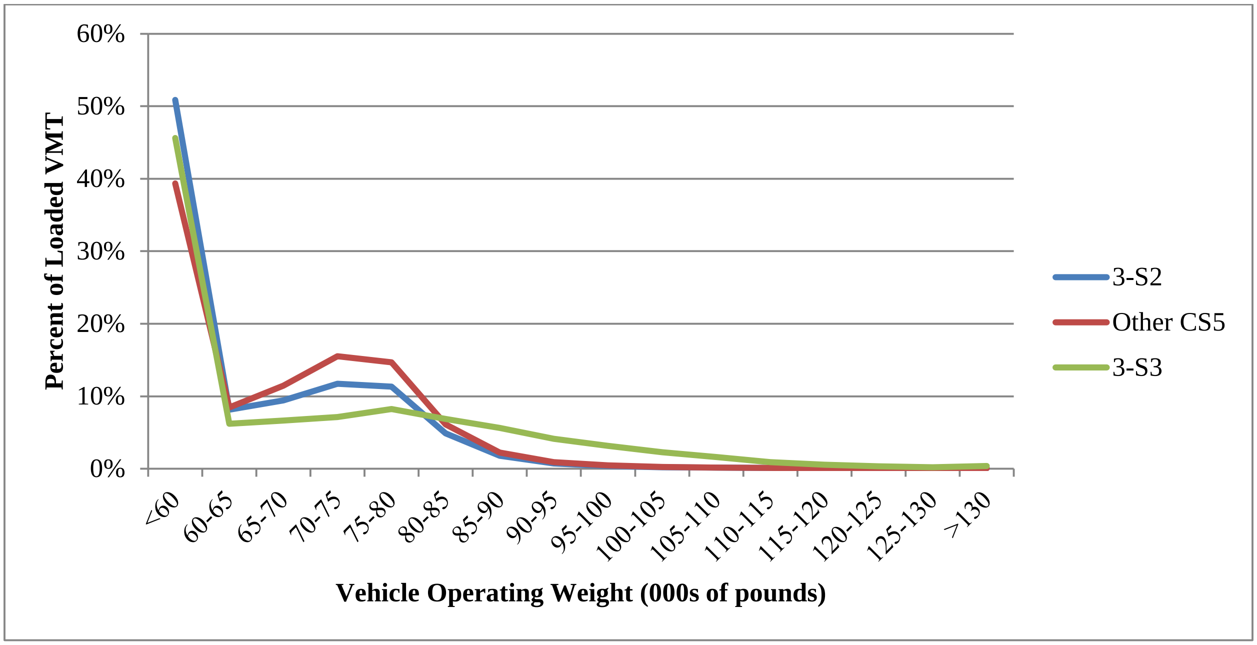


Figure 5: 2011 Base Case Operating Weight Distributions for Loaded Five and Six-axle Tractor-Semitrailers

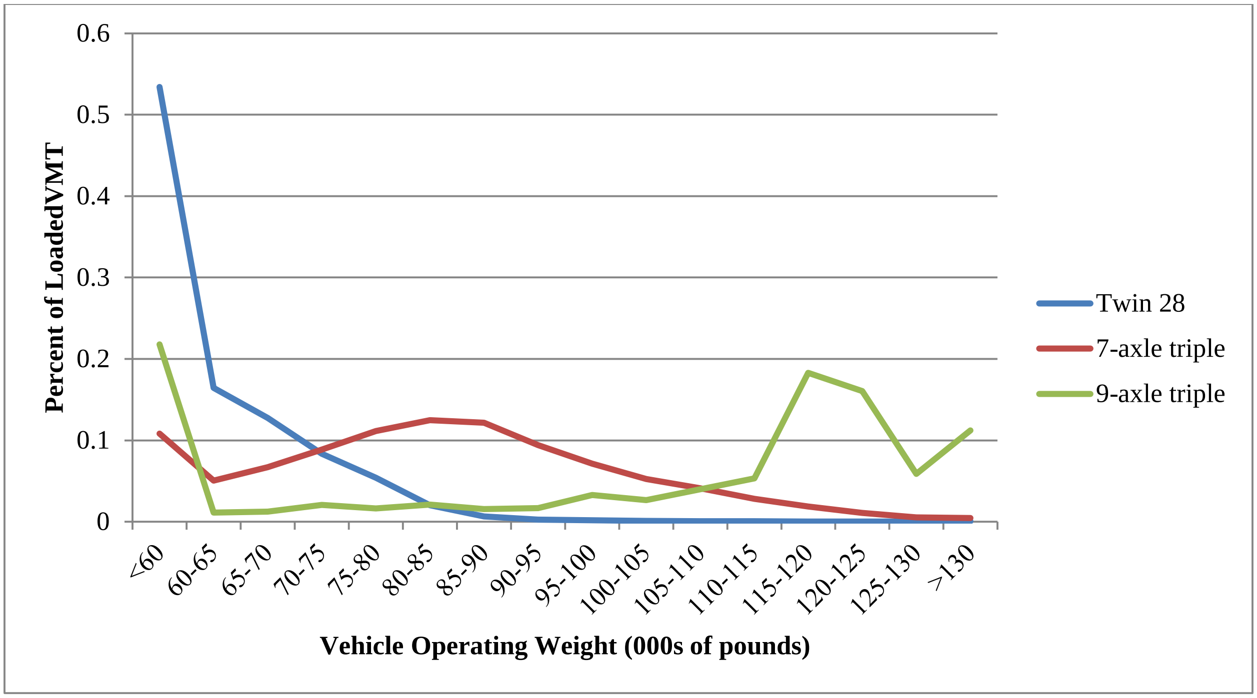


Figure 6: VMT 2011 Operating Weight Distribution for Loaded Twin 28-Foot Trailer and Triple Trailer Combinations

Figure 7 illustrates the share of VMT by five-axle (3-S2) tractor-semitrailers that potentially is susceptible to mode shifts if vehicles with higher GVW limits were allowed to operate. These vehicles travel more than 70 percent of total miles (and two-thirds of loaded miles) with operating weights of less than 70,000 pounds. These vehicles could load heavier but do not. Twenty-three percent of loaded 3-S2 VMT occur at operating weights between 70,000 and 80,000 pounds. These shipments could potentially benefit from higher weight allowances.

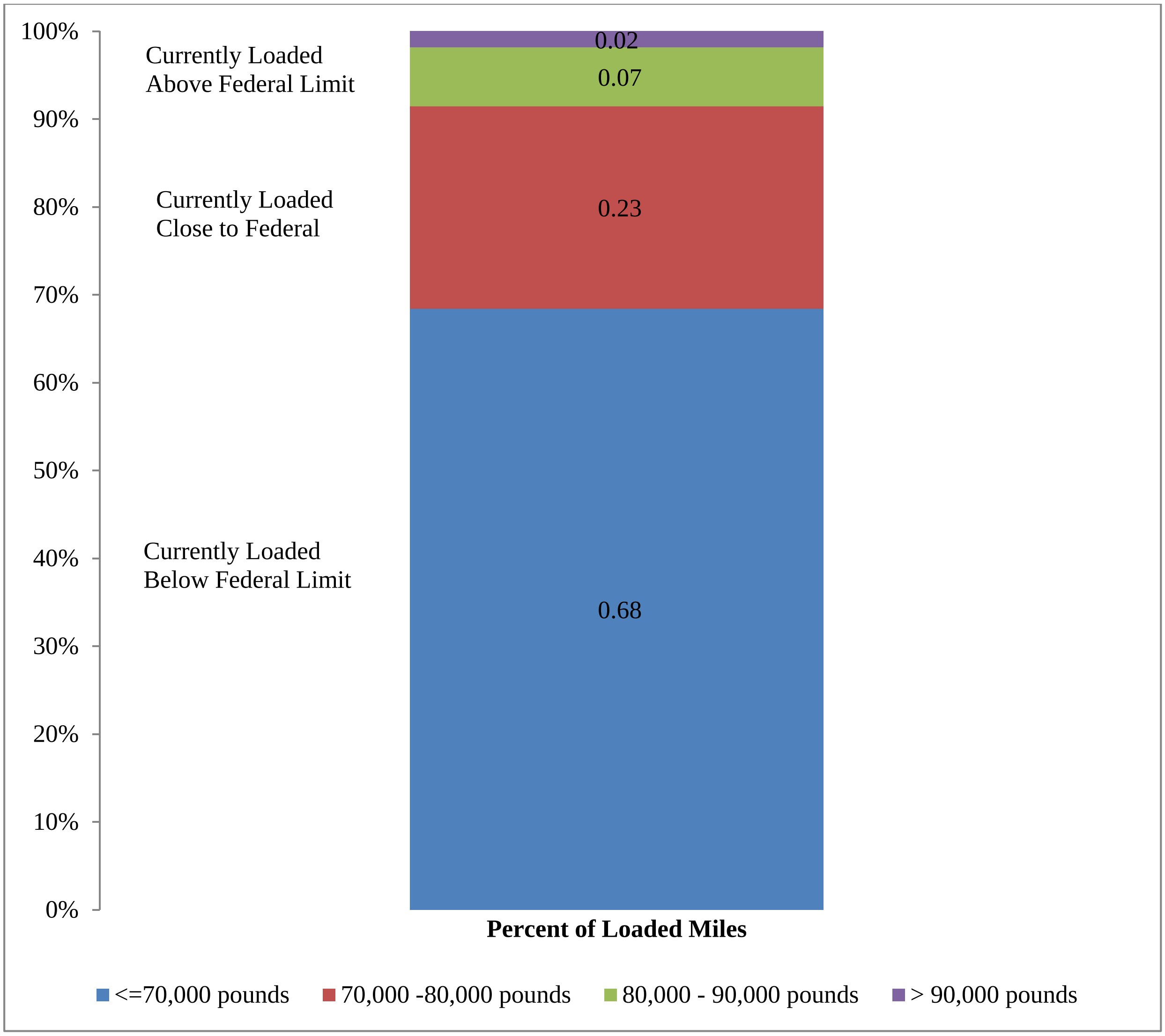


Figure 7: Share of Loaded VMT by 3-S2 that is Potentially Subject to Diversion

3.5 Calculation of Base Case Transportation Costs from Origin to Destination for Each Shipping Alternative

Scope

Truck rates are determined in large part based on the mileage between origin and destination, the equipment used to transport the shipment, and any special handling requirements to transport the commodity. In this subtask, transportation cost factors included in ITIC for base case and scenario vehicle configurations are updated and then applied to the FAF data on shipments of different commodities between different O-D pairs. These transportation costs, along with the non-transport logistics costs included in ITIC, are used to identify the most likely mode that would be chosen based on total logistics costs. Methods used are similar to those used in previous applications of ITIC by USDOT.

Methodology

The truck rate data used by FHWA in its last application of ITIC consisted of single trailer dry-van truckload rates for 113 market areas. Origins and destinations of the commodity flow database were mapped to one of the 113 markets in the truck rate database. One of the issues these rates reflect is existing lane imbalances, where head-haul/outbound rates higher than back-haul/inbound rates. The availability of more up-to-date rate information was examined, but no suitable truck rate databases were identified that were superior to the data last used by FHWA.

These market-based freight truckload rates were adjusted to account for several different factors including:

- Price differentials between dry-van trailers and specialized trailers (e.g. flatbed, tanker, refrigerated),
- Differences in empty-to-loaded ratios between dry-van and specialized trailers,
- The additional capital cost of multi-trailer configurations, and
- Overall changes in trucking costs between the year represented by the data and 2011, the base year for this analysis as reflected in the Producer Price Index for Transportation Services.

Differences in vehicle operating costs among the base case and scenario vehicles are important factors affecting the relative transportation costs of using different vehicle configurations. Among the vehicle operating cost components reflected in the ITIC model are cargo handling costs, line haul transportation costs, and pickup and delivery costs. These factors are specified for each vehicle configuration and body type analyzed in ITIC.

Similar cost components are included in the ITIC model for rail shipments. Among the rail cost elements are pickup and delivery costs, both per shipment and per mile. These costs vary for rail carload and TOFC/COFC moves. Revenues for shipments come directly from the Carload Waybill Sample.

The ITIC model was run against every record in the FAF database and the Carload Waybill database to estimate transportation costs by mode and vehicle configuration. This information was combined with estimates of non-transport logistics costs for each move to determine the mode and vehicle configuration with the lowest total logistics cost.

Results

The output of this effort is an updated ITIC model containing the most up-to-date data on the various transportation cost elements that affect mode choice decisions. Using these updated cost elements, costs were estimated for moves by base case and scenario vehicles of each commodity flow in the FAF and Carload Waybill Sample.

3.6 Calculation of Base Case and Scenario Non-Transport Logistics Costs for Each Shipping Alternative

Scope

Mode choice decisions are strongly influenced by non-transport logistics costs, including order cost, inventory carrying costs, storage, loss, and damage. In this subtask, non-transport logistic cost factors included in ITIC were reviewed, updated as necessary, and then applied to the FAF and Carload Waybill data on shipments of different commodities between different O-D pairs. These transportation costs, along with the non-transport logistics costs included in ITIC, are used to identify the most likely mode that would be chosen based on total logistics costs. The study ream used methods similar to those used by USDOT in previous applications of ITIC.

Methodology

Non-transport logistics costs in the ITIC model had been reviewed and updated by USDOT over the past few years so no major changes were required to the costs themselves.

For LTL operations, the USDOT study team opted to exclude non-transport logistics costs from the modal shift analysis since these vary primarily according to shipment size. Nothing in Scenarios 4-6—which analyzed vehicles primarily used for LTL shipments—would affect the size of individual shipments. The primary impact would be an increase in the number of shipments that could be hauled in a single trip.

For truckload freight, the study team calculated non-transport logistics costs for shipments of each commodity between each O-D pair and each potential mode. These non-transport logistics costs were combined with the transportation costs discussed in section 3.5 above to estimate total logistics costs for each move. These total logistics costs form the basis for estimating the choice of mode and vehicle configuration.

Results

The output of this sub-task is an estimate of non-transport logistics costs for moves of each commodity flow in the FAF and Carload Waybill Sample by base case and scenario vehicles.

3.7 Estimation of Total Logistics Costs and Scenario Impacts

Scope

This effort estimates the total logistics costs to move shipments of each commodity group between each origin and destination by base-case vehicles, railroads, and each scenario vehicle. The ITIC model selects the vehicle or mode with the lowest total logistics cost, including transportation costs and non-transport logistics costs. Each scenario involves only a single scenario vehicle. The ITIC model chooses either the base case vehicle/mode or the scenario vehicle. Results of the analysis of individual commodity movements between various origins and destinations are aggregated to estimate total changes from the base case that would occur if the scenario vehicle were allowed to operate.

Methodology

The analysis uses the ITIC model that has been described in preceding sections. Assumptions and limitations affecting the analysis are discussed above.

Results

Scenario 1

Scenario 1 would allow five-axle tractor semitrailers to operate at gross vehicle weights of 88,000 pounds. As discussed in the scenario descriptions, this vehicle could operate on the National Truck Network established in the Surface Transportation Assistance Act of 1982 and would have the same access off the network to reach terminals and facilities for food, fuel, rest, and repairs as the 80,000-pound, five-axle tractor-semitrailer currently operating widely in every State. For analytical purposes the USDOT study team assumes this vehicle to be able to travel directly to all origins and destinations identified in the FAF via the shortest path identified in the vehicle routing conducted for this study.

The primary impact of Scenario 1 would be to allow shipments currently moving in five-axle tractor-semitrailers to have a higher maximum GVW. For analytical purposes, the study team assumes that only truck traffic currently moving at weights above 75,000 pounds would be affected by this higher weight limit. Assuming that the same quantity of freight was transported under Scenario 1 as in the Base Case, allowing higher weights would reduce total travel since fewer trips would be required to haul the same quantity of goods.

Table 8 shows the overall change in VMT associated with increasing Federal weight limits for five-axle (3-S2) tractor-semitrailers from 80,000 pounds to 88,000 pounds and includes the Oth-CS5 designation, which represents a five-axle tractor-semitrailer with axles at the rear of trailer split by at least 8 feet. It is estimated that raising the Federal weight limit to 88,000 pounds for five-axle semitrailers would reduce total VMT by those vehicles by less than 1 percent. Few rail shipments shift to the heavier tractor-semitrailers analyzed in Scenarios 1-3. Those shipments that do shift from rail to truck under Scenarios 1-3 tend to be carload shipments that travel relatively short distances. Railroads, however, likely would have to reduce rates on many shipments to retain the freight traffic. This would have an adverse impact on their financial performance. Rail impacts are discussed in greater detail in Chapter 4.

**Table 8: Scenario 1 VMT for
5-axle Tractor-Semitrailers (millions)**

Base Case			Scenario 1		
3-S2	**Oth-CS5**	**Total**	**3-S2**	**Oth-CS5**	**Total**
113,952	17,050	131,003	113,226	16,916	130,142
Percent Change			-0.6%	-0.8%	-0.6%

Figure 8 shows how the weight distribution for five-axle tractor-semitrailers is estimated to shift under Scenario 1. The peak at the current Federal weight limit of 80,000 pounds would disappear, but a new peak at about 88,000 pounds would appear. As noted, it is assumed that shipments currently operating at less than 75,000 pounds would not be affected by the higher weight limit.

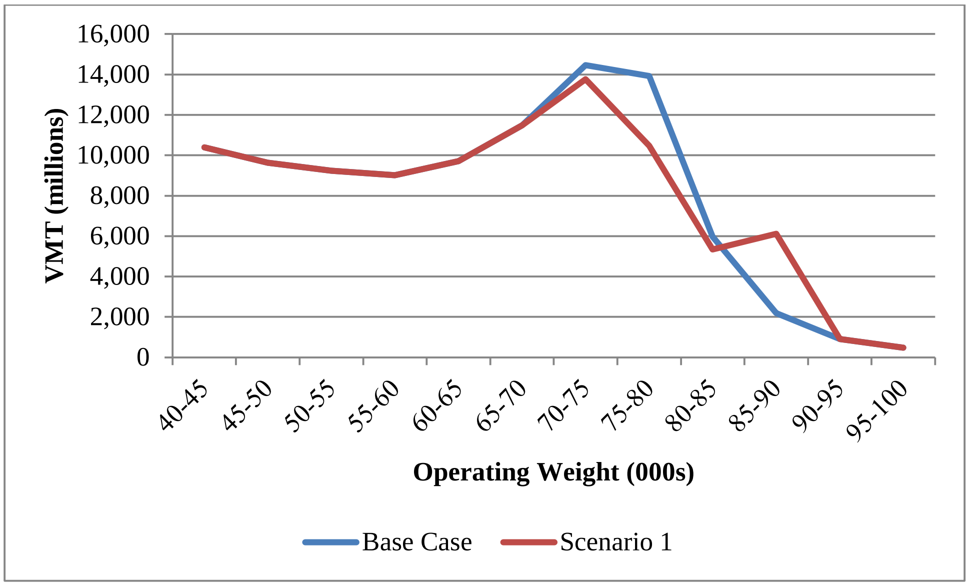


**Figure 8: Scenario 1 Shift in Weight Distribution
for 5-axle Tractor Semitrailers**

<u>Scenario 2</u>

Scenario 2 would allow a six-axle (3-S3) tractor-semitrailer to operate at a maximum GVW of 91,000 pounds on the National Truck Network with the same access to terminals and services off the network as a standard five-axle (3-S2) tractor-semitrailer with a maximum weight of 80,000 pounds. Shipments of bulk and other commodities that reach the vehicle's maximum gross weight before filling the cubic capacity of the trailer would see the greatest benefit from this scenario. Shipping traffic for these items would potentially shift away from existing five-axle tractor-semitrailers, and the weight distribution of traffic currently operating in six-axle semitrailers would shift upward toward the 91,000 pound gross vehicle weight limit assumed in this scenario.

Table 9 shows the change in VMT for vehicle classes affected by the increased weight limits assumed under Scenario 2. **Table 10** illustrates VMT change by operating weights.

Table 9: Changes in Total VMT under Scenario 2 (millions)

Base Case				Scenario 2			
3-S2	**Oth-CS5**	**3-S3**	**Total**	**3-S2**	**Oth-CS5**	**3-S3**	**Total**
113,952	17,050	2,351	133,353	101,054	14,660	16,438	132,152
Percent change				-11%	-14%	599%	-1%

Table 10: VMT Change by Operating Weight Distributions for Key Vehicle Configurations under Scenario 2 (Millions)

Operating Weight (lb.)	Base Case				Scenario 2			
	3-S2	**Oth-CS5**	**3-S3**	**Total**	**3-S2**	**Oth-CS5**	**3-S3**	**Total**
<= 70,000	81,282	10,927	1,418	93,627	81,282	10,927	1,418	93,627
70,001-76,000	14,766	2,840	195	17,801	13,585	2,614	195	16,394
76,001-82,000	11,864	2,212	219	14,294	3,178	594	4,872	8,643
82,001-88,000	3,621	652	167	4,440	659	119	4,454	5,232
88,001-94,000	1,164	210	122	1,495	1,096	197	5,268	6,561
> 94,000	1,255	210	230	1,695	1,255	210	230	1,695
Total	113,952	17,050	2,351	133,353	101,054	14,660	16,438	132,152

Figures 9 and 10 illustrate graphically how freight traffic volumes at different operating weights change in Scenario 2 for 3-S2 and 3-S3 vehicle configurations. Beginning at the 76,000 to 82,000 pound weight range there would be large decreases in traffic for 3-S2 configurations and large increases in volume for 3-S3 configurations. Projections indicate that some shippers would continue to utilize the 3-S2 configuration at weights above 80,000 pounds due to permit operations and grandfathered State limits. Increases in 3-S3 traffic are particularly dramatic at weights above 80,000 pounds.

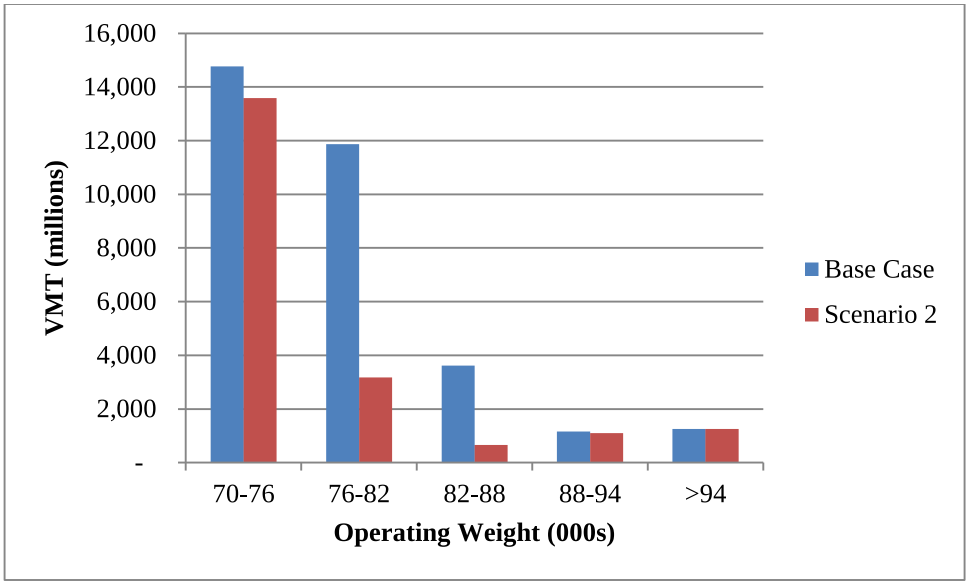


Figure 9: Scenario 2 Changes in 3-S2 Traffic by Operating Weight

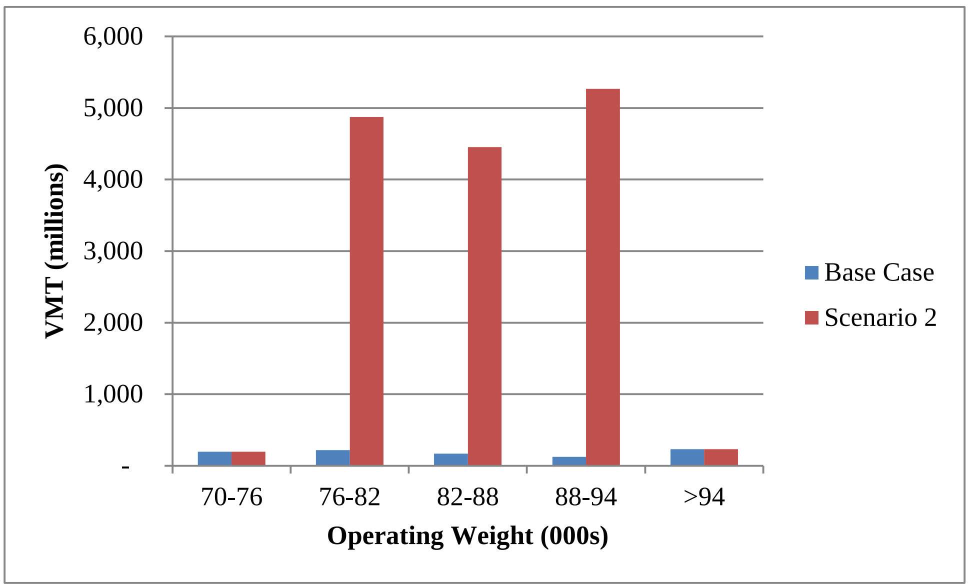


Figure 10: Scenario 2 Changes in 3-S3 Traffic by Operating Weight

<u>Scenario 3</u>

Scenario 3 is similar to Scenario 2 except the weight limit for six-axle tractor semitrailers is 97,000 pounds compared to 91,000 pounds in Scenario 2. The 97,000 pound 6-axle vehicle is assumed to be allowed on the entire National Truck Network and to have the same access off that network as current five-axle tractor-semitrailers.

Table 11 shows changes in total VMT for key vehicle configurations that could be expected under Scenario 3. Travel in the standard five-axle tractor-semitrailer is estimated to decrease by 14 percent while travel in the six-axle vehicle would increase by 700 percent. Total travel by these five- and six-axle semitrailers would decrease by 2 percent.

Table 11: Changes in Total VMT under Scenario 3 (Millions)

Base Case				Scenario 3			
3-S2	**Oth-CS5**	**3-S3**	**Total**	**3-S2**	**Oth-CS5**	**3-S3**	**Total**
113,952	17,050	2,351	133,353	97,613	14,021	18,841	130,475
Percent change				-14%	-18%	701%	-2%

Table 12 shows changes in the operating weight distributions for key vehicle classes under Scenario 3. **Figures 11 and 12** illustrate these changes graphically. As with Scenario 2, there is a significant shift of traffic from five- to six-axle vehicles. Projections indicate many freight shippers would be able to take advantage of the additional 6,000 pounds of payload under this scenario, contributing to a greater reduction in total VMT for Scenario 3 compared to Scenario 2.

Table 12: VMT Change by Operating Weight Distributions for Key Vehicle Configurations in Scenario 3 (Millions)

Operating Weight (lb.)	Base Case				Scenario 3			
	3-S2	**Oth-CS5**	**3-S3**	**Total**	**3-S2**	**Oth-CS5**	**3-S3**	**Total**
<= 62,000	66,315	8,389	1,183	75,888	66,315	8,389	1,183	75,888
62,001--68,000	10,872	1,784	175	12,831	10,872	1,784	175	12,831
68,001-74,000	13,593	2,584	187	16,364	13,593	2,584	187	16,364
74,001-80,000	14,356	2,711	219	17,286	4,729	899	584	6,213
80,001-86,001	5,597	1,018	181	6,796	637	116	3,759	4,512
86,001-92,000	1,684	305	141	2,129	195	35	6,060	6,291
92,001-98,000	661	115	97	874	398	69	6,724	7,191
>98,000	325	55	69	449	325	55	69	449
Total	113,952	17,050	2,351	133,353	97,613	14,021	18,841	130,475

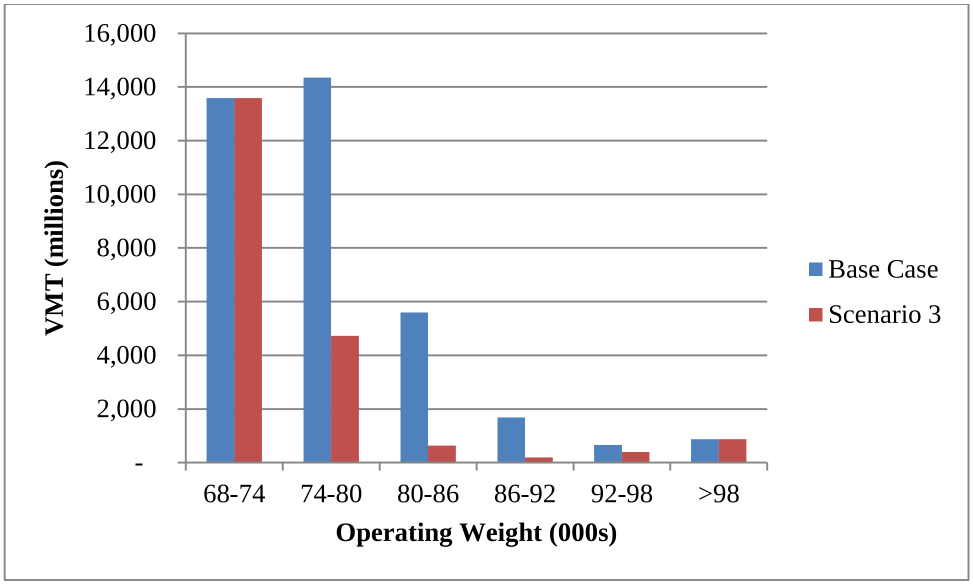


Figure 11: Scenario 3 Change in 3-S2 Traffic by Operating Weight

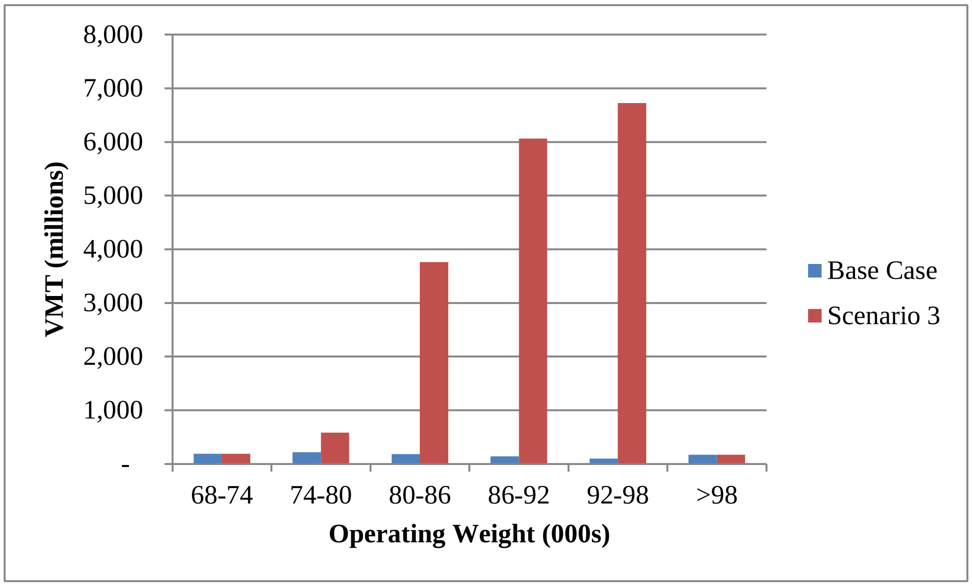


Figure 12: Scenario 3 Change in 3-S3 Traffic by Operating Weight

Figure 13 shows commodities that had the most shipments shift from the base case five-axle tractor-semitrailer to scenario vehicles and weights under Scenarios 1, 2, and 3. Most are bulk commodities that are hauled in various body types other than dry vans.

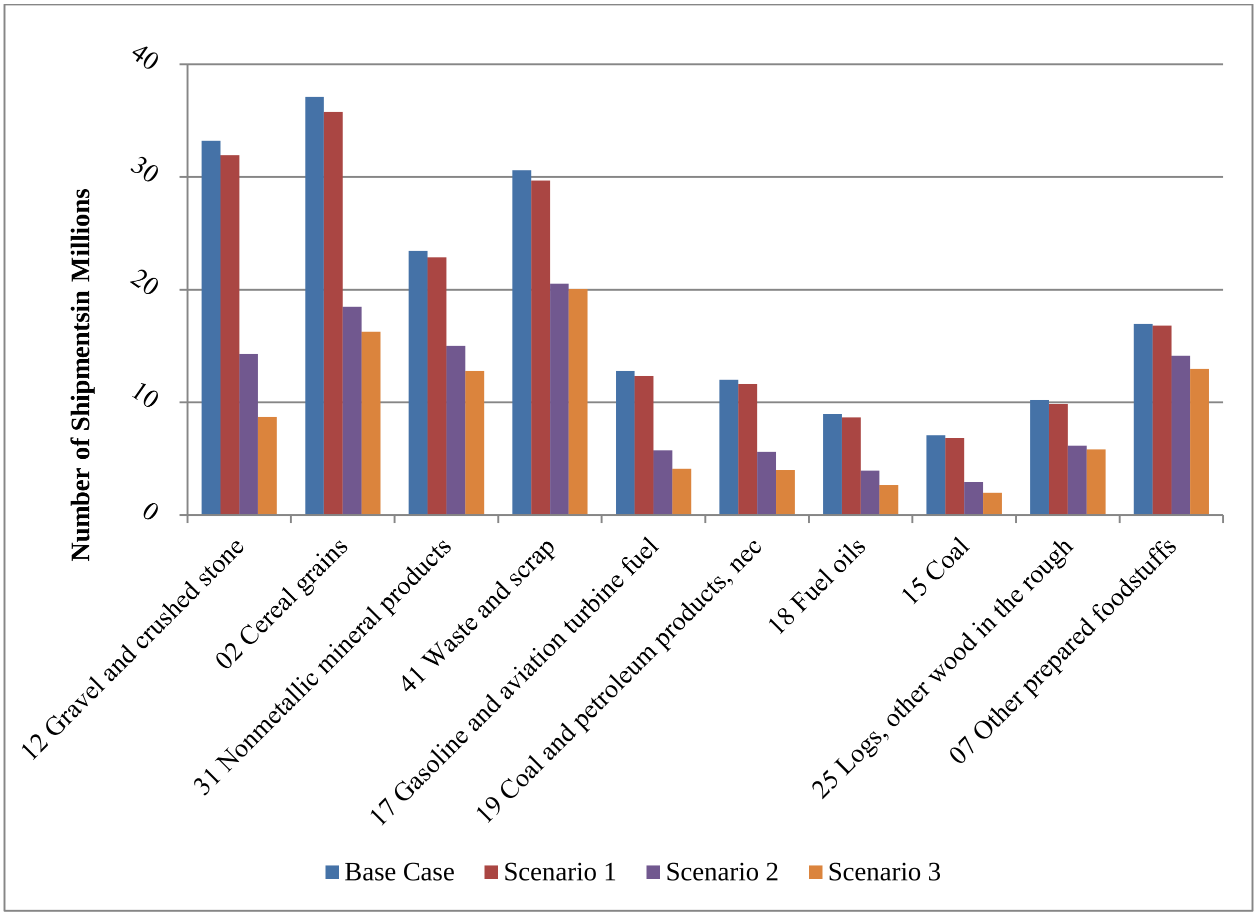


Figure 13: Changes in 3-S2 Shipments for Top 10 Commodities under Scenarios 1, 2, 3

<u>Scenario 4</u>

Scenario 4 analyzes the potential impacts of allowing twin 33-foot (2-S1-2) trailer combinations to operate at a maximum gross vehicle weight of 80,000 pounds. As noted in the scenario description, this analysis focuses on LTL cargo, including packages and mail. The twin 33-foot double trailers are assumed to operate on the same network as twin 28-foot doubles that are widely used for LTL operations today, and the new configuration would have the same access off that network to reach terminals and facilities for food, fuel, rest and repair.

Currently LTL over-the-road cargo is hauled primarily in five-axle tractor-semitrailers and twin 28-foot doubles. The FAF does not have a separate commodity group that includes all LTL shipments. The closest commodity group is mixed freight. In the analysis, mixed freight was used as a surrogate for LTL shipments with the recognition that shipments from other commodity groups also may be shipped in LTL operations. The VIUS differentiates LTL from TL shipments. Based on data from the VIUS, an estimated 17 percent of 3-S2 VMT is LTL traffic and 84 percent of 2-S1-2 traffic is LTL. The ITIC model was used to estimate the percentage of mixed cargo shipments that would shift from 3-S2 and 2-S1-2 (twin 28-foot doubles) configurations to the 2-S1-2 (twin 33-foot doubles) scenario vehicle. This percentage was applied to the portion of 3-S2 and 2-S1-2 (twin 28-foot doubles) traffic estimated to be used for LTL shipments.

Table 13 shows base case VMT for vehicles affected by truck size and weight changes analyzed in Scenario 4 and compares that VMT for those vehicle classes following shifts estimated under Scenario 4. The VMT for all other vehicle classes is assumed to be unaffected by changes under Scenario 4. Shifts to the twin 33-foot doubles from both five-axle semitrailers (including the 3-S2 and other CS5 configurations) and twin 28-foot doubles are estimated.

Table 13: Comparison of VMT for Key Vehicle Configurations under the Base Case and Scenario 4

Base Case VMT (millions)				Scenario 4 VMT (millions)			
3-S2	2-S1-2 (twin 28-ft doubles)	2-S1-2 (twin 33-ft doubles)	Total	3-S2	2-S1-2 (twin 28-ft doubles)	2-S1-2 (twin 33-ft doubles)	Total
131,003	4,832	0	135,835	118,407	1,334	13,140	132,881
Percent Change				-9.6%	-72.4%		-2.2%

Table 14 summarizes the changes in truck traffic estimated to occur if twin 33-foot doubles were allowed. Reductions in five-axle tractor-semitrailer and twin 28-foot doubles traffic due to diversions to the twin 33-foot double configuration are estimated to total 16 billion miles while the new VMT for twin 33-foot doubles is estimated to total 13.1 billion miles. A net reduction of almost 3 billion miles would result from modal shifts under this scenario.

Table 14: Scenario 4 Shifts in Traffic by Vehicle Class and Weight Group (millions of VMT)

Operating Weight (lb., 000s)	Vehicle Configuration				Net Change by Weight Group
	3-S2	Oth-CS5	2-S1-2 (twin 28-ft doubles)	2-S1-2 (twin 33-ft doubles)	
41-45	(2,425)	(241)	(278)	208	(2,737)
46-50	(1,742)	(172)	(397)	1,127	(1,185)
51-55	(2,263)	(240)	(603)	1,685	(1,422)
56-60	(2,226)	(272)	(775)	1,626	(1,648)
61-55	(1,765)	(261)	(651)	2,100	(577)
66-70	(837)	(144)	(448)	2,127	696
71-75	-	-	(256)	2,048	1,791
76-80	-	-	(86)	2,216	2,130
	-11,261	-1,333	-3,497	13,140	(2954)

Approximately 15 million miles of the total 13.1 billion miles of twin 33-foot doubles traffic estimated under Scenario 4 is estimated to come from diversion of intermodal shipments from rail. The remainder would come from shifts in traffic from other truck configurations. The additional cubic capacity of the twin 33-foot doubles compared to existing twin 28-foot doubles is not enough to divert significant amounts of intermodal traffic from the railroads.

Scenario 5

Scenario 5 assumes that a seven-axle triple trailer (2-S1-2-2) would be allowed to operate on a 74,500 mile network of Interstate and other principal arterial highways at a maximum GVW of 80,000 pounds. Both Scenario 5 and Scenario 6 assume that, because of their length and other operating characteristics, triples' access to roadways off the triples network would be limited to 2 miles. For analytical purposes, the USDOT study team assumed that if the origin or destination of a shipment is in a county through which the triples network passes, a terminal would be available within this 2-mile access distance. If the origin or destination of the shipment is not in a county through which the triples network passes, the triple configuration would have to be broken up, and twin trailers would have to be used until the triples network is available. Furthermore, for trips of less than 250 miles, the entire route would have to be on the triples network since it is assumed that the time necessary to break the triples into double trailers for drayage would render the diversion uneconomical. For trips longer than 250 miles it was assumed that a continuous distance of at least 250 miles on the triples network would be required before triples could be used. In practice, the relative costs of assembling and disassembling triples versus traveling the entire distance in doubles would vary from corridor to corridor depending on freight volume and shipper operations.

The assumption that triples would have very limited access to roadways off the triples network contrasts sharply with assumptions in USDOT's 2000 CTSW Study, which assumed triples would have wide access off the network. The basic reason for changing the access assumptions for the current study was to portray a more realistic picture of how triples might actually be operated even if truck size and weight alternatives beyond those currently permitted were to be allowed. Whereas the 2000 CTSW Study attempted to estimate the maximum impact that various increased truck size and weight options might have, the assumptions in the current study are intended to more closely portray the realities of implementation. What this means is that if Federal law permitted, certainly some States might grant wider access than is being assumed in this study, but the USDOT study team judged it to be unlikely that many of the Eastern States would grant wide access off the network given the high traffic volumes and dense urban operating environments throughout large stretches of the northeast and southeast.

As shown in **Table 6**, seven-axle triples traveled an estimated 165 million miles in 2011. Almost all of these miles were accounted for by LTL operations, including package delivery. Triples operations are currently limited to a few Western States and on turnpikes in Kansas, Indiana, and Ohio. These configurations are attractive to LTL carriers because they offer 50 percent more cubic capacity than standard 28-foot doubles.

Table 15 compares base case VMT for the vehicle classes affected by Scenario 5 with an estimated VMT for Scenario 5 vehicles that would result from shifts associated with the assumed size and weight change under Scenario 5. There is a large shift of VMT to triples 2-S1-2-2, but there also is a net increase in the VMT for twin 28-foot doubles (2-S1-2). While some freight currently carried in twin 28-foot double trailers would shift to triples, the limited triples network means that some shipments shifting to triples must travel as doubles for part of the trip.

Table 15: Comparison of VMT for Key Vehicle Configurations under the Base Case and Scenario 5

Base Case VMT (millions)					**Scenario 5 VMT (millions)**				
3-S2	**Oth-CS5**	**2-S1-2**	**2-S1-2-2**	**Total**	**3-S2**	**Oth-CS5**	**2-S1-2**	**2-S1-2-2**	**Total**
113,952	17,050	4,832	166	136,000	108,354	16,344	6,125	3,280	134,104
Percent Change					-4.9%	-4.1%	26.8%	1875.9%	-1.4%

Table 16 summarizes changes by both VMT and weight group estimated to result from nationwide introduction of seven-axle triples (2-S1-2-2) at a maximum GVW of 105,500 pounds under network and access assumptions for Scenario 5. As noted in the discussion of Scenario 4, LTL operations currently use both five-axle tractor-semitrailers and twin trailer combinations. Triples offer significant increases in cubic capacity compared to both those configurations and also provide an increase in weight as well.

Table 16: Scenario 5 Shifts in Traffic by Vehicle Class and Weight Group (millions of VMT)

Weight Group (lb., 000s)	**Vehicle Configuration**				**Net Change by Weight Group**
	3-S2	**Oth-CS5**	**2-S1-2**	**2-S1-2-2**	
41-45	(1,078)	(107)	31	-	(1,154)
46-50	(753)	(74)	149	-	(678)
51-55	(1,017)	(108)	134	20	(970)
56-60	(979)	(120)	150	181	(768)
61-55	(789)	(117)	239	323	(343)
66-70	(509)	(89)	206	268	(123)
71-75	(274)	(52)	266	280	220
76-80	(195)	(36)	115	332	215
81-85	-	-	-	360	360
86-90	-	-	-	326	326
91-95	-	-	-	283	283
96-100	-	-	-	243	243
101-105	-	-	-	492	492
Total	(5,597)	(706)	1,293	3,114	(1,896)

Under the Scenario 5 assumptions, triples traffic is estimated to increase from 165 million to over 3 billion miles annually based on 2011 freight volumes. Over 6.3 billion VMT would be diverted from five-axle tractor-semitrailers to triples operations, although not all of this travel would occur in triples. This 6.3 billion mile diversion of traffic represents almost 5 percent of total travel by five-axle tractor-semitrailers.

As noted above, triples cannot travel directly to all origins and destinations. Where the triples network does not directly serve origins and destinations, some of the freight traffic diverted to triples would have to travel in doubles. This accounts for the increase in doubles traffic shown in **Table 16.**

A significant portion of existing doubles traffic would also shift to triples under this scenario. Based on 2011 traffic volumes, an estimated 1.2 billion miles of 2-S1-2 travel would divert to triples. This represents approximately one-quarter of all 2-S1-2 traffic. The 1.2 billion miles of travel diverted from 2-S1-2 configurations would require only 810 million miles of travel by triples. The 1.2 million mile reduction in 2-S1-2 traffic and 810 million mile increase in triples traffic are included in **Table 16.**

The diversion of intermodal traffic from the railroads would result in about 11 million additional miles of travel by triples, which also is included in **Tables 15 and 16**.

The net reduction in total truck travel associated with Scenario 5 is estimated to be almost 2 billion miles, approximately 1.4 percent of total travel by 5-axle tractor-semitrailers, 5-axle doubles and 7-axle triples.

Scenario 6

Scenario 6 would allow nine-axle triple trailer combinations (3-S2-2-2) to operate on a 74,500 mile network of Interstate and other principal arterial highways at a gross vehicle weight of 129,000 pounds. While a small number of nine-axle triples currently operate in Western States, they primarily haul bulk commodities off the Interstate System. In nationwide operations, nine-axle triples could be expected to be used almost exclusively in LTL operations in much the same way that seven-axle triples (2-S1-2-2) operate today. The additional gross vehicle weight would allow them to carry heavier loads than they could under the 105,500 pound weight limit assumed in Scenario 5.

Table 17 compares total base case VMT for vehicles affected by Scenario 6 with VMT for those vehicles classes following shifts due to the size and weight changes assumed in Scenario 6. As with Scenario 5, traffic is shifted from five-axle tractor-semitrailers (3-S2) and twin 28-foot double configurations (2-S1-2) to the triple configuration (3-S2-2-2). Total twin 28-foot doubles traffic, however, increases as it did under Scenario 5 because triples cannot run from origin to destination for many of the shipments they haul. On portions of the route off the triples network, triples must break down and travel as doubles. Overall, VMT by vehicles affected by Scenario 6 is reduced by 1,944 million miles, 1.4 percent of the total base case travel by those vehicles classes.

Table 17: Comparison of VMT for Key Vehicle Configurations under the Base Case and Scenario 6

Base Case VMT (millions)					Scenario 6 VMT (millions)				
3-S2	**Oth-CS5**	**2-S1-2**	**3-S2-2-2**	**Total**	**3-S2**	**Oth-CS5**	**2-S1-2**	**3-S2-2-2**	**Total**
113,952.1	17,050.4	4,832.1	0.4	135,835.0	108,378.8	16,323.5	6,094.8	3,093.9	133,891.0
Percent Change					-4.9%	-4.3%	26.1%	812,104.1%	-1.4%

About 6.3 billion VMT would be shifted from five-axle tractor semitrailers to triples and doubles under this scenario—about the same amount as shifted under Scenario 5. Despite this greater diversion, the nine-axle triples travel 6 percent fewer miles under Scenario 6 than the seven-axle triples do in Scenario 5. This reflects the additional GVW allowed on the nine-axle triples, which means fewer trips are required to carry those commodities that reach the 105,500 pound weight limit assumed in Scenario 5 before they fill the vehicle's cubic capacity.

Table 18 shows the distribution of traffic shifts for Scenario 6 by operating weight. Most of the VMT shifting from the five-axle (3-S2) tractor-semitrailers is in relatively light weight groups. The greater cubic capacity of the triples allows them to carry more cargo at higher weights than is possible in tractor-semitrailers.

Table 18: Scenario 6 Shifts in Traffic by Vehicle Class and Weight Group (millions of VMT)

Operating Weight (lb., 000s)	Vehicle Configuration				Net Change by Weight Group
	3-S2	Oth-CS5	2-S1-2	3-S2-2-2	
41-45	(1,074.983)	(110.967)	31.066	(0.000)	(1,154.884)
46-50	(751.376)	(77.282)	149.843	0.000	(678.816)
51-55	(1,014.355)	(111.250)	134.568	(0.000)	(991.037)
56-60	(977.599)	(123.357)	150.127	100.579	(850.251)
61-65	(786.161)	(120.305)	240.328	196.546	(469.592)
66-70	(505.799)	(92.210)	200.795	307.323	(89.891)
71-75	(268.272)	(53.530)	158.527	259.530	96.255
76-80	(194.726)	(37.990)	84.828	312.739	164.852
81-85	(0.000)	0.000	93.229	347.396	440.625
86-90	(0.000)	0.000	19.359	341.348	360.707
91-95	0.000	0.000	(0.000)	328.131	328.131
96-100	(0.000)	(0.000)	(0.000)	265.248	265.248
101-105	0.000	0.000	(0.000)	230.925	230.925
106-110	(0.000)	0.000	(0.000)	156.951	156.951
111-115	(0.000)	0.000	(0.000)	110.496	110.496
116-120	0.000	(0.000)	(0.000)	72.080	72.080
121-125	(0.000)	(0.000)	0.000	45.348	45.348
126-130	0.000	(0.000)	0.000	18.868	18.868
Total	(5,573.271)	(726.892)	1,262.670	3,093.508	(1,943.985)

Figure 14 compares modal shifts to the triples configuration under Scenarios 5 and 6 by operating weight. In Scenario 5 there is a peak at the maximum GVW of 105,500 pounds, whereas in Scenario 6, which allows higher weight limits, the peak disappears and traffic is carried by the nine-axle triples at higher weights. The higher weight limits under Scenario 6 also result in fewer VMT being required to haul the traffic diverted from five-axle tractor semitrailers and 2-S1-2 configurations. The peak at the assumed maximum GVW for Scenario 5 results from the general assumption that traffic shifting to larger, heavier vehicles under the truck size and

weight scenarios will not operate above the limits for each scenario. Traffic in scenario vehicles that currently operate above the scenario weight limit are assumed to continue to do so since they likely are operating under special permits that the study assumes would continue to be issued.

As was the case in Scenario 5, allowing triples actually increases total travel by 2-S1-2 configurations, despite the fact that considerable 2-S1-2 traffic shifts to the 9-axle triples. About 1.2 billion miles of 2-S1-2 travel shifts to triples under Scenario 6, resulting in an increase of 809 million VMT by triples. This is essentially the same amount of diversion from 2-S1-2 configurations that was estimated in Scenario 5. Offsetting the shifts of 2-S1-2 VMT to triples is the increase in 2-S1-2 VMT required to operate triples when the triples network does not directly connect origins and destinations. The increase in total diversion under Scenario 6 compared to Scenario 5 comes almost exclusively from 5-axle tractor-semitrailers that typically carry heavier loads than 2-S1-2 configurations.

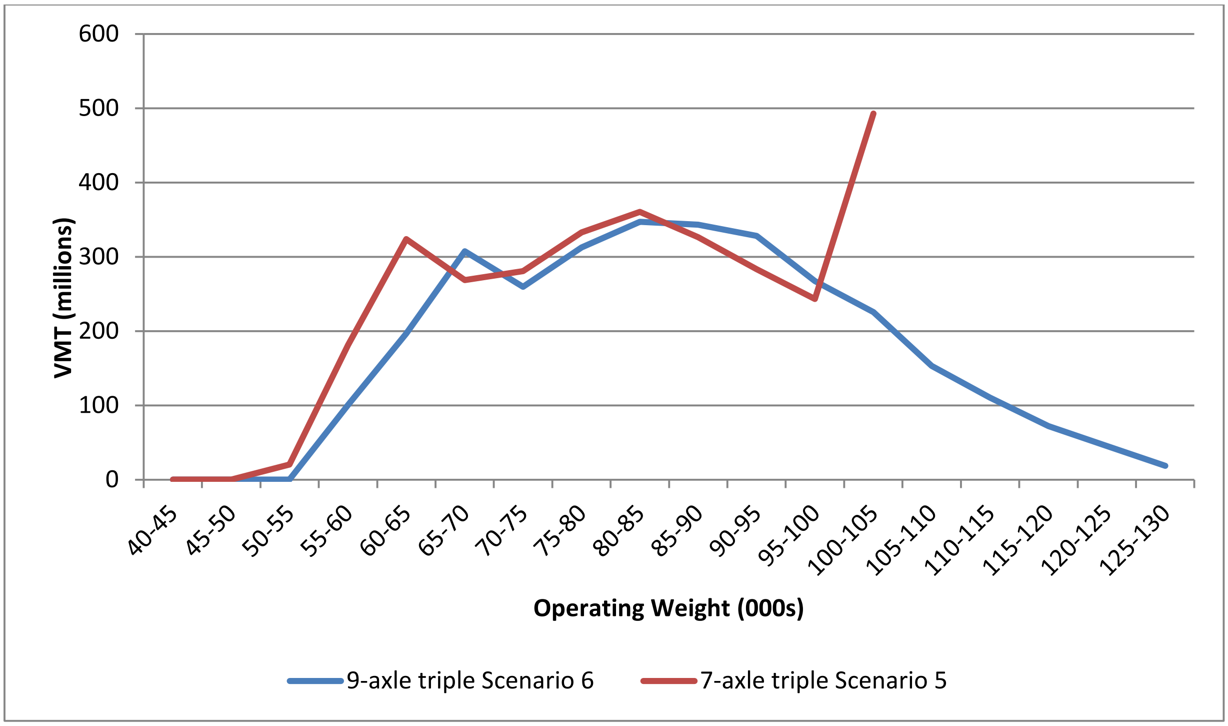


Figure 14: Comparison of Traffic Shifts to 7 and 9-axle Triples by Operating Weight

As with Scenario 5, there is a small amount of diversion from intermodal rail to nine-axle triples under Scenario 6. Diversion from rail adds a total of 11 million miles of highway travel composed of 9.5 million in triples and 1.6 million in 2-S1-2 configured vehicles, which are required to complete moves where either the origin or destination is not on the triples network.

Table 19 shows the percentage of individual shipments that are estimated to shift from either 5-axle tractor-semitrailers or standard 28-foot doubles to the scenario vehicles for scenarios 4, 5, and 6 by shipment distance. At all trip distances virtually all LTL shipments in 3-S2 and 2-S1-2 vehicles are shown to shift to the twin 33-foot double configuration analyzed in Scenario 4. Little or no shift is expected to triple trailer combinations for shorter trip distances. The lack of diversion for trips less than 250 miles in length reflects the general assumption that shipments traveling less than 250 miles would not shift unless the entire trip could be made on the triples network. In specific corridors there could be exceptions to this assumption, but in general the additional handling costs of assembling and disassembling triples for such short trips would reduce the benefits of using triples. Virtually all LTL shipments traveling over 750 miles, however, would shift to triples from both single and double trailer combinations.

Table 19: Percent of Loads Shifting from Base Case Vehicles to Scenario Vehicles for Scenarios 4, 5, and 6

	3-S2 Base Case Vehicle				DS5 Base Case Vehicle			
		Percent of Shipments Shifting to Scenario Vehicle				Percent of Shipments Shifting to Scenario Vehicle		
Shipment Distance (miles)	Base Case 3-S2 Shipments	Scen. 4 Twin 33 double	Scen. 5 Lighter triple	Scen. 6 Heavier triple	Base Case DS5 Shipments	Scen. 4 Twin 33 double	Scen. 5 Lighter triple	Scen. 6 Heavier triple
0 - 100	17,822,131	95	0	0	1,662,498	98	0	0
101 - 250	17,346,084	94	0	0	2,652,038	98	0	0
251 - 500	12,734,690	94	13	13	2,411,159	98	10	10
501 - 750	3,649,795	94	53	53	1,522,814	98	44	44
751 - 1000	1,723,198	94	79	79	847,963	98	74	74
1001 - 1500	1,501,046	94	94	94	628,760	98	92	92
1501 - 2000	533,877	94	98	98	156,561	98	98	98
2001 - up	572,345	95	100	100	106,756	99	100	100
Total	55,883,168	95	13	13	9,988,550	98	24	24

3.8 Cost Responsibility

The issue of cost responsibility often arises in connection with truck size and weight policy studies. Many truck size and weight options, including those examined in the current study, have highway investment implications, both in the near term and over time. These costs can be linked to changes in highway travel by different vehicle configurations at different weights as the result of the truck size and weight allowance changes. Many costs estimated in this study—including the pavement and bridge costs addressed later in this *Volume II: Pavement Comparative Analysis* and the *Volume II: Bridge Structure Comparative Analysis*—are related not just to operating weight but also to specific axle loadings for the various vehicle classes. To estimate the responsibility of different vehicle classes for changes in highway investment requirements, the distribution of axle loadings by vehicle classes affected by changes in truck size and weight allowances would have to be known.

Some have expressed interest in knowing how the impacts of truck size and weight allowance options might change if fees were imposed on trucks based on changes in their highway cost responsibility. Added fees would increase the relative cost of operating vehicles affected by different truck size and weight allowances and thus could affect the extent to which traffic shifts to those configurations from currently allowed configurations and from other modes. Estimating the fees that might be required to cover the added cost responsibility associated with different truck size and weight allowances would require an iterative process.

First, the added cost responsibility for each vehicle class affected by a modified size and weight allowance would have to be estimated under existing Federal and State highway user fees. Once the added cost responsibility was estimated, it would have to be translated into a cost per vehicle mile of travel for the affected vehicles. This additional cost would then have to be reflected in a new vehicle operating cost for each affected vehicle and the modal diversion and related impact analyses rerun to determine what changes charging vehicles for their additional cost responsibility in the first instance would have. Presumably the added cost responsibility would decrease and the additional user fee added to the second set of analyses would have to be adjusted to be closer in line with the new cost responsibility estimate.

While this type of analysis has some academic and policy interest, it also has real-world implications that should be considered. Primary among those is the fact that no single unit of government would likely see it as their responsibility to impose the full fee, since funding for operations and maintenance on the highways that would be most affected by truck size and weight allowance increases is a shared responsibility among Federal, State, and, in some cases, local governments.

In addition, there are implications for existing user fees. The most recent Federal highway cost allocation study and most State cost allocation studies have concluded that the user fees paid by operators of many heavy truck configurations currently are not adequate to cover their share of Federal or State highway cost responsibilities or their share of highway program costs. Imposing additional fees only on those vehicle classes responsible for changes in investment requirements associated with increased truck size and weight allowances raises questions concerning why user fees on other trucks should not be brought closer in line with their highway cost responsibility.

It is possible to address the cost responsibility issue purely through policy, in much the same way that the issue was addressed in the 1997 Federal highway cost allocation study, which noted the possibility or even desirability of taking a comprehensive look at overall highway user fee equity if truck size and weight limits were to be increased in such a way that significant additional highway investment might be required to accommodate the larger, heavier vehicles.

Nonetheless, a good starting point for discussion is presented in the Government Accountability Office study *A Comparison of the Costs of Road, Rail, and Waterways Freight Shipments That Are Not Passed on to Consumers.*[4] The study found that:

[4] United States Government Accountability Office, Report to the Subcommittee on Select Revenues Measures, Committee on Ways and Means, House of Representative, GAO-11-134, January 2011.

> *[F]reight trucking costs that were not passed on to consumers were at least 6 times greater than rail costs and at least 9 times greater than waterways costs per million ton miles of freight transport. Most of these costs were external costs imposed on society. Marginal public infrastructure costs were significant only for trucking.*

This is a demonstration that trucking currently falls short of meeting its cost responsibility, especially with respect to damage inflicted on the highway infrastructure.

CHAPTER 4 – SCENARIO IMPACTS ON TRANSPORTATION AND LOGISTICS COSTS AND RAIL CONTRIBUTION

A principal reason for considering changes in truck size and weight limits is to reduce total logistics costs associated with the movement of freight. Total logistics costs include not only the cost to transport goods from origin to destination, but also non-transport logistics costs such as inventory carrying costs, storage, loss, and damage. As discussed in the previous chapter, the comparison of these total logistics costs for individual shipments by base case and scenario modes and vehicles is the basis for estimating the potential traffic shifts associated with changes in truck size and weight limits.

This chapter summarizes estimates of overall changes in transportation and non-transportation logistics costs for the six truck size and weight scenarios analyzed in this 2014 CTSW Study. The effect of both truck-to-truck and rail-to-truck shifts on transportation and logistics costs is shown in **Table 20**.

Table 20: Annual Transportation and Logistics Cost Savings for Truck Shipments ($, millions)

	Scenarios (1-6)					
	5-axle 3-S2, 88,000 pounds (1)	6-axle 3-S3, 91,000 pounds (2)	6-axle 3-S3, 97,000 pounds (3)	Twin 33-foot trailers, 80,000 pounds (4)	Triples, 105,500 pounds (5)	Triples, 129,000 pounds (6)
Truck-to-truck						
Cost Savings	5,618	5,524	12,813	2,316	1,899	1,969
Percent change	1.6	1.6	3.7	6.8	5.6	5.8
Rail-to-truck						
Cost Savings	15	15	44	10	2	2
Rail rate reduction	116	116	336			
Total	131	131	380	10	2	2
Percent change	0.2	0.2	0.6	0.3	0.1	0.1
Total Savings	5,749	5,655	13,193	2,326	1,901	1,971
Total % Savings	1.4	1.4	3.2	6.3	5.1	5.3

Scenarios 1, 2, and 3 result in greater total cost savings, primarily because they affect a larger share of the overall freight transportation market. Savings resulting from shifts of base case truck traffic to the Scenario 1 and Scenario 2 vehicles would each result in savings of over $5.5 billion. Savings are slightly greater under Scenario 1 than Scenario 2 even though traffic shifts are slightly greater under Scenario 2. The main reason for the greater cost savings under Scenario 1 is the lower vehicle operating cost for the 5-axle tractor-semitrailers compared to the 6-axle vehicles analyzed in Scenario 2.

Savings from shifts of rail traffic to scenario vehicles would total $15 million for both Scenario 1 and 2. These cost savings were the result of the diversion of 2.3 million tons of freight traffic under each of Scenarios 1 and 2. Even greater cost savings were estimated to come from reductions in rail rates to keep traffic from diverting to the more productive trucks.

Scenario 3 resulted in the greatest cost reduction of all the scenarios – over $13 billion annually. The majority of this reduction came from truck-to-truck shifts as truck traffic captured the benefit of the higher weight allowed under this scenario. A total of 4.9 million tons of rail freight is estimated to divert to trucks under Scenario 3 size and weight limits. Commodities most impacted in each of Scenario 1, 2, and 3 are low value commodities where transportation costs are high relative to the value of the commodity and bulk, feedstock commodities. Commodities shipped in bulk equipment types, dump body, grain, tank, etc., have limited back haul opportunities and rates often must cover the cost of an empty return. At the other end of the spectrum, high value commodities were tested and often found to have lower total logistics cost at payloads below the study base case payload. In many of these cases, non-transport logistics costs that were twice as high as transportation costs were not uncommon. High value commodities generally did not benefit from the increased payload.

Savings from rail traffic were estimated to total $380 million, most of which was from rate reductions to retain traffic on the railroad. The alternative vehicles in Scenarios 1, 2, and 3 provide no productivity gain over intermodal units being hauled by rail for most rail intermodal moves. The typical intermodal payload is below 40,000 pounds and does not approach the current federal 80,000 pound weight limit. The competition from heavier truck weights affected rail rates to a much greater degree than it did diversion of rail shipments to truck. Rate reductions account for close to 90 percent of the revenue losses to the rail industry. The majority of the rail traffic impacted by the increased weight scenarios was carload traffic. The rail intermodal traffic base was generally less than 40,000 pound payloads, which when run in highway combinations is below the current weight federal limit. Rail rates are generally half truck rates, even when drays at both ends are included. What diversion was experienced was in relativity short hauls where rail rates are high relative to long haul intermodal markets and the dray is spread over fewer miles. The percentage change in total logistics costs (transportation and non-transport logistics costs) for Scenarios 1-3 reflects a comparison of total logistics costs to move all traffic in the configurations affected by each scenario in the base case to total logistics costs to haul the same traffic at the size and weight limits for each scenario.

Savings from Scenarios 4, 5, and 6 were not as great—between $1.9 and $2.3 billion per year. For these LTL freight scenarios, the non-transport portion of total logistics cost were not analyzed. Non-transport logistics costs are an important consideration when shipment size changes. In the LTL scenarios, individual shipment sizes are not changed, the number of shipments that can be consolidated into a load changes. This analysis considers only the change in line-haul transportation cost per unit of freight. Very little savings was attributable to traffic currently on the railroads. The rail intermodal LTL analysis included STCCs 46 and 47, Miscellaneous Mixed Shipments and Small Packaged Freight Shipments respectively, as a proxy for LTL shipments. The ability of the scenario vehicles to divert this intermodal freight is limited. Changes in total logistics costs for Scenarios 4-6 are calculated somewhat differently than for Scenarios 1-3 because those scenarios are assumed to apply only to LTL traffic. Total transportation costs associated with moving all non-local LTL traffic both by truck and by rail in the base case are compared with total transportation costs associated with moving the same traffic under the size and weight limits assumed for Scenarios 4-6. Non-transport logistics costs are assumed to remain the same since they primarily reflect impacts of individual shipment sizes that are assumed to be unaffected by the scenario size and weight limits. A total of 1.4 million tons of rail freight was estimated to divert to trucks under Scenario 4 and 2.4 million tons was estimated to divert to trucks under both Scenarios 5 and 6.

4.1 Rail Contribution and Revenue

An important indicator of the impact of lost traffic and rate reductions required to keep traffic on the railroad is rail contribution – the difference between revenues and costs that railroads can contribute toward meeting their fixed costs. The changes in truck size and weight limits included in Scenarios 1-6 would affect both rail revenues and rail expenses. Revenues would be lost both from traffic that diverts to the scenario vehicles and from rate reductions needed to keep traffic on the railroad. Expenses associated with hauling freight that diverts to truck would be avoided, however. For all scenarios these changes are relatively small.

Table 21 summarizes changes in revenues and expenses for each scenario. Numbers in parentheses represent the percentage change in rail revenues, expenses, and contribution. With the exception of Scenario 3, losses in revenues accounted for 0.5 percent or less of total rail revenues. Scenario 3 revenue losses are estimated to be about 1 percent of rail revenues. In all scenarios expenses foregone as the result of lost traffic are less than or equal to 0.25 percent. In dollar terms, the net loss of contribution toward railroad fixed costs is highest for Scenario 3 – over one-half billion dollars. Lost contribution for Scenarios 1 and 2 were both about $200 million. Lost contribution for Scenarios 4-6 ranged from $22 million to $15 million.

Table 21: Change in Rail Contribution Associated with Truck Size and Weight Scenarios 1-6

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Change in revenues ($ millions)	-259 (-0.4%)	-257 (-0.4%)	-685 (-1.0%)	-34 (-0.1%)	-27 (-0.0%)	-24 (-0.0%)
Change in expenses ($ millions)	-62 (-0.1%)	-61 (-0.1%)	-123 (-0.3%)	-11 (-0.0%)	-10 (-0.0%)	-9 (-0.0%)
Total loss of contribution ($ millions)	-197 (-1.1%)	-196 (-1.1%)	-562 (-3.1%)	-22 (-0.1%)	-17 (-0.1%)	-15 (-0.1%)

4.2 The Effect on Short Line Railroads

This section summarizes results of an analysis concerning the effects on short line railroads brought about by changes in truck sizes and weights. Short line railroads are Class II and Class III railroads as defined by the Surface Transportation Board (STB).[5] Input from the short line

[5] See Federal Register, Volume 79, No. 111, June 10, 2014, p. 33257. The Surface Transportation Board defines class of railroad based on revenue thresholds adjusted for inflation. For 2013, the most recent available, Class I

railroad industry indicates that approximately 90 percent of their traffic interlines with Class I railroads and thus is reflected in the STB Carload Waybill Sample. While flow data on these classes of carriers is not as robust as that for the Class I railroads, the data available and results from the analysis are instructive.

There are around 560 short line railroads operating in the U.S. Of these, 10 are Class II's with the remaining Class III's. Together these railroads originate or terminate about 18 percent of Class I carload freight or around 6.5 million carloads, annually and generate around $4 billion in revenues. While commodity makeup on these carriers is diverse, they principally serve rural communities and provide these areas the rail link to the Class I railroad network. Short line railroads provide two primary high level services: 1) extension of Class I railroads with the interlining and 2) regional/intrastate rail service.

Previous truck size and weight studies undertaken by the U.S. Department of Transportation (USDOT) did not consider the effects on short line railroads separately from the Class I railroads. In part, this was due to data limitations and concerns over interpreting the results. But with each subsequent study, the USDOT has attempted to expand the analysis, to the extent possible, to encompass all of the effects that truck size and weight changes place on the transportation system.

Similar to the Class I railroad analysis, the short line analysis examined the impacts of two distinct results; rate reductions or discounting on the part of the railroad to hold onto traffic and diversions from rail to truck when the carrier has to give up the traffic because it will not move the goods if revenues are below its variable cost. Here the short line analysis builds on the results from the ITIC model and the STB Carload Waybill Sample that were undertaken for the Class I railroads. The short line analysis is a subset of the overall analysis above.

To expand the above analysis to consider the effects on short line railroads, those records on the waybill sample were identified, where a short line railroad was an originating, intermediate, or terminating carrier. This is the "documented" set of short line moves. Industry experience tells us that sometimes short line railroads are not included on the waybill sample because the Class I handles the billing for these carriers. Overall, the waybill sample includes around 140 railroads, far short of the number of railroads operating in any year. To handle the unreported short line railroads, an additional dataset was developed that identified waybill records where the origin or destination was on a Class I railroad and there was access to a short line railroad within a reasonable range of their origin or destination. This dataset was referred to as the "potential" short line waybills. This data set identified any waybill record that could potentially use a short line railroad but did not include that short line on the waybill. (Only a portion of the waybill records were identified as using a short line railroad.) In summary, the documented data set included all the short line trips that could be identified in the waybill sample while the potential data set included any possible undocumented short line trip based on a short lines in close proximity to a Class I origin or destination.

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carriers had revenues of $467.0 million or more. Class II carriers have revenues ranging from $37.4 million to under $467.0 million. Class III carriers have revenues under $37.4 million. All switching and terminal carriers regardless of revenues are Class III carriers. (See 49 CFR 1201.1-1)

These two data sets provide the basis for the revenue estimates. However, data limitations do not allow a rail contribution analysis for the short line business. Likewise, data limitations precluded estimates of revenue impacts on short line railroads associated with Scenarios 4, 5, and 6. Below are the assumptions made in conducting the revenue analysis of the short line railroads:

- No changes from the main analysis were made to the assumptions on the frequency of diversions or the frequency of rate reductions on railroads, this analysis only identified those instances that included or potentially included a short line railroad.
- Revenue estimates for the documented data set only include the revenue attributed to that segment of the trip on the short line railroad.
- Revenue estimates on the potential short line data set are assumed to be 21 percent of the entire revenue on that waybill record. This estimate was derived using the average revenue of documented short line railroads where the origin or the termination was a short line directly connecting to a Class I railroad.
- Short line revenue losses from rate discounting are estimated by applying the proportion of revenue received by the short line to the overall revenue lost from discounting.[6]

See **Appendices F and H** for a detailed discussion on the methodology, data sets, models and assumptions.

Even with this more inclusive approach, comparisons across these two data sets proved difficult. The lower bound of impacts is based on estimated impacts of truck size and weight limit changes on documented short line rail moves. Additional potential revenue impacts are estimated for moves that could have involved a short line railroad based on the proximity of the short line to shipment origins or destinations. Combining these two estimates produces the worst case scenario of total revenue losses.

4.3 Results

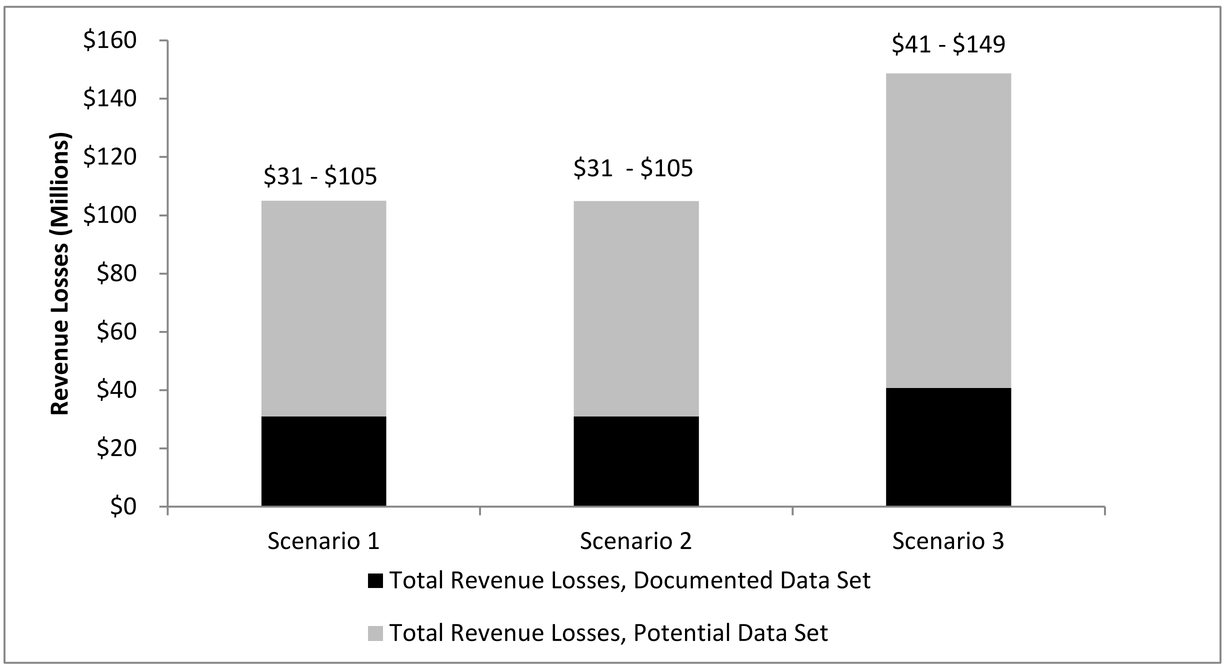
For the known short line waybills, rate reduction occurred on 16 two-digit Standard Transportation Commodity Codes (STCC) for Scenarios 1 through 3. Of these 16 commodity groups, the most impacted in terms of lost revenue included Pulp, Paper, or Allied Products; Chemicals or Allied Products; and Clay, Concrete, Glass or Stone Products, respectively. **Table 22** shows the revenue losses for the documented and potential data sets while **Figure 15** shows the range of estimated losses from the combined data set.

[6] For the potential data set, this will always be 21 percent.

Table 22: Losses in Short Line Revenues Associated With Truck Size and Weight Scenarios 1-3

$ in Millions	Scenario 1	Scenario 2	Scenario 3
Total Revenue Losses, Documented Data Set	$31	$31	$41
Total Revenue Losses, Potential Data Set	$74	$74	$108
Estimated Range of Revenue Losses	$31 - $105 (0.8% - 2.6%)	$31 - $105 (0.8% - 2.6%)	$41 - $149 (1.0% - 3.7%)

Figure 15: Range of Estimated Losses in Short Line Revenues Associated With Truck Size and Weight Scenarios 1-3 Short Line Combined Data Set



CHAPTER 5 – SCENARIO IMPACTS ON ENERGY AND EMISSIONS

5.1 Scope

The purpose of this subtask is to evaluate the effect of alternative truck configurations on the fuel consumption and greenhouse gas emissions of the fleet for each scenario. The baseline vehicles and alternative configurations were evaluated on a range of drive cycles to determine their load-specific fuel consumption and emissions. The results of this analysis will be combined with modal shift data to represent the overall fuel consumption and emissions impacts on the fleet.

5.2 Methodology

In previous truck size and weight studies such as the 2000 CTSW Study, a simple table showing truck fuel economy in miles per gallon as a function of vehicle configuration and combined vehicle weight was used as an input to the energy and emissions analysis. For example in the 2000 CTSW Study, a triple 28-foot trailer combination is listed as having 11 to 17 percent greater fuel economy than that of a 3-axle, 53-foot box van trailer operating at the same vehicle weight. In practice, the 28-foot triple combination should suffer from higher aerodynamic drag than the 53-foot box van trailer, and thus would be expected to have lower fuel efficiency.

The more recent OECD report "Moving Freight with Better Trucks" uses fuel consumption values from road tests conducted by the German trucking magazine *Lastauto Omnibus* (page 152). These tests are run at maximum GCW over a defined route on German highways.

The approach selected for this study is to use baseline engine and vehicle models that are calibrated against experimental data, and then modify the models to represent the range of alternative truck configurations selected for this 2014 CTSW Study. This approach was first used in a 2009 report by the Northeast States Center for a Clean Air Future (NESCCAF) entitled *Reducing Heavy-Duty Long Haul Combination Truck Fuel Consumption and* CO_2 *Emissions*. The approach used here is also being used by the Southwest Research Institute (SwRI) in a study of fuel efficiency technologies being conducted for the National Highway Traffic Safety Administration (NHTSA), under contract GS-23F-0006M/DTNH22-12-F-00428. The models used in this project have been previously developed and verified as part of this NHTSA project.

The engine selected for this project is a 2011 model Detroit DD15. This is a widely used long-haul truck engine that has more than 20 percent of the long haul market share. The DD15 meets US EPA 2010 emissions requirements, and a slightly modified version of the engine has since been certified to meet the EPA's 2014 greenhouse gas requirements. From a proprietary benchmarking program, SwRI has an extensive set of performance, emissions, and fuel consumption data on this engine. Under the NHTSA contract, the experimental data was used to build and calibrate a GT-POWER simulation model of the engine. GT-POWER is a commercially available engine simulation tool. Four different ratings of the engine were developed in GT-POWER for this study: 428 HP, 485 HP (the baseline rating), 534 HP, and 588 HP.

The alternative engine power ratings were developed in order to maintain power-to-weight ratios for some of the alternative vehicle scenarios. For some scenarios, a much higher power would be required to maintain baseline vehicle performance. For example, if gross combined weight (GCW) is increased from 80,000 pounds to 129,000 pounds, the baseline engine rating of 485 HP would need to increase to 782 HP in order to maintain the same vehicle acceleration and grade performance. Since engines with greater than 600 HP are not available in the US truck market, the USDOT study team decided to limit engine power to 588 HP and accept performance penalties for the highest vehicle weights. Detailed results of the engine simulation analysis are provided in **Appendix D**.

The tractor selected for this 2014 CTSW Study is a Kenworth T-700 high roof sleeper tractor. This truck is not offered with the DD15 engine, but it is offered with the Cummins ISX, another 15 liter engine with similar performance, emissions, and fuel consumption characteristics. Coast-down testing[7] of the tractor with a 53 foot box van trailer was performed by SwRI under an EPA project to obtain aerodynamic drag and rolling resistance characteristics of the tractor. The T-700 is an aerodynamic tractor using standard (not SmartWay[8]) tires, and the baseline trailer has no aerodynamic or low rolling resistance features. This tractor-trailer combination represents approximately the average current fleet vehicle performance from an aerodynamic and rolling resistance perspective.

The USDOT study team performed the vehicle simulation using SwRI's Vehicle Simulation Tool (VST). This software package is based on the National Renewable Energy Lab (NREL) Advisor vehicle simulation program, which has hundreds of users worldwide. SwRI's VST tool incorporates improvements to the original NREL component models and provides enhanced functionalities in ways that allow the user to define each component of the vehicle. Each component's set of parameters is defined in a Matrix Laboratory (MATLAB) scripting format that is used in conjunction with a Simulink model. Detailed results of the vehicle simulation analysis are provided in the **Appendix D**.

Another key factor in any analysis of vehicle fuel consumption and emissions is the drive cycle. For this study, four operational modes were evaluated:

1. Urban Interstate / Freeway Operation
2. Rural Interstate / Freeway Operation
3. Urban Non-Interstate / Non-Freeway Operation
4. Rural Non-Interstate / Non-Freeway Operation

FHWA used five drive cycles, which are combined to reflect each of the 4 operational modes. These drive cycles are summarized in **Table 23**:

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[7] Coast-down testing is a technique for establishing the dynamometer load which simulates the vehicle road load during EPA dynamometer fuel economy and emission testing.

[8] SmartWay tires are certain low-resistance tire models that the EPA has determined can reduce NOx emissions and fuel use by 3 percent or more, relative to the best selling new tires for line haul class 8 tractor trailers. See Source: http://epa.gov/smartway/forpartners/technology.htm for more information.

Table 23: Drive Cycles Used for Simulated Vehicle Operations

Cycle #	Cycle Name	Comments
1	World Harmonized Vehicle Cycle (WHVC)	Same as in NHTSA project
2	Low Speed NESCCAF	Same time scale, speed multiplied by 60/68
3	NESCCAF	Same as in NHTSA project
4	Urban / Suburban WHVC	First 1200 seconds of WHVC
5	GEM Urban (CARB)	Same as in NHTSA project

The World Harmonized Vehicle Cycle (WHVC) was developed by the United Nations as a chassis dynamometer emissions and fuel economy test procedure for trucks. The cycle includes three components: a low speed, stop-and-go urban cycle, a medium speed "rural" cycle with one stop, and a higher speed (55 MPH maximum) freeway component. The "urban/suburban" WHVC was created by truncating the cycle at the 1200 second mark (out of 1800 seconds total for the cycle). The NESCCAF cycle was developed for the *Reducing Heavy-Duty Long Haul Combination Truck Fuel Consumption and CO_2 Emissions Report* (NESCCAF, 2009). This cycle had input from vehicle manufacturers, users, and regulators, and represents an attempt to simulate a US long-haul duty cycle. There is some urban driving at the beginning and end of the cycle, with extended periods of high speed (65 to 68 MPH) cruise, and some interruptions in speed designed to mimic a limited amount of traffic congestion. The cruise sections include periods of +/- 1% and +/- 3% grade. The low speed NESCCAF cycle is the exact same cycle scaled down to limit the maximum speed to 60 MPH. Finally, the GEM Urban cycle is the low-speed urban cycle used by the EPA in their Greenhouse Gas Emissions Model, a simulation tool used to certify vehicles for compliance with the EPA's 2014 greenhouse gas emissions standards. This cycle was developed by the California Air Resources Board (CARB). Details of the vehicle drive cycles are provided in **Appendix D**.

The drive cycles were combined to handle the four operational modes as shown in **Table 24**.

Table 24: Mix of Drive Cycles for Four Operational Modes

Urban	Rural	Road Network
50% WHVC, 50% Low Speed NESCCAF	NESCCAF	Interstate / Freeway
50% Urban/Suburban WHVC, 50% Gem Urban	Low Speed NESCCAF	Non-Interstate / Non-Freeway

A key difference between the 2014 CTSW Study and the 2000 CTSW Study is that results are stated in terms of fuel consumption rather than fuel economy. In other words, the results are given in terms of how many gallons of fuel it takes to move the vehicle a mile or to deliver a ton of freight 1000 miles, or how many grams of emissions are emitted per vehicle mile or to move a ton of freight 1 mile. Differences in vehicle efficiency due to variations in tare weight and in aerodynamic drag are accounted for in this project's methodology. The results provided in this section will be combined with projected vehicle modal shift to provide predictions for the total fleet fuel consumption and emissions levels.

The fuel consumption methodology used in this project matches the methodology being used for the NHTSA contract. This methodology has been reviewed with NHTSA, EPA, and with the

National Research Council committee on Reducing the Fuel Consumption and Greenhouse Gas Emissions of Medium- and Heavy-Duty Vehicles, Phase 2.

For carbon dioxide (CO_2) emissions, the study assumes that standard petroleum-based diesel fuel is used. There is a fixed relationship between a gallon of fuel and the amount of CO_2 generated by burning it: 10.15 kilograms of CO_2 are generated for every gallon of diesel fuel consumed.

For the purpose of this study, the assumption was made that all involved vehicles comply with 2010 EPA nitrous oxide (NOx) requirements of 0.2 grams per brake horsepower-hour, with a 10 percent engineering margin. Based on benchmarking tests performed by SwRI, this is a conservative assumption for the types of vehicle operation simulated for this project. Also, the assumption is made that brake-specific NOx emissions are independent of engine speed and load. Again, SwRI's internally developed benchmarking data shows this to be a reasonable assumption over a fairly wide range of speed and load.

One additional assumption is required to allow a calculation of NOx emissions. For this 2014 CTSW Study, the team assumed that the average brake specific fuel consumption of the engine over the drive cycles is 200 g/kW-hr. In actual practice, a range of 190 to 220 g/kW-hr can be expected. Using these assumptions, 3.8 grams of NOx can be expected for every gallon of fuel consumed.

5.3 Results

A total of eight vehicle scenarios were run. Two of these alternative truck configurations represent the baselines: a 5-axle 53-foot trailer limited to 80,000 pounds and a 5-axle 28-foot double combination, also limited to 80,000 pounds. The configurations evaluated are listed below in **Table 25**.

Table 25: Tractor-Trailer Vehicle Scenarios Evaluated

Scenario	Configuration	# Trailers	# Axles	Tare Wt. (Pounds)	Allowed GCW (lb.)
	5-axle vehicle (3-S2) [control vehicle]	1	5	34,622	80,000
1	5-axle vehicle (3-S2)	1	5	34,622	88,000
2	6-axle vehicle (3-S3)	1	6	36,255	91,000
3	6-axle vehicle (3-S3)	1	6	36,255	97,000
	Tractor plus two 28-ft trailers (2-S1-2) [control vehicle]	2	5	31,376	80,000
4	Tractor plus two 33-foot trailers (2-S1-2)	2	5	33,738	80,000
5	Tractor plus three 28-foot trailers (2-S1-2-2)	3	7	41,454	105,500
6	Tractor plus three 28-foot trailers (3-S2-2-2)	3	9	47,852	129,000

Each vehicle was simulated over a range of payloads, up to the maximum GCW. Vehicles that had maximum GCWs above 80,000 pounds were evaluated with both the baseline engine and a higher rating intended to maintain performance or, in the case of Scenarios 5 and 6, at least limit the performance penalty for the higher GCW. **Table 26** below depicts the payloads along with the number of drive cycles evaluated and the total number of simulation runs required:

Table 26: Scenario Payloads, Engine Ratings, and Drive Cycles Evaluated

Scenario	Payloads To Be Simulated by Drive Cycle (Pounds)					Engine Ratings	Drive Cycles	# Of Runs
	1	2	3	4	5			
Control Vehicle	15,378	30,378	45,378	N/A	N/A	485 HP	All 5	15
1	15,378	30,378	45,378	53,378	N/A	485 HP, 534 HP	All 5	40
2	15,378	30,378	45,378	54,745	N/A	485 HP, 534 HP	All 5	40
3	15,378	30,378	45,378	60,745	N/A	485 HP, 588 HP	All 5	40
Control Vehicle	15,378	30,378	45,378	48,624	N/A	485 HP, 428 HP	All 5	40
4	15,378	30,378	46,262	N/A	N/A	485 HP	All 5	15
5	15,378	30,378	45,378	64,046	N/A	485 HP, 588 HP	1, 2, 3	24
6	15,378	30,378	45,378	64,046	81,148	485 HP, 588 HP	1, 2, 3	30

In addition to the payloads shown above, each vehicle was also simulated under two additional conditions: a zero payload (empty vehicle) simulation and a GCW of 200,000 pound payload simulation. These two additional simulations for each vehicle along with the payload scenarios shown above allowed estimation of all possible emissions and energy consumption rates at all possible payloads for each vehicle analyzed.

The result of these simulations were a set of rates describing the amount of fuel consumed and CO_2 and NOx emitted from each vehicle at different payloads for each of the four operational modes. These rates were then applied to the weight specific VMT distributions developed by the modal shift analysis. Only those vehicles that were analyzed by the modal shift analysis were considered in the energy and emissions analysis. The results of this analysis are discussed below.

Fuel Consumption Results

Each scenario demonstrates reductions to fuel consumption relative to the base case. This is consistent with the reductions in travel made possible by the increases in payload tested in each scenario. While most scenarios show comparable improvements, Scenario 3 shows the greatest overall reduction in fuel consumption. **Table 27** shows the changes to fuel consumption between each of the scenarios.

Table 27: Truck Fleet Annual Fuel Consumption (millions of gallons)

Scenario	Fuel Consumed	Change from Base Case
Base Case	21,797.9	0.0
Scenario 1	21,690.9	-107.0 (-.5%)
Scenario 2	21,688.8	-109.1 (-.5%)
Scenario 3	21,488.7	-309.2 (-1.4%)
Scenario 4	21,553.3	-244.7 (-1.1%)
Scenario 5	21,564.8	-233.2 (-1.1%)
Scenario 6	21,567.1	-230.9 (-1.1%)

GHG Emissions Results

Each scenario demonstrates reductions to greenhouse gas emissions relative to the base case scenario. This is consistent with the reduction of travel made possible by the increases in payload tested in each scenario. While most scenarios show comparable improvements, Scenario 3 shows the greatest overall reduction in greenhouse gas emissions. **Table 28** shows the changes to CO_2 emissions between each of the scenarios.

Table 28: Truck Fleet Annual CO_2 Emissions (millions of kilograms)

Scenario	CO_2 Emitted	Change from Base Case
Base Case	221,249.2	0.0
Scenario 1	220,162.9	-1,086.2 (-.5%)
Scenario 2	220,141.8	-1,107.4 (-.5%)
Scenario 3	218,110.5	-3,138.7 (-1.4%)
Scenario 4	218,765.7	-2,483.5 (-1.1%)
Scenario 5	218,882.7	-2,366.5 (-1.1%)
Scenario 6	218,906.0	-2,343.2 (-1.1%)

NOx Emissions Results

Each scenario demonstrates reductions to NOx emissions relative to the Base Case scenario. This is consistent with the reduction of travel made possible by the increases in payload tested in each scenario. While most scenarios show comparable improvements, Scenario 3 shows the greatest overall reduction in NOx emissions. **Table 29** shows the changes to NOx emissions between each of the scenarios.

Table 29: Truck Fleet Annual NOx Emissions (millions of grams)

Scenario	NOx Emitted	Change from Base Case
Base Case	82,832.2	0.0
Scenario 1	82,425.5	-406.7 (-.5%)
Scenario 2	82,417.6	-414.6 (-.5%)
Scenario 3	81,657.1	-1,175.1 (-1.4%)
Scenario 4	81,902.4	-929.8 (-1.1%)
Scenario 5	81,946.2	-886.0 (-1.1%)
Scenario 6	81,955.0	-877.3 (-1.1%)

CHAPTER 6 – SCENARIO IMPACTS ON TRAFFIC OPERATIONS

6.1 Task Scope

Longer and heavier trucks disrupt traffic operations on roadways more than regular vehicles. Disruption occurs in through traffic lanes, at roadway intersections, and on freeway interchanges. Common quantitative measures of disruption include hours of delay and congestion costs. Other performance measures such as density were considered, but the applications of these measures do not fit the scope of this project, which is aimed at evaluating truck impact on traffic operations in a national network.

This chapter presents estimates of changes in delay and associated congestion costs resulting from the truck size and weight policies tested in the six scenarios described in **Chapter 2**.

6.2 Basic Principles

Traffic Congestion

Traffic congestion is determined by the capacity of a given highway and the amount of traffic on it. In traffic engineering, the impact of trucks is assessed in terms of passenger car equivalents (PCE). A PCE represents the number of passenger cars that would use the same amount of highway capacity as the vehicle being considered under the prevailing roadway and traffic conditions. Further, highway capacity depends on the level of service that is intended for the highway. A level-of-service indicates traffic conditions in terms of speed, freedom to maneuver, traffic interruptions, comfort and convenience, and safety.

Trucks are larger and, more importantly, slower to accelerate to their desired speeds than passenger cars, which means they have a greater effect on traffic flow than individual passenger vehicles. The value of PCEs depends on the operating speed and grade of the highway section, the vehicle’s length, and its weight-to-horsepower ratio, which measures how a vehicle can accelerate. Previous research included in the 2000 CTSW Study indicated that on level terrain and in uncongested conditions conventional trucks may be equivalent to about two passenger cars in terms of their impact on traffic flow. In hilly or mountainous terrain and in heavily congested traffic, their effect on traffic flow often is much greater, and they may be equivalent to 15 or more passenger cars. **Tables 30 and 31** show PCEs for trucks with different weight-to-horsepower ratios operating in rural and urban areas under different conditions. The effects of differences in truck length and weight-to-horsepower ratios are quantified in those tables.

These tables are taken directly from the 2000 CTSW Study, which is one of the few studies analyzing truck PCEs with different weight-to-horsepower ratios. PCEs shown in the tables were estimated using simulation modeling since actual observations of the impacts of the vehicle configurations being analyzed in that study were not readily available. Resource constraints for the 2000 CTSW Study precluded validation of the simulation results, but validation would have been difficult anyway because many of the vehicle configurations being analyzed did not operate widely across the country. The methods and findings of the traffic operations analysis for the 2000 CTSW Study were subject to peer review as were all other parts of that study. The desk scan conducted for this 2014 CTSW Study did not uncover any peer review of these values since the 2000 CTSW Study was conducted. It also did not find new research examining the relative PCEs of different vehicle configurations under different operating environments. There were several research studies since the 2000 CTSW Study that examined PCEs under different operating environments, such as at intersections; however, none of these studies were conducted with a large array of truck configurations that could be applied in this study. For example, the 2010 HCM provides average PCE values representing a fleet mix of trucks instead of unique PCEs for trucks with different weight-to-horsepower ratios. As such, these research findings were considered supplemental rather than a substitute to the 2000 CTSW Study.

While the state-of-the-art in simulation modeling has improved since the 2000 CTSW Study was conducted, there is no research suggesting these improvements would significantly affect the relative PCEs for the scenario and base case vehicles being analyzed in the current 2014 CTSW Study. This is particularly true since this operation analysis is a nationwide policy study that is not intended for highway planning and design purposes at the local level. For Scenarios 1-3, the absolute values of the PCEs for base case and scenario vehicles are not critical since under the assumption of this study weight-to-horsepower ratios would be maintained where possible, so the scenario and base case vehicles would have the same PCEs. Impacts on delay and congestion costs would be primarily a function of the relative VMT for the scenario and base case vehicles. For Scenarios 4-6, the improved simulation models available today compared to those that were available for the 2000 CTSW Study could give somewhat different PCE values for base case and scenario vehicles, but the relative difference in PCEs should not be significantly different.

Table 30 shows PCEs for trucks on rural highways. It demonstrates that the highest PCEs occur on highways with the steepest grades and highest speeds. **Table 31** shows PCEs for trucks on urban highways. It again shows the effect of highway speed on PCEs. After grade and highway speed in importance is the weight-to- horsepower ratio of the trucks. Note that **Tables 30 and 31** are not intended to show extreme situations either in terms of roadway or vehicle characteristics; under some different settings the PCEs could be higher than shown in these tables.

The PCEs for all the traffic on a given roadway increase with increased sizes and weights of trucks and decrease with fewer trucks in the traffic stream. The net effect of these opposing changes for each scenario analyzed is presented in this chapter.

Table 30: Vehicle Passenger Car Equivalents on Rural Highways

Roadway Type	Grade Percent	Grade Length (miles)	Vehicle Weight-to-Horsepower Ratio (pounds/horsepower)	Truck Length (feet) 40	80	120
				Passenger Car Equivalents		
Four-Lane Interstate	0	0.50	150	2.2	2.6	3.0
			200	2.5	3.3	3.6
			250	3.1	3.4	4.0
	3	0.75	150	9.0	9.6	10.5
			200	11.3	11.8	12.4
			250	13.2	14.1	14.7
Two-Lane Highway	0	0.50	150	1.5	1.7	NS
			200	1.7	1.8	NS
			250	2.4	2.7	NS
	4	0.75	150	5.0	5.4	NS
			200	8.2	8.9	NS
			250	13.8	15.1	NS

Source: USDOT, *2000 Comprehensive Truck Size and Weight Study*
Key: NS = Not Simulated.

Other Traffic Effects

In addition to congestion, this 2014 CTSW Study assesses, but does not quantify in detail, the impact of longer and heavier trucks on the operation of traffic in the areas of vehicle off-tracking, passing, acceleration (including merging, speed maintenance, and hill climbing), lane changing (including weaving), sight distance requirements, clearance times, pedestrian areas, and work zones. As with congestion, the speed (a function of weight, engine power, and roadway grade) and length of a vehicle are the major factors of concern, although vehicle speed is more important than length in assessing congestion effects.

Off-tracking

There are several measures of a vehicle’s ability to negotiate turns or otherwise “fit” within the dimensions of the existing highway system, but the principal measure is low-speed off-tracking. Two other measures are high-speed off-tracking and dynamic high-speed off-tracking. High-speed off-tracking is a steady-state swing-out of the rear of a combination vehicle going through a gentle curve at high speed. Dynamic high-speed off-tracking is a swinging back and forth due to rapid steering inputs.

Table 31: Vehicle Passenger Car Equivalents on Urban Highways

Roadway Type	Traffic Flow Condition	Grade	Vehicle Weight-to-Horsepower Ratio (pounds/horsepower)	Truck Length (ft.) 40	80	120
				Passenger Car Equivalents		
Interstate	Congested	0	150	2.0	2.5	2.5
			200	2.5	3.0	3.0
			250	3.0	3.0	3.0
	Uncongested	0	150	2.5	2.5	3.0
			200	3.0	3.5	3.5
			250	3.0	3.5	4.0
Freeway and Expressway	Congested	0	150	1.5	2.5	2.5
			200	2.0	2.5	2.5
			250	2.0	3.0	3.0
	Uncongested	0	150	2.0	2.0	2.0
			200	2.5	2.5	2.5
			250	3.0	3.0	3.0
Other Principal Arterial	Congested	0	150	2.0	2.0	2.5
			200	2.0	2.0	3.0
			250	3.0	3.0	4.0
	Uncongested	0	150	3.0	3.0	3.5
			200	3.5	3.5	3.5
			250	3.5	4.0	4.0

Source: USDOT, 2000 Comprehensive Truck Size and Weight Study

On roadways with standard lane widths, the two high-speed off-tracking effects are not large enough to be of concern. Excessive low-speed off-tracking, however, can disrupt traffic operations and result in shoulder or inside curb damage at intersections and interchange ramp terminals that are used heavily by trucks.

Passing or Being Passed on Two-Lane Roads

Cars passing LCVs on two-lane roads would need up to an 8 percent longer passing sight distance compared to passing existing tractor-semitrailer combinations. For their part, longer trucks would also require longer passing sight distances to safely pass cars on two-lane roads. Heavier trucks also require more engine power to pass another vehicle if it is necessary to accelerate to pass the overtaken vehicle.

Heavy truck operators must be particularly cautious when passing on two-lane roads because standards for marking passing and no-passing zones on two-lane roads, developed in the 1930s, are based on cars passing cars. The operation of trucks in these zones was not considered when these standards were developed, nor has it been considered since then. However, this is partially mitigated by the fact that truck drivers have a better view of the road as they sit higher than car drivers.

Vehicle Acceleration at Ramps and Steep Grades

Acceleration performance determines a truck's basic ability to blend well with other vehicles in traffic, particularly at ramps where the merging and diverging maneuvers are needed. As a vehicle's weight increases, its ability to accelerate quickly for merging with freeway traffic and to maintain speed (especially when climbing hills) is degraded, unless larger engines or different gearing arrangements are used. These concerns may also be addressed by local policies that identify specific routes to ensure they are suitable for use by any vehicle at its proposed weight and dimensions. Aerodynamic truck designs, by reducing drag, provide a promising vehicle design solution to help trucks to accelerate and maintain speed as well.

On routes with steep grades that are frequently traveled by trucks, special truck climbing lanes are often built to accommodate truck acceleration and deceleration capabilities in order to reduce the congestion and safety impacts to passenger vehicles. Otherwise, trucks are expected to maintain reasonable grade climbing performance. In the past, hill climbing performance has been addressed by requiring larger trucks to be equipped with higher horsepower engines. While in some cases larger engines may be necessary to maintain grade climbing performance, experience has shown that a more easily enforceable approach is to specify minimum acceptable speeds on grades and minimum acceptable times to accelerate from a stop to 50 mph or to accelerate from 30 mph to 50 mph.

The 2008 Highway Performance Monitoring System (HPMS) provided highway grade data for the 48 contiguous States and the District of Columbia. **Table 32** summarizes the distribution of grades on different highway types.

Table 32: Distribution of Grade on Different Highway Functional Classes

Highway Type	Percent of Total Highway Miles	
	0.00 – 3.00 Percent Grade	3.01 or More Percent Grade
Rural Interstate	87	13
Rural Other Principal Arterial	88	12
Rural Minor Arterial	86	14
Rural Major Collector	83	17
Urban Interstate	89	11
Urban Freeways & Expressway	90	10
Urban Other Principal Arterial	91	9
Urban Minor Arterial	82	18
Urban Collector	91	9

Source: 2008 HPMS Data

In addition, highway design policies place limits on the steepness of grades. Federal policy for the Interstate System specifies maximum grades as a function of design speed. For example, highways with design speeds of 70 mph may not have grades exceeding 3 percent. Gradients may be up to 2 percent steeper than those limits in rugged terrain. Generally, the steepest grades to be encountered by heavy trucks are to be found in the mountainous areas of the western United States and, to a lesser extent, on some of the older highways in the northeastern States. As discussed previously, **Table 30** shows the marked effect that percent and length of grades have on truck climbing ability if the truck does not have a low ratio of GVW to horsepower.

In previous studies, fleet owners who operate large trucks (mostly in the West) were asked about their experience with combination vehicles. They said they purchase trucks with large enough engines that allow drivers to maintain reasonable and efficient speeds. Tractor manufacturers corroborated this, indicating that trucking companies and individual drivers want and buy trucks with large engines. Engine manufacturers build engines with up to 600 horsepower. These engines are sufficient to maintain a minimum speed of 20 mph for a 130,000-pound truck on a 6 percent grade. Over the past 20 to 30 years, engine power has grown at a more rapid rate than weight.

Traction

If single-drive-axle tractors are used in multi-trailer combinations, the tractor may not be able to generate enough tractive effort to pull the combination up a hill under slippery road conditions, especially if it is heavily loaded. In these cases, either tandem- axle tractors or tractors equipped with automatic traction control would be appropriate. Specially built tractors are used in Colorado to push multi-trailer combinations when they have traction problems.

Lane Changing and Weaving

Compared to conventional tractor-semitrailer combinations, longer vehicles require larger gaps in traffic flow in order to change lanes or merge with traffic. The effect of this performance characteristic is proportional to vehicle length and the surrounding traffic density. Limited research is available to quantify the specific impact of truck lane changing. The HCM 2010 weaving analysis uses the same truck PCE values as basic freeway segments. Nevertheless, skilled truck drivers can minimize impacts to traffic by limiting the number of lane changes and using extra caution when merging and weaving.

Intersection Requirements

Heavier vehicles entering traffic on two-lane roads from non-signalized intersections could take more time to accelerate up to the speed limit. If sight distances at the intersection are obstructed, approaching vehicles might have to decelerate abruptly, which could cause a crash or disrupt traffic flow. Longer trucks crossing non-signalized intersections from a stopped position on a minor road could increase by up to 10 percent the distance required for the driver of a car in the cross traffic to see the truck and bring the car to a stop without impacting the truck.

Table 33 shows how vehicle features affect traffic congestion, off-tracking, and operations. As indicated in the table, the most important parameters are vehicle length and weight, with speed being closely related to weight. Increases in allowable lengths may only be compensated for by limiting operations to multilane facilities except for short distances. Weight may be compensated for by requiring that vehicles be able to maintain sufficient speed in order to not disrupt traffic excessively on any route used.

Table 33: Traffic Operations Impacts of Truck Size and Weight Limits

Vehicle Features		Traffic Congestion	Vehicle Off-		Traffic Operations			
			Low Speed	High Speed	Passing	Acceleration (merging and hill climbing)	Lane Changing	Intersection Require-ments
Size	Length	- e	- E	+ e	- E	—	- E	- E
	Width	—	- e	+ e	- e	—	- e	—
	Height	—	—	- e	—	—	—	—
Design	Number of units	—	+ E	- E	—	—	- e	—
	Type of hitching	—	+ e	+ E	—	—	+ E	—
	Number of Axles	—	+ e	+ e	—	—	+ e	—
Loading	Gross vehicle weight	- e	—	- E	- E	- E	- e	- E
	Center of gravity height	—	—	- e	—	—	- e	—
Operation	Speed	+ E	+ E	- E	- E	—	+ e	+ E
	Steering input	—	- E	- E	—	—	- E	—

Source: USDOT, 2000 Comprehensive Truck Size and Weight Study
+/- As parameter increases, the effect is positive or negative.
E = Relatively large effect. e = relatively small effect. — = no effect.

Pedestrian Areas

The impact of trucks on pedestrians and bicyclists is low and sporadic along most roadway segments. However, when the paths of two groups cross each other at intersections, there is a risk of severe injury to unprotected pedestrians/bicyclists. Increased truck length, off-tracking, and rearward amplification are factors that could adversely affect the safety of pedestrians and cyclists on highways with larger trucks. Better route planning, safety education, and better traffic control are common countermeasures to improve truck safety in the pedestrian areas.

Work Zones

Although work zones certainly present hazards to all drivers, trucks are affected in particular due to their larger size, heavier weight, and inability to accelerate and decelerate in the same distance as other traffic. Work zones can result in narrow lanes, speed-limit adjustments, lane shifts, and stop-and-go traffic. All of these can create difficult challenges for trucks. To the extent that increased truck size and weight limits might necessitate additional pavement and bridge repairs, the number of work zones and the resulting impacts on traffic operations could potentially increase. (For detailed information on these impacts, please see *Volume II: Pavement Comparative Analysis* and *Volume II: Bridge Structure Comparative Analysis*) In general, there may also be the potential for longer or heavier trucks to have different impacts in work zones.

Local traffic regulations and the development of transportation management plans (TMPs) for specific work zones can mitigate work zone truck impacts. FHWA requires the development of TMPs for all Federal-aid highway projects to reduce traffic and mobility impacts, improve safety, and promote coordination within and around the work zone.[9] State and local transportation agencies need to develop and implement TMPs that best serve the mobility and safety needs of the local road users, construction workers, businesses, and community.

6.3 Methodology

Analytical Approach

As noted above, the analysis of the impacts of the increased truck size and weight allowance scenarios on traffic operations drew heavily from data and methods developed for the 2000 CTSW Study. Highway user delay and congestion costs were assessed using PCE values developed in the 2000 CTSW Study. That study used three traffic simulation models—one for Interstate highways, one for rural two-lane highways, and one for urban arterials to estimate PCEs for trucks with different weights, dimensions, and performance characteristics in different highway environments. To obtain PCEs by truck length and gross weight-to- horsepower ratio, the simulation models were run many times for two sets of representative roadway geometric conditions for each of the three highway types. A detailed description of methods used to estimate PCEs for different truck characteristics in different highway environments is presented in the paper, "Quantifying Traffic Operational Impacts of New Truck Configurations in the U.S. Highway Network**."**[10]

The truck vehicle miles of travel (VMT) by truck configuration and weight that is estimated to result from the increased truck size and weight allowance scenarios is substituted in the traffic delay model for the base case (2011) truck VMT, and the change in highway operating speed by functional class is calculated to obtain the change in delay for all highway users. This change in delay in vehicle hours is then multiplied by a time value of $17.24 per hour to obtain the change in congestion costs. This time value was taken from the Highway Economic Requirement System ($13.16 in 1994 dollars) and adjusted by the USDOT Guidance on Valuation of Travel Time in Economic Analysis that recommended a 1.6 percent compound growth rate for 2011.

Comparison to Previous TSW Studies

The 2014 CTSW Study is updated with several changes from the 2000 CTSW Study. These changes include updated speed-flow rate curves, updated roadway network based on the HPMS 2011 network data and an updated value of travel time that reflects the 2011 value.

[9] FHWA, *Work Zone Safety and Mobility Rules*, http://ops.fhwa.dot.gov/wz/resources/final_rule.htm. Last modified September 19, 2013.
[10] Elefteriadou, Lily and Nathan Webster, "Quantifying Traffic Operational Impacts of New Truck Configurations in the U.S. Highway Network," 1997, http://road-transport-technology.org/Proceedings/5%20-%20ISHVWD/Part%201/QUANTIFYING%20TRAFFIC%20OPERATIONAL%20IMPACTS%20OF%20NEW%20TRUCK%20CONFIGURATIONS%20IN%20THE%20U.S.%20HIGHWAY%20NETWORK%20-%20Elefteriadou%20.pdf

6.4 Results

Summary

The impacts of the policy scenarios on traffic – highway user delay, congestion costs, low-speed off-tracking, passing, acceleration (merging and hill climbing), lane changing, and intersection requirements – are discussed below.

Table 34 shows the changes in traffic delay and congestion costs for Scenarios 1 through 6. Overall the changes of VMT have minimal impact on travel speed. Nevertheless, all of the scenarios could marginally reduce delay and congestion costs compared to the base case.

Scenarios 3 and 4 could reduce delay and congestion costs over $850 million in 2011. This assumes that requirements are in place to ensure the heavier trucks have engines and braking systems with power sufficient to perform as existing trucks perform.

The remaining traffic operations impacts – off-tracking, passing, acceleration, lane changing, and intersection requirements – are evaluated in qualitative terms.

Table 34: Scenario 1-6 Traffic Impacts

Scenario	Traffic Delay (million vehicle-hours)	Changes in Traffic Delay (million vehicle-hours)	Congestion Costs ($, million)	Changes in Congestion Costs ($, million)
Base Case	60,531	-	$1,043,547	-
Scenario 1	60,516	-15 (-.02%)	$1,043,290	-$256 (-.02%)
Scenario 2	60,510	-21 (-.03%)	$1,043,189	-$358 (-.03%)
Scenario 3	60,481	-50 (-.08%)	$1,042,690	-$857 (-.08%)
Scenario 4	60,480	-51 (-.08%)	$1,042,672	-$875 (-.08%)
Scenario 5	60,501	-29 (-.05%)	$1,043,042	-$505 (-.05%)
Scenario 6	60,500	-30 (-.05%)	$1,043,022	-$525 (-.05%)

APPENDIX A: MODAL SHIFT DESK SCAN

CHAPTER 1 - INTRODUCTION

1.1 Purpose

This report presents a revised version of the Desk Scan (Subtask V.E.2) developed to support the Modal Shift Comparative Analysis (Task V.E.) of the 2014 *Comprehensive Truck Size and Weight Limits Study (2014 CTSW Study)*. This revised Desk Scan addresses the recommendations made by the National Academy of Science (NAS) Peer Review Panel concerning the originally submitted version of this scan.

The purpose of the revised Desk Scan is to:

- Reorganize and enhance the original Desk Scan; and
- Add any additional, relevant content that may have been identified since the submission of the original Desk Scan.

Specifically the desk scan has addresses the following four topics:

- Survey of analysis methods and a synthesis of the state of the art in modeling impacts
- Identification of data needs and a critique of available data sources
- Assessment of the current state of understanding of the impacts and needs for future research, data collection and evaluation
- Synthesis of quantitative results of past studies including reasonable ranges of values for impact estimates.

This desk scan includes a review of key literature related to estimates of modal shifts and related impacts associated with changes in truck size and weight limits as well as more general literature on mode choice. This desk scan is organized into three primary sections: 1) modal shift diversion studies, 2) travel fuel consumption studies, and 3) heavy truck impact on highway traffic operations. The literature review will address the NAS four issues for each of the three areas.

The purpose of this task is to estimate the extent to which changes in Federal truck size and weight limits might cause shifts in how freight is shipped including shifts between modes (*e.g.,* some traffic shifting from rail to truck) and shifts from one truck configuration to another (*e.g.,* shifts from configurations that were legal under current truck size and weight limits to configurations that would become legal under new size and weight limits). These shifts could affect the volume of truck traffic that would be required to carry a given amount of freight and the weights of trucks traveling on different parts of the highway system. These changes in turn will affect safety, infrastructure preservation costs, productivity, energy consumption, environmental emissions and other factors. Detailed estimates of changes in the characteristics of freight transportation associated with changes in truck size and weight limits will be required to assess the various potential impacts of those changes.

This report provides a scan of the literature on data and methods used in previous studies of freight modal diversion, and assesses how the data and methods used in previous studies meet requirements for nationwide modal diversion estimates in the current 2014 CTSW Study.

This section sets the context and requirements for the study and provides an overview of freight trends for the last 12 years using data from the Bureau of Transportation Statistics (BTS). The next section discusses the data available for analysis of modal diversion and discusses findings from other studies obtained from the desk scan. This is followed by a discussion of the methods used in the various studies. The report concludes with recommendations for the data and models to be used to estimate modal shifts for the 2014 CTSW Study and the challenges in developing those data and methods.

1.2 Study Requirements Related to Modal Diversion

Several different vehicle configurations will be examined in the 2014 CTSW Study, each with unique operating characteristics that will influence the types of highways that could be suitable for their use. Characteristics that would affect the suitability of different vehicle configurations to operate on different parts of the highway network include the vehicle's ability to negotiate curves of various widths; the ability to maintain speeds on grades; the rearward amplification of turning maneuvers in multi-trailer combinations; and the vehicle's overall dimensions. Potential impacts of allowing these different vehicle configurations to operate on different highway networks throughout the U.S. will be assessed including the potential diversion of freight from vehicles that are legal under existing federal truck size and weight limits to trucks that would become legal under higher federal weight limits. The modal shift analysis will also estimate potential diversion from other modes of transportation to vehicle configurations that could be allowed under higher federal truck size and weight limits. Limitations on the highway networks suitable for different vehicle configurations will affect the extent to which each configuration might be an economical alternative for transporting different types of commodities between different origins and destinations.

A highly disaggregated set of commodity flows will be required to assess feasibility and costs of moving different types of cargo between different origins and destinations by various vehicle configurations on different parts of the highway network. The USDOT, *Comprehensive Truck Size and Weight Study, 2000* (2000 CTSW Study), used county-to-county flows, which allowed a detailed analysis of the effects of limiting certain Longer Combination Vehicles (LCV) to the Interstate System. Larger aggregations of origin-destination data, at the BEA or FAF-region level for instance, would make this type of analysis much more difficult since Interstate System Highways likely would pass through most if not all of those larger regions. The 2000 CTSW Study found that limiting networks on which certain vehicle configurations were allowed to operate could significantly affect the costs and utilization rates of using different vehicle configurations, particularly between origins and destinations not directly served by highways available to all truck configurations. When LCVs were not allowed to travel off networks designated for their use, they had to be assembled and disassembled at staging areas to travel to destinations that were not immediately adjacent to the designated network, just as they currently have to do on certain eastern turnpikes. Depending on the shipment distance and commodity value, this requirement that LCVs be broken down to travel off the designated network made the difference between whether the LCV was used or whether the commodity was shipped by vehicles that did not have to be broken down to travel from origin to destination. Such impacts of having restricted networks available to certain vehicle configurations cannot be adequately assessed with highly aggregated commodity flow data.

1.3 Freight Trends

Between 2002 and 2007 the railroads' share of total freight ton-miles increased from 45 to 48 percent while trucking's share of ton-miles remained at about 42 percent over this period. The share of freight ton-miles shipped on navigable waterways (including shallow and deep draft and Great Lakes) fell from 13 to 10 percent (**Figure 1**). Trucking's share of vehicle-miles of freight transportation increased from 86 to 89 percent over this period while rail car-miles decreased from 14 to 11 percent.

Rail is efficient at moving heavy freight over long distances, as are water and pipeline freight services. Railroads also are important for intermodal moves of long-haul containerized freight, and in certain markets, short-line railroads successfully compete with trucks to haul large volumes of dense commodities relatively short distances. Trucks excel in providing time-sensitive delivery services for high-value goods being transported over medium and short-haul distances. Raw materials and heavy freight going long distances are likely to continue their journey by rail, or some combination of truck, rail, and water. With the future growth in freight, it is anticipated that freight rail will continue to make investments in the capacity required to move heavy and long-distance shipments. Railroads also are making investments to allow them to compete more vigorously with trucks for medium-distance freight traffic. It is in this area where potential impacts of changes in truck size and weight limits could have the greatest impact on the railroads. The US Department of Transportation's (USDOT) Federal Railroad Administration (FRA). **Table 1** shows the modal comparative advantage by market (USDOT FRA 2010, p. 17).

Figure 1. Shipment Characteristics by Total Modal Activity (Ton-Miles) for the United States: 2007 and 2002 (2007 Commodity Flow Survey)

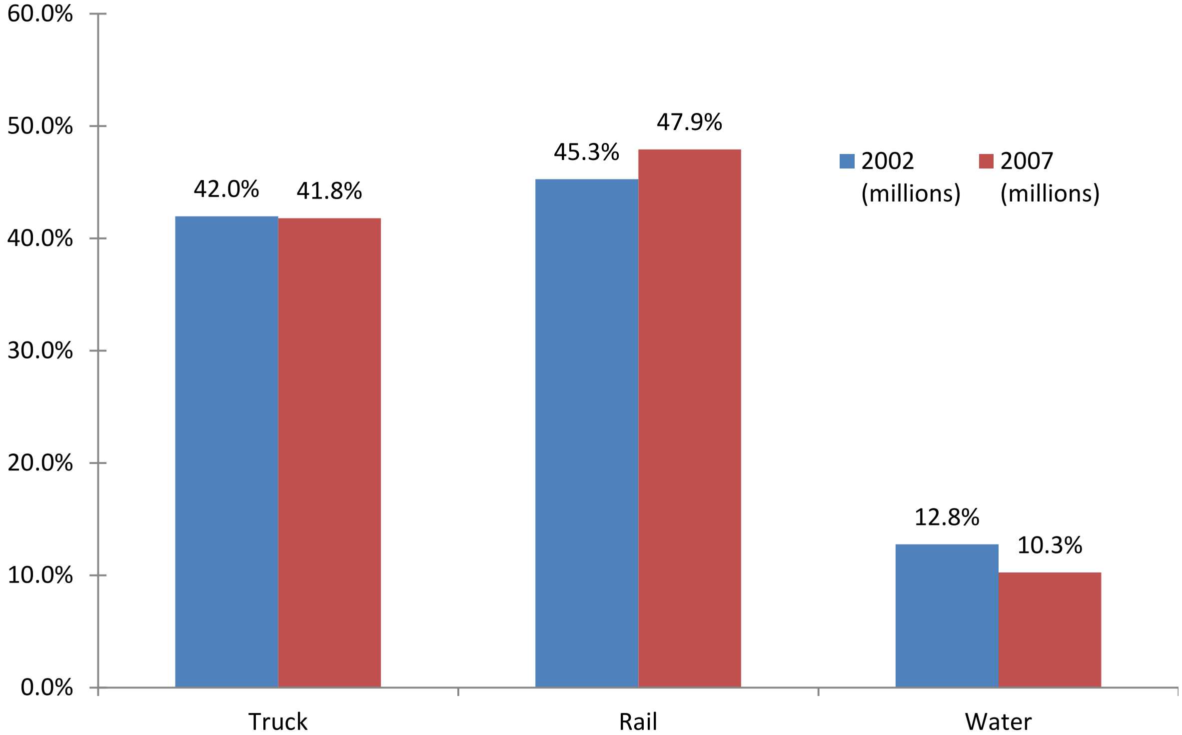


Table 1. Modal Comparative Advantage by Market (USDOT FRA 2010, p. 17)

WEIGHT	Intercity Distance in Miles				
	0-250	250-500	500-1,000	1,000-2,000	>2,000
Retail Goods/Light	Truck	Truck	Truck Rail Intermodal	Truck Rail Intermodal	Truck Rail Intermodal
Consumer Durables and Other Manufactured Goods/Moderate	Truck Rail	Truck Rail Rail Intermodal	Truck Rail Rail Intermodal	Truck Rail Rail Intermodal	Truck Rail Rail Intermodal
Bulk Goods/Heavy	Truck Rail Water	Rail Water Truck	Rail Water	Rail Water	Rail Water

The Federal Railroad Administration, in its 2010 National Rail Plan (FRA 2009), identifies a future need for more freight capacity. Particularly in the next 25 years it estimates there will be 2.8 billion more tons of freight and in the next 40 years – 4 billion more tons of freight. Two goals identified in the National Rail Plan are to support the current freight rail market share and growth and to develop strategies to attract 50 percent of all shipments 500 miles or greater to intermodal rail. As is identified in the study, some diversion to rail is a national goal.

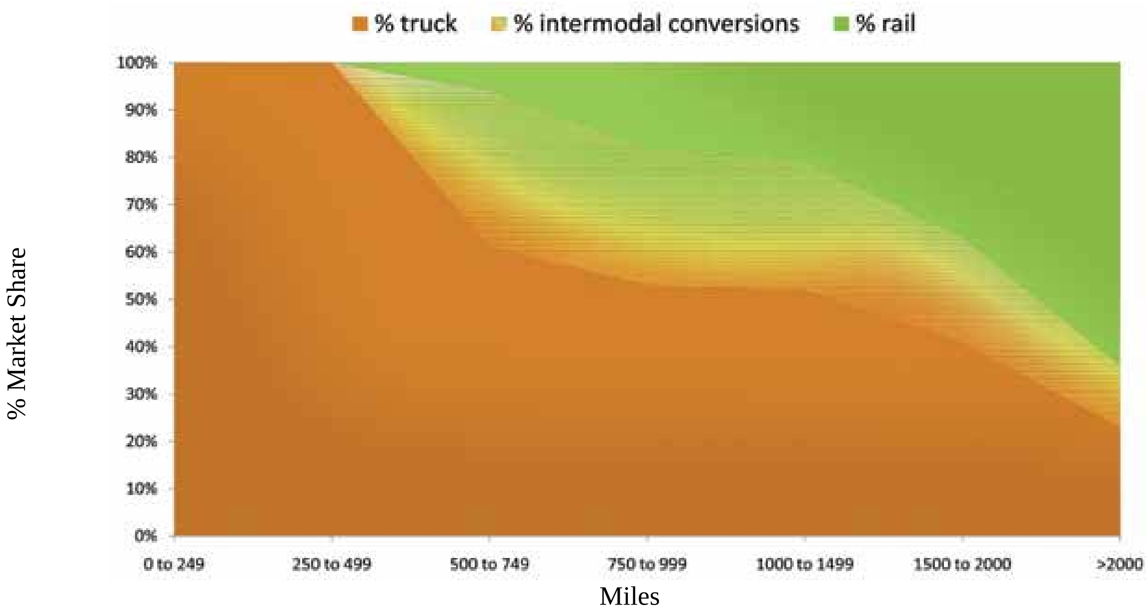
The National Rail Plan notes that the U.S. leads the world in terms of freight rail tonnage. Passengers and freight often travel along the same rail corridors making both reliability and safety a challenge. Two goals for freight rail identified in the report are as follows:

- Support the current freight rail market share and growth.
- Develop strategies to attract 50 percent of all shipments 500 miles or greater to intermodal rail.

The Plan notes that improving freight rail's intermodal market share and connections to ports will improve international trade opportunities and supports the President's National Export Initiative. In relation to rail intermodal, the report mentions that replacing 300 trucks with one long-distance, double stack train between Chicago and Los Angeles has the potential to save 75,000 gallons of fuel. Benefits of freight rail as compared to truck include enhanced safety, fuel efficiency, congestion mitigation, reduction of logistics cost, and reduction of greenhouse gases. These various impact areas are all considered in the 2014 CTSW Study, although in the context of changes in truck size and weight policy rather than in the context of investment strategies designed to support goals enunciated in the National Rail Plan. As shown in **Table 1**, rail currently carries about 47 percent of all ton-miles of freight moved by surface modes.

Figure 2 shows the additional market share needed for rail to move 50 percent of the 500-mile or greater market by 2035, one of the goals identified in the National Rail Plan.

Figure 2. Modal Shift Projection (USDOT Federal Rail Administration, National Rail Plan Progress Report 2010, p. 20



CHAPTER 2 - SUMMARY OF KEY MODAL SHIFT STUDIES AND RELATED DATABASES

Studies related to Federal truck size and weight policy date back 75 years. Major national studies include:

U. S. Department of Transportation Studies

a. The Western Uniformity Scenario Analysis 2004

b. The Comprehensive Truck Size and Weight Study 2000 (2000 CTSW Study)

c. Longer Combination Vehicle Operations in Western States 1986

d. The Feasibility of a Nationwide Network of LCVs 1985

e. Maximum Desirable Dimensions and Weights of Vehicles Operated on the Federal-Aid System 1964

f. Federal Regulation of the Sizes and Weight of Motor Vehicles 1941

Transportation Research Board Studies

a. Special Report 267: Regulation of Weights, Lengths, and Widths of Commercial Motor Vehicles 2002

b. Special Report 227: New Trucks for Greater Productivity and Less Road Wear, An Evaluation of the Turner Proposal 1990

c. Special Report 225: Truck Weight Limits: Issues and Options 1990

The Government Accountability Office Studies

a. Longer Combination Trucks: Potential Infrastructure Impacts, Productivity Benefits, and Safety Concerns 1994

b. Longer Combination Trucks: Driver Controls and Equipment Inspection Should be Improved

c. Truck Safety: The Safety of Longer Combination Vehicles is Unknown

The most recent studies that include estimates of potential modal shifts associated with truck size and weight policy changes are summarized in this desk scan.

A summary of recent truck size and weight research was published in 2011 under National Cooperative Highway Research Program (NCHRP) 20-07, Task 303 (Carson 2011). The scope of that study is very broad with modal shift being only one of many subject areas covered. This NCHRP study includes individual State studies as well as nationwide studies, but there is little discussion of analytical methods or data used to analyze potential modal shifts associated with various truck size and weight policy options. Detailed findings from the various nationwide studies are presented along with a number of general findings as follows:

- *The proportion of freight transported between rail and truck is determined by complex economic relationships intended to maximize profit for each respective mode. Rail industry revenues are directly related to transport rates established by the trucking industry—and vice versa—for all commodities that can be practicably carried by either mode.*

- *Increases in maximum allowable truck sizes and weights will predictably lead to lower truck transport costs; industry competition and regulatory pressure will translate these lower costs into lower transport rates. The rail industry has to either match the lower rates or lose traffic to the competing mode—in either instance, rail revenues will decline.*

- *The magnitude of revenue loss depends on the extent of trucking industry cost/rate reductions brought about by the increase in capacity, and by the proportion of existing rail traffic that will shift to truck if the relative transport rates of the two modes change.*

- *Estimates of rail to truck traffic diversion and subsequent losses in rail revenue are highly variable suggesting sensitivity to: (1) regional commodity movement/transportation infrastructure conditions, (2) the extent of truck payload capacity increases, and (3) evaluation assumptions.*

- *Shippers choosing between truck and rail often consider a trade-off between price and service. In terms of price-per-ton-mile, rail service is almost always less expensive than truck service. In terms of service quality, truck service offers door-to-door delivery and typically faster deliveries.*

- *For low-value commodities—such as coal, grain, or chemicals—the price of shipping is often a priority over the convenience of door-to-door service, providing rail a formidable advantage over highway movement.*

- *Intermodal operations that rely upon combined truck and rail transport for different segments of the trip experience the highest level of competition between truck and rail modes. Carload* operations that utilize boxcars also experience a high level of competition between these modes.

Other freight modal diversion studies have been conducted that are not cited in the NCHRP summary. Major studies uncovered in the desk scan are included in this report.

In the context of truck size and weight studies, modal diversion includes not just diversion of freight traffic from rail to truck as the result of changes in truck size and weight limits, but also shifts of traffic from truck configurations that are legal under existing truck size and weight limits to configurations that would become legal if size and weight limits were increased. Freight traffic is generally characterized as either “weigh out” or “cube out.” Weigh out traffic reaches the gross vehicle weight (GVW) limit at or before the cubic capacity of the cargo-carrying unit is filled. Weigh out traffic can benefit from increasing the maximum GVW of trucks. Some benefit would be realized by increasing the GVW limit of trucks that are the same length as existing configurations, but even greater more cargo could be hauled in each trip if both the cubic capacity and GVW of the vehicle were increased. Cube out traffic on the other hand fills the cargo-carrying unit before reaching the gross vehicle weight limit. Additional cubic capacity is required to carry more cube-out traffic, and this usually requires adding one or more trailers to the vehicle.

Mode choice involves consideration of more than just the relative cost of transporting cargo by various modes and vehicle configurations. Total logistics costs associated with each transport alternative must also be considered. The principal logistics costs related to alternative transportation modes are transit time, warehousing and inventory costs, and safety stock requirements. In general the higher the value of the good the more important are non-transportation logistics costs to the choice of mode. While differences between non-transportation logistics costs typically are greater between truck and rail, there are differences between truck configurations as well that must be considered in mode choice analyses.

2.1 Summary of Previous Modal Shift Studies

2.1.1 National Diversion Studies

2.1.1.1 Comprehensive Truck Size and Weight Study, 2000

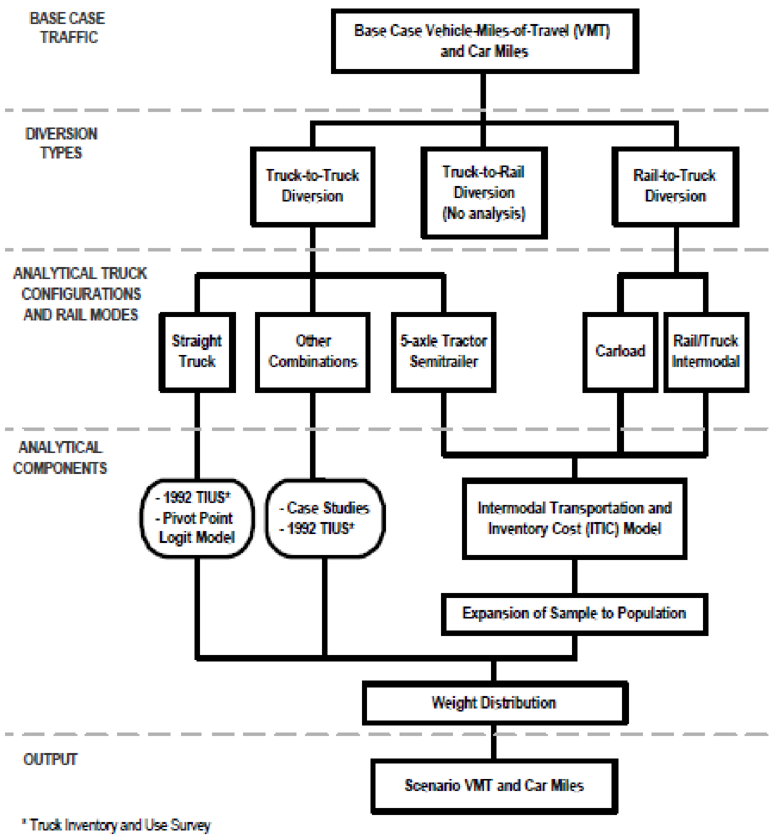
The USDOT's *Comprehensive Truck Size and Weight Study, 2000* (2000 CTSW Study) (USDOT 2000b) used a total logistics cost model and highly disaggregated commodity flow data to estimate mode choice decisions for shipments of different commodities to different origins and destinations. County-to-county flows of different types of commodities were evaluated to determine the lowest total logistics cost for each mode, taking into consideration among other things route restrictions that were assumed to be placed on various longer combination vehicle (LCV) configurations. County-level origins and destinations were necessary to reflect differences in the highway networks assumed to be available to different LCVs.

The 2000 CTSW Study estimated both diversions from one truck configuration to another and rail-to-truck diversion. The logistics cost model used in the 2000 CTSW Study was called the Intermodal Transportation and Inventory Cost(ITIC) Model and was based on the Association of American Railroads' (AAR) Intermodal Competition Model that had been used in the Transportation Research Board's *Special Report 225, Truck Weight Limits* Study (TRB 1990). The development and analytical framework of the ITIC model are described in greater detail in Appendix E.

No public commodity flow data by truck were available for the 2000 CTSW Study so the study relied on the North American Transportation Survey (NATS) conducted by AAR at truck stops to capture long haul truck moves, the Census Department's Truck Inventory and Use Survey (TIUS) and FHWA's Highway Performance Management System (HPMS). Rail flows came from the rail waybill database and rail rate data came from proprietary Surface Transportation Board (STB) data. This proprietary rate data was essential to the study since no other source of actual rail rates for different types of shipments in different corridors was available to compare to costs of moving the same commodities between the same origins and destinations by various truck configurations. Truck rate data was purchased from a private vendor because the data reflected differential rates in various markets.

Figure 3 shows the analysis of the scenario vehicle miles of travel (VMT) and car miles. Diversion of freight from one truck configuration to another accounted for a substantial share of the total change in truck VMT associated with Truck Size and Weight (TS&W) policy options.

Figure 3. Analysis of Scenario VMT and Car Miles (USDOT FHWA 2000, vol. 3, p. IV-2)



The analysis of truck-to-truck diversion was divided into short-haul shipments and longer-haul, primarily because suitable data on short-haul shipments were not available. Several policy scenarios were analyzed to isolate potential impacts of different vehicle configurations that might be allowed under different TS&W policy options. Both rail intermodal—containers or trailers going by rail for part of their journey—and rail carload moves were analyzed. Impacts of changes in TS&W limits examined in the study included safety, pavement and bridge deterioration, traffic operations, productivity, energy consumption, and environmental impacts.

2.1.1.1.1 Networks for Scenario Analysis

The 2000 CTSW Study assumed the following networks for the purposes of scenario analysis.

National Network for Large Trucks: The Surface Transportation Assistance Act (STAA) of 1982 required States to allow 48-foot semitrailers and 28-foot double trailer combinations (often referred to as “STAA doubles”) on specified highways. The National Network includes virtually all Interstate Highways as well as other highways. States are required to allow reasonable access for the STAA vehicles to and from the National Network.

National Highway System: With the National Highway System (NHS) Designation Act of 1995, Congress established the NHS. This system consists of the highways of greatest National interest, and includes the Interstate System, a large portion of the other principal arterial highways, and a small portion of mileage on other functional systems. MAP-21 expanded the National Highway System to include all highways classified as principal arterials.

Analytical Networks for Longer Combination Vehicles: Two illustrative networks were specified to analyze expanded LCV operations under the various scenarios. The USDOT emphasized that these networks, like the scenarios themselves, were purely for illustrative purposes and did not reflect the USDOT's position on where various vehicle classes should be allowed to operate. The network developed to test the operation of long double trailer combinations -- Rocky Mountain Doubles (RMDs) and Turnpike Doubles (TPDs) -- consisted of access-controlled, interconnecting segments of the Interstate System and other highways of comparable design and traffic capacity. The routes connected major markets and distribution centers. The network designed to evaluate the impact of allowing triple-trailer combinations to operate nationwide includes 65,000 miles of rural Interstate and other highways. Some urban Interstate highway segments were included for connectivity. This network included many low traffic highways in the U.S.-West and some four lane highways in the U.S.-East. The network designed for the operation of triple-trailer combinations is larger than the network used to analyze long double combination operations because triple trailer combination vehicles have better offtracking performance than long twin trailer combinations.

2.1.1.1.2 Scenario Analysis

Of the policy scenarios examined in the 2000 CTSW Study, three involved increased TS&W limits. These scenarios are described below.

The North American Trade Scenario This scenario would allow heavier tridem axles, up to either 44,000 or 51,000 pounds, to facilitate trade between the U.S. and its NAFTA partners. Such changes would allow the eight-axle B-train combinations used in Canada to operate on U.S. highways. It would also increase the use on U.S. highways of six-axle tractor-semitrailer combinations, which are currently much more common in Canada and particularly Mexico. The network would comprise 42,000 miles for Rocky Mountain Doubles and Turnpike Doubles, 60,000 miles for triples, and the existing National Network for eight-axle B-train doubles. The study noted that only 21 states allow LCVs, and that some eastern states only allow those vehicles on their turnpikes.

Longer Combination Vehicles Nationwide Scenario This scenario assumed that a national network over which these vehicles could operate. The network would comprise 42,000 miles for Rocky Mountain Doubles (RMD) and Turnpike Doubles (TPD), 60,000 miles for triples, and the existing National Network for eight-axle B-train doubles. Due to their poor offtracking, the scenario did not allow long double-trailer combinations (TPDs and RMDs) off the designated network. It is assumed that drivers of these vehicles would use staging areas—large parking lots—to disconnect the extra trailer and attach that trailer to another tractor for delivery to its final destination. Drayage is assumed to be along the most direct route off the network between the shipper or receiver and the network. The staging area costs are not included in the truck operating costs because it is unclear whether charges would be levied for use of the staging areas.

Triples Nationwide Scenario The Triples Nationwide Scenario would establish a national 65,000-mile network for seven-axle triple combinations weighing up to 132,000 pounds. Little diversion from rail intermodal was expected, however, because this scenario assumed that each triple-trailer combination can only handle containers up to 28 feet in length and the majority of rail intermodal traffic is transported in containers or trailers 40 feet or longer.

2.1.1.2 Western Uniformity Scenario Analysis

As the USDOT's 2000 CTSW Study was nearing completion, the Western Governors' Association (WGA) asked the USDOT to analyze another illustrative truck size and weight scenario in addition to the scenarios already included in the study. The "Western Uniformity Scenario" requested by WGA would assess impacts of lifting the LCV freeze and allowing harmonized LCV weights, dimensions, and routes among only those western states that currently allow LCVs (USDOT 2004). Specifically the WGA requested that USDOT analyze impacts of expanded LCV operations assuming that weights would be limited only by federal axle load limits and the federal bridge formula, with a maximum gross vehicle weight of 129,000 pounds.

LCVs have operated in western states for many years. Grandfather rights in effect since 1956 have allowed those vehicles to exceed the 80,000-pound federal weight limit on Interstate Highways. Until 1991 States could determine the weights and dimensions allowed under their grandfather rights, but the LCV freeze instituted in the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) prohibits States from increasing allowable LCV weights on the Interstate System or allowing longer LCVs on the National Network established in the Surface Transportation Assistance Act of 1982. Because grandfather rights in each of the western states differ, allowable weights and dimensions for LCVs in most western states vary.

Both the logistics cost model and the commodity flow data used for the 2000 CTSW Study were significantly improved for the Western Uniformity Scenario Analysis. The ITIC model, was made easier to use and logistics costs were updated and refined. The major improvement, however, in the Western Uniformity Scenario Analysis was in the commodity flow database. The Federal Highway Administration (FHWA) developed its Freight Analysis Framework (FAF) in 2002 and that database was used for the Western Uniformity Scenario Study. The FAF, which is discussed in more detail later in this desk scan, was based on the Census Bureau's Commodity Flow Survey (CFS) with additional data sources to fill in commodity flows that were not collected in the CFS. For the Western LCV Uniformity Scenario, a version of FAF having county-to-county flows was developed that allowed detailed assessments of the potential shift to LCVs based on the networks that would be available to those vehicles and the extent to which those networks served various origins and destinations at the county level. Without county level origins and destinations it would have been impossible to directly reflect network limitations for some LCVs when estimating potential diversion of traffic to those configurations since virtually all FAF regions are served by all highway systems. The limited networks assumed to be available to various types of LCVs, and the requirement that they assemble and disassemble for travel off those networks, significantly affected estimates of overall diversion and the configurations to which shipments were diverted.

2.1.1.3 TRB Special Report 225, Truck Weight Limits

The Transportation Research Board's 1990 *Special Report 225, Truck Weight Limits* was one of the most comprehensive analyses of truck size and weight policy options that had been done up to its publication date. The study analyzed impacts of 10 specific truck size and weight policy options including several that are similar to scenarios being analyzed in the current 2014 CTSW Study.

Base case forecasts of VMT and payload ton-miles for a future year (1995) were developed for 10 vehicle types, seven regions of the country, nine gross vehicle weight ranges, and four highway systems (rural and urban Interstate, other rural and other urban).

Interviews with 32 firms representing all segments of the trucking industry were a key input to developing forecasts of scenario VMT. No mathematical model was used to estimate shifts from one truck configuration to another, but the authors note that many perspectives were provided in the interviews that would be difficult to capture in a mathematical model. On the other hand findings depend to a great degree on the firms interviewed for the study and there is uncertainty about whether actual responses to truck size and weight changes would correspond to anticipated responses noted in the interviews.

It was assumed that State length limits and access policies for multi-trailer combinations would remain unchanged. Thus in regions where length limits would not allow longer combination vehicles, such vehicles would not be allowed in that region even under a scenario in which that vehicle otherwise would be allowed. Likewise in regions with restrictive access limits, multi-trailer vehicles might be restricted to the Interstate System whereas in the western states where LCVs have much broader access, scenario vehicles would retain that same degree of access.

Transportation costs were calculated for each vehicle, but those costs were not used to estimate modal shifts. Rather they were used in combination with estimated changes in miles traveled by each configuration to estimate changes in total transportation costs associated with each scenario. Costs considered in the study were driver costs, vehicle costs, fuel costs, tires, maintenance, and overhead costs. Cost estimates were developed from *The Truck Blue Book*, interviews with operators and dealers, and a review of estimates from previous studies. Costs were expressed in terms of cost per mile, cost per loaded mile, and cost per ton-mile. No non-transportation logistics costs were considered in the analysis. The Association of American Railroads'(AAR) Intermodal Competition Model was used to forecast potential truck/rail diversion. The Intermodal Competition Model represented the state of the practice at the time, but since this study was completed other models including the ITIC model have been developed. The ITIC model drew heavily from the Intermodal Competition Model.

Carl Martland of MIT conducted a study for the Coalition Against Bigger Trucks in 2007 to estimate potential competitive impacts of larger trucks on rail freight traffic (Martland 2007). The study creates a base case of 100 synthetic O-D movements intended to represent the traffic that is handled or could be handled by the railroad industry and handled at either the origin or destination by a short-line railroad. For each O-D movement, the study identifies the cost, capacity, and service characteristics offered by each transportation mode, and estimates the total logistics costs that would result from using each available mode for each O-D. The method then allocates the traffic to each mode based upon a comparison of the total logistics costs using a statistical logit model. If the costs are equal, all modes share the traffic equally; if one mode dominates, then that mode captures all the traffic. The resulting traffic is summed over all O-D pairs to get the mode share for the base case. For scenario evaluation new cases are structured based on changes to the performance characteristics of one or more modes, unit costs, and operating parameters and the results are subsequently compared to the base case for changes in market share by mode, changes in traffic volumes, and performance.

This approach cannot provide exact estimates of market changes, since actual conditions will often be more complex than what is covered by this methodology. However, this methodology does include the major factors known to influence mode choice, and it is broad enough to provide insight into the probable effects of new technologies or other changes in the competitive transportation environment. Technological or operating changes that result in significantly higher or lower logistics costs for one mode can be expected to cause significant changes in mode choice; technologies that afford only minor changes in total logistics costs will be unlikely to cause significant changes in mode choice. However, one drawback of the method is the allocation of all traffic to the dominant mode. The logit model determines the probability of choosing each mode, so allocating all traffic to the mode with highest probability likely over-allocates to that mode and under-allocates to other modes.

The data relies on values of trip distances, values/pound, density, and annual use rates from studies sponsored by the International Railroad Congress, and the American Short Line and Regional Railroad Association for short line rail traffic.

The study was conducted in coordination with the Association of American Railroads (AAR). The study uses a methodology developed at MIT and applied previously in various studies, including a similar study of the competitive effects of larger trucks on short line railroads. The methodology was applied in two analyses, each of which examines rail mode share for a set of generic origins and destinations under various assumptions concerning truck size and weight limits.

Martland conducted another study of Class 1 railroads using the same general methodology used in his 2007 study of short-line rail impacts. The study assesses the competitive impact of increases in truck size and weight limits on freight traffic handled by the Class I railroads. The study focuses on bulk traffic and general merchandise traffic, but does not analyze high-volume double-stack domestic freight or the movement of marine containers to and from ports. The study presents two analyses that address the effects of increases in truck size and weight on the rail market share for traffic handled by the rail industry. The first concerns the rail market share for the entire range of general merchandise and bulk freight, while the second focuses on the relative costs of moving bulk traffic short distances by rail and by truck.

Rather than analyzing data for actual shipments by truck and rail, the study analyzed hypothetical movements structured to represent a typical mix of commodity and customer characteristics. For each O-D movement, the estimated mode share was based upon a comparison of the total logistics costs for using rail, intermodal, and truck transportation. In addition to direct transportation costs, the total logistics costs included inventory costs, loading and unloading costs, and loss and damage.

The key steps in Martland's methodology are:

1. Prepare a base case:

   a. Create a set of origin-to-destination (O-D) movements to represent the traffic that is handled or could be handled by a railroad or group of railroads. Since each O-D will represent many actual O-Ds, it is necessary to structure the set of O-Ds to provide a realistic mix of customers (i.e. a realistic mix of commodities, trip distances, and annual use rates).

   b. Identify the cost, capacity, and service characteristics offered by each transportation mode serving each O-D.

   c. Estimate the total logistics costs that would result from using each available mode for each O-D.

   d. Allocate the traffic to each mode based upon a comparison of the total logistics costs. If the costs are equal, all modes share the traffic equally; if one mode dominates, then that mode captures all of the traffic.

   e. Sum over all O-D pairs to get the mode split for the base case.

2. Structure new cases to reflect a different operating environment:

   a. Change performance characteristics for one or more modes.

   b. Change unit costs

   c. Change operating parameters

3. Compare results of the new cases to the base case:

   a. Document changes in market share by mode

   b. Document changes in traffic volumes (tons, ton-miles or shipments by mode)

   c. Document changes in performance (cost, service, capacity)

Martland notes, "This approach cannot provide exact estimates of market changes, since actual conditions will often be more complex than what is covered by this methodology. However, this methodology does include the major factors known to influence mode choice, and it is broad enough to provide insight into the probable effects of new technologies or other changes in the competitive transportation environment. Technological or operating changes that result in significantly higher or lower logistics costs for one mode can be expected to cause significant changes in mode choice; technologies that only enable minor changes in total logistics costs will be unlikely to cause significant changes in mode choice."

Principal sources of data for the analysis came from the Surface Transportation Board's (STB) Carload Waybill Sample and earlier studies in which logistics costs associated with different types of operations had been estimated.

Babcock has examined the impacts of railroad abandonment on communities (Babcock 2003, 2007). His research measured quantifiable impacts of short-line railroad abandonment in Kansas through four research tasks. First, an assessment of Kansas county road conditions and financing was conducted to determine the ability of counties to absorb the resulting incremental heavy truck traffic. Second, the changes in wheat handling and transportation costs were computed. Third, the increase in truck-attributable road damage costs to Kansas county and state roads was computed. Fourth, the additional highway accident benefits and costs attributable to the resulting incremental truck traffic were calculated. He concluded that "losses of shortline railroads would have negative effects on rural Kansas communities, including increased road damage costs and reduction in farm income." Furthermore, energy consumption and emissions required to move freight would increase if shortline railroads were abandoned.

Middendorf and Bronzini (1994) of the Oak Ridge National Laboratory conducted a study for FHWA to determine the net effect of truck size and weight policy changes on shipper total logistics cost and how these effects might influence the demand for alternative tractor-trailer configurations. "Data on product characteristics, lane volumes, transportation cost, and other logistics costs gathered in the shipper survey were entered into a computer program called the Freight Transportation Analyzer (FTA). The FTA is a deterministic economic order quantity model adapted to incorporate transportation costs. For each lane observation in the survey dataset, the FTA calculated the shipper's annual freight, order, and inventory carrying costs for the shipper's current mode of transport as well as for two types of LCVs: the Rocky Mountain double and the turnpike double.

Original data of a highly confidential nature was required for this study. Many firms were willing to provide freight flow data, but were either unwilling or unable to specify critical logistics costs such as order processing cost and inventory carrying cost, even when assured of confidentiality. Some firms lacked the sophisticated logistics management systems necessary to respond fully to the detailed questions that were asked. As a result, the research was based on a limited sample of 297 product-specific traffic lane (origin-destination) movements obtained from a total of 72 companies.

The study concludes that, "An excellent indicator of whether or not a truckload shipper would benefit from switching to LCVs is the ratio of the shipper's current annual single trailer freight costs to annual inventory carrying costs. The research indicates that, when single trailer freight costs are two or more times greater than the inventory carrying costs, switching from single trailers to LCVs will in all likelihood greatly reduce the shipper's annual total logistics cost. On the other hand, when inventory carrying costs are roughly the same as or greater than the single trailer freight costs, the chances are good that switching from single trailers to LCVs will increase the shipper's annual total logistics cost."

Middendorf and Bronzini conclude that, "No single variable or combination of variables among the ones considered in this study appears to be highly effective at predicting how much or to what degree an individual shipper's annual total logistics cost would change as a result of switching to some type of LCV. The influence of product value, in particular, is much smaller than is commonly expected. Product value is significant only when annual traffic lane volumes fall below 15,000 cwt (680,385 kg) or 350,000 ton-mi (510,650 metric ton-km). Only at low annual shipment volumes do higher product values significantly increase the chances that LCV use will increase the shipper's total logistics cost. Other factors such as annual lane volume and lane distance are good indicators of whether or not a shipper would benefit from using LCVs, but they are not highly significant estimators of the amount that would be saved or lost. Further research with more detailed shipper data will be needed to produce better logistics cost models for alternative truck sizes and weights."

A major finding of the study is that, in most cases, use of LCVs would significantly reduce total logistics cost of truckload shippers and potentially cause shifts from conventional tractor-semitrailers to LCVs. More research with better data and more robust logistics cost models is needed to determine how much diversion would actually occur and what the cumulative nationwide impact on shippers' total logistics cost would be. Because of the small number of rail boxcar and intermodal observations in the shipper survey data, it was not possible to estimate the amount of diversion that might occur from rail to LCVs. The research indicates, however, that turnpike doubles operating under higher than existing GVW limits could reduce shippers' annual total logistics cost enough to induce some shippers to switch from rail boxcars and intermodal to LCVs. Additional research is needed to determine how much rail boxcar and truck-rail intermodal freight might be diverted.

A study is underway under the National Cooperative Freight Research Program to "develop a handbook for public practitioners that describe the factors shippers and carriers consider when choosing freight modes and provides an analytical methodology for public practitioners to quantify the probability and outcomes of policy-induced modal shifts."(TRB 2015) While the primary emphasis of this project is on policies to shift truck traffic to rail to reduce environmental emissions and congestion, findings should also be of use in analyzing impacts of truck size and weight policy options. No reports on this project are available at this time.

2.1.2 Recent State Modal Diversion Studies

2.1.2.1 Minnesota Truck Size and Weight Study

The Minnesota Department of Transportation conducted an extensive analysis of TS&W alternatives in cooperation with an advisory committee representing a variety of industries, all levels of government, and other interested organizations (Cambridge Systematics 2006). Alternative truck configurations considered in the study included 6 and 7-axle tractor-semitrailers at various weights and an 8-axle B-train double similar to vehicles commonly used in Canada.

"To guide estimates of the amount of freight that might shift to heavier trucks under each Scenario, tables were created to show the current distribution of truck traffic by truck type, operating weight, and highway system (Interstates, other trunk highways, and local)...With these distributions, estimates were made regarding the amount of Base Case freight (measured in payload ton-miles) moving in trucks that are at or close to Base Case weight limits. This weight-limited freight is a good candidate for shifting to heavier trucks if weight limits are increased."

"The principal shipper and carrier responses considered were changes in operating weights and the types of trucks used, in order to reduce the amount of truck VMT (and hence cost) to carry a given amount of freight. The following possibilities also were considered: 1) changes in limits might cause shifts from rail to truck, 2) changes in the total amount of freight shipped, 3) shifts in highway systems used by trucks and 4) shifts in the time of year for shipments (due to seasonal differences in limits). Sensitivity analysis was performed to investigate how different assumptions about the size of shifts might affect the overall evaluation of a scenario."

The impact areas covered in the study are:

- Truck traffic effects (including modal or system diversion);
- Transport costs;
- Pavement costs;
- Bridge posting and replacement;
- Bridge fatigue;
- Bridge decks;
- Bridge design;
- Crash costs; and
- Congestion costs.

"With these distributions, estimates were made regarding the amount of Base Case freight (measured in payload ton-miles) moving in trucks that are at or close to Base Case weight limits. This weight-limited freight is a good candidate for shifting to heavier trucks if weight limits are increased." The primary basis for estimating shifts among vehicle configurations was expert opinion based on characteristics of freight traffic in the State and viewpoints of shippers and carriers. No quantitative modeling was used to estimate potential shifts among vehicle configurations or between modes.

2.1.2.2 Wisconsin Truck Size and Weight Study

Cambridge Systematics conducted a study for the Wisconsin Department of Transportation, the purpose of which was "to assess potential changes in Wisconsin's TS&W laws that would benefit the Wisconsin economy while protecting roadway and bridge infrastructure and maintaining safety...The broad challenge of this evaluation is the ability of the TS&W changes to balance economic gains resulting from increased truck productivity with the potential costs to safety and infrastructure." (Cambridge Systematics 2009)

The methodology draws heavily upon past studies of truck size and weight limit changes by the Minnesota DOT, the USDOT, and the Transportation Research Board. Estimates of diversion from Base Case to Scenario configurations were developed for two cases:

1. Non-Interstates Only. Scenario configurations are not allowed on Interstate highways; and

2. All Highways. Scenario configurations are allowed on Interstate highways (this case would require a change in Federal truck size and weight regulations)."

New truck configurations examined in the study included 6-axle 90,000 pound tractor-semitrailer; 7-axle 97,000 tractor-semitrailer; 7-axle 80,000 pound single unit; 8-axle 108,000 pound twin trailer; 6-axle 98,000 pound tractor-semitrailer; and 6-axle truck-trailer combination.

Impacts were estimated in the following areas:

- Truck usage
- Goods movement costs
- Pavement and bridge impacts
- Bridge reconstruction, rehabilitation and posting costs
- Safety
- Congestion, and
- Energy and the environment

As with the Minnesota Truck Size and Weight Study, shifts among vehicle configurations were estimated using expert opinion based on characteristics of freight traffic in the State and viewpoints of shippers and carriers. No quantitative modeling was used to estimate potential shifts among vehicle configurations or between modes.

2.1.2.3 Montana

Jerry Stephens and colleagues at Montana State University conducted a study in 1996 of the Impact of Adopting Canadian Interprovincial and Canamax Limits on Vehicle Size and Weight on the Montana State Highway System (Stephens, et al. 1996). As in the Minnesota and Wisconsin studies, it was assumed that only weight limited vehicles would consider shifting to new configurations and operating weights. Data on existing vehicle weights operating on Montana highways were used. Between 33 and 66 percent of total freight carried on vehicles within 10 % of their weight limits was assumed to divert to alternative configurations. The authors note that, "In reality, the availability of proper shipping/receiving facilities, cost of new equipment, maneuverability requirements, type of haul, etc. will influence decisions of this kind, and some weight limited operators will choose to continue to use their existing configurations."

Estimates of diversion of traffic from rail to truck was based on findings of the TRB 225 study which estimated that ton-miles on highway system would increase by 3 3/4 % under Canadian Interprovincial Limits. Diversion estimates did not consider limiting the networks available to longer combination vehicles.

2.1.2.4 Texas

Bienkowski and Walton at the Southwest Region University Transportation Center prepared a paper analyzing The Economic Efficiency of Allowing Longer Combination Vehicles in Texas (Bienkowski and Walton 2011). "An LCV scenario for Texas was chosen, with specific routes and vehicle types. Operational costs for these vehicles were calculated on a cost per mile and cost per ton (or cubic yard) mile. The LCV scenario and the current truck base case were analyzed to find the number of truck trips, the number of miles, and the cost per mile for the chosen routes. These are then compared to estimate the change if LCVs were allowed in Texas."

To decide which types of LCVs would be safe and appropriate for Texas, the research team contacted companies interested in using LCVs. The first vehicle chosen was a 97,000 pound tridem semitrailer, which is not an LCV. The next configuration coupled two standard 53-foot semitrailers and was assumed to travel at a maximum gross weight of 138,000 pounds. Finally, that same double combination was studied at a gross vehicle weight of 90,000 pounds to serve cube-out traffic.

Based on operator surveys and input from industry contacts, the researchers decided that the following LCV scenario would be realistic for this study:

- LCV approval would affect primarily standard 5-axle tractor-semitrailers;
- 15% of current truck cargo currently hauled by 5-axle tractor-semitrailers would remain in this vehicle class;
- 35% would be transferred to the 97-kip tridem axle tractor-semitrailers;
- 20% would be transferred to the light doubles; and,
- The remaining 30% would become the 138-kip double 53s.

These shifts among configurations were based solely on expert opinion and not on a detailed analysis of the costs of using alternative configurations for hauling different commodities over different distances.

2.1.2.5 Virginia

Virginia has conducted several studies of freight movement along the I-81 corridor. A major focus of those studies is to estimate the potential for diverting truck traffic to rail in the corridor. A 2009 study evaluated several strategies for diverting traffic from truck to rail, one of which involved the use of cross-elasticities to estimate the change in traffic for one mode when prices for the other mode change (Commonwealth of Virginia 2009).

An important finding of that study that has implications for the current study is that "the literature on freight elasticities does not tell a clear story. One recent study (Littman 1999) cited compiled results from prior studies. The widest range cited suggests that price elasticities for trucking range from -0.04 to -2.97 and price elasticities for rail range from -0.08 to -2.68, depending on commodity. The narrowest range cited suggests that elasticities for both trucking and rail range from -0.25 to -0.35. The average value of -0.30 is suggested for the present analysis, mostly because it yields the most plausible results."

"For trucking, this means a 1 percent increase in price results in a 0.3 percent loss of traffic. Looking at the choice between truck and rail costs, it might be expected that for each 1 percent cost savings offered by rail, 0.3 percent of trucks might divert to rail when offered the choice."

The study notes, "The diversion estimates are very sensitive to price assumptions. Even relatively small changes in price can produce significant changes in the estimates. This analysis is based on average rates, but in practice, trucking and rail costs vary widely depending on the commodity, travel lane and distance, competitive market conditions, and other factors. Further analysis would be needed to accurately reflect these important differences.…We have relied on a general estimate of price elasticity. The best diversion models are based on corridor and commodity-specific elasticities not only for price, but also for changes in speed, reliability, and other factors."

This conclusion has significant implications for the use of cross-elasticities based on econometric analysis for the current 2014 CTSW Study. Detailed cross-elasticities for different commodities moving in different markets are not available, nor are elasticities that reflect changes in non-transportation logistics costs.

Another study of potential diversion of truck traffic to rail along the I-81 corridor in Virginia used the ITIC model in combination with the Transearch database (VDOT). "The purpose of the freight diversion analysis was to evaluate the potential for truck traffic currently using I-81 to divert to rail intermodal service, and to confirm assumptions from previous studies. Several steps were taken to develop a method for the modal diversion analysis:

- A literature review was conducted to evaluate previous studies that examined diversion potential in the corridor, and identify existing data sources for inputs to the model.
- Identified existing truck-to-rail diversion models and selected the FHWA's Intermodal Transportation and Inventory Cost Model (ITIC) for the analysis.
- Translated a set of assumptions provided by Norfolk Southern and others about rail capacity improvements into values which could be modeled in ITIC; and
- Developed a set of criteria to select certain commodity movements in the 1998 Virginia Transearch™ database which are considered modally competitive.

The ITIC model was selected for use in the mode diversion analysis after a review of existing truck-to-rail diversion models. An advantage of this model is that it was developed and is maintained by the FHWA Office of Transportation Policy Studies in cooperation with the Federal Railroad Administration. Most of the data required for the model (except for rail variable costs and drayage distances) are readily attainable, and the model is well documented by the USDOT. The model is currently being refined and upgraded by a steering group of rail and truck experts under the FHWA.

ITIC, which is described in more detail later in this desk scan, is non-proprietary and can be modified to fit various truck size and weight, rail and transportation cost scenarios. It was also used to evaluate route diversions based on tolling scenarios in the I-81 study area. ITIC predicts modal diversion by calculating and comparing the total logistics costs for different modes of freight transportation.

The Transearch™ database provides the base data for this analysis. Transearch™ provides commodity detail to the four digit level as well as the annual tonnage for a particular commodity flow between an origin and destination. Only records that have been assigned to I-81 were analyzed. It is also important to note that only movements greater than 500 miles were assumed to be divertible to rail. County to county movements in Virginia, and shorter interstate movements were not included in the analysis. Movements that meet the following criteria were selected for analysis:

- Lane Density — Over 12.5 tons moved annually; and
- Distance — The distance between the origin and destination of the movement will be greater than 500 miles."

2.1.3 International Studies

A recent NCHRP report summarized the experience in Canada operating under their revised framework for regulating the size and weight of commercial motor vehicles (TRB 2010). This was an ex post assessment of changes associated with changes in truck size and weight policy in Canada.

The study concluded that the "Memorandum of Understanding among Canadian Provinces regarding vehicle weights an dimensions limits had a significant effect on the composition of the trucking fleet in Canada. There were significant differences in fleets in various regions of Canada reflecting differences in the types of commodities hauled. The 8-axle B-train is clearly the vehicle of choice for heavy haul in the four western provinces and in the four eastern provinces, where it did not exist prior to the Memorandum of Understanding (M.o.U.)." "The M.o.U. introduced the tridem semitrailer and the 8-axle B-train, and these are now the third and fifth most common configurations across Canada." "The tractor-tandem semitrailer (T12-2) was the most common configuration, by a wide margin, in all provinces, and made almost two-thirds of all cross-border truck trips, a proportion more than 60% higher than for all trips in Canada."

The study highlights the fact that, "A formal body, including federal and provincial government representation, was established to develop and oversee the process of rationalizing size and weight policy based on scientific analysis. The basis for technical input was the Canadian Vehicle Weights and Dimensions Study, which was specifically conducted to provide scientific input. The size and weight study provided an understanding of vehicle infrastructure interaction and produced a set of vehicle performance metrics that were used to specify vehicle configurations that had desirable vehicle dynamic characteristics and could operate within the load capability and geometric constraints of the road network."

The study concluded that “Size and weight regulation needs to be thorough and comprehensive so that the desired outcomes are achieved and undesirable outcomes are prevented. There is a need for monitoring of the fleet as it evolves to ensure that undesirable vehicles are kept in check and that the objectives of the policy can be fully achieved.”

“The Canadian experience points to the simultaneous achievements of productivity, safety and environmental effects—aspects that are sometimes viewed as trade-offs.”

2.1.4 Studies Using Aggregate Data and Econometric Models

In a literature search conducted for the 2000 CTSW Study, the most relevant modal-diversion study using aggregate data that was identified was performed by Jones, Nix and Schwier (USDOT 1995). “This study developed two sets of estimates of modal diversion resulting from changes in truck costs per ton-mile for three different potential changes in tax policy. Both sets of results were derived using estimates of the cross-elasticities of railroad revenue and railroad ton-miles relative to changes in truck costs. One set of results was obtained by deriving implicit cross-elasticities from high and low estimates of modal diversion previously provided to the Roads and Transport Association of Canada (RTAC) by the Canadian National (CN) and Canadian Pacific (CP) railways. In that case one set of cross-elasticities was applied to all traffic carried by the CN without regard to commodity, and a second set was applied to all traffic carried by the CP. The second set of results was obtained using elasticities developed by commodity, for 18 commodity groups, by the Association of American Railroads (AAR). The AAR elasticities vary with the size of the change in costs as well as with commodity group. The AAR elasticities produced estimates of revenue diversion that were up to 40 percent higher than did the CN/CP elasticities, and estimates of ton-mile diversion that were about twice as large as those produced by the CN/CP elasticities. The most likely reason for these differences is differences in the original estimates of modal diversion from which the cross-elasticities were derived. Other possible reasons are differences in the character of the road system in the United States and Canada, and differences in the character (commodity value, length of haul, etc.) of the movements in the individual commodity groups in the two countries.

The differences in the two sets of results illustrate an important limitation in the use of this type of analysis — the results are only as good as the cross-elasticities used. A related issue is the degree to which the scenario to be analyzed is similar to the one used in developing the cross-elasticities. In particular, if the cross-elasticities are expressed relative to transport costs (rather than relative to total logistics costs), do both scenarios generate similar changes in non-transport logistics costs for truck transport? (Many size and weight policy changes affect inventory costs, but changes in transport tax policy generally do not.) Also, do both scenarios apply uniformly to all types of hauls, or does one apply primarily to relatively divertible traffic (*e.g.,* medium and long-haul traffic) and the other primarily to less divertible traffic?”

Since the 2000 CTSW Study several studies have used aggregate data to estimate the cross-elasticity of rail traffic with respect to trucking costs. Gerard McCullough of the University of Minnesota updated a study of the intercity freight markets that Ann Friedlaender and Richard Spady (FS) published in the *Review of Economics and Statistics* in 1980 (Friedlaender and Spady 1980). “The FS Study provided a macro-level perspective on the freight markets by focusing on transportation decisions in key industrial sectors—food, wood products, paper, chemicals, automobiles, and so on. The FS analysis and the current update of that analysis complement the short-run estimates of rail-truck competition levels. The FS analysis is based on a more generalized economic framework in which shippers have the flexibility to choose a range of productive inputs that includes truck and rail freight transportation along with labor, materials and capital. The FS framework thus provides a broader and longer term perspective on the potential effect that changes in TS&W regulations would have on the freight markets.

The diversion effects analyzed in the current study are based on a hypothetical ten percent decrease in trucking costs. This assumption is based in turn on the TS&W cost effects projected by the USDOT in its 2000 CTSW Study. The underlying assumption of the FS analysis is that freight shippers are business firms whose decisions can be modeled using statistical cost analysis. The elements of the cost analysis are industry output levels, freight movements and expenditures, firm levels of capital and materials, labor prices, truck prices, and rail prices. From their cost analysis, FS derive equations which specify how the shares of freight carried by each mode will respond to changes in truck and rail prices and other producer prices as well. The focus of both the FS analysis and the current analysis is on industry sectors where railroads and trucks compete for freight traffic."

The own-price and cross-price elasticities estimated in the study all had the proper sign and all were statistically significant. The report concludes that with a generalized 10 percent reduction in truck rates "the TS&W-related diversion effects ... would be consequential for railroads, shippers and general highway users."

Naleszkiewicz and Tejeda (2010) estimate truck to rail diversion using a freight mode choice model and the FAF database. The mode choice model is specified using a binomial logit functional form. The paper discusses the estimation of diversion in a risk adjusted framework which allows the capture of uncertainty associated not only with the diversion estimate but also forecasts of future freight traffic.

The proposition of the study is that rail capital improvement projects have the potential to divert trucks from highways by offering a lower-cost shipping alternative. The method uses a set of diversion filters first based on O-D pairs, followed by commodity filters, and finally distance. The mode choice model uses shipping costs as the primary variable and considers the price/mile and value of time/hour by truck and rail. The risk analysis is performed on the estimates of the logit regression over a range of possible values for the coefficients of the regression, using a distribution that is centered at the mean estimate and whose dispersion is proportional to the standard error of each estimator. This provides a risk-adjusted diversion function that assigns likelihoods to different possible market shares resulting from a given change in cost differentials. In addition, sensitivity analysis to estimate the market shares over a range of dependent and independent variables is useful to evaluate the accuracy and significance of the model estimates and permit the identification of critical variables affecting the market shares of each mode.

2.1.5 Studies of Mode Choice and Freight Demand

In addition to studies that have examined aggregate modal shifts associated with truck size and weight policy changes, there is another body of research that has examined mode choice decisions within the context of freight demand models. Holguin-Veras (2007) suggests that, "interactions between shippers and carriers determine mode choice." Shippers have preferences for shipment sizes that in many cases dictate the choice of mode, but where more than one mode could meet shipment size and frequency requirements, carrier prices, level of service, damage rates, and other factors will influence mode choice. He notes that, "in order to arrive at the joint optimum, shippers (through interaction with the carriers) need to become aware of the shape of the transport costs function, which has unit costs that decrease with shipment size. This then needs to be traded off against the inventory costs."

Abdelwahab and Sargious (1990) use economic order quantity models to examine tradeoffs between shipment size and mode. Total costs are a function of commodity value, inventory carrying cost, shipment size, usage rate, transit time and freight charges. The authors note that one of the earliest applications of an inventory-based approach to freight demand was a 1970 study by Baumol and Vinod. A major focus of Abdelwahab and Sargious is the relationship between freight rates and shipment size. Earlier studies had made simplifying assumptions that freight rates are independent of shipment size, but there was a recognition that freight rates generally vary by shipment size and may also vary by commodity value, density, and length of haul. The authors conclude that that there is dependence among freight rates, shipment size, and mode and that freight demand models should consider mode and shipment size simultaneously.

In a later paper Abdelwahab and Sargious (1991) investigate further the issues of mode choice and shipment size. They note Samuelson's position that "the relevant transportation choice which a shipper makes is not simply a choice between modes, but a joint choice of mode and shipment size. In most cases, the shipment size is practically mode determining….Hence, it follows that in freight demand modeling, shipment size and mode choice should always be modeled jointly." (Samuelson 1977). In particular Abdelwahab and Sargious examine theoretical aspects of modeling the interaction between two shipper choices, the discrete choice between modes and the continuous choice regarding shipment size. Similarly McFadden et. al (1986) developed an inventory-theoretic model that enables simultaneous analysis of determinants of mode choice, shipment size, and shipment frequency. Data issues hampered the empirical estimation of the model.

Cavalcante and Roorda (2010) developed a discrete/continuous model with shipment size as the continuous variable and vehicle-type choice as the discrete variable based on a shipper-based survey in Toronto. The study focused on the application of the model to urban goods movement as opposed to a nationwide or broad regional study. The modes studied included passenger vehicles, pickups/vans, single unit trucks, and tractor-semitrailers.

Hall (1985) examined relationships between shipment size and mode choice for truckload, less-than-truckload, and parcel delivery services. The model used was a variant of an economic order quantity model. Typical rate structures for each of the three types of service were developed and used along with inventory costs and other non-transportation logistics costs to identify the optimal mode and shipment size.

Abdelwahab and Sayed developed a neural network model of freight mode choice that they tested using 1977 Census of Transportation data on shipments by rail and truck. Shipments were characterized by a number of variables reflecting: (1) shipment attributes, such as size, value, density, special handling requirements, and shelf life; (2) modal attributes, such as, for each mode, duration and reliability of transit time, freight charges, susceptibility to loss and damage; and **(3)** market attributes, such as geographic location, volume of freight traffic on the origin-destination pair, and trip length. The authors tested the model and were able to predict the correct mode for 98 percent of shipments by truck and 73 percent of shipments by rail. They concluded that further development of neural network models was a promising approach to freight mode choice modeling.

Holguin-Veras (2002) examined the choice of truck configuration and shipment size as a discrete-continuous choice problem much as Abdelwahab and Sargious had examined the choice between truck and rail in the same way. A survey of truck drivers randomly selected at screenlines, cordons, and major trucking depots was conducted in Guatemala. "The sample, comprised of 5,276 observations of both empty and loaded trucks, was expanded on the basis of classified hourly traffic counts, and was post-processed to eliminate double counting. In addition to questions about trucking operational patterns, the truck drivers were asked basic questions about the shipper's characteristics. The sample contains information on shipment size, commodity types, and choice of commercial vehicles. The survey included questions on origins and destinations, type of vehicle, truck type, commodity type, shipment size, and economic sectors and activities at the origin and destination of the trip. This approach is similar to the one used by the commodity flow surveys" conducted by the Census Bureau. The truck configurations examined were pickups, single unit trucks, and tractor-semitrailers, so some methods and findings of this study are not germane to the issues being examined in the current study. The study examined the impacts of two policy options on vehicle choice – imposition of a weight-distance tax and changes in axle load limits – but found that neither had a significant impact. This perhaps was due to the trip characteristics and vehicle classes included in this study.

The econometric studies on mode choice and freight demand summarized above demonstrate the evolution of methodologies for analyzing optimum shipment size and vehicle configuration and some extended those methods to include analyses of truck size and weight limits. Many used the same types of transportation and logistics costs that are included in the ITIC model and several were based on national transportation databases such as the Census of Transportation. These studies, however, were not as comprehensive as the CTSW Study and did not require analysis of how changes in truck size and weight policy would affect travel by different vehicle configurations on different parts of the highway network and how vehicle weight distributions would be affected by changes in truck size and weight limits. All of these factors were important inputs to analyses of safety, infrastructure, energy and environmental impacts of truck size and weight policy changes.

2.1.6 Induced Demand

A key issue that has been raised in connection with potential increases in truck size and weight limits is the extent to which such changes might induce additional truck traffic because of lower costs associated with the use of larger, heavier trucks. A working paper was commissioned as part of USDOT's 2000 CTSW Study to examine this issue (Pickrell and Lee 1998). Pickrell and Lee of USDOT's Volpe Center stated the issue as follows: "To the extent that truck operators are constrained by regulations to operate differently from what they would choose to do without restrictions, the relaxation of truck size and weight regulations would allow truckers to carry more cargo at less cost. If it is assumed that trucking is a competitive industry, these savings will be passed on to shippers. Lower prices to shippers will induce some additional amount of freight movement, with more impact in the long run as producers and consumers respond directly and indirectly to the relatively lower prices. The question addressed here is how much additional truck freight?"

Pickrell and Lee distinguish two ways in which a reduction in truck freight costs could stimulate an increase in total freight shipments: (1) Changes in the composition of national output. "Prices for goods whose production and distribution costs include a significant trucking cost component would decline, and demand for these goods would increase in response. Producing and distributing the larger volumes of these goods demanded at their reduced prices would require an increase in the use of trucking services." (2) Substitution of trucking for other inputs to production. "Suppliers of goods would attempt to substitute trucking services for non-transportation inputs in their production and distribution processes, further increasing the number of ton-miles carried by truck. This could occur, for example, as suppliers relocate production or warehousing facilities to take advantage of lower shipping rates by distribution networks or even reorganize production processes to substitute transportation for other inputs in response to reduced costs for truck shipping."

For a hypothetical 10 percent reduction in trucking costs, the authors estimated the increase in truck shipping that would result through each of these two channels. The choice of 10 percent was for comparability with the reductions in trucking costs of between 5 and 12 percent that the 2000 CTSW Study estimated for its truck size and weight scenarios. The authors concluded that output compositional effects (the first of the channels identified above) would cause only a slight increase in truck freight, less than 0.3 percent. Although uncertainties about the parameter values underlying this estimate make it rather illustrative, the authors' conclusion appears sound. As the authors explain, trucking costs account for only a small share of production costs for most commodities; among the 48 commodity groups in their calculations, that share is less than 5 percent in all cases, and typically less than 2 percent. Therefore, a 10 percent reduction in trucking costs would produce only very small changes in the relative output prices of these commodities. Regarding the effects of input substitution (the second of the above-identified channels), the authors estimated that they would cause about a 2.5 percent increase in truck freight. However, this estimate is based on a highly conjectural value (0.25) for the elasticity of substitution between trucking and other inputs (a parameter that measures the extent to which these inputs are substitutable).

Winebrake et al. (2012) examine the issue of whether new regulations intended to reduce energy and GHG emissions may reduce trucking transportation costs and indirectly stimulate additional travel demand, thereby creating a direct ''rebound effect'' that could soften the effects of these policies. This analysis is analogous to the issue of whether reduced transportation costs associated with the use of more productive vehicles might induce additional VMT. Winebrake notes, "Literature examining the sources and magnitude of the rebound effect in the freight sector is still nascent. With a limited number of studies, concrete conclusions have not yet been constructed; nor has a framework been established for considering these studies in a policy context." Winebrake indicates that, "There are two types of freight elasticity estimates relevant to the rebound effect found in the literature: truck own-price elasticity, which measures a change in demand for trucking (in tons or ton-miles) in response to a change in trucking costs or freight rates and rail cross-price elasticity, which measures a change in demand for rail freight in response to a change in trucking costs or freight rates."

Winebrake summarized a number of studies that had estimated elasticities of demand for freight transportation as a function of transportation costs. All studies had shown some impact, but there was significant variation within and among each study, and differences in study scope, metrics, and other factors made it very difficult to generalize results. The authors summarize uncertainties in several areas that contribute to inconsistencies in study results. Those areas include type of commodity, shipment distance, transport region, availability of alternative modes, short-run vs. long-run impacts, and macroeconomic effects. The study concludes that more research is needed before elasticities of freight demand with respect to price can be used to estimate changes in VMT and fuel consumption.

2.1.7 ITIC Model

The ITIC model is used to evaluate truck-to-truck, rail carload-to-truck, and rail intermodal-to-truck diversion. The model has two modules – one for transportation costs, and one for inventory costs. While the inventory costs are calculated in the same manner for both rail and truck, the costs vary by mode. The transportation cost module is different for truck and rail as the two modes are represented by different datasets. Appendix E contains a detailed description of the evolution of the ITIC model and how it considers various factors important to modal shift analyses.

The ITIC model has been used with the Transearch commodity flow database as well as with county-level FAF data. When used with FAF data, the model takes as its inputs commodity flows by tonnage. Routes by different vehicle classes are determined for each O/D pair by commodity based on routes assumed to be available to each vehicle configuration. Commodity attributes (density, value, handling requirements (dry, temp controlled, bulk, etc.)), equipment type (van, reefer, bulk, etc.), highway network mileages, commodity/equipment-type/configuration load factors and O/D specific truckload volume freight rates by equipment-type/configuration are appended to the FAF flow data. For rail intermodal traffic being tested for diversion, rail line-haul and rail dray distance for costing freight rate of rail move is appended and the transportation costs for base and scenario cases are calculated.

The results of this analysis is fed into ITIC including annual commodity volume, handling requirements, shipment weight, base and scenario line-haul charges, dray charge (for rail intermodal), and line-haul and dray (for rail intermodal) miles.

The documentation of the ITIC model acknowledges that the model captures service quality considerations only in a "general way" and this is an artifact of the underlying data. Since detailed data is not available or is very difficult to get at the national scale, it is necessary to categorize the commodities more broadly. For example, "food and kindred products" would have included both canned goods and highly perishable goods. Service quality considerations present similar challenges for modeling choices of transportation mode. Choices between trucking and rail freight services (or rail combined with road) generally present a tradeoff between price and service quality. Rail freight is generally cheaper, but trucking has advantages in flexibility and speed, and often in reliability. It is difficult to quantify the service levels provided by each mode and the values that shippers assign to each service attribute.

2.1.7.1 Analysis of long-haul shipments

The assumption in the ITIC model is that the shipper chooses the transportation alternative that minimizes the sum of transportation and non-transportation logistics costs. The model adopts the conventional categorization of inventory costs as safety stock, cycle costs, and in-transit costs. For the calculation of safety stock, the model includes parameter values that measure the reliability of lead time for delivery. These values indicate lower reliability for rail carload than for other shipment options.

The ITIC model specifies that the amount of cycle inventory increases proportionally with the payload of the freight-moving unit. This means, for example, when a shipper switches to a truck with 20 percent more payload than a truck used previously, the amount of cycle inventory increases by 20 percent.

The scenario analyses assume that the total volume of freight that is shipped is fixed and does not attempt to estimate whether reductions in transportation costs would affect the total volume of freight shipped. As noted above, a brief study conducted by the Volpe Center for the 2000 CTSW Study concluded that any induced increase in truck freight traffic caused by reductions in shipping costs would be small enough to ignore without much loss of realism. Since changes in truck size and weight limits being examined in the current study are generally lower than changes examined in the 2000 CTSW Study, there is even greater reason to assume that any induced demand would not significantly affect estimated impacts.

2.1.7.2 Analysis of short-haul shipments

For short-haul shipments, the study notes that rail generally is not competitive with truck and considers only truck-to-truck substitution. For single unit trucks, substitution between three and four-axle trucks is a function of the change in their relative operating costs (induced by changes in TS&W limits). The 2014 TSW study assumes that there is no change in truck size and weight limits for single unit trucks. Short-haul combination trucks are assumed to have diversion that mirrors the diversion of long-haul combination trucks.

2.1.7.3 GAO Analysis of ITIC Model

The Government Accountability Office (GAO) evaluated the ITIC-IM model developed by the Federal Railroad Administration (FRA) as part of their evaluation of intercity passenger and freight rail. The ITIC-IM model is an extension of the original ITIC model that includes the ability to analyze impacts of a broader variety of changes that could affect truck-rail competition. To determine whether the available data and model assumptions were reliable for the purposes of the study, the GAO evaluated the ITIC-IM model input data for their relevance, completeness, accuracy, validity, and consistency. The GAO found that of the 26 variables used as input into the ITIC-IM model, empirical data were available for nine of the inputs. They concluded that "the issues of completeness, accuracy, validity, and consistency of our data negatively impact their reliability and increase the uncertainty of our estimates."

2.2 Summary of Mode Choice Methods and Past Studies

This section summarizes findings of the literature review of modal shift models and databases that might be applicable to the current 2014 CTSW Study. Many studies have examined the issue of freight mode choice using a variety of data and methods. The choice of data and methods in various studies typically is guided by the resources available for the study, the study scope and objectives, and other factors unique to each study. Thus in evaluating potential data and methods for the current 2014 CTSW Study, it is important to consider the unique requirements of this 2014 CTSW Study. Resources available for this study are greater than for most academic studies and State or regional studies. Along with the significant resources available for this 2014 CTSW Study comes an expectation that key issues will be examined rigorously and that the best, most reliable data will be used to analyze potential impacts of allowing various types of new configurations to use different parts of the highway system. **Table 2** compares different general approaches to conducting modal shift studies that have been used in past studies. Study methods can be broken down into three general methodologies – (1) those that estimate modal choice for individual shipments based on characteristics of those shipments, and costs associated with moving shipments by the various modes between various origins and destinations; (2) studies that rely on expert opinions of shippers and carriers concerning the likelihood of shipments of various commodities traveling different distances under a variety of operating conditions and restrictions shifting to alternative modes; and (3) aggregate methods that estimate cross-elasticities of demand for one made based on changes in price and other characteristics of shipments by another mode.

Most recent large scale studies have used disaggregate analyses of individual shipments, although several recent State studies have relied primarily on expert opinions of shippers and carriers. Most studies using disaggregate methods have used actual data, but some like the study by Martland used synthetic data in lieu of actual data. Actual data is preferred when resources permit since they are less likely to be challenged as being representative. This is especially true for studies such as the current 2014 CTSW Study when complex relationships involving different vehicle classes operating on different highway networks in different parts of the country are being analyzed.

Table 3 summarizes key freight mode choice studies in terms of their geographic scope, the modes considered in the study, the data used in the mode choice analysis, and the general methodology used to estimate mode choice. The methodologies correspond to those included in **Table 2**. Most national studies have used disaggregate total logistics cost models for at least part of the study, the exception being the academic study by McCullough which used econometric methods to estimate cross-elasticities of demand for one rail based on an assumed change in trucking rates. Recent State truck size and weight studies have tended to rely on expert opinion supplemented by sensitivity analysis.

Table 2. Assessment of Alternative Modal Shift Methodologies and Data		
	Advantages	**Disadvantages**
Disaggregate data and model	• Easier to understand than econometric models	• Very data intensive, especially if disaggregate universe data is used
Actual data	• Better representation of actual freight movements than synthetic data	• Since studies using actual data generally use more observations than those using synthetic data, data requirements are greater. • Actual data may not be available for all variables, especially if data must be publicly available
Disaggregate data	• Provides best representation of movements by all modes between all O-Ds • Allows differences between regions and vehicle configurations to be more accurately represented than with aggregate data that cannot capture important differences among networks, vehicle configurations, and geographic areas.	• Most data intensive • Highly disaggregated data not always publicly available • Use of data that is not publicly available may be criticized if source of those data is questionable or potentially biased • May require estimation if source data are not collected or reported at desired level of disaggregation

Table 2. Assessment of Alternative Modal Shift Methodologies and Data		
	Advantages	**Disadvantages**
Aggregate data	• More likely to be publicly available than highly disaggregate data • Not as data intensive as disaggregate data • Still reflects all movements by all modes	• May not allow all scenarios to be adequately analyzed since it may not reflect real cost differences of using different modes and vehicle configurations • May not allow impacts on different networks to be adequately assessed • Requires more assumptions about which configurations can be used and what the cost of using those configurations will be. This may lead to criticisms by those unhappy with results
Survey data	• Actual data on specific shipment characteristics from individual companies	• Costly to obtain • May not be representative of population
Estimated data	• Substitute for data that is not publicly available. • Reduces cost of collecting some data items • Sensitivity analysis can indicate degree to which results may vary if estimates do not reflect reality	• Estimates may be subject to criticism • Some basis is required to make estimates. In some cases there may not be a good basis for estimates.
Synthetic data	• Least data intensive than other methods • May be used to quickly assess general directions of impacts and perhaps relative order of magnitude	• As with estimated data, some basis is required for developing synthetic data • Results likely subject to greater criticism than other methods because they are not based on actual data • Difficult to capture all factors that affect modal choice

Table 2. Assessment of Alternative Modal Shift Methodologies and Data		
	Advantages	**Disadvantages**
Expert opinion	• Captures factors affecting shipper/carrier decision making that are difficult to reflect in a quantitative model • Does not require as much data as more quantitative methods • May be less costly and quicker method than quantitative model development • Opinions good for identifying most important factors affecting decisions	• Opinions may vary depending on who is interviewed • Actual responses to policy change may be different from ex ante anticipated responses • Opinions may be biased by local conditions and may not reflect responses in other markets • Opinions generally do not provide good evidence of the magnitude of responses to various options

Table 2. Assessment of Alternative Modal Shift Methodologies and Data		
	Advantages	**Disadvantages**
Aggregate econometric model	• Allows relationships revealed in one area to be estimated in other areas without extensive data collection	• Mathematical models are not as easily understood by the general public as other methods • Subject to statistical issues such as multicollinearity making it difficult to isolate impact of individual factors affecting mode choice • Difficult to reflect impacts of allowing different vehicles on different highway systems • Difficult to reflect complexity of mode choice decisions for individual commodities and markets • More amenable to analyzing binary choice between truck and rail than to estimating choice among multiple truck configurations • Difficult to use elasticities from other studies because elasticities vary by commodity, corridor, and by costs upon which they are estimated.

Table 3. Selected Freight Modal Shift Studies

Study	Scope		Principal Data Sources	Modal Shift Analysis Method
	Geographic	Modes		
2000 CTSW Study	National	Truck, Heavy Truck, Rail	NATS truck data, rail weighbill, TIUS, HPMS	ITIC disaggregate total logistics cost model
ORNL, 1994	National	Truck, Heavy Truck, Rail	Survey of firms in different industries; TIUS	Freight Transportation Analyzer disaggregate total logistics cost model

Table 2. Assessment of Alternative Modal Shift Methodologies and Data				
	Advantages		Disadvantages	
TRB 225, 1990	National	Truck, Heavy Truck, Rail	Forecasts of truck traffic, AAR	Expert opinion, disaggregate total logistics cost
Martland 2007, 2010	National	Truck, Heavy Truck, Rail	Synthetic data reflecting distribution of rail carload movements	Total logistics costs
McCullough, 2013	National	Truck, Rail	Aggregate industry costs	Econometric estimation of cross-elasticities
Western Uniformity Scenario, 2004	Regional	Truck, Heavy Truck, Rail	FAF, rail weighbill, TIUS, HPMS	ITIC disaggregate total logistics cost
Minnesota TSW Study, 2006	State	Truck, Heavy Truck	State VMT, weight distributions	Expert opinion, sensitivity analysis
Wisconsin TSW Study, 2009	State	Truck, Heavy Truck	State VMT, weight distributions	Expert opinion, sensitivity analysis
Montana	State	Truck, Heavy Truck, Rail	State VMT, weight distributions	Expert opinion, results from previous studies
Virginia	Corridor	Truck, Rail	State VMT data	Cross-elasticities from past studies
Virginia	Corridor	Truck, Rail	Transearch	ITIC disaggregate total logistics cost model
Texas LCV Study, 2011	Corridor	Truck, Heavy Truck	State VMT, weight distributions	Expert opinion

Several critical decisions must be made regarding the modal shift analysis for the current truck size and weight study. These include:

- the method (and specific model if applicable) to be used to estimate shifts among vehicle configurations and different modes as the result of the truck size and weight scenarios
- the source and level of disaggregation of data that will be needed to support analyses using the selected analytical tool
- the extent to which all data must be publicly available

Each of these factors is discussed below including tradeoffs associated with certain decisions.

2.2.1 Modal shift methodology

As shown in **Table 2**, there are three basic methods that have been used in recent studies examining potential modal shifts associated with changes in truck size and weight policy

- Disaggregate total logistics cost models
- Expert opinion, often accompanied by sensitivity analysis
- Aggregate econometric methods based on estimates of the cross-elasticity of demand for one mode based on changes in price or service characteristics of another mode.

Recent large-scale Federal studies have all used disaggregate total logistics cost models for at least part of the analysis, and logistics cost models have been used in other studies as well. Several recent State studies have used expert opinion coupled with sensitivity analysis. Only a very few studies have based their estimates of mode choice on estimates of cross-elasticities of demand between two modes.

A review of the literature indicates that there is no single cross-elasticity that can be used to reflect competitive relationships across modes for the movement of different commodities in different markets. The primary use of cross-elasticities has been to estimate potential truck to rail or rail to truck shifts resulting from some price or service change. In general, those studies that have used cross-elasticities have been interested only in general estimates of the overall impact on one mode associated with changes in another mode. They have not been interested in mechanisms by which those changes occur or differentiating impacts on different parts of the industry. No examples were found where cross-elasticities were used to estimate potential shifts among different truck configurations as the result of size and weight policy changes. Nor is there data upon which to adequately estimate cross-elasticities between modes based on different network availabilities. Based on these findings, it does not appear feasible to use cross-elasticities derived from aggregate econometric analysis to satisfy the requirements of the 2014 CTSW Study.

Recent State studies that have relied upon expert opinions of shippers and carriers to estimate changes in mode choice associated with truck size and weight policy changes have generally been focused on a narrower range of issues than the current truck size and weight study. Expert opinion is valuable when opinions are based on a clear understanding of the factors that will affect mode choice decisions, but the more complex the decisions, the harder it is for experts to reliably anticipate the overall response to policy changes. Most recent State studies have been primarily concerned about potential impacts of allowing heavier tractor-semitrailers to operate. Network limitations have been easily defined and it has been relatively easy to identify the universe of shipments that might divert to vehicles with higher gross vehicle weight limits. A nationwide study that includes larger, heavier trucks as well as rail and potentially water modes is more complex than the State studies that have relied on expert opinion. The impact of network limitations on certain vehicle configurations would be difficult for many experts to estimate and tradeoffs between rail and longer combination vehicles are not always clear. Perhaps the greatest drawback to the use of expert opinion for the current study, however, is the lack of objective criteria upon which modal shift estimates are made. Not everyone will agree who is an expert and even experts could be expected to disagree on the potential use of different configurations based on different individual assumptions about how they would operate. The lack of objective criteria for modal shift decisions could adversely affect the credibility of the study.

While there certainly are known weaknesses with existing disaggregate total logistics cost models, they do offer an objective basis upon which to estimate the changes in transportation and non-transportation logistics costs to move different commodities between different origins and destinations resulting from changes in truck size and weight limits. Existing models such as ITIC are transparent and have been used in enough different types of application to have some confidence in their use.

There are several reasons for using the ITIC model for the current 2014 CTSW Study. First, it is a model that was developed by the Department and that has been used both by FHWA and FRA. This should reduce any claims that the model is biased toward one mode or the other. Second, the ITIC model has undergone recent updates that should reduce the time it takes to get the model up and running. The ITIC model framework allows for testing the impact of alternative assumptions. There was an intensive search for modeling tools, but alternative models that would meet objectives of the current study were not found.

Conclusion: Based on factors discussed above, it is recommended that the ITIC model be used as the basis for estimating modal shifts for the truck size and weight study.

2.3 Data Requirements and Sources for Modal Shift Analysis

The analysis of potential modal shifts associated with truck size and weight policy changes is only as good as the data upon which it is based. As noted above, having good data on both the commodities being moved and the origins and destinations of commodity movements by different modes is essential to assessing which moves might shift to alternative modes and truck configurations. A review of commodity flow databases was conducted as part of the National Cooperative Freight Research Program (NCFRP) 20 Study, Developing Subnational Commodity Flow Data (Cambridge Systematics 2010).

For the purpose of this study, two data products are of primary interest: A multi-dimensional commodity flow matrix, the principal dimensions of which are the volumes of freight moving between various origins and destinations by mode and type of commodity; and a series of network routings showing how freight vehicles move over the nation's freight transportation network (highways, railways, waterways,).

2.3.1 Freight Analysis Framework (FAF) Data

One such multi-modal commodity flow database is the Freight Analysis Framework (FAF) developed by FHWA. This database was used in the Western Uniformity Scenario Analysis by FHWA. The FAF integrates data from a variety of sources to estimate commodity flows and related freight transportation activity among states, regions, and major international gateways. The original version, FAF1, provides estimates for 1998 and forecasts for 2010 and 2020. FAF2, provided estimates for 2002 plus forecasts through 2035. The latest version of the FAF, FAF3, is based on the 2007 Commodity Flow Survey (CFS) and provides estimates for 2007, plus forecasts through 2040.

FAF3 has a number of improvements to the commodity flow matrix over previous versions including:

- A roughly doubling of the number of U.S. shipping establishments sampled as part of the 2007 U.S. Commodity Flow Survey (from some 50,000 establishments in 2002, to approximately 100,000 establishments surveyed in 2007);

- The use of PIERS data to support improved allocations of imports and exports to FAF domestic zones of freight origination (for U.S. exports) and destinations (for U.S. imports);

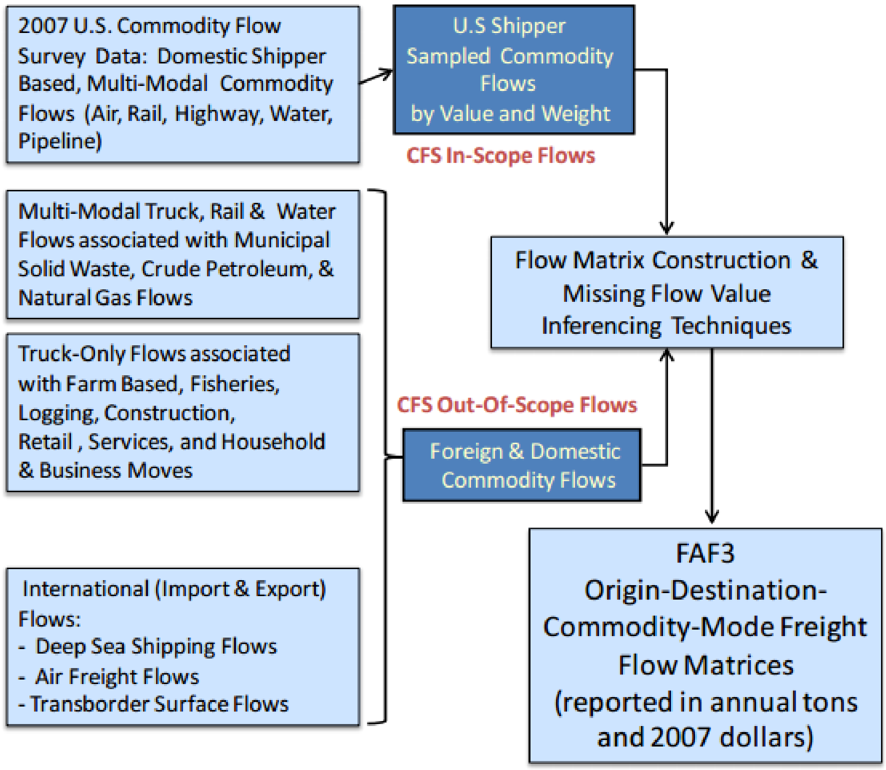
- Incorporation of additional federal datasets within an improved FAF3 log-linear modeling/iterative proportional fitting algorithm, as well as the development of estimates of flows for commodities that were out-of-scope for the CFS;

- Greater use of U.S. inter-industry input-output coefficients in estimating commodity flows that were out-of-scope for the 2007 CFS; and

- FAF3 provides an O-D specific treatment of natural gas products, which were evaluated only at the level of national or broad regional activity totals in FAF2 (Southworth 2010, p. 3).

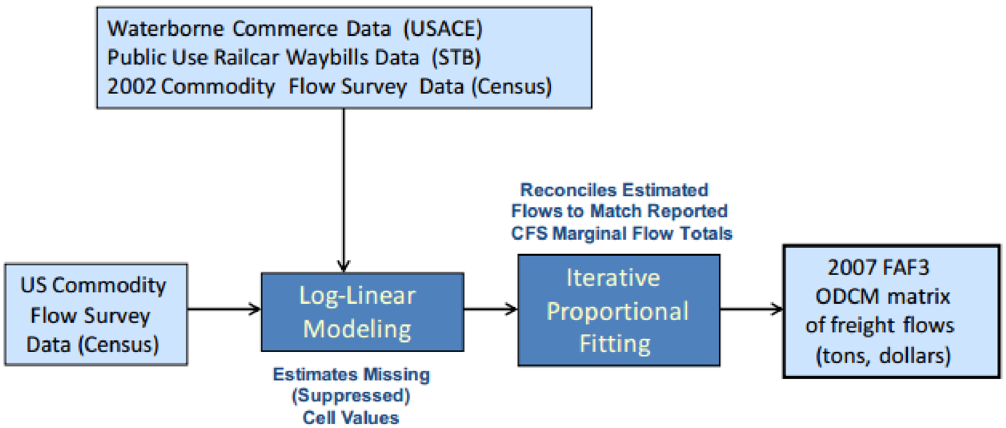
Figure 4 shows the FAF3 freight flow matrix construction process. The matrix construction begins with the data from the 2007 CFS, and uses the same geographic (123 domestic U.S. FAF zones) and commodity (43 Standard Classification of Transported Goods (SCTG) definitions as the CFS but uses a modified version of the CFS modal definitions (Southworth 2010, p. 7).

Figure 4. Overview of the FAF3 Freight Flow Matrix Construction Process (USDOT FHWA 2010, p. 7)



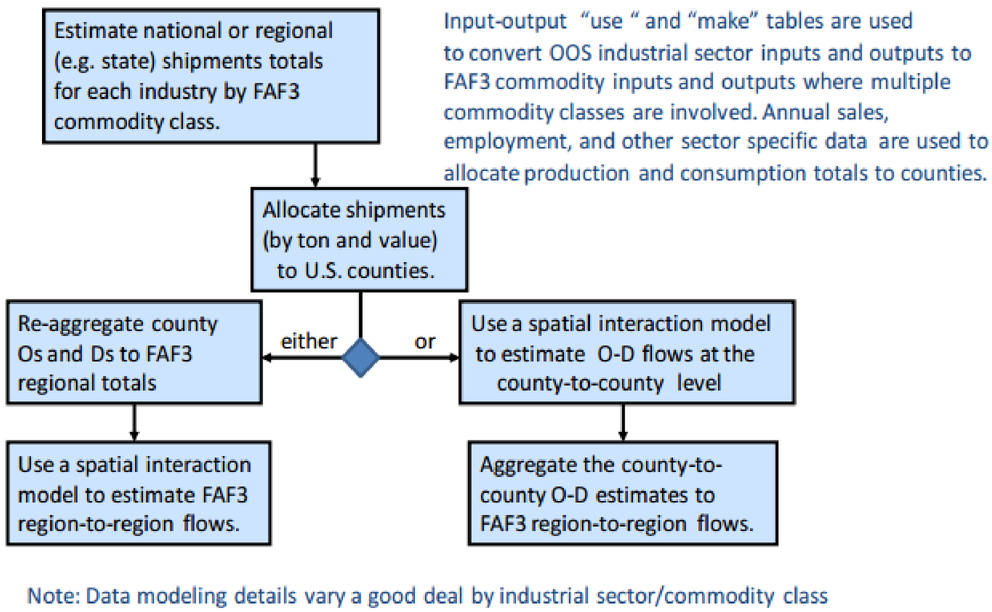
The CFS represents the best basis for FAF construction because it provides shipper sampled, and subsequently expanded estimates of both tons shipped and dollar value trades within and between all US regions for all modes of freight transportation. However, the CFS has a number of well researched weaknesses that require considerable additional effort in order to construct a complete accounting of freight movements within the United States (see TRB, 2006). First, the CFS does not collect secondary moves, *e.g.,* public warehousing where public means a for-hire service and not an auxiliary establishment of a manufacturer. Second, the CFS does not report imports, and CFS reporting of export flows is also subject to data quality issues resulting from limited sample size. Finally, the CFS either does not collect data from the following freight generating and receiving industries, or collects insufficient data to cover the industries in a comprehensive manner: Truck, rail and pipeline flows of crude petroleum, and natural gas; Truck shipments associated with farm-based, fishery, logging, construction, retail, services, municipal solid waste, and household and business moves; and Imported and exported goods transported by ship, air, and trans-border land (truck, rail) modes. In FAF3 these industries produce what are referred to in **Figure 4** as Non-CFS or Out-Of-Scope (OOS) to the CFS freight flows. Their estimation requires a good deal of data collection and integration into the larger flow matrix generation process. The data sources for these OOS flows are for the most part derived from freight carrier reported data sources, in some cases requiring the use of secondary or indirect data sources, such as location specific measures of industrial activity, employment or population, to allocate flows to specific geographic regions. These OOS flows represent some 32% of all U.S. freight movements measured on an annual tonnage basis. In addition to the OOS movements noted above, suppression of some in-scope flows is also an issue if there are insufficient CFS observations across mode, commodity, or origin and destination to protect confidentiality. The FHWA used a combination of log-linear modeling and Iterative Proportional Fitting (IPF) techniques to fill missing cell values, supplementing the CFS with data from the Surface Transportation Board (STB) Public Use Railcar Waybill data and US Army Corp of Engineers (USACE) Waterborne Commerce Data. **Figure 5** gives an overview of the process to estimate the missing cell values in the 2007 CFS.

Figure 5. Estimation of Missing Cell Values in the 2007 CFS (Southworth 2010, p. 10)



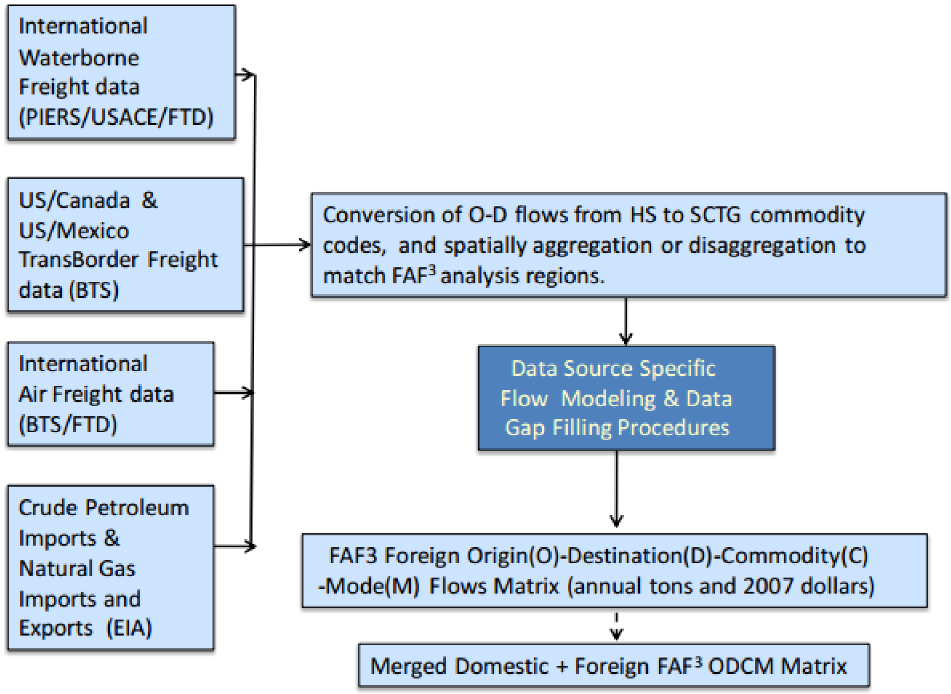
OOS flows were estimated using commodity specific datasets and different computational methods for each industrial class. Methods varied depending on whether flows were domestic or import/export. Where an industrial sector produces O-D flows in more than one commodity class, data from national inter-industry input-output tables were used to estimate how much freight each sector contributes to a specific set of SCTG 2-digit commodity flows. State and county level data on volume of production, industrial or commodity specific sector sales, or industrial sector employment is then used to allocate flows between origins and destinations. Spatial allocation formulas are then used to produce O-D flow volumes. Where truck movements were concerned this occurred in one of two ways. One way was to determine county level origin and destination activity totals and then apply a spatial interaction model to these county productions and attractions, with subsequent aggregation of inter-county flows back up to FAF3 region-to-region flow totals. The second way was to estimate origins and destinations of commodities at the FAF3 regional level and then estimate flow between each of the FAF3 regions. The specific form of spatial interaction model used also varied by commodity class. Either a distance decay coefficient was calibrated against an empirically derived average shipping distance, or a simple allocation was made based on market potentials (*i.e.*, on the relative size of a county's or region's demand for a specific commodity). County-level spatial interaction modeling here allows for cross-county flows to be captured that are also cross-FAF3 adjacent regional flows. Use of regional O and D shipment totals prior to spatial interaction modeling occurred where data sources proved more reliable at this less detailed level or geography. **Figure 6** shows the process for generating the OOS truck freight flows.

Figure 6. Process for Generating OOS Truck Freight Flows (Southworth 2010, p. 14)



Import and export freight flows in FAF3 are constructed from a variety of data sources, each of which has their own unique coding system and needs to be converted into FAF3's 2-digit SCTG codes, as well as have its flows either spatially aggregated or disaggregated to FAF3 analysis zones. **Figure 7** provides an overview of the FAF3 international data modeling. As shown in the figure, datasets from multiple private and public agencies such as the Bureau of Transportation Statistics (BTS), USACE, Energy Information Administration (EIA), US Census Bureau's Foreign Trade Division (FTD), Port Import Export Reporting Service (PIERS), etc., are used to construct FAF3's import-export freight flows.

Figure 7. FAF3 International Data Modeling ((Southworth 2010, p. 22)



Use of FAF in the Western LCV Uniformity Scenario. For the Western LCV Uniformity Scenario, a version of FAF having county-to-county flows was developed that allowed detailed assessments of the potential shift to LCVs based on the networks that would be available to those vehicles and the extent to which those networks served various shipment origins and destinations at the county level. The current release of FAF (version 3) has data available only at the FAF region level. If the modal diversion analysis were performed at this level of detail, it would be impossible to directly consider network limitations for some LCVs when estimating potential diversion of traffic to those configurations since virtually all FAF regions are served by all highway systems. In the Western LCV Uniformity Scenario analysis, the limited networks assumed to be available to various types of LCVs significantly affected estimates of overall diversion and the configurations to which shipments were diverted. To understand the effects of network limitations on some vehicle configurations, greater geographic disaggregation of freight flows is required than the current version of FAF provides.

While disaggregating the FAF to a county level enhances the analysis of potential truck size and weight policy options by allowing impacts of limiting certain vehicle configurations to particular highway networks to be assessed, it is important to recognize that uncertainties exist in the disaggregation process. The greatest uncertainty is in the exact quantity of particular commodities shipped into or out of individual counties within each FAF region. Various measures of industrial activity are available at the county level, but associating exact quantities of commodities demanded or supplied with different levels of industrial activity is imprecise. That is one reason why FHWA does not provide county level data to State and local governments – while the data may be good enough for national level policy analysis, they may not be good enough by themselves for more detailed freight planning studies at the State or regional level. Depending on the purpose and scope of such freight planning studies, State and local agencies may purchase more detailed data from third-party suppliers or they may do special

studies themselves to produce more accurate estimates of the commodity flows than could be produced simply by allocating regional totals on the basis of general measures of economic activity. Much greater precision is required for State and local planning studies that could lead to investment decisions than for national-level policy analyses.
The FHWA recently sponsored a workshop to "discuss national multimodal freight analysis framework (FAF) research. Participants discussed the state of the art, primary gaps in current capabilities, and strategies for addressing these gaps, particularly in the areas of multimodal freight networks, freight demand modeling, and origin-destination data disaggregation. Workshop participants identified several opportunities regarding new methods for data, as follows:

- Local-level details (e.g., local O-D data, local network data, local truck, local commodity truck, etc.) are not currently captured in the national FAF. Opening data for peer review and creating an architecture that allows information to be passed from the local level to the national level (i.e., establishing ground truth) could increase data validation.

- Data mining could supplement current national-level freight data to capture temporal and seasonal variations or enable tracking of commodity flows—the current FAF displays only in mode-centric, O-D, and annual flows.

- New automated methods for data manipulation could mitigate the variability of data quality—collected and reported on a State-by-State basis—and missing data, which limit the ability to support analysis of intermodal and national-level freight flows.

- Enhanced data could provide the ability to assign flows along a multimodal routable network, creating a "flowable" network, that is, one that enables tracking of flows from any origin to any destination."

2.3.2 IHS Global Insight Transearch

Transearch is a privately maintained comprehensive market research database for intercity freight traffic flows compiled by IHS Global Insight. The development of the Transearch database involves the fusion of various freight traffic data sources into a common framework for planning and analysis. The database provides detailed U.S. and cross-border origin-destination freight shipment data at the state, Bureau of Economic Analysis (BEA), county, metropolitan area, and zip-code level detail by commodity type (by Standard Transportation Commodity Classification (STCC) code) and major modes of transportation. Forecasts of commodity flows up to 30 years in the future are available for the following four modes – air, truck, water, and rail.

The data is compiled from the following sources: Commodity Flow Survey (CFS); Carload Waybill Sample; USACE Waterborne Commerce Statistics; Federal Aviation Authority (FAA) Airport Activity Statistics; Bureau of Census FTD; American Association of Railroads (AAR) Freight Commodity Statistics; and Inter-industry trade patterns. Transearch uses CFS data for the following: (TRB 2006, p.131)

- To calculate commodity $/ton values. The $/ton values maintained for Transearch production are updated annually for the intervening non-CFS years using inflation-based factors derived from sources such as the Producer Price Index;
- To calculate for-hire/private trucking mode share splits; To develop OD truck flows;
- To develop truck length-of-haul profiles;
- Identification of commodities moving via air mode; and
- Quality control.

Transearch has some limitations on how this data should be used and interpreted:

Mode Limitations – The Rail Waybill data used in Transearch is based on data collected by rail carriers terminating 4,500 cars or more annually. The waybill data contains some information for regional and short-line railroads, but only in regards to interline service associated with a Class I railroad. The rail tonnage movements provided by the Transearch database, therefore, represent only a portion of total rail shipments. Another issue with the rail waybill interlined shipments is that participating carriers may be billed for only their portion of the move, distorting the actual freight movements in the database.

Use of Multiple Data Sources – Transearch consists of a national database built from company-specific data and other available databases. To customize the dataset for a given region and project, local and regional data sources are often incorporated.

Data Collection and Reporting – The level of detail provided from some specific companies when reporting their freight shipment activities limits the accuracy of Transearch. If a shipper moves a shipment intermodally, for example, one mode must be identified as the primary method of movement. Suppose three companies make shipments from the Midwest U.S. to Europe using rail to New York then water to Europe. One company may report the shipment as simply a rail move from the Midwest to New York; another may report it as a water move from New York to Europe; the third may report the shipment as an intermodal move from the Midwest to Europe with rail as the primary mode. The various ways in which companies report their freight shipments can limit the accuracy of Transearch due to the reporting of unlinked trips. Unlike Transearch, FAF3 considers intermodal trips (truck-rail etc.) as a distinct mode in the development of the origin-destination flow matrix and is therefore able to represent trips more completely. The FAF3 reports trips as linked trips, i.e., in the same example above, the shipment is reported one trip using rail and water as the shipping modes.

Limitations of International Movements – Transearch does not report international air shipments through the regional gateways. Additionally, specific origin and destination information is not available for overseas waterborne traffic through marine ports. Overseas ports are not identified and Transearch estimates the domestic distribution of maritime imports and exports. Transearch data also does not completely report international petroleum and oil imports through marine ports. In FAF3 a variety of data sources such as the US Army Corp of Engineers International Waterborne Commerce, US Census Bureau’s Foreign Trade database, a FAF3-

specific extraction of data from the Port Import Export Reporting Service (PIERS), Bureau of Transportation Statistics (BTS) T100 Data, and BTS TransBorder Freight Database are used to estimate international flows from/to overseas by water, air, and truck to/from the FAF3 region along with the Port of Entry/Exit (POE).

Transearch's county-to-county market detail is developed through the use of Global Insights' Motor Carrier Data Exchange inputs and Global Insights' Freight Locator database of shipping establishments. Freight Locator provides information about the specific location of manufacturing facilities, along with measures of facility size (both in terms of employment and annual sales) and a description of the products produced. This information is aggregated to the county level and used in allocating production among counties. Much of the Motor Carrier Data Exchange inputs from the trucking industry are provided by zip code. The zip code information is translated to counties and used to further refine production patterns. A compilation of county-to-county flows and a summary of terminating freight activity are used to develop destination assignments.

Transearch is widely used for State and local freight planning purposes. It also can be used in conjunction with the TREDIS modeling system developed by the Economic Development Research Group to assess economic impacts of various changes in freight transportation service and performance. TREDIS, however, is not a logistics-based model and would not be able to estimate mode choice decisions based on changes in truck size and weight limits.

Transearch is the only nationwide proprietary commodity flow data uncovered in the desk scan that contains data on multiple modes of transportation. As discussed below, the Surface Transportation Board maintains a Carload Waybill Sample of rail shipments that has both public use and proprietary versions, but that database only contains data on rail moves.

Commodity Flow Survey - The Commodity Flow Survey (CFS) produces data on the movement of goods in the United States and provides information on commodities shipped, their value, weight, and mode of transportation as well as the origin and destination of shipments of commodities from manufacturing, mining, wholesale, and select retail and service establishments. The CFS covers business establishments with paid employees that are located in the United States and are classified by the North American Industry Classification System (NAICS) in mining, manufacturing, wholesale trade, and selected retail and service trade industries. The survey does not cover establishments classified in transportation, construction, and most retail and service industries. Farms, fisheries, foreign establishments, and most government-owned establishments are also excluded. The CFS captures shipments originating from select types of business establishments located in the U.S., except for Puerto Rico and other U.S. possessions and territories. Shipments traversing the United States from a foreign location to another foreign location are not included, nor are shipments from a foreign location to a U.S. location. However, imported products are included in the CFS at the point that they leave the importer's initial domestic location for shipment to another location. Shipments that are shipped through a foreign territory with both the origin and destination in the U.S. are included in the CFS data. The CFS data is one of the main building blocks of both FAF and Transearch, but by itself is not suitable for modal diversion analysis.

STB Public Use Waybill Data - The Public Use Waybill Sample (PUWS) is a non-proprietary version of the STB Carload Waybill Sample. The STB requires that all U.S. railroads that terminate more than 4,500 revenue carloads submit a yearly sample of terminated waybills. The waybills are sampled under two different plans, depending on the number of carloads on the waybill and weighted using appropriate multipliers for each sampling level, which are not disclosed, to represent total U.S. rail movements in that year. Use of the waybill data is subject to some qualifications. As with any sample, some portions of the total population are better represented than others. Since the full Carload Waybill Sample contains specific waybill information such as origin and termination freight station, junction points, and rail carrier identification, it is not suitable for public release. As an alternative, the Public Use Waybill Sample has been created from the original full sample by eliminating station and carrier information. Origin and termination points are reported by BEA area and junction points are reported by state or province, rather than by freight station or city name. Additionally, some waybill records are excluded from the PUWS. The PUWS only contains rail freight movements for commodities handled by at least three freight stations in the U.S. If a 5-digit commodity was not handled by at least three Freight Station Accounting Codes (FSACs) nationwide, the record is rejected for the PUWS. Commodities (with the exception of munitions data) are identified at the 5-digit STCC level. Because of the sensitive nature of the munitions data, this information is reported at the 2-digit STCC level (STCC 19) and no geographic coding for these records is included. The use of BEA economic areas in the PUWS is subject to the “three-FSAC rule”. This rule was adopted to protect against any disclosure of competitively sensitive waybill data in the Public Use file. Under this approach, a BEA economic area is only reported if there is activity for at least three FSACs on one railroad for a given commodity within that BEA, or if there are at least two more FSACs with activity than there are railroads in that BEA economic area for a given commodity. Records that do not pass the three FSAC rule are still included, but without any geographic coding. Intermediate junction data is shown only when both the originating and the terminating BEAs pass these criteria. Only about 45 to 50% of the total waybill records have full geographic data.

2.3.3 Networks

The FAF2 geospatial network coverage was used as the basis for updating the FAF3 network. It represents more than 447,400 miles of the nation’s highways comprised of Rural Arterials, Urban Principal Arterials, and all National Highway System (NHS) routes. The following roadways are included:

- Interstate highways;
- Other FHWA designated NHS routes;
- National Network (NN) routes that are not part of NHS;
- Other rural and urban principal arterials;
- Intermodal connectors;

- Rural minor arterials for those counties that are not served by either NN or NHS routes; and
- Urban bypass and streets as appropriate for network connectivity.

Updates from the FAF2 to the FAF3 network include:

- Updates to NHS designation and intermodal revisions current to version 2009.11 releases;
- Additions or updates to urban bypass or other state specific highway alignment; and
- Integration and updating of NN and LCV route designations, state link specific truck restrictions, clearances, and hazmat route restrictions.

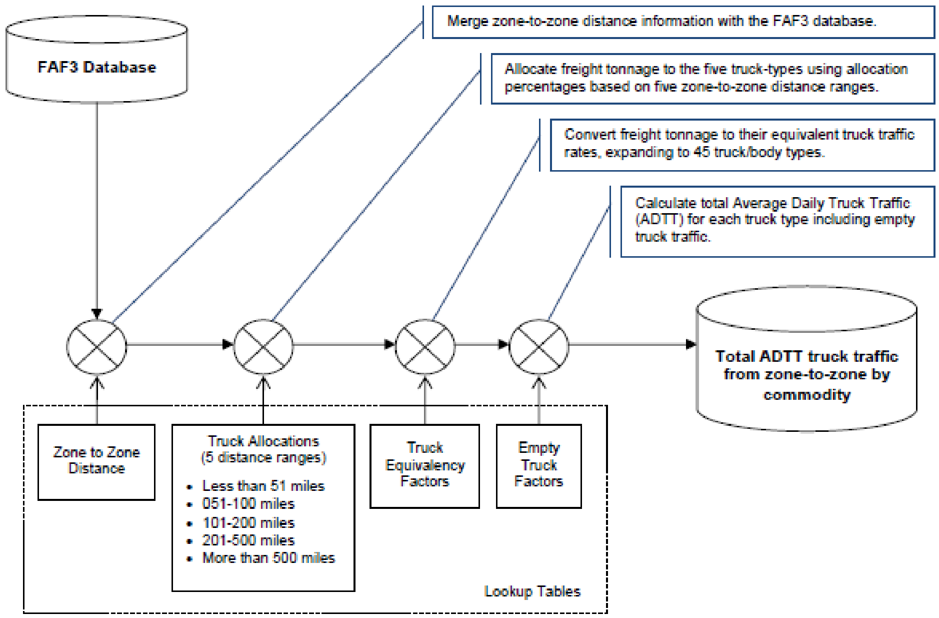
2.3.3.1 FAF3 Network and HPMS 2008 Data Integration Process

The 2008 HPMS database was selected for the 2007 network update to ensure base year information consistency. Typically each HPMS current year release (*e.g.*, 2008) is based on the last year (*e.g.*, 2007) state reported roadway inventory database. The link specific information was then further processed to minimize the attribute discrepancy at the state/or urban boundary and at other locations where link specific data gaps exist. For missing and non-sampled links, truck traffic percentages were updated using a combination of state specific functional class averages and/or correlations with adjacent link truck percentages. The 2040 values for average traffic volume and truck traffic were estimated using the state growth factor reported in the HPMS 2008 database and projected to 2040 using a linear growth algorithm.

The HPMS and NHS data sources both provide Linear Referencing System (LRS) information. However, due to changes in the submittal criteria, the two data sources have not maintained a common format that would allow direct relating of their respective data. To overcome this issue, HPMS and NHS data are related using algorithms, as necessary, for primary and secondary signage, mileposts, and translated LRS identifiers.

The FAF3 network has information on each link's truck restrictions, and the types of trucks and LCVs that are allowed on the network. The FAF3 data do not provide an estimation of the Average Daily Truck Traffic (ADTT) used to move freight between the shipping zones. The work flow diagram shown in **Figure 8** illustrates a general overview of the process of estimating the AADT. The primary source of information for developing the procedures for converting commodity flows in tons to truck trips was the 2002 Vehicle Inventory and Use Survey (VIUS) database. The VIUS provides national and state-level estimates of the total number of trucks by truck type.

Figure 8. Truck Conversion Flow Diagram (Battelle (2011), p. 3-2)



There are five groups of truck configurations, ranging from single unit trucks to tractor plus triple trailer combinations, nine types of truck body types, such as Dry Van, Flat Bed, and Tank. The allocation of FAF3 O-D tonnage for each truck configuration and body type was carried out for each commodity the truck carried. The conversion of commodity flows from tons to trucks is done in the following steps. The first step involves identifying the primary truck configurations (Single Unit Trucks, Truck plus Trailer Combinations, Tractor plus Semitrailer Combinations, Tractor plus Double Trailer Combinations, and Tractor plus Triple Trailer Combinations) and major truck body types (Dry Van, Flat Bed, Bulk, Reefer, Tank, Logging, Livestock, Automobile, and Other). This is followed by allocation of commodities to truck configurations used to transport these commodities. Following this, the average payload by vehicle group and body type is estimated and converted into the equivalent number of trucks. Finally, the percent of empty truck trips is calculated.

2.4 Future Research Needs Related to Estimating Modal Shifts Associated with Truck Size and Weight Policy Options

As indicated above, substantial research has been conducted over an extended period of time on potential impacts of changes in truck size and weight policy on shifts of traffic between modes and between different truck configurations. Research has been conducted at the national, regional, State, and corridor levels using a variety of analytical techniques and data sources. Analytical techniques have ranged from complex models of transportation logistics costs associated with the use of different modes to expert opinions about potential impacts. To a large degree methods have reflected the resources available to conduct the study and the scope of the study. Studies whose sole objective was to estimate potential impacts of truck size and weight options on modal diversion were more likely to use econometric methods or logistics models that are not linked to highway networks. Studies that also focused on estimating infrastructure, safety, and other outcomes of modal diversion have tended to use logistics models and disaggregate commodity flows that are linked to the highway network. State studies that have not had the resources available to many federal studies have often relied on expert opinion rather than data-intensive logistics cost models.

Data used in the various studies have ranged from highly disaggregate commodity flows synthesized from a variety of primary and secondary sources, to synthetic data meant to broadly represent different types of operations, to surveys of individual companies. Again the resources available to conduct the study and the study objectives strongly influence the data used in the study. Synthetic or survey data could not be used to produce defensible estimates of safety and infrastructure implications of modal diversion. A special analysis was conducted for the 2014 CTSW Study to disaggregate the FAF to produce county-to-county commodity flows. Additional research to improve estimates of county-to-county flows is needed. Several specific research activities to improve commodity flow databases were identified in a recent FHWA workshop and are discussed in Section 2.3.1 above.

There is a consensus across all past studies that larger, heavier trucks would divert traffic from truck configurations operating today and that traffic also could be diverted from the railroads, but the potential magnitude of impacts varies considerably among studies. Much of the difference can be accounted for by different assumptions in each study about the weights and dimensions of larger trucks, the networks on which they would operate, the potential response by the railroads to increased competition from the larger trucks, impacts of larger trucks on overall transportation and logistics costs, responses by shippers and carriers to the availability of larger, heavier trucks, and other factors.

Improving estimates of modal diversion will require additional research in several areas. First, estimates of the logistics costs associated with the use of different modes and truck configurations need to be improved. Currently the various logistics costs are assumed to be the same for all companies, but this clearly is not the case. Better information on how logistics costs vary for different types of companies would improve our understanding of impacts of truck size and weight changes, but as Middendorf and Bronzini found, it is very difficult to get good information from companies on their logistics costs. Second, because truck size and weight limits in the U. S. have not changed significantly in many years, there is very little empirical data on responses of different parts of the transportation industry to changes in truck size and weight limits. Truck size and weight limits have changed in Canada, Australia, and other countries, however. In depth examinations of impacts of changes in other countries could inform researchers in the U.S. and help calibrate models used to estimate modal shifts and other responses to truck size and weight changes. Third, the Vehicle Inventory and Use Survey is an important source of information on the way trucks are actually used in practice, providing such information as the percent of their mileage that is empty, the types of commodities carried in different vehicle configurations and body types, the average mileage traveled annually by different types of vehicles, etc. This survey has not been conducted in over ten years and information is becoming quite dated. A new Vehicle Inventory and Use Survey would provide much improved information for use in truck size and weight studies.

Another research need related to the ITIC model is the fact that it is an all-or-nothing model that assumes that all shipments of a particular commodity between the same O-D pairs will respond the same to a change in transportation or non-transportation logistics costs. Estimates could be improved if different probabilities could be assigned to modal shifts based on characteristics of the commodities, transportation modes and corridors involved. This likely would take considerable resources to develop

2.5 Comparison of Findings from Past Modal Shift Studies

As noted above, it is difficult to directly compare results from the various studies that have estimated modal diversion associated with truck size and weight policy options. Studies differ in, among other things

- geographic scale,
- the types and detail of changes they are attempting to estimate,
- the data and methods used
- the weights, dimensions, and vehicle configurations they are examining, and
- the metrics they use to measure impacts.

Nevertheless comparing findings of these studies can help shed light on factors that are important in understanding impacts of truck size and weight policy changes. **Table 4** shows findings from major studies whose results lend themselves to comparison with other studies.

Table 4. Comparison of Findings on Modal Shifts from Past Truck Size and Weight Studies

Study	Vehicles and Weights Analyzed k = thousands of pounds	Change in Truck VMT (percent)	Change in Rail Travel (percent)
Nationwide Studies			
USDOT, Comprehensive Truck Size and Weight Study (2000)	3S3-90k; Twin 33s-124k 3S3-97k; Twin 33s-131k RMD-120k; TPD-148k*; Triple-132k Triple-132k	(11) (11) (23) (20)	(5) 2/ (6) 2/ (20) 2/ (4) 2/
Martland, “Estimating the Competitive Effects of Larger Trucks on Rail Freight Traffic”, (2007) (impacts on short-lines only)	3S3-97k RMD-110k TPD-148k		(13) 3/ (18) 3/ (34) 3/

Martland, "Estimating the Competitive Effects of Larger Trucks on Rail Freight Traffic," (2010) (impacts on Class 1 railroads)	3S3-90k 3S3-97k RMD-129k TPD-129 TPD-148k Triple-110k		(13) 3/ (19) 3/ (36) 3/ (30) 3/ (60) 3/ (12) 3/
Regional Studies			
USDOT, Western Uniformity Scenario Analysis (2004)	RMD-129k; TPD-129K*;Triple-110k*	(25)	(.02) 3/
Cambridge Systematics, Minnesota Truck Size and Weight Project, Final Report, (2006)	3S3-90k; 3S4-97k; 3S3-2-108k; SU4-80k	**	NA
Cambridge Systematics, Wisconsin Truck Size and Weight Study, 2009 1/	3S3-90k 3S3-98k 3S4-97k 8-axle twin-108k SU7-80k 6-axle truck-trailer-98k	(.06) (0.4) (.18) (1.2) (.07) (0.5) (.06) (0.4) (.01) (.02) (.01) (.04)	NA
Stephens, Impact of Adopting Canadian Interprovincial and Canamax Limits on Vehicle Size and Weight on the Montana State Highway System, (1996)	Various vehicle classes allowed under Canadian Interprovincial and Canamax Standards	(<=3)***	NA
Bienkowski, The Economic Efficiency Of Allowing Longer Combination Vehicles In Texas (2011)	3S3-97k; TPD-90k; TPD-148k	(31)***	NA
McCullough, Long-Run Diversion Effects of Changes in Truck Size and Weight (TS&W) Restrictions: An Update of the 1980 Friedlaender Spady Analysis, 2013	NA – 10% reduction in truck costs assumed	7	8.5 4/

Numbers in parentheses are negative
NA= not analyzed
*Limited network
** No change in VMT reported, no % change in transport cost savings reported
*** Impacts of specific vehicle configurations were not reported
1/ Numbers in the left column are for non-Interstate operations only. Numbers in the right column assume vehicles can also operate on the Interstate System
2/ Estimated change in rail car-miles
3/Estimated change in ton-miles
4/Estimated change in net income

Reductions in truck travel estimated in the various studies ranged from a high of 31% in the Bienkowski study in Texas to little or no impact for some heavier configurations in Wisconsin. The major reason for such a large difference is the metric used to express results. In the Texas study changes are based only on shifts from the base vehicle configuration to the scenario configurations whereas changes in Wisconsin and Montana reflect estimated changes in overall heavy truck VMT including substantial VMT that would not be affected by the introduction of the scenario vehicles. Reductions in truck traffic estimated in USDOT's 2000 CTSW Study vary as one would expect with greater reductions being estimated for those vehicle classes offering the greatest increases in payload. The magnitude of impacts for turnpike doubles is mitigated, however, by the assumption that those vehicles would be limited primarily to the Interstate System and would have to assemble and disassemble for goods to get from origin to destination. Impacts estimated in the Western Uniformity Scenario are somewhat higher than estimated impacts in the 2000 CTSW Study because larger networks were assumed to be available to the larger vehicles.

Potential rail impacts estimated in studies by Martland are considerably higher than impacts estimated in the 2000 CTSW Study for several reasons. First, Martland's study examined only rail competitive traffic so the shifts to truck were higher on a percentage basis than shifts estimated in the 2000 CTSW Study which examined potential shifts for all rail traffic. Second, Martland did not consider the potential for railroads to reduce their rates to prevent diversion of traffic to the heavier trucks whereas the 2000 CTSW Study did assume that railroads would reduce rates. The actual extent to which railroads might reduce rates to maintain traffic would depend on factors unique to particular moves. The low estimates in the Western Uniformity Scenario analysis can be attributed in part to the study being regional in scope as opposed to local, and in part to the fact that larger vehicles already operate in many of the western States and thus the base case modal shares already reflect some competition with heavy trucks.

The credibility of modal shifts estimated in the studies reviewed above is difficult to determine. An important factor limiting the ability to assess the credibility of study findings is that there have been virtually no changes in federal or state truck size and weight limits over the last 30 years and thus observable modal shifts due to changes in truck size and weight limits are not available. This means there is little basis for calibrating estimates based on changes in transportation and logistics costs for the various modes to actual changes that have been observed in practice. Furthermore, reports available on most studies do not provide sufficient detail to adequately assess the credibility of findings. While major assumptions underlying each study generally are available, details concerning specific data sources often are not available, and these details could significantly affect study findings.

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CHAPTER 3 - ENERGY AND ENVIRONMENT

In 2007, heavy duty trucks (defined by EPA as on-highway vehicles with a GVW greater than 8,500 lb. and which are not Medium-Duty Passenger Vehicles) carried 71 percent of all freight moved in the U.S. by tonnage and 87 percent by value. Heavy-duty trucks are the largest source of Greenhouse Gases (GHG) in the transportation sector after light-duty vehicles and the total GHG emissions from this sector increased over 72 percent from 1990 to 2008.

Current diesel engines are 35-38 percent efficient over a range of operating conditions with peak efficiency levels between 40 and 45 percent depending on engine sizes and applications, while gasoline engines are approximately 30 percent efficient overall. This means that approximately one-third of the fuel's chemical energy is converted to useful work and two-thirds is lost to friction, gas exchange, and waste heat in the coolant and exhaust. Trucks use this work delivered by the engine to overcome overall vehicle-related losses such as aerodynamic drag, tire rolling resistance, friction in the vehicle driveline, and to provide auxiliary power for components such as air conditioning and lights. Lastly, the vehicle's operation, such as vehicle speed and idle time, affects the amount of total energy required to complete its activity.

3.1 State-of-the-Practice in Modeling Heavy Truck Fuel Consumption

Energy consumption and emissions of air pollutants have been considered in many previous truck size and weight studies at both the federal and state levels. A working paper prepared in connection with the 2000 CTSW Study highlighted the key issues surrounding truck size and weight policy and energy consumption, summarized studies conducted through 1994, and identified gaps in the literature that needed further research (Battelle 1995). Among those research needs were impacts of larger, heavier vehicles on fuel efficiency; impacts of new types of tires on fuel consumption; intermodal tradeoffs between trucks, rail, and other modes; and the impacts of environmental regulations on fuel consumption.

Battelle identified several aspects of truck size and weight regulation that could affect fuel consumption including:

- Vehicle weight – research to date had estimated a 50% increase in gross vehicle weight would lead to a much lower increase in fuel consumption,

- Vehicle dimensions – a "factor contributing to fuel consumption is the aerodynamic drag from longer or multiple trailers that might be used under increased TS&W limits. No studies have attempted to quantify what effect, if any, increased truck lengths would have on energy consumption. The Transportation Research Board's (TRB) analysis of Twin Trailer Trucks (TRB, 1986) indicated twin trailer combinations encounter greater air resistance than tractor-semitrailers and are less able to sustain high speeds.",

- Intermodalism – "recent studies have looked at the energy conservation impacts of intermodal freight transport. These studies all tend to support the position that direct comparisons should be made between truck and rail energy consumption, looking at specific commodity types and routes, rather than more generic application of industry wide energy efficiencies. Ton-miles of freight is probably the best measure for energy comparisons, provided that ton-miles are applied to specific commodities that travel by both modes. A commodity and route-specific application of a ton-mile measure recognizes differences between the modes."

- Tires – "increased use of double and triple trailer configurations can contribute to increased irregular tire wear. This can occur due to excessive movement on dolly axles (*Heavy Duty Trucking*, Feb. 1992, pp 68). Irregularly worn tires can increase friction and resistance, creating more load on the engine. The impact of worn tires has not been discussed in the literature, but it may be as significant as the improvements new tire technologies provide. Similarly, the effects of tire and axle loads on energy conservation have not been researched. To the extent these increase resistance and exacerbate load on the engine, fuel efficiency will be reduced."

The USDOT's 2000 CTSW Study used fuel consumption and emissions factors derived for the 1997 Federal Highway Cost Allocation Study (USDOT 1997) to estimate impacts of truck size and weight scenarios on energy and emissions. That research addressed the first of the research needs identified in the working paper by using then state-of-the-art models that included gross vehicle weight, tire rolling resistance, aerodynamic drag, speed, grades, and drive train efficiency among the factors used to estimate vehicle fuel consumption. Fuel consumption modeling, however, was limited to the truck tractor and did not consider rolling resistance and aerodynamic drag associated with trailers.

The USDOT's *Addendum to the Federal Highway Cost Allocation Study* (2000) included estimates of air pollution-related costs associated with motor vehicle travel. Pollutants analyzed in the study included particulates, sulfur dioxide, nitrous oxides, volatile organic compounds, carbon monoxide, and lead. Cost estimates were developed in cooperation with EPA and relied on EPA air quality models that take into account all sources of air pollution and the transport of pollutants within and between air sheds. EPA models did not break out various classes of heavy trucks, so findings could not be used directly for the current study, but they do demonstrate the complexity of translating emissions of various pollutants into economic costs. The study notes,

> *Air pollution costs attributable to motor vehicles were estimated by comparing levels of air pollution when all sources of pollution were present with air pollution when motor vehicle emissions were eliminated. Costs attributable to rural motor vehicle travel were estimated by eliminating all urban motor vehicle travel, and urban costs were estimated by eliminating rural travel. These methods were necessary to eliminate interactions between emissions in rural and urban areas that would make it impossible to estimate whether there are significant differences in costs associated with travel in rural and urban areas.*
>
> *About two-thirds of motor vehicle-related air pollution costs are attributable to urban travel and one-third to rural travel…. the sum of these costs for urban and rural travel individually is slightly greater than costs for all motor vehicle travel. This is explained by regional transport of both precursor emissions and air pollutants and the complex chemistry leading to the production of ozone and particulate matter.*

> *Except for PM_{10} and $PM_{2.5}$, automobiles account for the largest share of various motor vehicle emissions. Because of the complex chemical processes by which emissions are transformed into particulate matter, ozone, and other secondary pollutants, and variations in the transport of pollutants in different regions of the country, relative emissions attributable to different vehicle classes cannot be directly translated into relative air pollution costs without detailed air quality modeling that was beyond the scope of this project. For instance, while heavy trucks account for a large share of particulate emissions, they account for a smaller share of costs because significant portions of particulate matter are formed through chemical reactions involving other compounds emitted predominantly by light trucks and passen*ger vehicles.

This study represented one of the most detailed assessments of the nationwide air pollution costs associated with highway vehicles. The level of detail in this study is beyond the scope of most truck size and weight policy studies including the current study, but it highlights the fact that the full impact of changes in emissions cannot be assessed just by measuring emission levels themselves.

Carson (2011) recently summarized literature related to truck size and weight research, including impacts on fuel consumption and the environment. Her general findings were:

- "The impacts of increased truck size and weight limits on the environment are typically characterized in terms of energy consumption, harmful emissions, and noise levels.
  - Estimates are often derived from anticipated reductions in heavy truck VMT and do not directly differentiate between truck configurations or size and weight classes.
- With some consistency, fuel consumption is estimated to decrease with increased truck size and weight limits, attributable to anticipated reductions in heavy truck VMT.
- Harmful emissions impacts are largely inestimable for specific truck configurations or size and weight classes using contemporary models with the exception of CO_2—CO_2 production is directly proportional to diesel fuel use. As such, CO_2 production is also consistently estimated to decrease with increased truck size and weight limits, attributable to anticipated reductions in heavy truck VMT."

Scora, et al. (2010) modeled the impact of vehicle weight, speed, road grade, and roadway facility type using an emissions model they developed. On-road heavy-duty truck data for a variety of driving conditions was collected using a state-of-the-art mobile emission laboratory. A modal emission model for heavy duty diesel trucks was used to analyze the data. The authors found, "The optimal driving speed at which CO_2 emissions are minimized increases with increasing vehicle weight. For the modeled vehicle, the speed at which CO_2 emissions are minimized is close to 23 mph when there is no additional trailer weight and approaches 45 mph with a large trailer weight of 64,000 pounds." While vehicle weights were varied in the study, alternative vehicle configurations were not examined.

Woodrooffe et al. (2010) reported on a study for the Joint Transport Research Centre of the Organisation for Economic Co-operation and Development and the International Transport

Forum that benchmarked the safety and productivity of typical highway transport trucks from various countries. Among the metrics considered were fuel economy and CO_2 emissions. The energy and emission analysis included simplifying assumptions that vehicles travel at a constant speed of 90 km/h on level ground in calm wind conditions. Only two variables are considered, tire rolling resistance and overall vehicle aerodynamic drag. The power required to overcome aerodynamic drag and tire rolling resistance can be expressed as follows:

$$P=(F_R + F_A) * v = (C_R * m * g + ½ * p * C_D * A * v_x^2) * v$$

where

P = power required to overcome the resistive forces (expressed as watts),
F_R = tire rolling resistive force,
F_A = aerodynamic resistive force,
C_R = tire rolling resistance coefficient,
C_D = aerodynamic drag coefficient,
A = frontal area of the vehicle,
v = velocity of the vehicle,
p = air density,
m = mass, and
g = gravity

Different values for tire rolling resistance were used for standard dual-tire axles and wide-based single tires. A further simplifying assumption was made that the aerodynamic drag coefficient was the same for each vehicle configuration, regardless of the trailer length or number of trailers.

The amount of CO_2 produced per kWh was estimated as follows:

- Amount of diesel fuel consumed for truck applications is approximately 200 g/kWh (assuming 50% efficiency).
- The mass of diesel fuel is approximately 850 g/L.
- CO_2 emissions produced by diesel fuel are 2.668 kg/L.
- Therefore, the amount of CO_2 produced per kilowatt-hour is 0.628 kg

Woodrooffe concluded, “For the vehicles examined in this study, using fuel efficiency and CO_2 produced relative to the product of cargo mass and volume was found to be the performance measure most effective at differentiating vehicle efficiency performance.”

In as study for Wisconsin, Cambridge Systematics (2009) estimated potential fuel and emissions reductions associated with the use of 6 different vehicle configurations including 3 heavier tractor-semitrailers, a heavy straight truck, a heavier straight truck-trailer combination, and a heavy double trailer combination. The greatest reduction in fuel consumption and emissions was associated with a 6-axle tractor-semitrailer with a maximum gross vehicle weight of 98,000 pounds.

In a presentation to the 2009 Asilomar Conference on Transportation and Energy, Winebrake compared the energy efficiency of different modes of transportation. He noted that, “We can solve a large part of the energy and environmental problems of freight transportation by moving goods off trucks and onto trains and ships.” He demonstrated the savings possible through the use of rail and ships in different corridors based on an analysis conducted using the Geospatial Intermodal Freight Transportation (GIFT) model developed jointly by Rochester Institute of Technology and the University of Delaware. Winebrake indicated that the potential for mode shifting was a function of, among other things,

- The compatibility of the cargo to transportation by alternative modes,
- The feasibility of using alternative modes based upon the availability of required infrastructure, and
- The practicality of using alternative modes based on economic considerations.

He then identified a number of policy options for increasing the use of more energy-efficient modes including efficiency standards, taxes, subsidies, technology mandates, infrastructure investment, research and development, alternative low-carbon fuels, size and weight restrictions, and demand management.

Comer et al. (2012) used the same methodology to examine the tradeoffs associated with a shift from heavy-duty trucks to ships for freight transport in the Great Lakes region, with particular attention given to cross-border freight flows between the United States and Canada. The GIFT model includes “energy, environmental, economic, and speed attribute information (by mode) on each segment and node of the intermodal network. Attributes such as emissions of various pollutants (e.g., CO_2, PM10, NOx, SOx, CO, and VOCs), energy consumption (e.g., Btu), time, and economics (US$) have been incorporated into GIFT through a custom emissions calculator and graphical user interface that allows for user-defined inputs to be entered into the model. Each segment of the network takes on calculated attribute values based on the characteristics of the transport mode, segment speed, and other factors. Moreover, transfers between modes (occurring at rail yards, ports, and other intermodal transfer facilities) accrue time, cost, and emissions “penalties” using a hub-and-spoke approach that links each mode’s network to the facility hub through creation of “spokes.” Once the network includes such attribute data, the analyst can solve the network transportation problem for different single objective functions, such as least time, least cost, and least emissions (or a weighted multi-objective function applying a combination of these attributes).” As in Winebrake (2009), a number of policy options are identified to make ships more competitive with truck and rail.

An important aspect of estimating the relative fuel consumption and environmental emissions of different modes is to determine the fuel consumption and environmental benefits of heavy-duty truck technologies through testing and analysis. Significant research has been conducted since the 2000 CTSW Study on heavy truck fuel efficiency, but most has not been in the context of truck size and weight analysis.

Several methods are available to assess fuel consumption and greenhouse gas emissions from trucks. Truck fleets today often use SAE J1321 test procedures to evaluate criteria pollutant emissions changes based on paired truck testing. Light-duty trucks are assessed using chassis dynamometer test procedures. Heavy-duty engines are evaluated with engine dynamometer test procedures. Most large truck manufacturers employ various computer simulation methods to estimate truck efficiency. Each method has advantages and disadvantages. The Greenhouse Gas Emissions Model (GEM) was developed by the U.S. Environmental Protection Agency (US EPA) as a means for determining compliance with the proposed GHG emissions and fuel consumption vehicle standards for Class 7 and 8 combination tractors and Class 2b-8 vocational vehicles developed by US EPA and NHTSA respectively (EPA 2010). As both agencies' proposed compliance tool, GEM was designed with the following modeling attributes:

- Capable of modeling a wide array of medium- and heavy-duty vehicles over different drive cycles;
- Contains open source code, providing transparency in the model's operation;
- Freely available and easy to use by any user with minimal or no prior experience;
- Contains both optional and preset elements; and
- Managed by the agencies for compliance purposes.

The design of GEM focuses on the application of technologies having the largest impact on reducing vehicle GHG emission reductions or fuel consumption in the 2014-2017 timeframe. For the given timeframe, the model would allow various inputs to characterize a vehicle's properties (*e.g.,* weight, aerodynamics, and rolling resistance) and predict how the vehicle would behave when it to be operated over a particular driving cycle.

US EPA has validated GEM based on the chassis test results from "SmartWay"-certified tractors tested at the Southwest Research Institute. Since many aspects of one tractor configuration (such as the engine, transmission, axle configuration, tire sizes, and control systems) are similar to those used on a manufacturer's sister models, the validation work conducted on these vehicles is representative of the other Class 8 tractors.

The input values needed for the simulation model (*e.g.*, drag coefficient, tire rolling resistance coefficients, tire/wheel weight reduction, vehicle speed limiter, aerodynamic drag, tire rolling, resistance coefficient inputs, and extended idle reduction technologies) are obtained as manufacturer testing or model default values. The tool also has a range for vehicle speed limiter and default extended idle reduction technology benefit variables.

After parameters are input to the graphical user interface, GEM predicts the individual and cycle weighted fuel consumption and CO_2 emissions for three proposed test cycles – a Transient cycle, a 55 mph steady-state cruise cycle, and a 65 mph steady-state cruise cycle. The model can also be used to determine a level of technology necessary for a vehicle to meet a specified GHG standard and allows a manufacturer to estimate the benefits and costs of those changes to a particular vehicle for that level of GHG reductions.

While the GEM model can estimate fuel consumption based on detailed characteristics of a truck tractor, it does not estimate the effects on fuel consumption of trailer characteristics such as weight, aerodynamic drag, and the rolling resistance of tires. Bachman et al. (2005) cite a U.S. Department of Energy (DOE) report (DOE 2000) that indicates, “At a steady speed of 65 miles per hour on a flat road, aerodynamic drag and rolling resistance account for 21 percent and 13 percent, respectively, of the total energy used by a class 8 heavy-duty tractor.” They note that “measurements of whole-vehicle emissions from class 8 tractor-trailers are not readily available because historically such measurements involve dynamometer testing in the laboratory, and dynamometers suitable for class 8 tractor trailers are rare.” Bachman reports on a study of the emission benefits of improving trailer aerodynamics and reducing tire rolling resistance that was conducted in connection with EPA’s SmartWay Transport Partnership. This partnership between shippers, transportation providers, such as truck fleets, and the US EPA is designed to encourage shippers and fleets to reduce air pollution and greenhouse gas emissions through lower fuel consumption. Installation of devices to reduce aerodynamic drag and use of super single tires to reduce rolling resistance were found to improve fuel economy of tractor-semitrailers by 18 percent at highway speeds and offered even greater improvements in a suburban driving cycle. A similar study in Austria found reductions in fuel consumption of 12 percent when vehicle aerodynamics were improved and low rolling resistant tires were used (Eichlseder 2011).

In addition to estimating the impacts of rolling resistance on fuel economy and CO_2 emissions, Bachman also estimates impacts on NOx emissions. Particulate emissions are not measured because “PM is controlled by a more complex set of factors in addition to power output, including fuel composition, and transient engine properties, such as air/fuel ratio, oil leakage through piston rings, and exhaust gas temperature.” The tests conducted as part of the study show that “components designed to reduce power load not only reduce power load and improve fuel economy, but they also reduce NOx emissions. In some cases, NOx reductions may be disproportionately greater than improvements in fuel economy, although this may be an artifact of the particular engine design that was tested. Additional testing of other engine designs is necessary to quantify the relation between NOx reduction and improvements in fuel economy.” Thus relationships between NOx emissions and fuel economy are not as direct as relationships between CO_2 emissions and fuel economy and more specialized equipment is required to measure NOx emissions associated with different operating characteristics.

A National Academy of Sciences study (NAS, 2010) found that the relationship between the percent improvement in fuel economy (FE) and the percent reduction in fuel consumption (FC) is nonlinear; *e.g.*, a 10 percent increase in FE (miles per gallon) corresponds to a 9.1 percent decrease in FC, whereas a 100 percent increase in FE corresponds to a 50 percent decrease in FC. The study also found that Medium and Heavy Duty Vehicles (MHDVs) are designed as load-carrying vehicles, and consequently their most meaningful metric of fuel efficiency will be in relation to the work performed, such as fuel consumption per unit payload carried, which is load-specific fuel consumption (LSFC). Methods to increase payload may be combined with technology to reduce fuel consumption to improve LSFC. Therefore, the study recommended that regulators need to use a common procedure to develop baseline LSFC data for various applications, to determine if separate standards are required for different vehicles that have a common function.

Battelle (1995) summarizes findings on the relative fuel efficiency of truck and rail reported by Nix (1991). While these findings are quite dated, they nevertheless consistently show rail to be more fuel-efficient than trucking on a ton-mile basis.

An FRA study completed by ICF International in 2009 compares rail and truck fuel efficiency and concludes that rail is more fuel efficient (ICF 2009). This study is an update to a similar 1991 study to address the technological and operational improvements that have been realized between 1991 and 2009 for both rail and truck. The methodology used was the same as in the 1991 study so that the studies are comparable. The study evaluates and compares rail and truck fuel efficiency on corridors and for services in which both modes compete. An analysis of past and future trends is also provided in the study. Competitive movements are defined as those of the same commodity having the same (or proximate) origin and destination. The study does not compare economic efficiency of the modes, nor does it evaluate any individual criteria that influence mode choice.

Between 1990 and 2006 overall rail fuel efficiency had improved by about 21.5%, or about 1.2% per year. There have also been key developments in locomotive technology during the timeframe which include: adoption of electronic controls in all locomotive subsystems; continuing development of the diesel engine, including low-emissions models to meet US EPA Tier 2 requirements for emission standards; development of AC traction systems; locomotive truck and brake improvements; operator’s cab improvements; development of 6,000 hp engines; and hybrid and Genset locomotives. In addition, there have been improvements to non-locomotive technology that can impact fuel efficiency including 286,000 lb. gross weight cars; lightweight car construction; electronically controlled pneumatic brakes; specialized car types; use of distributed power; reduction of rolling resistance through rail lubrication; steerable or radial trucks; and low friction bearings. Some of these developments result in benefits to fuel economy of rail.

Similarly, there have been improvements in the trucking industry that have resulted in increased fuel efficiency. These include tractor and trailer aerodynamic improvements, tare weight reduction, improvements in transmissions and lubricants, and idle reduction technology. Other factors that have improved fuel efficiency for trucks include operational changes such as speed reductions, fuel cost increase, and anti-idling policies.

Twenty three movements were selected and analyzed for the study. Of the 23 movements studied, double-stack trains accounted for 48% rail movements, dry van trailers accounted for 47% of the truck movements. A summary of the findings indicates that rail is more fuel efficient than truck on all 23 movements in terms of ton-miles per gallon. The rail fuel efficiency ranges from 156 to 412 ton-miles per gallon in the study. The truck fuel efficiency ranges from 68 to 133 ton-miles per gallon.

Ratios comparing the fuel efficiency by rail and by truck were calculated for the movements. The analysis shows that the rail-truck fuel efficiency ratio varied by rail equipment type with tank cars resulting in the highest ratio (5.3) and auto rack representing the lowest ratio (1.9). The study also found that truck drayage and intermodal terminal operations account for 7% to 27% of total fuel consumed by intermodal trains. Empty mileage was also taken into consideration in this study. The study concludes that when empty miles are considered, all intermodal movements (double-stack and TOFC) and gondola movements are even more fuel efficient than comparable truck movements. For box cars and covered hoppers, rail is still more fuel efficient than trucks, but the gap between the two modes narrows when including empty miles.

In comparison with the results from the 1991 study, overall, double-stack trains appear to have become more fuel efficient. On the other hand, dry vans and container on chassis are somewhat less fuel efficient now than in the 1991 study, which may be explained by the more realistic representation of truck movements in the 2009 study. These factors can explain the increase in rail-truck fuel efficiency ratios for commodities moved in double-stack trains.

The following criteria were used to identify the competitive movements used in the study analysis:

- Movements that had comparable rail and truck mode shares
- Movements that were representative in terms of freight activity (measured in ton-miles)
- A mix of short, medium and long distance movements
- A mix of different commodities (and thus different equipment types)
- A mix of geographic regions.

The evaluation measures and compares fuel efficiency in ton-miles per gallon and also uses a rail-truck efficiency ratio, which is a ratio between rail and truck fuel efficiency as measured in ton-miles per gallon. The calculation of line-haul fuel consumption considers factors including distance, circuitry, grade profile, speed profile, vehicle characteristics, vehicle weight, and vehicle aerodynamic profile. Rail fuel efficiency also considers short branchline movements. Truck idling was factored into the truck fuel efficiency calculations.

Rail fuel consumption was calculated by two participating railroads using in-house train simulators. Fuel consumption from other movements such as drayage, were added separately. Truck fuel consumption was estimated using the MOVES/PERE model designed by the US EPA and fuel consumption from idling was added in separately.

As noted above, the US EPA is part of a SmartWay Transport Partnership whose goal is to encourage shippers and fleets to reduce air pollution and greenhouse gas emissions through lower fuel consumption. One strategy that is part of the SmartWay program is the use of longer combination vehicles. The US EPA says that, “LCVs are more fuel-efficient, on a ton-mile basis, than typical combination trucks. For example, a Rocky Mountain Double consumes 13 percent less fuel per ton-mile of freight, compared to a typical combination truck. This saves over $8,000 in fuel costs per year. Turnpike Doubles and Triples reduce fuel use per ton-mile by 21 percent, saving over $13,000 in annual fuel costs (Smartway Transport Partnership).”

The Northeast States Center for a Clean Air Future sponsored a study titled, “Reducing Heavy-Duty Long Haul Combination Truck Fuel Consumption and CO_2 Emissions,” (NESCCAF, 2009) that examined available and emerging technologies that could be used to reduce CO_2 emissions and lower fuel consumption from new heavy-duty long haul combination trucks in the United

States in the 2012 to 2017 timeframe. The core of the analysis consisted of a series of modeled simulations to predict the fuel saved by incorporating various combinations of technology and operational measures in new trucks. Vehicle and engine simulation modeling provided detailed information on the acceleration, braking, power, fuel economy, and emissions performance of different heavy-duty vehicle designs, including advanced powertrain designs. A baseline vehicle was specified that had engine, driveline, rolling resistance and aerodynamic characteristics typical of new vehicles at the time. Two simulation models were used to allow the evaluation of various packages of technology and operational measures: GT-POWER for engine cycle simulation and RAPTOR to model the vehicle, including the transmission and driveline. Both models were validated by comparing predicted fuel economy results to actual on-road vehicle fuel economy measurements, or to test cell engine fuel consumption results. The research team believed it was important to measure packages of improvements rather than individual improvements to avoid the possibility of double-counting benefits when assessing multiple options.

The test cycle used in this study was based on the California Heavy-Duty Diesel Truck Drive Cycle. Modifications were made to the California Cycle to make it more representative of nationwide long-haul trucking operations. Specifically, the portion of the cycle involving high-speed driving was increased, the average speed was increased by 8 percent, and two segments of both positive and negative grades were added. Because of these changes, results of the study may not be applicable to short-haul trucking operations.

In addition to a broad variety of technology measures, the study examined fuel consumption and emissions for alternative vehicle configurations as follows:

- Baseline 5-axle tractor-53-foot semitrailer combination with a maximum weight of 80,000 pounds
- 6-axle tractor-53-foot semitrailer combination with a maximum weight of 97,000 pounds
- Twin 28-foot trailer combination with a maximum weight of 80,000 pounds
- Twin 33-foot trailer combination with a maximum weight of 97,000 pounds
- Rocky Mountain Double combination with a maximum weight of 120,000 pounds
- Triple 28-foot trailer combination with a maximum weight of 120,000 pounds, and
- Turnpike Double combination with a maximum weight of 137,000 pounds

Noteworthy in this analysis is the fact that modeling applied to the entire vehicle combination, not just to the engine or truck tractor as in most other studies. The NESCCAF study recognized that operations of the heavier configurations with the same engine as was used on the base vehicle would degrade hill-climbing and acceleration performance. Engines with greater horsepower were tested with some of those configurations. While the more powerful engines increased fuel consumption relative to the base engine by from 4 to 7 percent, the fuel and emissions savings associated with the larger, heavier configurations were still substantial when compared to the baseline vehicle.

3.2 Data Requirements and Sources for Energy and Environmental Analysis

As with modal shift analyses, data requirements to estimate energy consumption and environmental emissions associated with truck size and weight policy changes may vary according to the study scope, objectives and resources. The basic data needed may include the distance assumed to be traveled by the base case and scenario vehicles; characteristics of the highways on which the trucks are operating; and characteristics of the vehicles that affect energy consumption and emissions.

Most past studies of energy and environmental impacts associated with freight transportation have not attempted to estimate the net effects of truck size and weight policy scenarios, taking into account changes in VMT and related fuel consumption and emissions associated with different vehicle classes operating at different weights. Many have simply compared the relative energy consumption of different vehicle configurations and modes assuming single average fuel consumption and emissions levels per unit of travel. Metrics used in those studies often are gallons consumed or grams emitted per ton-mile of travel. More detailed studies such as the NESCCAF study have used specific drive cycles to more fully represent the range of highway conditions that vehicles of interest are operated under, while other studies have simply assumed an arbitrary travel distance without varying the operating environment. The 2000 CTSW Study estimated the changes in VMT for various truck configurations by highway functional class and, based on characteristics of each functional class, estimated fuel consumption and emissions for each functional class. The primary source of information on characteristics of highway functional classes is the Highway Performance Monitoring System database maintained by FHWA based on information supplied by the States. For that study broad averages of characteristics such as grade and traffic characteristics were used as the basis for estimating fuel consumption and emissions.

Vehicle characteristics needed to estimate fuel consumption and emissions also vary according to the objectives and resources available for the study. The most common vehicle characteristic in past truck size and weight studies has been vehicle weight, but increasingly studies are also considering tire rolling resistance and aerodynamic drag in estimates of vehicle fuel economy and emissions. Most of those studies have limited themselves to characteristics of the truck tractor, not the entire vehicle combination. The most sophisticated studies, as reflected by the NESCCAF study, have used models that can account not only for characteristics of the truck tractor, but also the truck trailer(s). Again, most of those studies have not been conducted within the context of truck size and weight policy analysis, but the methods lend themselves to more robust estimates of fuel consumption and energy impacts associated with potential changes in truck size and weight limits.

3.3 Future Research Needs Related to Energy and Environmental Impacts of Truck Size and Weight Policy Options

Significant progress has been made in closing research gaps identified related to energy impacts identified above by Battelle in a working paper prepared for the 2000 CTSW Study (Battelle

1995). Understanding of the effects of tire rolling resistance, aerodynamic drag, and different engines on fuel consumption and CO_2 emissions has improved dramatically as illustrated by recent work by the NESCCAF (2009). Estimating NOx and particulate emissions is still more difficult than estimating CO_2 emissions, but recent regulations to reduce levels of those two pollutants have reduced the severity of environmental problems associated with those pollutants. The ability of compare fuel consumption and emissions of alternative modes has also been significantly improved with studies such as Winebrake (2009) and Comer (2010). Further work remains to reflect findings of these simulation studies into nationwide truck size and weight policy models and databases, but many of the research gaps are being closed.

3.4 Comparison of Findings from Past Energy and Environment Studies

As noted above, many of the studies that have estimated truck fuel consumption and environmental emissions have not been conducted within the broader context of truck size and weight policy analysis and thus have limited information about the net effect of changes in truck size and weight limits taking into account changes in VMT for different vehicle classes and weight groups. Many studies have compared the overall fuel efficiency and emissions of different truck configurations compared to rail and water. Those studies have uniformly found that truck and marine modes are more fuel efficient than trucking. Some studies such as Winebrake (2009) and Comer (2010) have examined fuel consumption and emissions in actual travel corridors where the availability of rail and water may be limited and a combination of trucking and rail or water modes is required. Drayage by truck to and from rail/water facilities reduces the energy and environmental advantage of those modes.

Comparing findings from past studies that have such different purposes and use different metrics is difficult. **Table 5** below shows results from three past studies that have analyzed fuel consumption or emissions for different vehicle configurations. The 2000 CTSW Study analyzed changes in fuel consumption associated with several policy scenarios and reflects net fuel savings taking into account the fuel efficiency of the scenario vehicles and changes in VMT for each vehicle class. Savings ranged from six percent for scenarios involving 6-axle tractor-semitrailers and twin 33-foot trailers to 13 percent and 14 percent for scenarios involving triples and turnpike doubles respectively. It must be noted that triples were assumed to have broad access to origins and destinations. The Northeast States Center for a Clean Air Future study compared the relative fuel efficiencies of different truck configurations to a standard 5-axle tractor-semitrailer. Fuel consumption for each vehicle was estimated for the same drive cycle and results were evaluated in terms of fuel required to haul the same quantity of freight the same distance for each vehicle class. The Wisconsin study is similar to the 2000 CTSW Study in that net fuel savings resulting from shifts of some freight to various scenario vehicles are estimated. Only the aggregate savings are reported so percentage changes in fuel consumption are not available. The greatest savings were estimated for the introduction of a 6-axle tractor-semitrailer with a gross vehicle weight of 98,000 pounds. Much lesser savings were estimated for a heavy single unit truck or a heavy truck-trailer combination.

Table 5. Comparison of Studies that Have Estimated Fuel Economy Differences Among Vehicle Classes

Study	Vehicles and Weights Analyzed k = thousands of pounds	Change in truck VMT (percent)	Change in fuel consumption/
USDOT, Comprehensive Truck Size and Weight Study (2000)	3S3-90k; Twin 33s-124k 3S3-97k; Twin 33s-131k RMD-120k; TPD-148k*; Triple-132k	(11) (11) (23) (20)	(6%)* (6%)* (14%)* (13%)*
USDOT, Western Uniformity Scenario Analysis (2004)	RMD-129k; TPD-129K*;Triple-110k*	(25)	(12.1)
Northeast States Center for a Clean Air Future (NESCCAF 2009)	3S3-97k Twin 33s-97k RMD-120k Triples-120k Turnpike Doubles-137k	NA	(5%)** (10%)** (21%)** (17%)** (25%)**
Wisconsin Truck Size and Weight Study (2009)	Twin 28s-108k 3S4-97k SU7-80k 3S3-90k 3S3-98k SU4-2-98K		240,000 gallons 540,000 gallons 40,000 gallons 450,000 gallons 1,420,000 gallons 60,000 gallons

RMD – Rocky Mountain Double
TPD – Turnpike Double
SU – Single Unit Truck
* Change in scenario fuel consumption/CO_2 emissions
** Difference from base case 3S2

As noted above Comer, et al. (2010) conducted a corridor analysis comparing various indicators of modal performance for truck, rail, and ship. **Table 6** presents some results from that analysis. Performance of the various modes differed significantly for the individual performance measures. The total distance traveled by truck and the total cost of the move was greater for trucks than for the other modes, but the total time to make the move was considerably less. Emissions of CO_2 were greater for trucks, but emissions of NOx and PM10 were less than emissions for the other two modes. The authors point out that the relative results are corridor specific and cannot be generalized to other corridors. The ICF study for FRA bears this out as they found significant variations in fuel consumption by truck and rail depending on the type of equipment used, the commodity being hauled, and other factors (ICF 2009).

Table 6. Comparison of Environmental and Other Factors For Shipments by Truck, Rail, and Ship in the Montreal to Cleveland Corridor

Primary mode	Truck	Ship	Rail
Total CO_2 (kg/TEU)	460	240	190
Total NOx (g/TEU)	1150	4400	3800
Total PM10 (g/TEU)	10	130	130
Total time (hr)	8	42	25
Total distance (mi)	550	510	530
Total cost ($/TEU)	480	400	430

Source: Comer (2010)

3.5 References for Energy and Environmental Impact Analysis

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CHAPTER 4 - TRAFFIC FLOW AND OPERATIONS

Traffic operations are influenced by roadway and traffic conditions along with vehicle characteristics, including size and weight. Heavy vehicles, including trucks, are significantly larger than passenger vehicles and have greater impact on traffic flow and operations. A report prepared in conjunction with the USDOT 2000 CTSW Study identified the following issues as of particular interest to federal policy considerations: passenger car equivalencies, capacity, level of service, and traffic stream costs (Battelle 1995). Larger, heavier trucks could affect the following aspects of traffic operations – maintaining speed on grades; weaving, merging, and changing lanes; highway capacity and level of service; and maneuvering through signalized intersections.

The report notes that traffic engineers use the concept of passenger car equivalencies (PCE) of trucks for analysis and design relating to highway capacity and level of service. PCEs represent the number of passenger cars that would consume the same percentage of a highway's capacity as the truck(s) under consideration.

The Highway Capacity Manual (HCM) has long been an important reference for factors affecting highway capacity, level of service, and traffic operations. The latest version of that TRB report was published in 2010. Heavy vehicles are defined in the HCM as those having "more than four tires touching the pavement". Trucks, buses and recreational vehicles make up the three groups of heavy vehicles. Trucks vary and the operational characteristics depend on the weight of its load and the engine performance. Heavy vehicles adversely impact traffic in two ways as explained in the HCM (Highway Capacity Manual 2010, Chapter 4):

1. They are larger than passenger cars and occupy more roadway space; and
2. They have poorer operating capabilities than passenger cars, particularly with respect to acceleration, deceleration, and the ability to maintain speed on upgrades.

According to the HCM, the second impact is more critical as the inability to keep pace with passenger vehicles can create large gaps that are not easily filled by passing maneuvers. Queues may also develop behind the heavy vehicle, especially on grades, resulting in roadway inefficiencies that are not easily overcome. When downgrades are steep enough to require operation in a low gear, heavy vehicles can impact downgrade movements as well, which also causes gaps and queues.

The HCM presents PCE values that vary as a function of road class, geometry, types of trucks, and percent trucks in the traffic stream. However, the values are not explicitly sensitive to parameters considered in TS&W investigations such as truck weight, length, and configuration.

The HCM identifies the methods for calculating traffic flow quality and accounts for heavy vehicles within the methodology for identifying Levels of Service (LOS). Other studies (Al-

Kaisy, Hall and Reisman 2002, Benekohal and Zhao 2000) have addressed the issue of traffic flow and operation with respect to trucks including other truck size and weight studies.

Carson reviewed the literature on the effects of truck weights and dimensions on congestion, an important aspect of traffic operations (Carson 2011). She developed the following general conclusions based on that literature review:

- Increases in allowable truck size and weight could impact highway congestion through resultant changes in either truck volumes or highway capacity:
  - Heavy truck VMT may either decrease as a result of increased truck capacity or increase in response to lower trucking transport costs.
  - Larger, heavier trucks may be less maneuverable and have less horsepower in relation to their weight, effectively reducing highway capacity.
- With some consistency, increases in allowable truck size and weight were predicted to result in a modest degradation in traffic flow and associated capacity however, anticipated corresponding reductions in heavy truck VMT were predicted to offset these negative impacts in the broader context of highway congestion.
  - Larger, heavier trucks would have inferior capabilities related to speed maintenance on upgrades; traction; and freeway merging, weaving, and lane changing and require increased intersection and passing sight distance.
- Prior studies have been criticized for oversimplifying the complex interactions between trucks and other vehicles in the traffic stream. Changing truck volumes, dimensions, and acceleration abilities will affect other vehicles' driving, acceleration, and braking patterns.

In a 1989 TRB report that examined the potential impacts of providing access for larger trucks a "modest degradation in traffic flow and associated capacity attributable to larger, heavier trucks" were anticipated (TRB 1989). Two vehicle characteristics were largely responsible for the adverse effects: "(1) higher average truck weights that may increase the vehicle weight-to-horsepower ratio, reducing speed and acceleration capabilities and (2) added truck length that challenges passing on two-lane roads and causes delays at intersections as trucks make turning maneuvers. The magnitude of these adverse impacts depends on the volume of larger, heavier trucks in the traffic stream."

TRB initiated a second comprehensive study that considered a series of specific truck configurations—each with lower axle weights but higher GVWs—intended for operation on Interstate and State highway systems (TRB 1990). Four prototype vehicle configurations were examined:

- 7-axle tractor-semitrailer with a 91,000-lb GVW limit and 60-ft length.
- 9-axle double trailer with a 114,000-lb GVW limit and 81-ft length (two 33-ft trailers).

- 9-axle B-train double with similar dimensions as above but with a different coupling arrangement between the two trailers.

- 11-axle double trailer with a 141,000-lb GVW limit

Table 7 summarizes potential impacts of these prototype configurations on various aspects of traffic operations

Table 7 Traffic Operations Characteristics of Turner Trucks Relative to Trucks Replaced

Characteristic	Comparison Between Turner Trucks and Trucks Replaced
Speed on upgrade	Turner trucks, if operated by existing range of engine power, would have lower hill-climbing speed than existing combination vehicles.
Traction ability	Nine-axle Turner double would be similar to existing twin 28-ft trailer truck, whereas the 11- axle Turner double would be slightly poorer. Both Turner trucks would have considerably poorer traction ability than existing tractor-semitrailers.
Passing on two-lane highways	Because of their extra length, prototype nine-axle Turner double would increase passing sight distance for cars passing heavy trucks by up to 7 percent relative to existing tractor-semitrailers.
Freeway merging, weaving, and lane changing	Relative to existing configurations, it would be more difficult for Turner trucks operating with the existing range of engine power to merge, weave, or change lanes. Extra length of Turner trucks would add to the difficulty of these maneuvers.
Freeway exiting maneuvers	Turner trucks, relative to existing combination vehicles, would not affect the ease or the safety of such maneuvers.
Unsignalized intersection sight distance for trucks to cross	Prototype Turner doubles would increase sight distance required by up to 10 percent relative to existing 28-ft twins.
Unsignalized intersection sight distance for trucks to turn	Prototype Turner trucks, if operated with the existing range of engine power, would increase sight distance required because of their lower acceleration capability.
Signal timing	The yellow-phase of traffic signals is already inadequate for existing combination vehicles; the extra length of Turner vehicles would worsen the problem.
Downhill operations	Prototype Turner trucks are not expected to be less safe than existing combination vehicles. Use of retarders and antilock brake systems that modulate foundation and auxiliary brakes would further enhance safety of downhill operations.
Longitudinal barriers	Existing barriers to restrain/redirect vehicles are inadequate for all heavy trucks.
Splash and spray	Extra length of Turner vehicles would increase the duration in which motorists' vision is impaired by the spray; it would not affect the spray intensity, however.

Characteristic	Comparison Between Turner Trucks and Trucks Replaced
Truck blind spots Blockage of view Aerodynamic buffeting	Turner trucks would be no worse than trucks they would replace.

Carson summarizes findings from this TRB study as follows: "According to this study's results, Turner trucks would have inferior capabilities related to speed maintenance on upgrades; traction; and freeway merging, weaving, and lane changing. In addition, Turner trucks would require increased intersection sight distance for trucks to cross and turn at unsignalized intersections and yellow-phase duration in signal timing plans. Other vehicles attempting to pass Turner trucks on two-lane highways would require increased passing sight distance and would be subjected to an increased duration of splash and spray. Other operational characteristics—including freeway exiting maneuvers, downhill operations, the effectiveness of longitudinal barriers, truck blind spots, blockage of view, and aerodynamic buffeting—were predicted to be no different for Turner trucks than other truck configurations currently in use. This study also estimates that the predicted use of Turner trucks would reduce heavy truck VMT by 3.4 percent, potentially offsetting the negative impacts to traffic flow and operations."

Impacts on congestion were estimated in the Minnesota Truck Size and Weight Study (Cambridge Systematics 2006). That study used findings from the 1997 Federal Highway Cost Allocation Study on average added delay per 1,000 PCE VMT on various highway functional classes to estimate changes in delay associated with each truck size and weight scenario and multiplied changes in delay by the value of time to estimate changes in the congestion costs.

Congestion costs associated with the potential introduction of various vehicle configurations were also estimated in the Wisconsin truck size and weight study (Cambridge Systematics 2009). Changes in PCE VMT were estimated for each vehicle configuration and resulting changes in speed were estimated based on speed versus volume functions in the Highway Economic Requirements System model to estimate delay associated with changes in traffic volumes.

The USDOT 2000 CTSW Study analyzed the "passenger-car equivalents" for different truck lengths and weight-horsepower ratios. **Table 8 and 9** illustrate the findings of this study separated by rural and urban highways.

Table 8. Vehicle Passenger Car Equivalents -- Rural Highways (USDOT, Comprehensive Truck Size and Weight Study, 2000.)

Roadway Type	Grade		Vehicle Weight to Horsepower Ratio (pounds/ horsepower)	Truck Length (feet)		
	Percent	Length (miles)		40	80	120
Four-Lane Interstate	0	0.50	150	2.2	2.6	3.0
			200	2.5	3.3	3.6
			250	3.1	3.4	4.0
	3	0.75	150	9.0	9.6	10.5
			200	11.3	11.8	12.4
			250	13.2	14.1	14.7
Two-Lane Highway	0	0.50	150	1.5	1.7	Not Simulated
			200	1.7	1.8	Not Simulated
			250	2.4	2.7	Not Simulated
	4	0.75	150	5.0	5.4	Not Simulated
			200	8.2	8.9	Not Simulated

Table 9. Vehicle Passenger Car Equivalents -- Urban Highways (USDOT, Comprehensive Truck Size and Weight Study, 2000).

Roadway Type	Traffic Flow Condition	Grade	Vehicle to Horsepower Ratio (pounds/horsepower)	Truck Length (feet)		
				40	80	120
Interstate	Congested	0	150	2.0	2.5	2.5
			200	2.5	3.0	3.0
			250	3.0	3.0	3.0
	Uncongested	0	150	2.5	2.5	3.0
			200	3.0	3.5	3.5
			250	3.0	3.5	4.0
Freeway and Expressway	Congested	0	150	1.5	2.5	2.5
			200	2.0	2.5	2.5
			250	2.0	3.0	3.0
	Uncongested	0	150	2.0	2.0	2.0
			200	2.5	2.5	2.5
			250	3.0	3.0	3.0
Other Principal Arterial	Congested	0	150	2.0	2.0	2.5
			200	2.0	2.0	3.0
			250	3.0	3.0	4.0
	Uncongested	0	150	3.0	3.0	3.5
			200	3.5	3.5	3.5
			250	3.5	4.0	4.0

In both rural and urban areas, vehicle length has only minor effects on PCEs. Steep grades have a dramatic impact on PCEs especially for vehicles with high weight to horsepower ratios that cannot maintain their speed on upgrades. Weight-to-horsepower ratios also affect operations in urban areas since vehicles that cannot accelerate quickly adversely affect traffic operations.

The 2000 CTSW Study summarized the effects of large truck characteristics on traffic flow and operations. Impacts on several aspects of traffic operations could not be quantified so estimated impacts were expressed in terms of the direction and magnitude of the impact without numerical estimates. **Table 10** shows those estimated impacts from the 2000 CTSW Study.

Table 10. Summary of Effects of Truck Size and Weight Characteristics on Highway and Traffic Operations (USDOT, Comprehensive Truck Size and Weight Study, 2000).

Vehicle Features		Traffic Congestion	Vehicle Offtracking		Traffic Operations			
			Low Speed	High Speed	Passing	Acceleration (merging and hill climbing)	Lane Changing	Intersection Requirements
Size	Length	- e	- E	+ e	- E	—	- E	- E
	Width	—	- e	+ e	- e	—	- e	—
	Height	—	—	- e	—	—	—	—
Design	Number of units	—	+ E	- E	—	—	- e	—
	Type of hitching	—	+ e	+ E	—	—	+ E	—
	Number of Axles	—	+ e	+ e	—	—	+ e	—
Loading	Gross vehicle weight	- e	—	- E	- E	- E	- e	- E
	Center of gravity height	—	—	- e	—	—	- e	—
Operation	Speed	+ E	+ E	- E	- E	—	+ e	+ E
	Steering input	—	- E	- E	—	—	- E	—

+/- As parameter increases, the effect is positive or negative.
E = Relatively large effect. e = relatively small effect. -- = no effect.

This table shows that in regards to traffic congestion, the speed of large trucks has a large effect compared with length and weight. Issues related to the length of the vehicle include low speed offtracking, passing, lane changing and intersection requirements. The greater the length of a vehicle, and associated wheel base distance, the more offtracking will occur. Vehicles with longer wheel bases must operate at slow speeds and may require crossing lane lines to negotiate sharp turns at intersections, resulting in traffic delay for other vehicles. Larger and heavier trucks require more time and space to make passing and lane change maneuvers, also resulting in traffic delay for other vehicles. Larger vehicles are slower to accelerate to their desired speeds than passenger cars, and require larger gaps in traffic flows in order to change lanes or merge with traffic.

In a study, sponsored by the Association of American Railroads, Roger Mingo used the FRESIM model to estimate PCEs for different types of truck configurations (Mingo 1994). Large numbers of FRESIM runs were made varying the traffic composition and percent trucks in the traffic stream. Regression analysis was used to estimate the relative effect of each vehicle type on traffic speeds simulated in FRESIM compared to the passenger vehicle. Results of the analysis are shown in **Table 11**. The PCEs for doubles and LCVs are higher than estimates developed for the 1997 Federal Highway Cost Allocation Study, but there is insufficient documentation to determine potential reasons for the differences.

Table 11. Passenger Car Equivalents for Different Truck Classes Based on Speeds on Rolling Freeway Sections with Different Percent Trucks in the Traffic Stream

Truck Type	PCE (18%)	PCE (14%)	PCE (10%)
Single-Unit	1.263	1.486	1.526
Medium Load	2.030	2.507	3.666
Full Load	3.254	3.363	4.260
Double-Bottom	5.399	6.143	7.097
Long Combination	10.272	12.368	

The **Western Uniformity Scenario Analysis** was conducted as a follow-on to the USDOT's 2000 CTSW Study to analyze the impacts of lifting the LCV freeze and allowing consistent LCV weights, dimensions and routes among Western States that already allowed LCVs. Various impacts were considered as part of the study, including traffic flow and operations related to LCVs.

The study states that large trucks affect traffic flow due to their size, acceleration, and braking characteristics which can negatively affect the LOS. The study analyzed potential traffic operation impacts in the 13 western States included in the scenario analysis. Much of the same methodology used in the USDOT 2000 CTSW Study was used for the analysis in this report. Substantial improvements in data and some analytical methods had been realized between 2000 and 2004, so the improved information was used. The vehicles analyzed were a twin-trailer configuration with two 48-foot semitrailers and one with 45-foot trailer lengths. In the summary, however, only the impacts of the 48-foot configuration are reported. For the traffic operations analysis, the variables analyzed include traffic delay in million vehicle-hours, congestion costs, low-speed off-tracking, passing, acceleration, lane changing and intersection requirements.

Study assumptions affecting estimates of the impacts on traffic operations include limited networks for LCVs, no LCV operations in congested urban areas, and the use of more powerful tractors on LCVs to maintain typical weight/horsepower ratios. Another factor affecting estimates of traffic operations impacts is the fact that the western States included in the analysis are rural in character – neither California nor Texas which have large metro areas and heavy traffic volumes were included in the study. Taking into account the assumption that some freight will move to the more productive scenario trucks, the traffic operations will not degrade or for some variables may even improve with the Western Uniformity Scenario. It is important to note that the assumption that increased engine power is available for those configurations with increased gross vehicle rates was used. **Table 12** below shows the traffic operation impact and the resulting change using the Western Uniformity Scenario.

Table 12. Western Uniformity Scenario Traffic Impacts (USDOT, Western Uniformity Scenario Analysis, 2004, p. VIII-8).

Impact	2000 (base case)	2010 (scenario)
Traffic Delay (million vehicle-hours)	National Total 3,599*	Small decrease
Congestion Costs ($ million)	National Total $67 billion***	Small decrease
Low-Speed Off-tracking		Degradation (28-30 feet** for turnpike double versus 16 feet for semitrailer)
Passing		Requires operating restrictions.
Acceleration (merging and hill climbing)		Requires sufficient engine power.
Lane Changing		Some degradation due to additional length. (This is counterbalanced by decrease in heavy truck VMT.)
Intersection Requirements		Some degradation due to additional length. (This is counterbalanced by decrease in heavy truck VMT.)

*Computed by Texas Transportation Institute as the aggregate for 68 urban areas (not comparable with
USDOT Comprehensive Truck Size and Weight 2000, Volume III).
**28 feet off-tracking for twin 45-foot TPDs and 30 feet off-tracking for twin 48-foot TPDs.
***Estimated for 75 largest urban areas.

Ingle documents the literature on PCEs dating back to the 1965 HCM (Ingle 2004). The scope of his research was to evaluate PCEs for basic freeway segments for trucks with a broader range of weight-to-power ratios. Such results should make freeway capacity analysis more accurate for mixed vehicle flow with a non-typical truck population. In addition, the effects of high proportions of trucks, pavement type and condition, truck aerodynamic treatment, number of freeway lanes, truck speed limit, and level of congestion were considered. The analysis was conducted using the INTEGRATION traffic simulation model.

Ingle developed the following conclusions based on the results of his research:

1. A truck fleet with multiple weight-to-horsepower ratios performs about the same as the homogeneous fleet assumed in the HCM. However, weight-to-horsepower (wt/hp) ratio was found to significantly affect PCEs – the PCEs for an average weight-to-horsepower

ratio of 112,5 lbs/hp are 22 percent less than the average wt/hp ratio while PCEs for a 175 lbs./hp ratio were 30 percent higher than for the average wt/hp ratio. Ingle notes that 175 lbs/hp represents the 85th percentile of trucks on I-81 in Virginia based on a survey of those vehicles.

2. PCEs for grades longer than 1 mile remain relatively constant so no extension of the HCM values for grades longer than 1 mile is necessary

3. PCEs vary up to the point where trucks make up 60 percent of the traffic stream, but after that point do not vary

4. Pavement type and condition can significantly affect PCEs when trucks account for a small portion of the traffic stream, but there is no impact associated with pavement conditions with higher proportions of trucks

5. PCEs for three-lane segments are lower than PCEs for two-lane segments when trucks are a small proportion of the traffic stream, but this effect is not found at higher truck percentages. Lane restrictions were not found to affect PCE values

6. Setting truck speed limits below speed limits for passenger vehicles increases the PCE value for trucks.

Ingle develops extensions of the PCE values contained in the 2000 HCM to account for these findings.

Al-Kaisy examined factors that contribute to the effect of heavy vehicles on traffic operations and level of service (Al-Kaisy 2006). He notes that two factors are primarily responsible for the effects of heavy vehicles on traffic operations -- their dimensions and their performance. The influence of these factors differs depending on three conditions: terrain, saturated versus unsaturated traffic, and traffic levels for unsaturated conditions. On level terrain the influence of heavy trucks is mainly attributed to their dimensions, but in rolling and especially mountainous terrain the vehicle's performance becomes important. As traffic volumes rise, heavy vehicle performance becomes an increasingly important influence on traffic operations.

Al-Kaisy notes that there has been a long-standing debate about the definition of passenger car equivalency due in part to the loose treatment of the subject in different editions of the Highway Capacity Manual (HCM). The 1965 HCM defined equivalency as “the number of passenger cars displaced in the traffic flow by a truck or a bus, under the prevailing roadway and traffic conditions.” Average speed was used as the criterion to derive PCE factors for freeways and multilane highways. The 2000 HCM defines PCE as “the number of passenger cars displaced by a single heavy vehicle of a particular type under specified roadway, traffic and control conditions.”

Recent work has noted that PCEs may vary depending on the type of traffic impact being studied. Van Aerde and Yagar note that “passenger car equivalents have generally been assumed to be similar for capacity, speed, platooning, and other types of analysis. This notion appears to be incorrect and is perhaps one of the main sources of discrepancies among the various PCE studies.” (Van Aerde 1984)

The synthesis of previous truck size and weight studies and issues conducted for the 2000 CTSW Study identified other issues related to traffic operations. Heavy trucks can affect traffic operations when merging, weaving and changing lanes. “TS&W considerations can have important effects on these maneuvers because of their effects on gap size requirements and acceleration performance. Little is known about the effects of different percentages of trucks with variable size and weight on the ability to merge and change lanes in traffic streams of varying speed and density.” The report noted that “ramp junctions and weaving areas are so site-specific as to their geometric design and operating speeds that simulation of those specific intersections is probably the only analytical method that will give reasonable precision.”

Truck operations can also affect traffic operations at intersections. Larger and/or heavier vehicles can affect traffic operations at intersections in many ways including: (1) requiring extra time to accelerate up to the posted speed limit; (2) altering sight lines; (3) increasing sight distance requirements; (4) altering signal timing requirements. Many of these traffic disruption effects can be mitigated with the use of powertrains that ensure acceleration performance equivalent to or better than current vehicles.

4.1 Data Requirements and Sources for Traffic Operations Analysis

Estimating impacts of truck size and weight policy options on traffic operations requires several sources of data. One important data element is an estimate of the passenger car equivalents of the vehicles to be analyzed. The HCM generally does not contain the level of detail required to differentiate impacts of the scenario vehicles, and since the scenario vehicles being analyzed typically are not in widespread use, it is difficult to estimate the PCEs empirically. Thus most recent studies have relied on the use of simulation models such as FRESIM to estimate PCEs for the vehicles in question. As noted above, PCEs vary according to many factors including grades, vehicle length, weight-to-horsepower ratios, percent trucks in the traffic stream, and levels of congestion. Past studies generally have used different values for some or all of these factors and have come up with somewhat different PCE values for the various vehicle configurations. Differences can also be attributed to the use of different traffic simulation models with different model assumptions.

Impacts of changes in the PCE VMT (PCE weighted VMT) on delay and congestion costs depend on highway characteristics for each highway class (distribution of numbers of lanes, grades, traffic volumes) and relationships between speeds and volumes for the different types of highway. Highway characteristics may come from a number of sources depending on the scope of the study, but in recent nationwide studies they have come from the Highway Performance Monitoring System maintained by FHWA based on data reported by the States. Speed-volume relationships for different types of highways typically come from the *Highway Capacity Manual*. In each version of the HCM, there typically are some adjustments to the speed-volume relationships based on more recent data and analytical techniques.

Estimates of changes in traffic volumes by vehicle class, operating weight, and highway class typically come from the mode shift analysis used in the particular study. Past studies have varied widely in the level of traffic detail used.

4.2 Future Research Needs Related to Traffic Operations Analysis

As noted above, many vehicle classes of widespread interest in truck size and weight policy studies are not in widespread use or are not used at all in the U.S. This makes it difficult to calibrate and validate traffic simulation models that have been used to date as a primary tool for estimating impacts of larger, heavier vehicles on traffic operations. Care must be taken when extrapolating results of studies in other countries to ensure that results are not applied to quite different operating environments that may exist in the U.S. Several traffic operations impacts have been only qualitatively assessed in past Federal studies. Research might be undertaken to validate those qualitative assessments through discussions with officials in States where larger vehicles currently are operating or some actual data collection. As with international studies, care must be taken to ensure that the operating environment is clearly related to any impacts that are observed.

4.3 Comparison of Findings from Past Traffic Operations Analyses

As with impacts of modal shifts, energy consumption and environmental emissions, it is difficult to directly compare past studies because the vehicle classes and operating contexts vary as well as the metrics used to express impacts. **Table 13** compares changes in delay and congestion costs estimated in four past studies. The 2000 CTSW Study was the only study that expressed changes in percentage terms. The largest reduction in delay and congestion costs was for the triples scenario, but the magnitude of the reduction is largely due to a study assumption that triples would not be limited to a designated network of Interstate and other freeways but would be allowed to travel to origins and destinations. The study report recognizes that this degree of access would be unlikely in many parts of the country if triples were to become legal. The Western Uniformity Scenario Analysis did not quantify congestion impacts, but indicated that a slight decrease in congestion could be expected.

Two State studies estimated congestion cost savings associated with allowing various truck configurations to operate. Minnesota analyzed four different truck configurations, a 6-axle tractor semitrailer operating at 90,000 pounds, a 7-axle tractor-semitrailer with a maximum gross vehicle weight of 97,000 pounds, an 8-axle twin trailer combination with a gross vehicle weight of 108,000 pounds, and a 4-axle single unit truck with a maximum weight of 80,000 pounds. These vehicles were all assumed to meet Federal truck size and weight limits which meant that all but the heavy single unit truck were prohibited from operating on the Interstate System. Congestion cost reductions were greatest for the two tractor-semitrailer combinations followed by the twin trailer combination and the single unit truck.

Wisconsin analyzed six candidate truck configurations as shown in **Table 13**. Two scenarios were analyzed for each configuration, one which prohibited the scenario trucks from using the Interstate System and one in which they could operate on Interstate highways. In both cases the tractor-semitrailer combination with the greatest gross vehicle weight reduced congestion costs the most. As in Minnesota the single unit truck and truck trailer combination reduced congestion costs the least. Allowing the heavier vehicles to operate on the Interstate System was found to reduce total congestion costs significantly more than limiting vehicles to non-Interstate highways. Baseline congestion costs were not reported in the study so it was impossible to estimate the percentage reduction in congestion costs as was done in the 2000 CTSW Study.

Table 13. Changes in Congestion Delay and Costs Estimated in Three Previous Truck Size and Weight Studies

Study	Vehicles and Weights Analyzed k = thousands of pounds	Change in Delay	Change in Congestion Costs
USDOT, Comprehensive Truck Size and Weight Study (2000)	3S3-90k; Twin 33s-124k 3S3-97k; Twin 33s-131k RMD-120k; TPD-148k*; Triple-132k Triple-132k	(0.2%) (0.2%) (3%) (8%)	(0.2%) (0.2%) (3%) (8%)
USDOT, Western Uniformity Scenario Analysis (2004)	RMD-129k; TPD-129K*;Triple-110k*	Small decrease	Small decrease
Cambridge Systematics, Minnesota Truck Size and Weight Project, Final Report, (2006)	3S3-90k; 3S4-97k; 3S3-2-108k; SU4-80k		($180,000) ($230,000 ($80,000) ($50,000)
Cambridge Systematics, Wisconsin Truck Size and Weight Study, 2009 (non-Interstate only)	3S3-90k 3S3-98k 3S4-97k 8-axle twins-108k SU7-80k 6-axle truck-trailer-98k		($920,000) ($1,890,000) ($850,000) ($490,000) ($80,000) ($60,000)
Cambridge Systematics, Wisconsin Truck Size and Weight Study, 2009 (Interstate and non-Interstate)	3S3-90k 3S3-98k 3S4-97k 8-axle twins-108k SU7-80k 6-axle truck-trailer-98k		($3,400,000 ($11,000,000) ($4,100,000) ($1,650,000 ($90,000) ($260,000)

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APPENDIX B: MODAL SHIFT PROJECT PLAN/SCHEDULE

B.1 Objective

The *U.S. USDOT Comprehensive Truck Size and Weight Limits Study – Volume II: Modal Shift Comparative Analysis* will provide estimates of the changes in a base case of modal freight activity under existing Federal truck size and weight regulations that might be expected to occur as a result of changes in Federal truck size and weight regulations. In order to estimate these changes in freight activity, FHWA will first establish a base case using commodity flow data for each mode being considered in the analysis. The base case will reflect modal shares of total base-year freight volumes and vehicle miles of travel (VMT) by truck configuration by commodity and origin-destination under current Federal truck size and weight limits. After the base case is established, the team will consider several scenario cases of changes in Federal truck size and weight regulations. The scenario cases will be determined by the USDOT. For each of the scenarios considered, the team will estimate changes in freight transportation activity, including:

- Shifts of truck freight tonnage from the base case configuration to a scenario configuration. These shifts are referred to as intra-modal shifts.
- Shifts of truck travel from lower class highways to higher class highways due to easing of more restrictive Federal size and weight regulations in the base case than State regulations applicable off the Interstate System.
- If a scenario's parameters include a more restricted highway network for the alternative configuration(s) being examined, shifts of truck travel from lower class highways to higher class highways due to shifts in truck volumes to scenario configurations that are allowed only on the more restricted highway network than base case configurations.
- Shifts of freight tonnage transported by a non-highway mode (e.g., rail, water) in the base case to truck in a scenario. These shifts are referred to as inter-modal shifts.

The shifts described above will be reflected in a change from the base case to the scenario case in the volume of truck travel (measured as VMT) and the distribution of that VMT by truck configuration, highway functional class, and gross vehicle weight. These changes in trucking activity, along with any commensurate changes in rail, water, and other freight activity, will be used in other tasks to estimate scenario impacts on highway safety, traffic operations, infrastructure wear and tear, energy consumption, the environment, and on the economy. Specifically, impacts will be estimated as the difference between impacts from base case movements by various freight modes and impacts from scenario case activity.

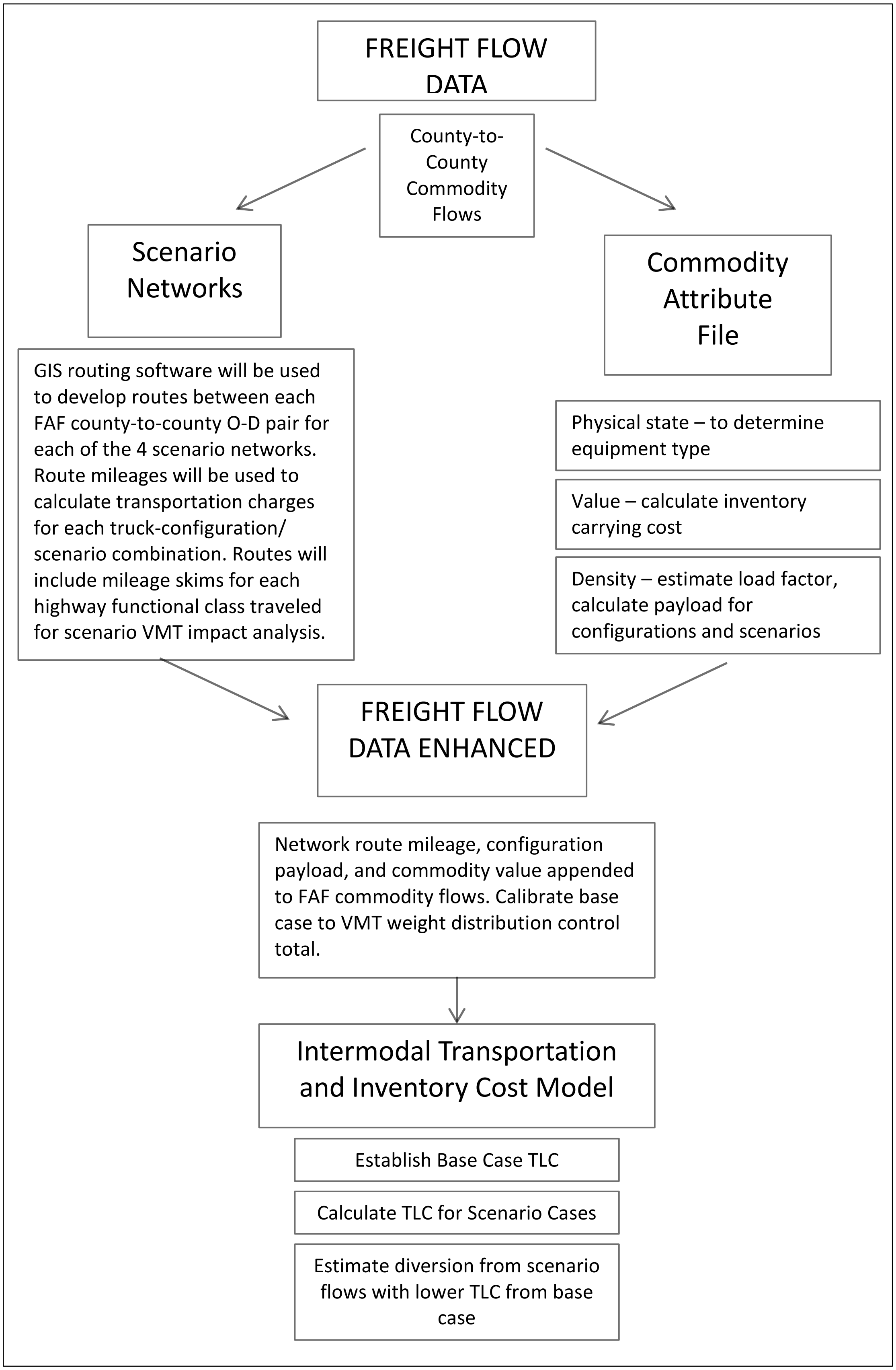
B.2 Approach

Each case (the base case and each scenario case) will be analyzed through a series of subtasks to estimate total logistics costs for each shipping alternative being considered for each freight flow in the analysis. The subtasks include:

- Determining freight flow data by commodity, origin-destination, and mode;
- Estimating shipment size for each shipping alternative;
- Establishing truck flow assignment to various highway networks;
- Assigning freight to highway equipment, including: body type, configuration, and payload;
- Calculating total highway travel by body-type, configuration, highway network and vehicle operating weight;
- Calculating base case transportation costs from origin to destination for each shipping alternative;
- Calculating base case non-transport logistics costs for each shipping alternative;
- Calculating scenario transportation costs from origin to destination for each shipping alternative
- Calculating scenario non-transport logistics costs for each shipping alternative
- Assigning freight to shipping alternatives based on total logistics costs; and
- Evaluating base case and scenario case freight volumes on highway infrastructure, safety, environment, energy consumption, and the economy.

Figure B1 on the following page illustrates the mode shift methodology. Each step is explained in detail following **Figure B1**.

Figure B1: Mode Shift Methodology



Subtask: Freight Flow Data

The team will use commodity flow data for truck from Federal Highway Administration's (FHWA) Freight Analysis Framework (FAF) database, disaggregated to the county level by Oak Ridge National Laboratory.

Subtask Detail: Non-Highway Mode Freight Flows

The 2014 CTSW Study will consider shifts from rail and water modes to highway modes. USDOT will evaluate the suitability of FAF data for these two modes for use in the study. Rail moves in the FAF data are based on the Surface Transportation Board (STB) Public Use Waybill file, but the Carload Waybill Sample contains more accurate route distances. Comparisons will be made to determine how significant the difference is and the implications for estimates of modal shifts.

Rail traffic will be analyzed as two distinct modes in considering the potential for diversion to alternative truck configurations and scenarios being considered for this study: 1) rail carload traffic and 2) rail intermodal traffic. Truck and rail competition for carload traffic and intermodal traffic are very different. Carload traffic requires rail sidings for loading and unloading at both origin and destination, while intermodal traffic is picked up and delivered by highway at both ends of the move, with truck and rail serving as substitutes for the line-haul portion of the move. Carload capacities are generally several multiples of what a single truck configuration can haul and often consist of multiple cars or make up an entire "unit" train of 100 cars or more. Intermodal shipment sizes are similar, if not identical, to highway shipment sizes – the intermodal box will move on both rail and highway networks, and its utilization for hauling freight is interchangeable with highway-only equipment. The commodities that move by rail carload are generally lower value, bulk commodities (e.g., coal, non-metallic minerals, ores) or commodities requiring specialized equipment and handling (e.g., chemicals). The commodities that move by highway are generally higher value and are more sensitive to the on-time service performance advantage that highway has over rail carload.

Rail carload traffic will be further broken down into two analysis methodologies – one for traffic serviced by short-line/regional, Class II, and Class III rail carriers and one for the Class I rail carriers. Again, truck and rail competition are very different depending on the size of the rail network and customer base. Smaller, short-line, and regional railroads serve a small number of customers over short distances, either hauling products to a Class I rail network connection, or hauling limited, often specialized commodities over short distances. The rail network of small carriers are usually lines that were once part of a Class I rail network, but could not be operated profitably under the cost structure of the Class I Rail Carriers. Trucks compete more effectively with these small rail operators for the short-haul, specialized-commodity traffic, where the loss of a single customer could force the rail operator out of business. The Carload Waybill Sample includes some but not all moves by Class II and Class III rail carriers. Shipments included in the

Waybill will be analyzed using the ITIC model, but shipments not in the Waybill will be analyzed more qualitatively based on available information.

For analysis of mode shifts of rail intermodal traffic, the team will develop, in consultation with USDOT's Federal Railroad Administration (FRA), an expected drayage distance that will act as a proxy for the truck movements for each origin and destination to a rail intermodal terminal.

Waterway traffic to be considered for the study will be developed in consultation with USDOT's Maritime Administration (MARAD). Short-sea shipping potential to reduce highway truck travel is currently being considered for public funding. A 2006 case study of four short-sea shipping corridors developed transportation rates for short-sea shipping that may be relevant for this study in estimating its market share potential with existing Federal size and weight limits and how that potential would change under a hypothetical increase in size and weight limits. The team will evaluate the development of short-sea shipping rates used in this study for its applicability to the current study.

Subtask Schedule and Product: The study team will develop a complete freight flow database for truck, rail, and water by December 21, 2013. This database will be in an appropriate format for use in subsequent tasks that require these data.

Subtask: Freight Flow Assignment to Highway Network

The assignment of freight flows to highway networks provides the mileage base for estimating the transportation costs of moving freight from origin to destination by truck. Truck rates are determined by distance, shipment weight, equipment type, and special handling requirements of the commodity. These rates are generally quoted in dollars/cents per mile.

The project statement of work stipulates that four highway networks are to be analyzed in the study: the Interstate System, the National Highway System, the Principal Arterial System and NHS Intermodal Freight Connectors, and the National Truck Network. The team anticipates that at least some longer combination vehicles (LCV) included in the analysis will be restricted to higher classification highways (i.e., those with limited access and egress) resulting in more circuitous LCV routings than for some freight flows in non-LCVs traveling on a denser highway network. For those configurations limited to higher-order systems, scenarios will assume that staging areas will be necessary to allow those vehicles to assemble and disassemble for entry to and exit from the restricted network. The capital and operating cost of staging areas will be incorporated into the freight rates for those configurations that require the facilities.

Because infrastructure design standards and traffic operations vary across highway functional classifications, information on functional classification of truck travel in each case analyzed is necessary to assess the impacts of truck travel on safety, infrastructure, traffic operations, energy consumption, and the environment required for the 2014 CTSW Study.

Subtask Detail: County-to-County Flows

There are some 3,000 county level jurisdictions in the United States, giving rise to a potential of some 4.5 million unique (unordered) county pairs. An unknown fraction of these pairs have freight flows between them. For each of the four highway networks included in the analysis, network routes will be generated for each county pair for which a freight flow exists in the data. In those cases where a restricted LCV network is not continuous between an origin and destination (O-D) county pair, the off-network mileage for a continuous route over unrestricted network links will be accumulated separately from the restricted LCV network mileage. This off-network mileage will be used in estimating the costs of off-network transportation to move the multiple trailers of an LCV as single trailers over the unrestricted network links.

The network routings between counties will be developed using GIS software – e.g., Transcad, ESRI. For each route generated, the output will include, at a minimum, the identification of each of the two counties in the pair and the miles of travel along the generated route by highway classification.

Subtask Schedule and Product: The study team will complete highway network assignment for base case and scenario traffic moving between each origin and destination pair by December 21, 2013.

Subtask: Freight Assignment to Highway Equipment

The assignment of freight to highway equipment is a key component of determining transportation costs. Specialized equipment, such as tankers, has higher capital costs and higher empty-to-loaded mileage ratios than general freight equipment, such as dry vans. These differences in capital costs and operating characteristics result in differences in the per-mile rates charged by operators of specialized equipment.

Like differences in equipment body types, differences in equipment configurations also affect capital costs and operating characteristics. A twin or triple LCV configuration requires the additional capital of the added trailer(s) and may require a change in driver operations to efficiently move trailers between staging areas and off-network points of pickup/delivery.

Another important consideration in assigning freight to highway equipment is the payload weight. Weigh-in-motion (WIM) data show that over seventy percent of travel by five-axle tractor-semitrailer configurations is at gross vehicle weights of 70,000 lbs. or less, even though this configuration is legal up to 80,000 lbs. At the other end of the spectrum, over 8 percent of five-axle travel is at gross vehicle weights in excess of 80,000 lbs. The WIM distributed VMT data for every State, including States without grandfathered limits in excess of the 80,000-lb. Federal weight limit, and those that allow travel at weights above 80,000 lbs. Some of this traffic is operating legally under State permit and some is operating illegally. The process of assigning freight to highway equipment in the base case will include calibrating the result to approximate existing WIM data for VMT and weight distributions by vehicle configuration.

Subtask Detail: Cargo-Unit Body Type

The discontinued Vehicle Inventory and Use Survey (VIUS) provides the best available source of information on the operating characteristics of trucks by equipment type. The survey included information on commodities carried, typical payload weight, number of axles, cargo-unit body type, number of trailers, and empty miles. Although the survey was last conducted in 2002, because Federal size and weight limits have generally remained unchanged since then, the information is still useful and will be used in assigning commodity types by cargo-unit body type.

Subtask Detail: Configuration

Much of the truck travel in the United States uses configurations that do not fall within the parameters of traffic that serves as a candidate for shifting from one truck configuration to an alternative configuration being considered in the study; for example, three-axle tractor-semitrailer and three-axle single-unit truck configurations operating at Federal Bridge Formula limits currently have higher legal weight alternative configurations options and don't utilize them. In addition, several of the alternative configurations being analyzed in the 2014 CTSW Study already operate in some areas of the country.

In developing the 2014 CTSW Study's base case, FHWA will assign traffic from the commodity flow data used in the study to yield distributions of truck VMT by configuration and functional class that approximate existing data for truck VMT distributions. Base case traffic that is designated as having a higher weight-legal alternative configuration in the base case—e.g., three-axle tractor-semitrailer, three-axle single-unit truck at 60,000 lbs. or less in the base case—will not be evaluated for a shift in scenario cases. Likewise, traffic assigned to one of the alternative configurations in the base case will not be considered for a configuration shift to a lower cube or weight configuration in scenario cases, although it may be assigned a higher payload weight in the base case configuration in the scenario case than in the base case.

Subtask Detail: Payload

In conjunction with the assignment of commodity flow volumes by configuration and functional class described above, the team will develop commodity specific payload factors for each equipment type (cargo body type and configuration). Commodities are commonly classified as "weigh-out" or "cube-out," as determined by whether they fill the cubic capacity of the cargo carrying unit before reaching the maximum legal gross vehicle weight (cube-out) or reach the legal gross vehicle weight limit before filling the cubic capacity of the cargo carrying unit (weigh-out). Commodities with densities of 13 lbs. per cubic foot or greater, which is most commodities, are technically weigh-out commodities for a five-axle tractor-semitrailer (3-S2) configuration limited to 80,000 lbs. gross vehicle weight, yet national weight distributions developed from weigh-in-motion data for 3-S2s indicate that over 70 percent operate at 70,000 lbs. gross vehicle weight or less. About a fourth of those loads weigh less than 35,000 lbs. and can be attributed to empty backhauls. The balance represents partial loads and “floor-out” commodities that fill the floor space but not the full interior height of the trailer. Payload factors will represent the typical payload of the commodity as a percentage of the maximum payload the configuration can legally carry. These factors will vary by cargo body type, where bulk equipment types generally utilize a higher percentage of maximum allowable payload than general freight equipment. The maximum payload will be calculated as the Federal weight limit for the configuration minus the vehicle tare weight. Commodity specific payload factors will be scaled by commodity density and payload information from the VIUS.

Subtask Detail: Freight Assignment to Highway Equipment

Commodity-specific characteristics of the three freight assignment parameters described above, cargo-unit body type, configuration and payload, will be catalogued in a database of commodity attributes. The commodity attribute database will include VIUS information on the distribution of commodity VMT by equipment configuration, cargo-unit body type and typical payload, as well as commodity density and value characteristics.

Truck freight volumes from the commodity flow data will be “loaded” to base case configurations according to commodity attributes. This process will generate the number of truck trips between origins and destinations necessary to transport the commodity flow data volumes. Applying route mileages between origins and destinations generated in the highway network assignment subtask to the truck trips data will provide an estimate of truck VMT by configuration, distributed by gross vehicle weight. This result will be calibrated to approximate existing WIM data by configuration through iterative adjustments to commodity attribute configuration and payload values. This process will likely necessitate applying a distributed range of commodity-specific payload factors to achieve the WIM target weight distributions. Existing WIM data indicates that 8.5 percent of 3-S2 VMT operates at weights in excess of 80,000 lbs. The iterative calibration of the freight assignment subtask will result in a similar percentage of base case 3-S2 VMT operating above the nominal Federal weight limit, as well as other configurations operating above nominal Federal limits.

Subtask Schedule and Product: The study team will develop a complete assignment of the various types of commodities to different types of highway equipment and operating weight distributions by January 8, 2014.

Subtask: Calculation of Base-case Transportation Costs

Truck rates are determined in large part on the mileage between origin and destination, the equipment used to transport the shipment and any special handling requirements to transport the commodity. FHWA will evaluate and update as necessary for application to this 2014 CTSW Study the market truck rate data used by FHWA in mode shift estimates in previous size and weight analyses.

The team will consult with FRA and MARAD to develop transportation rates for base case rail and waterway traffic that will be analyzed for potential diversion to highways as a result of changes to Federal truck size and weight limits. The team expects to draw on FRA's experience in developing rail rates for rail-competitive truck traffic in their Inventory Transportation and Inventory Cost (ITIC) analyses of truck-to-rail diversion of tolling and positive train control, as well as MARAD's work on developing rates in its 2006 report of four case studies.

Subtask Detail: Market Truck Rate Data

The truck rate data FHWA obtained for the Strategic Multimodal Analysis project consists of single trailer dry-van truckload rates between points in the United States as assigned to 113 market areas. These rates reflect lane imbalances where they exist, with head-haul/outbound rates higher than back-haul/inbound rates. FHWA will investigate the possibility of obtaining a more current database of truckload market-based freight rates, but if unable to do so, will utilize the existing data.

FHWA will update, if necessary, and supplement truckload market-based freight rates to reflect price differentials between dry-van trailers and specialized trailers (e.g., flatbed, tanker, refrigerated), differences in empty-to-loaded ratios between dry-van and specialized trailers and the additional capital cost of multi-trailer configurations.

FHWA will map origins and destinations of the commodity flow database to their respective markets in the truck rate database. The output of this subtask will be a database of truck rates for each origin-destination pair differentiated by trailer type and configuration.

Subtask Detail: Calculation of Base-case Transportation Costs

Base-case transportation costs for truck volumes will be calculated by application of the truck rate database to the base-case truck loads developed in the Freight Assignment to Highway Equipment subtask.

Base-case transportation costs for traffic on other modes that would potentially divert to highway modes under increased Federal truck size and weight regulations will be developed collaboratively with FRA and MARAD. The costs developed for these modes will be used to develop total logistics costs for the rail or waterway move that will be used for comparison against truck total logistics costs in determining the mode selected in scenario cases.

Subtask Schedule and Product: The study team will develop a complete base case transportation cost estimate for each mode and each origin-destination pair by January 15, 2014.

Subtask: Calculation of Base-case Non-Transport Logistics Costs

Non-transport logistics costs are those costs associated with the ownership of inventory. They include inventory carrying costs, storage, loss, damage and obsolescence. The team will utilize FHWA's Inventory Transportation and Inventory Cost model (ITIC) to estimate these cost.

<u>Subtask Detail: Application of ITIC to Base Case</u>

The team will review the various versions of ITIC model, including the ITIC-IM version developed by FRA for estimating diversion from highway to rail, and the version used in FHWA analysis for the Western Governors LCV Uniformity and Strategic Multimodal Analysis studies. FHWA will incorporate updated and improved coding and algorithms developed by FHWA and FRA into the version used previously for FHWA studies in order to perform a complete analysis of mode shifts resulting from the use of the alternative truck configurations being considered in the 2014 CTSW Study. The logic for estimating shipper responses to small changes in total logistics costs associated with hypothetical changes in truck configurations will receive particular attention.

Once the ITIC model is updated, FHWA will load the base-case freight volumes into the model, including the transportation costs estimated in the previous subtask. The non-transport logistics costs estimated in ITIC will be added to the transportation costs to establish base case total logistics, against which total logistics costs for alternative configuration scenarios will be assessed for intra- and inter-modal shifts of traffic.

Subtask Schedule and Product: The study team will develop a complete base case non-transport logistics cost estimate for each commodity movement by each mode between each origin-destination pair by January 22, 2014.

Subtask: Calculation of Scenario Transportation Costs by Highway for Each Alternative Configuration Being Considered

Each of the alternative configurations to be evaluated in the study increases the cargo carrying capacity of trucks and is expected to decrease the transportation costs per ton of freight per mile traveled. For some of the alternative configurations, the cost reduction per ton per mile of travel will be partially offset by more circuitous routing on higher classified highways than the base case configuration traveled, as well as assembling and disassembling LCVs at staging areas for access to and egress from restricted LCV highway networks.

Calculation of scenario costs will follow the same process used to calculate base case costs: assignment of commodity flow to equipment type, configuration, and payload. Equipment assignment in the scenario is the same cargo-body assigned in the base case. The configuration assignment is determined by the alternative configuration(s) being considered in the scenario.

Subtask Detail: Scenario Payload

Payloads for each scenario will be calculated from the payload factors developed for the base case described previously. For scenarios with single trailer alternative configurations – e.g., 88,000 lbs., five-axle tractor-semitrailer – mode shifts from base case configurations to be considered will be limited to traffic that approaches the existing 80,000-lb. Federal weight limit. For example, a base case five-axle tractor-semitrailer with a gross vehicle weight of 50,000 lbs. will not be considered for mode shift to the 88,000-lb., five-axle tractor-semitrailer alternative configuration.

For multi-trailer configurations, payloads will capped at the lower of the weight limit allowed on the alternative configuration and the weight increase from the base case configuration that is proportional to the increase in cubic capacity from the base case configuration. Using the five-axle tractor-semitrailer example from above, the approximately 30,000-lb. payload would be legal on each trailer of a turnpike double configuration of two trailers having the same length as the base case trailer. In this case, the scenario payload would be twice that of the base case.

Subtask Schedule and Product: The study team will develop a complete transportation cost estimate for movements of each commodity by each mode (including scenario vehicles) between each origin-destination pair by January 22, 2014.

Subtask: Calculation of Scenario Non-Transport Logistics Costs

The process for calculation of non-transport logistics costs for scenario cases is identical to the process for calculation of those cost for the base case described previously. Once calculated, scenario non-transport logistics costs are added to transportation costs to generate total logistics cost for the scenario case being evaluated. These costs are stored in the ITIC model for comparison with base case total logistics costs.

Subtask Schedule and Product: The study team will develop complete non-transport logistics cost estimates for movements of each commodity by each mode (including scenario vehicles) between each origin-destination pair by January 29, 2014.

Subtask: Freight assignment to mode based on total logistics costs

Once base case and scenario case total logistics costs have been calculated, the two costs can be compared and a decision made as to which mode the traffic would use in the base case and in the scenario case. For each case, truck volumes are summarized by configuration, highway functional class and gross vehicle weight. As previously discussed, the base case result is calibrated to yield approximate VMT and weight distributions of existing available data. Scenario truck volumes are similarly summarized, providing scenario VMT distributed by highway functional class and weight.

Example: Mode Shift VMT illustrates an example of VMT analysis output results for three configurations by functional class, base and scenario cases, and weights. Mode Shift VMT are estimates of travel levels produced as an output of modeling the effects of various scenarios applying the ITIC Model. These VMT results are summarized in Tables B1 and B2.

TABLE B1: MODE SHIFT EXAMPLE - VEHICLE CLASS SUMMARY

Vehicle Class	VMT				
	Base Case	Share of Total (%)	Scenario	Share of Total (%)	% Change on VC
CS5	120,265,894,135	98.0%	74,184,983,133	64.6%	-38.3%
CS6	2,292,533,161	1.9%	13,978,668,642	12.2%	509.7%
DS8+	147,162,257	0.1%	26,652,177,084	23.2%	18010.7%
Total	122,705,589,552	100.0%	114,815,828,859	100.0%	-6.4%

TABLE B2: MODE SHIFT EXAMPLE - FUNCTIONAL CLASS SUMMARY

Highway Functional Class		VMT				
		Base Case	Share of Total (%)	Scenario	Share of Total (%)	% Change on FC
Rural	Interstate	37,662,793,121	30.7%	37,595,485,996	32.7%	-0.2%
	Other Principal Arte	20,897,225,593	17.0%	21,054,972,705	18.3%	0.8%
	Minor Arterial	6,601,138,274	5.4%	3,959,971,528	3.4%	-40.0%
	Major Collector	5,123,182,147	4.2%	3,364,531,007	2.9%	-34.3%
	Minor Collector	887,335,589	0.7%	591,820,452	0.5%	-33.3%
	Local	1,893,623,455	1.5%	1,245,718,620	1.1%	-34.2%
	All Rural	73,065,298,179	59.5%	67,812,500,309	59.1%	-7.2%
Urban	Interstate	23,509,176,295	19.2%	24,299,090,663	21.2%	3.4%
	Freeways/Express	9,124,769,856	7.4%	10,139,976,699	8.8%	11.1%
	Other Principal Arte	11,852,073,966	9.7%	8,818,538,124	7.7%	-25.6%
	Minor Arterial	4,104,113,392	3.3%	2,964,334,609	2.6%	-27.8%
	Collector	679,537,266	0.6%	500,792,419	0.4%	-26.3%
	Local	370,620,600	0.3%	280,596,036	0.2%	-24.3%
	All Urban	49,640,291,374	40.5%	47,003,328,550	40.9%	-5.3%
Total Rural and Urban		122,705,589,552	100.0%	114,815,828,859	100.0%	-6.4%

Subtask Schedule and Product: The study team will develop complete base case and scenario case mode assignments, output VMT by configuration, highway functional class and weight group by February 5, 2014.

Subtask: Evaluation of Base-case and Scenario Truck Volumes on Certain Factors

The estimated modal shifts resulting from the introduction of the alternative configurations as illustrated in **Example: Mode Shift VMT** will impact multiple factors related to highway transportation, including safety, pavement costs, bridge costs, energy consumption, the environment and the economy. Some of these impacts are likely to be positive and some are likely to be negative. Safety, pavement, and bridge impacts are analyzed in Tasks V.A, V.B, and V.C of the 2014 CTSW Study. Impacts on energy consumption, environmental impacts, cost responsibility, and productivity are included in this task.

Subtask Detail: Evaluation of Fuel Consumption, Air Quality and other Environmental Impacts

Fuel consumption of the various truck configurations will be evaluated at different operating weights in developing an MPG/GVW profile for each configuration. The U.S. Environmental Protection Agency (EPA) Greenhouse Gas Emissions Model (GEM) open source vehicle modeling and simulation software will be used to perform the fuel economy and emissions analysis, using GEM vehicle models to represent each configuration to be evaluated. The vehicle models will be calibrated with drag and rolling coefficients measured in previous test programs.

Outputs of the analysis will include the load specific (per ton-mile) fuel consumption, carbon dioxide (CO2), nitrous oxides (NOx), sulfur oxides (SOx), volatile organic compounds (VOC), and particulate matter (PM) emissions for each vehicle configuration. FHWA will develop a spreadsheet model that will estimate the impacts of these outputs on the entire vehicle fleet. The spreadsheet model will apply the vehicle fuel consumption and emissions rates per vehicle-miles-traveled to a set of weighted traffic profiles. These profiles will represent the vehicle composition of the fleet, the VMT and the duty cycles traveled by these vehicles. This information will be provided to the fuel and emissions modeling team by the mode diversion team and will represent the different fleet configurations and travel patterns determined in each scenario considered by the diversion team. The end result will be a model capable of reporting system wide changes to fuel consumption and emissions as a consequence of adopting different standards on truck size and weight.

Data from FRA's recent report, *Comparative Evaluation of Rail and Truck Fuel Efficiency on Competitive Corridors*, will be used to estimate changes in energy and emissions associated with potential diversion of traffic from rail to truck associated with the various scenarios.

To evaluate the noise pollution occasioned by the alternative configurations, FHWA will assess the suitability of the noise analysis from the 2000 CTSW Study for this project. The FHWA Office of Planning, Environment and Realty will consult on the suitability of Traffic Noise Model (http://www.fhwa.dot.gov/ environment/noise/traffic_noise_model/) for assessing the difference in noise pollution from the change in VMT and vehicle configurations in the traffic mix resulting from the introduction of the alternative configurations.

Subtask Schedule and Product: The study team will develop a complete evaluation of the fuel consumption and air quality impacts of each scenario by March 1, 2014.

Subtask Detail: Evaluation of Traffic Operations Impacts

The analysis of impacts of the scenario vehicles on traffic operations will closely follow the analysis of traffic operations impacts in the 2000 CTSW Study. Passenger car equivalents will be estimated for each scenario vehicle based on a review of recent literature. As in the 2000 CTSW Study, congestion delays will be estimated using traffic simulation models reflecting operations on different types of highways. The truck VMT by truck configuration and weight that is estimated to result from scenario configurations is substituted in the traffic delay model for the base case truck VMT, and the change in highway operating speed by functional class is calculated to obtain the change in delay for all highway users. This change in delay in vehicle hours is then multiplied by a time value to obtain the change in congestion costs.

Longer, heavier trucks also affect other aspects of traffic operations such as passing, acceleration (merging and hill climbing), lane changing, and intersection requirements. The magnitude of these impacts is too site-specific to model quantitatively on a nationwide basis. Impacts will be discussed qualitatively with an emphasis on factors that affect the magnitude of impacts compared to base case vehicles.

Subtask Schedule and Product: The study team will develop a complete evaluation of traffic operations impacts of each scenario by March 1, 2014. This will include quantitative estimates of changes in congestion-related delay as well as qualitative assessments of how scenario vehicles would affect other aspects of traffic operations.

Subtask Detail: Evaluation on Cost Responsibilities

Detailed assessments of changes in the cost responsibility for pavement and bridge improvement costs associated with the various scenarios are included in other tasks. Cost responsibility estimates from those tasks along with other quantitative and qualitative information developed in this study on costs attributable to different vehicle classes will be summarized in this subtask. This will not constitute a comprehensive highway cost allocation study, but will provide a broad overview of how costs associated with the operations of vehicles analyzed in the various scenarios are attributed to different vehicle configurations and weight groups.

Subtask Schedule and Product: A complete evaluation of the cost responsibility of the various scenario vehicles for changes in pavement and bridge costs will be developed by March 7, 2014. Summaries of the impacts of scenario vehicles on safety, traffic operations, energy consumption, emissions, and other environmental factors will also be included to present an overall picture of the relative impacts of each of the scenario vehicles.

Subtask Detail: Evaluation on Freight Transportation Costs

The team will evaluate the change in Total Logistics Costs as estimated by ITIC and its transportation and non-transportation components. Based on past studies, the largest impact on transportation costs will be on traffic currently moving by truck. The team will summarize the changes in transportation costs and non-transportation logistics cost for the base case and each scenario analyzed, and report changes in costs for each scenario case in total and separately by the base case mode of the shifted traffic. In the case of traffic diversions from the rail mode, the evaluation will include the ability of the railroads to cover the lost contribution of diverted traffic to network fixed costs and the secondary effects of additional diversions of rail traffic due to rate increases necessary to cover that lost contribution, or rail line abandonment where the remaining traffic base cannot support fixed network costs. Analysis of these impacts on the railroads will be similar to that conducted for the 2000 CTSW Study. FRA staff will be consulted to determine if methods used in the 2000 CTSW Study need refinement.

Primary diversion on the short-line/regional rail operator will be further assessed as to secondary effects of viability of the operator to cover fixed costs of the network with remaining customer-base/business. The team will rely on short-line rail industry expertise for this assessment.

Limited rail-to-rail competition in some long-haul rail carload traffic markets in the Class I segment of the analysis allows railroads to price their service above what they would be able to charge if competition for the traffic existed. In these markets, competition from the increased productivity offered by the 2014 CTSW Study's alternative configurations may put downward pressure on rail rates. Traffic in these markets will be assessed for potential reduction in rail rates, but generally will be assumed to be retained by the railroad.

Subtask Schedule and Product: The study team will develop a complete evaluation of changes in total freight logistics costs associated with each scenario vehicle will be developed by March 1, 2014.

Subtask Detail: Impacts on Economic Productivity

The team will evaluate the effects of changes in Federal truck size and weight limits on the productivity of different parts of the freight transportation industry. The discussion will address direct and indirect costs and benefits of the size and weight changes, how those costs and benefits are quantified, and the net direction of impacts when the various factors are considered together. This analysis will be based primarily on an assessment of industries that would benefit the most if scenario vehicles were allowed to operate and the magnitude of the reduction in total logistics costs those industries might realize. The team will provide a breakout of industries most able to benefit from the alternative configurations and, to the extent possible, the geography of the benefits and the costs of operating those vehicles. The analysis will show the relative benefits and costs of the various scenarios but will not constitute a comprehensive benefit-cost analysis of any individual scenario.

Subtask Schedule and Product: The study team will develop an evaluation of impacts of each scenario on economic productivity with different sectors of the economy by March 7, 2014.

B.3 Task Data Needs

The methodology for the modal shift analysis establishes base case and scenario case modal freight activity using the Intermodal Transportation and Inventory Cost (ITIC) model. The ITIC uses costing algorithms to estimate the total logistics costs of freight by alternative transportation modes. Data requirements for the model include:

- *Comprehensive freight flow data*, which is annual commodity flow volumes between origins and destinations. The FAF3 database will be the source of commodity flow data. The Oak Ridge National Laboratory is disaggregating the data to provide county-level origin-destination data for the commodities and modes included in the FAF. The impact analyses to be conducted in the study require detailed origin and destination locations; i.e., county-to-county flows. Disaggregate flows are necessary to properly assign scenario configurations to the highway networks to which they will be restricted. The **Example: Mode Shift VMT** illustrates how truck freight will shift across configurations, highway functional classes and gross vehicle weights from a base case analysis to a scenario analysis. The VMT distributions output from the mode shift analysis will provide the inputs for the 2014 CTSW Study's analyses for infrastructure, safety, traffic operations, energy, and environmental impacts.
- *Network route miles*, which is defined as mileage by highway functional class for each scenario network analyzed. Highway networks include the National Truck Network as defined in 23 CFR Part 658; **Example: Mode Shift VMT**; the Principal Arterial System and National Highway System Intermodal Freight Connectors; the National Highway System as designated and in use September 1, 2012; and the Interstate System as designated and in use September 1, 2012. The team will use GIS software (e.g., Transcad, ESRI) to generate route miles between each origin-destination pair for each truck configuration being analyzed. Mileage between O-D pairs may differ by configuration if certain configurations are assumed to be prohibited on certain parts of the highway system.
- *Commodity attributes*, which include density (pounds per cubic foot); value (dollars per pound); handling requirements (e.g., refrigerated, hazardous). FHWA's existing values for commodity density will be reviewed using available sources, such as the National Motor Freight Classification, if available, and industry contacts. Commodity values will be derived from 2007 Commodity Flow Survey (CFS) value and tonnage data. Commodity values calculated from the 2007 CFS will be mode-specific; that is, the value of a commodity hauled by truck will be calculated as the total commodity value hauled by truck divided by the tonnage volume hauled by truck. Each mode hauling the given commodity will similarly

have a mode-specific commodity value calculated. The reason for calculating mode-specific commodity values is the lack of specificity in the CFS commodity groupings, which allows for a broad range of commodities within a single CFS commodity group. Most CFS commodity groups are assigned a higher value per pound for products moved via truck than those moved via rail; for example, the value of "Articles of Base Metal" transported by truck in the 2007 CFS was $1.32/pound, while the value transported by rail was $0.41/pound. Commodity value affects inventory carrying costs, one component of the non-transportation logistics costs that will affect shipper mode choice in the diversion analysis.

- *Freight rates*, which are truck rates from the market rate database. The study team will obtain market-based truck rate data either through purchase from a vendor, such as TransCore DAT, or by updating FHWA's 2006 truck rate database to analyze year price levels. Rail rates will be developed with Federal Railroad Administration (FRA) input based on rates in STB's railroad waybill sample. Waterway rates will be developed with MARAD input based on their rate development for the 2006 report, *Four Corridor Case Studies of Short-sea Shipping Services*.
- *Equipment costs and operating characteristics* will be obtained from publicly available and industry sources. Information on new equipment prices will be collected from truck and trailer manufacturers, dealers, and purchasers. The study team will use industry contacts to obtain this equipment pricing information. Price information for truck-tractors at horsepower ratings necessary to maintain speed for the configurations being analyzed and trailer prices for dry-van, flatbed, refrigerated, tanker, and dry-bulk cargo bodies will be collected. Empty/loaded ratios by equipment type will be estimated from the 2002 VIUS to develop rate differentials from dry-van rates for other equipment types.

Table B3 summarizes data sources for the modal split analysis and methods for bring those data to the 2011 analysis year.

Table B3. Modal Shift Data Requirements and Sources

Data Need	Data Source	Method for Bringing Data to 2011 Analysis Year
Commodity Flow Data	2007 county-to-county FAF	Expand by factors applied to FAF3 database at FAF regional level
Network Route Miles	2011 National Highway Planning Network	No expansion necessary
Truck Payloads	2002 VIUS	No expansion necessary
Commodity Value	2011 FAF	No expansion necessary
Truck Rates	TransResearch International	Trucking – General Freight Producer Price Index
Rail Rates	STB Confidential Waybill	No expansion necessary
Equipment costs	Trucking industry	No expansion necessary
Empty-loaded ratios	2002 VIUS	No expansion necessary

APPENDIX C: INTERMODAL TRANSPORTATION AND INVENTORY COST MODEL

C.1 Introduction

The Intermodal Transportation and Inventory Cost (ITIC) is a computer model for performing policy analysis of issues concerning long haul freight movement, such as modal diversion or the assessment of economic benefits associated with changes in transportation policy or infrastructure. The model replicates the decision-making tradeoffs made by a logistics manager in selecting the mode and shipment size used to re-supply a company's inventory of a particular product. The implications of making alternative choices are assessed in terms of both modal choice and in dollars and cents.

C.2 About The Program

ITIC was developed to estimate the diversion potential generated by a change in the transportation levels of service or price that would likely be caused by improvements in transportation infrastructure, transportation operations, or government policy. It can also be used to calculate estimates of the economic benefits associated with such a change. The ITIC model is a disaggregate demand model. The model chooses the transportation alternative with the lowest total logistics cost. This process is repeated for a large number of disaggregate observations from a representative sample of shipper movements. The model summarizes the statistics on the analyzed sample to estimate mode share and travel demand.

The ITIC model was first developed in 1995 for the U.S. Department of Transportation's *Comprehensive Truck Size and Weight Study* (2000 CTSW Study). The model has undergone improvement over the years, but has remained in continuous use since its development. The ITIC model is used in the 2014 CTSW Study to estimate traffic diversion from existing truck configurations to alternative truck configurations, and to estimate the diversion of railroad traffic to the same potential vehicle configurations.

This documentation describes the ITIC model logic used for the comprehensive truck size and weight study mandated under MAP-21. The 2014 CTSW Study estimates shifts of highway freight and rail freight to trucks with alternative configurations (i.e., increased weight limits, increased cubic capacity, or increases in both weight and cubic capacity). The base-case control vehicles from which traffic shifts occur are five-axle tractor semitrailer (the control single) and five-axle twin 28-foot trailer (the control double), each with a GVW of 80,000 lbs. The alternative truck configurations and their associated gross-vehicle weight limits are five-axle tractor semitrailer at 88,000 lbs. (scenario 1); six-axle tractor semitrailer at 91,000 lbs. (scenario 2) or 97,000 lbs. (scenario 3); five-axle twin 33-ft. trailers at 80,000 lbs. (scenario 4); seven-axle triple trailers at 105,500 lbs. (scenario 5); and nine-axle triple trailers at 129,000 lbs. (scenario 6). These size and weight specification were chosen for analytical purposes only. They do not reflect weights or sizes that FHWA believes are necessarily appropriate. Other vehicle configurations could also be tested, but the user would have to supply the attributes of those configurations required by ITIC. Those attributes are described in this documentation.

The technical documentation will discuss the methodology and data utilized by the ITIC model. The ITIC model can provide policy information assessing diversion to alternative truck configurations or rail intermodal as measured against a conventional five-axle tractor 53-foot semitrailer combination or a five-axle twin 28-foot trailer combination.

The ITIC Model Methodology

The ITIC Model uses theoretical and empirical foundations with a long history of development that has covered more than 36 years.[11] The methodology has been used in dozens of policy studies by both government and the private sector examining changes in infrastructure, transportation operations, pricing policy, government policy, and possible advances in technology. It will be useful therefore, to describe the underlying economic theory which serves as the theoretical basis for the model, the diversion model itself, the model components and organizational structure, the databases used as input, and the processes which are used to prepare the data.

Model Overview

The model was designed as a discrete choice model for use with disaggregate freight movement databases. The approach used in the ITIC freight diversion model is based on an earlier mainframe model—the Translog Shipper Cost Model—developed by a research team at the Massachusetts Institute of Technology (MIT) Center for Transportation Studies,[12] which has served as the conceptual design for later models. The most notable of these is the Intermodal Competition Model (ICM) employed by the Association of American Railroads for analyses of policy issues of significance to the railroad industry. While both the ITIC and ICM are discrete choice models, the ITIC and ICM differ in their approaches to the probability that a given commodity flow moves by the transport mode being analyzed. ITIC assigns all moves to the transportation alternative having the lowest total logistics cost, while the ICM is based on a continuous probability model of mode choice estimated from observed mode shares in freight markets. Where real-world transportation mode choice decisions are made primarily on differences in the logistics costs included in ITIC, ITIC would be expected to produce reliable estimates of modal shifts. This would most likely be the case for long-run truck-to-truck modal shifts after shippers and carriers have had the opportunity to adjust equipment and distribution patterns to reflect cost and other operational differences between equipment allowed under

[11] Roberts, Paul O., and J.R. Ginn, Stockout Costs in Inventory Management, Harvard Business School Working Paper, 71-9, April, 1971.
[12] Roberts, Paul O., *The Translog Shipper Cost Model*, MIT Center for Transportation Studies Report No. 81-1, U.S. Department of Transportation University Research Program, Cambridge Massachusetts, June, 1981.

previous size and weight limits and equipment allowed under new truck size and weight limits. To the extent that factors not accounted for in the logistics costs included in ITIC influence potential shifts between rail and truck, ITIC may not be as accurate in estimating rail-to-truck mode shifts. Significant effort would be required to develop a nationwide model that reflected the influence of these other factors. This was beyond the scope of the current project.

This overview will present the theoretical basis for the model, a description of the conceptual framework within which the model system resides, and a brief review of the functions of the logistics cost module.

Theoretical Basis for the Model

Economic theory treats transportation just like any other factor used in production. The problem is that it is different, not only in terms of its nature, but also in terms of its impact on each of the other inputs. The theory of the firm is based on the assumption that each firm minimizes the costs required to produce a given quantity of output. Transportation, though only one of the factors of production, is different in that it is not consumed directly, but is a service used only in processing other inputs or outputs. If transport costs are excessive, this results in higher costs for those inputs that require transport, which in turn, results in a higher cost for the delivered product.

The neoclassical approach used by economists in modeling the behavior of shippers who face competing modes is typified by the work of Friedlaender and Spady,[13] who begin with the observation that truck and rail transportation are only two of many inputs used by the firm in producing its basic products. In their choice of inputs they attempt to select that set which maximizes profits, using more of one input and less of another. Transportation is then, according to the neoclassical approach, just another input. The firm values each input in terms of its marginal contribution to profits.

To implement the neoclassical approach requires information not only on the transportation expenditures made by the firm, but also on all of the other inputs, including land, labor and capital. Further, this approach requires that one know all of the inputs for a particular industry and their roles in the production process. Implementing the neoclassical approach as an everyday decision analysis tool becomes unworkable without gross oversimplification. It is therefore not practical for our purposes here, though it does shed light on the manufacturing tradeoffs that are possible and the role of transportation in the process.

[13] Friedlaender, A.F. and R.H. Spady, *Hedonic Rates and the Derived Demand for Freight Transportation*, Center for Transportation Studies, Massachusetts Institute of Technology, Cambridge, MA, 1977.

Other models of freight demand have been explored in the literature. In 1988, a Transportation Research Board Study of freight demand[14] summarized the models and the freight flow data that are generally available to practitioners in this field. None of these has achieved prominence for a variety of reasons, the most important of which is that many are aggregate models. Chiang,[15] in his doctoral dissertation, provides an explanation of the problems that are associated with most of these aggregate models:

> *Most of the existing freight models are correlative rather than explanatory and completely insensitive to changes in transport level-of-service measures. This is due to a number of factors; first, the data limitations. Data which can be used to undertake a careful estimation of disaggregate behavioral freight demand model are almost nonexistent. Thus, researchers in the past have been constrained to either piecing together useful aggregate data to estimate an aggregate demand model* [16] *or to using shipper surveys to estimate very limited shipper choice models.* [17]
>
> *A second limitation comes from the fundamental difficulties which most researchers have experienced in attempting to apply economic theories of derived demand to freight demand analysis without making unattractive simplifying assumptions. One frequently used assumption is constant transport cost. That is, the freight rate is assumed not to be influenced by the quantity shipped. This makes the model policy insensitive to changes in the transportation level-of-service. In fact, in practice freight rates are a decidedly decreasing function of shipment size. There are clearly economies to the shipper to large shipment sizes.*
>
> *Finally, the true cost of transport should include inventory costs as well as tariff charges which results from the logistics management process and are thus also a function of shipment size.*

A second approach taken by economists and other transportation researchers is to assume that the inputs required in the production process are those already observed moving in the transport system. The traffic departments of most firms routinely record individual records concerning these shipments. As Chiang points out "It is clear that the firm is the basic decision-making unit in freight transportation." These records kept by the firm include bills of lading, carload waybills and truck freight bills. Each is an indication of the use of a product in the production process of a manufacturer, or the distribution process of a wholesale distributor, or a retail merchandiser. Different suppliers, modes, or shipment sizes are possible alternatives to the observed

[14] Jack Fawcett, Associates, *Transportation Demand Forecasting*, Transportation Research Board Special Report, 1988.
[15] Y.S. Chiang, *A Policy Sensitive Model of Freight Demand*, PhD Dissertation, Department of Civil Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts, 1979.
[16] Examples include, Morton (1969), Tihansky (1972), Wang and Epstein (1975) and Sloss (1971).
[17] For examples see articles in *Mathematica* by, Miller (1972), and in (1969), and Watson et al. (1974).

movement, but the use of the product as input to the firm's production process is taken as fixed. This does not seem an unreasonable assumption over the short term.

Freight demand models of this second type have been reported on by Roberts, Chiang and Ben Akiva;[18] Winston;[19] and others. The philosophy underlying the diversion component of these models is that the receiver is a rational economic decision maker who attempts to minimize the total cost of acquiring the inputs he needs for production; shipping them to the place he needs them in the process, storing them until their use, and protecting the company against possible shortages during the process. In short, the receiver attempts to minimize total logistics costs for the delivered product. This involves not only the selection of the mode of transport to be used, but also the selection of the supplier of the product, the choice of inventory control system, the location of warehouses and the firm's overall strategy for serving the market. The process is too complex to address in detail at this point, however, the basic theoretical foundation of the model described here is based on this concept.

Applications of This Family of Models

These findings have been incorporated into modal choice models used in a number of freight policy studies.[20] [21] One such model, the Intermodal Competition Model,[22] has been used by the Association of American Railroads to investigate the potential diversion from rail that would occur if longer combination vehicles were allowed to operate on the Nation's Interstate Highway System. In addition to the 2000 CTSW Study cited earlier, the U.S. Department of Transportation has used the ITIC model to assess rail-to-truck and truck-to-truck diversion in the Western Uniformity Scenario Analysis, a regional truck size and weight scenario requested by the Western Governors' Association[23] and FRA's analysis of the economic benefits of positive train control.[24]

[18] Paul O. Roberts, Moshe Ben Akiva, M. Terziev, and Y.S. Chiang, *Development of A Policy Sensitive Model For Forecasting Freight Demand*, M.I.T. Center for Transportation Studies, CTS Report 77-11, Cambridge, MA, April 1977.
[19] Winston, Clifford, *Mode Choice in Freight Transportation*, Department of Economics, University of California, Berkeley, CA 1978.
[20] Roberts, Paul O., with Mark Terziev, James Kneafsey, Lawrence Wilson, Ralph Samuelson, Yu Sheng Chiang, and Christopher Deephouse, *Analysis of the Incremental Cost and Trade-Offs Between Energy Efficiency and Physical Distribution Effectiveness in Intercity Freight Markets*, MIT Center for Transportation Studies, Report CTS 76-14, Cambridge, MA, November, 1976.
[21] Roberts, P. O. with Tom Brigham, and Carol Miller, *An Equilibrium Analysis of Selected Intercity Freight Markets: Truck with Double Trailers vs. TOFC Shuttle Trains*, MIT Center for Transportation Studies Report CTS 77-25, Cambridge, MA, December, 1977.
[22] The Intermodal Competition Model was programmed for the AAR by an outside contractor from a model design developed by Dr. Paul O. Roberts and described in *The Translog Shipper Cost Model* Op. Cit., 1981.
[23] FHWA, *Western Uniformity Scenario Analysis*, Washington, DC, 2003.
[24] Federal Railroad Administration, *Study of the Benefits of Positive Train Control*, 2004.

Model Development for the MAP-21 Comprehensive Truck Size and Weight Study

Prior ITIC analyses have used Excel workbook versions of the model logic. Because Excel is limited to approximately 1 million records, which would not accommodate the disaggregated data required for the 2014 CTSW Study, statistical programing software packages were used for the analysis. Equations from existing Excel versions of ITIC, including: ITICV22 (1/25/2001 – 2000 CTSW Study); ITIC_2006 (4/7/2006 – Western Uniformity version); ITIC_5000 (3/15/2010 – developed to process smaller sample for quick turnaround analyses) were reviewed for logical consistency across the various versions. After verification of consistency with the logic appropriate for this study, the Excel workbook equations were written into World Programming System code and then translated to the free open-source R-language statistical programming language software to provide no-cost access to software capable of processing the code.

Variables Affecting Choice of Supplier, Shipment Size, and Mode

The factors influencing a shipper's choice of mode are complex and highly interdependent. They involve tradeoffs between the cost of transportation and overall transit time and delivery reliability, but there are more subtle underlying factors.[25] Research reveals that the principal decisions in this mode selection process are those that affect the receiver of the goods rather than the shipper. Typically, the receiver is the buyer of goods, the shipper is the seller and the ownership of the goods is usually transferred legally at the time the shipment is loaded onto the conveyance. Thus, the shipper is typically the receiver's "agent" in the process and it is his wishes that are honored in the size of shipment and the choice of mode. It is therefore appropriate to view the process as involving a single decision-maker—the shipper/receiver.

The most important tradeoffs involve the annual use of a product by the receiver. High annual use of a product allows the receiver to order large replacement shipments and to take advantage of the low transport costs afforded by economies of scale in shipping associated with large shipment sizes.[26] High value of the product imposes a penalty to ordering more than can be readily used by tying up capital in inventory. Excess inventory can be avoided by ordering product more frequently in smaller shipment sizes. Small shipment sizes carry their own penalties. Ordering is a costly process. Smaller shipment sizes typically carry high unit cost of transportation, and if the shipment size is smaller than a full vehicle load, the load must be picked up at the origin by the freight carrier and consolidated before shipment, then deconsolidated and delivered at the destination end. Most LTL, less than truckload, trucking, parcel carriers and airfreight systems perform consolidation/deconsolidation of smaller

[25] Roberts, Paul O., *Factors Influencing the Demand for Freight Transport*, CTS Discussion Paper 8-75, MIT Center for Transportation Studies, Cambridge, Massachusetts, August 1975.
[26] Roberts, P.O. and A.S. Lang, *The Tradeoffs Between Railroad Rates and Service Quality*, Report 78-12, MIT Center for Transportation Studies, Cambridge, Massachusetts, May 1978.

shipments into full vehicle loads. The consolidation and deconsolidation processes are also expensive, sometimes exceeding the cost of line haul transportation.

Other variables can also play an important role. The density of a product influences the choice of vehicle either by loading “heavy,” in which case **payload** is important, or loading “light,” in which case **cube** is more important. Shelf life influences choice of mode by placing a premium on transit time, where longer travel time leads to less time available on the grocer’s shelf before the product spoils. Loss and damage may lead to a need for emergency shipments. Many variables turn out to be important to the process.

Tradeoffs Made By the Shipper/Receiver

Most of these variables affecting the choices of the receiver have been incorporated into the ITIC Model. The program develops the tradeoffs that would be made by a receiver who is attempting to minimize the total logistics costs associated with maintaining an inventory of the product for use in manufacturing or wholesale trade. The variables are used to develop each of the individual cost factors listed on the right hand side of the figure above. They include the type of receiver, variables that describe the product, information on the current mode of transport and potential new modes and the attributes of the product being carried.

These variables are used to write equations for each of the components of the receiver’s total logistics costs as a function of the principal choice variables (i.e., choice of supplier, choice of mode, and choice of shipment size). Total logistics costs can be expressed in cost per unit, cost per hundredweight or annual cost. Transport charges are added to logistics costs to give the total transportation and logistics cost of the strategy. If different suppliers are considered, with different purchase costs, the total delivered cost per unit or per hundredweight is given. Most receivers will select that strategy with the minimum total delivered cost. This program can be used to examine those circumstances under which one mode will be chosen over other modes.

Truck-to-truck diversion involves decisions made by carrier management as to what equipment to use to accomplish a particular movement. By contrast, rail-to-truck, or truck-to-rail diversion involves a decision by the shipper/receiver to use another entirely different mode of transport. This “between modes” type of decision is more complex, involving the evaluation of tradeoffs in equipment availability, transit time and reliability of delivery, freight loss and damage experience and the size of the potential shipment and its suitability for movement on the mode in question. The shipper’s rationale for making these decisions must be modeled if these tradeoffs are to be evaluated properly.

Cost of Movement to the Receiver

In the model, the person responsible for making the modal decision can be viewed as attempting to select that mode and shipment size which for a particular origin to destination movement will minimize the total logistics cost of the goods being shipped to the receiver. Demand for transportation service by a particular mode may grow or shrink in response to changes in service or cost, depending on its impact on the individual shippers' own business and the other alternatives available. However, the model assumes that all of the product used annually will move by one of the alternatives.

In the model these key variables may be grouped into three major groups:

1. Shipper/receiver attributes
2. Commodity attributes
3. Transport attributes

As described earlier, the most important variable appears to be one of the shipper/receiver attributes, the annual use of the product by the receiver. Clearly, rail as a mode is uniquely capable of handling larger individual shipments than truck. The typical carload can handle shipment weights up to 200,000 lbs. or more, while a maximum single unit truckload payload is around 50,000 lbs. Rail carload shipments of 100 tons are routine, and multi-car shipments of 1,200 tons or more can be handled on the same bill of lading. Unit trains moving as much as 10,000 tons (20 million lbs.) are also common. By contrast, if a shipper must take a 200,000-lb. shipment in order to use rail (instead of the 20,000-lb. shipment he would like to take), it could result in thousands of dollars of unwanted inventory cost. Shipper modal choice behavior, then, depends heavily on the amount of product used annually.

Commodity attributes are also important determinants of shipper behavior. The product being shipped determines the loading and handling requirements as well as the maximum size of shipment that can be accommodated in a given piece of equipment. These variables include:

- Density
- Value per pound
- Shelf life
- Typical packaging

The relevant product data are appended to the individual movement observation in the input data prepared by the user for input into the model. The product data represent averages developed by FHWA and FRA for use in mode choice modeling.

Variables describing the transport attributes of the modes under consideration have also proven to be important. These include:

- Transit time
- Reliability
- Loss and damage experience

These and other variables are incorporated into a "shipper's utility function" within the model. Models for estimating level of services attributes are included in the ITIC model. The obvious choice for the shipper's utility function is the "total logistics cost" associated with the ordering, transport, inventory, and use of the product being shipped. Total logistics cost is the item that the shipper is attempting to minimize when he selects one mode of transportation over another or one shipment size over another.

The components included in the shipper's total logistics cost function include:

- Ordering cost
- Capital carrying cost in transit
- Capital carrying cost in inventory
- Warehousing cost
- Loading and unloading cost
- Safety stock carrying cost
- Cost of loss and damage claims

These variables (along with a few parameters and descriptive variables) allow the total logistics costs of acquiring, shipping and storing the product to be computed by the model.

Selecting a Source of Disaggregate Data

To perform an analysis using the ITIC model, one begins by identifying potential freight movements that will be impacted by the policy change under study. If the question that is being addressed is the ability of a new intermodal service to attract existing truck moves, the disaggregate data base should be a representative sample of individual truck moves. If, on the other hand, the policy question under study is how much diversion of rail traffic is likely to occur if new, larger trucks are allowed on the roadway, the disaggregate data base should be a representative sample of rail movements. The data to be used, therefore, depends on the policy question that is being addressed. The source of potential diversions to another mode or shipment size should be used as the disaggregate sample.

Rail Carload and Intermodal Data

The Surface Transportation Board's Carload Waybill Sample (STB waybill) contains a sample of waybill shipping documents from all U.S. railroads that terminate a minimum of 4,500 revenue carloads annually. Sampling rates vary by method of reporting, manual and computerized, and the number of carloads on the shipping document. Sampling rates range from 1 percent to 20 percent for manual submissions and from 2.5 percent to 50 percent for computerized submissions. Data fields from the waybill sample provided for use in this study included:

- Record serial number
- Intermodal service code
- Rebill code
- Intermodal equipment flag
- Nominal car capacity (not used)
- AAR equipment type
- Expansion factor
- Four-digit STCC code (commodity classification and hazmat classification)
- Carloads
- Tons
- Intermodal units
- Short-line miles
- Total route distance
- Revenue
- Variable cost
- Origin county FIPS
- Destination county FIPs
- Car ownership (rail or private – not used)
- Intermodal equipment owner mark (analyzed, not used)
- Short line RR flags (originating, terminating, both, junction frequency, analyzed, not used)

Truckload Movement Data - The Freight Analysis Framework

FHWA's Office of Freight Management and Operations sponsors the Freight Analysis Framework (FAF), a derivative database of the commodity flow survey data collected by the Bureau of the Census. FAF data includes tonnage and value commodity flows between 123 geographic regions of the United States by transport mode. For this study, FAF truck flows were disaggregated to the county level to allow for detailed highway network assignment.

FAF county-to-county truck tonnage volumes were assigned to truck configuration and cargo body type using information from the 2002 VIUS. The VIUS data were analyzed by commodity, vehicle configuration, cargo body type and primary operating area (as a proxy for length of haul) to allocate FAF volumes to trucks. Table C1 shows the overall tonnage allocation by vehicle class and length of haul category.

Table C1. FAF Tonnage Allocation by Vehicle Class

Vehicle Class	< 100 Miles	100 to 200 Miles	> 200 Miles	Total
Single Unit Truck	32.6%	3.4%	1.1%	16.7%
Single Unit Truck pulling Trailer	5.6%	3.0%	1.3%	3.7%
3 & 4 Axle Tractor Semitrailer	4.3%	4.8%	0.9%	3.3%
5 Axle Tractor Semitrailer	41.5%	64.2%	89.6%	61.1%
6 Axle Tractor Semitrailer	5.9%	7.1%	1.8%	4.9%
7 and more Axle Tractor Semitrailer	1.6%	3.2%	0.0%	1.4%
5 Axle Double	4.3%	9.9%	3.8%	5.4%
6 or more Axle Double	4.3%	4.5%	1.3%	3.4%
Triple	0.0%	0.0%	0.2%	0.0%
Total	100%	100%	100%	100%

Commodity Attributes

The ITIC model uses two commodity attributes in its computations. These are the density, measured in pounds per cubic feet, and commodity value, measured in dollars per pound. In the 2000 CTSW Study, commodity density and value were read into the model from lookup tables. Density was used in the estimations of truck payload weight and storage space requirements. As described in the payload section of this documentation, density is no longer used to determine payload. And as described in the truckload movement data section, commodity value for this study was part of the FAF database used.

Annual Use of the Product

Establishing the annual level of use of a product by the receiver is one of the most problematic factors in running the ITIC model; however, we know that annual use is clearly the most important determinant of shipment size.

For truck movements or intermodal movements, the annual use is typically much smaller than for shipments by rail carload. Annual uses of less than about 250,000 lbs. per year (about five truckloads) will almost certainly go by truck, especially if the product is expensive, or the product has a short shelf life. Above 1 million lbs. per year, the low cost of transporting a 200,000-pound carload shipment by rail becomes more and more attractive. If the development of annual use rates for observed truck shipments is impossible, one could use a Monte Carlo simulation to draw representative use rates from a distribution. County Business Patterns[27] reports by four-digit Standard Industrial Classification (SIC) code the number of firms by size

[27] *County Business Patterns* is issued annually by the Department of Commerce, Bureau of the Census, Washington, DC.

that exists in each county in the United States. This can be used to help develop a typical use rate distribution for use in the process.[28] However, implicit in the FAF, the annual use is considered to be the volume on each record.[29]

For observed rail movements one can use the Rail Carload Waybill Sample to develop this information. By sorting the waybill data to group all of the movements of a particular commodity destined to a single point and summing the tons carried, you have a proxy for the amount of that good used by a single receiver at that point—the annual use. Obviously, the more exclusive the definition of the origin and destination (FSAC) [30] and the more defined the product code (seven-digit STCC), the better the result. A FSAC is the Freight Station Accounting Code used by an individual railroad. A FSAC is typically the loading or unloading point of a single receiver.

There is typically no fundamental difference between the use rates of a product traveling by trailer-on-flat-car (TOFC) rail and one moving by truckload truck. Consequently, if the policy question concerns diversion from TOFC-to-truck, or from truck-to-TOFC, the annual use rate is irrelevant because the shipment sizes that can be used by the two modes are essentially the same. The tradeoffs that matter in choosing the mode are difference in rates and service quality. At the same annual use, low value and high density would appear to favor TOFC, while high value and high cube would tend to favor truck. Container-on-flat-car (COFC) movements are typically international shipments, so these same conclusions don't necessarily hold for those movements.

Truck Payloads

The amount of product that can be carried in a truck is a consequence of the truck size and weight laws that exist at a given point in time. These laws are quite complex, involving axle loadings and their spacing as dictated by the Federal Bridge Formula.[31] The laws are different in some of the Western States, in part because at the time the upper limit on weight was set at 80,000 lbs., these States already allowed higher weight limits. Consequently, these States were "grandfathered" at the higher weights. Travel on the Interstate Highway System beyond State borders, however, is currently limited to a total weight of 80,000 lbs. Consequently, the amount of product that can be loaded into a truck is 80,000 lbs. less the tare weight of the empty truck. For a heavy-loading commodity, like bricks for example, the payload is around 50,000 to 55,000 lbs. For a light-loading commodity like Styrofoam balls, the payload may be only 20,000 lbs. because the trailer cubes out before the weight limit is reached. It should be noted that the weigh-out vs. cube-out aspect is a function of preprocessing the data based upon the commodity weight

[28] Chiang, Y.S. and P.O. Roberts, *Representing Industry and Population Structure for Estimating Freight Flows*, MIT Center for Transportation Studies CTS Report 76-8, Cambridge, Massachusetts, August 1976.
[29] It is very unlikely that a location with shipments less than two truckloads per year would obtain large enough benefits from mode diversion to overcome the initial cost and inertia of the change.
[30] *Freight Station Accounting Code Directory*, Association of American Railroads, Accounting Division, American Railroads Building, Washington, DC, 20036.
[31] The Federal Bridge Formula is a formula used by highway engineers to define limits on the weight and spacing of roadway wheel loadings of highway vehicles for use in bridge design.

per cubic foot and the available cubic feet for loading. The applicable truck payload weight is key to estimating the number of truck trips associated with the annual use rate.

Beginning with the analysis for the Western Uniformity Scenario, the estimation of payload has been made based on an analysis of payload weights by commodity, truck configuration, and truck body type attributes from the 2002 Vehicle Inventory and Use Survey (VIUS). While several iterations of this method did not exactly replicate the targeted weight distribution developed for study VMT control totals, it did produce a result closer to that distribution than the weigh-out cube-out payload method used in the 2000 CTSW Study.

Table C2, compares the VIUS Payload method with the Weigh-out Cube-out method in relation to the observed weight distribution from the VMT control total weight distribution. The table truncates GVW below 50,000 lbs. to eliminate empty moves from the control total distribution from the comparisons – by definition the two payload estimation method distributions include only loaded VMT. When included, control total VMT under 50,000 lbs. accounts for 40 percent of total VMT at weights between 20,000 lbs. and 50,000 lbs., some portion of which is empty movements. For the VIUS Payload Model method, 6 percent of total loaded VMT is at weights between 30,000 lbs. and 50,000 lbs. The control total VMT includes 10 percent of loaded VMT above 80,000 lbs. and the VIUS payload method yields 13 percent of loaded VMT above 80,000 lbs. The ITIC Weigh-out Cube-out Method yields no loaded VMT below 60,000 lbs. or above 80,000 lbs.

Table C2. VMT, Payload, and Weight Distributions

Weight Group Upper Bound	Control Total CS5 VMT (millions)			VIUS Payload Weight Distributions CS5 VMT (millions)			Weigh-out Cube-out Weight Distributions CS5 VMT (millions)		
	VMT	Percent	Cumulative Percent	VMT	Percent	Cumulative Percent	VMT	Percent	Cumulative Single Percent
50,000	19,990	20	20	4,841	5	5%	0	0	0
60,000	18,237	19	39	10,254	11	16%	105	0	0
70,000	21,158	22	61	21,162	23	39%	9,952	12	12
78,000	23,537	24	85	35,134	38	77%	13,957	17	30
80,000	4,817	5	90	9,466	10	87%	56,639	70	100
over 80,000	10,276	10	100	12,010	13	100%	0	0	100
Total VMT	98,016			92,866			80,653		

The results of this comparison indicate that the amount of actual Combination-Tractor-Single Trailer, 5-axle configuration (CS5) travel of loaded VMT with GVW of between 78,000 lbs. and 80,000 lbs., as captured by weigh-in-motion data, is on the order of 5 percent, while the weigh-out cube-out method produces a share of about 70 percent. Since the VIUS Payload method for estimating payloads and distributing operating weights comes closer to the observed weight distribution of CS5 vehicles, that method was used in this study rather than the weigh-out cube-out method used in the 2000 CTSW Study.

Truckload Trucking Rates

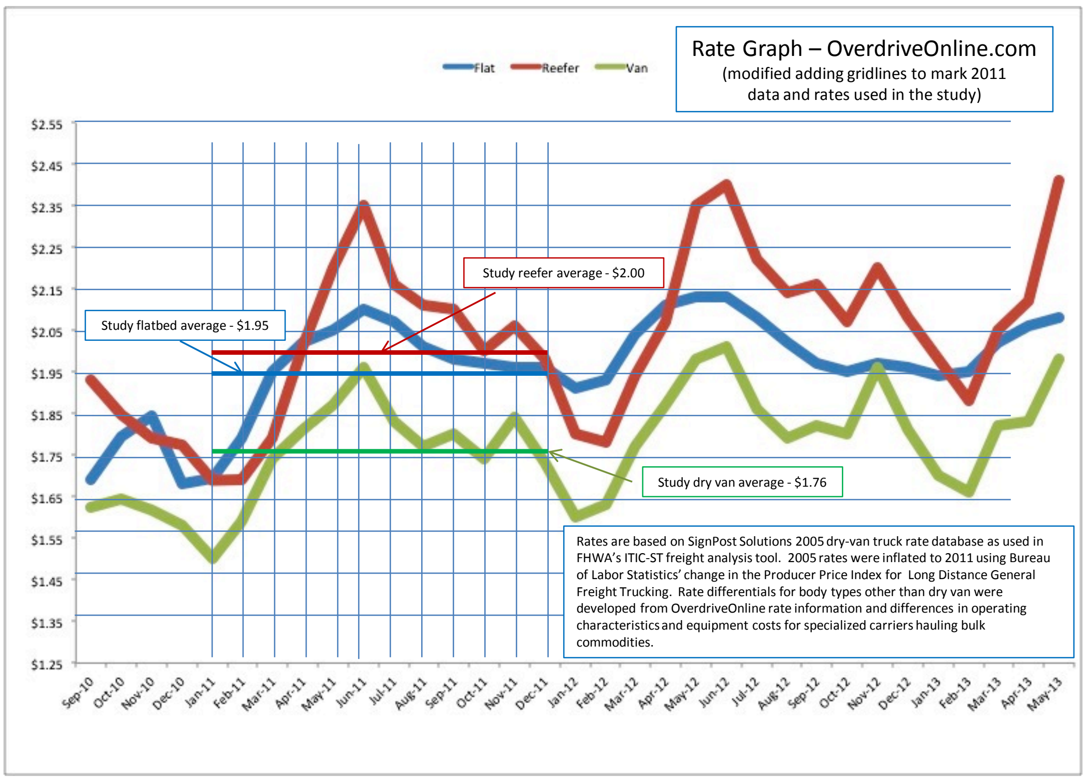
Truckload rates for dry van movements are extremely competitive throughout North America. Although there is a great deal of spread in observed rates, even on the same traffic lane, overall rates appear to reflect the repositioning costs needed to correct equipment imbalances. In the real world, competition drives the rates to adjust for these load imbalances. The rates observed for truckload movement in each city-pair market tend to reflect this phenomenon. This occurs because the number of loaded trucks moving into some regions is larger than the number of loads desiring to move out. Trucks carrying goods out of an equipment surplus region typically charge a lower rate because they know they will have a difficult time securing outbound loads and must either lower their outbound prices or wait longer to get a load. When more loads move out of a region than move in, there is typically a shortage of equipment. Shippers are willing to pay more to attract a carrier. Consequently, outbound rates from an equipment deficit region are typically higher.

FHWA purchased a truckload rate database from Class 8 Solutions. The data captured dry van truckload rates between locations in the United States that were divided into 120 markets, which were used in the Western Uniformity and subsequent studies. Although these data were proprietary, FHWA obtained an agreement from the successor to Class 8 Solutions' licensing rights, Trans-Research International, to include rates averaged over state-to-state origin-destination pairs in the ITIC-ST version of the ITIC model that was made available to the public.

The truckload rate database consisted of CS-5 dry-van truckload rates for 2005 between the 120 markets contained in the database. Individual counties were assigned to the appropriate database market by matching the three-digit prefix zip code for the county seat to the three-digit zip code market assignment provided by the vendor. For initial use in the Western Uniformity Scenario, rate differentials for different body types – Flatbed, Refrigerated and Bulk – were developed from differences in operating characteristics, such as empty/loaded mileage ratios, and equipment costs. Similarly, rate differentials for different configurations were developed from equipment cost data. For the 2014 CTSW Study, those rates used in the Western Uniformity Scenario were inflated from 2005 to 2011 by 17 percent, the change in the Bureau of Labor Statistics Producer Price Index for General Freight Trucking between 2005 and 2011. The resulting county-to-county rates were then aggregated by origin-destination state and grouped into mileage blocks of 25 miles. A tonnage volume weighted average rate was then calculated for state-to-state flows within each mileage block. In this manner, moves of similar distance between states; for example Guilford County, NC (Greensboro) and Davidson County, TN (Nashville) and Buncombe County, NC (Asheville) and Shelby County, TN (Memphis) would have the same state-based rate but would not reveal the more detailed rate information between the 120 market divisions in the database.

Figure C1 below shows the Study's average 2011 rates for dry-van, flat-bed and refrigerated service as compared to publically available monthly data during the same time frame. As the graph shows, the rates used for the study fall within the range of rates observed over the course of the year.

Figure C1. 2011 Rates



http://www.overdriveonline.com/reefer-van-rates-skyrocket-in-may/

Rail Carload Rates

The Surface Transportation Board's Carload Waybill Sample (STB waybill) contains a sample of waybill shipping documents from all United States railroads that terminate a minimum of 4,500 revenue carloads annually. Sampling rates vary by method of reporting (i.e., manual and computerized) and the number of carloads on the shipping document. Sampling rates range from 1 percent to 20 percent for manual submissions and from 2.5 percent to 50 percent for computerized submissions.

Revenues on individual records of the waybill sample may misrepresent rate adjustments as annual volume thresholds are met or other factors that are not transparent to the user of waybill data. For example, Wolfe and Linde cite 56 waybill records on the 1988 Public Use sample of unit train moves of wheat from Oklahoma City BEA to Houston BEA with revenue per car mile ranging from $3.41 per mile to less than $0.03 per mile.[32] For this study, the revenues and variable costs of all records of the same four-digit STCC commodity, moving the same distance between the same origin and destination in the same rail car type are combined and divided by the car-miles generated by those moves to calculate consistent revenue and variable costs per car-mile for the analysis. This treatment provides a transportation cost that is consistent with the single truck rate applied to all moves in the same equipment type between the same origin and destination.

Rail Intermodal Rates

Similar to carload records, waybill revenues for intermodal records moving between the same origin and destination in the same car type service show significant variance that may mask information regard volume discounts or other factors. Confounding the issue of revenues on intermodal records is the service provide by the carrier, as indicated on the Service Plan Code. Railroads provide service that ranges from ramp-to-ramp service, where the dray at neither end is included in the service provided, to door-to-door service, where the dray at both ends is included in the service. For purposes of this study, intermodal rates were developed from waybill records with ramp-to-ramp service. A drayage fee of $225 at both origin and destination was added to the rail transportation cost to arrive at the door-to-door transportation cost of intermodal. This amount corresponds to the minimum charge truck-load rate and isn't inconsistent with an on-line drayage rate calculator for a dray distance between 20 and 40 miles.

Rail Variable Cost

Rail variable costs play a role in deciding what traffic to accept and what to reject. When intermodal rates calculated by the model from the procedure described above fall below 110 percent of rail variable costs, plus drayage costs for the move, the load is refused by rail and allowed to select truck at its original truck rate. Variable cost is increased to assure a minimum contribution to the railroad's overhead. These figures are used to limit possible diversion to the rail mode. Clearly, rail management does not want to compete aggressively to attract (or to hold on to) traffic where the revenues are below short-term variable costs. Also, including drayage costs in the acceptance threshold assures that inordinately distant, and consequently costly, shipment origins/destinations from intermodal terminals will be rejected. The rail variable costs included in the ITIC database were estimated using cost data from Reebie Associates (currently Global Insight) and then modified to include box costs. The rail variable cost range from 80

[32] Wolfe, K. Eric and W.P. Linde, "The Carload Waybill Statistics: Usefulness for Economic Analysis," *Journal of the Transportation Research Forum*, Volume 36, No. 2, 1997, pp. 26 – 41.

cents per mile in the under 500 mile segment to 47 cents per mile for 1500 miles and up. These costs vary by the traffic density (annual rail shipments) and distance between selected rail corridors.

Data that is not included

In a true disaggregate methodology, the “proof” that a shipment of a given size went by a certain mode is typically documented by either paper or electronic record of the movement. A waybill, or freight bill, shows the date of the shipment, the name of the shipper, the name of the receiver, the origin and destination, the size of shipment, the mode, the freight changes, and any special handling requirements. What is not typically available is the level of service variables that prevailed on the observed mode at the time of the shipment. The ITIC allows a user to easily change these factors to test alternative service variables. These must be inferred from the mileage, the conditions of transit, any terminal operations that were known to occur, etc. Also missing on the freight bills are the total tons of the product used annually by this receiver. The disaggregate input data file must contain all of this data with estimates of those data elements that are missing from the paper record.

Benefits Analysis

The direct economic benefits of a policy change that impacts the logistics cost of shippers can be developed directly from the model output. This is possible because the model measures the change in the shipper/receiver utility function in dollar terms caused by shifting from using one alternative to using another. The logistics cost savings is the direct dollar saving to the shipper of making the shift.[33] When aggregated over all shippers it is the first round economic impact of the policy change. If, for example, a new TOFC service is able to attract users away from their existing mode of transportation, the change in the total logistics cost of shifting to the new, lower cost mode is fully reflected in the shipper’s reduced total logistics costs. By aggregating this savings over all shippers, the entire initial dollar saving of the shipping community is developed. This saving will be reflected in the company’s profitability and can be saved as retained earnings, kept by the owners, passed on to customers in the form of lower prices, or used to hire new staff and expanding the productive capacity of the firm.

It should be noted that the first round economic impact is just that—a first round. Once the savings has been distributed, it could result in further growth in the economy of the trading regions. The best way to measure these secondary and tertiary economic impacts is to employ one of the macroeconomic models that can use the logistics savings outputs of the ITIC model as an input to the macroeconomic model and trace the flow of economic impacts that emanate from this first set of economic savings.

[33] The model is an “all or nothing” choice based on a comparison of total logistics costs for the alternatives modeled.

Further Research and Data Needs

A key component of allocating FAF commodity volumes to individual truck trips is shipment size. As discussed previously, determining shipment size using a weigh-out cube-out logic results in GVWs that are skewed to the 80,000-lb. maximum weight limit, contrary to the weight distribution derived from observed WIM data. Although the commodity flow survey instrument includes shipment weight, this information has not been published by commodity since the 1997 survey, and even then in weight ranges too broad to be useful in determining payload weights. Including cargo body type on the survey and publishing shipment weights at a greater level of detail than in the past would provide much needed information in allocating the aggregate commodity flows to individual truck trips.

Development of a continuous probability model could improve the predictive capability of the model, particularly for estimates of modal shifts between rail and truck.

APPENDIX D: ENERGY AND THE ENVIRONMENT METHODOLOGY

D.1 Scope

The purpose of this subtask is to evaluate the effect of alternative vehicle scenarios on the fuel consumption and greenhouse gas emissions of the fleet. The baseline vehicles and alternative configurations were evaluated on a range of drive cycles to determine their load-specific fuel consumption and emissions. The results of this analysis will be combined with modal shift data to represent the overall fuel consumption and emissions impact on the fleet.

D.2 Methodology

In previous truck size and weight studies such as the USDOT's *Comprehensive Truck Size and Weight Study, 2000* (2000 CTSW Study), a simple table showing truck fuel economy in miles per gallon as a function of vehicle configuration and combined vehicle weight was used as an input to the energy and emissions analysis. For example, a triple 28-ft. trailer combination is listed as having 11 percent to 17 percent better fuel economy than that of a three-axle, 53-ft. box van trailer operating at the same vehicle weight. In practice, the 28-ft. triple-trailer combination suffers from higher aerodynamic drag than the 53-ft. box van trailer, and thus would be expected to have lower fuel efficiency.

The more recent OECD report "Moving Freight with Better Trucks" (OECD, 2011) uses fuel consumption values from road tests conducted by the German trucking magazine Lastauto Omnibus (page 152). These tests are run at maximum GCW over a defined route on German highways.

The approach selected for this study is to use baseline engine and vehicle models that are calibrated against experimental data and then modify the models to represent the range of vehicle scenarios selected for this project. This approach was first used in a 2009 report by the Northeast States Center for a Clean Air Future (Reducing Heavy-Duty Long Haul Combination Truck Fuel Consumption and CO_2 Emissions, NESCCAF, 2009). The approach used here is also being used by the Southwest Research Institute (SwRI) in a study of fuel efficiency technologies being conducted for the National Highway Traffic Safety Administration (NHTSA). The models used in this project have been previously developed and verified as part of this NHTSA project.

The engine selected for this project is a 2011 model Detroit DD15. This is a widely used long-haul truck engine which has more than 20 percent of the long-haul market. The DD15 meets US EPA 2010 emissions requirements, and a slightly modified version of the engine has since been certified to meet the EPA's 2014 greenhouse gas requirements. From a proprietary benchmarking program, SwRI has an extensive set of performance, emissions, and fuel consumption data on this engine. Under the NHTSA contract, the experimental data was used to build and calibrate a GT-POWER simulation model of the engine. GT-POWER is a commercially available engine simulation tool. Four different ratings of the engine were developed in GT-POWER for this study: 428 HP, 485 HP (the baseline rating), 534 HP, and 588 HP.

The alternative engine power ratings were developed in order to maintain power-to-weight ratios for some of the alternative vehicle scenarios. For some scenarios, a much higher power would be required to maintain baseline vehicle performance. For example, if GCW is increased from 80,000 lbs. to 129,000 lbs., the baseline engine rating of 485 HP would need to increase to 782 HP in order to maintain the same vehicle acceleration and grade performance. Since engines over 600 HP are not available in the U.S. truck market, the decision was made to limit engine power to 588 HP and accept performance penalties for the highest vehicle weights.

The tractor selected for this study is a Kenworth T-700 high roof sleeper tractor. This truck is not offered with the DD15 engine, but it is offered with the Cummins ISX, another 15 liter engine with similar performance, emissions, and fuel consumption characteristics. Coast-down testing of the tractor with a 53-ft. box van trailer was performed by SwRI under an EPA project to obtain aerodynamic drag and rolling resistance characteristics of the tractor. The T-700 is an aerodynamic tractor using standard (not SmartWay) tires, and the baseline trailer has no aerodynamic or low rolling resistance features. This tractor-trailer combination represents approximately the average current fleet vehicle performance from an aerodynamic and rolling resistance perspective.

Vehicle simulation was performed using SwRI’s Vehicle Simulation Tool. This software package is based on the National Renewable Energy Lab (NREL) Advisor vehicle simulation program, which has hundreds of users worldwide. SwRI’s VST tool incorporates improvements to the original NREL component models, and provides enhanced functionalities in ways that allow the user to define each component of the vehicle. Each component’s set of parameters is defined in a MATLAB scripting format that is used in conjunction with a Simulink model.

Another key factor in any analysis of vehicle fuel consumption and emissions is the drive cycle. For this study, four operational modes were evaluated:

1. Urban interstate / freeway operation
2. Rural interstate / freeway operation
3. Urban non-interstate / non-freeway operation
4. Rural non-interstate / non-freeway operation

Five drive cycles were combined to reflect each of the four operational modes. The drive cycles are summarized in **Table D1.**

Table D1. Drive Cycles Used for Simulated Vehicle Operations

Cycle #	Cycle Name	Comments
1	WHVC	Same as in NHTSA project
2	Low Speed NESCCAF	Same time scale, speed multiplied by 60/68
3	NESCCAF	Same as in NHTSA project
4	Urban / Suburban WHVC	First 1200 seconds of WHVC
5	GEM Urban (CARB)	Same as in NHTSA project

Cycle 1 used the World Harmonized Vehicle Cycle (WHVC), which was developed by the United Nations as a chassis dynamometer emissions and fuel economy test procedure for trucks. The cycle includes three components: a low-speed cycle, a stop-and-go urban cycle, a medium-speed "rural" cycle with one stop, and a higher speed (55 mph maximum) freeway component. The "urban/suburban" WHVC in cycle 4 was created by truncating the cycle at the 1,200 second mark (out of 1,800 seconds total for the cycle).

Cycle 2, the NESCCAF cycle (NESCCAF, 2009), had input from vehicle manufacturers, users, and regulators, and represents an attempt to simulate a U.S. long-haul duty cycle. There is some urban driving at the beginning and end of the cycle, with extended periods of high speed (65 to 68 mph) cruise, and some interruptions in speed designed to mimic a limited amount of traffic congestion. The cruise sections include periods of +/- 1 percent and +/- 3 percent grade.

The low speed NESCCAF cycle (cycle 2) is the exact same cycle but scaled down to limit the maximum speed to 60 mph.

Finally, cycle 5, the GEM Urban cycle, is the low-speed urban cycle used by the EPA in their Greenhouse gas Emissions Model, a simulation tool used to certify vehicles for compliance with the EPA's 2014 greenhouse gas emissions standards. This cycle was developed by the California Air Resources Board (CARB). Figures D-1 to D-4 show details of each drive cycle.

Figure D1. CARB urban cycle

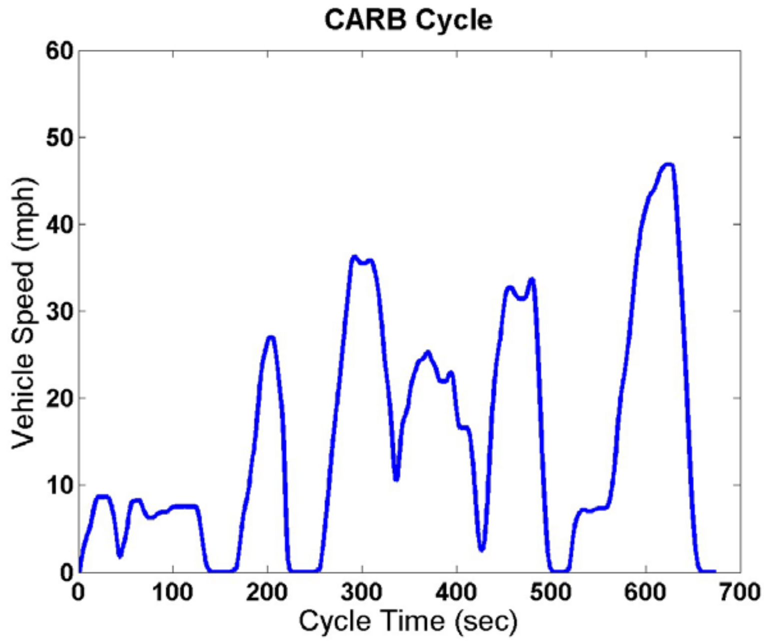
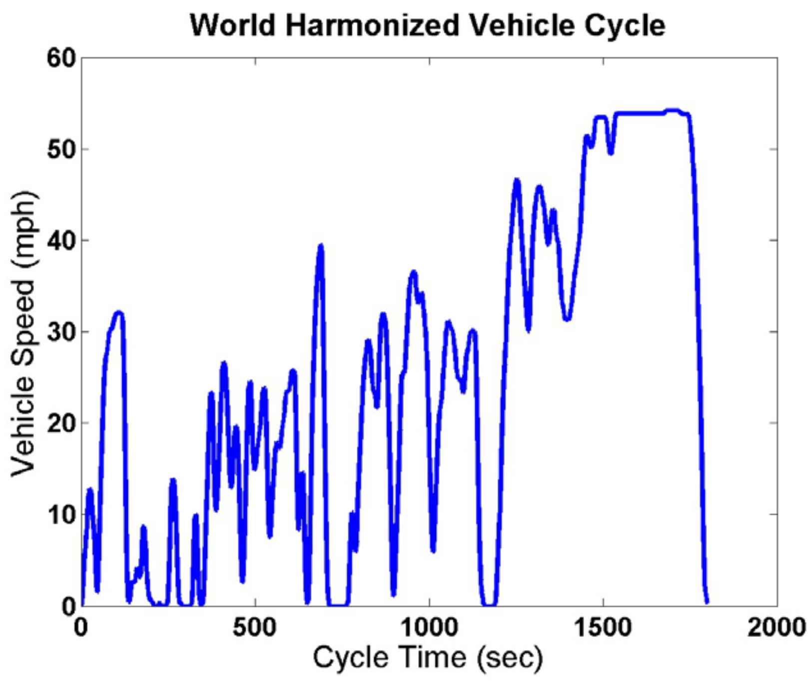


Figure D2. WHVC cycle



(The first 1200 seconds of the WHVC are used with the CARB cycle to simulate urban non-freeway driving. The full cycle is used to simulate urban freeway driving with congestion.)

Figure D3. NESCCAF Cycle with Grades

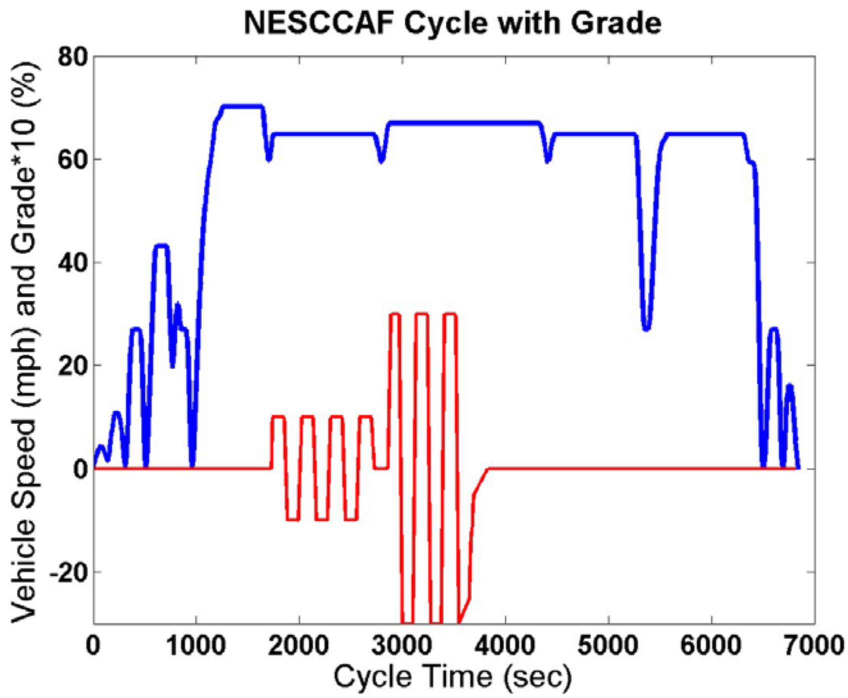
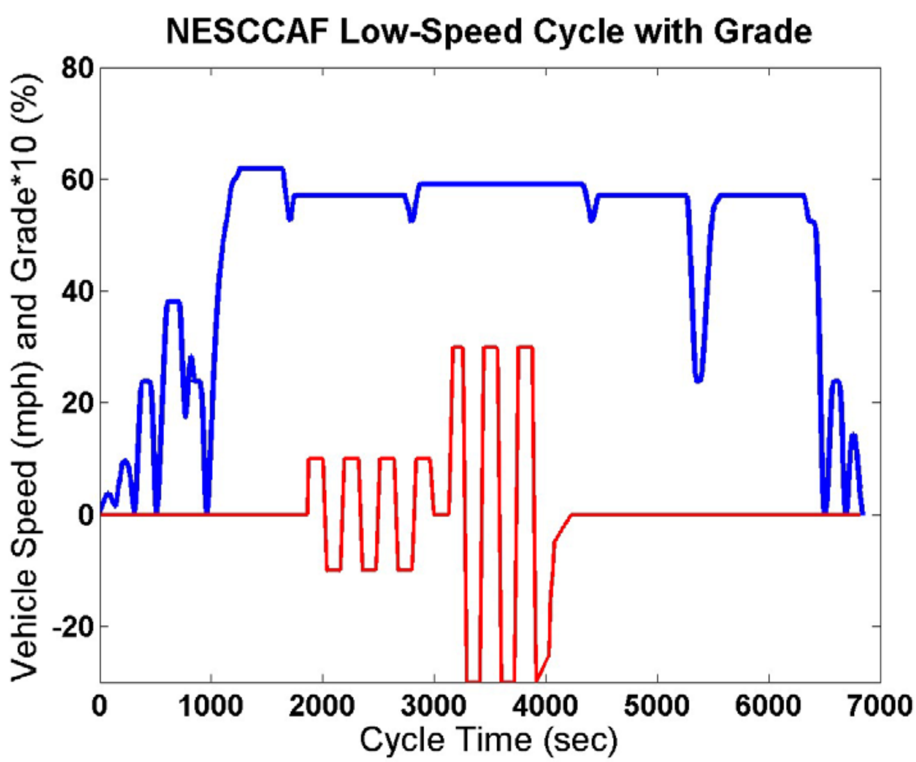


Figure D4. Low Speed NESCCAF Cycle with Grades



The drive cycles were combined to handle the four operational modes as shown in **Table D2.**

Table D2. Mix of Drive Cycles for Four Operational Modes

Urban	Rural	Road Network
50% WHVC, 50% Low Speed NESCCAF	NESCCAF	Interstate / Freeway
50% Urban/Suburban WHVC, 50% Gem Urban	Low Speed NESCCAF	Non-Interstate / Non-Freeway

A key difference between the 2014 and the 2000 CTSW Studies is that results are in terms of fuel consumption rather than fuel economy. In other words, the results are in terms of how many gallons of fuel it takes to move the vehicle a mile or to deliver a ton of freight 1,000 miles, or how many grams of emissions are emitted per vehicle mile or to move a ton of freight a mile. Differences in vehicle efficiency due to variations in tare weight and in aerodynamic drag are accounted for in this project’s methodology. The results provided in this section will be combined with projected vehicle modal shift to provide predictions for the total fleet fuel consumption and emissions levels.

The fuel consumption methodology used in this project matches the methodology being used for the NHTSA study on fuel efficiency technologies being conducted by SwRI. This methodology has been reviewed with NHTSA, EPA, and in April 2014 with the National Research Council committee on Reducing the Fuel Consumption and Greenhouse Gas Emissions of Medium- and Heavy-Duty Vehicles, Phase 2.

For carbon dioxide (CO2) emissions, the study assumes that standard petroleum-based diesel fuel is used. There is a fixed relationship between a gallon of fuel and the amount of CO2 generated by burning it. 10.15 kilograms of CO2 are generated for every gallon of diesel fuel consumed.

For the purpose of this study, the study team assumes that all involved vehicles comply with 2010 EPA nitrous oxide (NOx) requirements of 0.2 grams per brake horsepower-hour, with a 10 percent engineering margin. Based on benchmarking tests performed by SwRI, this is a conservative assumption for the types of vehicle operation simulated for this project. The study team also assumes that brake-specific NOx emissions are independent of engine speed and load. Again, SwRI’s internally developed benchmarking data shows this to be a reasonable assumption over a fairly wide range of speed and load. One additional assumption is required to allow a calculation of NOx emissions. For the 2014 CTSW Study, the study team assumed that the average brake specific fuel consumption of the engine over the drive cycles is 200 g/kW-hr. In actual practice, a range of 190 to 220 g/kW-hr can be expected. Using these assumptions, 3.8 grams of NOx can be expected for every gallon of fuel consumed.

Emissions Assumptions

For trucks complying with EPA 2010 and newer emissions standards, NOx emissions are roughly proportional to fuel consumption. Exceptions occur when vehicles are stuck in traffic congestion. Under these conditions, the exhaust system temperatures drop, and the selective catalytic reduction (SCR) NOx reduction system has degraded performance or, in extreme cases, ceases to function. Our analysis does not include operating scenarios where SCR performance is degraded, so we make the assumption that NOx is proportional to fuel consumption.

In order to calculate NOx, two assumptions are required. One is the estimated brake-specific fuel consumption (BSFC) of the engine in g/kW-hr over a drive cycle. Given the fuel map of the engine used in this study, we assumed a drive cycle average BSFC of 200 grams per kilowatt-hour. The next assumption is a NOx emissions rate of 0.24 g/kW-hr (0.18 g/HP-hr). This is a typical rate from 2010 and later certified engines, taken from public certification data available on the California Air Resources Board web site. Older engines will have a substantially higher NOx emissions rate, but for this study, we did not include the emissions characteristics of older engines.

Given the assumptions above, NOx emissions can be determined as follows:

0.24 g/kW-hr NOx / 200 g/kW-hr fuel consumption = 0.0012 g of NOx per gram of fuel

With 454 grams per pound, and a fuel density of 7 pounds per gallon of diesel fuel,

0.0012*454*7 = 3.8 grams NOx per gallon of fuel consumed

This rate was used with the fuel consumption results to determine grams of NOx per mile driven.

The calculation of CO_2 per gallon of fuel depends only on fuel consumption and the hydrogen / carbon ratio of the fuel, since in a diesel engine, all available carbon can be expected to form CO_2. From the US Energy Administration website, 1 gallon of diesel fuel yields 10.15 kg of CO_2. As a result, the CO_2 emissions (in kilograms) equals the fuel consumption in gallons/mile times a multiplier of 10.15.

Engine Fuel Maps

A total of four engine ratings were evaluated: 428 HP, 485 HP (the baseline engine used for all vehicle scenarios), 534 HP, and 588 HP. For Scenarios 5 and 6, it is not practical to increase engine power enough to maintain performance. Scenario 6, with a weight limit of 129,000 lbs. would require 782 HP to have the same performance as the baseline 80,000-lb. vehicle with 485 HP. All four engine ratings were derived using the same 2011 model Detroit Diesel DD15 engine as the baseline, so engine displacement was not changed. This engine was thoroughly mapped by SwRI during a benchmarking project, and the experimental results were used to validate the GT-POWER engine model of the baseline 485 HP rating. The GT model was then used to develop the alternative ratings.

Figure D5. Fuel Consumption Map for the 428 HP Engine Rating.

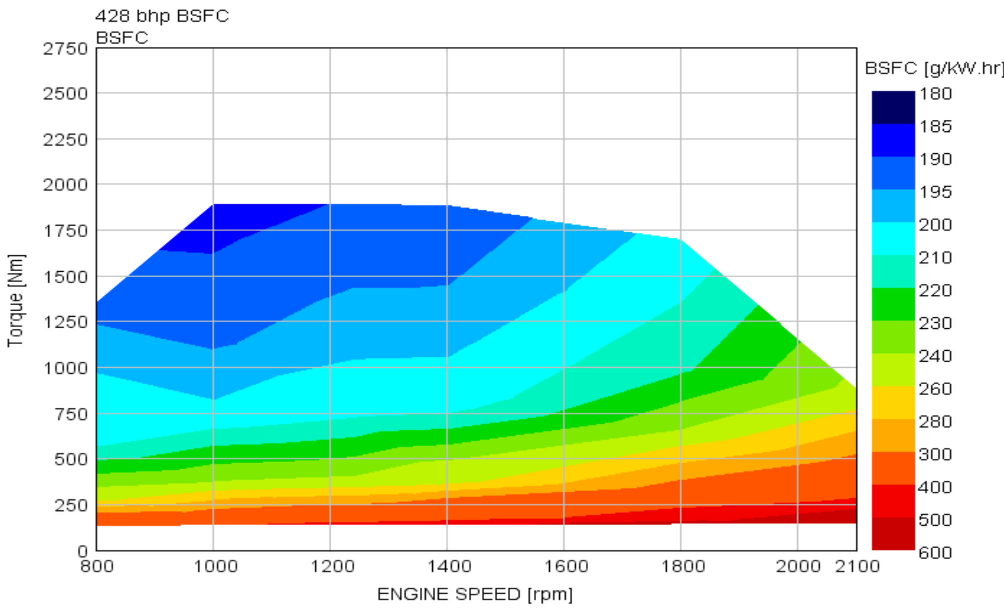


Figure D6. Fuel Consumption Map for the 485 HP (Baseline) Engine Rating.

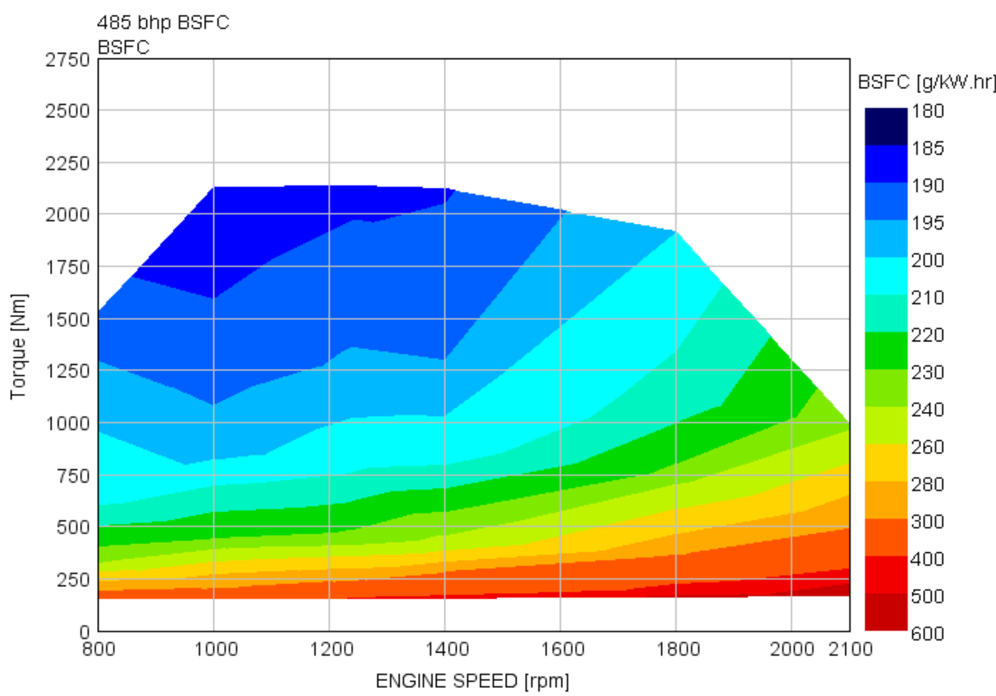


Figure D7. Fuel Consumption Map for the 534 HP Engine Rating.

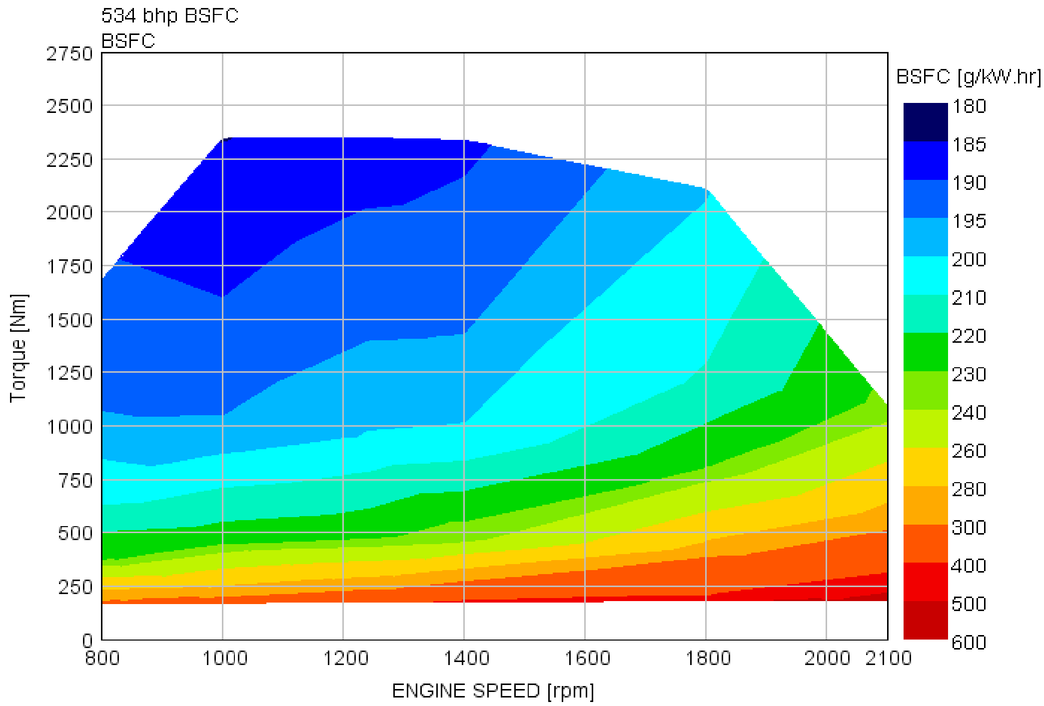
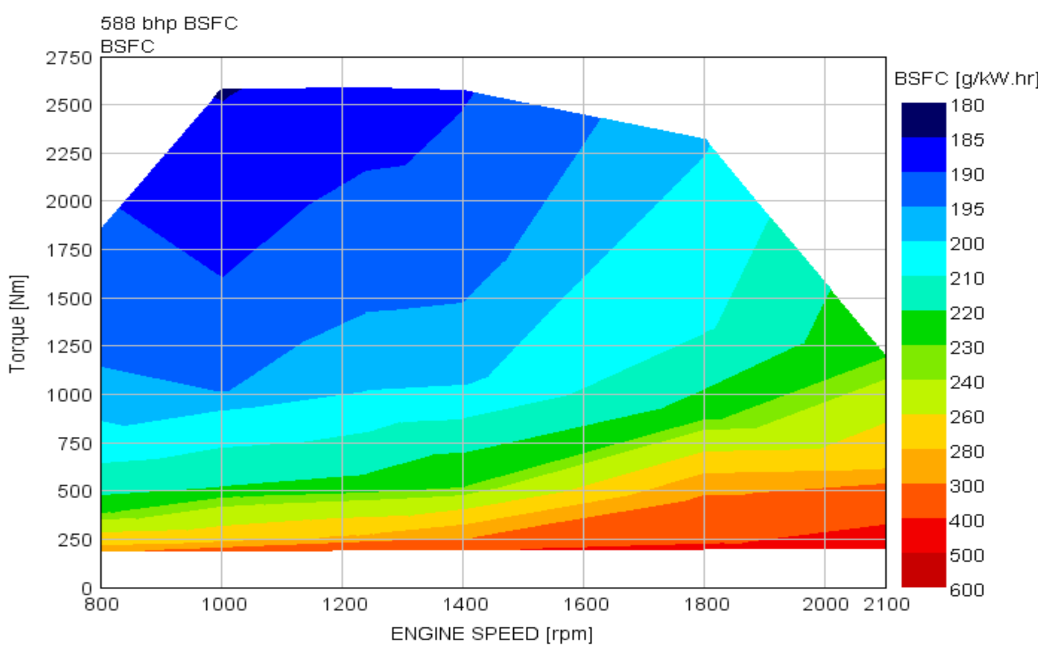


Figure D8. Fuel Consumption Map for the 588 HP Engine Rating.



Test Plan

For the vehicle baselines and for each vehicle scenario, fuel consumption and emissions were determined over a range of payload (and thus total vehicle weight). The range evaluated included zero payload (the truck at its empty weight), several payloads up to the maximum allowed weight for the vehicle scenario, and an overloaded vehicle weight of 200,000 lbs. The overloaded weight point was run to accommodate vehicles which run over the legal weight limit. The following vehicle configurations and payloads were evaluated:

A total of eight vehicle scenarios were run. Two of these vehicles represent the baselines: a five-axle 53-ft. trailer limited to 80,000 lbs., and a five-axle 28-ft. double-trailer combination, also limited to 80,000 lbs. The configurations evaluated are listed below in **Table D3**:

Table D3. Tractor-Trailer Vehicle Scenarios Evaluated

Vehicle	Configuration	# Trailers	# Axles	Tare Wt. (Pounds)	Allowed GCW (lb)
A	5-axle vehicle (3-S2) [baseline]	1	5	34,622	80,000
B	5-axle vehicle (3-S2)	1	5	34,622	88,000
C	6-axle vehicle (3-S3)	1	6	36,255	91,000
D	6-axle vehicle (3-S3)	1	6	36,255	97,000
E	Tractor plus two 28-ft trailers (2-S1-2) [baseline]	2	5	31,376	80,000
F	Tractor plus two 33-foot trailers (2-S1-2)	2	5	33,738	80,000
G	Tractor plus three 28-foot trailers (2-S1-2-2)	3	7	41,454	105,500
H	Tractor plus three 28-foot trailers (3-S2-2-2)	3	9	47,852	129,000

Each vehicle was simulated over a range of payloads, up to the maximum GCW. Vehicles that had maximum GCWs above 80,000 lbs. were evaluated with both the baseline engine and a higher rating intended to maintain performance or, in the case of Vehicles G and H, at least limit the performance penalty for the higher GCW. The payloads are shown in **Table D4** below, along with the number of drive cycles evaluated and the total number of simulation runs required:

Table D4. Vehicle Payloads, Engine Ratings, and Drive Cycles Evaluated

Vehicle	Payloads To Be Simulated, Pounds					Engine Ratings	Drive Cycles	# Of Runs
	1	2	3	4	5			
A	15,378	30,378	45,378			485 HP	All 5	15
B	15,378	30,378	45,378	53,378		485 HP, 534 HP	All 5	40
C	15,378	30,378	45,378	54,745		485 HP, 534 HP	All 5	40
D	15,378	30,378	45,378	60,745		485 HP, 588 HP	All 5	40
E	15,378	30,378	45,378	48,624		485 HP, 428 HP	All 5	40
F	15,378	30,378	46,262			485 HP	All 5	15
G	15,378	30,378	45,378	64,046		485 HP, 588 HP	1, 2, 3	24
H	15,378	30,378	45,378	64,046	81,148	485 HP, 588 HP	1, 2, 3	30

In addition to the payloads shown above, each vehicle was also simulated under two additional conditions: a zero payload (empty vehicle) simulation and a GCW of 200,000 simulation. These two additional simulations for each vehicle along with the payload scenarios shown above allowed the CDM Smith team to estimate all possible emissions and energy consumption rates at all possible payloads for each vehicle analyzed. The final schedule of vehicle simulations according to GCW is shown on **Table D5**.

Table D5. Vehicle Gross Combined Weights

Vehicle	Gross Combination Weight, Pounds							
	Allowed	**0**	**1**	**2**	**3**	**4**	**5**	**6**
A	80,000	34,622	50,000	65,000	80,000	200,000		
B	88,000	34,622	50,000	65,000	80,000	88,000	200,000	
C	91,000	36,255	51,633	66,633	81,633	91,000	200,000	
D	97,000	36,255	51,633	66,633	81,633	97,000	200,000	
E	80,000	31,376	46,754	61,754	76,754	80,000	200,000	
F	80,000	33,738	49,116	64,116	80,000	200,000		
G	105,500	41,454	56,832	71,832	86,832	105,500	200,000	
H	129,000	47,852	63,230	78,230	93,230	111,898	129,000	200,000

D.3 Findings

The result of these simulations were a set of rates describing the amount of fuel consumed and CO2 and NOx emitted from each vehicle at different payloads for each of the four operational modes. These rates were then applied to the weight specific VMT distributions developed by the modal shift analysis. Only those vehicles that were analyzed by the modal shift analysis were considered in the energy and emissions analysis. Other vehicles not a part of the modal shift analysis were not considered. The rates calculated are shown in **Tables D6 through D29.**

Table D6. Urban Freeway, Fuel: Engine 1

Scenario	Urban Interstate / Freeway Gal/mile						
	0	1	2	3	4	5	6
A	0.124	0.141	0.158	0.176	0.339	n/a	n/a
B	0.124	0.141	0.158	0.176	0.185	0.339	n/a
C	0.126	0.143	0.160	0.178	0.189	0.341	n/a
D	0.126	0.143	0.160	0.178	0.196	0.341	n/a
E	0.128	0.144	0.161	0.178	0.182	0.338	n/a
F	0.130	0.146	0.163	0.182	0.341	n/a	n/a
G	0.143	0.159	0.177	0.193	0.215	0.351	n/a
H	0.149	0.167	0.184	0.202	0.223	0.242	0.358

Table D7. Rural Freeway, Fuel: Engine 1

Scenario	Rural Interstate / Fwy Gal/mile						
	0	1	2	3	4	5	6
A	0.135	0.146	0.159	0.172	0.298	n/a	n/a
B	0.135	0.146	0.159	0.172	0.178	0.298	n/a
C	0.136	0.148	0.161	0.173	0.181	0.300	n/a
D	0.136	0.148	0.161	0.173	0.186	0.300	n/a
E	0.145	0.155	0.167	0.180	0.183	0.301	n/a
F	0.147	0.157	0.169	0.183	0.303	n/a	n/a
G	0.160	0.171	0.183	0.196	0.211	0.311	n/a
H	0.164	0.177	0.189	0.202	0.218	0.231	0.317

Table D8. Urban Freeway, CO_2: Engine 1

Scenario	Urban Interstate / Freeway Kilograms CO2/mile						
	0	1	2	3	4	5	6
A	1.26	1.43	1.61	1.78	3.44	n/a	n/a
B	1.26	1.43	1.61	1.78	1.88	3.44	n/a
C	1.28	1.45	1.63	1.80	1.91	3.46	n/a
D	1.28	1.45	1.63	1.80	1.99	3.46	n/a
E	1.30	1.46	1.63	1.81	1.84	3.44	n/a
F	1.32	1.48	1.66	1.84	3.46	n/a	n/a
G	1.45	1.62	1.79	1.96	2.18	3.56	n/a
H	1.52	1.70	1.87	2.05	2.26	2.46	3.64

Table D9. Rural Freeway, CO_2: Engine 1

Scenario	Rural Interstate / Fwy Kilograms CO2/mile						
	0	1	2	3	4	5	6
A	1.37	1.49	1.62	1.75	3.03	n/a	n/a
B	1.37	1.49	1.62	1.75	1.81	3.03	n/a
C	1.38	1.50	1.63	1.76	1.84	3.04	n/a
D	1.38	1.50	1.63	1.76	1.89	3.04	n/a
E	1.47	1.58	1.70	1.83	1.85	3.06	n/a
F	1.49	1.59	1.72	1.85	3.07	n/a	n/a
G	1.62	1.73	1.86	1.99	2.15	3.16	n/a
H	1.67	1.79	1.92	2.05	2.21	2.35	3.22

Table D10. Urban Freeway, NOx: Engine 1

Scenario	Urban Interstate / Freeway Grams NOx/mile						
	0	1	2	3	4	5	6
A	0.47	0.54	0.60	0.67	1.29	n/a	n/a
B	0.47	0.54	0.60	0.67	0.70	1.29	n/a
C	0.48	0.54	0.61	0.68	0.72	1.29	n/a
D	0.48	0.54	0.61	0.68	0.74	1.29	n/a
E	0.49	0.55	0.61	0.68	0.69	1.29	n/a
F	0.50	0.56	0.62	0.69	1.29	n/a	n/a
G	0.54	0.61	0.67	0.74	0.82	1.33	n/a
H	0.57	0.64	0.70	0.77	0.85	0.92	1.36

Table D11. Rural Freeway, NOx: Engine 1

Scenario	Rural Interstate / Fwy Grams NOx/mile						
	0	1	2	3	4	5	6
A	0.51	0.56	0.61	0.65	1.13	n/a	n/a
B	0.51	0.56	0.61	0.65	0.68	1.13	n/a
C	0.52	0.56	0.61	0.66	0.69	1.14	n/a
D	0.52	0.56	0.61	0.66	0.71	1.14	n/a
E	0.55	0.59	0.64	0.68	0.69	1.14	n/a
F	0.56	0.60	0.64	0.69	1.15	n/a	n/a
G	0.61	0.65	0.70	0.74	0.80	1.18	n/a
H	0.62	0.67	0.72	0.77	0.83	0.88	1.20

Table D12. Urban Non-Freeway, Fuel: Engine 1

Scenario	Urban Non-Interstate / Non-Freeway Gal/mile						
	0	1	2	3	4	5	6
A	0.190	0.196	0.226	0.256	0.588	n/a	n/a
B	0.190	0.196	0.226	0.256	0.273	0.588	n/a
C	0.194	0.199	0.229	0.260	0.279	0.590	n/a
D	0.194	0.199	0.229	0.260	0.291	0.590	n/a
E	0.186	0.191	0.220	0.250	0.257	0.580	n/a
F	0.191	0.196	0.225	0.257	0.583	n/a	n/a

Table D13. Rural Non-Freeway, Fuel: Engine 1

Scenario	Rural Non-Interstate / Non-Freeway Gal/mile						
	0	1	2	3	4	5	6
A	0.118	0.130	0.144	0.157	0.296	n/a	n/a
B	0.118	0.130	0.144	0.157	0.164	0.296	n/a
C	0.119	0.132	0.146	0.159	0.167	0.297	n/a
D	0.119	0.132	0.146	0.159	0.172	0.297	n/a
E	0.125	0.136	0.149	0.162	0.165	0.297	n/a
F	0.127	0.138	0.152	0.165	0.299	n/a	n/a

Table D14. Urban Non-Freeway, CO_2: Engine 1

Scenario	Urban Non-Interstate / Non-Freeway Kilograms CO2/mile						
	0	1	2	3	4	5	6
A	1.93	1.99	2.29	2.60	5.96	n/a	n/a
B	1.93	1.99	2.29	2.60	2.77	5.96	n/a
C	1.97	2.02	2.32	2.64	2.83	5.99	n/a
D	1.97	2.02	2.32	2.64	2.96	5.99	n/a
E	1.89	1.94	2.23	2.54	2.61	5.89	n/a
F	1.93	1.98	2.28	2.61	5.92	n/a	n/a

Table D15. Rural Non-Freeway, CO_2: Engine 1

Scenario	Rural Non-Interstate / Non-Freeway Kilograms CO2/mile						
	0	1	2	3	4	5	6
A	1.20	1.32	1.46	1.60	3.00	n/a	n/a
B	1.20	1.32	1.46	1.60	1.66	3.00	n/a
C	1.21	1.34	1.48	1.61	1.69	3.02	n/a
D	1.21	1.34	1.48	1.61	1.75	3.02	n/a
E	1.27	1.38	1.52	1.65	1.68	3.02	n/a
F	1.29	1.40	1.54	1.68	3.04	n/a	n/a

Table D16. Urban Non-Freeway, NOx: Engine 1

Scenario	Urban Non-Interstate / Non-Freeway Grams NOx/mile						
	0	1	2	3	4	5	6
A	0.72	0.74	0.86	0.97	2.23	n/a	n/a
B	0.72	0.74	0.86	0.97	1.04	2.23	n/a
C	0.74	0.76	0.87	0.99	1.06	2.24	n/a
D	0.74	0.76	0.87	0.99	1.11	2.24	n/a
E	0.71	0.73	0.84	0.95	0.98	2.20	n/a
F	0.72	0.74	0.85	0.98	2.22	n/a	n/a

Table D17. Rural Non-Freeway, NOx: Engine 1

Scenario	Rural Non-Interstate / Non-Freeway Grams NOx/mile						
	0	1	2	3	4	5	6
A	0.45	0.50	0.55	0.60	1.12	n/a	n/a
B	0.45	0.50	0.55	0.60	0.62	1.12	n/a
C	0.45	0.50	0.55	0.60	0.63	1.13	n/a
D	0.45	0.50	0.55	0.60	0.65	1.13	n/a
E	0.47	0.52	0.57	0.62	0.63	1.13	n/a
F	0.48	0.52	0.58	0.63	1.14	n/a	n/a

Table D18. Urban Freeway, Fuel: Engine 2

Scenario	Urban Interstate / Freeway Gal/mile						
	0	1	2	3	4	5	6
B	0.12	0.141	0.159	0.176	0.186	0.345	n/a
C	0.13	0.143	0.161	0.178	0.189	0.346	n/a
D	0.13	0.144	0.161	0.179	0.197	0.353	n/a
E	0.13	0.144	0.161	0.178	0.181	0.331	n/a
G	0.14	0.160	0.178	0.195	0.217	0.365	n/a
H	0.15	0.168	0.186	0.204	0.225	0.246	0.373

Table D19. Rural Freeway, Fuel: Engine 2

Scenario	Rural Interstate / Fwy Gal/mile						
	0	1	2	3	4	5	6
B	0.14	0.147	0.160	0.173	0.180	0.303	n/a
C	0.14	0.149	0.161	0.175	0.183	0.305	n/a
D	0.14	0.149	0.162	0.176	0.189	0.309	n/a
E	0.15	0.155	0.168	0.180	0.182	0.291	n/a
G	0.16	0.172	0.185	0.198	0.213	0.326	n/a
H	0.17	0.178	0.191	0.204	0.220	0.235	0.333

Table D20. Urban Freeway, CO_2: Engine 2

Scenario	Urban Interstate / Freeway Kilograms CO2/mile						
	0	1	2	3	4	5	6
B	1.26	1.43	1.61	1.79	1.89	3.50	n/a
C	1.28	1.45	1.63	1.81	1.92	3.51	n/a
D	1.29	1.46	1.63	1.82	2.00	3.59	n/a
E	1.30	1.46	1.63	1.80	1.84	3.36	n/a
G	1.46	1.63	1.80	1.98	2.20	3.70	n/a
H	1.53	1.70	1.89	2.07	2.29	2.49	3.79

Table D21. Rural Freeway, CO_2: Engine 2

Scenario	Rural Interstate / Fwy Kilograms CO2/mile						
	0	1	2	3	4	5	6
B	1.38	1.49	1.62	1.76	1.83	3.08	n/a
C	1.39	1.51	1.64	1.77	1.85	3.09	n/a
D	1.40	1.51	1.64	1.78	1.92	3.14	n/a
E	1.47	1.58	1.70	1.82	1.85	2.95	n/a
G	1.64	1.75	1.88	2.01	2.16	3.31	n/a
H	1.69	1.81	1.94	2.07	2.23	2.38	3.38

Table D22. Urban Freeway, NOx: Engine 2

Scenario	Urban Interstate / Freeway Grams NOx/mile						
	0	1	2	3	4	5	6
B	0.47	0.54	0.60	0.67	0.71	1.31	n/a
C	0.48	0.54	0.61	0.68	0.72	1.32	n/a
D	0.48	0.55	0.61	0.68	0.75	1.34	n/a
E	0.49	0.55	0.61	0.67	0.69	1.26	n/a
G	0.55	0.61	0.67	0.74	0.82	1.39	n/a
H	0.57	0.64	0.71	0.77	0.86	0.93	1.42

Table D23. Rural Freeway, NOx: Engine 2

Scenario	Rural Interstate / Fwy Grams NOx/mile						
	0	1	2	3	4	5	6
B	0.52	0.56	0.61	0.66	0.68	1.15	n/a
C	0.52	0.56	0.61	0.66	0.69	1.16	n/a
D	0.52	0.57	0.62	0.67	0.72	1.18	n/a
E	0.55	0.59	0.64	0.68	0.69	1.10	n/a
G	0.61	0.65	0.70	0.75	0.81	1.24	n/a
H	0.63	0.68	0.73	0.78	0.83	0.89	1.27

Table D24. Urban Non-Freeway, Fuel: Engine 2

Scenario	Urban Non-Interstate / Non-Freeway Gal/mile						
	0	1	2	3	4	5	6
B	0.191	0.197	0.226	0.257	0.274	0.604	n/a
C	0.195	0.200	0.230	0.260	0.280	0.606	n/a
D	0.196	0.201	0.231	0.261	0.293	0.624	n/a
E	0.185	0.190	0.220	0.250	0.257	0.561	n/a

Table D25. Rural Non-Freeway, Fuel: Engine 2

Scenario	Rural Non-Interstate / Non-Freeway Gal/mile						
	0	1	2	3	4	5	6
B	0.118	0.131	0.144	0.158	0.165	0.298	n/a
C	0.119	0.132	0.146	0.159	0.168	0.299	n/a
D	0.120	0.133	0.146	0.160	0.174	0.302	n/a
E	0.125	0.136	0.149	0.162	0.165	0.294	n/a

Table D26. Urban Non-Freeway, CO_2: Engine 2

Scenario	Urban Non-Interstate / Non-Freeway Kilograms CO2/mile						
	0	1	2	3	4	5	6
B	1.94	1.99	2.30	2.61	2.78	6.13	n/a
C	1.98	2.03	2.33	2.64	2.84	6.15	n/a
D	1.99	2.04	2.34	2.65	2.98	6.34	n/a
E	1.88	1.93	2.23	2.54	2.61	5.69	n/a

Table D27. Rural Non-Freeway, CO_2: Engine 2

Scenario	Rural Non-Interstate / Non-Freeway Kilograms CO2/mile						
	0	1	2	3	4	5	6
B	1.20	1.33	1.46	1.60	1.67	3.02	n/a
C	1.21	1.34	1.48	1.62	1.70	3.04	n/a
D	1.22	1.35	1.48	1.63	1.77	3.07	n/a
E	1.27	1.38	1.52	1.64	1.67	2.98	n/a

Table D28. Urban Non-Freeway, NOx: Engine 2

Scenario	Urban Non-Interstate / Non-Freeway Grams NOx/mile						
	0	1	2	3	4	5	6
B	0.73	0.75	0.86	0.98	1.04	2.29	n/a
C	0.74	0.76	0.87	0.99	1.06	2.30	n/a
D	0.74	0.76	0.88	0.99	1.12	2.37	n/a
E	0.70	0.72	0.84	0.95	0.98	2.13	n/a

Table D29. Rural Non-Freeway, NOx: Engine 2

Scenario	Rural Non-Interstate / Non-Freeway Grams NOx/mile						
	0	1	2	3	4	5	6
B	0.45	0.50	0.55	0.60	0.63	1.13	n/a
C	0.45	0.50	0.55	0.61	0.64	1.14	n/a
D	0.46	0.51	0.56	0.61	0.66	1.15	n/a
E	0.48	0.52	0.57	0.61	0.63	1.12	n/a

Rates were interpolated for each weight category for which modal shift VMT were provided. In total, there were 100 weight categories used in the modal shift analysis. Each weight category covered a 2,000-lb. range starting with 0 lbs. as the lower bound of the lowest category and ending with 200,000 lbs. as the upper bound of the highest category. The mid-point of each range was used as the average weight of the category. Rates were interpolated to the average weights of each category. The weight categories are shown in **Table D30**.

Table D30. Modal Shift Weight Categories

Wt. Category	Min lb.	Max lb.	Mid lb.
1	1	2,000	1,001
2	2,001	4,000	3,001
3	4,001	6,000	5,001
4	6,001	8,000	7,001
5	8,001	10,000	9,001
6	10,001	12,000	11,001
7	12,001	14,000	13,001
8	14,001	16,000	15,001
9	16,001	18,000	17,001
10	18,001	20,000	19,001
11	20,001	22,000	21,001
12	22,001	24,000	23,001
13	24,001	26,000	25,001
14	26,001	28,000	27,001
15	28,001	30,000	29,001
16	30,001	32,000	31,001
17	32,001	34,000	33,001
18	34,001	36,000	35,001
19	36,001	38,000	37,001
20	38,001	40,000	39,001
21	40,001	42,000	41,001
22	42,001	44,000	43,001
23	44,001	46,000	45,001
24	46,001	48,000	47,001

Wt. Category	Min lb.	Max lb.	Mid lb.
25	48,001	50,000	49,001
26	50,001	52,000	51,001
27	52,001	54,000	53,001
28	54,001	56,000	55,001
29	56,001	58,000	57,001
30	58,001	60,000	59,001
31	60,001	62,000	61,001
32	62,001	64,000	63,001
33	64,001	66,000	65,001
34	66,001	68,000	67,001
35	68,001	70,000	69,001
36	70,001	72,000	71,001
37	72,001	74,000	73,001
38	74,001	76,000	75,001
39	76,001	78,000	77,001
40	78,001	80,000	79,001
41	80,001	82,000	81,001
42	82,001	84,000	83,001
43	84,001	86,000	85,001
44	86,001	88,000	87,001
45	88,001	90,000	89,001
46	90,001	92,000	91,001
47	92,001	94,000	93,001
48	94,001	96,000	95,001
49	96,001	98,000	97,001
50	98,001	100,000	99,001
51	100,001	102,000	101,001
52	102,001	104,000	103,001
53	104,001	106,000	105,001
54	106,001	108,000	107,001
55	108,001	110,000	109,001
56	110,001	112,000	111,001
57	112,001	114,000	113,001
58	114,001	116,000	115,001
59	116,001	118,000	117,001
60	118,001	120,000	119,001
61	120,001	122,000	121,001
62	122,001	124,000	123,001
63	124,001	126,000	125,001
64	126,001	128,000	127,001
65	128,001	130,000	129,001
66	130,001	132,000	131,001

Wt. Category	Min lb.	Max lb.	Mid lb.
67	132,001	134,000	133,001
68	134,001	136,000	135,001
69	136,001	138,000	137,001
70	138,001	140,000	139,001
71	140,001	142,000	141,001
72	142,001	144,000	143,001
73	144,001	146,000	145,001
74	146,001	148,000	147,001
75	148,001	150,000	149,001
76	150,001	152,000	151,001
77	152,001	154,000	153,001
78	154,001	156,000	155,001
79	156,001	158,000	157,001
80	158,001	160,000	159,001
81	160,001	162,000	161,001
82	162,001	164,000	163,001
83	164,001	166,000	165,001
84	166,001	168,000	167,001
85	168,001	170,000	169,001
86	170,001	172,000	171,001
87	172,001	174,000	173,001
88	174,001	176,000	175,001
89	176,001	178,000	177,001
90	178,001	180,000	179,001
91	180,001	182,000	181,001
92	182,001	184,000	183,001
93	184,001	186,000	185,001
94	186,001	188,000	187,001
95	188,001	190,000	189,001
96	190,001	192,000	191,001
97	192,001	194,000	193,001
98	194,001	196,000	195,001
99	196,001	198,000	197,001
100	198,001	200,000	199,001

Rates for each weight category were interpolated through a simple method of linear interpolation considering the rates calculated during the vehicle simulations at each GCW. Example rate interpolations for rural fuel consumption and CO_2 emissions are shown in **Figures D9 to D10**. Rates for all other road types and emissions were interpolated in a similar manner.

Figure D9. Rural Freeway Fuel Consumption

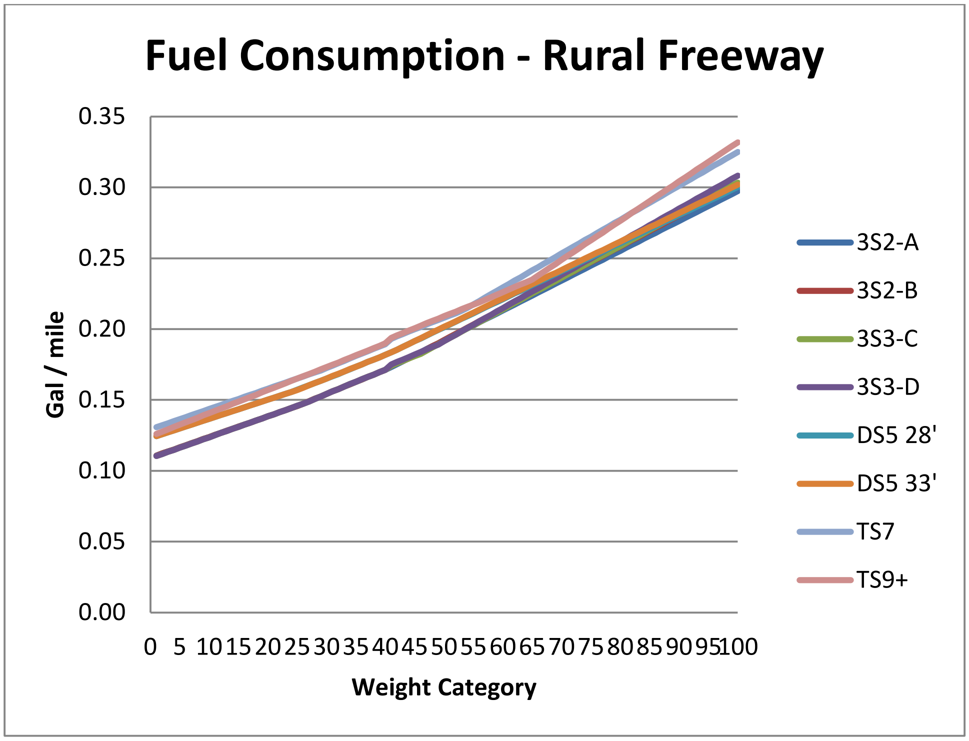
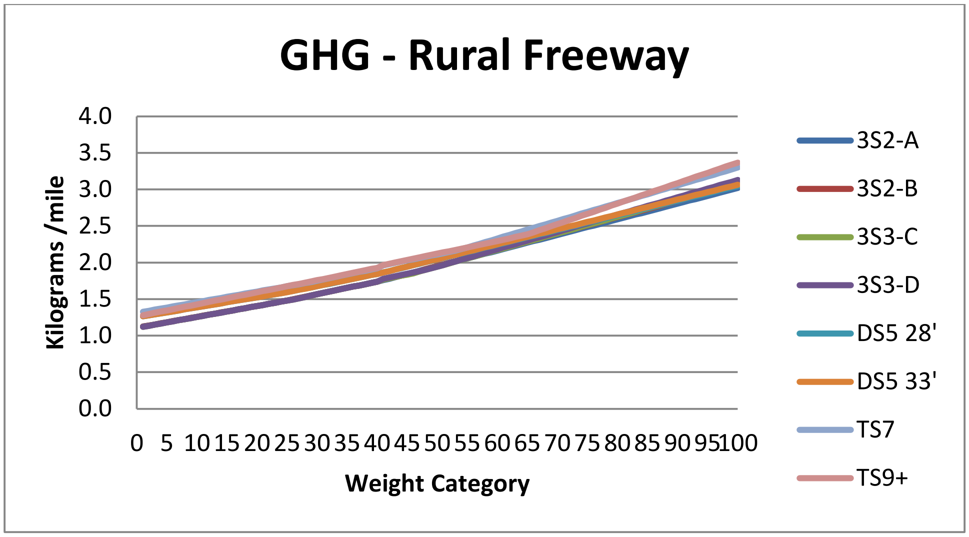


Figure D10. Rural Freeway CO_2 Emissions



D.4 Fuel Consumption Results

Each scenario demonstrates reductions to fuel consumption relative to the Base Case scenario. This is consistent with the reduction of travel made possible by the increases in payload tested in each scenario. While most scenarios show comparable improvements, Scenario 3 shows the greatest overall reduction in fuel consumption. **Tables D31–D38** show the changes to fuel consumption between each of the scenarios.

Table D31. Base Case Annual Fuel Consumption (Gallons)

	3S2	Other 5-Axle	3S3	Other 6-Axle	DS5 - 28'	DS5 - 33'	TS7	TS9+	Total
Rural Freeway	5,540,458,139	808,386,523	74,072,296	163,883	316,650,889	0	7,731,330	20,623	6,747,483,683
Rural Non Freeway	4,096,153,084	731,562,199	136,499,262	201,570	130,654,453	0	0	0	5,095,070,568
Urban Freeway	4,711,424,888	663,637,122	66,805,132	386,171	216,860,877	0	4,746,591	5,164	5,663,865,945
Urban Non Freeway	3,545,743,139	491,156,625	119,521,477	289,295	134,818,125	0	0	0	4,291,528,661
Urban	8,257,168,027	1,154,793,747	186,326,610	675,466	351,679,002	0	4,746,591	5,164	9,955,394,607
Rural	9,636,611,223	1,539,948,722	210,571,559	365,453	447,305,342	0	7,731,330	20,623	11,842,554,251
Freeway	10,251,883,028	1,472,023,645	140,877,429	550,053	533,511,766	0	12,477,921	25,787	12,411,349,628
Non Freeway	7,641,896,222	1,222,718,823	256,020,740	490,866	265,472,578	0	0	0	9,386,599,229
National Total	17,893,779,250	2,694,742,468	396,898,168	1,040,919	798,984,344	0	12,477,921	25,787	***21,797,948,857***

Table D32. Scenario 1 Annual Fuel Consumption (Gallons)

	3S2	Other 5-Axle	3S3	Other 6-Axle	DS5 - 28'	DS5 - 33'	TS7	TS9+	Total
Rural Freeway	5,510,693,114	803,064,755	74,072,296	163,883	316,650,889	0	7,731,330	20,623	6,712,396,889
Rural Non Freeway	4,073,790,184	726,924,101	136,499,262	201,570	130,654,453	0	0	0	5,068,069,571
Urban Freeway	4,688,899,268	659,697,841	66,805,132	386,171	216,860,877	0	4,746,591	5,164	5,637,401,044
Urban Non Freeway	3,529,970,349	488,462,900	119,521,477	289,295	134,818,125	0	0	0	4,273,062,147
Urban	8,218,869,617	1,148,160,741	186,326,610	675,466	351,679,002	0	4,746,591	5,164	9,910,463,191
Rural	9,584,483,298	1,529,988,856	210,571,559	365,453	447,305,342	0	7,731,330	20,623	11,780,466,460
Freeway	10,199,592,382	1,462,762,596	140,877,429	550,053	533,511,766	0	12,477,921	25,787	12,349,797,933
Non Freeway	7,603,760,533	1,215,387,002	256,020,740	490,866	265,472,578	0	0	0	9,341,131,718
National Total	17,803,352,915	2,678,149,598	396,898,168	1,040,919	798,984,344	0	12,477,921	25,787	***21,690,929,651***

Table D33. Scenario 2 Annual Fuel Consumption (Gallons)

	3S2	Other 5-Axle	3S3	Other 6-Axle	DS5 - 28'	DS5 - 33'	TS7	TS9+	Total
Rural Freeway	4,822,730,647	679,744,757	882,948,571	163,883	316,650,889	0	7,731,330	20,623	6,709,990,699
Rural Non Freeway	3,542,497,248	615,917,162	777,662,505	201,570	130,654,453	0	0	0	5,066,932,938
Urban Freeway	4,111,989,678	558,402,098	744,999,403	386,171	216,860,877	0	4,746,591	5,164	5,637,389,982
Urban Non Freeway	3,083,056,100	411,846,430	644,519,715	289,295	134,818,125	0	0	0	4,274,529,666
Urban	7,195,045,777	970,248,529	1,389,519,119	675,466	351,679,002	0	4,746,591	5,164	9,911,919,648
Rural	8,365,227,895	1,295,661,919	1,660,611,076	365,453	447,305,342	0	7,731,330	20,623	11,776,923,637

	3S2	Other 5-Axle	3S3	Other 6-Axle	DS5 - 28'	DS5 - 33'	TS7	TS9+	Total
Freeway	8,934,720,325	1,238,146,855	1,627,947,974	550,053	533,511,766	0	12,477,921	25,787	12,347,380,681
Non Freeway	6,625,553,347	1,027,763,593	1,422,182,221	490,866	265,472,578	0	0	0	9,341,462,604
National Total	15,560,273,672	2,265,910,448	3,050,130,195	1,040,919	798,984,344	0	12,477,921	25,787	***21,688,843,285***

Table D34. Scenario 3 Annual Fuel Consumption (Gallons)

	3S2	Other 5-Axle	3S3	Other 6-Axle	DS5 - 28'	DS5 - 33'	TS7	TS9+	Total
Rural Freeway	4,628,095,069	644,381,550	1,046,269,869	163,883	316,650,889	0	7,731,330	20,623	6,643,313,213
Rural Non Freeway	3,393,023,212	585,174,939	907,416,972	201,570	130,654,453	0	0	0	5,016,471,146
Urban Freeway	3,951,530,289	530,072,019	884,668,480	386,171	216,860,877	0	4,746,591	5,164	5,588,269,591
Urban Non Freeway	2,958,233,937	390,306,932	757,018,830	289,295	134,818,125	0	0	0	4,240,667,120
Urban	6,909,764,226	920,378,952	1,641,687,310	675,466	351,679,002	0	4,746,591	5,164	9,828,936,711
Rural	8,021,118,281	1,229,556,489	1,953,686,841	365,453	447,305,342	0	7,731,330	20,623	11,659,784,359
Freeway	8,579,625,358	1,174,453,569	1,930,938,349	550,053	533,511,766	0	12,477,921	25,787	12,231,582,804
Non Freeway	6,351,257,149	975,481,872	1,664,435,802	490,866	265,472,578	0	0	0	9,257,138,266
National Total	14,930,882,507	2,149,935,441	3,595,374,151	1,040,919	798,984,344	0	12,477,921	25,787	***21,488,721,070***

Table D35. Scenario 4 Annual Fuel Consumption (Gallons)

	3S2	Other 5-Axle	3S3	Other 6-Axle	DS5 - 28'	DS5 - 33'	TS7	TS9+	Total
Rural Freeway	5,008,619,599	746,572,780	74,072,296	163,883	79,434,597	751,356,206	7,731,330	20,623	6,667,971,314
Rural Non Freeway	3,702,769,945	676,366,490	136,499,262	201,570	35,767,501	493,020,862	0	0	5,044,625,629
Urban Freeway	4,258,504,967	613,842,062	66,805,132	386,171	63,628,601	593,841,200	4,746,591	5,164	5,601,759,888
Urban Non Freeway	3,213,459,241	455,248,700	119,521,477	289,295	43,056,590	407,341,370	0	0	4,238,916,674
Urban	7,471,964,208	1,069,090,762	186,326,610	675,466	106,685,192	1,001,182,570	4,746,591	5,164	9,840,676,563
Rural	8,711,389,544	1,422,939,270	210,571,559	365,453	115,202,098	1,244,377,068	7,731,330	20,623	11,712,596,944
Freeway	9,267,124,566	1,360,414,843	140,877,429	550,053	143,063,199	1,345,197,405	12,477,921	25,787	12,269,731,203
Non Freeway	6,916,229,186	1,131,615,189	256,020,740	490,866	78,824,091	900,362,232	0	0	9,283,542,304
National Total	16,183,353,752	2,492,030,032	396,898,168	1,040,919	221,887,289	2,245,559,638	12,477,921	25,787	***21,553,273,506***

Table D36. Scenario 5 Annual Fuel Consumption (Gallons)

	3S2	Other 5-Axle	3S3	Other 6-Axle	DS5 - 28'	DS5 - 33'	TS7	TS9+	Total
Rural Freeway	5,327,583,445	782,031,065	74,072,296	163,883	215,686,876	0	280,151,877	20,623	6,679,710,065
Rural Non Freeway	3,833,125,049	690,677,043	136,499,262	201,570	322,873,511	0	0	0	4,983,376,435
Urban Freeway	4,492,685,645	637,637,232	66,805,132	386,171	193,406,572	0	223,216,236	5,164	5,614,142,151
Urban Non Freeway	3,391,198,197	473,178,391	119,521,477	289,295	303,379,459	0	0	0	4,287,566,820
Urban	7,883,883,841	1,110,815,624	186,326,610	675,466	496,786,031	0	223,216,236	5,164	9,901,708,971
Rural	9,160,708,494	1,472,708,108	210,571,559	365,453	538,560,387	0	280,151,877	20,623	11,663,086,500
Freeway	9,820,269,090	1,419,668,297	140,877,429	550,053	409,093,448	0	503,368,112	25,787	12,293,852,216

Non Freeway	7,224,323,246	1,163,855,434	256,020,740	490,866	626,252,970	0	0	0	9,270,943,255
National Total	17,044,592,335	2,583,523,731	396,898,168	1,040,919	1,035,346,418	0	503,368,112	25,787	***21,564,795,471***

Table D37. Scenario 6 Annual Fuel Consumption (Gallons)

	3S2	Other 5-Axle	3S3	Other 6-Axle	DS5 - 28'	DS5 - 33'	TS7	TS9+	Total
Rural Freeway	5,327,583,493	782,031,072	74,072,296	163,883	215,580,605	0	7,731,330	275,516,335	6,682,679,014
Rural Non Freeway	3,833,472,337	690,755,233	136,499,262	201,570	320,048,782	0	0	0	4,980,977,185
Urban Freeway	4,492,759,987	637,651,122	66,805,132	386,171	192,825,758	0	4,746,591	222,304,295	5,617,479,055
Urban Non Freeway	3,391,501,536	473,231,616	119,521,477	289,295	301,414,289	0	0	0	4,285,958,214
Urban	7,884,261,523	1,110,882,738	186,326,610	675,466	494,240,047	0	4,746,591	222,304,295	9,903,437,269
Rural	9,161,055,830	1,472,786,305	210,571,559	365,453	535,629,387	0	7,731,330	275,516,335	11,663,656,198
Freeway	9,820,343,480	1,419,682,194	140,877,429	550,053	408,406,362	0	12,477,921	497,820,630	12,300,158,069
Non Freeway	7,224,973,873	1,163,986,849	256,020,740	490,866	621,463,071	0	0	0	9,266,935,398
National Total	17,045,317,353	2,583,669,043	396,898,168	1,040,919	1,029,869,434	0	12,477,921	497,820,630	***21,567,093,467***

Table D-38. Truck Fleet Annual Fuel Consumption

Scenario	Fuel Consumed (millions of gallons)	Difference w.r.t. Base Case
Base Case	21,797.9	0.0
Scenario 1	21,690.9	-107.0
Scenario 2	21,688.8	-109.1
Scenario 3	21,488.7	-309.2
Scenario 4	21,553.3	-244.7
Scenario 5	21,564.8	-233.2
Scenario 6	21,567.1	-230.9

D.5 GHG Emissions Results

Each scenario demonstrates reductions to greenhouse gas emissions relative to the base case scenario. This is consistent with the reduction of travel made possible by the increases in payload tested in each scenario. While most scenarios show comparable improvements, Scenario 3 shows the greatest overall reduction in greenhouse gas emissions. **Tables D39–D46** show the changes to CO_2 emissions between each of the scenarios.

Table D39. Base Case Annual CO2 Emissions (Kilograms)

	3S2	Other 5-Axle	3S3	Other 6-Axle	DS5 - 28'	DS5 - 33'	TS7	TS9+	Total
Rural Freeway	56,235,650,116	8,205,123,208	751,833,808	1,663,410	3,214,006,524	0	78,472,999	209,320	68,486,959,385
Rural Non Freeway	41,575,953,799	7,425,356,318	1,385,467,514	2,045,937	1,326,142,694	0	0	0	51,714,966,261
Urban Freeway	47,820,962,615	6,735,916,788	678,072,093	3,919,631	2,201,137,901	0	48,177,899	52,416	57,488,239,344
Urban Non Freeway	35,989,292,857	4,985,239,741	1,213,142,995	2,936,349	1,368,403,971	0	0	0	43,559,015,913
Urban	83,810,255,472	11,721,156,529	1,891,215,088	6,855,980	3,569,541,872	0	48,177,899	52,416	101,047,255,256
Rural	97,811,603,915	15,630,479,526	2,137,301,322	3,709,347	4,540,149,218	0	78,472,999	209,320	120,201,925,646
Freeway	104,056,612,731	14,941,039,996	1,429,905,901	5,583,041	5,415,144,425	0	126,650,898	261,736	125,975,198,729
Non Freeway	77,565,246,656	12,410,596,058	2,598,610,509	4,982,286	2,694,546,665	0	0	0	95,273,982,174
National Total	181,621,859,387	27,351,636,054	4,028,516,410	10,565,327	8,109,691,090	0	126,650,898	261,736	***221,249,180,902***

Table D40. Scenario 1 Annual CO2 Emissions (Kilograms)

	3S2	Other 5-Axle	3S3	Other 6-Axle	DS5 - 28'	DS5 - 33'	TS7	TS9+	Total
Rural Freeway	55,933,535,105	8,151,107,261	751,833,808	1,663,410	3,214,006,524	0	78,472,999	209,320	68,130,828,427
Rural Non Freeway	41,348,970,372	7,378,279,629	1,385,467,514	2,045,937	1,326,142,694	0	0	0	51,440,906,145
Urban Freeway	47,592,327,569	6,695,933,088	678,072,093	3,919,631	2,201,137,901	0	48,177,899	52,416	57,219,620,597
Urban Non Freeway	35,829,199,039	4,957,898,438	1,213,142,995	2,936,349	1,368,403,971	0	0	0	43,371,580,792
Urban	83,421,526,608	11,653,831,526	1,891,215,088	6,855,980	3,569,541,872	0	48,177,899	52,416	100,591,201,389
Rural	97,282,505,477	15,529,386,890	2,137,301,322	3,709,347	4,540,149,218	0	78,472,999	209,320	119,571,734,572
Freeway	103,525,862,674	14,847,040,349	1,429,905,901	5,583,041	5,415,144,425	0	126,650,898	261,736	125,350,449,025
Non Freeway	77,178,169,411	12,336,178,067	2,598,610,509	4,982,286	2,694,546,665	0	0	0	94,812,486,937
National Total	180,704,032,085	27,183,218,416	4,028,516,410	10,565,327	8,109,691,090	0	126,650,898	261,736	***220,162,935,962***

Table D41. Scenario 2 Annual CO2 Emissions (Kilograms)

	3S2	Other 5-Axle	3S3	Other 6-Axle	DS5 - 28'	DS5 - 33'	TS7	TS9+	Total
Rural Freeway	48,950,716,067	6,899,409,283	8,961,927,995	1,663,410	3,214,006,524	0	78,472,999	209,320	68,106,405,598
Rural Non Freeway	35,956,347,063	6,251,559,196	7,893,274,428	2,045,937	1,326,142,694	0	0	0	51,429,369,318
Urban Freeway	41,736,695,227	5,667,781,300	7,561,743,943	3,919,631	2,201,137,901	0	48,177,899	52,416	57,219,508,318
Urban Non Freeway	31,293,019,412	4,180,241,270	6,541,875,112	2,936,349	1,368,403,971	0	0	0	43,386,476,113
Urban	73,029,714,639	9,848,022,569	14,103,619,055	6,855,980	3,569,541,872	0	48,177,899	52,416	100,605,984,431
Rural	84,907,063,130	13,150,968,479	16,855,202,423	3,709,347	4,540,149,218	0	78,472,999	209,320	119,535,774,916
Freeway	90,687,411,294	12,567,190,583	16,523,671,938	5,583,041	5,415,144,425	0	126,650,898	261,736	125,325,913,916
Non Freeway	67,249,366,475	10,431,800,466	14,435,149,540	4,982,286	2,694,546,665	0	0	0	94,815,845,431
National Total	157,936,777,769	22,998,991,049	30,958,821,478	10,565,327	8,109,691,090	0	126,650,898	261,736	***220,141,759,348***

Table D42. Scenario 3 Annual CO2 Emissions (Kilograms)

	3S2	Other 5-Axle	3S3	Other 6-Axle	DS5 - 28'	DS5 - 33'	TS7	TS9+	Total
Rural Freeway	46,975,164,953	6,540,472,735	10,619,639,166	1,663,410	3,214,006,524	0	78,472,999	209,320	67,429,629,107
Rural Non Freeway	34,439,185,603	5,939,525,632	9,210,282,268	2,045,937	1,326,142,694	0	0	0	50,917,182,134
Urban Freeway	40,108,032,432	5,380,230,995	8,979,385,077	3,919,631	2,201,137,901	0	48,177,899	52,416	56,720,936,351
Urban Non Freeway	30,026,074,461	3,961,615,365	7,683,741,120	2,936,349	1,368,403,971	0	0	0	43,042,771,266
Urban	70,134,106,893	9,341,846,360	16,663,126,197	6,855,980	3,569,541,872	0	48,177,899	52,416	99,763,707,617
Rural	81,414,350,556	12,479,998,368	19,829,921,434	3,709,347	4,540,149,218	0	78,472,999	209,320	118,346,811,241
Freeway	87,083,197,384	11,920,703,730	19,599,024,243	5,583,041	5,415,144,425	0	126,650,898	261,736	124,150,565,459
Non Freeway	64,465,260,064	9,901,140,997	16,894,023,388	4,982,286	2,694,546,665	0	0	0	93,959,953,399
National Total	151,548,457,448	21,821,844,727	36,493,047,631	10,565,327	8,109,691,090	0	126,650,898	261,736	***218,110,518,858***

Table D43. Scenario 4 Annual CO2 Emissions (Kilograms)

	3S2	Other 5-Axle	3S3	Other 6-Axle	DS5 - 28'	DS5 - 33'	TS7	TS9+	Total
Rural Freeway	50,837,488,931	7,577,713,721	751,833,808	1,663,410	806,261,162	7,626,265,489	78,472,999	209,320	67,679,908,840
Rural Non Freeway	37,583,114,938	6,865,119,871	1,385,467,514	2,045,937	363,040,130	5,004,161,750	0	0	51,202,950,139
Urban Freeway	43,223,825,416	6,230,496,932	678,072,093	3,919,631	645,830,305	6,027,488,176	48,177,899	52,416	56,857,862,868
Urban Non Freeway	32,616,611,297	4,620,774,302	1,213,142,995	2,936,349	437,024,391	4,134,514,908	0	0	43,025,004,243
Urban	75,840,436,714	10,851,271,234	1,891,215,088	6,855,980	1,082,854,696	10,162,003,084	48,177,899	52,416	99,882,867,111
Rural	88,420,603,869	14,442,833,591	2,137,301,322	3,709,347	1,169,301,292	12,630,427,239	78,472,999	209,320	118,882,858,980
Freeway	94,061,314,347	13,808,210,652	1,429,905,901	5,583,041	1,452,091,467	13,653,753,665	126,650,898	261,736	124,537,771,708
Non Freeway	70,199,726,236	11,485,894,173	2,598,610,509	4,982,286	800,064,521	9,138,676,658	0	0	94,227,954,382
National Total	164,261,040,583	25,294,104,825	4,028,516,410	10,565,327	2,252,155,988	22,792,430,323	126,650,898	261,736	***218,765,726,091***

Table D44. Scenario 5 Annual CO2 Emissions (Kilograms)

	3S2	Other 5-Axle	3S3	Other 6-Axle	DS5 - 28'	DS5 - 33'	TS7	TS9+	Total
Rural Freeway	54,074,971,969	7,937,615,311	751,833,808	1,663,410	2,189,221,793	0	2,843,541,548	209,320	67,799,057,159
Rural Non Freeway	38,906,219,247	7,010,371,983	1,385,467,514	2,045,937	3,277,166,135	0	0	0	50,581,270,816
Urban Freeway	45,600,759,293	6,472,017,908	678,072,093	3,919,631	1,963,076,702	0	2,265,644,791	52,416	56,983,542,834
Urban Non Freeway	34,420,661,695	4,802,760,671	1,213,142,995	2,936,349	3,079,301,511	0	0	0	43,518,803,221
Urban	80,021,420,988	11,274,778,579	1,891,215,088	6,855,980	5,042,378,214	0	2,265,644,791	52,416	100,502,346,056
Rural	92,981,191,215	14,947,987,294	2,137,301,322	3,709,347	5,466,387,928	0	2,843,541,548	209,320	118,380,327,975
Freeway	99,675,731,262	14,409,633,219	1,429,905,901	5,583,041	4,152,298,495	0	5,109,186,339	261,736	124,782,599,993
Non Freeway	73,326,880,942	11,813,132,654	2,598,610,509	4,982,286	6,356,467,647	0	0	0	94,100,074,037
National Total	173,002,612,204	26,222,765,873	4,028,516,410	10,565,327	10,508,766,142	0	5,109,186,339	261,736	***218,882,674,031***

Table D45. Scenario 6 Annual CO2 Emissions (Kilograms)

	3S2	Other 5-Axle	3S3	Other 6-Axle	DS5 - 28'	DS5 - 33'	TS7	TS9+	Total
Rural Freeway	54,074,972,453	7,937,615,382	751,833,808	1,663,410	2,188,143,136	0	78,472,999	2,796,490,801	67,829,191,988
Rural Non Freeway	38,909,744,219	7,011,165,613	1,385,467,514	2,045,937	3,248,495,142	0	0	0	50,556,918,424
Urban Freeway	45,601,513,864	6,472,158,884	678,072,093	3,919,631	1,957,181,443	0	48,177,899	2,256,388,598	57,017,412,412
Urban Non Freeway	34,423,740,593	4,803,300,903	1,213,142,995	2,936,349	3,059,355,030	0	0	0	43,502,475,870
Urban	80,025,254,457	11,275,459,787	1,891,215,088	6,855,980	5,016,536,473	0	48,177,899	2,256,388,598	100,519,888,283
Rural	92,984,716,672	14,948,780,995	2,137,301,322	3,709,347	5,436,638,278	0	78,472,999	2,796,490,801	118,386,110,412
Freeway	99,676,486,317	14,409,774,265	1,429,905,901	5,583,041	4,145,324,579	0	126,650,898	5,052,879,399	124,846,604,401
Non Freeway	73,333,484,812	11,814,466,516	2,598,610,509	4,982,286	6,307,850,171	0	0	0	94,059,394,294
National Total	173,009,971,129	26,224,240,781	4,028,516,410	10,565,327	10,453,174,750	0	126,650,898	5,052,879,399	***218,905,998,695***

Table D46. Truck Fleet Annual CO_2 Emissions

Scenario	**CO_2 Emitted (millions of kilograms)**	**Difference w.r.t. Base Case**
Base Case	221,249.2	0.0
Scenario 1	220,162.9	-1,086.2
Scenario 2	220,141.8	-1,107.4
Scenario 3	218,110.5	-3,138.7
Scenario 4	218,765.7	-2,483.5
Scenario 5	218,882.7	-2,366.5
Scenario 6	218,906.0	-2,343.2

D.6 NOx Emissions Results

Each scenario demonstrates reductions to NOx emissions relative to the Base Case scenario. This is consistent with the reduction of travel made possible by the increases in payload tested in each scenario. While most scenarios show comparable improvements, Scenario 3 shows the greatest overall reduction in NOx emissions. **Tables D47–D54** show the changes to NOx emissions between each of the scenarios.

Table D47. Base Case Annual NOx Emissions (Grams)

	3S2	Other 5-Axle	3S3	Other 6-Axle	DS5 - 28'	DS5 - 33'	TS7	TS9+	Total
Rural Freeway	21,053,740,930	3,071,868,787	281,474,726	622,754	1,203,273,378	0	29,379,054	78,366	25,640,437,996
Rural Non Freeway	15,565,381,718	2,779,936,355	518,697,197	765,966	496,486,920	0	0	0	19,361,268,157
Urban Freeway	17,903,414,575	2,521,821,063	253,859,503	1,467,448	824,071,333	0	18,037,046	19,624	21,522,690,592
Urban Non Freeway	13,473,823,927	1,866,395,174	454,181,614	1,099,323	512,308,876	0	0	0	16,307,808,913
Urban	31,377,238,502	4,388,216,237	708,041,117	2,566,771	1,336,380,208	0	18,037,046	19,624	37,830,499,505
Rural	36,619,122,648	5,851,805,143	800,171,924	1,388,721	1,699,760,298	0	29,379,054	78,366	45,001,706,153
Freeway	38,957,155,505	5,593,689,851	535,334,229	2,090,203	2,027,344,711	0	47,416,100	97,990	47,163,128,588
Non Freeway	29,039,205,645	4,646,331,529	972,878,811	1,865,289	1,008,795,796	0	0	0	35,669,077,070
National Total	67,996,361,150	10,240,021,380	1,508,213,040	3,955,492	3,036,140,507	0	47,416,100	97,990	***82,832,205,658***

Table D48. Scenario 1 Annual NOx Emissions (Grams)

	3S2	Other 5-Axle	3S3	Other 6-Axle	DS5 - 28'	DS5 - 33'	TS7	TS9+	Total
Rural Freeway	20,940,633,832	3,051,646,068	281,474,726	622,754	1,203,273,378	0	29,379,054	78,366	25,507,108,180
Rural Non Freeway	15,480,402,701	2,762,311,585	518,697,197	765,966	496,486,920	0	0	0	19,258,664,369
Urban Freeway	17,817,817,218	2,506,851,797	253,859,503	1,467,448	824,071,333	0	18,037,046	19,624	21,422,123,968
Urban Non Freeway	13,413,887,325	1,856,159,021	454,181,614	1,099,323	512,308,876	0	0	0	16,237,636,159
Urban	31,231,704,543	4,363,010,818	708,041,117	2,566,771	1,336,380,208	0	18,037,046	19,624	37,659,760,126
Rural	36,421,036,533	5,813,957,653	800,171,924	1,388,721	1,699,760,298	0	29,379,054	78,366	44,765,772,549
Freeway	38,758,451,050	5,558,497,865	535,334,229	2,090,203	2,027,344,711	0	47,416,100	97,990	46,929,232,147
Non Freeway	28,894,290,026	4,618,470,606	972,878,811	1,865,289	1,008,795,796	0	0	0	35,496,300,528
National Total	67,652,741,076	10,176,968,471	1,508,213,040	3,955,492	3,036,140,507	0	47,416,100	97,990	***82,425,532,675***

Table D49. Scenario 2 Annual NOx Emissions (Grams)

	3S2	Other 5-Axle	3S3	Other 6-Axle	DS5 - 28'	DS5 - 33'	TS7	TS9+	Total
Rural Freeway	18,326,376,459	2,583,030,077	3,355,204,570	622,754	1,203,273,378	0	29,379,054	78,366	25,497,964,658
Rural Non Freeway	13,461,489,541	2,340,485,216	2,955,117,520	765,966	496,486,920	0	0	0	19,254,345,163
Urban Freeway	15,625,560,775	2,121,927,974	2,830,997,732	1,467,448	824,071,333	0	18,037,046	19,624	21,422,081,932
Urban Non Freeway	11,715,613,179	1,565,016,436	2,449,174,919	1,099,323	512,308,876	0	0	0	16,243,212,732
Urban	27,341,173,954	3,686,944,410	5,280,172,651	2,566,771	1,336,380,208	0	18,037,046	19,624	37,665,294,664
Rural	31,787,866,000	4,923,515,293	6,310,322,089	1,388,721	1,699,760,298	0	29,379,054	78,366	44,752,309,821
Freeway	33,951,937,233	4,704,958,051	6,186,202,302	2,090,203	2,027,344,711	0	47,416,100	97,990	46,920,046,589
Non Freeway	25,177,102,720	3,905,501,652	5,404,292,439	1,865,289	1,008,795,796	0	0	0	35,497,557,896
National Total	59,129,039,953	8,610,459,703	11,590,494,741	3,955,492	3,036,140,507	0	47,416,100	97,990	***82,417,604,485***

Table D50. Scenario 3 Annual NOx Emissions (Grams)

	3S2	Other 5-Axle	3S3	Other 6-Axle	DS5 - 28'	DS5 - 33'	TS7	TS9+	Total
Rural Freeway	17,586,761,263	2,448,649,891	3,975,825,501	622,754	1,203,273,378	0	29,379,054	78,366	25,244,590,208
Rural Non Freeway	12,893,488,206	2,223,664,769	3,448,184,494	765,966	496,486,920	0	0	0	19,062,590,355
Urban Freeway	15,015,815,098	2,014,273,673	3,361,740,226	1,467,448	824,071,333	0	18,037,046	19,624	21,235,424,447
Urban Non Freeway	11,241,288,961	1,483,166,343	2,876,671,552	1,099,323	512,308,876	0	0	0	16,114,535,055
Urban	26,257,104,058	3,497,440,016	6,238,411,778	2,566,771	1,336,380,208	0	18,037,046	19,624	37,349,959,502
Rural	30,480,249,469	4,672,314,660	7,424,009,995	1,388,721	1,699,760,298	0	29,379,054	78,366	44,307,180,563
Freeway	32,602,576,361	4,462,923,564	7,337,565,727	2,090,203	2,027,344,711	0	47,416,100	97,990	46,480,014,654
Non Freeway	24,134,777,167	3,706,831,112	6,324,856,047	1,865,289	1,008,795,796	0	0	0	35,177,125,411
National Total	56,737,353,527	8,169,754,676	13,662,421,773	3,955,492	3,036,140,507	0	47,416,100	97,990	***81,657,140,065***

Table D51. Scenario 4 Annual NOx Emissions (Grams)

	3S2	Other 5-Axle	3S3	Other 6-Axle	DS5 - 28'	DS5 - 33'	TS7	TS9+	Total
Rural Freeway	19,032,754,477	2,836,976,565	281,474,726	622,754	301,851,470	2,855,153,582	29,379,054	78,366	25,338,290,994
Rural Non Freeway	14,070,525,790	2,570,192,661	518,697,197	765,966	135,916,502	1,873,479,276	0	0	19,169,577,392
Urban Freeway	16,182,318,875	2,332,599,836	253,859,503	1,467,448	241,788,686	2,256,596,559	18,037,046	19,624	21,286,687,576
Urban Non Freeway	12,211,145,116	1,729,945,059	454,181,614	1,099,323	163,615,043	1,547,897,207	0	0	16,107,883,362
Urban	28,393,463,991	4,062,544,895	708,041,117	2,566,771	405,403,728	3,804,493,765	18,037,046	19,624	37,394,570,938
Rural	33,103,280,266	5,407,169,226	800,171,924	1,388,721	437,767,972	4,728,632,858	29,379,054	78,366	44,507,868,386
Freeway	35,215,073,352	5,169,576,402	535,334,229	2,090,203	543,640,155	5,111,750,141	47,416,100	97,990	46,624,978,571
Non Freeway	26,281,670,906	4,300,137,720	972,878,811	1,865,289	299,531,545	3,421,376,483	0	0	35,277,460,754
National Total	61,496,744,258	9,469,714,122	1,508,213,040	3,955,492	843,171,700	8,533,126,623	47,416,100	97,990	***81,902,439,325***

Table D52. Scenario 5 Annual NOx Emissions (Grams)

	3S2	Other 5-Axle	3S3	Other 6-Axle	DS5 - 28'	DS5 - 33'	TS7	TS9+	Total
Rural Freeway	20,244,817,092	2,971,718,047	281,474,726	622,754	819,610,129	0	1,064,577,131	78,366	25,382,898,247
Rural Non Freeway	14,565,875,186	2,624,572,762	518,697,197	765,966	1,226,919,341	0	0	0	18,936,830,453
Urban Freeway	17,072,205,450	2,423,021,483	253,859,503	1,467,448	734,944,972	0	848,221,695	19,624	21,333,740,174
Urban Non Freeway	12,886,553,147	1,798,077,887	454,181,614	1,099,323	1,152,841,945	0	0	0	16,292,753,915
Urban	29,958,758,597	4,221,099,369	708,041,117	2,566,771	1,887,786,917	0	848,221,695	19,624	37,626,494,090
Rural	34,810,692,278	5,596,290,810	800,171,924	1,388,721	2,046,529,471	0	1,064,577,131	78,366	44,319,728,700
Freeway	37,317,022,541	5,394,739,530	535,334,229	2,090,203	1,554,555,102	0	1,912,798,827	97,990	46,716,638,421
Non Freeway	27,452,428,333	4,422,650,649	972,878,811	1,865,289	2,379,761,286	0	0	0	35,229,584,369
National Total	64,769,450,874	9,817,390,179	1,508,213,040	3,955,492	3,934,316,388	0	1,912,798,827	97,990	***81,946,222,790***

Table D53. Scenario 6 Annual NOx Emissions (Grams)

	3S2	Other 5-Axle	3S3	Other 6-Axle	DS5 - 28'	DS5 - 33'	TS7	TS9+	Total
Rural Freeway	20,244,817,273	2,971,718,074	281,474,726	622,754	819,206,297	0	29,379,054	1,046,962,073	25,394,180,252
Rural Non Freeway	14,567,194,880	2,624,869,885	518,697,197	765,966	1,216,185,373	0	0	0	18,927,713,301
Urban Freeway	17,072,487,949	2,423,074,262	253,859,503	1,467,448	732,737,880	0	18,037,046	844,756,322	21,346,420,411
Urban Non Freeway	12,887,705,838	1,798,280,141	454,181,614	1,099,323	1,145,374,297	0	0	0	16,286,641,212
Urban	29,960,193,787	4,221,354,403	708,041,117	2,566,771	1,878,112,177	0	18,037,046	844,756,322	37,633,061,623
Rural	34,812,012,153	5,596,587,959	800,171,924	1,388,721	2,035,391,670	0	29,379,054	1,046,962,073	44,321,893,553
Freeway	37,317,305,222	5,394,792,336	535,334,229	2,090,203	1,551,944,177	0	47,416,100	1,891,718,396	46,740,600,662
Non Freeway	27,454,900,718	4,423,150,026	972,878,811	1,865,289	2,361,559,670	0	0	0	35,214,354,514
National Total	64,772,205,940	9,817,942,362	1,508,213,040	3,955,492	3,913,503,847	0	47,416,100	1,891,718,396	***81,954,955,176***

Table D54. Truck Fleet Annual NOx Emissions

Scenario	**NOx Emitted (millions of grams)**	**Difference w.r.t. Base Case**
Base Case	82,832.2	0.0
Scenario 1	82,425.5	-406.7
Scenario 2	82,417.6	-414.6
Scenario 3	81,657.1	-1,175.1
Scenario 4	81,902.4	-929.8
Scenario 5	81,946.2	-886.0
Scenario 6	81,955.0	-877.3

D.7 Vehicle Performance Results

Increases in allowed vehicle weight will naturally have an impact on vehicle performance. For this task, two metrics were evaluated. The first is the maximum speed that is achieved while the truck climbs a 3 percent grade. This speed is an indicator of how much a truck might slow traffic while climbing a grade. The second metric is 0 to 60 mph acceleration time, an indicator of how a truck might slow traffic when accelerating from a traffic light. Vehicle performance was evaluated both with the baseline 485 HP engine rating, and with alternative ratings.

In general, increasing maximum allowed vehicle weight will lead to a reduction in performance. This can be balanced by increased engine power, but at some weight, the truck will need more power than is currently available on the market. Since the highest rating currently available is 600 HP, our evaluation of alternative ratings stopped at 588 HP. The 588 HP rating can provide vehicle performance at 97,000 lbs., which matches the performance of the 80,000-lb. baseline vehicle with the baseline 485 HP engine. At 129,000 lbs., a 782 HP engine would be needed to match the baseline vehicle and engine performance. Note that performance values were not calculated for empty vehicles (payload 0) or overloaded vehicles (payload 6). In each table below, the highest payload evaluated represents the legal weight limit for that vehicle.

Table D55. Maximum Speed on a 3% Grade with the Baseline 485 HP Engine.

Scenario	Configuration	Maximum Speed on 3% Grade, MPH				
		1	2	3	4	5
Base 1	5-axle vehicle (3-S2) [baseline]	63.5	55.7	46.4		
1	5-axle vehicle (3-S2)	63.5	55.7	46.4	45.3	
2	6-axle vehicle (3-S3)	63.1	54.3	46.1	44.5	
3	6-axle vehicle (3-S3)	63.1	54.3	46.1	42.4	
Base 2	Tractor plus two 28-ft trailers (2-S1-2)	63.7	57.1	46.7	46.3	
4	Tractor plus two 33-foot trailers (2-S1-2)	63.8	57.1	46.5		
5	Tractor plus 3 28-foot trailers (2-S1-2-2)	59.3	47.3	45.2	36.4	
6	Tractor plus 3 28-foot trailers (3-S2-2-2)	54.2	46.3	43.0	34.1	32.8

Table D56. Maximum Speed on a 3% Grade with the Alternative Engine Rating.

Scenario	Configuration	Engine Rating	Max. Speed on 3% Grade, MPH				
			1	2	3	4	5
1	5-axle vehicle (3-S2)	534 HP	65.1	61.0	49.8	46.5	
2	6-axle vehicle (3-S3)	534 HP	64.7	60.2	48.2	46.2	
3	6-axle vehicle (3-S3)	588 HP	65.6	63.2	56.3	46.7	
Base 2	Tractor plus two 28-ft trailers (2-S1-2)	428 HP	60.8	48.5	45.1	44.0	
5	Tractor plus 3 28-foot trailers (2-S1-2-2)	588 HP	64.3	60.2	50.3	45.5	
6	Tractor plus 3 28-foot trailers (3-S2-2-2)	588 HP	62.9	56.1	46.8	44.1	36.3

Table D57. Zero to 60 MPH Acceleration Times with the Baseline 485 HP Engine.

Scenario	Configuration	Zero to 60 MPH Accel. Time, Seconds				
		1	2	3	4	5
Base 1	5-axle vehicle (3-S2) [baseline]	45.9	59.8	75.2		
1	5-axle vehicle (3-S2)	45.9	59.8	75.2	84.1	
2	6-axle vehicle (3-S3)	47.3	61.5	77.0	87.5	
3	6-axle vehicle (3-S3)	47.3	61.5	77.0	94.5	
Base 2	Tractor plus two 28-ft trailers (2-S1-2)	43.7	57.8	73.3	76.9	
4	Tractor plus two 33-foot trailers (2-S1-2)	44.6	58.4	74.4		
5	Tractor plus 3 28-foot trailers (2-S1-2-2)	54.2	69.7	86.8	111.1	
6	Tractor plus 3 28-foot trailers (3-S2-2-2)	61.3	77.6	95.9	122.0	150.0

Table D58. Zero to 60 MPH Acceleration Times with the Alternative Engine Ratings.

Scenario	Configuration	Engine Rating	Zero to 60 MPH Accel. Time, Sec.				
			1	2	3	4	5
1	5-axle vehicle (3-S2)	534 HP	41.0	53.0	66.0	73.4	
2	6-axle vehicle (3-S3)	534 HP	42.3	54.4	67.5	76.3	
3	6-axle vehicle (3-S3)	588 HP	38.1	48.5	59.7	72.1	
Base 2	Tractor plus two 28-ft trailers (2-S1-2)	428 HP	50.9	68.4	88.2	92.8	
5	Tractor plus 3 28-foot trailers (2-S1-2-2)	588 HP	42.6	53.7	65.6	81.9	
6	Tractor plus 3 28-foot trailers (3-S2-2-2)	588 HP	47.7	59.3	71.9	89.0	106.3

APPENDIX E: TRAFFIC OPERATIONS IMPACT ANALYSIS APPROACH

This documentation is intended to describe the methodology and procedures of the traffic operations impact analysis. Much of the analysis was based on analyses conducted for the USDOT's *Comprehensive Truck Size and Weight Study, 2000* (2000 CTSW Study). Principles and methods in the spreadsheet model developed for the 2000 CTSW Study were judged to still be applicable to the estimate of delay and congestion costs for this study. Some improvements and updates were made to the 2000 CTSW Study model and underlying data to make it more consistent with HCM 2010 and other more recent analytical tools.

E.1 Methodology

The spreadsheet model used in traffic operations impact analysis was originally developed by Pennsylvania State University, and is now updated with 2011 network variables and new speed-flow rate curves from the 2010 *Highway Capacity Manual*. For the traffic operations impacts outside the spreadsheet model, context was provided in the document to evaluate their impacts in qualitative terms.

In principle, traffic congestion is a function of the difference between the capacity of a given highway and the amount of traffic on it. In this study, the impact of trucks on traffic operations is assessed in terms of passenger car equivalents (PCE). The value of PCEs depends on the operating speed and grade of the highway section, the vehicle's length, and its weight-to-horsepower ratio, which measures how a vehicle can accelerate. After PCE values are determined, they are applied to VMT (vehicle miles traveled) from previous mode split tasks to derive the "PCMT" (passenger car miles traveled) on various highway functional classes. The PCMT is used to calculate a flow rate (passenger cars per hour), which can then be compared to the speed-flow rate curve included in the HCM 2010 to determine the link speed. As a result of this study, the VHT (vehicle hours traveled) is calculated based on the values of VMT and speed, and economic cost is reported by applying the economic value of travel time.

Network

For this update, functional class and length of the 2011 highway network (FHWA Highway Statistics Series) were used. In addition, sample data from 2008 HPMS network was used to derive the geometric and congestion split.

Table E1. Network Length, Geometric and Congestion Splits

F_SYSTEM	FC	Lane-Mile	Pr(g<3)	Pr(g>=3)	Pr(v/sf<0.8)	Pr(v/sf>=0.8)
1	RI	139,526	0.872	0.128	0.045	0.955
2	ROPA	282,569	0.879	0.121	0.020	0.980
3	RMA	240,023	0.857	0.143	0.021	0.979
4	RMjC	843,318	0.829	0.171	0.005	0.995
5	RMnC	526,107	0.829	0.171	0.005	0.995
6	RLoc	4,075,567	0.829	0.171	0.005	0.995
7	UI	92,714	0.892	0.108	0.352	0.648
8	UOFE	53,852	0.895	0.105	0.315	0.685
9	UOPA	277,348	0.907	0.093	0.110	0.890
10	UMA	230,272	0.819	0.181	0.090	0.910
11	UCol	252,041	0.911	0.089	0.061	0.939
12	ULoc	1,554,283	0.911	0.089	0.061	0.939

Source*:* Lane-Miles from *Highway Statistics 2011*, Table HM-260.

Table E1 illustrates the network length, geometric types, and degree of congestion for different highway functional classes. The network was modeled with the geometrics and congestion splits as shown in **Table E2**. Note that the definitions of geometric types and traffic congestion are kept the same as in the 2000 CTSW Study; however, the splits have been updated based on the 2011 network data.

Table E2. Functional Classes and Segment Geometries.

	Geometric Type		Geometric Type Split		% of Lane-Miles Congested	
FC	**Segment 1**	**Segment 2**	**Segment 1**	**Segment 2**	**Congested**	**Non-Congested**
RI	ri0_12	ri3_34	0.85	0.15	0.05	0.95
ROPA	r20_12	r24_34	0.90	0.10	0.02	0.98
RMA	r20_12	r24_34	0.85	0.15	0.02	0.98
RMjC	r20_12	r24_34	0.85	0.15	0.00	1.00
RMnC	r20_12	r24_34	0.85	0.15	0.00	1.00
RLoc	r20_12	r24_34	0.85	0.15	0.00	1.00
UI	ri0_12	ri3_34	0.90	0.10	0.35	0.65
UOFE	ri0_12	ri3_34	0.90	0.10	0.32	0.68
UOPA	ua_11	ua_2l	0.90	0.10	0.10	0.90
UMA	ua_11	ua_2l	0.80	0.20	0.10	0.90
UCol	ua_11	ua_2l	0.90	0.10	0.05	0.95
ULoc	ua_11	ua_2l	0.90	0.10	0.05	0.95

Notes: Geometric Characteristic as follows:

a	=	ri0_12	Rural (or Urban) Interstate, 0%-3% Grade
b	=	ri3_34	Rural (or Urban) Interstate, 3%-6% Grade
c	=	r20_12	Rural Arterial, 0%-4% Grade
d	=	r24_34	Rural Arterial, 4% Grade or higher
e	=	ua_11	Urban Arterial, 0%-3% Grade
f	=	ua_2l	Urban Arterial, 3% Grade or higher
n	=	none	All others, not used in this analysis

Vehicle. Trucks are larger and, more importantly, slower to accelerate to their desired speeds than passenger cars, and thus have a greater effect on traffic flow. In hilly or mountainous terrain and in congested traffic, their effect on traffic flow often is much greater, and they may be equivalent to 15 or more passenger cars. The value of PCEs depends on the operating speed and grade of the highway section, the vehicle's length, and its weight-to-horsepower ratio, which measures how a vehicle can accelerate.

In the 2000 CTSW Study, traffic operations impacts were assessed using three traffic simulation models—one for Interstate highways, one for rural two-lane highways, and one for urban arterials. As these models are sensitive to vehicle length, gross weight, and engine power, the analysis for this Study is sensitive to these factors. To obtain PCEs by truck length and gross weight-to- horsepower ratio, the models were run many times for two sets of representative roadway geometric conditions (relatively level versus mountainous) for each of the three highway types.

The effects of differences in truck length and weight-to-horsepower ratio are shown in the tables below.

Table E3. PCE for Different Truck Dimensions at Different Segment Geometries

ri0_12						ri3_34					
LENGTH	**WTHP**	**PCE**	**PCEnc**	**PCEnnc**	**PCEno**	**LENGTH**	**WTHP**	**PCE**	**PCEnc**	**PCEnnc**	**PCEno**
40	150	2.22	2.0	2.5	2.0	40	150	9.01	1.5	2.0	9.0
40	200	2.54	2.5	3.0	2.5	40	200	11.29	2.0	2.5	11.5
40	250	3.13	3.0	3.0	3.0	40	250	13.19	2.0	3.0	13.0
40	300	3.72	3.0	3.5	3.5	40	300	15.09	2.0	3.5	15.0
80	150	2.59	2.5	2.5	2.5	80	150	9.55	2.5	2.0	9.5
80	200	3.34	3.0	3.5	3.5	80	200	11.77	2.5	2.5	12.0
80	250	3.36	3.0	3.5	3.5	80	250	14.05	3.0	3.0	14.0
80	300	3.38	3.0	4.0	3.5	80	300	16.33	3.0	3.5	16.5
120	150	3.01	2.5	3.0	3.0	120	150	10.46	2.5	2.0	10.5
120	200	3.60	3.0	3.5	3.5	120	200	12.40	2.5	2.5	12.5
120	250	4.03	3.0	4.0	4.0	120	250	14.73	3.0	3.0	14.5
120	300	4.46	3.0	4.0	4.5	120	300	17.06	3.0	3.5	17.0
r20_12						**r24_34**					
LENGTH	**WTHP**	**PCE**	**PCEnc**	**PCEnnc**	**PCEno**	**LENGTH**	**WTHP**	**PCE**	**PCEnc**	**PCEnnc**	**PCEno**
40	150	1.53	1.5	1.5	1.5	40	150	4.98	5.0	5.0	5.0
40	200	1.66	1.5	1.5	1.5	40	200	8.22	8.0	8.0	8.0
40	250	2.43	2.5	2.5	2.5	40	250	13.78	14.0	14.0	14.0
40	300	3.20	3.0	3.0	3.0	40	300	19.34	19.5	19.5	19.5
80	150	1.70	1.5	1.5	1.5	80	150	5.36	5.5	5.5	5.5
80	200	1.83	2.0	2.0	2.0	80	200	8.90	9.0	9.0	9.0
80	250	2.67	2.5	2.5	2.5	80	250	15.07	15.0	15.0	15.0
80	300	3.51	3.5	3.5	3.5	80	300	21.24	21.0	21.0	21.0
120	150	1.87	1.5	1.5	1.5	120	150	5.74	6.0	6.0	6.0
120	200	2.0	2.5	2.5	2.5	120	200	9.58	10.0	10.0	10.0
120	250	2.91	2.5	2.5	2.5	120	250	16.36	16.0	16.0	16.0
120	300	3.82	4.0	4.0	4.0	120	300	23.14	22.5	22.5	22.5
ua_11						**ua_21**					
LENGTH	**WTHP**	**PCE**	**PCEnc**	**PCEnnc**	**PCEno**	**LENGTH**	**WTHP**	**PCE**	**PCEnc**	**PCEnnc**	**PCEno**
40	150	1.25	1.5	1.5	1.5	40	150	1.87	2.0	3.0	2.0
40	200	1.57	1.5	1.5	1.5	40	200	2.00	2.0	3.5	2.0
40	250	1.84	2.0	2.0	2.0	40	250	2.37	3.0	3.5	2.5
40	300	2.11	2.0	2.0	2.0	40	300	2.74	3.0	3.0	2.5
80	150	1.78	2.0	2.0	2.0	80	150	2.20	2.0	3.0	2.0
80	200	1.75	2.0	2.0	2.0	80	200	2.22	2.0	3.5	2.0
80	250	2.25	2.5	2.5	2.5	80	250	2.69	3.0	4.0	2.5
80	300	2.75	3.0	3.0	3.0	80	300	3.16	3.0	4.0	3.0
120	150	2.43	2.5	2.5	2.5	120	150	2.38	2.5	3.5	2.5
120	200	2.62	2.5	2.5	2.5	120	200	2.56	3.0	3.5	2.5
120	250	3.01	3.0	3.0	3.0	120	250	3.15	4.0	4.0	3.0

Source*: 2000 CTSW Study*; red numbers denote extrapolation values.

In addition to general PCE values, three alternative PCE values are included to model effects under different traffic conditions:

- PCEnc denoting PCE values under new congested situations,
- PCEnnc denoting PCE values under new-non-congested conditions, and
- PCEno denoting all other conditions.

In addition to simulation results, at some situations where PCE values were not simulated (shown in red in the table), the PCEs were calculated using extrapolation for later computation conveniences. The tables are not intended to show extreme situations either in terms of roadway or vehicle characteristics; under some different settings the PCEs could be higher than shown in those tables.

It is important to note that using 2000 simulation results should not cause inconsistencies with the HCM 2010. The 2010 HCM provides average PCE values representing a fleet mix of trucks instead of unique PCEs for trucks with different weight-to-horsepower ratios. The values presented in the HCM reference the same research as the 2000 CTSW study. While the state-of-the-art in simulation modeling has improved since the 2000 study was conducted, there is no research suggesting these improvements would significantly affect the relative PCEs for the scenario and base case vehicles being analyzed in the current study.

Capacity. Network capacity is evaluated using the most recent speed-flow rate curve data from the HCM 2010. The updated speed-flow rate tables for different roadway segments are shown below.

Table E4. Speed Flow Rates

ri0_12			ri3_34			r20_12		
Lower Flow	Upper Flow	Speed	Lower Flow	Upper Flow	Speed	Lower Flow	Upper Flow	Speed
0	500	70.00	0	499	67.53	0	300	55.25
500	750	70.00	499	749	67.53	300	452	55.25
750	999	70.00	749	999	66.59	452	607	53.78
999	1250	70.00	999	1250	65.23	607	762	52.98
1250	1500	69.97	1250	1500	62.76	762	918	52.63
1500	1750	68.96	1500	1751	58.16	918	1062	51.81
1750	2000	66.49	1751	1907	50.05	1062	1199	50.80
2000	2247	62.58	1907	1907	31.73	1199	1199	51.31
2247	2313	57.28						
2313	2313	55.63						
r24_34			**ua_1l**			**ua_2l**		
Lower Flow	Upper Flow	Speed	Lower Flow	Upper Flow	Speed	Lower Flow	Upper Flow	Speed
0	300	50.58	0	199	38.08	0	178	39.11
300	452	50.58	199	299	38.08	178	267	39.11
452	606	48.32	299	400	37.06	267	357	37.87
606	762	46.78	400	500	36.51	357	446	37.19
762	917	45.63	500	599	35.93	446	535	36.91
917	1060	44.30	599	700	35.55	535	625	36.36
1060	1197	42.61	700	800	34.65	625	713	35.10
1197	1197	41.71	800	901	34.43	713	803	34.74
			901	1001	36.52	803	891	36.37
			1001	1102	34.41	891	891	33.95
			1102	1199	32.78			
			1199	1199	29.13			

Source: Based on 2000 CTSW Study analysis adjusted to reflect *2010 Highway Capacity Manual* speed-flow rate function curves

In general, the speeds tend to be higher than these included in the 2000 CTSW Study. This is consistent with the higher roadway capacity presented in HCM 2010 and other recent studies.

Limitations

The 2014 CTSW Study model employs a very general approach in computing roadway capacity and travel speed. As a result, variations in time and location were not factored into the model. In addition, the model focuses on the corridor and network levels, but does not take into consideration extra delay caused at hot spots such as at interchange ramps and at grade intersections. Instead, these issues were discussed qualitatively in other sections.

The 2014 CTSW Study has assessed, but not quantified in detail, the impact of longer and heavier trucks on traffic operations in the areas of vehicle off-tracking, passing, acceleration (including merging, speed maintenance, and hill climbing), lane changing (including weaving), sight distance requirements, clearance times, pedestrian areas, and work zones. As with congestion, the speed (a function of weight, engine power, and roadway grade) and length of a vehicle are the major factors of concern, although vehicle speed is more important than length in assessing congestion effects.

Among the subject areas, vehicle off-tracking, passing, acceleration, lane changing, sight distance, and clearance time requirements were discussed in the 2000 CTSW Study. Truck impacts in these areas remain the same over time. Therefore, the contexts in these areas were included in a very similar fashion in this study. In addition, the 2014 CTSW Study included two new areas, namely pedestrian areas and work zones. The significance of truck impacts on traffic operations and safety impacts was identified. However, as with some other factors, research on truck impacts in these two areas is limited, and any original data collection or new simulation modeling to produce quantitative impact estimates in these areas was beyond the scope of this study.

A user guide including a step-by-step procedure for the application of spreadsheet model follows.

2014 CTSW Traffic Operations Impact Analysis Model User Guide

The Traffic Operations Impact Analysis Model is developed as part of the 2014 CTSW Study. The model uses Excel Spreadsheet (Microsoft Excel 2010) to calculate travel time and delay on the national truck network, based on mode split for certain truck dimension changes (scenarios). The model approach was based on the approach adopted in the 2000 CTSW Study, but was updated with the 2011 truck network data and most recent capacity analysis guidance.

Step-by-Step Procedure

1. Compute VMT: The first step is to summarize the VMT by functional class and weight for the entire Nation. For each scenario, a “VMT and Weight” distribution table by State is provided from preceding tasks. A functional class/weight (“**fcw**”) index column needs to be inserted to the distribution table, and the SUMIF function needs to be used to summarize the tabular data matching the prescribed fc and weight criteria. Due to the large amount of calculations involved, it is recommended that users save the summary nationwide VMT table in a separate file and break the data links between files to avoid computation freeze.

2. Compute PCE and input network variables. The 2011 network geometry and congestion split have been saved in the “Network” worksheet, PCE values for different truck sizes on the roadway segments with different geometrics are computed in the “PCE” worksheet with the interpolation or extrapolation templates, and the base speed-flow rate tables for the roadway segments are saved in the “Capacity” worksheet. These values are

considered essential basis for this model, and shouldn't be changed unless there is a new type of vehicle (new scenario) or new network information (new update).

3. Compute PCEMT. For each roadway function class, there is a worksheet computing PCEMT under each scenario. The names of tabs follow the convention of FCScenario. For example, RI01 denotes Rural Interstate Scenario 01. For any new scenario, users can simply copy an existing tab under the same function class and rename it with a new scenario. Move the national VMT table generated in step 1) to the workbook, name it MSScenario Number, for example, MS06 (denoting Mode Split Scenario 06). Select the range of cells D5 to AE24, replace the worksheet names contained in the equations to the worksheet names denoting the new scenario VMT. The PCEMT is automatically computed after the data is linked to the right worksheet. After computing PCEMT, other variables, including travel speed and VHT, are also automatically computed.

4. Summarize results. Each "Scenario XX" worksheet summarizes the model results for a specific scenario. The easiest way to analyze a new scenario is to copy an existing scenario summary tab and rename it for the new scenario. After the summary sheet is created, change the value of cell A1 to match the new scenario name. The spreadsheet model will take the last two letters of the new scenario name and look for VMT and VHT values across different function classes. For example, if the value of "Scenario 05" is coded in **cell A1**, the model will automatically look up VMT and VHT Values across worksheets RI05, ROPA05, RMA05, and so on. The annual cost is calculated with a travel time unit cost of $17.24, which represents the 2011 cost and is derived from a growth factor of the 2000 model value. The unit cost is saved in **Cell I47** in the Scenarios worksheet if the user needs to update this value.

APPENDIX F: RAIL FINANCIAL MODEL

The process for estimating the post-diversion impact on the rail industry that could result from the decreased number of rail shipments and rate reductions to hold onto traffic is described in this appendix. The objective of this analysis is to compute a revised rail industry balance sheet, for the analysis year 2011 for the illustrative 2014 CTSW Study scenarios. In this way, the scenario impact on revenue, freight service expense (FSE), contribution, and ROI resulting from changes in traffic can be assessed.

The rail impact analysis employs two models, the US Department of Transportation's Intermodal Transportation and Inventory Cost (ITIC) Model and an Integrated Financial Model described in Figure F-1. Both are discussed below. These models required inputs from: 1) Class I railroad financial and operating statistics as compiled by the Association of American Railroads (AAR) in the *Analysis of Class I Railroads—2011*; and 2) the 2011 Surface Transportation Board's (STB's) Carload Waybill Sample. The data used from the *Analysis of Class I Railroads* is compiled from R-1 reports submitted by the railroads to the STB.

The revenue and traffic diversions used to assess rail impacts are derived from the ITIC Model. The model uses the STB Carload Waybill Sample as the basis for rail freight flows and estimates transportation and inventory costs for moving freight by rail and truck under different truck size and weight (TSW) scenarios.

In this analysis, the ITIC model allows the railroads to respond to increased truck competition by lowering their own rates down to variable cost, if necessary, to prevent diversion of rail freight to trucks. If motor carriers can offer shippers lower transportation and inventory costs than rail variable cost plus inventory costs, then the model assumes that the railroad will lose the traffic and it will divert to truck. As truck transportation costs decrease, the rail industry will experience three separate but related post-diversion effects:

- Fewer rail shipments will reduce rail revenue.
- As the railroads offer discounted rail rates to shippers to compete with motor carriers, additional revenue will be lost.
- As rail ton-miles decrease due to losses in traffic, the unit (ton- mile) costs of handling the remaining freight traffic will increase.

It is important to note that for diverted traffic, railroads lose revenue and some costs. When discounting to hold traffic, railroads lose revenue but all costs remain.

The post-diversion effects listed above are measured by the following key ITIC model outputs: 1) the remaining rail revenues after accounting for losses in revenues from both diversion and from discounting to hold traffic, and 2) the remaining post-diversion ton-miles used to assess the effect of diversion on rail FSE.

The ITIC Model provides values for revenue and ton-miles for both the base case and each scenario. Percent changes from the base case to the scenario were calculated from these values.

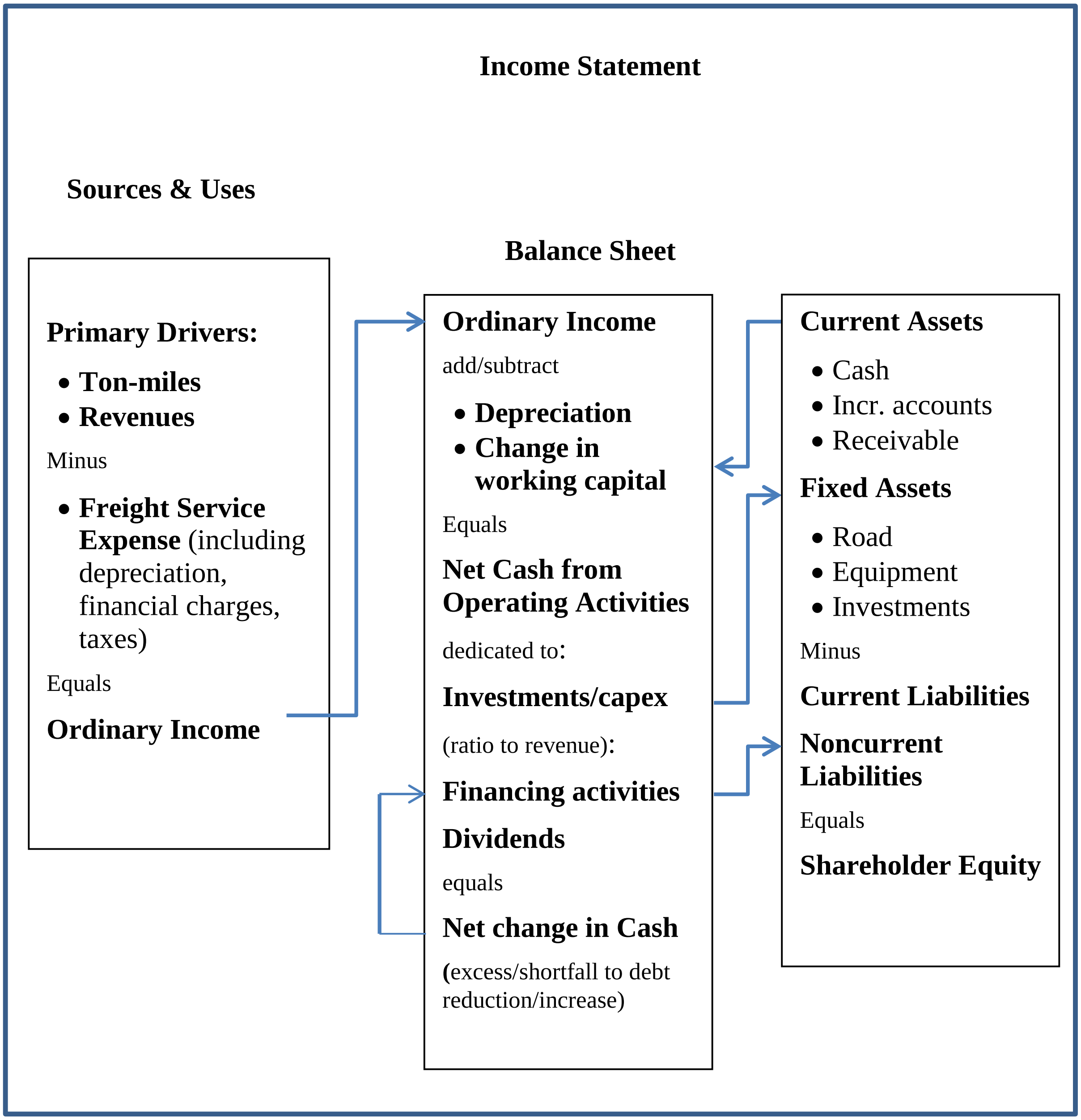
These percent changes were then applied to financial and operating statistics collected by the AAR to determine the revenues and ton-miles used as inputs into an Integrated Financial Model.

The Integrated Financial Model was used to estimate the impact that changes in TSW regulations would have on the rail industry's financial condition. This is the same model used to estimate financial impacts on the railroads for the 2000 CTSW Study. As inputs, this model uses ITIC model outputs and the change in FSE with respect to changing ton-miles (cost elasticity) derived in the STB's Christensen study, "A Study of Competition in the U.S. Freight Railroad Industry and Analysis of Proposals that Might Enhance Competition (Volume 2, p. 9-11)." The methodology for applying the elasticity was best described by Gerard McCullough in his 1993 dissertation, A Synthetic Translog Cost Function for Estimating Output-Specific Railroad Marginal Costs. The FSE represents variable cost, the variable and fixed cost portions of depreciation charges, and interest expense railroads' incur.

According to Christensen Associates more recent measure, the cost elasticity for the industry is 0.862. As railroads lose traffic, measured in ton-miles, and the associated revenues, reductions in cost do not decrease in a one-to-one relationship with ton-miles as noted by the elasticity value, 0.862. Rather, railroads shed costs much more slowly because of the high fixed and common cost component of total costs that characterize the industry. To illustrate, if there were a 10 percent decline in rail ton-miles, the application of the 0.862 elasticity coefficient indicates that freight cost would decline only 8.6 percent. As a consequence, the cost to handle the remaining traffic in terms of cost per ton-mile would increase in the post-diversion case as would be expected in a decreasing cost industry. This increased cost for remaining rail traffic represents an offset to shipper cost savings experienced by truck and former rail shippers as a result of truck size and weight changes, yielding the net national change in shipper costs.

Figure F-1 presents a "wiring diagram" that demonstrates how the Integrated Financial Model works. The model links the Income Statement, Sources and Uses of Funds, and Balance Sheet information, as well as ROI for the rail industry, to evaluate each of the truck size and weight scenarios under consideration. The model imports the independent variables noted above — percent changes in revenues and ton-miles — from the ITIC model into the Income Statement to calculate the effects on the industry balance sheet. By using measured changes in the Income Statement variables—revenues, expenses (including FSE), income, and cash generated and expended—the model produces a revised industry Balance Sheet as output. The output includes a new FSE resulting from a change in ton-miles. The Integrated Financial Model is also used to calculate the post-diversion ROI, and the increase in rail rates that would be required to return the rail industry to pre-diversion financial conditions.

Figure F-1 Integrated Financial Model of the Railroad Industry



The following is an explanation of the Integrated Financial Model.

What is an Integrated Financial model?

In order to evaluate the financial outcomes, the team used the **Vanness Brackenridge Group Economic and Financial Model**. This model is fully integrated from source data to analytical sectors to economic-financial reports. The model structure is comprehensive in that it provides reports at various levels of reporting detail. This model has been used in many assignments worldwide.

An integrated model assessment (sometimes called enterprise modeling) links the Income Statement, Sources and Uses of Funds, and Balance Sheet information as well as Rate of Return (IRR) or Net Present Value (NPV) of the enterprise evaluated, for the scenarios under consideration. This allows the user to declare or import independent variables for activity and financial drivers, under various scenarios, for the choices under study.

MODEL STRUCTURE

Overall Reporting Sectors:

·Activity levels
- Statement of Revenues
- Statement of Expenses
- Income Statement
- Cash Flow Statement
- Investment/Debt Portfolio
- Balance Sheet
- Capital Investment Schedule(s)

Supporting Report Sectors (as req'd):

- Activity levels by type/distance
- Tariffs by type/distance/other fares
- Staffing and productivity
- Material and supply requirements
- Fuel consumption module reporting by type
- Public Service Obligation (Subsidy) module
- Capital Program by specific elements
- Equipment utilization and rents

Income Statement Primary Drivers:

Among the primary independent variables that have been specified are:

- Ton-Miles
- Revenues
- Freight Service Expenses
- Depreciation
- Fixed Charges
- Income Taxes.

Sources and Uses of Funds (Cash Flow) Significant Assumptions:

- **Income from Continuing Operations Depreciation and Amortization** is carried from the Income Statement.
- **Increase/Decrease in Deferred Taxes**.
- **Increase/Decrease in Accounts Receivable and other Current Assets Increase/Decrease in Accounts Payable and Other Current Liabilities**
- **Investments/Capital**
- **Dividends Principal Payments on Debt/Finance Leases**
- **All Other Accounts**

Balance Sheet Significant Assumptions:

- **Current Assets Gross Fixed Assets** (Road, Equipment, etc.) before depreciation
- **Accumulated Depreciation and Amortization**
- **Current Liabilities Total Non-Current Liabilities**, the sum of long term debts, lease liabilities and deferred tax credits.
- **Shareholders' Equity** is the sum of Current and Net Fixed Assets minus Current and Non-Current Liabilities.

Discussion of Increased Costs of Handling Post Diversion Traffic and "Contribution Effects"

Post diversion, the rail industry and the individual railroads will suffer on two counts. They will lose the revenue associated with the diverted movements. But they will also suffer increased marginal costs to move the traffic which remains.

This increased cost to move the remaining traffic reduces any beneficial effects on total logistics costs (in "systemic" terms) from truck diversion at lower apparent cost and cuts against railroad profitability as well.

The Financial Model has been programmed to calculate new operating costs for reduced ton-miles of activity and including the effect of *increasing marginal cost* as a result of volume loss.

Calculating Post Diversion Costs

Calculation of post diversion operating cost equivalents is a two-step process. Christensen Associates have given us the elasticity of modified Freight Service Expenses (FSE) with respect to changing ton-miles which for the industry as a whole is 0.862.

First, a new FSE is estimated, based on the changed ton-miles post diversion. The higher cost level, due to decreasing efficiencies of scale, is calculated and compared with the cost level prevailing at the base case level of activity. As a practical matter of calculation, the formulas are conveniently expressed in terms of the aggregate cost levels, and then compared as follows;

Step 1. Predicted FSE (Cost) change for given level of ton-miles change:

$$x * e * C_1 = C_2$$

Where: *x* = percent change in ton-miles; e = coefficient of change in FSE (cost) relative to a change in ton-miles ; C_1 = base FSE; C_2 = new FSE post-diversion;

Step 2. The second step in this process entails computing the change in cost levels attributable to the loss of volume, and, therefore, the increased marginal cost for handling remaining post diversion railroad traffic.

Base case cost per ton-mile:

$$C_1/Q_1 = CCM_1$$

Where: CCM_1 = base case cost per ton-mile

Post diversion ton-miles traveling at the old CCM_1 cost per ton-mile:

$$((Q_1(1\text{-}x)) * CCM_1 = C_3$$ Where $C_3 = Q_2$ volume moved at old cost per ton-mile

And, comparing C_2 with C_3 yields the increased costs attributable to higher post diversion marginal cost per ton-mile:

$$C_2 - C_3 = \text{Increased cost to handle post diversion ton-miles.}$$

$$\text{or } C_3 = (e-1)*C1*x$$

Discussion of the Concepts of Diversion Impacts on Rail Industry Finances

Revenue Loss:

An analysis of financial impact of diversions on the industry must take into effect both revenue and cost components. Revenue losses will result from the out of hand losses due to the diversion of traffic *per se*. A “second order” effect would be the predictable rail response to the losses, namely the temptation to cut competing rates. The diversion model takes this into account by hypothetically lowering rail rates on competing traffic to the variable cost threshold, but not beyond. Both revenue elements are provided to the economic and financial model. The latter rate decreases could be claimed as a net benefit, were it not for the following phenomenon.

A “third order” and more subtle effect derives from the temptation of the railroads to raise rates for other traffic to replace the revenues lost. In effect, the railroads could be predicted to try to replace the lost contribution from any given level of revenues lost. Their options for doing so would, however, be limited. Ultimately, only *captive shippers*[34] could be tapped for additional revenues. Non-captive shippers might pay increased rates temporarily, but would eventually bolt, leading to another round of diversions, losses and retaliation. Thus, all but captive should be ruled out as a long term source of make-up revenues, were it possible to precisely define who is and who is not a captive shipper. Unfortunately, that is not within the scope of this 2014 CTSW Study, so here it is assumed remaining rail shipments are at least “short term captive” within the time frame of the 2014 CTSW Study.

[34] Generally, captive shippers are those which do not enjoy viable competitive alternatives to the serving rail carrier by virtue of the product shipped or their location or both.

APPENDIX G: VMT AND WEIGHT DISTRIBUTION ESTIMATES METHODOLOGY

The USDOT's *Comprehensive Truck Size and Weight Study, 2014* (2014 CTSW Study) compiled all relevant data, including (1) vehicle classification and weigh-in-motion (WIM) data collected by the states and reported via the Vehicle Travel Information System (VTRIS) and Traffic Monitoring Analysis System (TMAS) data reporting systems, (2) tables of VMT published on the FHWA website, (3) a custom control-total spreadsheet that includes VMT totals by broad vehicle and highway types for ten groups of states, and (4) WIM data collected under the long-term pavement performance (LTPP) program. Most data covered years from 2010 through 2013, and all data were adjusted to control totals for 2011.

FHWA's process for estimating VMT data started with the 2012 control-total spreadsheet. We adjusted these control totals based on the 2011 VM1 table version that was included on FHWA's website on late January 2014. We factored the 2012 spreadsheet totals up or down so that we precisely matched the 2011 VM1 tables. Using vehicle classification data and the January 2014 website version of FHWA's VM-2 table, we split the control totals for the groups of States, broad classes of vehicle types, and groups of highway types into the 13 vehicle types estimated in the classification data, 12 functional highway classes, and 51 States, adjusting the auto estimates such that the 2011 VM2 tables were precisely matched. Using WIM data, we further split the 13 vehicle types into 28 detailed vehicle classes (VC) and 100 operating weight groups (OGW) needed for the CTSW Study, and developed detailed arrays of axle weights and types for each combination of VC and OGW.

The detailed breakdowns were aggregated to the levels of detail required for each phase of analysis of the 2014 CTSW Study. Bridge analysis, for example, required arrays of axle weights and types for two broad groups of States and with all vehicle classes and OGWs grouped together. Pavement analysis required grouping by the ten regions used earlier (groups of states chosen based on similar truck size and weight characteristics), and required aggregating the 24 truck classes into no more than 10. By starting with the full level of detail needed for all phases of the study, all the phases were able to use the same set of travel data, aggregating as needed to suit their purposes.

VMT Control Totals

The table below shows FHWA's estimated 2012 control totals (in millions of VMT) for broad classes of vehicles on six types of highways in each of ten groups of States (or regions).

Table G1. VMT Control Totals Provided by FHWA

Region/Hwy Type	Auto /MC	Light Trucks	Bus	Single Unit	Combination	Total VMT
1	**230,142.388**	**58,827.182**	**1,893.698**	**10,951.156**	**18,043.832**	**319,858.256**
Rural Arterial	18,048.666	5,891.008	160.022	1,138.271	2,638.827	27,876.795
Rural Interstate	13,333.829	3,447.334	191.004	831.124	4,769.184	22,572.475
Rural Other	32,291.238	12,172.477	238.690	2,123.543	1,469.261	48,295.209
Urban Arterial	80,633.485	18,019.783	695.006	3,290.113	3,184.486	105,822.872
Urban Interstate	38,372.192	7,265.506	346.003	1,572.613	5,188.615	52,744.929
Urban Other	47,462.978	12,031.074	262.973	1,995.491	793.459	62,545.975
2	**102,317.575**	**19,369.021**	**669.198**	**3,683.845**	**3,284.450**	**129,324.089**
Rural Arterial	7,309.897	1,806.959	72.505	495.503	372.679	10,057.542
Rural Interstate	4,695.168	1,014.173	56.251	280.643	533.630	6,579.864
Rural Other	8,599.914	2,446.979	76.038	603.400	298.473	12,024.805
Urban Arterial	41,002.226	7,024.977	214.561	1,106.878	608.372	49,957.013
Urban Interstate	24,294.251	3,568.661	185.803	702.945	1,347.966	30,099.626
Urban Other	16,416.120	3,507.272	64.039	494.476	123.331	20,605.238
3	**831,798.463**	**226,999.903**	**6,274.314**	**38,911.724**	**62,443.344**	**1,166,427.749**
Rural Arterial	99,045.487	33,847.309	853.946	6,020.198	9,954.758	149,721.698
Rural Interstate	60,807.820	16,954.380	784.441	3,449.638	20,170.334	102,166.613
Rural Other	104,195.560	38,837.777	922.285	6,881.630	4,778.102	155,615.355
Urban Arterial	286,972.423	68,991.874	1,622.023	11,128.811	9,259.945	377,975.075
Urban Interstate	128,970.507	30,297.857	1,016.417	5,226.790	14,737.913	180,249.485
Urban Other	151,806.666	38,070.707	1,075.202	6,204.656	3,542.292	200,699.523
4	**69,962.445**	**18,001.568**	**99.375**	**1,660.805**	**4,823.793**	**94,547.987**
Rural Arterial	9,394.728	2,931.631	20.265	247.230	915.966	13,509.819
Rural Interstate	3,624.472	857.857	12.693	104.191	689.670	5,288.884
Rural Other	7,512.484	3,107.282	4.546	252.310	488.709	11,365.331
Urban Arterial	29,725.355	5,692.169	33.571	581.899	1,268.242	37,301.237
Urban Interstate	11,398.468	2,601.995	28.300	267.274	1,425.988	15,722.025
Urban Other	8,306.937	2,810.635	-	207.901	35.218	11,360.691
5	**187,276.324**	**40,164.319**	**1,585.871**	**8,858.397**	**14,365.355**	**252,250.265**
Rural Arterial	29,166.287	7,896.345	280.810	2,031.508	3,106.958	42,481.908
Rural Interstate	14,100.153	2,980.894	194.054	919.745	4,758.350	22,953.198
Rural Other	25,707.647	6,426.714	239.210	1,742.493	1,015.664	35,131.728
Urban Arterial	63,167.416	11,524.719	478.089	2,527.600	2,065.579	79,763.404
Urban Interstate	27,232.586	6,710.331	221.803	1,002.589	3,122.641	38,289.950
Urban Other	27,902.235	4,625.315	171.904	634.462	296.162	33,630.077
6	**55,933.755**	**27,815.150**	**462.544**	**2,797.015**	**7,502.814**	**94,511.279**
Rural Arterial	10,499.871	7,035.578	122.128	764.575	2,186.659	20,608.811
Rural Interstate	6,606.522	3,026.633	54.393	351.011	3,018.520	13,057.079
Rural Other	6,157.461	5,315.492	95.668	537.486	876.911	12,983.018
Urban Arterial	18,840.905	7,427.276	109.021	580.893	603.087	27,561.182
Urban Interstate	7,808.644	1,860.979	32.047	288.747	651.352	10,641.770
Urban Other	6,020.352	3,149.191	49.287	274.303	166.286	9,659.419

Region/Hwy Type	Auto /MC	Light Trucks	Bus	Single Unit	Combination	Total VMT
7	**39,203.433**	**16,268.682**	**163.380**	**3,263.318**	**2,655.273**	**61,554.084**
Rural Arterial	3,799.037	1,953.920	19.130	456.525	394.951	6,623.562
Rural Interstate	3,302.918	1,381.109	17.362	308.120	591.747	5,601.255
Rural Other	3,963.446	2,201.943	17.277	508.098	330.430	7,021.195
Urban Arterial	15,509.561	5,674.335	58.761	1,083.654	604.165	22,930.476
Urban Interstate	7,634.792	2,738.777	28.163	464.150	528.867	11,394.749
Urban Other	4,993.679	2,318.598	22.687	442.771	205.113	7,982.847
8	**68,639.914**	**26,488.572**	**761.506**	**6,869.749**	**9,289.014**	**112,048.756**
Rural Arterial	9,396.810	5,018.872	140.683	1,358.451	1,593.023	17,507.840
Rural Interstate	6,487.680	3,155.938	74.891	748.073	3,545.053	14,011.634
Rural Other	7,229.228	4,638.608	124.737	1,261.134	1,016.722	14,270.428
Urban Arterial	21,745.139	6,551.912	194.217	1,467.093	995.912	30,954.273
Urban Interstate	9,527.176	3,884.008	63.028	1,031.525	1,668.656	16,174.393
Urban Other	14,253.881	3,239.235	163.950	1,003.473	469.650	19,130.188
9	**260,482.111**	**104,720.560**	**1,615.655**	**17,133.808**	**28,068.647**	**412,020.781**
Rural Arterial	31,553.921	16,696.547	233.001	3,314.790	6,600.044	58,398.303
Rural Interstate	18,920.528	7,625.758	225.897	1,444.271	7,812.748	36,029.202
Rural Other	24,719.519	15,486.602	213.761	3,357.862	3,572.955	47,350.700
Urban Arterial	110,004.623	36,168.935	507.190	5,199.245	4,839.161	156,719.154
Urban Interstate	40,774.431	13,053.516	245.108	2,077.673	4,329.993	60,480.721
Urban Other	34,509.089	15,689.201	190.698	1,739.968	913.746	53,042.701
10	**238,897.915**	**62,432.858**	**1,229.024**	**10,830.288**	**12,881.574**	**326,271.659**
Rural Arterial	15,978.958	5,763.398	133.389	1,366.605	1,925.327	25,167.676
Rural Interstate	10,489.477	3,444.831	63.402	811.895	2,802.008	17,611.613
Rural Other	9,758.448	3,722.067	98.764	692.820	468.759	14,740.859
Urban Arterial	123,835.992	29,261.720	538.559	5,189.753	4,373.754	163,199.779
Urban Interstate	51,892.235	12,148.063	192.499	1,904.365	2,612.487	68,749.649
Urban Other	26,942.805	8,092.778	202.411	864.849	699.240	36,802.083
Grand Total	**2,084,654.324**	**601,087.814**	**14,754.565**	**104,960.105**	**163,358.097**	**2,968,814.904**

Splitting VMT among States, Highway Functional Classes, and 13 FHWA Vehicle Classes

The USDOT study team used available 2012 and 2013 classification data in the newer “TMAS” format, as well as some 2011 and 2012 classification data in the older “VTRIS” format. We processed all the files and summarized total counts by the 13 FHWA vehicle classes for each station. We obtained data from a total of 1,756 classification stations, although some of the stations had much less than the hoped for 24/7/365 data.

We used station description files to assign a highway functional class to each station in each State and compiled tables of total vehicle counts for each functional class and State. After assembling this data, we found that the data covered about 40 percent of the functional class / state combination, so we opted to use older, more complete data to cover the gaps. Using the combination of new and old data as well as observed differences in truck percentages as we move to the lower functional classes, we derived a preliminary (unadjusted) estimate of vehicle class proportions for the 13 classes on each highway functional class in each State.

FHWA publishes annual estimates of travel by highway type and state (VM-2 table). We applied the preliminary set of vehicle class proportions to the traffic volumes from the January 2014 FHWA website version of the 2012 VM-2 table to convert the vehicle class proportions into preliminary estimates of VMT. As described in the next section, we used WIM data to refine and expand these preliminary estimates.

Splitting VMT into 28 Vehicle Classes Used in CTSW Study

In FHWA's classification data, vehicles are classified based solely upon the measured number of vehicle axles and their axle spacings. The advantage WIM measurements offer is that the number of vehicle axles and their spacing are also measured along with the weight of each axle. On the other hand, virtually all the WIM data we obtained came from vehicles traveling in only one lane of a multilane facility, so was very likely biased in the population of vehicles observed. Further, light vehicles were usually filtered out of weight compilations, so we could not use WIM data to derive truck percentage estimates. The team assumed, however, that the right-lane / other-lanes biases were similar for subclasses of the 13 FHWA classes, thus allowing reasonably accurate splitting or reassignment of each class.

As with past studies that have evaluated the effects of truck size and weight policy, the 2014 CTSW Study needs to classify heavier trucks into more categories than are included in the 13-class scheme to allow evaluation of differential changes in travel patterns for particular vehicle configurations (seven-axle triples vs. nine-axle triples, for example). Further, the axle weight distributions for subsets of some of the 13 classes are apt to vary substantially among themselves. Better differentiation among the subsets allows a higher degree of precision in the analysis.

The 2014 CTSW Study used 28 vehicle classes, listed in the table below.

Table G2. Vehicle Classifications Used in the 2014 CTSW Study

Class	Name	Description
1	Auto / MC	Auto and motorcycle
2	LT4	Light truck with 4 tires
3	SU2	Single-unit truck with 6 tires
4	SU3	Single-unit truck with 3 axles
5	SU4+	Single-unit truck with 4 or more axles
6	CS3	Tractor-semitrailer with 3 axles
7	CS4	Tractor-semitrailer with 4 axles
8	3S2	3-axle tractor, 2-axle tandem-axle semitrailer
9	Oth CS5	Other tractor semitrailer with 5 axles
10	3S3	3-axle tractor, 3-axle tridem-axle semitrailer
11	Oth CS6	Other tractor semitrailer with 6 axles
12	CS7+	Tractor-semitrailer with 7 or more axles
13	CT3/4	Truck-trailer with 3 or 4 axles
14	CT5	Truck-trailer with 5 axles
15	CT6	Truck-trailer with 6 axles
16	CT7	Truck-trailer with 7 axles
17	CT8	Truck-trailer with 8 axles
18	CT9+	Truck-trailer with 9 or more axles
19	DS5	Double trailer truck with 5 axles
20	DS6	Double trailer truck with 6 axles
21	DS7	Double trailer truck with 7 axles
22	DS8	Double trailer truck with 8 axles
23	DS9+	Double trailer truck with 9 or more axles
24	TS7	Triple trailer truck with 7 axles
25	TS8	Triple trailer truck with 8 axles
26	TS9+	Triple trailer truck with 9 or more axles
27	Bus2	Bus with 2 axles
28	Bus3	Bus with 3 axles

The team constructed a detailed vehicle classification algorithm that built upon the weight/spacing algorithm used for compiling the LTPP WIM data. By using a combination of axle weights and spacings, we could much more accurately assign vehicles to the correct class.

The team drew upon two sources of WIM data: (1) data submitted to FHWA by each State as part of its traffic monitoring program, and (2) data collected at each LTPP WIM site and compiled by FHWA. The state-supplied data came from 451 WIM stations and included nearly 400 million vehicle observations; the LTPP data included about 250 million weight observations from 19 sites. Most WIM data were from 2010 to 2013.

The team applied the classification algorithm to all the truck weight observations and cross-tabulated the axle-spacing-only, initial 13 classes with the assignment of the same vehicles based on the 28-class, weight-and-spacing algorithm. We developed a cross-tabulation array for each State that allowed us to reassign the 13-class VMT estimates into more accurate 28-class estimates for each State and functional class. Three States, Alaska, North Carolina, and North Dakota, did not have sufficient WIM data to develop their own reassignment arrays, so we used substitute reassignment arrays from the nearby states of Washington, South Carolina, and South Dakota, respectively.

The team proportionally adjusted each of the 28 vehicle class VMTs in each State and functional class such that we precisely matched the FHWA control totals for each region and highway type.

Adjusting VMT to 2011 Published Control Totals

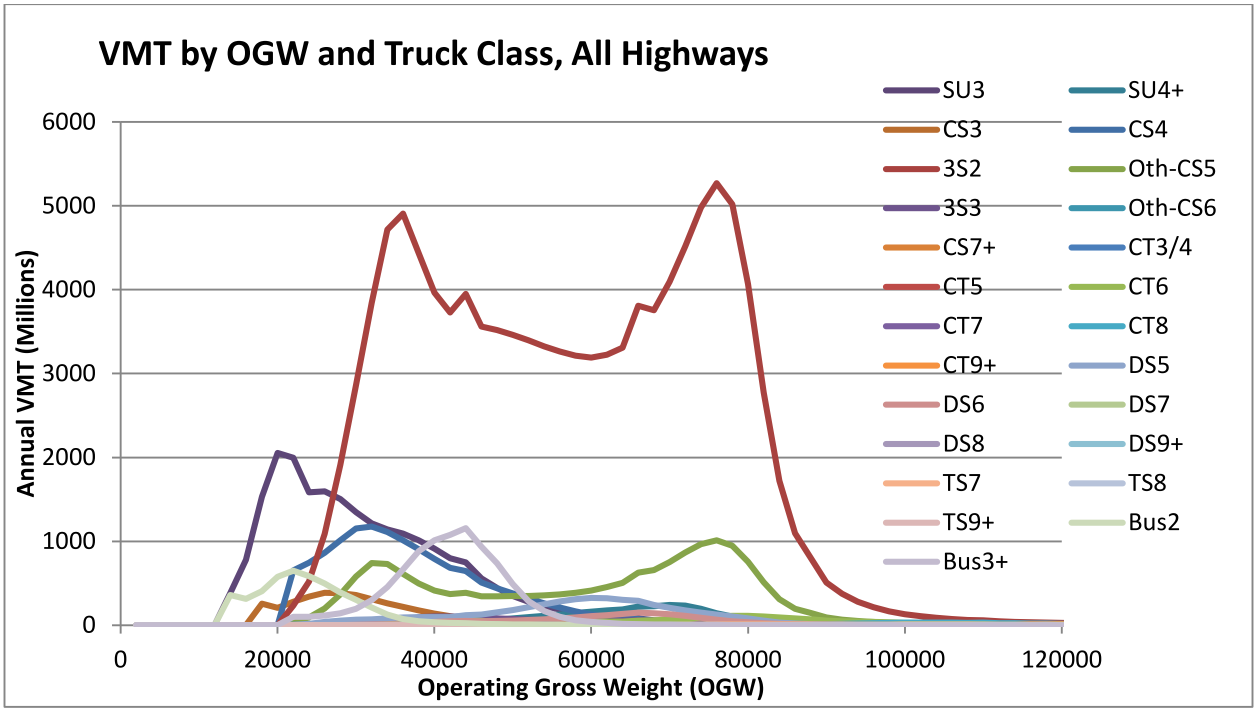
In addition to the VM-2 table described in the previous section, FHWA publishes annual estimates of travel by broad type of vehicle in the VM-1 table. Since the 2014 CTSW Study had settled upon 2011 as the year of analysis, the study team adjusted the 2012 control total estimates to match the published control totals for 2011. Because the year-to-year changes were relatively small, and because we had relatively little interest in travel estimates for the predominant two broad classes (auto/motorcycle and light truck), the team opted for an easily-replicable, three-step adjustment approach rather than a more complicated iterative-proportional-splitting technique.

FHWA first multiplied the VMT estimates for all vehicles in each state and functional class by the ratio of the corresponding 2011 to 2012 VM-2 table estimates. We then calculated ratios of VMT from the 2011 VM1 table (the version posted on the FHWA website on January 22, 2014) to the grand totals for all the vehicles in each broad type of vehicle. Finally, we adjusted auto / motorcycle VMT as needed so that total VMT for all vehicles in each FHWA calibration cell (region / highway type combination) remained unchanged.

Operating Weight and Axle Weight Distributions

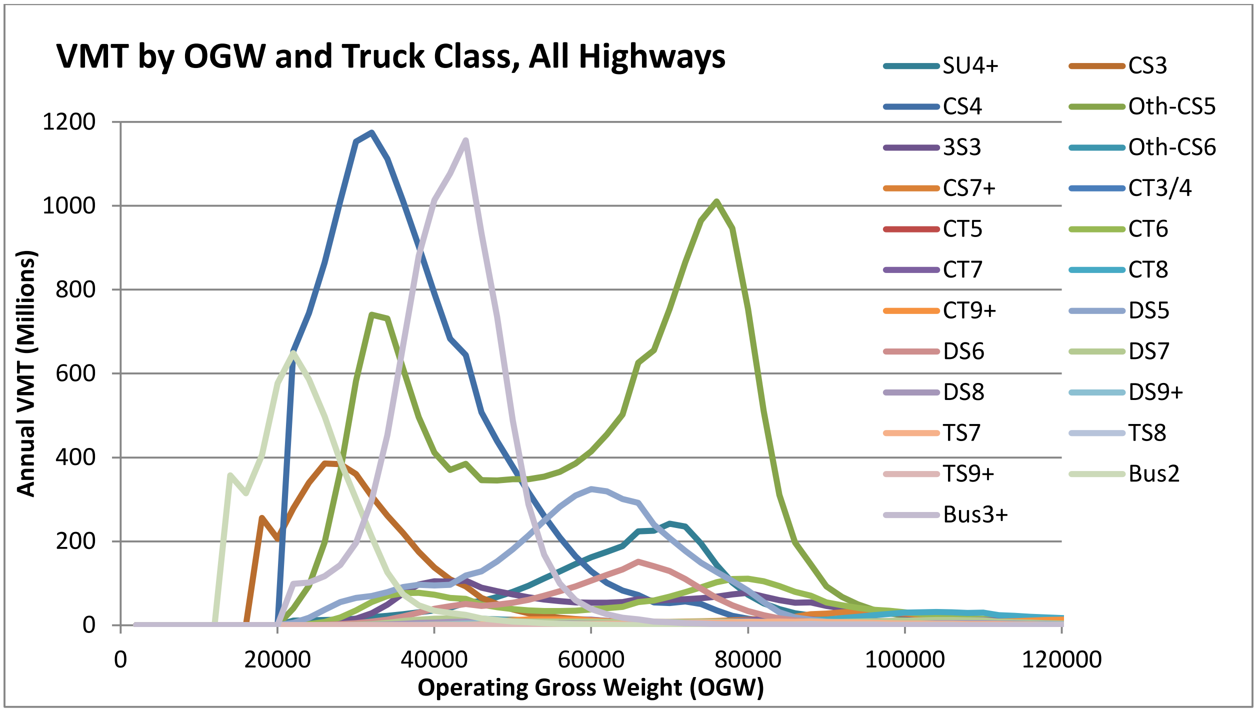
The study team used the same WIM data described in a previous section to derive operating gross weight (OGW) and axle weight distributions for use in various phases of the 2014 CTSW Study. The OGW distributions consist of estimates of proportions of VMT in each 2,000-lb. OGW increment with upper bounds from 2,000 to 198,000 lbs., as well as a final increment of 198,001 lbs. and up. There is a unique OGW distribution for each of the 10 regions. For individual vehicle classes, OGW distributions are assumed to be the same on all highway functional classes within a region. This assumption was necessary because there was insufficient WIM data to develop separate OGW distributions by highway class. The two graphs below provide a good overview of the overall distribution of vehicle classes and operating weights considering all highway travel in the base year. The first graph excludes travel by light vehicles and two-axle trucks to highlight the larger truck classes. Note the dominance of the common 3-S2 configuration when considering all travel on all highways.

Figure G3. VMT by OGW and Truck Class, All Highways



The next graph removes the two most common classes (SU3 and 3S2) to show the relative importance of the remaining truck classes.

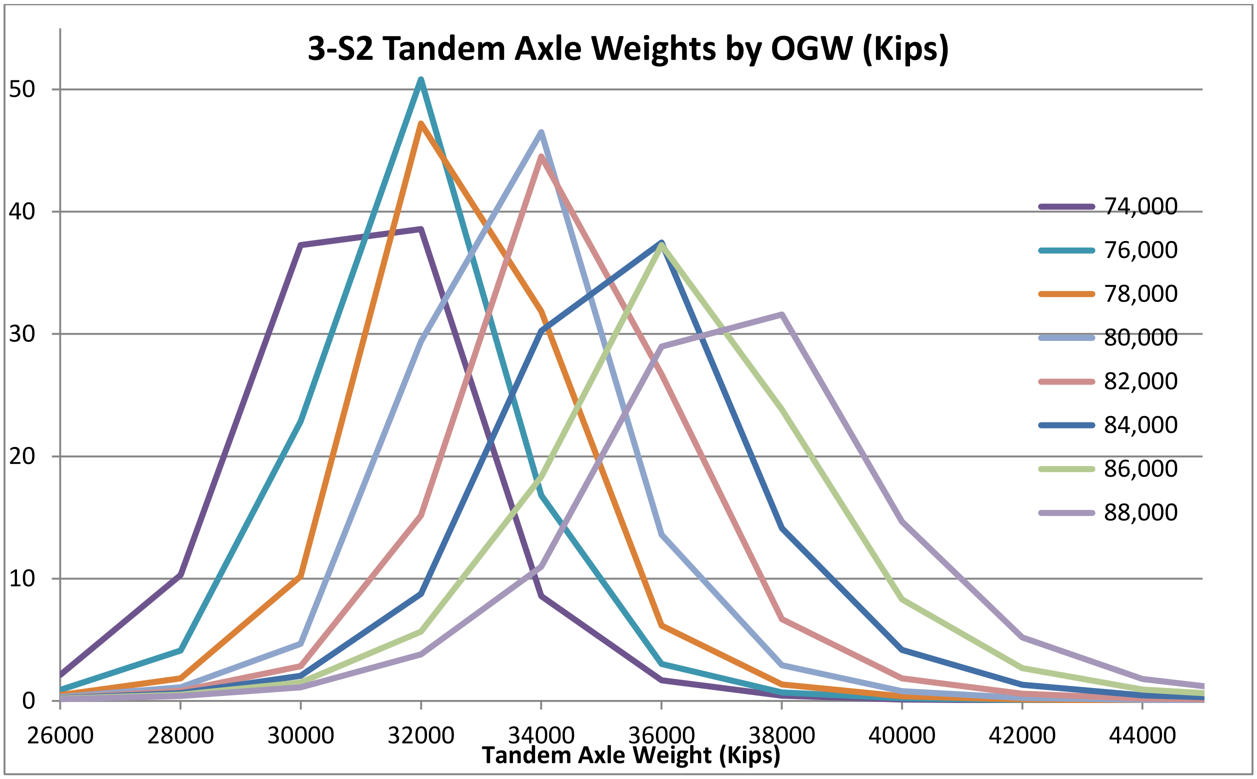
Figure G4. VMT by OGW and Truck Class, All Highways without SU3 and 3S2



Axle weight distributions consist of numbers of axle per vehicle falling into each of four axle types (steering axle, single load axle, tandem load axle, and tridem load axle) and 40 weight groups for each type of axle (centered on 1,000-lb. categories for single axles, 2,000-lb. categories for tandem axles, and 3,000-lb. categories for tridem axles). For example, weight group 1 for single axles covers axles from 1 to 1,500 lbs.; group 2 includes axles from 1,501 to 2,500 lbs., and so on. Group 40 includes single axles operating at 39,501 lbs. and above. Tandem axle group 1 includes axles from 1 to 3,000 lbs., group 2 axles from 3,001 to 5,000 lbs., etc.

Each OGW of each vehicle class in each region has a unique axle weight and type distribution. The figure below illustrates a sample of tandem axle weight distributions for selected 3-S2 vehicles in one traffic region. Note the range of prevalent axle weights within a given operating weight group—an important factor to consider when evaluating the relative impacts of a particular configuration operating a particular gross vehicle weight.

Figure G5. 3-S2 Tandem Axle Weights by OGW (Kips)



For the bridge analysis, all axle weights and types for all vehicle classes are grouped together, and the 12 functional classes are grouped into three highway types for each of two regions. For the pavement analysis, the 28 vehicle classes are grouped into 8 classes, all OGWs in each class are grouped together, and the 12 functional classes are grouped into 3 highway types. Other phases of analysis require other groupings of the data.

APPENDIX H: RAIL CONTRIBUTION AND REVENUE ANALYSIS

Truck Size and Weight Short Line Analysis Methods

This document outlines the technical approach to the analyses of the effects on short line railroads brought about by changes in truck sizes and weights. Short lines are Class II and Class III railroads as defined by the Surface Transportation Board (STB). There are around 560 short line railroads operating in the U.S. Of these, 10 are Class II's with the remaining Class III's. Together these railroads originate or terminate about 18 percent of Class I carload freight or around 6.5 million carloads, annually and generate around $4 billion in revenues. While commodity makeup on these carriers is diverse, they principally serve rural communities and provide these areas the rail link to the Class I railroad network. Short line railroads provide two primary high level service: 1) extension of Class I railroads with the interlining and 2) regional/intrastate rail service.

Similar to the Class I railroad analysis, the short line analysis examined the impacts on operating revenues resulting from both rate reductions or discounting on the part of the railroad to hold on to existing rail traffic and lost revenue due to diversion of traffic from rail to trucks when the railroad has to give up the traffic because it will not move the goods below cost. The short line analysis uses the ITIC model and the 2011 STB Carload Waybill Sample in the same way as was done for the analysis of potential impacts on the Class I railroads.

To consider the effects on short line railroads, those records on the waybill sample were analyzed, where a short line railroad was identified as an originating, intermediate, or terminating carrier. This is the "documented" set of short line moves. This data set includes any waybill that reports a short line railroad. Overall, the waybill sample documents moves by around 140 short line railroads, far fewer than the total number of short line railroads operating in any year. Industry experience tells us that sometimes short line railroads are not included on the waybill sample because the Class I railroad handles the billing/settlement for these carriers. To handle the unreported short line railroads, an additional dataset was developed that identified waybill records where the origin or destination was on a Class I railroad and there was access to a short line railroad within a reasonable range of their origin or destination. This dataset was referred to as the "potential" short line waybills. This data set included any waybill record that could potentially have involved a short line railroad but did not identify that short line on the waybill.

The short line analysis employed two data sources to develop revenue impacts for the illustrative truck size and weight scenarios. First, the analysis used the 2011 STB Carload Waybill Sample. The Waybill Sample was used in conjunction with the ITIC model to estimate rail shipments potentially affected by the scenario truck size and weight limits and short line revenues affected by the scenarios. Finally, the 2011 Centralized Station Master (CSM) was used to determine which waybills on the Waybill Sample would be geographically relevant to short line railroads.

Short line rail impacts were analyzed after total rail impacts were estimated. Initially all rail shipments potentially affected by the scenario truck size and weight limits were identified through the application of ITIC. Subsequently those shipments were further analyzed to assess which might have included movements by short lines for part of the trip. As explained below, some waybill records explicitly included the short line portion of the move while short line operations for other moves had to be inferred based on the proximity of short line railroads to origins and destinations of waybill records.

Documented Short Line Data Set

The documented short line data set includes any waybill record where a short line was specifically identified as being involved along some portion of the route. To construct the documented short line data set, we identified each waybill sample where a short line was an originating, intermediate, or terminating carrier. Next, those waybills were crossed referenced with the set of all rail waybills that were identified as being affected by the scenario truck size and weight policy changes. The dataset of documented waybills involving short line moves that would be affected by scenario changes was broken down into two sets: those for which rail traffic would be diverted to trucks and those for which short lines could be expected to discount their prices to keep the traffic from diverting to truck. As expected, diversions or rate reductions occurred across multiple scenarios for the same waybill. For example, if rail traffic reflected by a waybill is diverted in Scenario 1, diversion would also occur in Scenarios 2 and 3 because the size of the truck increases with each scenario.

To estimate the revenue impacts from diverted traffic, the analysis used the waybill sample revenue estimates. The waybill includes revenue for each railroad on each part of the journey. This estimate of revenue differs slightly from that of the analysis for all railroads which used average revenue for particular origin and destination pairs. For the revenue impacts due to diverted traffic, the results aggregated the revenue across the waybills by including only the revenue received by the short line segment of the trip. The analysis assumes that all revenue on a diverted waybill is lost. Revenue losses were estimated only for Scenarios 1-3. Potential revenue losses associated with Scenarios 4-6 could not be estimated due to data constraints.

To estimate the revenue lost due to discounting rates to keep traffic on the rail, the analysis used the revenue reduction totals as estimated in the original analysis. These totals include revenue for the entire haul and, therefore, could not explicitly be broken down by revenue lost on Class I railroads versus short line railroads. To estimate the revenue lost on short line railroads, the analysis first estimated the percent of total revenue on each waybill for a given short line. Next, the analysis applied this percent to the total revenue lost due to discounting to estimate the loss to short line railroads only. This step assumes that the lost revenue due to discounting is lost in the same proportion as the revenue received. In theory, a Class I could absorb a larger percentage of these losses or vice versa, but no information was available to estimate differential rate reductions.

Potential Short Line Data Set

As noted above, not all short line operations are directly reflected on waybill records. The CSM data provides geographical information on railroad junctions and allows waybills that potentially included short line operations to be identified when the waybill record does not include information on short line involvement. A potential short line data set (waybills that potentially involved short line moves that were not specifically noted in the waybill itself) was developed to attempt to estimate the full range of potential short line impacts associated with scenario truck size and weight limit changes. This potential short line data set consists of all waybills with origins or destinations at junctions with a short line railroad, but which do not indicate that a short line was involved in the move. There was no way to determine which of these records actually involved a short line, so this data set includes all potential waybill records that could have included short line operations that were not reported. As with the documented short line data set, waybills in the potential short line data set were matched with waybills from the overall analysis of potential rail impacts associated with each scenario to identify the potential short line moves that could be affected by truck size and weight changes.

Because none of these records actually have the short line documented at the origin or destination, these waybill records could not provide revenue explicitly for the short line portion of the trip. To assign the revenue to short line railroads, the analysis first examined the entirety of the waybill sample to identify waybill records with similar trip characteristics. The waybill was used to identify any trip where a short line railroad provided the origin or destination segment of the trip and connected to a Class I railroad (these records are already included in the documented dataset). From this sample, the analysis estimated the average percent of revenue a short line received when providing service and connecting to a Class I railroad. Next, this percent was applied to the total revenue on a waybill to estimate the hypothetical short line revenue.

Using this methodology, the analysis needed to assume that there is no systematic bias in the way waybills are and are not reported for short line railroads. This revenue would not be a good proxy for an unreported short line trip if the true population of unreported short line trips were inherently different from those that are reported. For example, if unreported short line trips were overall shorter than the ones reported or if particular routes were systematically not reported on the waybill, the revenue estimates would not be a good proxy for the unreported short line trip. This data set should be thought of as an upper bound to the potential of unreported short line trips. Obviously, not all short line trips are unreported. This dataset provides an illustrative example of the worst case impacts on the unreported short lines but makes no claims as to which, where, or how often short line railroads go unreported.

End Notes:

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