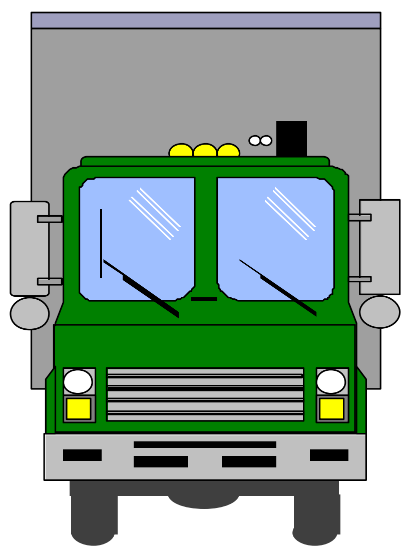
CHAPTER IX

Traffic Operations



Introduction

Longer and heavier trucks tend to disrupt traffic flow on roadways more than conventional vehicles. However, more trucks of any size or weight would also disrupt traffic. Disruption occurs in the through traffic lanes, at roadway intersections, and on freeway interchanges. Common measures of disruption include hours of delay and congestion costs.

This chapter presents estimates of changes in delay and associated congestion costs resulting from the truck size and weight (TS&W) policies tested in the five illustrative scenarios: Uniformity, North American Trade, Longer Combination Vehicles (LCVs) Nationwide, H.R. 551, and Triples Nationwide. Qualitative assessments of other, related, impacts are also discussed.

Basic Principles

Traffic Congestion

Traffic congestion depends on the capacity of and the amount of traffic on a given highway. It is assessed in terms of passenger car equivalents (PCE). 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. 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.

Trucks are larger and, more importantly, accelerate more slowly than passenger cars, and thus have a greater effect on traffic flow than passenger cars. 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 congested traffic their effect on traffic flow often is much greater and they may be equivalent to 15 or more passenger cars. The actual number of PCEs depends on the operating speed and grade of the highway section, the vehicle's length, and its weight- to-horsepower ratio which is a measure of how the vehicle can accelerate. Tables IX-1 and IX-2 show PCEs for trucks operating in rural and urban areas under different conditions. The effects of differences in truck length and weight-to-horsepower ratio is shown in those tables. The tables are not intended to show extreme situations either in terms of roadway or vehicle characteristics; under different characteristics the PCEs could be higher than shown in those 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 IX-1 shows PCEs for trucks on rural highways. It demonstrates that the highest PCEs occurs on highways with the steepest grades and highest speeds. Table IX-2 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.

Other Traffic Effects

In addition to congestion, this Study has assessed, but not quantified in detail, the impact of longer and heavier trucks on the operation of traffic in the areas of vehicle offtracking, passing, acceleration (including merging, speed maintenance,

Table IX-1. 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
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
			250	13.8	15.1	Not Simulated

and hill climbing), lane changing, sight distance requirements, and clearance times. 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.

Offtracking

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 offtracking. Two other measures are high-speed offtracking and dynamic high-speed offtracking. High-speed offtracking , is steady-state swing out of the rear of a combination vehicle going through a gentle curve at high speed. Dynamic high-speed offtracking is a swinging back and forth due to rapid steering inputs. On roadways with standard lane widths, the two high-speed offtracking effects are not large enough to be of concern. Excessive low-speed offtracking can disrupt

Table IX-2. Vehicle Passenger Car Equivalents on Urban Highways

Roadway Type	Traffic Flow Condition	Grade	Vehicle Weight-to-Horsepower Ratio (pounds/horsepower)	Truck Length 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

traffic operations and result in shoulder or inside curb damage at intersections and at interchange ramp terminals designed like intersections that are used heavily by trucks. There is little, if any, link between low-speed offtracking and the likelihood of serious crashes (fatal or injury-producing). This is due to the vehicle's very low speed when turning sharply. The reader is referred to Chapter VII, Roadway Geometry, for a detailed discussion of offtracking.

Standard STAA doubles (two 28-foot trailers) and triple-trailer combinations (three

Table IX-3. Effects of Speed Differentials on Crash Involvement

Speed Differential (mph)	Crash Involvement	Involvement Ratio (related to 0 speed differential)
0	247	1.00
5	481	1.95
10	913	3.70
15	2,193	8.88
20	3,825	15.49

28-foot trailers) exhibit better low-speed offtracking performance than a standard tractor and 48-foot or 53-foot semitrailer combination, as they have more articulation points in the vehicle combination and use trailers with shorter wheelbases.

Passing or Being Passed on Two-Lane Roads

Cars passing LCVs on two-lane roads could 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. Also heavier trucks require more engine power to pass another vehicle if it is necessary to accelerate to pass the overtaken vehicle.

Operators of longer or heavier vehicles have to be more diligent to avoid potential passing conflicts. Standards for marking passing and no-passing zones on two-lane roads, developed in the 1930's, 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 mitigated by the fact that truck drivers have a better view of the road as they sit higher than car drivers.

Vehicle Acceleration

Acceleration performance determines a truck's basic ability to blend well with other vehicles in traffic, which is of particular concern in cases where frequent truck-car conflicts can be anticipated. This issue needs to be addressed when considering the ability of a given segment of roadway to safely accommodate longer and heavier trucks. Poor acceleration is a concern as it can result in large speed differentials between vehicles in traffic, and crash risks increase significantly with increasing speed differential.

Table IX-3 indicates that crash involvement may be from 15 times to 16 times more likely at a speed differential of 20 miles-per-hour (mph).

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 screening routes to ensure they are suitable for use by any vehicle at its proposed weight and dimensions. Aerodynamic truck designs, by reducing drag, help trucks to accelerate and maintain speed as well.

On routes with steep grades

Table IX-4. Distribution of Grades on Arterial Highways

Grade (percent)	0.00 - 0.49	0.50 - 2.49	2.50 - 4.49	4.50 - 6.49	6.50 or more
Miles of Highways (thousands)	64.7	47.4	15.2	4.6	1.2
Percent of Total	48.6	35.6	11.4	3.4	0.9

that are frequently traveled by trucks, special truck climbing lanes have been built. Otherwise, trucks should be able 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. However, this type of specification can be counterproductive, since larger engines consume more fuel and emit more air pollutants. While in some cases, larger engines may be necessary to maintain grade climbing performance, experience has shown that a more easily enforced 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.

Grades

The Highway Performance Monitoring System (HPMS) provided the highway grade data for the 48 contiguous States and the District of Columbia. The highway types examined were rural freeway, rural multilane, rural two-lane, urban freeway, and urban arterial. Table IX-4 summarizes this information by mileage. It shows that almost half of the highway system has a grade of no more than 0.5 percent and that more than 80 percent has a grade of no more than 2.5 percent.

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

Figure IX-1. Highway Performance Monitoring System

The Highway Performance Monitoring System database is the primary source of information for the Federal government about the Nation's highway infrastructure. This is the most comprehensive nationwide data system in use for any aspect of the Nation's infrastructure. Data collection is the responsibility of the States, and it is updated each year. The States forward the data to the Federal Highway Administration, which maintains and uses these data for a variety of strategic planning and highway investment evaluation uses. The Office of Highway Policy Information is responsible for receiving, reviewing, and tabulating these data.

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.

Table IX-1 shows the marked effect that percent and length of grade have on truck climbing ability if the truck does not have a low ratio of GVW to horsepower.

Industry Experience with Heavier Trucks

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. Trucks today maintain speed and accelerate better than they ever have.

Traction

If single-drive-axle tractors are used in multitrailer 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 multitrailer combinations when they have traction problems.

Lane Changing

Compared to conventional tractor-semitrailer combinations, longer vehicles require larger gaps in traffic flows in order to change lanes or merge with traffic. Skilled drivers can compensate for this vehicle property by minimizing the number of lane changes they make and using extra caution when merging. The effect of this performance characteristic is proportional to vehicle length and the traffic densities in which a given vehicle operates.

Intersection Requirements

Heavier vehicles entering traffic on two-lane roads from unsignalized 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 unsignalized 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.

How truck size (dimensions), design features, loading (weight distribution), and operation affect traffic congestion, offtracking, passing, acceleration, lane

Table IX-5. Traffic Operations Impacts of Truck Size and Weight Limits

Vehicle Features		Traffic Congestion	Vehicle Offtracking		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	—

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

changing, and intersection requirements are shown in Table IX-5 This table shows that the important parameters are vehicle length and weight with speed 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.

A feature of each scenario that eliminates certain traffic impacts is that axle loads are not increased. This means that there is no increased demand on any one set of brakes for stopping or descending long steep grades due to trucks being heavier as, necessarily, they must have more axles to be allowed to carry more weight.

Analytical Approach

Highway user delay and congestion costs 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 for two sets of representative roadway geometric conditions for each of the three highway types.

The truck vehicle-miles-of-travel (VMT) by truck configuration and weight that is estimated to result from new TS&W policy scenarios 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 of $13.16 per hour to obtain the change in congestion costs. This value was taken from the Highway Economic Requirement System ($10.92 in 1990 dollars) and adjusted for increased fuel consumption and inflation for 1994.

Assessment of Scenario Impacts

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

It can be seen that the Triples Nationwide scenario, which would increase the weight limit significantly, could reduce delay and congestion costs by up to 7.6 percent in 2000. This assumes that requirements are in place to ensure the heavier trucks have engines with power sufficient to perform as existing trucks perform. Truck engines with enough power to accelerate a truck up to traffic speed and to maintain speed on grades at the same performance level as 80,000-pound vehicles are available on the market today for combinations weighing up to 130,000 pounds. Regarding time to pass or clear intersections, the longest truck combinations would require from 10 percent to 15 percent more time for these traffic maneuvers than a five-axle semitrailer combination.

As reference numbers for the delay and congestion cost for each scenario, the estimated delay on U.S. highways in 1994 is 18.7 billion hours and the costs for this aggregate delay were estimated to have been $246.5 billion. This estimate is based on data in *Highway Information Quarterly*, June 1998, Office of Highway Policy Information, FHWA and VMT estimates from the DOT's *1997 Federal Highway Cost Allocation Study*. With no change in TS&W policy, in the year 2000 the aggregate delay and associated costs are estimated to increase by 19 percent to 22.3 billion hours and $292.9 billion respectively.

Vehicle offtracking is assessed in terms of the costs to improve geometric features to the extent necessary to remove any traffic operations problem that results from excessive offtracking. These costs are included in Chapter VII, Roadway Geometry, and discussed here in qualitative terms. The remaining traffic operations impacts-- passing, acceleration, lane changing, and intersection requirements -- are also discussed in qualitative terms.

Table IX-6. Uniformity Scenario Traffic Impacts

Impact	1994	2000 (base case)	2000 (scenario)
Traffic Delay (million vehicle-hours)	18,700	22,300	22,400
Congestion Costs ($million)	246,500	292,900	294,800
Low-Speed Offtracking		Some degradation from 1994 resulting from VMT increase for long double combinations	Improvement for roadways on which long doubles now operate but would not in the future.
Passing		Some degradation from 1994 resulting from VMT increase	Negligible change over 2000 base case
Acceleration (merging and hill climbing)		Some degradation from 1994 resulting from VMT increase	Negligible change over 2000 base case
Lane Changing		Some degradation from 1994 resulting from VMT increase	Negligible change over 2000 base case
Intersection Requirements		Some degradation from 1994 resulting from VMT increase	Negligible change over 2000 base case

Uniformity Scenario

As a result of the shift of freight from heavier and longer vehicles to five-axle semitrailer combinations at 80,000 pounds, this scenario would increase traffic congestion and associated costs in the year 2000 by 0.4 percent (see Table IX-6).

North American Trade Scenarios

These scenarios are estimated to improve traffic operations in a small way across all impacts (see Table IX-7). However, for some of the impacts, this is based on the assumption the requirements are in place to ensure that increased engine power for those configurations with increased gross vehicle weights. Traffic delay and congestion costs would be slightly more (0.2 percent) in 2000 than they would be otherwise.

Longer Combination Vehicles Nationwide Scenario

The large increase in LCV use resulting from this scenario would have several adverse effects if their operations were not restricted (see Table IX-8).

The scenario assumes these traffic operations problems would be addressed by restricting the use of these LCVs to multilane divided

Table IX-7. North American Trade Scenarios Traffic Impacts

Impact	1994	2000 (base case)	2000 (scenario)
Traffic Delay (million vehicle-hours)	18,700	22,300	22,000
Congestion Costs ($million)	246,500	292,900	289,500
Low-Speed Offtracking		Some degradation from 1994 resulting from VMT increase for long double combinations	No impact. Featured vehicle off-tracks the same or less than baseline vehicle
Passing		Some degradation from 1994 resulting from VMT increase	Requires operating restrictions.
Acceleration (merging and hill climbing)		Some degradation from 1994 resulting from VMT increase	Requires sufficient engine power.
Lane Changing		Some degradation from 1994 resulting from VMT increase	Some degradation due to additional length. (This is counterbalanced by large decrease in heavy truck VMT.)
Intersection Requirements		Some degradation from 1994 resulting from VMT increase	Some degradation due to additional length. (This is counterbalanced by large decrease in heavy truck VMT.)

highways with entry and exit only at interchanges where needed improvements have been made. Otherwise, traffic operations and safety could be expected to be degraded on two-lane highways and during periods of peak traffic congestion. As these LCVs are heavier, as well as longer, provision for adequate engine power would need to be required to ensure smooth traffic flow through freeway interchanges and up steep grades. However, it is estimated that this scenario would reduce user delay and congestion costs by 3 percent below that which can otherwise be expected in 2000.

H.R. 551 Scenario

This scenario, by eliminating semitrailers longer than 53 feet, will somewhat improve traffic flow through intersections where these longer trailers now operate. Beyond this, as shown in Table IX-9, its impacts are negligible.

Table IX-8. Longer Combinations Nationwide Scenario Traffic Impacts

Impact	1994	2000 (base case)	2000 (scenario)
Traffic Delay (million vehicle-hours)	18,700	22,300	21,600
Congestion Costs ($million)	246,500	292,900	284,300
Low-Speed Offtracking		Some degradation from 1994 resulting from VMT increase for long double combinations	Significant degradation (27.0 feet for turnpike double versus 16.5 feet for semitrailer)
Passing		Some degradation from 1994 resulting from VMT increase	Requires operating restrictions.
Acceleration (merging and hill climbing)		Some degradation from 1994 resulting from VMT increase	Requires sufficient engine power.
Lane Changing		Some degradation from 1994 resulting from VMT increase	Some degradation due to additional length. (This is counterbalanced by large decrease in heavy truck VMT.)
Intersection Requirements		Some degradation from 1994 resulting from VMT increase	Requires operating restrictions (LCVs should not operate through intersections with significant traffic volumes or insufficient sight distances for other traffic.)

Triples Nationwide Scenario

As with the LCVs Nationwide Scenario, this scenario would result in a large increase in the use of triple-trailer combinations. However, offtracking is not a problem for triple-trailer combinations, although length and additional weight remain significant concerns in regard to traffic operations. Also, this scenario can be expected to reduce highway user delay and congestion cost by 8 percent from that which can be expected in 2000 (see Table IX-10).

Table IX-9. Triples Nationwide Scenario Traffic Impacts

Impact	1994	2000 (base case)	2000 (scenario)
Traffic Delay (million vehicle-hours)	18,700	22,300	20,600
Congestion Costs ($million)	246,500	292,900	270,500
Low-Speed Offtracking		Some degradation from 1994 resulting from VMT increase for long double combinations	Some improvement as a triple trailer combination offtracks less (12.7 versus 16.5 feet) than semitrailer combinations.
Passing		Some degradation from 1994 resulting from VMT increase	Requires operating restrictions.
Acceleration (merging and hill climbing)		Some degradation from 1994 resulting from VMT increase	Requires sufficient engine power.
Lane Changing		Some degradation from 1994 resulting from VMT increase	Some degradation due to additional length which is counterbalanced by decrease in heavy truck VMT.
Intersection Requirements		Some degradation from 1994 resulting from VMT increase	Additional length requires sufficient sight distances for other traffic.

Table IX-10. Triples Nationwide Scenario Traffic Impacts

Impact	1994	2000 (base case)	2000 (scenario)
Traffic Delay (million vehicle-hours)	18,700	22,300	20,600
Congestion Costs ($million)	246,500	292,900	270,500
Low-Speed Offtracking		Some degradation from 1994 resulting from VMT increase for long double combinations	Some improvement as a triple trailer combination offtracks less (12.7 versus 16.5 feet) than semitrailer combinations.
Passing		Some degradation from 1994 resulting from VMT increase	Requires operating restrictions.
Acceleration (merging and hill climbing)		Some degradation from 1994 resulting from VMT increase	Requires sufficient engine power.
Lane Changing		Some degradation from 1994 resulting from VMT increase	Some degradation due to additional length which is counterbalanced by decrease in heavy truck VMT.
Intersection Requirements		Some degradation from 1994 resulting from VMT increase	Additional length requires sufficient sight distances for other traffic.