Southwest Washington Regional Transportation Council

Clark County Freight Mobility Study

Technical Memorandum:

Task 3.C.2: Basic Principles of Truck Mobility

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Heffron Transportation, Inc.

Prepared For:

RTC

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The purpose of this technical memorandum is to communicate the basic operating and design principles for truck mobility to professional staff in both planning and public works. The application of these principles can result in improved roadway design for truck mobility while not over-designing. Over-designing for trucks can result in impacts to other modes, environmental impacts, and excessive cost. Understanding these principles can also improve land use planning to make sure nearby uses are compatible with those that generate large volumes of trucks, and to improve site design. And finally, information included in this technical memorandum may be used in other reports in order to communicate the most salient principles of truck mobility to decision-makers and stakeholders of transportation projects.

1. How do truck operating characteristics differ from passenger vehicles?

Trucks are bigger and heavier than passenger vehicles, and therefore, are slower to accelerate, require longer stopping distances, and have larger turning radii than a passenger vehicle. Heavy trucks take longer to pull out of a driveway or side street and require a longer gap in traffic to enter a roadway. Trucks are more adversely impacted by uphill grades. The truck operating speed on a highway is determined by the truck speed at the beginning of the grade, the grade of slope, and the grade length. On long uphill grades, trucks eventually reach a crawl speed.

Mobility on arterials and local access streets is affected by the street width and the turning radius at intersections. Where the turn radii are tight, drivers often swing wide, encroaching into the adjacent lane, so that the truck does not ride up on to a sidewalk or encroach onto a shoulder area. This is of particular concern on two lane streets where the truck must encroach into the oncoming traffic lane. On arterial streets with higher volumes of truck traffic, such turning movements can seriously disrupt the flow of traffic and can create safety concerns.

Roadway grades, length of grade, and turning radii are key concerns of truck drivers. On freeways, the slope and length of grade affects truck operating speed at the merge point, as well as downstream of the merge, until the truck can accelerate to the highway speed limit. Tight loop ramps with steep super-elevation further limit the ability for a truck to accelerate. Trucks consume highway capacity at a greater proportion when they are merging or traveling below the speed of traffic on the highway.

2. How do the operating characteristics differ by type of truck?

The Federal Highway Administration (FHWA) has established a vehicle classification system that uses 13 vehicle types distinguished by the number of axles. The classifications were originally established for use in pavement and bridge design. However, when describing trucks for the purpose of transportation planning or traffic operations analysis, the 13 classifications are often grouped into three primary categories: light (small), medium, and heavy (large). Appendix A summarizes the 13 vehicle classifications by number, name, the planning terminology, size of truck and number of axles. The three groupings are defined as follows:

- **Light trucks** are a single unit, have two axles and up to six tires. This size truck performs light commercial activity, and includes small delivery trucks such as those operated by UPS. On highways and arterials the operating characteristics are similar to a passenger car.

- **Medium trucks** have three or four axles. A heavy garbage truck or a single dump truck would be categorized as a "medium" truck. Medium trucks carry heavier loads, require a wider turning radius, and use more capacity on highways and arterials than a passenger car.

- **Heavy trucks** have five or more axles and a "tractor-trailer" configuration. The operating characteristics differ substantially from a passenger car, with slower acceleration speeds, longer stopping distances, different sight lines, and a large turning radius. On a flat grade, their operating characteristics consume approximately double the lane capacity as compared to a passenger car, and this can increase with grade, alignment, and the proportion of trucks in the traffic stream.

Oversize loads are trucks that are over-length, over-height, over-width, and/or over-weight. The mobility of an oversize load is more restricted than either the medium or heavy trucks. Oversized loads require a permit in both Oregon and Washington and may also require a lead or follow-car to warn and buffer motorists from their limited mobility. The City of Vancouver and Clark County are uniquely challenged to accommodate over-sized loads carrying wind turbine parts from the Port of Vancouver to wind turbine farms in eastern Oregon and Washington.

It is the length of wheel base that governs the truck turning path for each truck type. The longer the wheel base, the wider the turning radius of the truck. Table 1 shows overall dimensions, wheel base and the minimum turning radius for the predominant truck types. Table 1 includes passenger vehicle, a city bus, and a typical oversize load for comparison.

Table 1. Vehicle Dimensions, Wheel Base, and Turning Radii

Vehicle Type	Symbol	Overall Dimensions [1]			Wheel Base [2]	Minimum Design Turning Radius
		Height	Width	Length		
Passenger Car [3]	P	4.25	7	19	11	24
City Transit Bus[3]	CITY-BUS	10.5	8.5	40	25	42
Single-Unit Truck[3]	SU	11-13.5	8	30	20	42
Semitrailer Small[3]	WB-40	13.5	8	45.5	40	40
Semitrailer Large[3]	WB-50	13.5	8.5	55	50	45
Double Semitrailer [4]	Double	13.5	8.5	70	65	50
Oversize Load wind turbine blades & tower maximum[5]	n/a	16.8	18	188	varies	133' inner radius

1. *All dimensions in feet.*
2. *Wheel base measured from the turning axle to the rear axle.*
3. *Source: American Association of State Highway and Transportation Officials (AASHTO), A Policy on Geometric Design of Highways and Streets, 2004, Exhibit 2-1 and Exhibit 2-2.*
4. *Dimensions are based on a turning template for a double tank truck.*
5. *Typical oversize load of wind turbine parts that are common in Clark County. The dimensions of other types of oversize loads could vary substantially.*

3. What are the design considerations for trucks at intersections?

Intersections serving large trucks need larger corner radii and flatter approach grades than intersections where traffic is predominantly passenger cars. Enlarged radii are typically needed only for right-turning trucks; constraints for left-turning trucks can often be solved by moving the stop bar for the opposing cross-street traffic back from the intersection. Wider turning radii may also be needed on two-lane streets where a turning truck would otherwise need to cross into the opposing direction of traffic at the start or end of the turn. On multi-lane streets, a truck can sometimes encroach into the adjacent lane that is moving in the same direction without creating an operational or safety concern. Finally, the choice of the corner radii should also consider pedestrian crossing distance, which if lengthened, would require additional pedestrian crossing time at a traffic signal. This can affect traffic operations at an intersection.

The "design vehicle" is identified by the responsible agency and is based on truck volume, truck percentage in the traffic stream, a balance with other vehicle types, capacity, and safety. The designer applies a "truck turning template" to evaluate the path of the turning truck and the design requirements for the intersection. If, however, the turning traffic is mostly passenger vehicles, it may not be cost-effective to design for the occasional large truck. The American

Association of State Highways and Transportation Officials (AASHTO) provides the following general guidance for corner radii: [1]

For passenger vehicles – 15 to 25 feet. These radii can be used at minor cross streets where there are only occasional turning trucks or at major intersections where there are parking lanes. Parking should be restricted for an appropriate distance from the corner.

- Minor cross streets – 25 feet.
- Minor cross streets where limited encroachment into adjacent lane is desired – 30 feet.
- Intersections with high volumes of right-turning trucks or buses – 40 feet.

4. What are the design considerations for trucks on highways and rural arterials?

On highways, the slope and length of grade affects truck operating speeds. The affect of reduced truck speed is to increase the passenger car equivalent (E_T) of a truck, which impacts the amount of highway capacity consumed by the truck. Unequal speeds in the traffic steam also increases passing maneuvers, which reduces the safety of a highway. A medium or heavy truck traveling at speed on a flat highway has a passenger car equivalent (E_T) of 1.5. In other words, trucks consume the same space and capacity as one-and-a-half passenger cars. Table 2 presents the passenger car equivalents for trucks on a grade. The E_T increases as steeper grade results in decreasing truck speed, and as the speed differential increases, trucks begin to consume more capacity. Note that as the percentage of trucks increases the E_T decreases because as trucks form a platoon the effect is to reduce the passenger car equivalent of each truck. On rural highways and arterials there may never be the volume of trucks that achieve the reduced E_T of a platoon.

Table 2. Passenger Car Equivalents for Trucks for Grade Lengths of ¼ to ½ Mile

	Percentage of Trucks						
Upgrade	**2%**	**4%**	**5%**	**6%**	**8%**	**10%**	**15%**
<2 %	1.5	1.5	1.5	1.5	1.5	1.5	1.5
>2-3 %	1.5	1.5	1.5	1.5	1.5	1.5	1.5
>3-4 %	2.0	2.0	2.0	2.0	2.0	2.0	1.5
>4-5 %	3.0	2.5	2.5	2.5	2.0	2.0	2.0

Source: Source: Highway Capacity Manual 2000. Transportation Research Board, Exhibit 23-91.

[1] American Association of State Highway and Transportation Officials (AASHTO), 2004, page 619.

Highways are designed to meet the requirements of truck turning radii for all legal-sized trucks whenever possible, balanced by local conditions that could result in an extremely high cost of construction and/or unacceptable localized impact. Auxiliary left and right turn lanes are often provided on highways to mitigate the negative safety and operational effects of slower-moving traffic. Trucks need longer distances to decelerate and accelerate, which can affect the need for and length of such a lane. Guidelines for auxiliary lanes are presented in the *Washington State Department of Transportation (WSDOT) Design Manual, Chapter 1310.*

The sight distance needed for a truck to turn onto a highway may also be longer than a passenger vehicle. Because trucks accelerate more slowly, they need a longer gap in traffic to complete a turn from a stop and enter the highway without impacting traffic flow. The longer the time gap, the longer the required intersection sight distance. The time gap is identified by AASHTO for passenger cars, single-unit trucks, and combination trucks (tractor-trailer trucks). The sight distance then varies depending on the type of movement—left turn from a stop, right turn from a stop, or crossing maneuver—since the distance traveled during the maneuver varies. Table 3 shows the conditions for the time gap and affect on sight distance for left turns from a stop.

Table 3. Effect of Trucks on Intersection Sight Distance – Left Turn from Stop

Design Vehicle	Time Gap (seconds)[1]	Design Speed[2]	ISD[3] (feet)	Design Speed	ISD (feet)
Passenger Car	7.5	45 mph	500	60 mph	665
Single-unit truck	9.5	45 mph	630	60 mph	840
Combination truck	11.5	45 mph	760	60 mph	1,015

1. *American Association of State Highway and Transportation Officials (AASHTO), 2004, Exhibit 9-54.*
2. *Design speed is 10 mph over the posted speed.*
3. *Intersection Sight Distance. Values are rounded for design.*

5. What are the design considerations for trucks on freeways and ramps?

On freeways, the slope and length of grade affects truck operating speeds the same as previously presented in Table 2. The affect of reduced truck speed is to increase the passenger car equivalent (E_T) of a truck, which impacts the amount of highway capacity consumed by the truck. As the percentage of trucks increases, the E_T decreases, because as trucks form a platoon, the effect is to reduce the passenger car equivalent of each truck. Freeway design guidelines usually limit the grade on the mainline and ramps to 5%.

Table 4 presents select speed-distance relationships for trucks accelerating on an uphill grade from a stop condition. Trucks must accelerate from a stop condition at ramp terminals and ramp meters. For a typical ramp design with a three percent uphill grade and 1,000 feet of ramp length, heavy trucks are entering the highway at 29 mph.

Table 4 Speed-Distance for Acceleration of a Typical Heavy Truck

3 Percent Grade		5 Percent Grade	
Distance (feet)[1]	**Speed (mph) [2]**	**Distance (feet)**	**Speed (mph)**
500	27	500	22
1,000	29	1,000	24
1,500	31	1,500	25

Source: AASHTO, A Policy on Geometric Design of Highways and Streets, 2004, Exhibit 3-56.

1. *Distance from a stop condition.*
2. *Miles per Hour (mph)*

An uphill grade on a ramp or a short ramp affects the speed that a truck can reach before the merge point with the freeway mainline. A truck's ability to accelerate is hindered by the curvature and super-elevation (side slope) of a ramp, such as the conditions that exist at a loop ramp. During congested conditions when freeway speeds have decreased to below 20 mph, slow-moving trucks have little effect on mainline traffic flow. However, in the periods just before unstable flow begins and freeway speeds are above 35 mph, slow-moving trucks that merge into traffic can then reduce the speed of the entire mainline. Freeway ramps with meter shorten the effective acceleration length of the on-ramp.

Design solutions to increase the truck speed at the merge point include: lengthening freeway ramps to provide a longer acceleration distance; flattening the grade; enlarging the radius of loop ramps; changing the ramp configuration; and/or allowing trucks to bypass a ramp meter.

6. Conclusion

The efficient movement of freight by truck supports the vital economic base in Clark County and the State of Washington's international trade network. Trucks moving freight rely on capacity and uncongested conditions to reduce travel time, improve reliability, minimize collisions, and reduce cost. The most obvious solution to increasing capacity is to increase the number of lanes on a roadway. However, given the competition for major project funding, and other project design constraints, improving truck mobility through design can both preserve the capacity already built in to a roadway and improve mobility for trucks. In addition, knowledge of design principles for truck mobility can enhance site design for industrial land and other truck-trip generating facilities, and their access to the Clark County transportation system.

Appendix A

Table A-1. Truck Type Nomenclature

Class Number [1]	Name	Truck Group [2]	Size and Typical Weight
1	Bikes		
2	Cars and Trailers		<16,000 lbs
3	2 Axle Long	Pass Veh/Light4	<16,000 lbs
4	Buses		
5	2 Axle 6 Tire	Light	<16,000 lbs
6	3 Axle Single	Medium	Single Unit 16 – 52,000 lbs
7	4 Axle Single	Medium	Single Unit 16 – 52,000 lbs[5]
8	<5 Axle Double	Heavy	Tractor Trailer – one trailer >52,000 lbs
9	5 Axle Double	Heavy	Tractor Trailer – one trailer >52,000 lbs
10	>6 Axle Double	Heavy	Tractor Trailer – one trailer >52,000 lbs
11	<6 Axle Multi	Heavy	Tractor Trailer – two trailers >52,000 lbs
12	6 Axle Multi	Heavy	Tractor Trailer – two trailers >52,000 lbs
13	>6 Axle Multi	Heavy	

1. *Federal Highway Administration Classifications.*
2. *Groupings of truck categories for the purpose of a transportation planning study. These categories were originally defined in the Congestion Relief Analysis, PSRC Travel Model Documentation Final Report, Chapter 10.0 Truck Model, August 24, 2006, Cambridge Systematics, Inc.*
3. *Trucks are sometimes grouped by into these categories.*
4. *Category 3 has often been classified as a "Light Truck." However, recent observations have found that this type of vehicle is most often a larger passenger vehicle such as a pick-up truck or a sports utility vehicle built on a large pick-up truck frame (e.g., Chevy Suburban). Category 3 has been excluded from most groupings of truck counts.*
5. *Class 8 and 9 trucks may exceed these typical weights for extra heavy loads such as a concrete truck.*

Figure A-1. Example Truck Classifications

Class 5: Single Unit Delivery Truck Light Truck	
Class 7: Four-Axle Single Truck Medium Truck	
Class 8: Four Axle Tractor Trailer Heavy Truck	
Class 9: 5 Axle Tractor Trailer Heavy Truck	
Class 12: Six Axle Truck (two trailers) Heavy Truck	
Class 13: Eight Axle Tractor Trailer Heavy Truck	

Source : Heffron Transportation, Inc., June 2009. Some of the photos are from WSDOT's training website at: http://training.ce.washington.edu/wsdot/Modules/04_design_parameters/trucks_buses.htm