APPENDIX E

Truck Bottlenecks and Geometrics

This appendix reviews a number of roadway features that are specifically linked in the crash and design literature to truck performance. Identification of these roadway features offers a basis for locating and mitigating truck bottlenecks. Table E-1 summarizes the correlation between design geometrics and truck bottlenecks, as well as possible solutions for addressing these types of truck bottlenecks.

Table E-1. Safety and Design Considerations and Roadway Features

Source	Roadway Consideration
Qin (2013) (94)	Truck crash frequency impacted by AADT, AADTT, shoulder width, pavement condition, signal density.
Donnell (2001) (95)	Truck safety considerations, including swept path width, acceleration and decelerations, curb-return radii at intersections, horizontal curve, vertical curves and median intersections, and car truck mix.
Porter (2012) (96)	Horizontal curve radius impacts on truck roll over rates.
Dong (2014) (97)	Truck cashes at urban intersections that may be related to intersection angles.
Sultana (2014) (98)	Truck crash frequency related to driveway access along urban arterials. Factors include commercial driveway throat width, commercial driveway throat width with flare, the proportion of divided commercial driveway, signal density, and shoulder width.
Khattak (2003) (99)	Truck roll-over risk on curves.
Dissanayake (2012) (100)	Factors for limited access highways which can be used to change the occurrence of large truck crashes, including horizontal curvature, vertical grade, lane width, and shoulder width area.
Morris (2014) (101)	Impact of vertical grades and lane widths on truck speeds (large trucks should be primary design consideration for multilane roads with grade > 4%).
AASHTO (2011) (102)	Green Book design criteria for trucks includes sight distance, lane width, horizontal curves, cross-slope breaks, and vertical clearance.
Middleton (2003) (103)	Relevant design parameters for trucks, including stopping sight distance, intersection and channelization, lane width, shoulder width and composition, acceleration lanes, and cross section elements such as sideslopes, traffic barriers, and passive signs.
Brewer (2012) (104)	Median width impacts on truck crashes.
Poe (2008) (105)	Truck design considerations include horizontal alignment, vertical alignment (grades), cross section, shoulder widths, ramp and interchange design, and intersections.
Gong (2009) (106)	Truck bottlenecks caused by steep grades, lane drops, and signalized intersections.

Specific roadway attributes which impact truck performance and are derived from the literature as seen in Table E-1 include the following:

Truck swept path widths (Offtracking): Offtracking is when a truck makes a turn and its rear wheels do not follow the same path as its front wheels. Offtracking increases with the spacing between the axles of the vehicle and decreases for larger radius turns. There are two types of offtracking, including low-speed and high-speed. Low-speed off tracking is related to intersection curb return radii while high-speed offtracking is related to highway horizontal curves. (107, 108) Geometric measures for offtracking include mainline horizontal curves, horizontal curves on ramps, curb return radii for at-grade ramp termini and curb return radii for at-grade intersections. (109)

Infrastructure improvements: According to the U.S. DOT truck weight study, the feasibility of widening each curve radius to reduce offtracking can be easy or difficult depending on the available, unimpeded availability of right-of-way, available to increase the turn radius. (110)

Vertical curves: A vertical curve or alignment is where there is an intersection between two slopes on a roadway. Studies of crashes using GIS data in Washington State (for all vehicles) indicate an increase in the vertical grade tends to increase accident frequency. (111) For trucks, an important element in vertical curve design is sight distance which, at night also impacts the effective distance for a truck's headlights. Vertical alignment impacts trucks more than cars because of the truck operating characteristics. There are a number of measures for a vertical curve which include length of grade and tangent between grades.

Infrastructure improvements: Vertical curves are modified by a change in a road's profile and grade. Costs vary depending on maximum and minimum gradients, required sight distance criteria, surrounding land and topography, and other roadway features such as horizontal curves. (112)

Horizontal curves. A horizontal curve is the transition between two tangents of a roadway and is a primary truck safety and design consideration. Excessive truck acceleration at a horizontal curve can cause the truck to skid off of the road or overturn. (113) Notable horizontal curve problems for trucks occur on freeway on- and off-ramps. (114) The measure for horizontal curves includes the curve's radius and central angle.

Infrastructure improvements: There are many different corrective options for poor horizontal curves, including enhancing the delineation along the curve, providing adequate sight distance, widening the roadway, improving or restoring the super elevation, or modifying the horizontal alignment. (115)

Lane Width and Number of Lanes: Lane widths are critical for truck driver safety. (116) On a high-speed roadway, the primary safety concerns with reductions in lane width are crashes related to lane departure, including run-off-road crashes. A study of safety risks for trucks on arterial also identified lane width as a casual factor in truck crash occurrence and crash severity. (117) Lane drops (reduction in number of lanes) are another source of truck bottlenecks. (118) Lane widths are measured without shoulders.

Infrastructure improvements: Widening lanes or removing lane drops.

Shoulder Width: Shoulders provide areas to maneuver and avoid crashes, as well as for emergency parking for disabled vehicles. (119) Trucks off-tracking into a shoulder can improve operations. (120) A study of safety risks for trucks on arterials also found shoulder widths as a casual factor in truck crash occurrence and crash severity. (121) The study also identified different shoulder widths for inside and outside shoulders.

Infrastructure improvements: Widening shoulders.

Grades. Trucks can have a five percent increase in speed on downgrades and a seven percent or more decrease in speed on upgrades when compared to operations on level terrain. (122) Measurement of grade is typically percent slope.

Infrastructure improvements: Mitigation of grade includes changing the slope, adding truck climbing lanes, or using tunnels to bypass the grade.

Intersections. Intersection design can vary considerably but for trucks medians at intersections on highways with partial or no access control present significant operational and safety concerns. Selection of the appropriate design vehicle for crossing and turning movements, including U-turns, is one of the key factors in selecting the median width and length of the opening at a divided highway intersection. (123) Signalized intersections have also been identified specifically as creating trucks bottlenecks. (124)

Infrastructure Improvements: There are many mitigation approaches for intersections that perform poorly for trucks. They include changing angles and turning radius and widening medians. Another option is conversion to a roundabout.