Abridgment

Offtracking of the Larger Combination Commercial Vehicles

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ABSTRACT

Recent legislative enactments at all government levels have resulted in increases in trucks and tractor-trailer combinations. Section 138/415 of the Surface Transportation Assistance Act of 1982 called for a feasibility study of a national intercity truck route network for commercial vehicles up to 110 ft long. Naturally these changes in overall vehicle size will have an impact on highways and their operations, especially on roads with restrictive geometrics. To assess the ability of a vehicle to operate, one characteristic, its offtracking, must be evaluated. Several studies involving offtracking are reviewed and it is noted that there is a need for additional study of the problems associated with very long combination vehicles. The offtracking characteristics of very long vehicles, as well as those of less extreme vehicles, are described. Two methods of measuring offtracking are used, mathematical formulation and an adjustable scale model. Curves that illustrate vehicle offtracking paths were produced with the model. The formula was used to compute and compare the maximum offtracking of the vehicles studied. The results are tabulated and sample templates provided.

Because of the interest in large trucks, mostly generated by federal legislation and some state legislation that calls for the elimination or reduction of size restrictions, there is a need for some documentation of the turning characteristics of these vehicles. Some work has already been done by agencies such as the Western Highway Institute (WHI), the California Department of Transportation, and the Society of Automotive Engineers on offtracking characteristics; however, little effort has been directed at the offtracking characteristics of the new larger combination truck units with very great overall lengths (approximately 118 ft).

Insight is provided, through offtracking curves and computed maximum offtracking, as to the characteristics of these supertrucks in comparison with shorter, more conventional vehicles. A review of previous offtracking work is presented along with methods of drawing the curves and calculating maximum offtracking.

OFFTRACKING REVIEW

Offtracking is defined in many ways, but all mean the same thing; that is, offtracking is the difference in paths of the frontmost inside wheel and rearmost inside wheel of a vehicle as it negotiates a turn. Actually, whether the distance is measured between the front and rear inside wheels, outside wheels, or the center of the axles is of no consequence; it will be the same. A similar term is "trackwidth," which is the total width of the path a vehicle makes as it traverses a corner and which is measured from the frontmost outside tire path to the rearmost inside tire path. This gives an indication of the minimum pavement width necessary to accommodate the vehicle around a corner.

It will be shown that the most important factors in offtracking are the radius and degree of turn and the length and configuration of the vehicle. Of course, many factors affect the offtracking of vehicles and they cannot all be accounted for in any predictable manner. Although vehicle length and configuration and turn radius are the main determining factors, speed and superelevation of the turn can have significant effects. Indeed, if a truck combination is going fast enough, centripetal effects may reduce offtracking to zero and may produce an overall negative offtrack effect. Likewise, a slow-moving trailer on a highly superelevated curve will experience more severe offtracking than expected. Still other factors include driver expertise, condition of the truck and its loads, wind and weather, and the condition of tires and road surface. Only by recording the paths of actual vehicles can all factors be taken into account. The modeling and mathematical methods of simulating offtracking cannot account for any of these extraneous yet real influences. All this should be taken into consideration when the results presented here are viewed.

Several methods may be used to determine the amount of offtracking for a given vehicle at a given turning radius. They are

1. Observation of actual vehicles,
2. Mathematical formulation, and
3. Simulation with models.

Observing real truck combinations would be the most accurate method and would include all the minor factors affecting offtracking. Unfortunately, few agencies can afford the time and expense of acquiring all the needed vehicles and driving them through countless possible turn situations.

Finding a vehicle's maximum offtracking for a given turn radius is most easily accomplished by using a mathematical formulation. Although the exact equation is awkward to work with, nearly perfect approximations can be used with great ease and are well suited for making comparisons of different vehicles or turns. Unfortunately, the formulation gives no indication of the shape of the curves or where along the curve the maximum offtracking will

occur. Also, in cases where the vehicle's rear axle passes to the inside of the turn radius center or where the vehicle does not maintain a given turn radius long enough to achieve maximum offtracking, the equations cannot be used.

Simulation with models requires considerably more (but not excessive) work than the equations and produces a much more complete representation of a vehicle offtracking pattern. It can be used for any vehicle at any turn radius (or even combination of turns), and offtracking can be measured anywhere along the curve. More detailed discussion of mathematical formulas and models will be presented after a discussion of some previous offtracking studies.

PREVIOUS WORK

Studies that use the methods just mentioned have been made on this topic for some time. Several studies that were used as a basis for this report are discussed.

On the basis of observations of actual vehicles in simulated turning situations, Leisch (1) produced a set of offtracking templates that have been used by many state highway departments. The origin and use of the templates, which consist of offtracking curves of five vehicles at various turning radii, were documented in an HRB paper (2).

The Society of Automotive Engineers (SAE) has, in its publications, provided mathematical formulations to describe offtracking (3). The general formula for a single-unit vehicle is

$$OT = \{WB^2 + [(TR^2 - WB^2)^{1/2} - HT]^2\}^{1/2} - (TR^2 - WB^2)^{1/2} + HT$$

where

OT = offtracking [maximum for given turning radius (TR)],
WB = wheelbase, and
HT = front wheel trackwidth divided by 2.

Similar formulas for articulated vehicles are even more complex and unwieldy. Fortunately, WHI developed an equation that accurately approximates the SAE equation and that is uniform regardless of vehicle configuration (4). The much simpler formula, which is also discussed in an AASHTO report entitled Offtracking Considerations for Truck Tractor-Trailer Combinations (5), is

$$MOT = R - (R^2 - \sum L^2)^{1/2}$$

where

MOT = maximum offtracking,
R = turn radius, and
$\sum L^2$ = sum of the squares of axle spacings.

WHI also describes and compares other methods of measuring offtracking, including the use of this formula, models, actual equipment, and graphics. Two methods, the mathematical formula and models, are used to address some turn problems, including urban street intersections.

Unfortunately, WHI did not address larger vehicles such as large doubles with two 48-ft trailers. Generally, though, the WHI publication remains very informative and was useful throughout this study.

VEHICLE OFFTRACKING STUDY

Proposals fostered by the Surface Transportation Assistance Act (STAA) of 1982 spurred several legislative initiatives in many states throughout the United States, which resulted in allowing a range of trucks, tractor-semitrailer combinations, and other combinations to operate at increased lengths and widths. In Texas, House Bill 1601 removed overall length restrictions on vehicles using semitrailer combinations while placing limits on individual trailers and semitrailers of 57 ft. However, because of other state and federal limitations, the more common trailer lengths will be 28 (and 28.5) ft and 48 ft. House Bill 1602 increased allowable widths from 96 in. to 102 in.

The work presented in this study was done at two different times. Initially templates were constructed for the use of the Texas State Department of Highways and Public Transportation (SDHPT) following a specific request. Later this work was expanded to include additional vehicles and different template forms.

As a result there are two sets of vehicles and two types of curves. The first set, as stipulated by the SDHPT, involves several tractor-semitrailer combinations with 48- or 57-ft semitrailers and double combinations with 28.5- or 48-ft trailers. These vehicles were used in making templates that follow the pattern established by Leisch and include turn radii of 45, 60, and 75 ft.

Given the new laws governing vehicle size limitations, the second set of vehicles consists of those believed to be a good representation of probable combinations. It includes tractor-semitrailers, doubles, triples, a truck-trailer combination, and buses, with wheelbases ranging from 30 ft for a bus to 108 ft for a double with 48-ft trailers. Only right-angle turns with a radius of 25 or 30 ft, such as might be encountered in an urban intersection, are included in the templates.

METHODS

Two methods are used in this paper to evaluate offtracking--mathematical formulas and models. An equation was used to estimate the maximum offtracking of the vehicles and the models were used to produce curves that show the shape of the vehicle's path.

Mathematical Formulation

As a means of comparing the effects on offtracking of different vehicle configurations and different turn radii, the mathematical formula developed by WHI is utilized. Its accuracy and ease of use make this method of evaluation a worthy tool for anyone.

Tractrix Integrator

A main element of this paper is to provide curves that reveal the effects of longer truck combinations. The instrument used to produce these curves is called a Tractrix Integrator, which is a model used to simulate actual vehicle offtracking characteristics.

It is a device that has a scaled bar supported at one end by a pointer and steadying frame. Attached at the other end below the bar is an inked wheel that makes a trail of ink as the bar is moved.

To use the Tractrix Integrator, the distance between the pointer and wheel is adjusted to a desired scale. The pointer is moved carefully over some fixed path representing the path followed by the front axle of a vehicle. As the Tractrix Integrator is moved, the rear wheel is marking the path of the rear axle of the vehicle. To model combination vehicles, the path of the tractor is modeled; then the

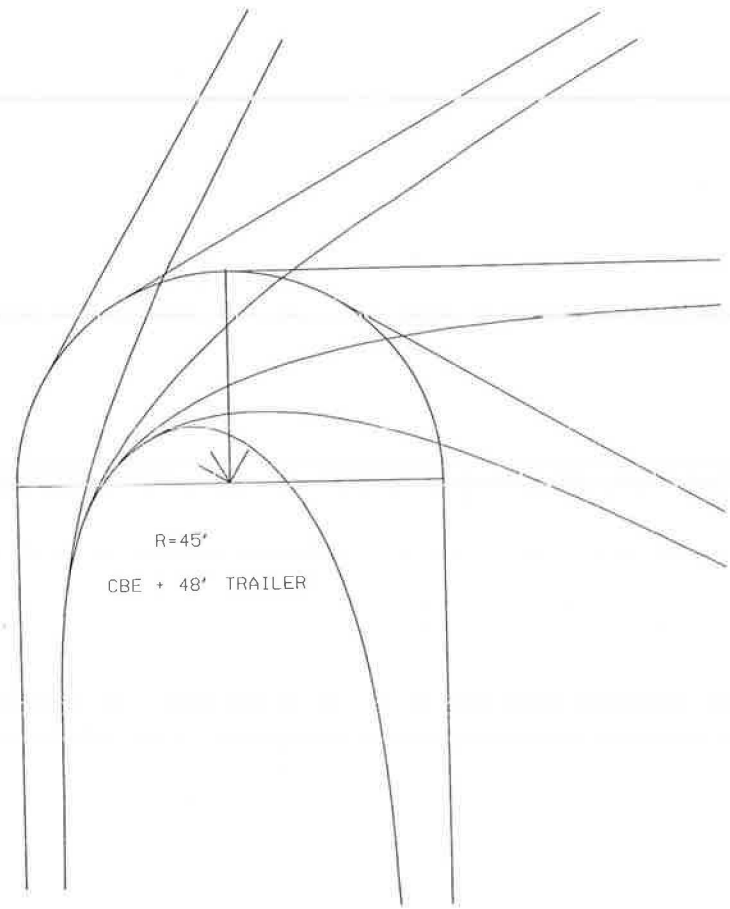

FIGURE 1 Sample offtracking template.

Tractrix Integrator is adjusted to the scale of the trailer. The pointer is pulled along the path of the rear tractor axle so that the trailer rear axle path is produced. Successive passes of the Tractrix Integrator may be made to represent any vehicle configuration.

The resulting curves closely replicate the expected paths and track widths of the outside front wheel and inside rear wheel. The advantage of this type of representation is that the maximum offtracking can be measured for any degree of turn and turn radius, as well as the amount of offtracking anywhere along the curve. Also, these curves can be used in a case where the path of the rear axle tracks inside the center of radius of curvature, a case where mathematical formulas are unusable. It should be noted that these curves are only approximations of actual vehicle paths. Some simplification is done concerning vehicle configuration; for instance, kingpin placement is always assumed to be directly over the rear axle set of the tractor. Effects of such simplification are small, however, and are not of concern in this paper.

RESULTS

The primary objective of this project was the production of offtracking templates that could be used to aid in the design or evaluation of roadway geometrics. The result is a set of 18 templates covering 14 vehicles with combinations of vehicle type and turn type that total 74. These templates (Figure 1) and descriptions of the vehicles are available from the Center for Transportation Research, University of Texas at Austin. Presented in Tables 1 and 2 is a summary of some offtracking measurements taken from those templates.

Also performed was an evaluation of maximum offtracking by using the WHI formula. This computation is easy to perform for any specific vehicle; consequently, tabulated results are not presented here. Figure 2 is included, however, to illustrate track-width characteristics of several relevant vehicles.

The trend toward excessive, and in some cases unacceptable, offtracking for large twin-trailer vehicles is evident. Poor offtracking characteristics will detract from whatever benefits are offered by those vehicles. Alternatively, triple-trailer vehicles, although offering many of the same advantages as large doubles of similar overall length, do so without the detrimental excessive offtracking.

TABLE 1 Measured Offtracking: Set 1

		Offtracking (ft) by Turn Radius (ft) and Degree					
	Vehicle	45		60		75	
No.	Configuration	90°	180°	90°	180°	90°	180°
1	3-S2	18.6	27.9	14.8	20.7	13.1	14.7
2	3-S2	21.7	35.3	18.5	25.7	15.7	19.7
3	3-S2	23.3	36.5+	19.9	28.5	17.1	21.7
4	3-S1-2	10.9	14.1	9.1	10.3	7.5	7.6
5	3-S2-4	–	–	–	35.5	20.5	27.3

TABLE 2 Measured Offtracking: Set 2

No.	Vehicle Configuration	Offtracking (ft) by Turn Radius (ft) and Degree 25, 90°	30, 90°
6	SU-30	–	12.2
7	SU-35	–	15.2
8	3-2	–	14.5
9	2-S1	12.7	–
10	2-S1-2	19.0	–
11	2-S1-2-2	24.1	–
12	3-S2	21.5	–
13	3-S2-2	27.0	–
14	2-S2-4	33.4	–

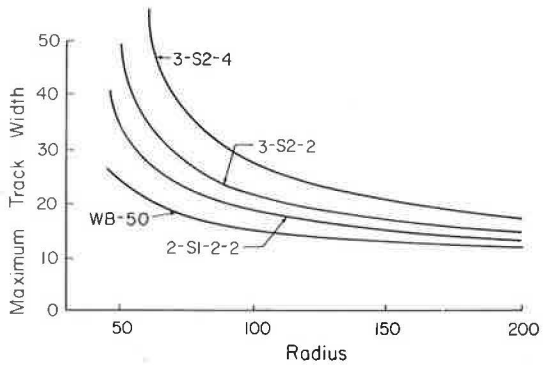

FIGURE 2 Vehicle trackwidth characteristics.

CONCLUSION

The information developed and presented in this paper is intended to further the discussion and appreciation of selected characterizations of the longer "super" combination commercial vehicles introduced in Section 138/415 of the STAA of 1982. These units and their inherent features must be assessed in order for the highway engineer to consider appropriate modifications to currently accepted highway geometric design policies and procedures. The highway engineering profession must remain abreast of emerging trends such as these vehicle units and their effects in order to provide effective guidance to elected or administrative officials as well as dialogue with the motor carrier industry. In this manner, they are better able to provide constructive judgments surrounding the benefits and costs to a national asset--the collective national highway infrastructure.

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