Use of the WHI Offtracking Formula

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ABSTRACT

Offtracking is the phenomenon that occurs when the trailing axles of a turning vehicle increasingly migrate toward the curve center until they finally reach a maximum steady-state offset from the steering alignment path. Steady-state offtracking is achieved when the projected extensions of all fixed axles pass through the curve center. For turns of 120 degrees or less, maximum offtracking observed will seldom fully achieve that of the steady state; however, the clean geometric relationships that exist at the steady-state condition make it possible to readily quantify and use this worst-case performance as a basis of comparison for various vehicle configurations. The Western Highway Institute (WHI) offtracking formula provides a relatively straightforward method of closely approximating the steady-state expectations for any given vehicle or combination. However, the vehicle dimensions required and the implications of their use in the formula need to be fully understood to ensure that calculations are performed and interpreted correctly. The purpose of this paper is to establish the basis for a correct understanding of the data requirements and the use of the WHI offtracking formula.

The Surface Transportation Assistance Act (STAA) of 1982 provided badly needed new funding for U.S. highway facilities but is also a "mixed blessing" from several different points of view. Surely, no thinking person can deny that the 48-ft semitrailer, now mandated nationwide, has brought about a major upheaval in the arena of geometric design standards. Further, the double-trailer phenomenon, new to some sectors of the country, has given rise to a renewed interest in a reexamination of truck turning requirements.

Properly used, the WHI offtracking formula can provide considerable insight into the highly variable turning requirements associated with different vehicle configurations. The purpose of this paper is to establish the basis for a correct understanding of the data requirements and use of this relatively simple offtracking formula.

OFFTRACKING DEFINITIONS

Offtracking is most frequently recognized by its consequences, but the subject has a history of documented study going back at least 25 years. During the period of recorded study, several different definitions have been advanced, each typically reflecting the concerns of the research approach. A brief explanation of the basic research methodologies and perspectives will be presented to help develop a basis for understanding the concepts currently used to define and quantify offtracking. These methodologies include full-scale tests; scale-model tests; mathematical and graphic procedures; and, most recently, computer-model simulations.

Full-Scale Tests

The earliest offtracking research involved measurements using actual vehicles on test-track curves of known radius. One offtrack definition that evolved from this type of work dates back to 1966 and comes from Stevens, Tignor, and LoJacono (1), who indicated that

> Offtracking is the path of the outside of the outer tire on a rear or trailing axle that deviates inward toward the center of a turn from the circular path of the outside of the outer front tire, while the vehicle or trailer combination is making a turn.

The definition obviously comes from a practical highway engineering perspective and accounts for the entire minimum pavement width required. This perspective establishes the overall objective for the final offtrack measurement of interest, and the methodology ultimately provides the basis for the validation of the alternative estimating procedures.

Scale-Model Tests

Scale-model work proved much more expeditious than did dealing with actual vehicles, and these tools provided most of the source drawings from which existing turning templates were originally developed. The definitions of offtracking that evolved were much less explicit and are typified by this 1962 statement from a Society of Automotive Engineers (SAE) report (2):

> In general, offtracking is defined as the difference in the path of the first inside front wheel and of the last inside rear wheel as a vehicle negotiates a curve.

The tractrix integrator, Figure 1, is perhaps the most widely known and used of the template-drawing scale-model devices. It is distinctive in that the line-width relationships developed capture the relative distances desired, but the physical aspect of tire width must be considered an additive factor.

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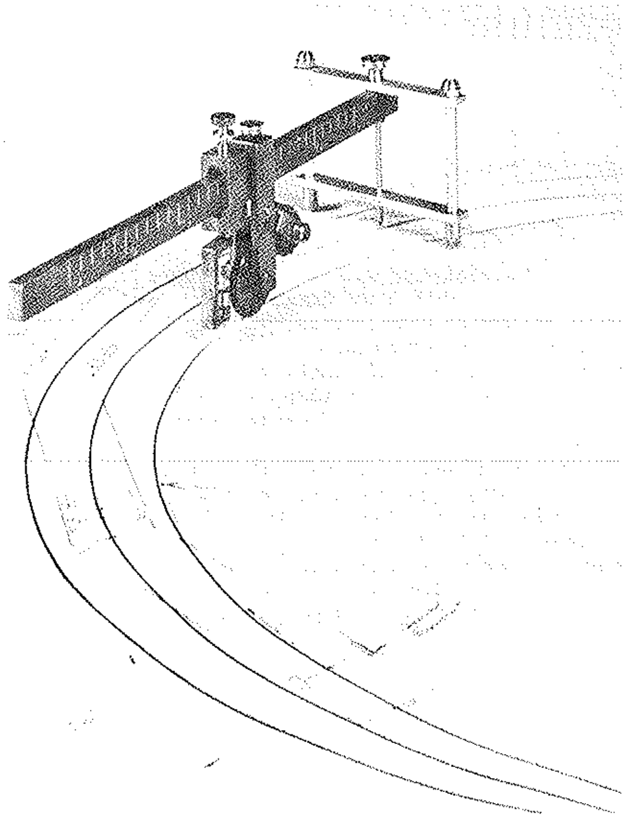


FIGURE 1 Tractrix integrator.

Mathematical and Graphic Techniques

The mathematical and graphic techniques depend quite explicitly on the geometric relationships demonstrated in offtracking. These properties are shown in Figure 2 and are pictured verbally in this definition, which appeared in the 1964 SAE Handbook (3,p.877).

> Offtracking is the difference in radii from the turning center to the vehicle centerline at the foremost and rearmost axles of a vehicle or combination and represents the increase beyond the tangent track occasioned by a turn.

Notice that, as illustrated, the vehicular centerline taken in combination with the adjacent radius lines from the turning center form a series of right triangles.

The oft-referenced SAE offtracking formula is based on the well-known Pythagorean theorem from geometry that the square of the hypotenuse of a right-angle triangle is equal to the sum of the squares of the other two sides. Although simple in theory, the vehicle-specific formulas proceed from a basis that is less than obvious for a two-axle vehicle and become increasingly more complex as additional axles are considered.

The SAE formula for offtracking of a single two-axle vehicle is

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

where

OT = offtracking,
WB = wheelbase,
HT = front wheel track ÷ 2, and
TR = turning radius of outside front wheel.

The complexity of the SAE formula stems from the need to deal with turning centers located at the vehicular centerline rather than on the path of the turning radius. The annually published SAE handbooks carefully defined and explained this formula up to and through the 1972 issue. However, beginning with the 1973 volume (4,p.1209), SAE dropped much of the prior detail and revised the text to include this statement:

> In recent years, there have been developed data which are accurate enough to use for

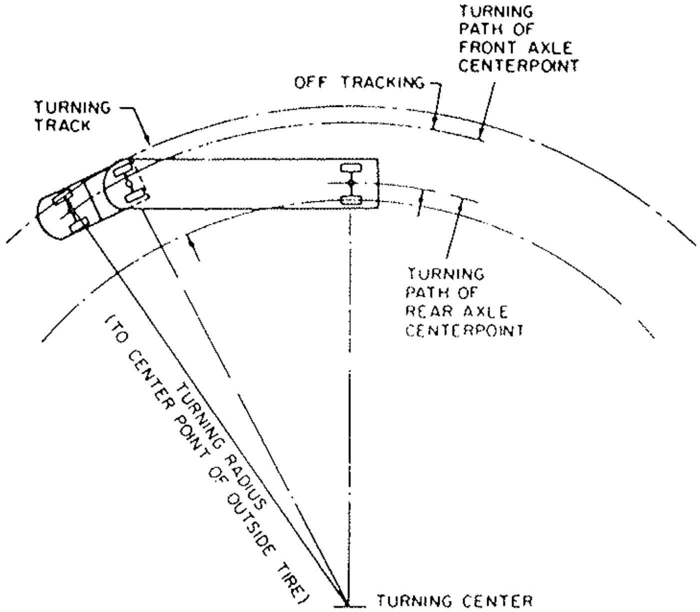


FIGURE 2 Typical offtracking geometrics.

> all practical purposes. The method was developed by the Western Highway Institute. . . . It is this method, easy to calculate and simple to apply, which is recommended as a general practice.

A detailed discussion of the WHI formula, its derivation, and its accuracy in comparison with results obtained via other methods is presented in WHI's Research Committee Report 3 (5).

The WHI equation for the calculation of maximum offtracking uses as one basis the summation of the squares of the components of the overall wheelbase. Thus the WHI concept is frequently referred to as the "sum of the squares" and, all too often, mistakenly as the "sum of the squares of wheelbases." This latter misconception can be and has been the source of some grave misjudgments concerning relative turning capability. Before further discussion of the WHI formula, one remaining offtrack methodology demands consideration.

Computer Modeling

Manual methods of computation previously constrained mathematical offtracking analyses to a comparison of the maximum values occurring at some variable but unspecified degree of turn. However, the mathematical theory and the computational muscle now exist to fully define the transient offtrack values for any turning condition. As might be expected, an expanded definition of offtracking results from this new capability and one such is as follows (6,p.4):

> Offtracking is the phenomenon which occurs when the trailing axles of a turning vehicle increasingly migrate toward the curve center until finally reaching a maximum steady state offset from the steering alignment path. The measured quantity of offtracking is defined as the radial distance separating the rear axle center path from the front axle center alignment path.

This definition recognizes that offtrack values increase along with the degree of turn--up to the point at which a steady-state condition finally develops. Offtrack at the steady-state condition is, obviously, that which the manual methods have typically termed "maximum."

Figure 3, taken from the report of Woodrooffe et al. (6), quoted previously, graphically portrays the offtrack cycle for one specific vehicle combination as it enters into and completes a 360-degree turn.

Notice that the resulting offtrack is apparent well before and ends well beyond the curvature points defined by the steering input. As indicated for this combination, offtrack increases rapidly through the first 60 degrees of turn and very quickly approaches the steady-state value even though the theoretical point of occurrence may be referenced to a significantly larger angle. Overall, this Canadian transient offtrack model appears to replicate observed movements reasonably well. It should be recognized that field tests and their associated measurements do tend to be somewhat erratic and may also display some sensitivity to deviations from the planned steering input.

The positional relationships, graphically shown in Figure 4, illustrate the points of the following technical definition of steady-state offtracking (6,p.4):

> [A] condition where a projected extension of all fixed axles of a vehicle pass through the curve center forming a right angle triangle with the vehicle where the hypotenuse is the alignment curve radius and the right angle is formed by the vehicle wheelbase and the radius of curvature at the trailing axle center.

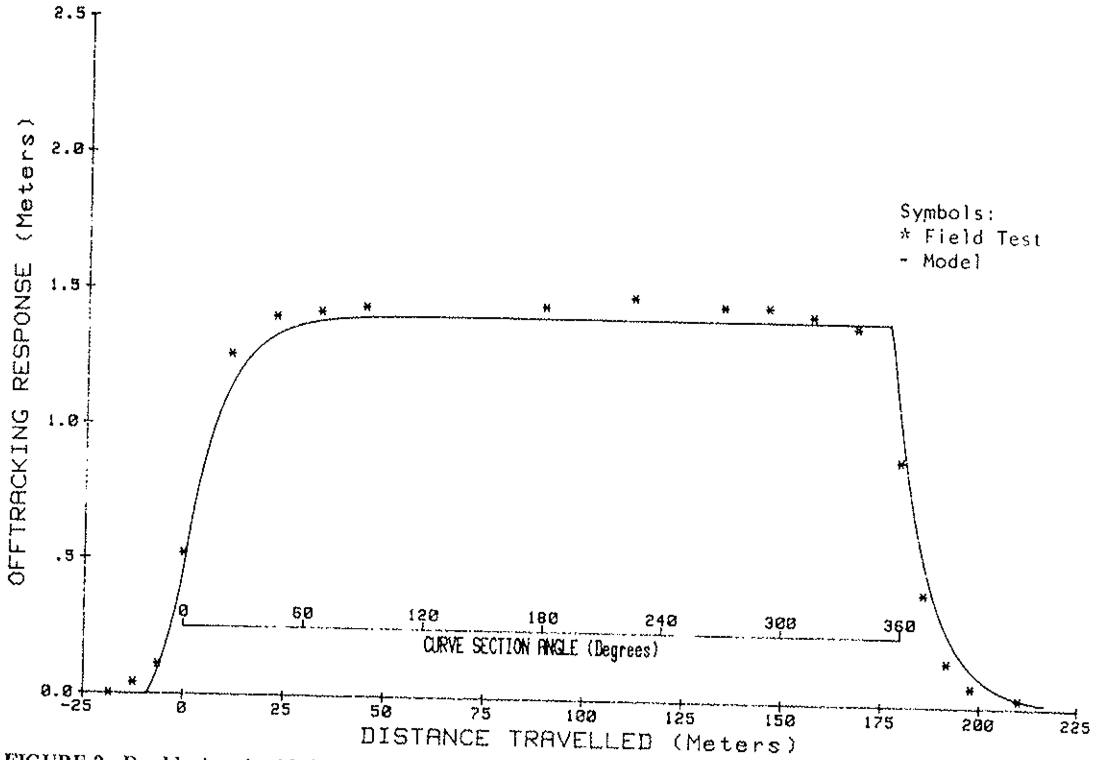


FIGURE 3 Double A-train, 28.6-m radius, 360-degree turn *(6)*.

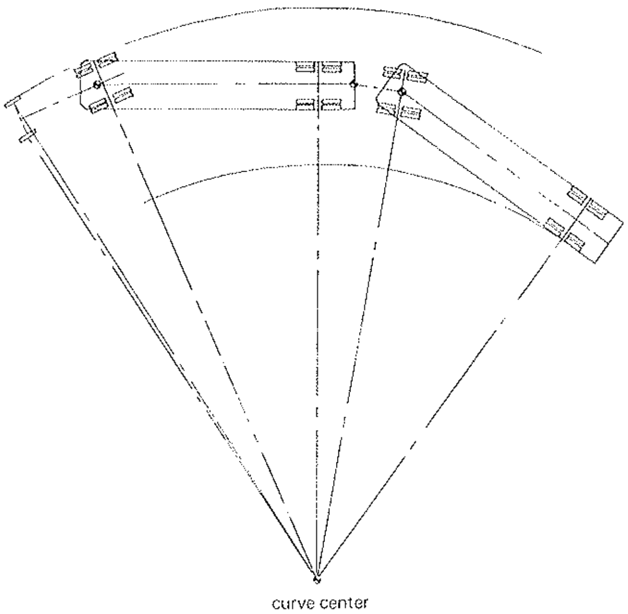


FIGURE 4 Graphic representation of steady-state offtracking.

It can be seen that when the steady-state condition has been reached the SAE and WHI formulas are both directly applicable. However, if the degree of turn is less than that required to reach steady state, the maximum-point formulas will always overstate the expected response. It should also be noted that the maximum-point formulas may break down for long vehicles on short-radius curves. This will occur when the curve center falls between the path of the rearmost axle and the curve itself.

CONSIDERATIONS FOR USE OF FORMULAS

The general form of the WHI offtracking equation is

$$OT_{max/ss} = R - (R^2 - \Sigma L^2)^{1/2} \qquad (2)$$

where

R = radius of the curve followed by the front axle center and
L = individual component distances between points effecting or directly affecting turnability.

The offtrack value to be calculated is in actuality an estimate of the maximum or steady-state value. As computed, the value is centerline related but can readily be correlated with any other comparison points given the correct add-on constants. Figure 5 shows several of the significant offtracking components and terms.

Turning Track

Although comparative offtrack values for different vehicle configurations are the primary products visualized from WHI formula use, turning track comparisons are of interest as well. This dimension may also be referred to as swept width or track width; however, the latter term should be avoided if at all possible because it has another quite different connotation as a vehicle dimension. Turning track, or swept width, can be computed as the sum of offtrack and effective width where effective width includes an overhang component. AASHTO policy suggests the use of 8 ft 6 in. as the appropriate add-on factor for effective width.

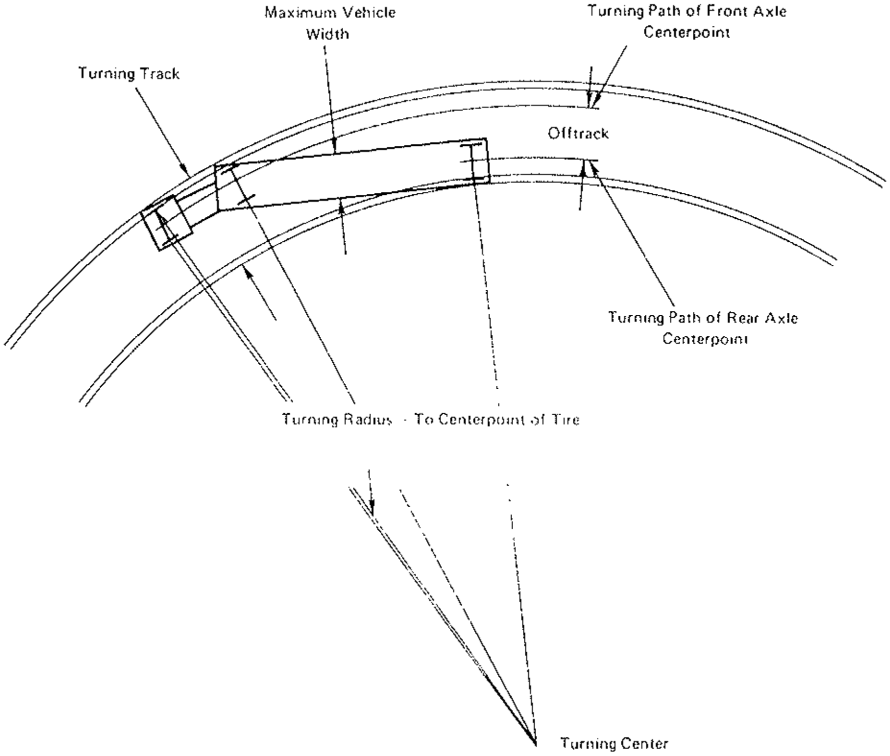


FIGURE 5 Schematic of turning track components and terms.

Turning Radius

In offtrack computation, the first radius of concern is the turning radius. As used, turning radius (TR) is taken to be the alignment path of the outer front tire at its centerpoint. For computational purposes, however, the formulas relate to the geometry found at the centers of axles. The computational centerline radius (R) is therefore that of the centerline of the outer front tire (TR) less one-half of the front axle track (i.e., half-track or HT). Restated in algebraic form:

$$R = TR - HT \tag{3}$$

Front Axle Track

A common mistake is to assume that the half-track value is one-half the maximum vehicle width. A simple function of vehicle width obviously results in overstating the effective turning radius. However, the point is that front axles on heavy-duty trucks are typically narrower than are all other axles in the unit.

The information shown in Figure 6 comes directly from a major manufacturer's data book and clearly indicates that the front axle can reasonably be assumed to be approximately 80 in. This being the case, half-track as used for computational purposes should be taken as 40 in. or 3.33 ft.

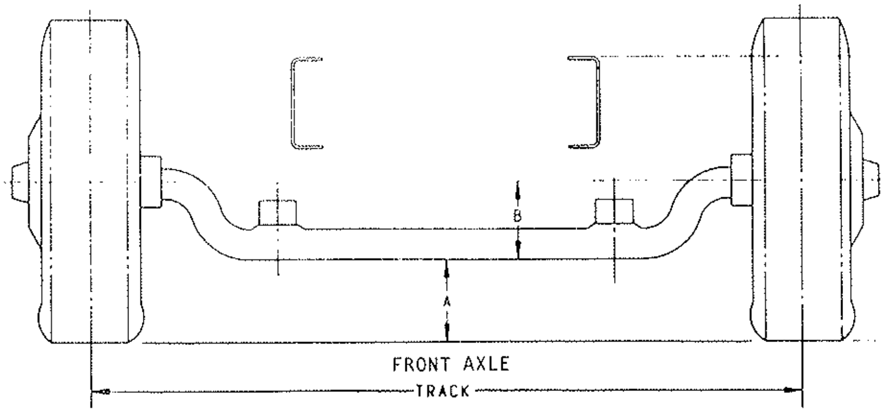
Elements of Vehicle Length

It is worthy of note that, from an offtracking standpoint, multiple axles of an axle group operating together within a single suspension system are treated as though they were a single axle located at the geometric center of the group. As shown in Figure 7, this is consistent with the general definition of wheelbase. Other typical dimensions in Figure 7 are suggested to serve as a test of reasonableness for the designation of representative length dimensions.

Overall length of truck combinations is still an active controlling factor even though trailer-only limits are now the rule on the Interstates and other designated highways. These length limits, coupled with various bridge table requirements, have acted to largely predetermine many truck length characteristics. Although this subject is admittedly a separate, unrelated issue, it is mentioned briefly here to encourage some consistency in the selection of dimensions for representative "analytical" models of various vehicle combinations.

Understanding the sum of L^2s (ΣL^2) portion of the WHI formula is undoubtedly the key to ensuring proper use. The Ls are defined as the distances between points involved in or directly affecting turnability. Figure 8, an axles-only schematic of a tractor-semitrailer-full trailer (double-trailer unit), will be used as the basis for the explanation of Ls.

Wheelbase dimensions are obviously significant



		TRACK CHART		TRACK
FT6	20-7.5	DISC	5.40	81.29
FT6	20-7.5	CAST	4.75	80.57
FS6	20-7.5	DISC	5.40	81.29
FS6	20-7.5	CAST	4.75	80.57
FXG	20-7.0	DISC	6.06	82.13
FXG	20-7.0	CAST	4.75	79.40
F54	20-7.5	DISC	5.40	80.46
F54	20-7.5	CAST	4.25	80.12
FT7	20-7.5	DISC	5.40	80.46
FT7	20-7.5	CAST	4.25	80.12
FS7	20-7.5	DISC	5.40	80.46
FS7	20-7.5	CAST	4.25	80.12
FT4	20-7.5	DISC	5.40	80.46
FT4	20-7.5	CAST	4.25	80.12
FS4	20-7.5	DISC	5.40	80.46
FS4	20-7.5	CAST	4.25	80.12
F43	20-7.5	DISC	6.06	77.58
F43	20-7.5	CAST	4.75	76.98
FT2	20-7.5	DISC	6.00	78.18
FT2	20-7.5	CAST	4.00	77.86
FS2	20-7.5	DISC	6.00	78.18
FS2	20-7.5	CAST	4.00	77.86
F48	20-7.5	DISC	6.00	78.18
F48	20-7.5	CAST	4.00	77.86
FRW	20-7.5	DISC	6.00	78.18
FRW	20-7.5	CAST	4.00	77.86
FRD	20-7.5	DISC	6.00	78.18
FRD	20-7.5	CAST	4.00	77.86
FVM	20-7.5	DISC	6.00	69.00
FVM	20-7.5	CAST	4.00	76.42
AXLE RPO	WHEEL SIZE	TYPE	WHEEL OFFSET	TRACK

AXLE RPO

FVM	F050 FRONT AXLE	5000 POUND CAPACITY	HYDRAULIC
FS2	F070 FRONT AXLE	7000 POUND CAPACITY	AIR TRUCK
FT2	F070 FRONT AXLE	7000 POUND CAPACITY	AIR TRACTOR
F48	F070 FRONT AXLE	7000 POUND CAPACITY	HYDRAULIC
FRD	F070 FRONT AXLE	7500 POUND CAPACITY	AIR TRUCK
FRW	F070 FRONT AXLE	7500 POUND CAPACITY	HYDRAULIC
FS4	F120 FRONT AXLE	9000 POUND CAPACITY	AIR TRUCK
FT4	F120 FRONT AXLE	9000 POUND CAPACITY	AIR TRACTOR
F43	F120 FRONT AXLE	9000 POUND CAPACITY	HYDRAULIC
FS7	F120 FRONT AXLE	12000 POUND CAPACITY	AIR TRUCK HD
FT7	F120 FRONT AXLE	12000 POUND CAPACITY	AIR TRACTOR HD
F54	F120 FRONT AXLE	12000 POUND CAPACITY	HYDRAULIC
FS6	FL931 FRONT AXLE	18000 POUND CAPACITY	AIR TRUCK
FT6	FL931 FRONT AXLE	18000 POUND CAPACITY	AIR TRACTOR

→ Front Axle Track ~ 80''
Other Comparables (℄ Outside Duals)
Tractor ~ 84½''
Trailer (Std.) ~ 84½''
Trailer (Wide) ~ 90½''

FIGURE 6 Front axle dimensions.

General:

Wheelbase - The distance between the ℄ (centerline) of the lead axle and the ℄ of the trailing axle or axle group for any given vehicle unit: i.e., to ℄ of tandems

Tractors:

Bumper to ℄ front axle - 28"-30" typical for long haul

Wheelbase - highly variable

- cab-over-engine (COE) without sleeper (4x2) - 116" typical
- conv. with sleeper (6x4) - 212" typical

5th wheel offset - adjustable typical

- forward for load transfer to front axle
- back - nonsensical
- zero offset yields greatest offtrack

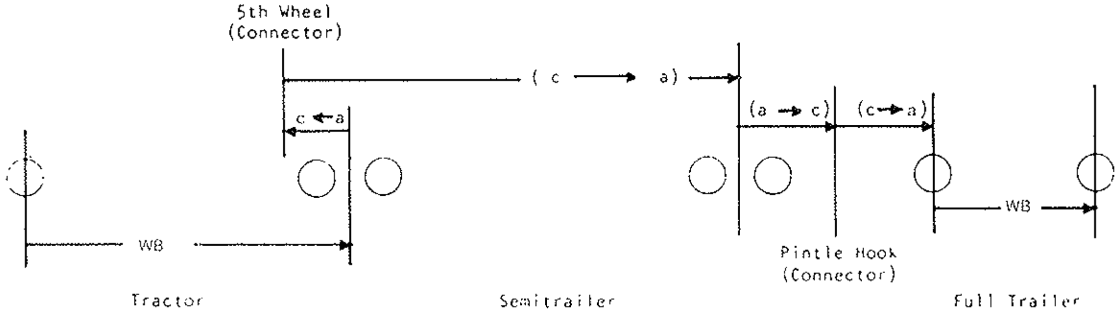
Trailers

Kingpin setting fixed - 28"-48", 36" typical

Rear overhang - from ℄ of rear axle/axle group

- short doubles units: 3-4 ft. (fixed)
- longer conv. units: 4-12 ft. (fixed/slider)

FIGURE 7 Elements of vehicle length.



General Form Formula:

$$OT_{max} = R - \sqrt{R^2 - \Sigma L^2}$$

where

L's may be = WBs (wheelbases)
= ac's (axle→ connectors)
= ca's (connector→ axle)

FIGURE 8 Axles and connectors concept.

but are definitely not all used in the calculations. The Ls actually represents the trace or single path from front to rear that connects adjacent axles or axle-group centerlines with each other or with intervening points of articulation (connectors). As indicated, the relevant axle-related dimensions are wheelbases (WB) and the unit connectors are typically fifth wheels or pintle hooks, or both.

Traces from axles (a) to connectors (c) are referenced as ac's and will always be found to produce contra-offtrack behavior (negative offtracking). The ac's when squared are always treated as negative values in the L^2s summation. (The negative offtrack phenomenon has long been recognized and is used to advantage in some types of combinations; however, personal verification is left to intuition or other sources.)

Traces from connectors (c) to axles (a) complete the normal list of options for L measurements. Referred to as ca's, these traces react in the same manner as a wheelbase in both the calculations and the turning process. It perhaps goes without saying that in the Ls summation process the number of ac's must equal the number of ca's.

Summarizing then, the Ls may be wheelbases (WBs), axle-to-connectors (ac's) or connector-to-axles

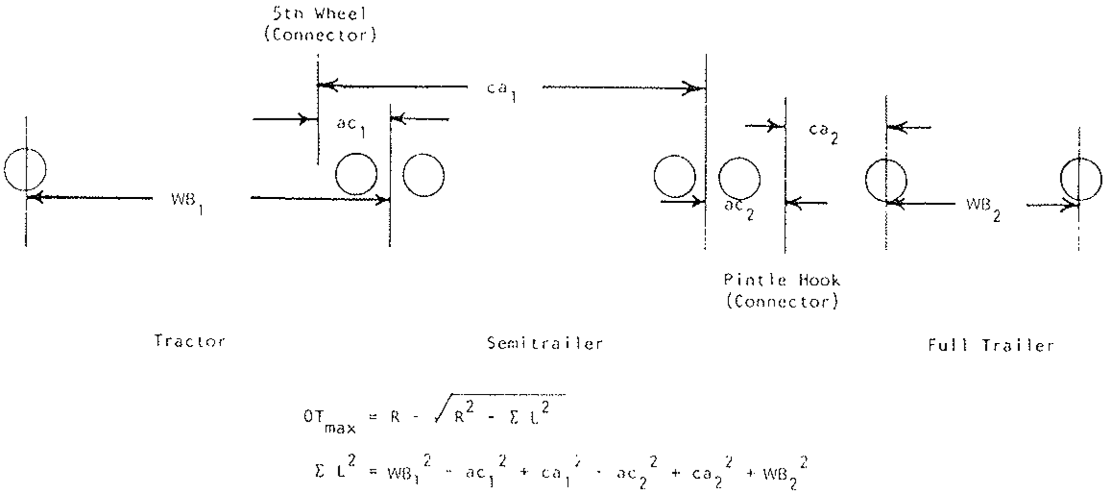


FIGURE 9 General case illustration.

(ca's). Further, ac's will always generate negative L^2s. Referring to Figure 9, the ΣL^2 is shown written in algebraic form for the illustrative, general case doubles unit. Following the L trace from front to rear with all ac's negative after squaring, the ΣL^2 statement is as follows:

$$\Sigma L^2 = WB_1^2 - ac_1^2 + ca_1^2 - ac_2^2 + ca_2^2 + WB_2^2 \qquad (4)$$

where

WB_1 = tractor wheelbase (as properly defined),
ac_1 = fifth wheel offset (irrespective of forward or back),
ca_1 = kingpin to rear tandem centerline,
ac_2 = centerline of rear tandem to pintle hook,
ca_2 = pintle hook to centerline of dolly axle (trailer 2), and
WB_2 = trailer 2 wheelbase (dolly fifth wheel offset = 0).

Note again that the number of ac's equals the number of ca's, even though an ac value, for example, may actually be zero. It will also be observed that the second trailer could also have a small fifth wheel offset, in which case an ac_3 and a ca_3 would replace the WB_2 shown.

For the fifth wheel offset, small values, say 1 ft or less, have virtually no impact as an ac because values less than 1, when squared, become even smaller. However, the ca difference compared with the corresponding wheelbase can and does become significant. The rule is: when a fifth wheel offset is the desired assumption, always use the ac and ca terms rather than the corresponding wheelbase.

SAMPLE CALCULATIONS

The first step in any offtrack calculation is to sort out and harmonize the various length components such that (a) all of the Ls are accounted for and realistic and (b) the sum of the parts equals the overall. This is not always as easy as might be imagined; and some visual aid, such as an axles-only schematic, will prove invaluable. It is recommended that this step precede any calculation effort--even if done on a computer.

Selected Combination

The Ls concepts were worked through with a somewhat unusual doubles configuration, a Rocky-Mountain double; this unit will also be used to illustrate the calculation process. Figure 10 is a fully dimensioned drawing of one such combination with the Ls components identified hereafter.

These particular units were assembled and used in the 1984 Multistate Highway Transportation Agreement (MHTA) over-the-road demonstration tests. The dimensions are exaggerated somewhat in comparison with normal practice. The purpose of the test was to gather real-world data for input to the FHWA Longer Combination Network Study, and FHWA insisted that the STAA dimensional maximums be used as the basis for the study.

L^2 Calculation

When the L components have been identified, the sum of L^2s computation is straightforward. Referring to Figure 10, the math, including the conversion of all measurements to the common units base, is as follows:

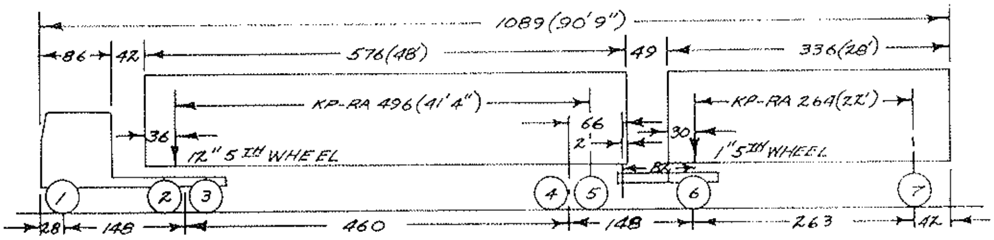
Component (in.)	L(ft)	L^2
WB_1 = 148	12.333	152.10
(-) ac_1 = 12	1.000	(1.00)
ca_1 = 472	39.333	1,547.08
(-) ac_2 = 66	5.500	(30.25)
ca_2 = 82	6.833	46.69
(-) ac_3 = 01	.083	Ignore
ca_3 = 264	22.000	484.00

ΣL^2 = 2,198.62

The selection of feet as the basis for computation is primarily a matter of number size convenience; however, because offtrack comparisons are often a matter of inches it is recommended that calculation accuracy be maintained to at least tenths of a foot and preferably to hundredths, as shown. Notice that the ΣL^2 is a characteristic of the vehicle itself and is totally independent of any turning radius considerations.

Selection of Intersection Radii

The turn radius of interest may be a special case (a given) or alternatively may be selected to represent



"Ls" Components

$$\Sigma L^2 = WB_1^2 - ac_1^2 + ca_1^2 - ac_2^2 + ca_2^2 - ac_3^2 + ca_3^2$$

where

$WB_1 = 148''$

$ac_1 = 12''$

$ca_1 = 496'' - 24''$

$= 472''$

$ac_2 = 66''$

$ca_2 = 82''$

$ac_3 = 1''$

$ca_3 = 264''$

FIGURE 10 Sample calculations, Rocky-Mountain double.

some particular class of facility. WHI analysis indicates that the following turning radii assumptions are reasonable and generally representative:

- Principal city streets = 60 ft,
- Rural state highways = 100 ft, and
- Freeways (cloverleaf) = 165 ft.

To complete the sample calculation process, two of these radii will be used to estimate the offtrack performance expected for the selected combination.

60-Ft Turning Radius Calculation

Given

TR = 60 ft (principal city street),
HT = 3.33 ft (1/2 front axle),
R = TR − HT
= 56.67 ft,
R^2 = 3,211.49, and
ΣL^2 = 2,198.62 (constant calculated earlier),

then

$$\begin{aligned} MOT_{60} &= R - [(R^2 - \Sigma L^2)^{1/2}] \\ &= 56.67 - [(3{,}211.49 - 2{,}198.62)^{1/2}] \\ &= 56.67 - 31.83 \\ &= 24.84 \text{ ft.} \end{aligned}$$

100-Ft Turning Radius Calculation

Given

TR = 100 ft (rural state highway),
HT = 3.33 ft (1/2 front axle),
R = TR − HT
= 96.67 ft,
R^2 = 9,345.09, and
ΣL^2 = 2,198.62 (same constant),

then

$$\begin{aligned} MOT_{100} &= R - [(R^2 - \Sigma L^2)^{1/2}] \\ &= 96.67 - [(9{,}345.09 - 2{,}198.62)^{1/2}] \\ &= 96.67 - 84.54 \\ &= 12.13 \text{ ft.} \end{aligned}$$

The simplicity of the final calculation points out once again the significance of the ΣL^2 as the key to the proper understanding and use of the WHI formula.

Maximum Turning Track Calculation

Consideration of the practical highway engineer's definition of offtracking leads again to the determination of minimum pavement requirements (i.e., turning track or swept width). AASHTO policy guidance makes this a simple task and suggests that a constant of 8.5 ft be added to the indicated offtrack value. If

U = turning track and

$$U_{tr} = MOT_{tr} + 8.50 \qquad (5)$$

then for the selected combination,

$$U_{60} = 24.84 + 8.50 = 33.34 \text{ ft}$$
$$U_{100} = 12.13 + 8.50 = 20.63 \text{ ft}$$

The AASHTO constant, on closer examination, appears to have been somewhat overgenerous as originally specified for use with 96-in.-wide units. As a result, there appears now to be no strong argument for using a larger value in conjunction with 102-in.-width turning performance.

OVERVIEW OF WHI FORMULA

In introducing the subject, various definitions of offtracking were given to illustrate the unique characteristics of the WHI formula. It was pointed out that the formula yields a maximum or steady-state value related to the centerline of the vehicle. An understanding of front axle track width and its relationship to turning radius was emphasized, and the real world of truck length components was discussed with respect to the identification and handling of the Ls in the ΣL^2 determination.

The sample calculations used an uncommonly long vehicle configuration and short-radius curves to illustrate

- The concepts of axle-connector (negative offtrack term) and connector-axle distances as they interrelate with overall wheelbase to determine the vehicle-dependent value ΣL^2,
- The correct half-track adjustment of the turning radius to determine the vehicle centerline radius (R), and
- The relative simplicity of the calculations when the formula components have been properly defined.

As a general overview of the formula application, it can be said that the WHI offtrack formula is an accurate and expeditious tool for comparing worst-case vehicle turning performance. Worst case is emphasized because the steady-state values as computed virtually always exceed those for a 90-degree turn. Be aware, however, that the formula may break down for long units on short-radius curves.

Not even mentioned was that the mathematical formulation of the Canadian transient offtrack model now offers the capability to compute maximum offtrack for any given degree of turn. The formulas available in the report by Woodrooffe et al. (6) can be used to adjust the steady-state value when it has been determined. That discussion, however, is a follow-on subject and will not be attempted as part of this presentation.

Offtracking calculations and their interpretations are indeed skills that are "honed" only with frequent use. Further, when improperly used any special-purpose tool will fail to do the job for which it was designed. The purpose of this presentation has been to outline the concepts and procedures required to correctly use the WHI offtracking formula.

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Vehicle Offtracking Models

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ABSTRACT

When a vehicle turns, the rear wheels track inside the path traced by the front wheels. This behavior is called offtracking and can lead to problems when large trucks operate in confined areas. The methods that have been used by designers to estimate the offtracking of heavy trucks are reviewed, and then a computer method for graphing the complete swept path of an arbitrary vehicle making any type of turn at low speed is described. The method is valid for nearly all truck configurations in use on the highways, including double and triple combinations. The paper includes several example plots, and a computer program that uses this method, developed for the Apple II computer, is described. The program is available free from the Federal Highway Administration.

Motor vehicles typically employ a single steered front axle followed by one or more unsteered rear axles. In low-speed turns, the rear wheels track inside the paths taken by the front wheels, such that the path swept by the vehicle is wider than the vehicle itself. Figure 1 shows how this behavior results in an additional swept width, called offtracking, for the vehicle. Offtracking can pose problems whenever there is not enough space to accommodate both the width of the vehicle and the additional offtracking displacement. Thus engineers laying out geometric designs for intersections, parking areas, and other locations with restricted geometry need to address the potential offtracking requirements of the largest vehicles that will be using the area.

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