Offtracking Calculation Charts for Trailer Combinations

Offtracking, Turning Track Widths and Curb Radii for Single-Unit Vehicles and Trailer Combinations on Turns of Various Degrees and Radii

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In this report the offtracking characteristics of single unit vehicles and combination vehicles are described. Offtracking values were obtained with scale models of vehicles making turns on turning radii varying from 25 to 225 feet. The offtracking data are shown in two charts, one for 90-degree turns and one for 270-degree turns, for vehicle wheelbases ranging from 5 to 55 feet.

Individual vehicle offtrackings are influenced by three variables: the degree of turn, the length of vehicle wheelbase, and the turning radius. It was found that the offtracking measurements of a trailer combination may be calculated by adding the offtracking measurements of the individual vehicles in the combination. The research also found that the offtracking is greatest when the projection of the rear axle axis passes through the turning radius center, even though the projections of the other axles on the vehicle or trailer combination do not, at the same time, pass through the turning radius center.

●WITH THE expansion of the Interstate System and increasing usage of the nation's highways, new demands are being made on highway designers. Strong emphasis is directed to designing highways which provide good traffic flow, traveling ease, and maximum safety.

Changes are also taking place in the vehicles which use the highways. Size and weight regulations for commercial vehicles are being reevaluated and changed, and more and bigger vehicle combinations are using the highways. With these changes comes the need for more information on the handling characteristics of such vehicles.

The turning characteristics and offtracking behavior of single-unit trucks and trailer combinations are of particular interest to the highway engineer for use in the design of highway curves, city street turns and freeway entrance and exit ramps. Until recently only limited information has been readily available for turns of different degrees and turning radii.

Data from the vehicle manufacturers have been sparse. There have been several other studies made on vehicle steering performance, but most of the material reported thus far has provided information on the operation of a few specific vehicles and combinations on minimum radius turns. The data presented usually relate only to maximum resulting offtracking values without regard to the degrees of turn made by the vehicle before exiting onto a tangent.

There have also been a number of sketches, drawings and detailed descriptions of the minimum turning paths of various specific vehicles. Such information is of value, but is inadequate because it does not allow for easy interpolation of offtracking measurements between different classes of vehicles, or for comparisons of vehicles of different wheelbases operated on turns of different radii. Even the SAE offtracking formulas (1) require the use of specific vehicle dimensions and yield only maximum offtracking values for a particular trailer combination. Thus, in order to make a comparison of the offtracking characteristics of a number of different trailer combinations, or to determine a range of values for some particular turning radius, a long and tedious process of individually calculating the offtracking for each variation in vehicle dimensions is required.

In addition, previously reported offtracking data have been based on measurements taken from the center of the axles of the vehicle. This may be satisfactory for automotive engineering uses but for the highway engineer it necessitates the adding or subtracting of additional factors. In this report, all offtracking values and turning radius measurements are to the outside of the outer tire of an axle.

The research reported in this paper was planned to develop a simpler, quicker and more comprehensive method of calculating offtracking. The technique used to accomplish this is a series of charts which are so constructed as to allow for direct reading and calculation of offtracking values for almost all practical highway vehicles and trailer combinations. The information is reported for the important turns of 90 and 270 degrees and for outer front wheel turning radii from 25 to 225 feet. The range of turns and turning radii covers most of the vehicle turns made on city streets and at rural intersections, including at-grade intersections, diamond interchanges and separated cloverleaf interchange ramps.

The fundamental premise on which the data and methods contained in the report are based is that the sum of the offtracking of the individual vehicles of a highway trailer combination closely approximates the total offtracking of the combination. Starting with this premise, the pattern of research included experiments with vehicle models which led to the establishment of patterns and values of vehicle offtracking behavior which are related to variations in wheelbase length, turning radius and degree of turn. The final purpose was to develop methods of plotting these data for rapid use and comparison.

In approaching the data contained in this report there is a need for preciseness in definitions. This is because in some instances two or more engineering organizations have defined the same terms differently. There are also a few terms used in the paper which have not been previously defined by others. A definition of terms is given in the Appendix, and it is recommended that it be reviewed carefully before continuing.

FUNDAMENTALS OF OFFTRACKING

Offtracking is the phenomenon in which the paths of the wheels of a rear axle of a single-unit power vehicle, or of a trailer combination, deviate inward toward the center of a turn from the circular turning path of the outside front wheel. When operating on uniform radius turns individual vehicles, whether in combinations or single-unit vehicles, offtrack in similar patterns of turns. The front wheels of a power unit do not offtrack, but all other axles on a vehicle, or on a trailer combination, do offtrack on a turn.

While the preponderance of highway vehicles have non-steerable rear axles, there is a small minority of vehicles which have various methods of rear steering. In this study only vehicles with non-steering rear axles were considered, and the data refer only to such vehicles.

For practical vehicle-highway geometrics, and important value of offtracking is the greatest offtracking that occurs when a single-unit vehicle or a trailer combination makes a turn of 270 degrees. With short wheelbase single-unit vehicles, the greatest offtracking may occur early in the first 90-degree segment of a turn, but with very long trailer combinations, it may take the full 270 degrees of turn before the greatest offtracking is attained.

With the longer trailer combinations, the offtracking during a 90-degree turn will be substantially less than their greatest offtracking on a 270-degree turn. Further, on 90-degree turns the front wheels of the power vehicle of a long trailer combination will run for some distance on the exit tangent before its greatest offtracking is attained. It is difficult to calculate the offtracking of long wheelbase trailer combinations when the front wheels of the power vehicle travel on the exit tangent, but the solution can be obtained with scale models of vehicles. Of course, with very short wheelbase single-unit vehicles, which reach their greatest offtracking before 90 degrees of turn, any travel on the exit tangent does not increase the amount of offtracking.

On turns, the offtracking characteristics of single-unit vehicles, and of the individual vehicles in trailer combinations, are affected by several interlocking factors. The factors are:

1. The degree of a turn.
2. The wheelbase of each individual vehicle in a trailer combination.
3. The uniform turning radius of the outside of the outer front tire of the power vehicle. (This turning path of the outside of the outer front tire usually is the outer pavement or curb radius on a specific turn.)
4. The radius of the outside of the outer front tire on a trailer's real or virtual front axle with reference to the turning radius center when the towing vehicle is at its point of greatest offtracking on a specific turn.
5. In trailer combinations, the rear trailing axle of each leading vehicle acts as a real or a virtual front axle of the following trailing vehicle. The virtual front axles of trailing vehicles are as follows: (a) On semitrailers, the tractor rear axle is the semitrailer's virtual front axle. (b) On trailer converter dollies, or on non-detachable front axle assemblies of full trailers, the virtual front axle of such semitrailer-type assemblies is located on the centerline of the towing vehicle's pintle hook, which is the same location as the center of the pintle hook eye of the towbar. (c) On full trailers, the axle of the trailer converter dolly is its virtual front axle; however, with non-detachable front axle assemblies, such a front axle of a full trailer is its real front axle. Both types of front axles for full trailers perform similarly.

ILLUSTRATIONS OF TURNING AND OFFTRACKING PHENOMENA

Single-Unit Vehicles

The principles of offtracking phenomena are illustrated in Figures 1, 2, 3, and 4, which show the action of vehicles with Ackerman steering on turns.

In Figure 1 a long single-unit vehicle is shown at its entrance tangent position just before entering a curve. It will be noticed that the projections of the two stub axles of the front wheels and of the rear axle are parallel, and do not intersect. During a turn the projections of the front wheel stub axles and the rear axle of long vehicles vary from parallel when on the entrance tangent, to various intersecting positions during a turn (Fig. 2), and the projections reverse towards parallelism when the front wheels leave the turn on an exit tangent (Fig. 3). Thus, the offtracking rear wheels travel in a double spiral curve.

In Figure 2 the vehicle has not attained its greatest offtracking on a 90-degree turn; in fact, it is still in transition from its starting position, even though the front wheels are at the exit tangent. It will be noted that, while the projections of the stub axles of the front wheels pass through the turning radius center, the axis of the rear axle does not pass through the turning radius center.

In such situations, the greatest offtracking will occur after the outer front tire of the vehicle is on its exit tangent, as shown in Figure 3, where the front end of the
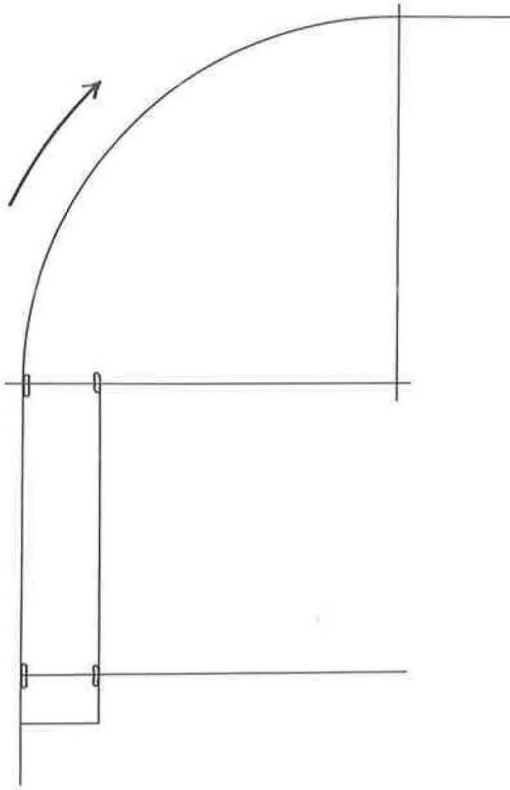
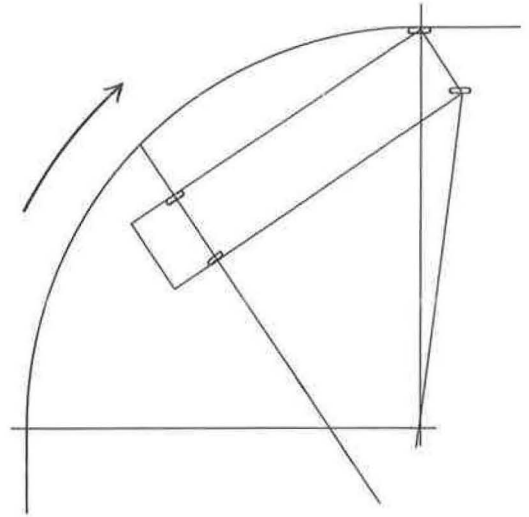Figure 1. A long wheelbase vehicle in tangent position about to enter turn.

Figure 2. A long wheelbase vehicle which has completed 90 degrees of turn but which has not yet obtained its greatest offtracking.

vehicle has moved down the exit tangent until the projected axis of the rear axle passes through the turning radius center. This point of greatest offtracking during a 90-degree turn was observed in the operation of the vehicle models. It will be noted that the axes of the front wheels no longer pass through the original turning radius
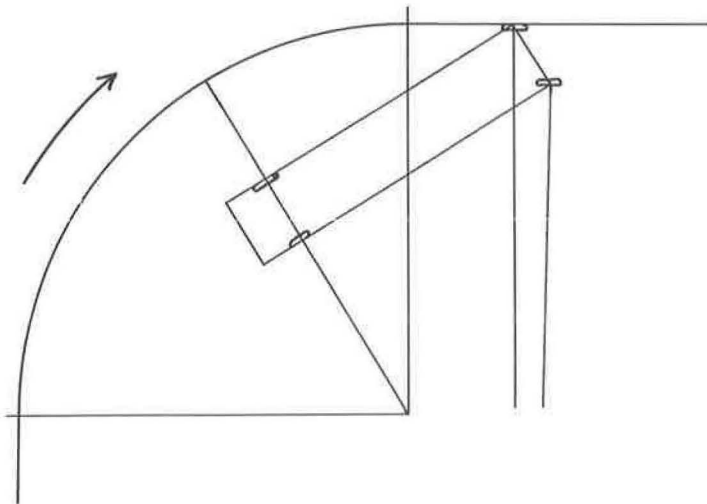

Figure 3. A long wheelbase vehicle which has reached its point of greatest offtracking after traveling some distance on an exit tangent.
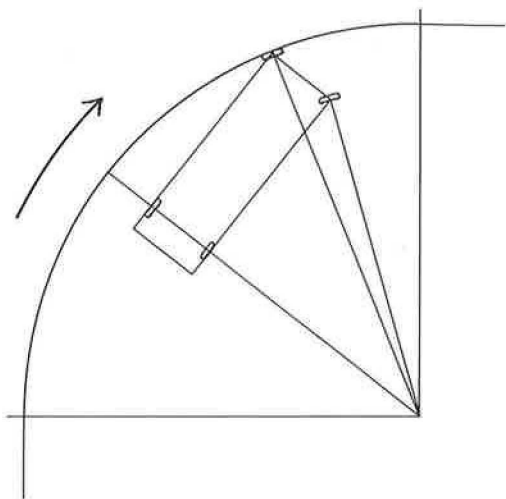
Figure 4. A short wheelbase vehicle which has reached its point of maximum offtracking.
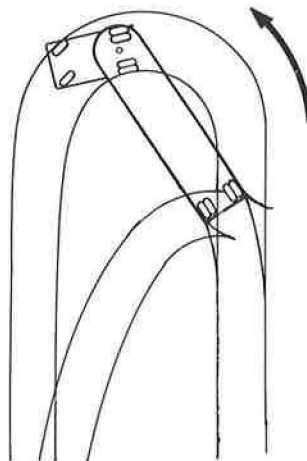
Figure 5. A long wheelbase combination on a short radius turn in which the semitrailer backs up and pivots behind the turning radius center.

center, but the axis of all axles will intersect at some distance behind the turning radius center. The amount of greatest offtracking in such situations was measured with the vehicle models, but cannot be calculated by the SAE equations.

With short wheelbase, single-unit vehicles, such as passenger cars and small trucks, the vehicle's maximum offtracking usually will occur during the first 90-degree segment of a turn. This situation is illustrated in Figure 4. Here the axes of all axles intersect at the turning radius center. The offtracking values of such vehicles were measured with the vehicle models and are included in the offtracking charts (Figs. 10-12). However, the offtracking values of these short wheelbase vehicles can be solved by the SAE equations.

Trailer Combinations

It is desirable that trailer combinations, when negotiating highway curves or at-grade intersections, move continuously and progressively forward at a reasonably rapid speed. Because of their articulated construction, however, trailer combinations may not travel in a continuous, smooth path when the turning radius is shorter than the trailer wheelbase. Such nonuniform type of travel is possible with trailer combinations because fifth wheel pivot type steering permits a trailer to turn 90 degrees or more from the longitudinal axle of the towing vehicle. The angle through which the power vehicle can turn is limited, of course, by its steering cramp angle and its wheelbase.

An example of a trailer combination offtracking in a noncontinuous, irregular manner is shown in Figure 5. When trailer combinations are negotiating 180-degree turns and the turning radius is less than the length of the trailer's wheelbase the rear axle will pass behind the turning radius center and will pivot and travel backwards in an irregular path. The rear axle of long trailer combinations traveling short radius 270-degree turns also exhibits similar backing and pivoting characteristics. Such reverse travel and pivoting of the rear axle can only be considered in very close quarters, as in buildings where the drivers carefully manipulate the trailer combinations at creep speeds. The charts included in this report are not applicable to this type of irregular offtracking.

Trailer combinations negotiating 90-degree turns, however, travel in a continuous and smooth path regardless of which side of the turning radius center the semitrailer passes on. Figure 6 shows a long wheelbase trailer combination following a relatively
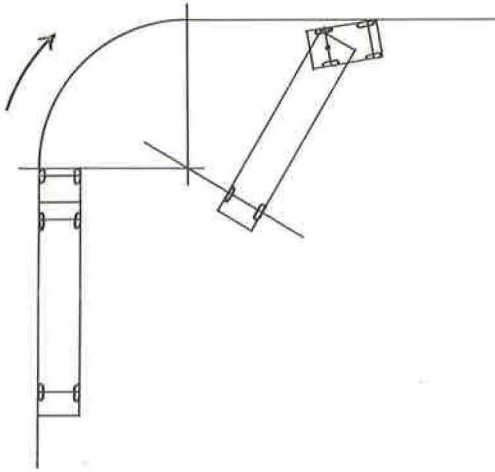
Figure 6. A long wheelbase combination on a short radius turn in which the semitrailer passes in back of the turning radius center.

short turning radius, a situation typical of city street operations. Because the outer rear tire on the rear axle passes behind the turning radius center, the greatest offtracking cannot be calculated with the SAE equations but can be and was measured with the vehicle models. The greatest offtracking on such a turn occurs when the projection of the rear axle, as shown in Figure 6, passes through the turning radius center even though the front wheels of the power vehicle are on the exit tangent.

The problems associated with long trailer combinations negotiating curves having short turning radii are troublesome, particularly on city streets and diamond approaches to controlled access highways. Such problems will be further magnified if, in the future, longer single trailer combinations are permitted. In general, double trailer combinations offtrack less than long single trailer combinations, as is shown later.

FACTORS IN OFFTRACKING DETERMINATIONS

One important feature of vehicle offtracking is that the greatest offtracking for any degree of smooth and continuous turn occurs when a projection of the axis of the rear axle of a vehicle is on a radial passing through the turning radius center. This phenomenon was observed with the vehicle models, which were equipped with a scale that projected from the outer end of the trailing rear axle. It was observed that the greatest outer rear tire offtracking occurred when the rear axle was parallel with a radial line passing through the turning radius center on the model test pattern.

The various measurements of offtracking data which are of interest and use to the highway design engineer are: (a) dimensions of vehicles and trailer combinations; (b) turning radius of specified turn; (c) offtracking of trailing rear axle; (d) turning track width; and (e) inside curb radius (for zero clearance with tire).

The dimensions of vehicles and trailer combination are needed so that the design engineer will know the sizes of vehicles to be considered in a specific turn situation. Dimensions of the individual vehicles in a trailer combination needed are: (a) wheelbase of each vehicle, (b) width over the tires, and (c) on double cargo vehicle combinations, the rear overhang of each towing vehicle and the spacing between the vehicles.

The outer curb radius of a specific turn usually is determined by the location and terrain situation in the turning area.

Offtracking is the radial distance between the outer front wheel turning radius of the outside of the outer front tire of a vehicle, and the radius of the outside of the outer rear tire of a rear trailing axle, at its point of greatest offtracking. Offtracking amounts for single-unit vehicles and individual vehicles of trailer combinations can be obtained from the offtracking charts.

The turning track width is the amount of offtracking plus the width over the tires of the dual tires on a rear axle, or the width of the cargo body if it is significantly greater than the width over the dual tires. This dimension was assumed as 8.0 feet in this study because it is the predominant width at present. However, the newly revised 1965 AASHO Size and Weight Recommendations carry a provision for over-the-tire widths of 8.5 feet.

The inside pavement or curb radius on a turn is the radius from the turning radius center to the outside of the innermost rear tire on the rear axle at the point of its

greatest offtracking for a specific turn. The inside curb radius equals the original front wheel turning radius minus the turning track width. This inside curb radius will permit a perfectly driven trailer combination, following the specified outer curb turning radius, to just clear the inner curb at its point of greatest offtracking. Practically, the actual inner curb radius should be some amount shorter in order to permit variations in driver manipulation.

Offtracking Values of Single-Unit Power Vehicles

The procedures for determining the offtracking amounts of individual single-unit vehicles from the offtracking charts require only a single reference to either the 90-degree or the 270-degree chart. The procedures are described later.

Offtracking of a Trailer Combination

The offtracking of a trailer combination on a specific turn is a summation of the offtracking of the individual vehicles making up the trailer combination. Each vehicle in a trailer combination offtracks individually in accordance with its wheelbase, and the radius from the turning radius center to the outside of the outer front tire on its real or virtual front axle. The problem is to determine the turning radius of the real or virtual outer front tire of each individual trailer vehicle in the train. Because all trailing vehicles (semitrailers, trailer converter dollies or non-detachable full trailer front axle assemblies, and full trailers) offtrack and steer like semitrailers, it is necessary to assume a virtual, or real, front axle for each such semitrailer-like unit. The point of greatest offtracking for the rear axle of each towing vehicle on a specific turn will prescribe the turning radius of each following semitrailer-like unit. As one proceeds from the front axle of a trailer combination, there is a progressive series of changed, usually reduced, turning radii for the outer tire of the virtual front axle for each semitrailer-like unit. Thus by analyzing each semitrailer-like unit in the order it appears in the trailer combination, using in sequence the turning radius of the outer front tire on each real or virtual front axle, it is possible to obtain a series of separate offtracking measurements for each vehicle, which can be added together to give the greatest overall offtracking of the complete trailer combination. The procedure for making these progressive steps in calculations is described later.

When determining the offtracking of trailer combinations having full trailers, the phenomenon of negative offtracking must be considered. Negative offtracking occurs when the outer rear corner of the cargo body, opposite the pintle hook, swings outside of the path of the outside of the outer rear tire on a turn as shown in Figure 7. In effect, negative offtracking increases the turning radius of the following semitrailer-like unit. The magnitude of negative offtracking depends on the wheelbase of the towing vehicle, the length of rear overhang to the centerline of the pintle hook, the turning radius, and the degree of turn. The negative offtracking values for practical power vehicles and towing semitrailers are given later in Tables 1 and 2. The tables were used because of the difficulty of presenting four variables in graph form.
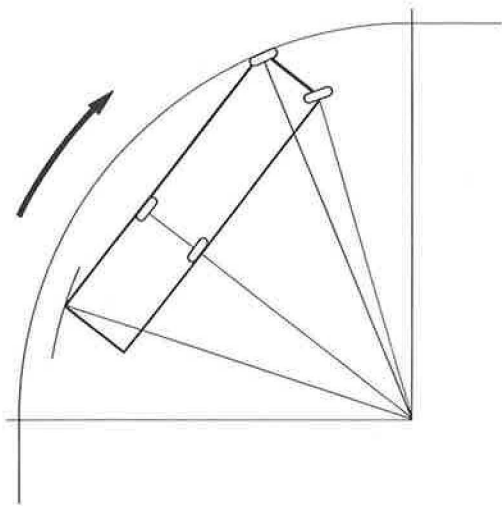

Figure 7. Negative offtracking in which the path of the outer rear corner of the body has a greater radius than the path of the outer rear wheel.

HIGHWAY VEHICLE STEERING SYSTEMS

Ackerman Steering

In order to understand the various aspects of vehicle turning and offtracking, it is first necessary to know something about the systems of steering used on most highway vehicles. Single-unit vehicles, automobiles, light trucks, tractive trucks, and tractors are equipped with Ackerman type steering. The Ackerman system was invented in Germany about 1817 and first patented by an Englishman in 1818. It is preferred over other steering systems because it provides better stability to the front end of the vehicle during a turn.

In the Ackerman system the two front wheels are mounted on short stub axles which are in turn connected to the steering kingpins. The kingpins are connected to the front wheel spring suspension and are supported by the vehicle chassis, or in some cases by a rigid "beam type" front axle. During a turn the front wheels are pivoted on the kingpins by the steering linkage and other mechanisms which are connected to the driver's steering wheel.

Vehicles equipped with Ackerman steering are limited in the amount of offtracking which they can attain by the minimum turning radius curve which can be followed by the outer front wheel. This minimum turning radius usually is limited by the degree to which the inner front wheel may be turned because of mechanical obstructions. This limit to the turning capability of the inner front wheel is commonly called the "cramp angle." On most over-the-road trucks the maximum cramp angle is between 30 and 35 degrees. Recently, however, the manufacturers of city delivery trucks have been widening the distance between front wheels and are obtaining cramp angles of 45-50 degrees. The offtracking charts in this report are designed to include such vehicles.

Fifth Wheel Steering

Semitrailers, full trailers, and trailer converter dollies all operate with a fifth wheel pivot steering principle which is different from the previously discussed Ackerman system. Since trailers are never operated by themselves it is not necessary for them to have the front end stability required for power vehicles. In the fifth wheel pivot type of steering system the front wheels are mounted at the ends of a rigid one-piece axle. This axle is pivoted about a kingpin which is mounted above the lateral center of the axle, where it is connected to the trailer body.

In the case of semitrailers the rear axle of the tractor acts as the virtual front axle of the trailer. In most designs the trailer kingpin, surrounded by a lubricated bearing plate, is attached to the underside of the semitrailer, usually about 3 feet back from the front end of the trailer. Another bearing plate, equipped with a kingpin locking device, is mounted on the tractor chassis, just over the rear axle. This device, known as the fifth wheel, engages and holds the trailer kingpin and allows the trailer to be pulled and steered by the tractor. This system permits easy coupling or uncoupling and the interchanging of trailers.

Full trailers are basically semitrailers which have one of two types of front axle assemblies. In one type the front axle is permanently attached to the trailer, and in the other the front axle may be removed. The removable front axle assemblies are known as trailer converter dollies. They consist of one or more one-piece axles supported by a spring suspension system and with a fifth wheel mounted above the center of the axle. Both the trailer converter dollies and the permanently attached type front axle assemblies have towbars affixed at a 90 degree angle to the axle. This towbar has an eye which engages a vertical pintle hook on the rear end of its towing vehicle. Once engaged, the towbar may pivot freely about its pintle hook, limited only by any interferences with rear frame parts of the towing vehicle. Because of this free pivoting action of the towbar, both types of front axle assemblies of full trailers act as short wheelbase semitrailers in making a turn. Thus a full trailer turns and offtracks like a semitrailer connected in tandem to another semitrailer, both of which have pivot steering.

In considering the steering and offtracking behavior of these full trailer front axle assemblies it may be assumed that their virtual front axle is located at the center of the pintle hook. Thus, the wheelbase of such devices is measured from the center of the towbar eye to the center of the axle.

With fifth wheel pivot steering there is no cramp angle problem and the angular relationship between the towing vehicle and the semitrailer is not restricted and may be as much as 90 degrees or more.

VEHICLE MODELS AND INSTRUMENTATION

The relationships on offtracking contained in this report were obtained primarily through the use of scale models of highway vehicles. The models were designed to provide a good simulation of actual vehicle turning characteristics for a wide variety of different types and lengths of single unit vehicles and trailer combinations. In order to expedite the study, models were designed as detachable components which could be quickly assembled or disassembled. The models, which were equipped with an Ackerman steering mechanism, were constructed to a scale of 0.75 in. = 1 ft and with the width over the tires equal to 8 model feet. For simplicity in manipulation and measurements of the models, the width over the tires on the front wheels was made 8 model feet, the same as the model width over the rear tires. These few inches of additional width over the front tires are not significant to the highway design engineer, as he must allow a far greater width clearance for differences in vehicle manipulation on the road.

The models were operated on a smooth surface composed of 4- by 8-foot panels placed on a level concrete floor. The panels were assembled into a 16- by 16-foot square, centered on which were painted circles simulating highway curves ranging from turning radii of 25 to 100 model feet. Radial lines, at 10-degree intervals, and tangents were then superimposed upon the test layout as shown in Figure 8. Turning radii of 165 and 225 model feet were obtained by placing 8 additional panels about the original 16- by 16-foot square.
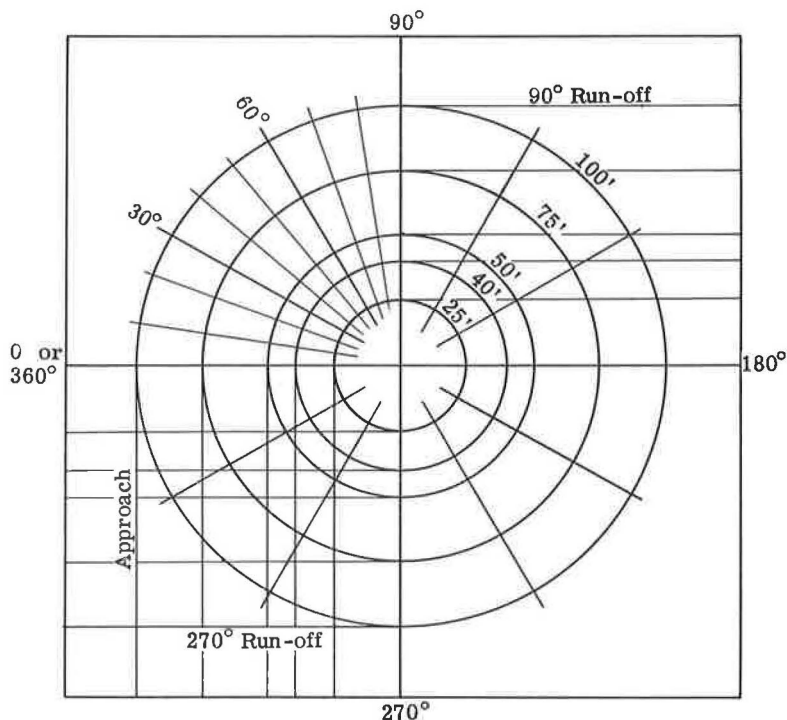

Figure 8. Schematic arrangement of guidelines on floor panels.

Before each individual test was conducted, the vehicle and axle alignment of the model was first checked on an 8-foot long approach tangent. If the model followed the tangent without any perceptible deviation, it was then guided so that the outside of the outer front wheel followed the circular curve selected for the test.

Offtracking tests were conducted with models representing various types of single unit vehicles and trailer combinations. Included were models of power vehicles with wheelbases ranging from 5 to 30 model feet, tractive truck models with considerable rear overhang, and semitrailer models with wheelbases ranging from 5 to 55 model feet. Full trailer model tests were not conducted since full trailers offtrack like semitrailers, regardless of whether they are equipped with trailer converter dollies or non-detachable front axles.

It should be noted that in the semitrailer model tests the trailer kingpin was positioned directly over the center of the front axle of a short wheelbase tractor model as shown in Figure 9. With the kingpin in this position any offtracking of the tractor did not affect the trailer offtracking; however, the tractor did provide model stability.

In all of the model tests the greatest offtracking was measured at the rear or trailing axle of a vehicle or trailer combination. In order to ascertain the magnitude of negative offtracking on tractive trucks having long rear overhangs, an additional off-tracking measurement was taken at the outer rear corner of the model opposite the pintle hook centerline. In order to expedite the determination of the greatest off-tracking, a scale was mounted on the vehicle models as shown in Figure 9. Offtrack-ing data were obtained by the model assemblies for both 90- and 270-degree turns. Single tires were used on the models at the place of the outer tires in order to give best consistency for various turning paths of the model.
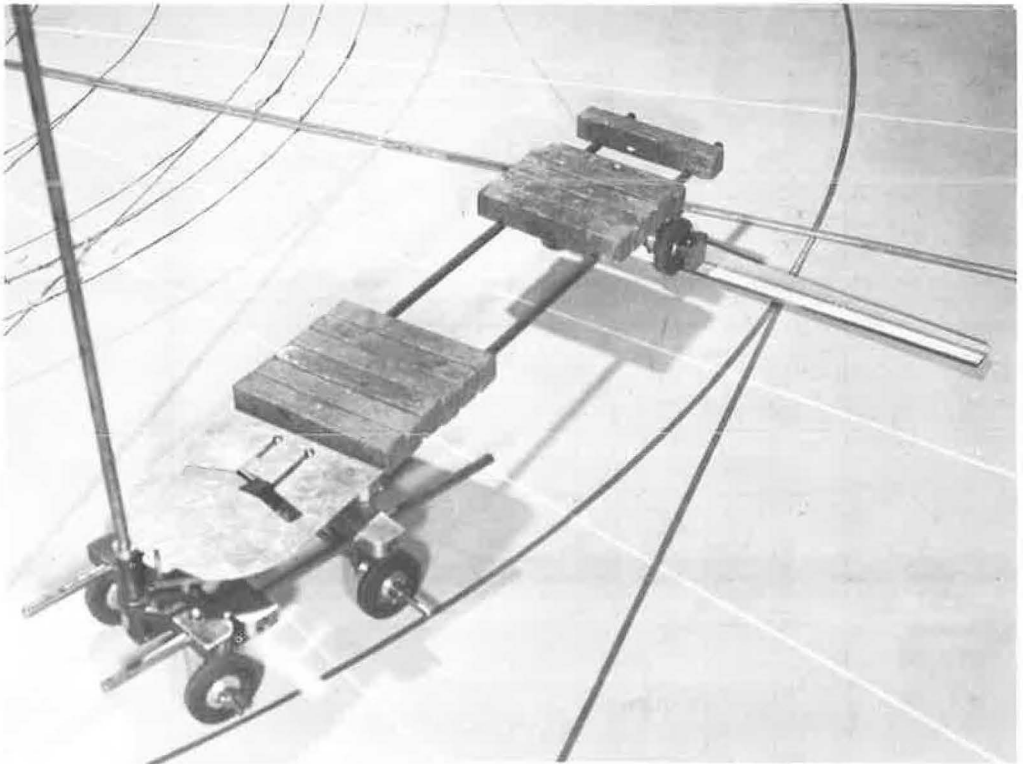

Figure 9. Semitrailer model with fifth wheel pivot steering.

THE USE OF THE OFFTRACKING CALCULATION CHARTS

The results obtained from the vehicle models are presented on two charts, Figure 10 for 90-degree turns and Figure 11 for 270-degree turns. The charts have been designed to permit the rapid determination of offtracking for both single unit vehicles and trailer combinations. For single unit vehicles the offtracking is determined directly. Determination of the offtracking for combination vehicles is accomplished by adding together the offtracking of the individual units of the combinations.

Semilogarithmic graph paper has been used in preparing both charts. The ordinate, in logarithmic scale, represents offtracking in feet. The logarithmic scale was selected in order to reduce the height of the ordinate for publication. The abscissa represents the turning radius in feet and it is shown on an equal interval scale. Wheelbase curves have been drawn in 5-foot increments.

With the use of the charts, vehicle offtracking may be evaluated for turning radii of 25 to 225 feet and for wheelbase lengths of 5 to 55 feet. The 25-foot turning radius represents the shortest radius turn studied with the models. Above a 225-foot turning radius, the offtracking of single-unit vehicles and trailer combinations approaches the "maximum" offtracking as calculated by the SAE equations (1). The charts also indicate the approximate limits of the minimum radii of turns possible when an Ackerman type steering system is employed and when the front wheel cramp angle is 50 degrees. The following examples explain how the charts are to be used.

Single Unit Vehicles

The offtracking for single-unit vehicles can be determined directly from the charts. For example, the greatest offtracking for a 2-axle truck negotiating a turning radius of 70 feet on a 90-degree turn would be found from Figure 10. Assuming the 2-axle truck had a wheelbase of 30 feet, the greatest offtracking would be 6.4 feet. If the same 2-axle truck was negotiating a 70-foot radius curve through a 270-degree turn, then the greatest offtracking would be 7.0 feet as determined from Figure 11.

If the minimum turning radius for this 2-axle truck is desired, it can be approximated by the dashed curve shown on the charts. Assuming the front wheel cramp angle is 50 degrees, Figure 10 indicates that a 30-foot wheelbase single-unit truck cannot negotiate a curve having a turning radius less than 45 feet.

If the offtracking is desired for a vehicle having a wheelbase between those represented by the wheelbase curves on either Figure 10 or 11, then Figure 12 may be used to interpolate between the wheelbase curves. For example, if in the above problem the offtracking had been desired for an 11-foot wheelbase single-unit truck, the following procedure would be employed. Take the vertical distance found on either Figure 10 or 11 between the 10- and 15-foot wheelbase curves and locate the same distance vertically on Figure 12 between the 10- and 15-foot lines. At this location on Figure 12, the vertical distance between the 10- and 11-foot lines is then carried back to the initial chart, and located vertically above the 10-foot wheelbase curve. The offtracking is then read from either Figure 10 or 11 on the ordinate horizontally opposite the point representing the 11-foot wheelbase. When negotiating a 90-degree turn, the greatest offtracking for this single-unit vehicle is 0.9 feet.

Tractor Semitrailers

Offtracking is determined for tractor semitrailers by adding together the offtracking of the individual vehicles of the combinations. For example, the greatest offtracking for a 2-S2 vehicle combination negotiating a turning radius of 100 feet through a 270-degree turn would be found from Figure 11. The dimensions of the sample 2-S2 trailer combination are given in Figure 13.

First, the greatest amount of offtracking is determined for the tractor having a 10-foot wheelbase. Reference to Figure 11 indicates that the greatest tractor offtracking will be 0.54 feet. After finding the tractor offtracking, the semitrailer offtracking is determined. In arriving at the semitrailer offtracking, it is required that its turning radius and wheelbase be known. Both Figures 10 and 11 have been prepared to take
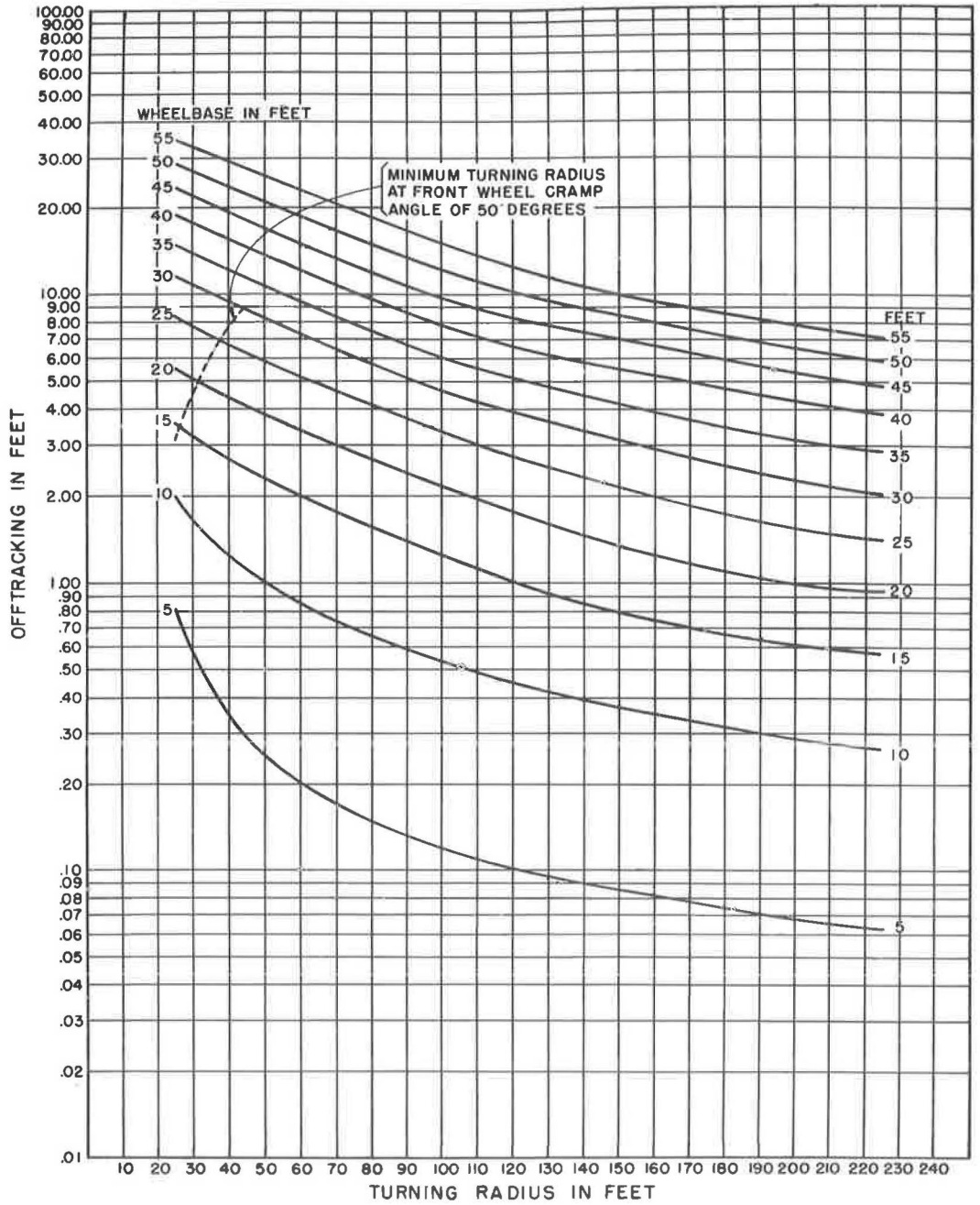
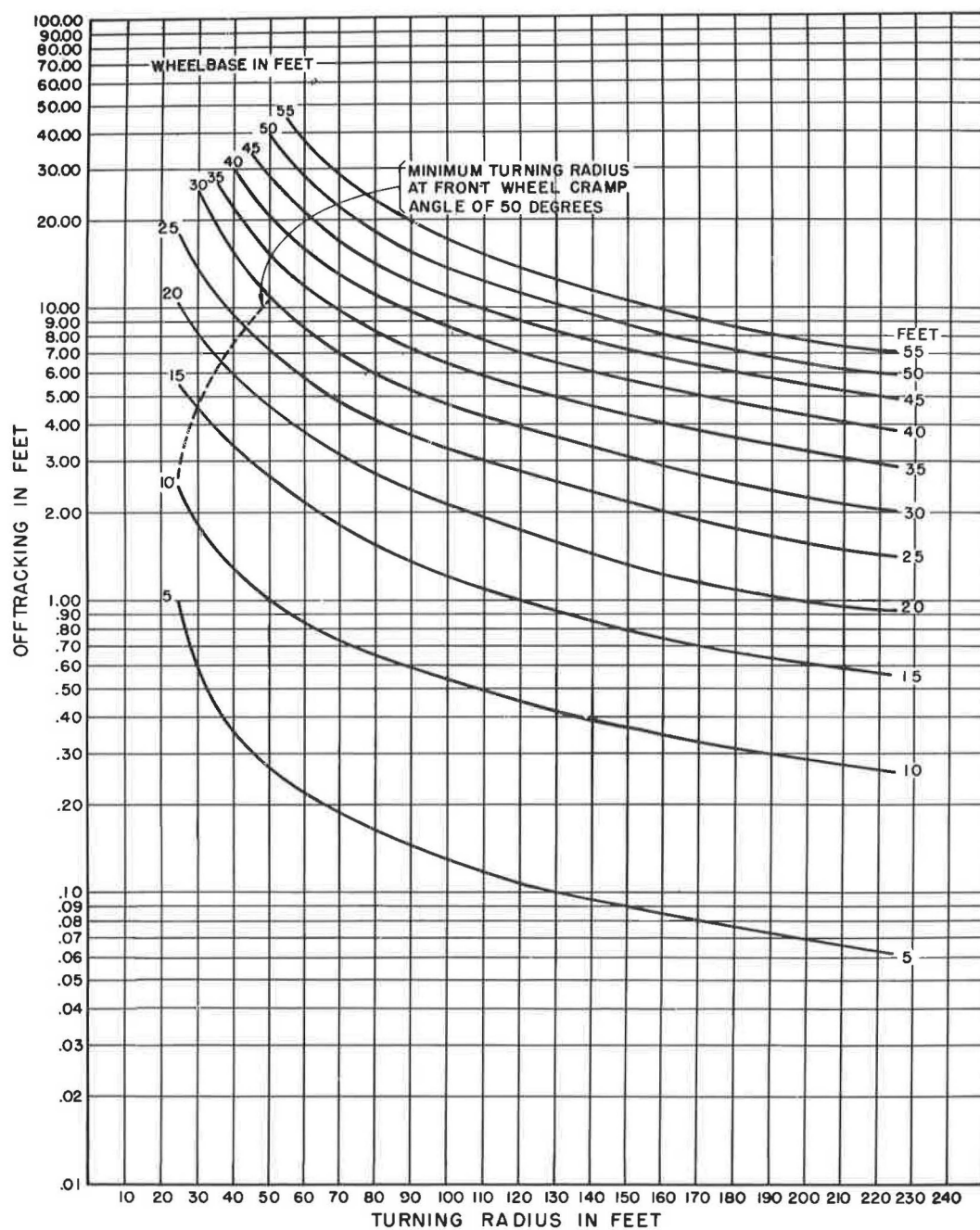Figure 10. Offtracking vs turning radius for 90-degree turns, various wheelbases.

Figure 11. Offtracking vs turning radius for 270-degree turns, various wheelbases.

WHEELBASE
IN FEET
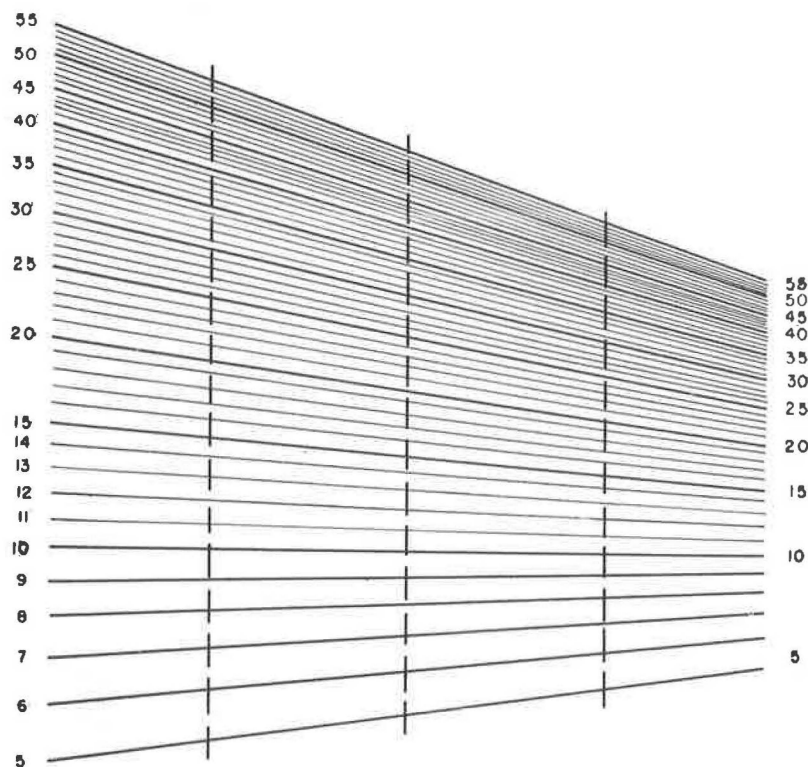
Figure 12. Interpolation guide for wheelbase lengths between 5-foot interval wheelbase curves.

into consideration the assumption that the kingpin is located "directly above" the centerline of the rear axle of the tractor. Then in effect the rear axle of the tractor becomes the virtual front axle of the semitrailer.

The semitrailer turning radius is computed by subtracting the tractor offtracking from the tractor turning radius and is found to be 99.5 feet. The semitrailer wheelbase is the distance from the kingpin to the centerline of the rear axle on the semitrailer. In this example, the semitrailer has a tandem rear axle. Therefore, the wheelbase, which is 29 feet, is the distance from its kingpin to the centerline between the tandem axles. Figure 11 indicates that the greatest semitrailer offtracking will be 4.4 feet when the turning radius is 99.5 feet and the wheelbase is 29 feet.

The offtracking of the entire 2-S2 tractor semitrailer, with an overall length of 50 feet, negotiating a turning radius of 100 feet through a 270-degree turn is the sum of the tractor offtracking and the semitrailer offtracking which is 0.54 plus 4.4 or 4.94 feet. The turning track width is the sum of the offtracking and the width over the tires. In this example the width over the tires is eight feet; therefore, the turning track width is 4.94 plus 8.00 or 12.94 feet. The radial distance from the turning radius center to the inside curb is equal to the turning radius minus the turning track width. In this example, the inside curb radius equals 100.00 minus 12.94, or 87.06 feet.

The values for both the turning track width and the inside curb radius are computed values obtained from the charts. However, in design problems highway engineers may desire to use a turning track width greater than computed from the charts in order to assure proper traffic operations. Thus, in the above example, an inside curb radius may be designed somewhat less than 87 feet.

Tractor Semitrailers and Full Trailers

The offtracking for tractor semitrailers and full trailers is determined from Figures 10 and 11 in much the same way as for tractor semitrailers. For example, assume the 2-S2 tractor semitrailer used in the previous example is connected to a 30-foot long full trailer as shown in Figure 13.

In determining the offtracking of the 2-S2-2 type tractor semitrailer and full trailer combination, the offtracking of the individual vehicles of the combination are added together. As previously determined the tractor semitrailer's greatest offtracking, in reference to the centerline between the tandem axles, was 4.94 feet when negotiating a 100-foot turning radius through 270 degrees. But before the offtracking is known for the entire 2-S2-2 type vehicle combination, the offtracking for both the trailer converter dolly and the full trailer must be determined.

The trailer converter dolly is connected to the semitrailer at a pintle hook located 7 feet behind the centerline between the tandem axles. It is apparent that the phenomenon of "negative offtracking" is present in that the path of the outer rear corner of the semitrailer swings outward from the turning radius center. The magnitude of negative offtracking is found from Table 1 or 2. With a wheelbase of approximately 30 feet, a turning radius of nearly 100 feet and a 7-foot rear overhang to the pintle hook, the negative offtracking of the virtual front axle of the dolly is 0.26 feet for a 270-degree turn.

The pintle hook was assumed to be in the center of the virtual front axle of the trailer converter dolly. Knowing the offtracking for the tractor semitrailer, the turning radius can be determined for the virtual front axle of the trailer converter dolly. The trailer converter dolly turning radius is found by subtracting the tractor semitrailer offtracking, 4.94 feet, from the turning radius of the tractor and adding to that quantity the value of negative offtracking. Thus, the turning radius of the trailer converter dolly's virtual front axle would be 100.00 minus 4.94 plus 0.26 or 95.32 feet. With the trailer converter dolly having a wheelbase of 7 feet and with a turning radius of 95.32 feet, the dolly offtracking can be determined from Figure 11 as 0.28 feet.

After finding the greatest offtracking of the trailer converter dolly, the offtracking for the full trailer is determined. The turning radius for the full trailer is computed in the same way as for the semitrailer. Thus, the turning radius of the virtual front axle of the full trailer is 95.32 minus 0.28 or 95.04 feet. The kingpin on the full trailer is assumed to be "directly above" the centerline of the dolly axle. If a tandem axle dolly had been used, the kingpin would be located "directly above" the centerline between the tandem axles. In effect the dolly axle is the virtual front axle of the full trailer. With a full trailer wheelbase of 24 feet and with a turning radius of 95.04 feet, the full trailer offtracking is determined from Figure 11 as 3.2 feet.

The offtracking of the entire 2-S2-2 tractor semitrailer and full trailer with an overall length of 83 feet is the sum of the offtracking of the individual vehicles minus the negative offtracking. The greatest offtracking for this 2-S2-2 combination would be 0.54 + 4.40 + 0.28 + 3.20 - 0.26 or 8.16 feet when negotiating a 100-foot turning
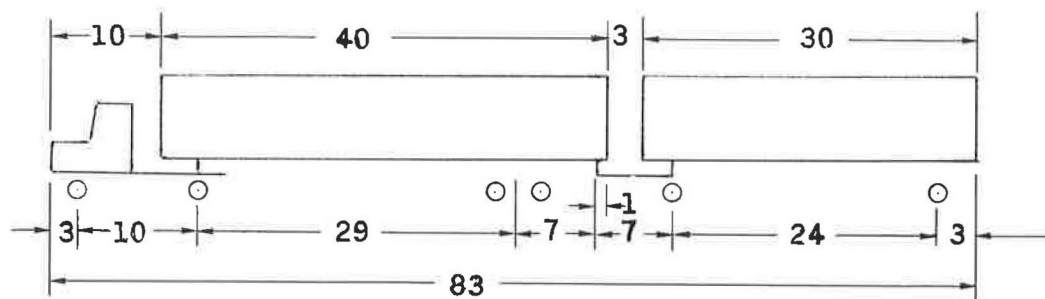

Figure 13. Dimensions in feet of trailer combination used in demonstrating calculation charts.

TABLE 1

NEGATIVE OFFTRACKING VALUES FOR 90-DEGREE TURNS

Wheelbase, Feet	Turning Radius of Outside of Outer Front Wheel, Feet	Offtracking of Outside of Outer Rear Wheel, Feet	Negative Offtracking, Feet[a]				
			3-Foot Overhang	5-Foot Overhang	7-Foot Overhang	9-Foot Overhang	11-Foot Overhang
10	25	2.00	0.19	0.54	1.04	1.70	
	30	1.71	0.16	0.44	0.85	1.40	
	40	1.27	0.12	0.32	0.63	1.03	
	50	1.01	0.00	0.26	0.50	0.82	
	60	0.85	0.00	0.21	0.41	0.68	
	70	0.75	0.00	0.18	0.35	0.58	
	80	0.67	0.00	0.16	0.31	0.51	
	90	0.60	0.00	0.15	0.27	0.45	
	100	0.54	0.00	0.13	0.25	0.39	
15	25	3.62	0.20	0.55	1.11	1.78	2.75
	30	3.24	0.17	0.46	0.88	1.45	2.17
	40	2.70	0.12	0.33	0.64	1.07	1.59
	50	2.30	0.00	0.26	0.51	0.84	1.25
	60	2.00	0.00	0.22	0.42	0.69	1.03
	70	1.75	0.00	0.18	0.36	0.59	0.88
	80	1.55	0.00	0.16	0.31	0.51	0.77
	90	1.38	0.00	0.14	0.28	0.46	0.68
	100	1.23	0.00	0.13	0.25	0.41	0.61
20	25	5.43	0.22	0.62	1.23	1.96	2.97
	30	5.05	0.18	0.51	0.96	1.56	2.33
	40	4.40	0.13	0.35	0.68	1.12	1.66
	50	3.89	0.10	0.27	0.53	0.87	1.29
	60	3.45	0.00	0.22	0.43	0.71	1.15
	70	3.08	0.00	0.19	0.37	0.60	0.90
	80	2.72	0.00	0.16	0.32	0.52	0.78
	90	2.41	0.00	0.14	0.28	0.46	0.69
	100	2.17	0.00	0.13	0.25	0.41	0.62
25	25	8.37	0.27	0.74	1.43	2.28	3.31
	30	7.80	0.20	0.58	1.08	1.75	2.58
	40	6.80	0.14	0.37	0.73	1.20	1.77
	50	5.93	0.10	0.28	0.55	0.91	1.35
	60	5.28	0.00	0.23	0.45	0.74	1.09
	70	4.61	0.00	0.19	0.37	0.62	0.92
	80	4.10	0.00	0.16	0.32	0.53	0.79
	90	3.70	0.00	0.14	0.28	0.47	0.70
	100	3.34	0.00	0.13	0.25	0.42	0.62
30	25	11.71	0.33	0.92	1.76	2.73	3.96
	30	10.90	0.23	0.66	1.24	2.01	2.94
	40	9.50	0.15	0.41	0.79	1.30	1.92
	50	8.30	0.11	0.30	0.58	0.96	1.43
	60	7.27	0.00	0.24	0.46	0.76	1.14
	70	6.41	0.00	0.20	0.38	0.63	0.94
	80	5.70	0.00	0.17	0.33	0.55	0.81
	90	5.11	0.00	0.15	0.29	0.48	0.71
	100	4.62	0.00	0.13	0.26	0.42	0.63
35	25	15.08	0.44	1.19	2.22	3.47	4.89
	30	14.20	0.28	0.77	1.48	2.38	3.45
	40	12.55	0.16	0.46	0.88	1.44	2.12
	50	11.10	0.12	0.32	0.62	1.04	1.53
	60	9.60	0.00	0.25	0.48	0.80	1.19
	70	8.49	0.00	0.20	0.40	0.65	0.98
	80	7.52	0.00	0.17	0.38	0.56	0.83
	90	6.78	0.00	0.15	0.29	0.49	0.72
	100	6.10	0.00	0.13	0.26	0.43	0.64

[a]Outer rear corner opposite pintle hook.

TABLE 2

NEGATIVE OFFTRACKING VALUES FOR 270-DEGREE TURNS

Wheelbase, Feet	Turning Radius of Outside of Outer Front Wheel, Feet	Offtracking of Outside of Outer Rear Wheel, Feet	Negative Offtracking, Feet[a]				
			3-Foot Overhang	5-Foot Overhang	7-Foot Overhang	9-Foot Overhang	11-Foot Overhang
10	25	2.58	0.20	0.55	1.07	1.74	
	30	1.90	0.16	0.44	0.86	1.41	
	40	1.27	0.12	0.32	0.63	1.03	
	50	1.01	0.00	0.25	0.50	0.82	
	60	0.85	0.00	0.21	0.41	0.68	
	70	0.75	0.00	0.18	0.35	0.58	
	80	0.67	0.00	0.16	0.31	0.51	
	90	0.60	0.00	0.14	0.27	0.45	
	100	0.54	0.00	0.13	0.25	0.41	
15	25	10.40	0.31	0.83	1.59	2.55	3.68
	30	4.60	0.18	0.49	0.95	1.55	2.28
	40	3.43	0.12	0.33	0.67	1.09	1.63
	50	2.68	0.00	0.26	0.51	0.85	1.26
	60	2.18	0.00	0.22	0.42	0.70	1.03
	70	1.83	0.00	0.18	0.36	0.59	0.88
	80	1.61	0.00	0.16	0.31	0.51	0.77
	90	1.38	0.00	0.14	0.28	0.46	0.68
	100	1.23	0.00	0.13	0.25	0.41	0.61
20	25	18.93	0.70	1.79	3.19	4.79	4.49
	30	8.70	0.21	0.58	1.12	1.82	2.67
	40	6.24	0.13	0.37	0.72	1.18	1.75
	50	4.72	0.10	0.27	0.54	0.89	1.30
	60	3.71	0.00	0.22	0.43	0.71	1.06
	70	3.10	0.00	0.19	0.37	0.60	0.90
	80	2.73	0.00	0.16	0.32	0.52	0.78
	90	2.41	0.00	0.14	0.28	0.46	0.69
	100	2.17	0.00	0.13	0.25	0.41	0.62
25	25						
	30	14.25	0.28	0.77	1.55	2.39	3.46
	40	9.70	0.15	0.41	0.80	1.31	1.93
	50	7.27	0.11	0.29	0.57	0.95	1.39
	60	5.80	0.00	0.23	0.45	0.74	1.10
	70	4.81	0.00	0.19	0.37	0.62	0.92
	80	4.17	0.00	0.16	0.32	0.53	0.79
	90	3.70	0.00	0.14	0.28	0.47	0.70
	100	3.34	0.00	0.13	0.25	0.42	0.62
30	25						
	30	26.01	1.00	1.80	4.07	5.85	7.71
	40	14.85	0.18	0.49	0.88	1.52	2.20
	50	11.21	0.12	0.32	0.63	1.03	1.53
	60	8.67	0.00	0.24	0.48	0.78	1.17
	70	7.18	0.00	0.20	0.39	0.64	0.96
	80	6.07	0.00	0.17	0.33	0.55	0.81
	90	5.26	0.00	0.15	0.29	0.48	0.71
	100	4.70	0.00	0.13	0.26	0.42	0.63
35	25						
	30	38.00					
	40	18.80	0.20	0.58	1.13	1.83	2.68
	50	15.65	0.13	0.36	0.71	1.16	1.72
	60	12.50	0.00	0.26	0.51	0.85	1.26
	70	10.15	0.00	0.21	0.41	0.67	1.00
	80	8.50	0.00	0.17	0.34	0.56	0.84
	90	7.35	0.00	0.15	0.30	0.49	0.73
	100	6.57	0.00	0.13	0.26	0.43	0.65

[a]Outer rear corner opposite pintle hook.

radius curve through a 270-degree turn. The turning track width would be 8.16 + 8.00 or 16.16 feet.

In summary, the following computations were performed:

Turning radius on curve	100.00 feet	
Tractor offtracking		0.54 feet
Semitrailer turning radius	99.46	
Semitrailer offtracking		4.40
Negative offtracking		-0.26
Turning radius of dolly	95.32	
Dolly offtracking		0.28
Turning radius of full trailer	95.04	
Full trailer offtracking		3.20
Total combination offtracking		8.16 feet

Truck-Full Trailers

The greatest offtracking for truck full trailers can also be determined from Figures 10 and 11. The same techniques are used for determining the offtracking of the individual vehicles of a truck-full trailer combination as are used for determining the offtracking of a tractor semitrailer full trailer combination.

VEHICLE OFFTRACKING COMPARISONS

To illustrate that different types and sizes of vehicle combinations offtrack differently, several representative long trailer combinations have been selected. The dimensions of the trailer combinations are given in Table 3, and their offtracking characteristics are shown in Table 4. It can be seen in Table 3 that the 2-S1, 2-S2, and 3-S2 combinations have overall lengths shorter than either of the 2-S1-2 combinations. It should be noted in Table 4, however, that the 65 foot long 2-S1-2 combination offtracks less than either of the tractor semitrailer combinations and the other 2-S1-2 combination has approximately the same offtracking as the tractor semitrailers.

In view of the fact that vehicles do offtrack differently, highway design engineers use as guides the highway design vehicles recommended by the American Association of State Highway Officials. As a further illustration, the offtracking characteristics of the 1965 proposed revision of the AASHO highway design vehicles are also given in Table 4. Table 5 gives the dimensions of these design vehicles.

MODEL AND SAE OFFTRACKING COMPARISONS

Model offtracking results were compared to values computed by the SAE offtracking equations. Comparisons were made for 90- and 270-degree turns on 50- and 150-foot

TABLE 3
DIMENSIONS IN FEET OF TRAILER COMBINATIONS SHOWN IN TABLE 4

		2-S1	2-S2	3-S2	2-S1-2	2-S1-2	3-S2-4
1.	Type of trailer combination						
2.	Length of each trailer	40.0	40.0	40.0	27.0	30.0	40.0
3.	Front bumper to nose of first trailer	10.0	15.0	15.0	8.0	8.0	16.0
4.	Space between trailers	—	—	—	3.0	3.0	3.0
5.	Overall length	50.0	55.0	55.0	65.0	71.0	99.0
6.	Width over tires	8.0	8.0	8.0	8.0	8.0	8.0
7.	Wheelbase, tractor (to center line of tandem axle)	10.0	15.0	15.0	8.0	8.0	16.0
8.	Front bumper to front axle of tractor	3.0	3.0	3.0	3.0	3.0	3.0
9.	Wheelbase, semitrailer	34.0	29.0	32.0	21.0	24.0	32.0
10.	Rear pintle hook overhang of semitrailer	—	—	—	3.0	3.0	5.0
11.	Wheelbase of trailer converter dolly	—	—	—	6.0	6.0	6.0
12.	Wheelbase, full trailer	—	—	—	21.0	24.0	32.0
13.	Rear overhang of trailer	3.0	8.0	5.0	3.0	3.0	5.0
14.	Overall length	50.0	55.0	55.0	65.0	71.0	99.0

TABLE 4

VEHICLE OFFTRACKING COMPARISONS

Class of Trailer Combination	Overall Length (ft)	90-Degree Turn 50-Foot Turning Radius			270-Degree Turn 150-Foot Turning Radius		
		Offtracking (ft)	Turning Track Width (ft)	Inside Curb Radius (ft)	Offtracking (ft)	Turning Track Width (ft)	Inside Curb Radius (ft)
Long Trailer Combinations							
2-S1	50	11.3	19.3	30.7	4.5	12.5	137.5
2-S2	55	10.3	18.3	31.7	3.7	11.7	138.3
3-S2	55	11.7	19.7	30.3	4.3	12.3	137.7
2-S1-2	65	9.4	17.4	32.6	3.3	11.3	138.7
2-S1-2	71	12.5	20.5	30.5	4.4	12.4	137.6
3-S2-4	99	22.0	30.0	20.0	8.1	16.1	133.9
Proposed 1965 Revision of AASHO Highway Design Vehicles							
Passenger Car	19	1.1	7.1	42.9	0.4	6.4	143.6
2	30	3.8	12.3	37.7	1.2	9.7	140.3
2-S2	50	7.8	16.3	33.7	2.7	11.2	138.8
3-S2	55	11.8	20.3	29.7	4.2	12.7	137.3

TABLE 5

DIMENSIONS IN FEET OF PROPOSED 1965 REVISION OF ASSHO HIGHWAY DESIGN VEHICLES SHOWN IN TABLE 4

1. Type of design vehicle	Passenger Car	Single Unit Truck or Bus	2-S2 Combination WB-40	3-S2 Combination WB-50
2. Length of trailer	—	—	36	37
3. Front bumper to nose of trailer	—	—	14	18
4. Overall length	19	30	50	55
5. Width over tires	6	8.5	8.5	8.5
6. Wheelbase, passenger car, single unit, or tractor	11	20	13	18
7. Front bumper to front axle	3	4	4	3
8. Wheelbase, semitrailer	—	—	25	30
9. Rear overhang	5	6	8	4
10. Overall length	19	30	50	55

TABLE 6

MODEL AND SAE OFFTRACKING COMPARISONS

Trailer Combination	Overall Length in Feet	Trailer Length in Feet	Offtracking in Feet			
			90-deg Turn, 50-ft Turning Radius		270-deg Turn, 150-ft Turning Radius	
			Model	SAE Equation	Model	SAE Equation
2-S1	50	40	11.30	16.62	4.47	4.36
2-S1	55	40	13.00	18.75	4.96	4.81
2-S2	50	40	8.90	11.69	3.28	3.26
2-S1	55	40	10.30	13.51	3.72	3.69
3-S2	50	40	10.00	14.46	3.87	3.90
3-S2	55	40	11.65	16.45	4.30	4.34
2-S1-2	65	2X27	9.38	—	3.28	3.06
2-S1-2	71	2X30	12.48	—	4.41	4.32
3-S2-4	99	2X40	21.97	—	8.12	8.16

turning radii, respectively. In that most of the vehicle models had obtained their maximum offtracking prior to the 270-degree exit tangent, the results could be validated by comparing them to the maximum offtracking value computed by the SAE equations. The results of some of the comparisons are given in Table 6.

It should be noted in Table 6 that the tractor-semitrailer models negotiating the 90-degree turns on the 50-foot turning radius curve did not obtain SAE maximum offtracking. For the tractor semitrailer and full trailer models negotiating the same turns, the SAE offtracking equation is not applicable and the maximum offtracking could not be computed in that the trailing rear axle of the combination passed behind the turning center.

FURTHER RESEARCH PROBLEMS

1. The work reported in this study included only 90-degree and 270-degree turns; hence, if similar data are needed on turns of different degrees, models and procedures similar to those employed in this study can be used.

2. The amount of variation in maneuvering of long trailer combinations may be worthy of study at a variety of cloverleaf intersections.

3. It is believed that the width over-the-tires has almost no effect on the offtracking characteristics of the outside of the outer tires of a trailer combination. This appears certainly to be the case with trailers, but for power vehicles with Ackerman steering a considerable increase in width over the front tires may have some further limiting effects, as discussed briefly in the paragraphs describing Ackerman steering.

4. It is necessary to determine more precisely the percentage relationships between the turning radii and the wheelbases of various trailers in order to prevent any trailer backup and pivot motion on 180- and 270-degree turns.

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Appendix

GLOSSARY OF DEFINITIONS AND TRADE TERMS

Angle of Turn. —The angle through which a vehicle travels in making a turn (AASHO, 2).

Axle. —For simplification, only the singular term "axle" is used in the text and it may designate either a single axle or the centerline between tandem axles, depending on the vehicles being investigated. The reason for this simplification is that on the centerline between tandem axles lies the theoretical turning center of a tandem axle assembly.

Cramp Angle. —The cramp angle is the limit of the turning ability of the front wheels of an Ackerman type front axle, and is limited by the construction of the mechanical parts around the front axle kingpin pivot mechanisms. This construction limits the degree to which the inner front wheel may be turned and also limits the turning of the outer front wheel.

Fifth Wheel. —The fifth wheel is a lubricated bearing plate, mounted on a tractor chassis, or on a trailer converter dolly chassis, and arranged with an internal clutch device to engage and hold the kingpin of a trailer. The fifth wheel clutch engages and locks on contact with the trailer kingpin, but requires a manual release by the driver in order to separate the trailer kingpin and the fifth wheel.

The manual fifth wheel is in predominate use at present. In earlier developments of an "automatic" fifth wheel, the fifth wheel was attached to the trailer and connected to its landing gear, while the kingpin was mounted on the towing vehicle. A few of these automatic fifth wheels are in use today, but only in local cartage service with a captive fleet of semitrailers.

Kingpin. —The term kingpin has two different meanings in automotive design. Hence, the precise meaning of the term is determined by the context in which the term is used:

1. A kingpin of a front axle of a power vehicle is a vertical or near-vertical shaft that is the pivot which connects each stub axle that carries a front wheel of a power vehicle to the rigid center of an Ackerman type front axle. All Ackerman type front axles have two kingpins, one at each end of the rigid center of the front axle.

2. A kingpin of a trailer is a vertical pivot shaft attached near the front of and on the centerline of the underside of a trailer chassis, and is surrounded by a lubricated bearing plate. It engages a fifth wheel on either a towing tractor or on a trailer converter dolly, or is permanently connected to the center of a non-detachable front axle of a full trailer. A trailer is pulled by and pivots around its kingpin.

Radius of Inside Curb. —The radius of the inside curb is the radial difference between the turning radius and the turning track width, when the offtracking of the vehicle is at its greatest amount for a given turn. Note: The shortest radial distance from the turning center to the inside curb may occur at only one point (instantaneous) on a 90-degree turn. On a 270-degree turn, the shortest curb radius may remain constant for some interval or distance before the exit tangent.

Minimum Turning Radius. —The radius of the minimum turning path of the outside of the outer front tire. Note: Vehicle manufacturers' data books usually give "minimum turning radius" to the centerline of the outer front tire (AASHO, 2).

Negative Offtracking. —Negative offtracking is the phenomenon during a turn that causes the radius of the path of the outer rear corner of a vehicle to be greater than the radius of the turning path of the outside of the vehicle's outer rear tire. For example, this phenomenon occurs on a tractive truck, or a trailer, with a cargo body extending back of the rear axle, as the outer rear corner of the cargo body swings outside of the path of the outside of the outer rear tire on a turn.

Offtracking. —Offtracking is the phenomenon in which the path of the outside of the outer tire on a rear, or trailing, axle of a vehicle or a trailer combination 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.

Outside of Tire. —The outside of a tire means the external side of a tire farthest away from the vehicle chassis.

Outside of Outer Tire. —The outside of the outer tire of a vehicle means the outside of the outermost tire (on an axle) on the outer side of a turn.

Outside of Innermost Rear Tire. —The outside of the innermost rear tire of a vehicle means the outside of the rear tire nearest the turning radius center.

Overall Length. —The overall length of a vehicle or trailer combination is the distance between the front bumper of the power vehicle and the rear bumper or guard on the rear vehicle.

Pintle Hook. —A vertical hook device attached to the rear of a tractive truck or to the rear of a leading (towing) semitrailer in a double trailer combination. The pintle hook engages the towing eye (ring eyelet) at the front end of the towbar of a trailer converter dolly, or the towbar of a full trailer non-detachable front axle assembly.

Power Vehicles. —There are three general classes of power vehicles:

1. Single-unit trucks are power vehicles with Ackerman front axle steering, and equipped with a cargo body but not equipped to pull a trailer.

2. Tractive trucks are power vehicles with Ackerman front steering which are equipped with a cargo body and a pintle hook attached to and recessed into their rear frame members in order to pull a full trailer.

3. Tractors for commercial freight use are legally defined as "truck-tractors" to differentiate them from farm or industrial tractors. However, the single term, tractor, is used in this report to mean a power vehicle of short wheelbase that is equipped with Ackerman front wheel steering, and with a fifth wheel to engage and pull a semi-trailer.

Rear Axles of Trailers. —Rear axles of trailers predominantly are attached through springing suspensions and mechanisms to the trailer chassis so as to be in a fixed alignment with the longitudinal centerline of the trailer.

Rear Overhang. —The rear overhang of a tractive truck, of a semitrailer, or of a full trailer is the distance between the centerline of the vehicle's rear axle, and the centerline of its pintle hook.

Steering System. —There are two generally used types of steering systems:

1. The Ackerman steering system for front axles of power vehicles consists of a three-piece articulated axle with two front wheels which are mounted on short stub axles. The stub axles are attached to opposite ends of the rigid center section of the front axle by the front axle kingpins. The short stub axles are pivoted about the axle kingpins by steering arms and mechanisms connected to the driver's steering wheel.

2. Fifth wheel pivot steering is similar to that used at the front ends of two-axle, horse-drawn wagons. The front axle is a one-piece, rigid axle with the front wheels at each end of the axle. The rigid axle pivots about a kingpin located above the lateral center of the axle. Surrounding the kingpin are two lubricated bearing surfaces; the lower one is attached to the axle assembly, the upper bearing plate is attached to the underside of the vehicle chassis on its longitudinal centerline. These bearing plates give lateral and longitudinal stability to the cargo vehicle, and enable the trailer to be pulled by means of the kingpin. This type of steering is predominantly used at the front end of trailers.

3. Pintle hook steering through a towbar is similar in action to fifth wheel pivot steering except that no vehicle weight rests on the pintle hook.

Trailers. —There are three classes of trailers:

1. A semitrailer is a cargo trailer equipped with one or more axles at or near its rear, and so constructed that a substantial part of its tare weight and its cargo weight rests upon a tractor through the tractor fifth wheel.

2. A full trailer is basically a semitrailer which has been converted into a full trailer by one of two methods. In one method, the front axle and spring suspension are permanently connected to the chassis of the trailer. The second method is to combine a semitrailer with a trailer converter dolly.

3. A trailer converter dolly is a very short wheelbase semitrailer. It consists of an axle which is attached through a spring suspension system to a platform (chassis) which carries a lower fifth-wheel plate. It has a towbar mechanism affixed at 90 degrees to its axle. The front end of the towbar is equipped with a towing eye which engages with a pintle hook on the rear of the towing vehicle.

Towbar. —A bar, or a V-shaped assembly of two bars, attached to the chassis of a trailer converter dolly, or to the non-detachable front axle assembly of a full trailer, and so constructed that it has a towing eye at its forward end, and exerts a pulling force in the middle of and at 90 degrees to the axle of a trailer converter dolly, or to a full trailer non-detachable front axle.

Trailer Combinations. —For ease of identification, trailer combinations are identified by the numerical axle arrangement code defined in the SAE Handbook (3). In this code, the first single separate numeral means the number of axles on the tractor or tractive truck. Semitrailers are identified by a capital S in front of the second code axle number. A final single number without a prefix in the axle number code indicates a full trailer. Samples of this code are as follows:

2-S1 means a 2-axle tractor and a 1-axle semitrailer.

3-S2 means a 3-axle tractor and a 2-axle semitrailer.

2-S1-2 means a 2-axle tractor and a 1-axle semitrailer pulling a 2-axle full trailer; also called a double trailer combination.

3-2 means a 3-axle tractive truck pulling a 2-axle full trailer.

4-6 means a 4-axle tractive truck pulling a 6-axle full trailer.

3-S2-4 means a 3-axle tractor and a 2-axle semitrailer pulling a 4-axle full trailer; also called a double trailer combination.

Turning Path. —The path of a designated point on a vehicle making a turn (AASHO, 2).

Turning Radius. —The radius of the circular turning path of the outside of the outer front tire from the turning radius center.

Turning Radius Center. —The turning radius center is that point which is the center of the circular turning path that is followed by the outside of the outer front tire of the power vehicle.

Turning Track Width. —The radial distance between the turning paths of the outside of the outer front tire and the outside of the rear tire which is nearest the center of the turn (AASHO, 2).

Wheelbase. —There are several measures of wheelbase depending upon the vehicle. These are defined below.

1. The wheelbase of a single-unit power vehicle (truck or tractor) is the distance between the centerline of the front axle and the centerline of the rear axle. As mentioned earlier, the centerline between any tandem axles always is used as the reference point for wheelbase measurements shown in the charts.

2. On semitrailers, the wheelbase is the distance between the trailer kingpin and the centerline of the rear axle.

3. On trailer converter dollies, which are in effect short semitrailers, the wheelbase is the distance between the center of the towing eye of the towbar and the centerline of the dolly's axle.

4. On full trailers, the wheelbase is the distance between the kingpin of the trailer and the centerline of the rear axle, as in the case of semitrailers.

5. On complete trailer combinations, the overall wheelbase is the distance between the front axle of the power vehicle and the rearmost axle when the trailer combination is strung out in a straight line. This overall wheelbase may differ from the sum of the wheelbases defined above.

Width Over Tires. —The width over tires is the outside-to-outside distance over the tires on an axle.

Note: The meanings of the two following SAE terms are different from the definitions and measurements of offtracking that are used in this report. In order that care may be taken not to confuse the meanings, the SAE definitions are given below.

Turning Center, SAE. —The turning center is that point about which all parts of a vehicle or combination of vehicles revolve in describing a turn of constant radius and to which all wheel spindles are normally radial. In the case of two-axled bogies or tandems in which the axles are constrained to parallelism, the interaxle trunnion or its equivalent is assumed to be radial from this point (SAE, 3). Note: The location of this turning center moves around as a trailer combination enters a curve from a

tangent, proceeds around the curve, and leaves on an exit tangent. This turning center should not be confused with outer front wheel turning radius center used in this study.

Offtracking, SAE. —Offtracking is the difference in radii from the turning center to the vehicle centerlines at the foremost and rearmost axles of a vehicle or combination and represents the increase beyond the tangent track occasioned by a turn (SAE, 3).