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A SIMPLIFIED PROCEDURE FOR COMPUTING VEHICLE OFF-TRACKING ON CURVES

FEDERAL HIGHWAY ADMINISTRATION

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16. Abstract

This report presents a simplified procedure for computing vehicle offtracking on curves. It was developed during a research effort to determine what the offtracking requirements were if the width of buses for operation on the Interstate Highway System was increased from 96 to 102 inches. The procedure was developed by modifying the existing procedures to identify critical bus offtracking. Modification consisted of the use of an additional geometric relationship required to calculate "swept width," a parameter considered to be more significant than "offtracking," per se. Swept width is the apparent width of a vehicle as it executes a turning maruever. The basic data for 15 buses and three tractor-semitrailer combinations, with widths of 96 and 102 inches, and a full-sized station wagon were analyzed. Results of this analysis revealed that critical swept width does not occur until a curvature of 27 degrees, or a radius of 212 feet or less, is reached. Swept width is not a problem for buses using the through traffic lanes on the Interstate Highway System, because curves as sharp as 27 degrees occur only on ramps designed for low speed and one-lane operation.

The procedure developed can be used by highway design personnel to select a maximum degree of curvature which would permit a vehicle to stay within the selected lane width and by regulatory agencies when permits are requested for movement of vehicles that exceed the legal maximum width, length or both.

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UNITED STATES GOVERNMENT

Memorandum

DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION

DATE: March 22, 1974

SUBJECT: Transmittal of Research Report No. FHWA-RD-74-o "A Simplified Procedure for Computing Vehicle Offtracking on Curves"

In reply refer to: HRS-41

FROM : Director, Office of Research
Washington, D.C. 20590

TO : Regional Federal Highway Administrators
Regions 1, 3-10

Sufficient copies of this report are being distributed to provide a minimum of one copy to each regional office, one copy to each division office, and two copies to each State highway or transportation department.

This report presents a simplified procedure developed during a staff research effort by modifying an existing procedure to identify critical bus offtracking. This modification consisted of the use of an additional geometric relationship required to calculate "Swept Width," a parameter considered to be more significant than "offtracking," per se. Swept width is the apparent width of a vehicle as it executes a turning maneuver.

Utilization of this procedure will enable highway design personnel to select a maximum degree of curvature which will permit a vehicle to stay within the selected lane width. It will also be useful to regulatory agencies which issue permits for vehicles that exceed the legal maximum width, length, or both.

A limited number of additional copies of this report are available for official use from the Environmental Design and Control Division (HRS-41), Office of Research. Additional copies for the public are available from the National Technical Information Service, Department of Commerce, 5285 Port Royal Road, Springfield, Virginia 22151. A small charge will be imposed for each copy ordered from NTIS.

Charles F. Scheffey

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The contributions of previous offtracking studies by State highway agencies in Arizona, California, Idaho, Illinois, Iowa, Michigan, Nevada and Oregon and the Western Highway Institute were especially appreciated.

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INTRODUCTION

The Secretary of Transportation requested that the National Highway Traffic Safety Administration (NHTSA) and the Federal Highway Administration (FHWA) undertake a cooperative research effort to provide definitive information on the safety of wide buses. The information was used to formulate the Department's recommendation to Congress as to whether 102-inch (8 1/2 feet) wide buses should be permitted to use the Interstate Highway System. Eligibility for Federal-aid currently limits width to 96 inches (8 feet) except in 11 States where wider vehicles are permitted under a "Grandfather Clause." [1/]

NHTSA and FHWA divided the basic objective--a determination as to whether or not 8 1/2-foot wide buses could safely use the Interstate Highway System--into six research tasks:

- Task 1 - Aerodynamic Characteristics, Disturbances, and Effects
- Task 2 - Lateral Placement of Vehicles
- Task 3 - Lateral Stability of Buses
- Task 4 - Offtracking on Sharp Curves
- Task 5 - Bus Accident Data Analysis
- Task 6 - Consolidation of Results

This study is in response to Task 4, "Offtracking on Sharp Curves." Although the primary objective of this research effort was to establish critical offtracking situations due to 8 1/2-foot wide buses, the procedure developed will be useful to those interested in the safety, design, and operation of highway facilities or large highway vehicles.

[1/] A provision in the Federal Act permits exceptions to the prescribed width maximum in States where greater limits were legally permitted July 1, 1956.

Definitions of terms used in report

Because of the variation in meaning of the terms used when offtracking is discussed, it is well to define those terms as used in this report.

Effective Axle - That line where all wheels on a wheel assembly contribute equally to the tractive effort of that assembly.

Effective Wheelbase - Distance between the effective axles.

Front Overhang - The distance between the outermost point of the front bumper and the leading effective axle.

Offtracking - The difference in radii from the turning center to the center of the leading effective axle and the rearmost effective axle, during a turning maneuver.

Swept Width - The difference in the path described by the outermost point on the vehicle (generally the front corner on the outside of the turn) and the innermost point of the vehicle (the body over the centerline of the rear most effective axle).

Wheel Path - That path described by the outside of the outermost tire of the vehicle during a turn and the outside of the innermost rear tire during a turn. For example, during a right turn maneuver the tires describing the wheel path are the left front and right rear tires.

Reference to Figure 1 on page 7 will clarify the meaning of these terms.

SUMMARY

A relatively good understanding of the offtracking of trucks has been developed in previous research. Consequently, only a simple modification of existing procedures was necessary to identify critical bus offtracking situations. The modification consisted of the use of an additional geometric relationship required to calculate "swept width," a parameter considered to be more significant than "offtracking," per se. Offtracking is defined as the deviation between the paths of the front and rear axles

during a turning maneuver. Swept width is the [illegible] overall width of a bus as it executes a turn[illegible]. This approach identified critical situations at low cost and permitted time for more sophisticated offtracking research, if necessary. Such studies were not considered necessary because:

1. Critical offtracking situations occur only on ramps which are off the Interstate Highway System through traffic lanes and are designed for one-lane operation at low speeds. The critical situations were identified as ramps having a curvature of 27 degrees or more, or a radius of 212 feet or less. In these situations when the bus is operating at low speed, its apparent width has little or no effect on the driving path of a following car.

2. A literature review indicated that driver experience was a major factor in determining how much more than the minimum a vehicle would offtrack. Further, this review indicated that extensive human factors research would be necessary to simulate the effect of driver experience on offtracking, but would add little to the precision of predicting the bus swept width on sharp curves.

3. The literature review also indicated that sophisticated vehicle dynamics models are available which can be modified to predict the effects that bus speed and weight have on offtracking. Because sharp curves require low speed operation, the modified vehicle dynamics models would add little to the precision of predicting swept width on sharp curves.

The "swept width" computations revealed that the most critical 8 1/2-foot wide bus configuration was the MC-6, the same configuration used in the aerodynamics, lateral placement, and lateral stability research tasks. The swept width of this bus utilized the full 12-foot lane width on a curvature of 27 degrees. The swept width of the 8-foot wide configuration of the same basic bus, the MC-7, did not reach the 12-foot lane width until a curvature of 31 degrees was employed.

Fortunately, swept width is not a problem for buses using the through traffic lanes of the Interstate Highway System, because curves as sharp as 27 degrees occur only on ramps designed for low speed and one-lane operations, such as loops of cloverleaf interchanges. Moreover, there is always at least a two-foot wide shoulder on each side of the ramp which will accommodate the bus overhang. The 6-inch difference in swept width is of no practical importance because there would be no adverse effect on the safety of the bus passengers or passenger car occupants who may be following a wider bus on the same ramp. The increase in swept width between the 8 1/2-foot wide bus and the 8-foot wide bus on the critical 27 degree curve is the 6-inch difference in bus width.

RESEARCH APPROACH

The offtracking task began by reviewing the pertinent literature on the subject which included reports by the American Association of State Highway Officials (AASHO)[1], Bureau of Public Roads (now the Federal Highway Administration)[2], Society of Automotive Engineers (SAE)[3], and the Western Highway Institute (WHI)[4]. Also an inquiry was made to each State highway agency for reports and other documentation of any offtracking studies they had conducted. Of the State studies reviewed, a Nevada Department of Highways' study[5] which was jointly sponsored by five State agencies, three industrial associations, and four trucking firms, proved to be most helpful in providing insight into the offtracking problem.

The literature review indicated that three major approaches have been used in determining offtracking requirements; (1) full-scale measurements, (2) small-scale model measurements and (3) mathematical equations. The use of scale-model measurements is less expensive and time consuming if offtracking data were required for a large number of specific vehicle combinations. The available mathematical offtracking requirement equations vary from the comple[illegible] SAE offtracking equation to the abbreviated, but valid, offtracking equation developed by WHI.

The assumption that the geometry of a situation is the controlling factor in a turning maneuver was strengthened by the following observations obtained from the literature:

1. A vehicle may not achieve its maximum offtrack in turns of less than 90 degrees, which would tend to make the offtracking computation more severe than would be expected in "real situations."

2. A study performed by the Nevada Department of Highways indicated that the experience of a driver greatly influenced the offtracking requirements of his vehicle as he selects the path, which may vary from the path assumed in any experimental or mathematical process.

BASIC DATA

For this study, 19 vehicle configurations were selected as a representative sample for determining the effects of offtracking when the width is increased from 8 feet to 8 1/2 feet.

Basic data for the buses were supplied by the Bus and Truck Supply Company (Trailways), Motor Coach Industries (Greyhound) and General Motors Corporation (primary suppliers to transit companies). Twelve bus configurations were selected for the existing 8-foot and 8 1/2 foot widths. Three of the 8-foot widths were modified by increasing only the width to 8 1/2 feet. To provide a comparison with trucks, two tractor-semitrailer combinations (C-50 and WB-50) employed in developing AASHO design standards were analyzed including a modification of the 8 1/2-foot width to an 8-foot width. For further comparison, offtracking of a full-sized station wagon was also computed. Table 1 shows the key dimensions of these vehicle types.

In geometry it is axiomatic that no two points on a line perpendicular to a radius of a circle will describe the same circle, when these points are separated by some distance, as the radius is rotated. When this phenomenon takes place during a vehicle turning maneuver, it is referred to as "offtracking." Figure 1 illustrates offtracking and the various other offtracking characteristics.

The WHI equation, which computes maximum vehicle offtracking based upon the geometry of a vehicle and the highway horizontal curve, was employed as the basic equation for the research. The equation was expanded to provide the capability of computing swept width and wheel path width which are considered to be more meaningful to traffic and design engineers, than offtracking, per se.

Table 1. Vehicle Dimensions (in feet)

Vehicle Characteristics	General Motors Corporation									
	City Transit				Suburban Transit			Intercity		
	MD-4279	MD-4277	MD-4225	MD-4223	MD-4222	MD-4218	MD-4218 MOD	MD-7020	MD-7029	MD-7029 MOD
Overall length	35.12	35.12	40.04	40.04	35.12	40.04	40.04	35.07	39.99	39.99
Overall width	7.98	8.48	7.98	8.48	7.98	7.98	7.98	7.98	7.98	7.98
Track width	8.00	8.50	8.00	8.50	8.00	8.00	8.50	8.00	8.00	8.50
Wheelbase	19.58	19.58	23.73	23.73	19.58	23.73	23.73	21.63	26.55	26.55
Effective wheelbase	19.58	19.58	23.73	23.73	19.58	23.73	23.73	21.63	26.55	26.55
Front overhang	6.85	6.85	6.85	6.85	6.85	6.85	6.85	6.01	6.01	6.01
Rear overhang	8.69	8.69	9.46	9.46	8.69	9.46	9.46	7.43	7.43	7.43

Vehicle Characteristics	Bus and Truck Supply Company		Motor Coach Industries			AASHO Design Truck Combinations			Full-size Station Wagon
	Trailways		Greyhound						
	05-04'	05-04' MOD	MC-5	MC-6	MC-7	C-50	WB-50 MOD	WB-50	
Overall length	40.00	40.00	34.96	39.96	39.96	50.00	55.00	55.00	18.17
Overall width	8.00	8.50	8.00	8.50	8.00	8.00	8.00	8.50	6.67
Track width	8.00	8.00	8.00	8.50	8.00	8.00	8.00	8.00	5.29
Wheelbase	23.79	23.79	21.75	23.50	23.75	14.00	16.00	16.00	9.92
Effective wheelbase	22.27	22.27	21.75	24.71	24.75	16.00	18.09	18.00	9.92
Trailer wheelbase	-	-	-	-	-	22.00	26.00	26.00	-
Effective trailer wheelbase	-	-	-	-	-	26.00	30.00	30.00	-
Total wheelbase	-	-	-	-	-	44.00	50.00	50.00	-
Front overhang	7.13	7.13	5.73	6.21	5.85	3.00	3.00	3.00	3.29
Rear overhang	9.08	9.08	7.48	10.25	10.36	3.00	2.00	2.00	4.96

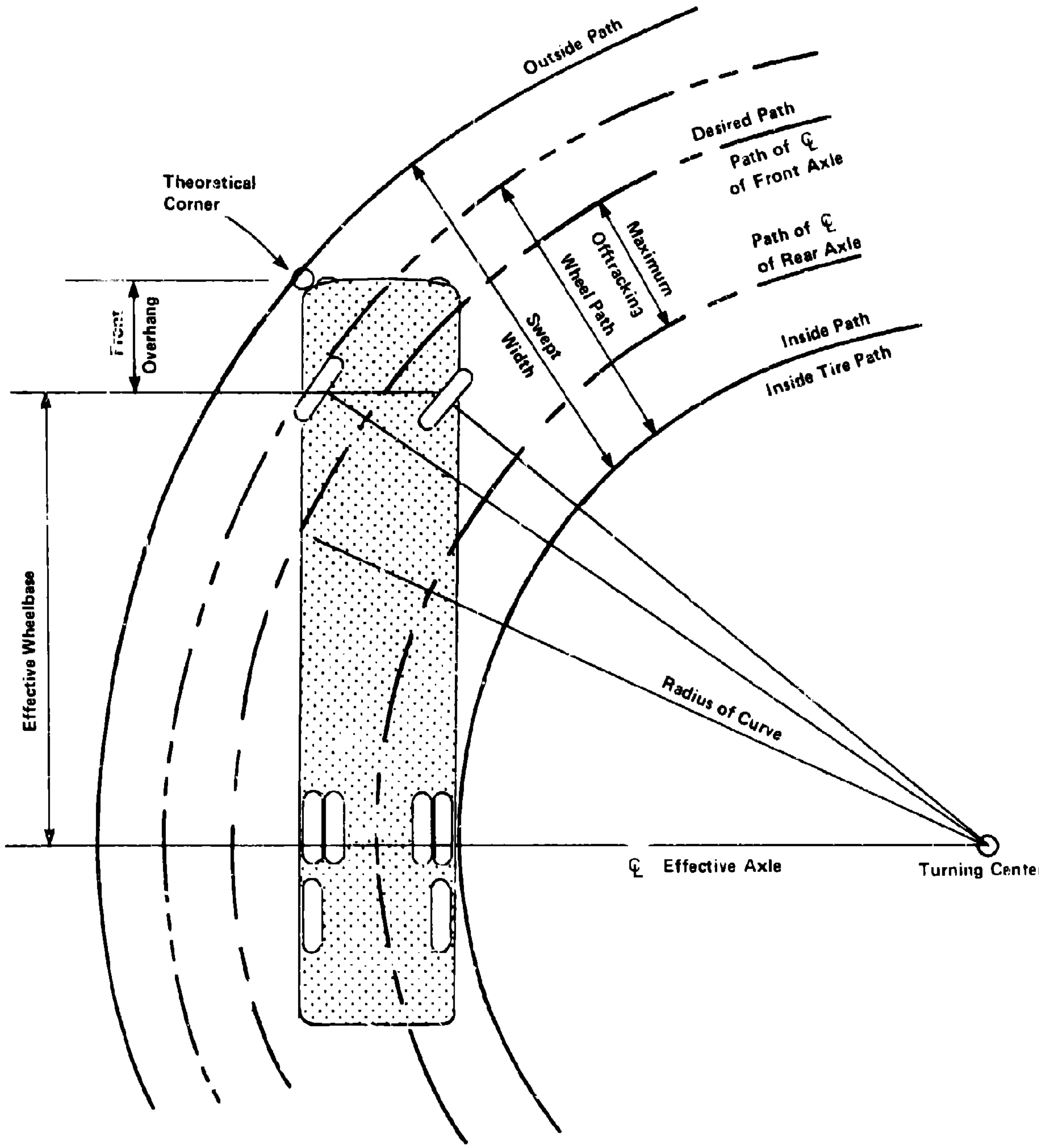


FIGURE 1 - TURNING PATH CHARACTERISTICS

The WHI equation for computing maximum offtracking is:

$$MOT = R - \sqrt{R^2 - \Sigma(WB^2)}$$

where,

MOT = Maximum offtrack

R = Radius of the desired vehicle path

WB = Effective wheelbase

$\Sigma(WB^2)$ = The sum of the squares of all wheelbases comprising a given vehicle combination.

Because vehicles have both width and length, offtracking makes the vehicle appear wider in cross section on a curve than it will on tangent. The visual effect of the phenomenon is the "swept width" which will influence a driver to alter his desired path to avoid the perceived hazard. The equation for swept width is:

$$SW = \sqrt{(WB_1+FOH)^2+(R+\tfrac{1}{2}TW)^2} - (R-MOT-\tfrac{1}{2}TW)$$

where,

SW = Swept width
WB = Effective wheelbase
FOH = Front overhang
R = Radius
TW = Track width
MOT = Maximum offtrack

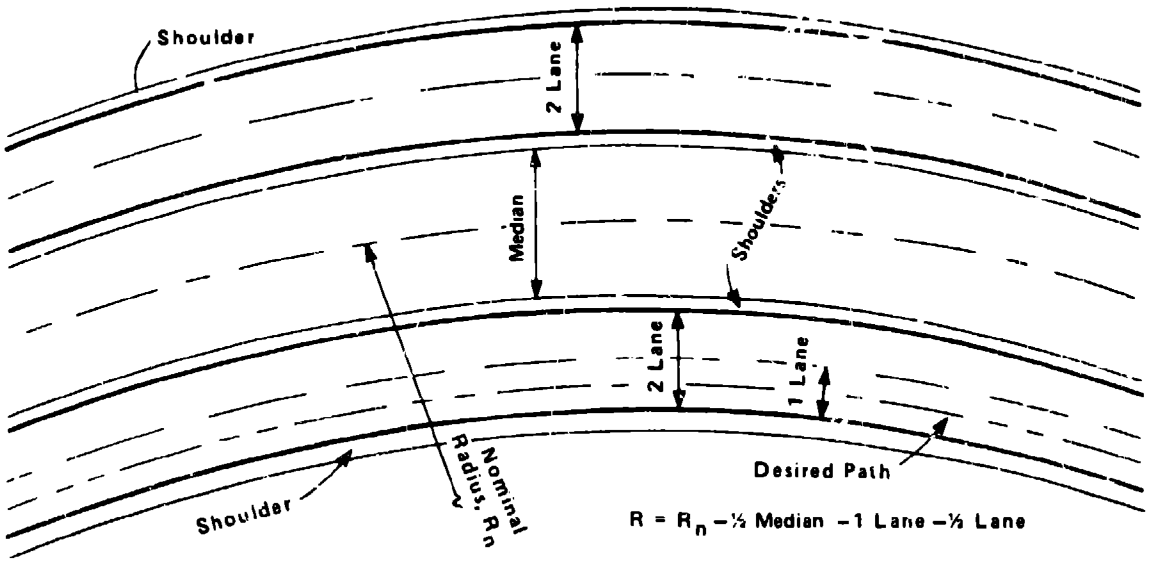
The equation for wheel path is:

$$WP = MOT+TW$$

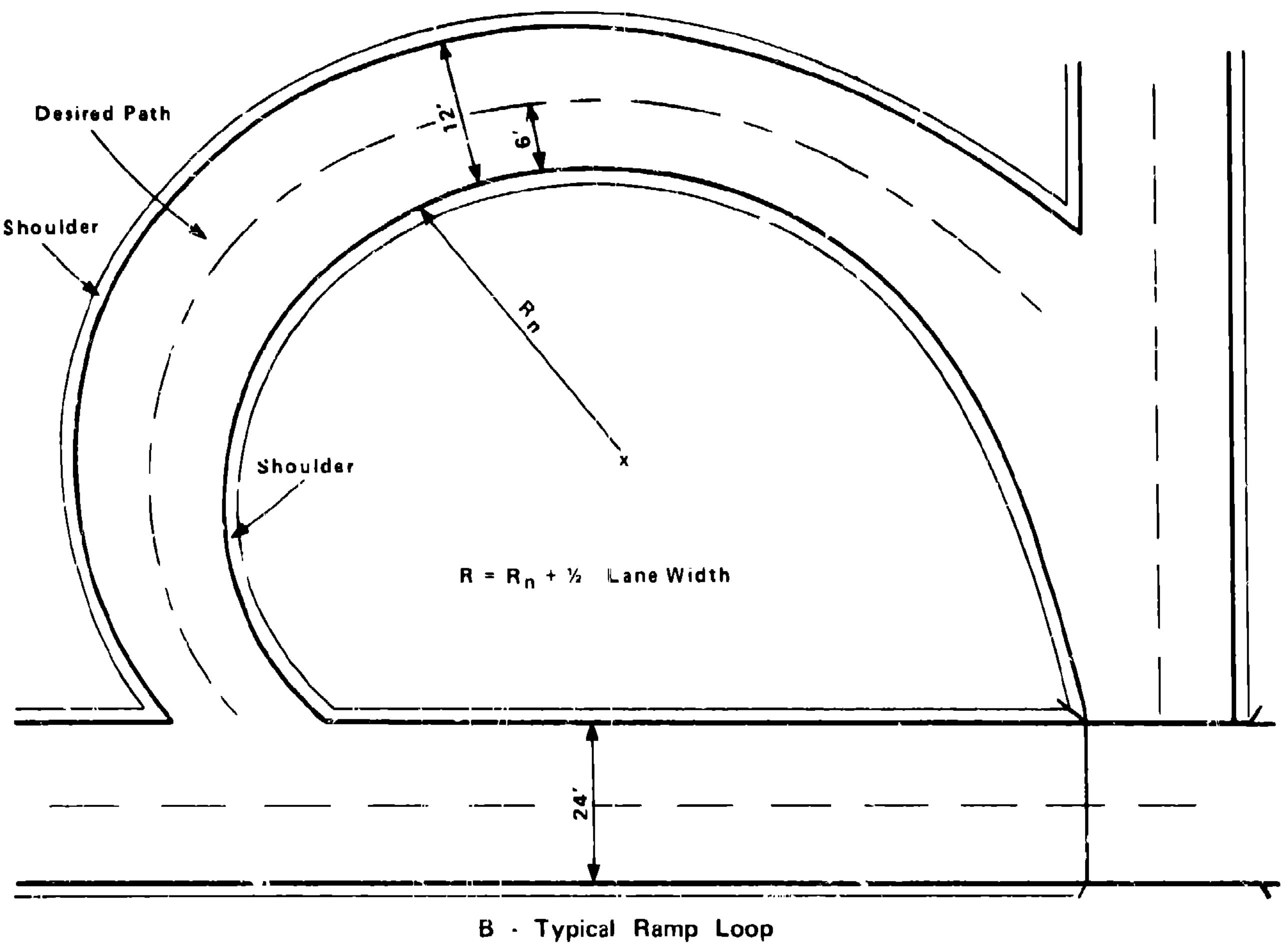
where,

WP = Wheel path
MOT = Maximum offtrack
TW = Track width

The swept width was computed for a series of curves which occur on the Interstate Highway System both on the mainline and on ramps. Mainline curvatures were computed for curves of 0 to 9 degrees and the ramp curvatures for curves of 0 to 38 degrees for each of the 19 vehicle types. Figure 2 shows a typical mainline curve and a typical loop



A - Typical Mainline Curve, 4-Lane Section



B - Typical Ramp Loop

FIGURE 2 - INTERSTATE HIGHWAY CURVE DESCRIPTIONS

ramp found on the Interstate Highway System. Table 2 shows the computer input required for the analysis.

RESULTS

Critical swept width situations were identified to occur only on ramps which are off the Interstate highway through traffic lanes and are designed for one-lane operation at low speeds. The critical situations were identified as ramps having a curvature of 27 degrees or more, or a radius of 212 feet or less. In these situations when the bus is operating at low speed, its apparent width has little or no effect on the driving path of a following car.

In table 3, a comparison is made of swept width at that point where it becomes critical for a 12-foot lane for four vehicle types. As shown in this table, the MC-6 bus reaches the critical point on the curve of 27 degrees and the critical point for the MC-7 bus occurs on a curvature of 31 degrees. The swept width of the WB-50 tractor-semitrailer combination reaches the 12-foot lane width on a ramp with a curvature of 24 3/4 degrees and the WB-50 modified tractor-semitrailer slightly exceeds it at the 28 1/2 degree curve. Thus, the situation is less critical for the 8 1/2-foot wide MC-6 bus than the 8 1/2 foot WB-50 tractor-semitrailer combination at the 28 1/2 degree curve. It is also noted that the difference in swept width for the MC-6 and MC-7 buses, for the curves shown in table 3, is only 0.50 feet, or the 6-inch difference in bus width. For comparison purposes, the swept width on mainline curves for 3 and 7 degrees are also shown. These are the maximum curvature generally found on Interstate highways with design speeds of 70 miles per hour and 50 miles per hour, respectively. It may be seen that the swept width is well within the lane width of 12 feet.

Table 2. Vehicle types and dimensions used for wheelbases, track width, body width and front overhang (Dimensions shown in inches)

Vehicle Type	Wheel-base 1	Wheel-base 2	Truck Width	Body Width	Front Overhang
05- 04 (8')	267.20	-	96.00	95.40	85.50
05- 04 (8 1/2')	267.20	-	96.00	101.40	85.50
MC-5	261.00	-	96.00	96.00	68.75
MC-6	296.50	-	102.00	101.50	74.50
MC-7	297.00	-	96.00	96.00	70.25
MD-4279	235.00	-	96.00	95.76	82.24
MD-4277	235.00	-	102.00	101.76	82.24
MD-4225	284.76	-	96.00	95.76	82.24
MD-4223	284.76	-	102.00	101.76	82.24
MD-4222	35.00	-	96.00	95.76	82.24
MD-4218	284.76	-	96.00	95.76	82.24
MD-4218 MOD*	284.76	-	102.00	101.76	82.24
MD-7020	259.50	-	96.00	95.76	72.12
MD-7029	318.54	-	96.00	95.76	72.12
MD-7029 MOD*	318.54	-	102.00	101.76	72.12
C-50	192.00	312.00	96.00	96.00	48.00
WB-50 MOD*	216.00	360.00	96.00	96.00	36.00
WB-50	216.00	360.00	102.00	102.00	36.00
Station Wagon	119.00	-	63.52	80.00	39.50

*Indicates width modification only.

Table 3. Comparison of the critical swept width for four vehicle types (in feet)

Vehicle Type	Body Width	Degree of Curve					
		Mainline		Ramps			
		3°.00'	7°.00'	24°.45'	27°.00'	28°.30'	31°.00'
MC-6	8.5	8.88	9.48	11.72	12.00	12.19	12.50
MC-7	8.0	8.42	9.02	11.22	11.51	11.69	12.00
WB-50	8.5	8.95	9.59	12.00	12.31	12.52	12.86
WB-50 MOD	8.0	8.45	9.09	11.50	11.81	12.02	12.36

The offtracking requirement of an 8 1/2-foot wide bus, 40-feet long is the same as that of an 8-foot wide bus of the same length. For purposes of comparison, the bus offtracking requirement is about half that of a tractor-trailer combination either 8- or 8 1/2-feet wide and 55-feet long (1.61 feet vs. 3.23 feet). However, a bus offtracks about six times more than a station wagon, 6-feet 8-inches wide and 18-feet long (1.61 feet vs. 0.26 feet). Since the offtracking requirement is a function of the wheelbase, a more descriptive comparison is swept width which includes the offtracking requirement and accounts for differences in vehicle widths.

Based upon these computations of the swept width requirements for the vehicles analyzed, the required widths are well within the 12-foot lane widths on Interstate through traffic lanes and ramps. Also, the effects of inertia of the vehicle would probably not cause the vehicle to exceed the lane boundary. Moreover, there is always at least a two-foot wide shoulder on each side of the ramp which will accommodate the bus overhang.

Further calculations were made with various combinations of width and length of a vehicle The results showed that swept width was more sensitive to changes in the length of vehicles rather than to the width.

OTHER USES FOR THIS PROCEDURE

The procedure developed can be used by highway design personnel to select a maximum degree of curvature which would permit a vehicle to stay within the selected lane width and widths of entrances to terminal facilities. It can be used to check design to insure that the additional width a larger vehicle appears to gain when negotiating a curve will not exceed selected safety boundaries which may cause a following or meeting driver to hazardously veer his vehicle out of a "safe path" because of the larger vehicle. Another use of this procedure would be concerned with the movement of outsized vehicles, either in width, length or both, to select routes over which to travel. Additionally, the regulatory agency which must act upon permits to move outsized vehicles must determine the routes these vehicles can use and the critical points along the route where special traffic controls must be exercised to both protect the normal traffic and the outsized vehicle.

In each of the above cases, all that is required to perform the necessary calculations are appropriate physical dimensions of the vehicle, either design or actual, and those of the curve or intersection, either designed or existing. These data can then be inserted into the off-tracking program such as the FORTRAN IV program in Appendix A. Appendix B shows the computer input data and samples of the printout data are shown in Appendix C.

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APPENDIX A - FORTRAN IV PROGRAM


```
               C
               C      USE DOUBLE PRECISION FOR ALL REAL NUMBERS
               C
 0001                 IMPLICIT REAL*8 (A-H,O-Z)
               C
               C      MAXIMUM OF 21 DIFFERENT VEHICLES MAY BE TREATED IN A SINGLE RUN
               C
 0002                 DIMENSION WB1(21), WB2(21), TW(21), OW(21), FOH(21), TYPE1(21),
                     *          TYPE2(21)
               C
               C      STATEMENT FUNCTION TO COMPUTE RADIUS GIVEN DEGREE OF CURVE IN MINUTES
               C
 0003                 RADIUS(MDC) = 1080000. / (3.141592653589793D0 * DFLOAT(MDC))
               C
               C      READ THE SMALLEST DEGREE OF CURVE,THE LARGEST DEGREE OF CURVE AND
               C      THE INCREMENTAL DEGREE OF CURVE AND CONVERT TO MINUTES
               C
 0004                 READ(1,9000) IDLO,IMLO,IDHI,IMHI,IDINC,IMINC
 0005           9000  FORMAT (3(I3,1X,I2,2X))
 0006                 WRITE (3,9100) IDLO,IMLO,IDHI,IMHI,IDINC,IMINC
 0007           9100  FORMAT (T10,'|',15X,'DEGREE OF CURVE: FROM',I4,'-',I2,' TO',
                     *        I4,'-',I2,' BY',I4,'-',I2,T90,'|',///)
 0008                 MLO = IMLO+60*IDLO
 0009                 MHI = IMHI+60*IDHI
 0010                 MINC = IMINC+60*IDINC
               C
               C      READ THE NUMBER OF VEHICLES AND THEIR DIMENSIONS
               C
 0011                 READ (1,9000) NVEHCL
 0012                 READ (1,9200) (TYPE1(I),TYPE2(I),WB1(I),WB2(I),TW(I),OW(I),
                     *          FOH(I),I=1,NVEHCL)
 0013           9200  FORMAT (2A8,5F8.0)
               C
               C      WRITE THE VEHICLE DIMENSIONS
               C
 0014                 WRITE (3,9300) (TYPE1(I),TYPE2(I),WB1(I),WB2(I),TW(I),OW(I),
                     *          FOH(I),I=1,NVEHCL)
 0015           9300  FORMAT (T10,'|',33X,'WHEEL-  WHEEL-    TRACK     BODY  FRONT',
                     *        T90,'|',/,T26,'VEHICLE TYPE       BASE 1  BASE 2   ',
                     *        'WIDTH    WIDTH  OVERHANG',/,('0',T10,'|',15X,2A8,3F8.2,
                     *        F9.2,F8.2,T90,'|'))
               C
               C      LOOP THRU ALL DESIRED CURVES
               C
 0016                 DO 200 MINUTE = MLO, MHI, MINC
               C
               C      COMPUTE RADIUS OF CURVE AND WRITE PAGE HEADER
               C
 0017                 R = RADIUS(MINUTE)
 0018                 JDEG = MINUTE / 60
 0019                 JMIN = MINUTE - 60 * JDEG
 0020                 WRITE (3,9400) JDEG,JMIN,R
 0021           9400  FORMAT ('1',T10,'|',15X,I3,'-',I2,' DEGREE CURVE, RADIUS =',
                     *        F9.2,T90,'|',///,T10,'|',35X,'OFF-TRACK',5X,
```

```
                  *        'WHEEL TRACK     SWEPT',T90,'|',/,T26,'VEHICLE TYPE',
                  *        8X,'WIDTH (FT)     WIDTH (FT)      WIDTH (FT)')
 0022                R = ( R + 6.0 ) * 12.0
               C
               C     LOOP THRU ALL VEHICLES
               C
 0023                DO 100 IV = 1, NVEHCL
               C
               C     COMPUTE OFF TRACK WIDTH -- OT
               C
 0024                OT = R - DSQRT ( R*R - WB1(IV) * WB1(IV) - WB2(IV) * WB2(IV)   )
               C
               C     COMPUTE SWEPT WIDTH -- SW
               C
 0025                T1 = FOH(IV) + WB1(IV)
 0026                T2 = R + 0.5 * OW(IV)
 0027                SW = (DSQRT (T1*T1+T2*T2) - R + OT + 0.5 * OW(IV)) / 12.0
               C
               C     COMPUTE WHEEL TRACK WIDTH -- WP
               C
 0028                WP = ( OT + TW(IV) ) / 12.0
 0029                OT = OT / 12.0
               C
               C     WRITE THE COMPUTED VALUES
               C
 0030                WRITE (3,9500) TYPE1(IV),TYPE2(IV),OT,WP,SW
 0031           9500 FORMAT ('0',T10,'|',15X,2A8,F12.2,F14.2,F15.2,T90,'|',5X)
               C
               C     END OF LOOPS
               C
 0032            100 CONTINUE
 0033            200 CONTINUE
 0034                STOP
 0035                END
```

SUBPROGRAMS CALLED

SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION
IBCOM#	AC	DSQRT	B0						

SCALAR MAP

SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION
R	C8	DT	D0	T1	D8	T2	E0	SW	E8
WP	F0	IDLO	F8	IMLO	FC	IDHI	100	IMHI	104
IDINC	108	IMINC	10C	MLO	110	MHI	114	MINC	118
NVEHCL	11C	I	120	MINUTE	124	JDEG	128	JMIN	12C
IV	130								

ARRAY MAP

SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION
WB1	138	WB2	1E0	TW	288	OW	330	FUH	3D8
TYPE1	480	TYPE2	528						

FORMAT STATEMENT MAP

SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION
9000	5D0	9100	5DD	9200	624	9300	62F	9400	6C9
9500	76B								

```
*OPTIONS IN EFFECT*  NOID,EBCDIC,SOURCE,NOLIST,NODECK,LOAD,MAP
*OPTIONS IN EFFECT*  NAME = MAIN    , LINECNT =       56
*STATISTICS*    SOURCE STATEMENTS =       35,PROGRAM SIZE =      3058
*STATISTICS*  NO DIAGNOSTICS GENERATED
```

APPENDIX B - INPUT DATA

DEGREE OF CURVE: FROM 0-15 TO 38-30 BY 0-15

VEHICLE TYPE	WHEEL-BASE 1	WHEEL-BASE 2	TRACK WIDTH	BODY WIDTH	FRONT OVERHANG
05 - 04 8'	267.20	0.0	96.00	95.40	85.50
05 - 04 8.5'	267.20	0.0	96.00	101.40	85.50
MC - 5	261.00	0.0	96.00	96.00	68.75
MC - 6	296.50	0.0	102.00	101.50	74.50
MC - 7	297.00	0.0	96.00	96.00	70.25
MD - 4279	235.00	0.0	96.00	95.76	82.24
MD - 4277	235.00	0.0	102.00	101.76	82.24
MD - 4225	284.76	0.0	96.00	95.76	82.24
MD - 4223	284.76	0.0	102.00	101.76	82.24
MD - 4222	235.00	0.0	96.00	95.76	82.24
MD - 4218	284.76	0.0	96.00	95.76	82.24
MD - 4218 MOD	284.76	0.0	102.00	101.76	82.24
MD - 7020	259.50	0.0	96.00	95.76	72.12
MD - 7029	318.54	0.0	96.00	95.76	72.12
MD - 7029 MOD	318.	0.0	102.00	101.76	72.12
C - 50	192.00	312.00	96.00	96.00	48.00
WB - 50 MOD	216.00	360.00	96.00	96.00	36.00
WB - 50	216.00	360.00	102.00	102.00	36.00

APPENDIX C - PRINTOUT DATA

24- 0 DEGREE CURVE, RADIUS = 238.73

VEHICLE TYPE	OFF-TRACK WIDTH (FT)	WHEEL TRACK WIDTH (FT)	SWEPT WIDTH (FT)
US - 04 8'	1.02	9.02	10.70
US - 04 8.5'	1.02	9.02	11.19
MC - 5	0.97	8.97	10.48
MC - 6	1.25	9.75	11.62
MC - 7	1.25	9.25	11.13
MD - 4279	0.78	8.78	10.17
MD - 4277	0.78	9.28	10.66
MD - 4225	1.15	9.15	11.01
MD - 4223	1.15	9.65	11.50
MD - 4222	0.78	8.78	10.17
MD - 4218	1.15	9.15	11.01
MD - 4218 MOD	1.15	9.65	11.50
MD - 7020	0.96	8.96	10.47
MD - 7029	1.44	9.44	11.55
MD - 7029 MOD	1.44	9.94	12.04
C - 50	1.91	9.91	10.71
WB - 50 MOD	2.51	10.51	11.40
WB - 50	2.51	11.01	11.90

24-15 DEGREE CURVE, RADIUS = 236.27

VEHICLE TYPE	OFF-TRACK WIDTH (FT)	WHEEL TRACK WIDTH (FT)	SWEPT WIDTH (FT)
05 - 04 8'	1.03	9.03	10.72
05 - 04 8.5'	1.03	9.03	11.22
MC - 5	0.98	8.98	10.51
MC - 6	1.26	9.76	11.65
MC - 7	1.27	9.27	11.16
MD - 4279	0.79	8.79	10.19
MD - 4277	0.79	9.29	10.69
MD - 4225	1.16	9.16	11.04
MD - 4223	1.16	9.66	11.53
MD - 4222	0.79	8.79	10.19
MD - 4218	1.16	9.16	11.04
MD - 4218 MOD	1.16	9.66	11.53
MD - 7020	0.97	8.97	10.49
MD - 7029	1.46	9.46	11.58
MD - 7029 MOD	1.46	9.96	12.08
C - 50	1.93	9.93	10.74
WB - 50 MOD	2.54	10.54	11.43
WB - 50	2.54	11.04	11.93

24-30 DEGREE CURVE, RADIUS = 233.86

VEHICLE TYPE	OFF-TRACK WIDTH (FT)	WHEEL TRACK WIDTH (FT)	SWEPT WIDTH (FT)
05 - 04 8'	1.04	9.04	10.75
05 - 04 8.5'	1.04	9.04	11.25
MC - 5	0.99	8.99	10.53
MC - 6	1.28	9.78	11.68
MC - 7	1.28	9.28	11.19
MD - 4279	0.80	8.80	10.21
MD - 4277	0.80	9.30	10.71
MD - 4225	1.18	9.18	11.07
MD - 4223	1.18	9.68	11.57
MD - 4222	0.80	8.80	10.21
MD - 4218	1.18	9.18	11.07
MD - 4218 MOD	1.18	9.68	11.57
MD - 7020	0.98	8.98	10.52
MD - 7029	1.47	9.47	11.62
MD - 7029 MOD	1.47	9.97	12.11
C - 50	1.95	9.95	10.77
WB - 50 MOD	2.57	10.57	11.47
WB - 50	2.57	11.07	11.97

24-45 DEGREE CURVE, RADIUS = 231.50

VEHICLE TYPE	OFF-TRACK WIDTH (FT)	WHEEL TRACK WIDTH (FT)	SWEPT WIDTH (FT)
05 - 04 8'	1.05	9.05	10.78
05 - 04 8.5'	1.05	9.05	11.28
MC - 5	1.00	9.00	10.56
MC - 6	1.29	9.79	11.72
MC - 7	1.29	9.29	11.22
MD - 4279	0.81	8.81	10.23
MD - 4277	0.81	9.31	10.73
MD - 4225	1.19	9.19	11.10
MD - 4223	1.19	9.69	11.60
MD - 4222	0.81	8.81	10.23
MD - 4218	1.19	9.19	11.10
MD - 4218 MOD	1.19	9.69	11.60
MD - 7020	0.99	8.99	10.54
MD - 7029	1.49	9.49	11.65
MD - 7029 MOD	1.49	9.99	12.15
C - 50	1.97	9.97	10.80
WB - 50 MOD	2.59	10.59	11.50
WB - 50	2.59	11.09	12.00