Geometric Considerations Of Long Combination Vehicle Maneuvers On Roadway Intersections In Brazil

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ABSTRACT

In the last fifteen years there has been a growing trend towards the use of Long Combination Vehicles (LCVs) on Brazilian roads, operating mainly in the agricultural sector. They operate under special permits with an overall length limit of 30 meters and GCWs ranging from 63 to 74 tons. The vast majority of roads that carry these vehicles are two-lane highways with traffic in both directions and at-grade intersections.

The paper presents a compatibility analysis of the maneuvering characteristics of typical LCVs with the horizontal geometry of at-grade intersections. The method used is the simulation of low-speed offtracking with the Auto*TURN* package.

It is concluded that LCV maneuvering capability is not necessarily more critical than the maneuvering capability of certified long wheelbase semitrailers.

INTRODUCTION

Like in many other countries, the great change in performance characteristics of freight vehicles in the last three decades requires an update of geometric design standard procedures, in order to cope with changes in regulation that permit the traffic of longer vehicles.

Brazilian regulation has been traditionally influenced by foreign rules and recommendations, like the American Association of State Highway and Transportation Officials (AASHTO), the Society of Automotive Engineers (SAE) and others to a smaller extent, concerning road design and construction criteria and vehicle manufacturing and certification standards. The National Transportation Council (CONTRAN) certifies only vehicles with up to one articulation for unrestricted traffic, assuming that the performance of vehicles with two or three articulations is too critical.

Geometric design of two lane highways with traffic in both directions derives from the late sixties and has been strongly influenced by the AASHO blue book procedures. The more recent AASHTO design criteria have not yet been incorporated to Brazilian standards.

The study objective is to investigate the impact of the traffic of combination vehicles on the horizontal geometry of at-grade intersections of two-lane highways. The traffic of LCVs is investigated vis-à-vis the maneuvering characteristics of certified vehicles. It is assumed that roads should be constructed to a standard that supports at least all certified vehicles.

The method used is the simulation of low-speed offtracking with the Auto*TURN* package by Transoft Solutions [12].

REGULATION OF COMBINATION VEHICLE CHARACTERISTICS IN BRAZIL

In the study, a distinction has been made between Combination Vehicles (CVs) and Long Combination Vehicles (LCVs). Combination vehicles certified for unrestricted traffic are called CVs. Figure 1 shows, as examples, the 1 and 3 axle Semitrailer and the truck coupling a full trailer, called "Romeu e Julieta". Present dimensional limits [8] are: overall length of 18.15 m (60 feet) for semitrailers and 19.80 m (65 feet) for the truck+full trailer; overall width of 2.60 m (8.5 feet) and overall height of 4.40 m (14.5 feet). LCVs are the combination vehicles which have more than one articulation and are, in general, longer than the CVs. They operate under a special permit (CONTRAN - Resolution 631/84) [8]. Figure 2 shows examples of these vehicles, called "Treminhão" and "Rodotrem". The triple trailer has not yet been proposed by any Brazilian operator, although it could, in principle, be operated under the same special permit.

The basic conditions established in Resolution 631/84 are:

- Total vehicle length must be less than 30 meters;
- Vehicles must have lateral reflectors every 3 m to provide lateral night visibility over the total length;

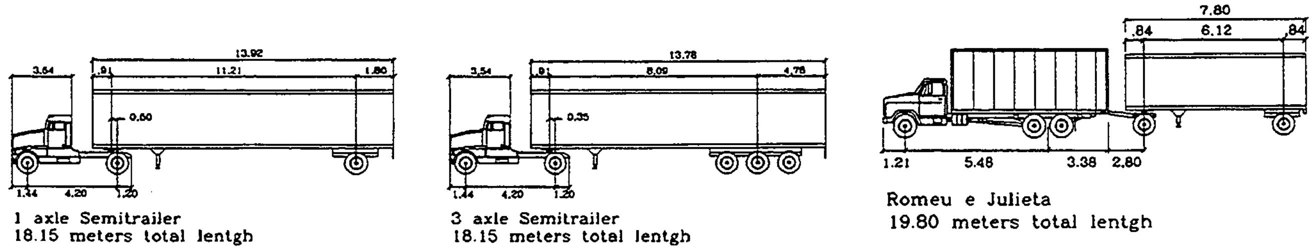


Figure 1. Certified vehicles in Brazil.

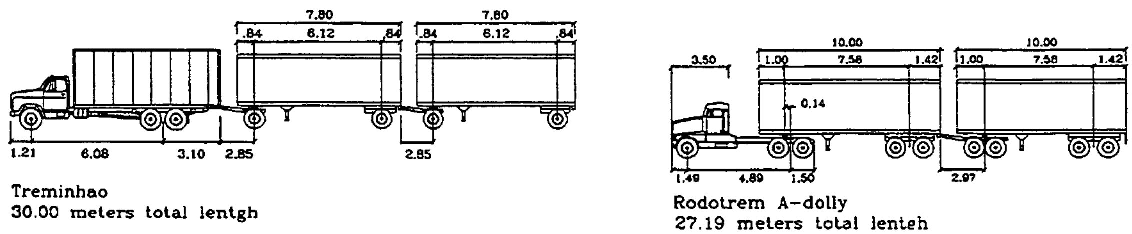


Figure 2. Vehicles that travel under special permits in Brazil.

- The traffic of LCVs is allowed between 6 am and 6 pm and speeds must not exceed 60 km/h. Under special circumstances, when the horizontal geometry of the road and its safety conditions have been verified, the night traffic of these vehicles can be authorised.

It should be noted that, in the legislation, no reference is made with respect to performance characteristics (power/weight ratio, breaks etc.), driver training, safety programs, approved routes and/or appropriate insurance.

GEOMETRIC DESIGN RULES AND STANDARD PROCEDURES IN USE IN BRAZIL

The Federal Highway Department - DNER establishes the geometric design standards for federal highways. The design of state and municipal roads is mainly based on State Highway Department standards which, in general, apply the federal standards. Geometric design criteria is mostly based on the AASHO blue book [1] and is not closely related to present freight transport by combination vehicles. The vehicles considered are the single truck and the tractor+semitrailer WB-40.

To account for offtracking, DNER [3] calculates extra widths through the use of EQ (1) that is based on a single unit vehicle configuration and, in general, a wheelbase of 6 m is used in the design process. As can be observed, it also includes a second term that depends on speed and curve radius to account for high-speed negative offtracking:

$$s = n(R - \sqrt{R^2 - b^2}) + \frac{V}{10\sqrt{R}} \qquad (1)$$

where s = total extra width; n = number of lanes; R = curve radius; b = wheelbase of design vehicle; V = design speed.

For low-speed steady state offtracking analysis, EQ (1) is very similar to the more recent Western Highway Institute (WHI) formula [6], EQ (2), that can be used to determine maximum offtracking of single unit and combination vehicles.

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

where OT_{max} = maximum offtracking; R = curve radius; ΣL = sum of wheelbases, overhangs and lengths of links that influence offtracking.

In 1975 and 1976, respectively, DNER [4] and IPR [7] published new studies with respect to geometric design standards, but none of these references has brought additional contributions to solve the problem of compatibilty of design standards with the maneuvering characteristics of combination vehicles on at-grade intersections.

SIMULATION OF COMBINATION VEHICLE OPERATION ON AT-GRADE INTERSECTIONS

THE SIMULATION MODEL

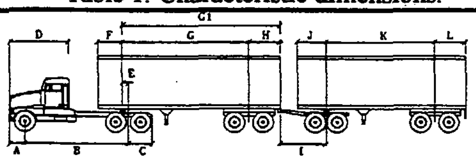
Auto*TURN* operates within Auto*CAD* to generate low-speed offtracking curves, based on the tractrix interative process described by Garlick et al. [5], and presents vehicle swept path or path of tires, for a certain geometric situation. The total swept path is related to the point where the vehicle produces the highest amount of offtracking and is represented by an orthogonal line to the envelope curves.

During the simulation process it is always assumed that the path of the front axle center is positioned at the center of the traffic lane designed with Auto*CAD*.

The program examines two different aspects of combination vehicle offtracking on constant radius curves: steady state and transient values.

Descriptive Parameters Auto*TURN* uses the characteristic dimensions presented on Table 1.

Table 1. Characteristic dimensions.



A	Tractor front overhang
B	Tractor wheelbase
C	Tractor rear overhang
D	Cab length
E	Distance from kingpin to tractor rear axle
F	First trailer front overhang
G	Distance from fifth wheel to first trailer rear axle (for the A-dolly connection);
G1	Distance from fifth wheel to first trailer rear (for the C-dolly connection);
H	First trailer rear overhang
I	Dolly length (towbar)
J	Second trailer front overhang
K	Distance from dolly connection to second trailer rear axle
L	Second trailer rear overhang
	Trailer width = 2.6 meters

INTERSECTION LAYOUTS

The operation of vehicles on generic intersections established by DNER [3], Figure 3, and on real intersections designed by the State of São Paulo Road Department - DER-SP, Figure 4, has been investigated. They are representative of typical intersections of secondary rural highways, as well as freight terminal and industry entrances.

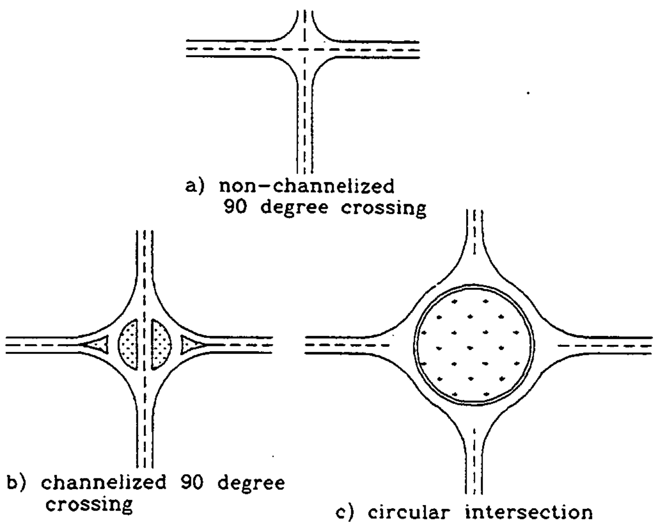


Figure 3. Generic DNER intersections.

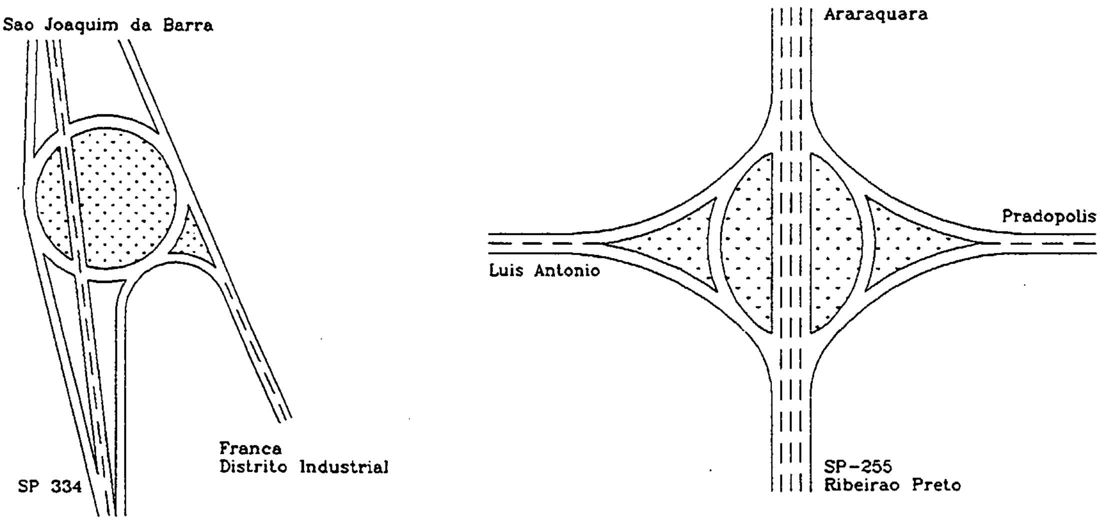


Figure 4. Real DER-SP intersections.

VEHICLE CONFIGURATIONS

The definition of a design vehicle is a controversial subject, as it involves economic aspects of freight transport and safety for other users. In this study it is assumed that the geometry of intersections should be compatible, at least, with the unrestricted traffic of certified freight vehicles throughout the national road system. Therefore, the 1 axle Semitrailer, shown in Figure 1, has been considered as the reference-vehicle for the analysis of results. The LCVs that have been investigated in the study are the ones with most frequent traffic on Brazilian roads illustrated in Figure 2. The operation of the "Rodotrem" has also been evaluated for the C-dolly connection, since this connection offers a better offtracking performance.

ANALYSIS OF RESULTS

The first step has been the evaluation of relative maneuvering performance through the steady state offtracking characteristics for different radii, using the WHI formula, EQ (2).

The results in Table 2, which also include maneuvering characteristics of the Western Double, the B-train, the 48' Semitrailer and the Triple, show extra width requirement classification for different compositions. The research conducted by Russo [9] shows that this relative classification remains the same in terms of extra width requirements for transient offtracking.

In this paper, only a few of a large amount of simulations developed by Russo [9] are presented in the appendix to illustrate the basic results that have been analysed.

Table 2. ΣL^2 and maximum steady state offtracking for different radii.

Vehicle	ΣL^2	Maximum Offtracking (OT_{max}) (m) — Curve Radius (m)					
		30.0	40.0	50.0	60.0	70.0	80.0
"Romeu e Julieta"	63.90	1.08	0.81	0.64	0.53	0.46	0.40
3 axle Semitrailer	82.97	1.42	1.05	0.84	0.70	0.60	0.52
West. Double C	104.17	1.79	1.32	1.05	0.87	0.75	0.65
West. Double A	114.20	1.97	1.45	1.16	0.96	0.82	0.72
"Treminhão"	117.80	2.03	1.50	1.19	0.99	0.85	0.74
"Rodotrem" C	119.53	2.06	1.52	1.21	1.00	0.86	0.75
1 axle Semitrailer	**143.05**	**2.49**	**1.83**	**1.45**	**1.20**	**1.03**	**0.90**
B-train	148.67	2.59	1.90	1.51	1.25	1.07	0.93
"Rodotrem" A	145.61	2.53	1.86	1.48	1.23	1.05	0.92
48' Semitrailer	165.58	2.90	2.13	1.68	1.40	1.19	1.04
Triple	165.86	2.90	2.13	1.69	1.40	1.19	1.04

Source: Table 5.1 in [9].

The non-channelized 90 degree crossing requires extra pavement width for all investigated combination vehicles, the amount varying with the combination type, as can be observed from Figures 6 to 8.

Figure 8 also shows the advantage of the C-dolly over the A-dolly in terms of offtracking of LCVs. Since the C-dolly is provided with a double drawbar that does not articulate at the connection with the preceding semitrailer, the dolly works as an increase of the trailer's rear overhang. Analytically, this type of coupling mechanism upgrades vehicle performance, since the distance to be subtracted from the sum of distances (ΣL), in EQ (2), is larger.

Figure 5 presents a graphical comparison of the offtracking condition for alternative types of coupling mechanisms. Depending on its dimensions, even the B-train could have a better performance than the A-dolly.

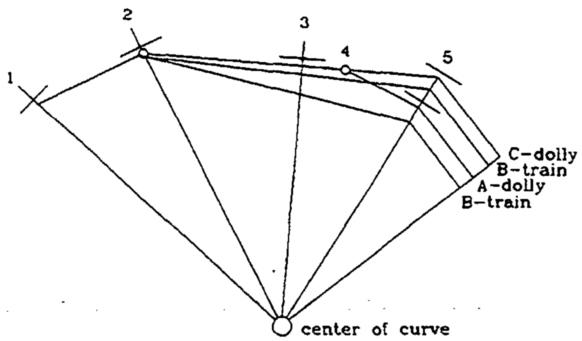


Figure 5. Comparison of offtracking condition for alternative coupling mechanisms (steady state).

In the channelized 90 degree crossing, Figure 9, the 1 axle Semitrailer offtracks outside of the paved area in the first entrance curve to the right and over the central island. As this kind of channelized crossing is very common on secondary rural highways, the non-compatibility of its geometric characteristics with the maneuvering of combination vehicles affects traffic safety and induces infrastructural damage.

Figure 10 shows a modification of the channelized crossing of Figure 9, to make it compatible with the maneuvering of the 1 axle Semitrailer. The central radius has been increased from 16.0 to 30.0 m and an extra width has also been provided so that the right lane has a total width of 8.5 meters. This new standard would permit all investigated vehicles to maneuver without offtracking over the central island.

The circular intersection, which is commonly observed on Brazilian secondary rural highway intersections with high traffic volumes, is compatible, in principle, with the maneuvering characteristics of all investigated vehicles, even for a very small radius of 20.0 m, Figures 11 to 13, because of the 7.0 m lane width standard. In general, on a circular intersection, vehicles reach a steady state condition, producing a constant amount of offtracking during a certain time. It is important to observe, however, that proper signalization to prevent passing along the central curve is required for small radii. If two lanes of 3.5 m are provided, indicating that passing is permitted, in principle, as it is usually the case, minimum curve radii should be much larger than the values presently used. Table 3 presents minimum recommended values to provide a safe operation for different combination vehicles.

Table 3. Minimum curve radii at dual lane circular intersections

Vehicle	R_{min} (m)
	Circular intersections Lane width = 3.5 m Maximum offtracking = 0.5 m
"Romeu e Julieta"	64.2
3 axle Semitrailer	83.2
"Treminhão"	118.1
"Rodotrem" C	119.8
1 axle Semitrailer	**143.3**
"Rodotrem" A	145.9

The simulation of combination vehicles maneuvering on real intersections, Figures 14 to 18, shows that the offtracking is considerably larger than the provided lane width, therefore indicating that design standards adopted by DER-SP are not compatible either with the 1 axle Semitrailer or common LCVs.

CONCLUSIONS

No references were found, in the literature review, about rules and standard procedures concerning offtracking of combination vehicles in Brazil. The literature review also shows that geometric design criteria are still based on the AASHO blue book, without any correlation with maneuvering characteristics of modern combination vehicles.

The analysis of simulation results shows that LCVs are not necessarily more critical than certified CVs in terms of compatibility with road design standards.

It is concluded that non-channelized and channelized 90 degree crossings, which are common at intersections with gravel roads originated at farming sites, as well as intersections with secondary paved roads or access to agricultural industries, do not provide sufficient extra-width for the traffic of the certified CVs or LCVs.

It is also concluded that the traffic of these vehicles on circular intersections requires larger radii in order to allow the vehicles to remain within their traffic lane.

With respect to alternative types of coupling mechanisms, the C-dolly improves performance in terms of offtracking.

Of the investigated vehicles, the "Rodotrem" with A-dolly coupling has shown the worst performance in terms of offtracking, while the truck+full trailer CV "Romeu e Julieta" has shown the best performance.

It is important to point out the limitation of the applicability of foreign standards to design Brazilian at-grade intersections:

- The more recent AASHTO green book edition [2] does not provide procedures for the design of at-grade intersections like the ones described in this paper. At-grade intersection traffic rules on North-American secondary highways, specially on curves to the left, are different from Brazilian rules. In the United States, vehicles stop on a turn lane until they find a gap on the opposing traffic to make a left turn. This is the reason why design procedures for right curves are applicable to left curves as well. In Brazil, on the other hand, left turns can only be made at channelized intersections, where vehicles leave the main traffic stream to the right and cross over both traffic streams. This is one of the reasons why on intersections with higher traffic volumes, circular intersections (roundabouts) substitute 90 degree channelized intersections.
- AASHTO rules and procedures are based on the observation of drivers and vehicle performance in the United States, whose characteristics are different from Brazilian characteristics. In a country as large as Brazil, characteristics vary even from State to State and are strongly influenced by different cultural aspects.

It is also true that Brazilian regulators continue to judge LCVs through the evaluation of overall dimensions and GCWs, instead of performance characteristics.

Like Sweatman [11], the authors conclude that performance standards should be used for heavy vehicle regulations and concession of special traffic permissions. Regulation should focus on desired results and provide a rational process for road geometric design modifications as well as vehicle design changes. The European Economic Community - EEC standard for a minimum radius turning template [10], although perhaps too retrictive, represents a good example of a performance standard.

A simulation method that evaluates different vehicle/road interactions is usefull to establish criteria based on the behaviour of freight vehicles, particularly LCVs. Expected performance standards can be specified, which will support vehicle dimensional regulation. As a consequence, better compatibility between road design and performance characteristics of vehicles can be expected, improving safety for all users, leading to greater dimensional uniformity, helping regulation criteria to be more consistent and promoting equivalent productivity increases with more uniform transport costs in all Brazilian States.

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APPENDIX

SIMULATION RESULTS

Generic Intersections

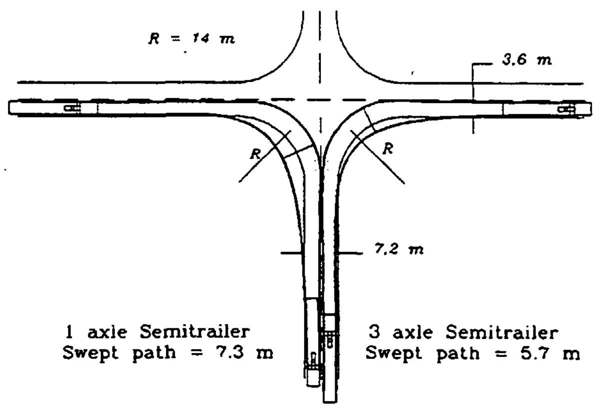

Figure 6. 1 axle Semitrailer and 3 axle Semitrailer on right curves in the 90 degree crossing.

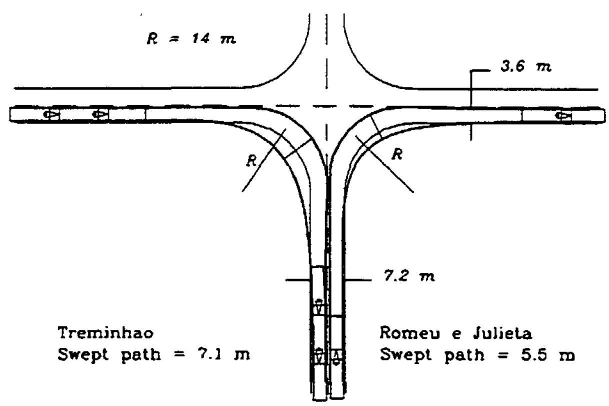

Figure 7. "Treminhão" and "Romeu e Julieta" on right curves in the 90 degree crossing.

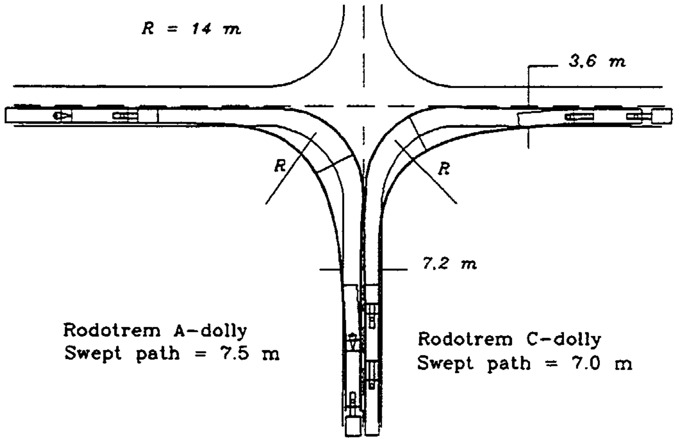

Figure 8. "Rodotrem" A-dolly/"Rodotrem" C-dolly.

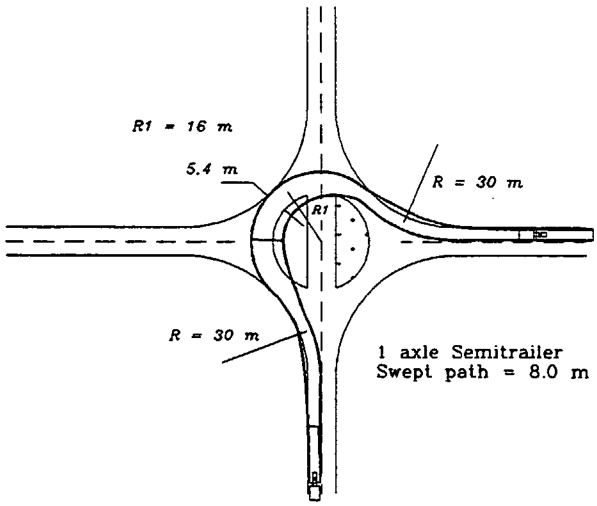

Figure 9. 1 axle Semitrailer on a left curve.

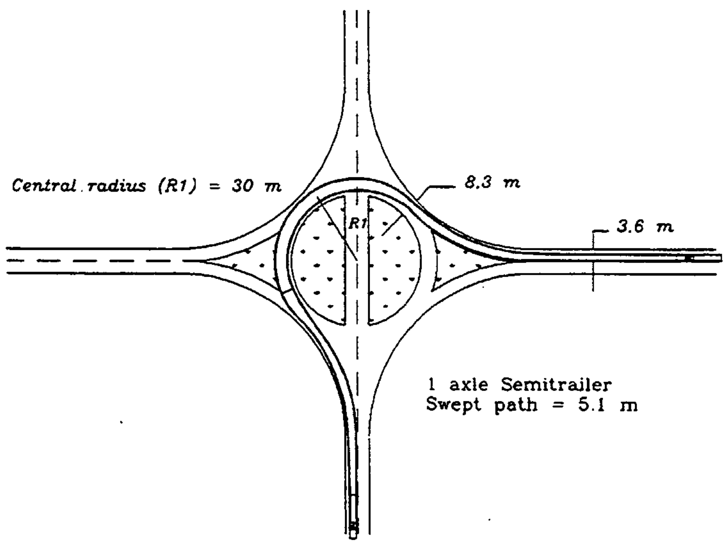

Figure 10. Channelized crossing with central island correction for the traffic of the 1 axle Semitrailer.

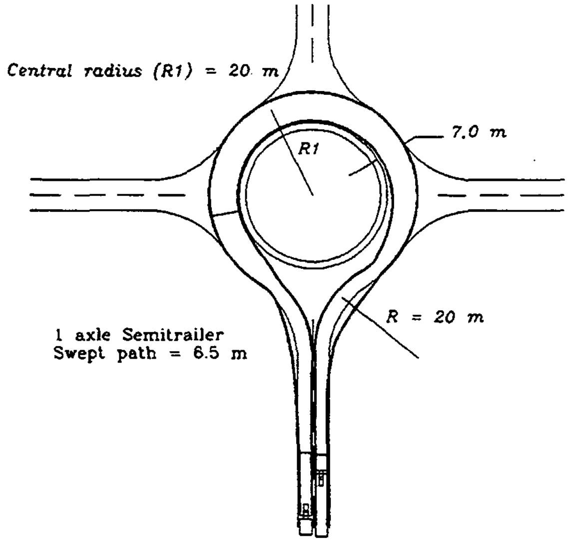

Figure 11. 1 axle Semitrailer in the circular intersection.

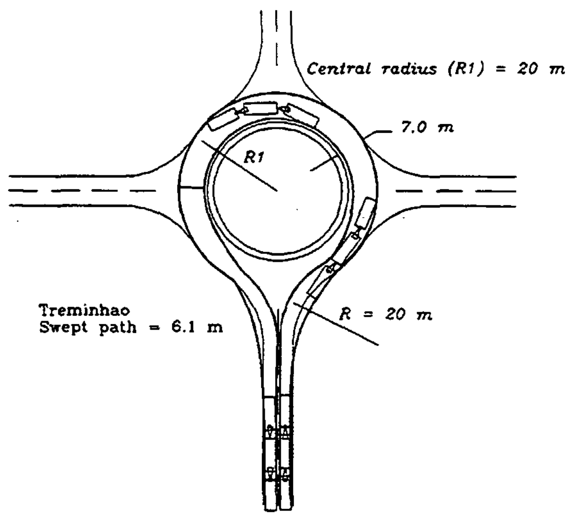

Figure 12. Operation of the "Treminhão" in the 20 meter radius circular intersection.

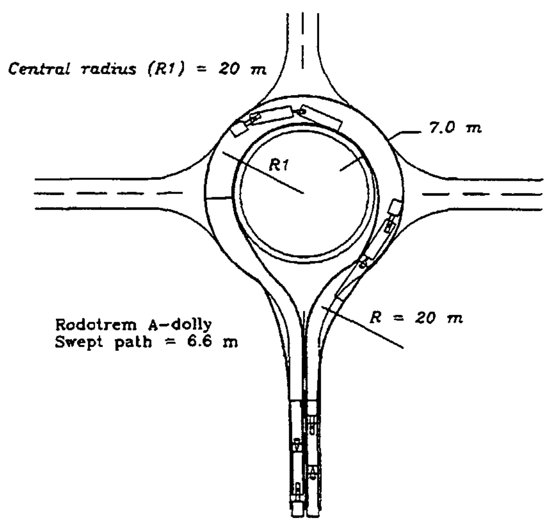

Figure 13. "Rodotrem" A-dolly in the circular intersection.

Real Intersections

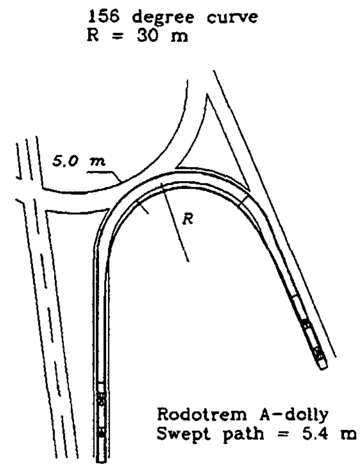

Figure 14. "Rodotrem" A-dolly in the access to Franca Industrial District.

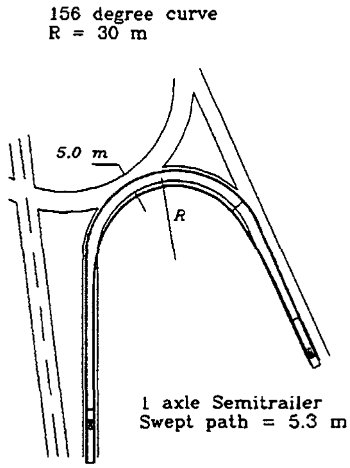

Figure 15. 1 axle Semitrailer.

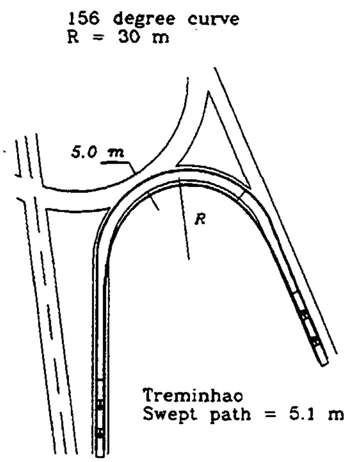

Figure 16. "Treminhão".

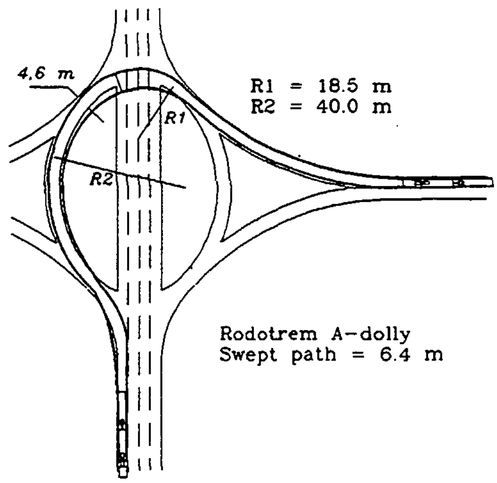

Figure 17. Pradópolis-Luís Antônio with SP-255 and the traffic of the "Rodotrem" A-dolly.

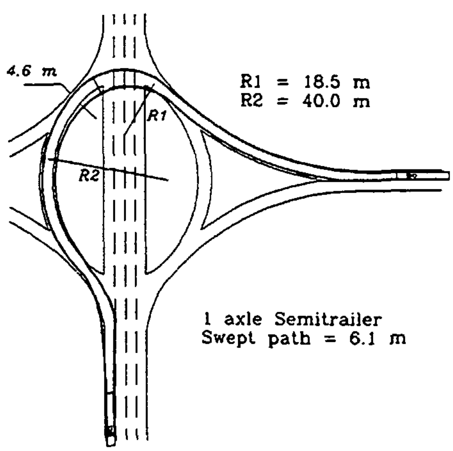

Figure 18. 1 axle Semitrailer.