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

Maria Rachel de Araujo Russo and João A. Widmer
University of São Paulo, Engineering School of São Carlos, Department of Transportation, Brazil

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 AutoTURN 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. They operate under a special permit (CONTRAN - Resolution 631/84). LCVs are the combination vehicles which have more than one articulation and are, in general, longer than the CVs. They operate under special permits.

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;

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]. 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,
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:

\[ s = n(R - \sqrt{R^2 - b^2}) + \frac{V}{10\sqrt{R}} \quad (1) \]

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.

\[ OT_{\text{max}} = R - \sqrt{R^2 - \Sigma L^2} \quad (2) \]

where \( OT_{\text{max}} \) = maximum offtracking; \( R \) = curve radius; \( \Sigma L \) = sum of wheelbases, overhangs and lengths of links that influence offtracking.

In 1975 and 1976, respectively, DNER [4] and IPR [5] published new studies with respect to geometric design standards, but none of these references has brought additional contributions to solve the problem of compatibility 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

AutoTURN operates within AutoCAD to generate low-speed offtracking curves, based on the tractrix interactive 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 AutoCAD.
The program examines two different aspects of combination vehicle offtracking on constant radius curves: steady state and transient values.

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

<table>
<thead>
<tr>
<th>Characteristic dimensions</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Tractor front overhang</td>
</tr>
<tr>
<td>B</td>
<td>Tractor wheelbase</td>
</tr>
<tr>
<td>C</td>
<td>Tractor rear overhang</td>
</tr>
<tr>
<td>D</td>
<td>Cab length</td>
</tr>
<tr>
<td>E</td>
<td>Distance from kingpin to tractor rear axle</td>
</tr>
<tr>
<td>F</td>
<td>First trailer front overhang</td>
</tr>
</tbody>
</table>

**Table 1. Characteristic dimensions.**

![Diagram](image)

**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.
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. $\Sigma L^2$ and maximum steady state offtracking for different radii.

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>$\Sigma L^2$</th>
<th>Curve Radius</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>30.0</td>
<td>40.0</td>
</tr>
<tr>
<td>&quot;Romeu e Julieta&quot;</td>
<td>63.90</td>
<td>1.08</td>
</tr>
<tr>
<td>3 axle Semitrailer</td>
<td>82.97</td>
<td>1.42</td>
</tr>
<tr>
<td>West. Double C</td>
<td>104.17</td>
<td>1.79</td>
</tr>
<tr>
<td>West. Double A</td>
<td>114.20</td>
<td>1.97</td>
</tr>
<tr>
<td>&quot;Treminhão&quot;</td>
<td>117.80</td>
<td>2.03</td>
</tr>
<tr>
<td>&quot;Rodotrem&quot; C</td>
<td>119.53</td>
<td>2.06</td>
</tr>
<tr>
<td>1 axle Semitrailer</td>
<td>143.05</td>
<td>2.49</td>
</tr>
<tr>
<td>B-train</td>
<td>148.67</td>
<td>2.59</td>
</tr>
<tr>
<td>&quot;Rodotrem&quot; A</td>
<td>145.61</td>
<td>2.53</td>
</tr>
<tr>
<td>48' Semitrailer</td>
<td>165.58</td>
<td>2.90</td>
</tr>
<tr>
<td>Triple</td>
<td>165.86</td>
<td>2.90</td>
</tr>
</tbody>
</table>

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.

The analysis of simulation results 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.

![Figure 5. Comparison of offtracking condition for alternative coupling mechanisms (steady state).](image-url)
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 restrictive, represents a good example of a performance standard.

A simulation method that evaluates different vehicle/road interactions is useful 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.

ACKNOWLEDGMENTS

The authors wish to express their gratitude to the Engineering Research Division of the University of Michigan Transportation Research Institute (UMTRI), in particular to Paul Fancher, Zevi Bareket, Thomas Gillespie, Chris Winkler and Robert Ervin for their technical support and friendship dedicated to Ms. Russo, from October/92 to April/94, when she was conducting research for her Ph.D. thesis, on which results this paper is based. In addition, we would like to thank CNPq, the National Council for Scientific and Technological Development, for providing Ms. Russo with a scholarship during her research at UMTRI and for supporting our expenses to participate in the Fourth ISHVWD.

REFERENCES

behavior. Department of Vehicle Dynamics, Institute of Road Vehicles TNO, Delft, Holand.


Oral presentation at the 73rd TRB Annual Meeting, Washington, D.C., USA.


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.
Rodotrem A-dolly
Swept path = 7.5 m

Rodotrem C-dolly
Swept path = 7.0 m

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

1 axle Semitrailer
Swept path = 8.0 m

Figure 9. 1 axle Semitrailer on a left curve.

1 axle Semitrailer
Swept path = 5.1 m

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

156 degree curve
$R = 30 \text{ m}$

Rodotrem A-dolly
Swept path = 5.4 m

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

156 degree curve
$R = 30 \text{ m}$

1 axle Semitrailer
Swept path = 5.3 m

Figure 15. 1 axle Semitrailer.

156 degree curve
$R = 30 \text{ m}$

Treminhão
Swept path = 5.1 m

Figure 16. "Treminhão".

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

1 axle Semitrailer
Swept path = 6.1 m

Figure 18. 1 axle Semitrailer.