Comparative study of software for road geometric design

Lopes, Emerson Cordeiro; Menezes, Raiane Rintielle Vaz; Silva, Taciano Oliveira da; Pitanga, Heraldo Nunes; Santos, Afonso de Paula dos; Ferraz, Antônio Santana

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Emerson Cordeiro Lopes
Universidade Federal de Viçosa, Brasil
emerson.ufv@gmail.br

Raiane Rintielle Vaz Menezes
Universidade Federal de Viçosa, Brasil

Taciano Oliveira da Silva
Universidade Federal de Viçosa, Brasil

Heraldo Nunes Pitanga
Universidade Federal de Viçosa, Brasil

Afonso de Paula dos Santos
Universidade Federal de Viçosa, Brasil

Antônio Santana Ferraz
Universidade Federal de Viçosa, Brasil

Abstract:

This study compared the results obtained in developing a highway geometric design through the use of the softwares *TCP-MDT*, *AutoCAD Civil 3D* and *TopoGRAPH*. For this, the results were compared taking into account the technical recommendations of the National Department of Transportation Infrastructure (DNIT). The parameters evaluated were: modeling with contour lines; horizontal layout; vertical layout; superwidth; superelevation; and earth moving calculation. In the digital modeling, small differences were found in the contour, both in the mesh and the final product. There was no difference in the results for the horizontal layout between softwares. For vertical layout, there was a slight difference in the terrain profile possibly caused by the digital modeling of the programs. In superwidth, *TopoGRAPH* and *TCP-MDT* were the ones that best met the Brazilian standards. To calculate the superwidth, the best results were found with *AutoCAD Civil 3D* and *TCP-MDT*. Besides, there were small differences between the respective land volumes computed by the softwares, which may have larger magnitude for a project with greater longitudinal extension. Therefore, it is concluded that the choice of the software can affect since the technical parameters until the planning of the work, with implications on the overall cost.

Keywords: road geometric design, softwares, earthwork.

Introduction

The geometric design of a road has the objective of connecting two or more locations appropriately, that is, observing the conditions of safety and comfort of the users and the technical-economic conditions of the region where the road will pass (Antas, Álvaro, Gonçalo, & Lopes, 2010). In a road, the horizontal and vertical alignments are composed by a set of straight sections (tangents) connected by horizontal and vertical

curves, and the cross sections provide valuable information about earth movements volumes in cut and fills (Pontes Filho, 1998; Pimenta & Oliveira, 2004).

For the design of a geometric road, the following elements must be represented: width of tracks; traffic lanes number and shoulder; drainage devices; tangent lengths; ramps; radius of curves; superelevation; superwidth; visibility distance; among others. Its design requires a structured sequence of routines whose purpose is to define the geometric parameters to be adopted for the road according to the design speed and the type of relief (*Departamento Nacional de Estradas de Rodagem* [Dner], 1999). With this information, it is possible to define the track geometry. Informatics contributes greatly to streamline the road geometric design and facilitate numerous simulations of layout alternatives, quickly and accurately, making possible the evaluation of the geometric design from the point of view of the driver (Han, Middleton, Muzyczka, Minty, & Clayton, 2005, Kühn & Jha, 2006; Kühn & Hendrick, 2010; Kühn, Volker, & Kubik, 2011; Winner, Ancochea, & Graupner, 2012; Figueira, Larocca, Quintanilha, & Kabbach Jr., 2014).

Road geometric designs gain technical quality when executed in specific computer programs. This allows for increased productivity and cost reduction through rapid simulations of different scenarios, minimizing errors and improving the final quality of the project (Van Der Horst & Hogema, 2011; Figueira et al., 2014).

In several computer programs developed for planning roads, three-dimensional visualization technologies have been used, these have contributed not only to the evaluation of the impact of a highway project in the region of its surroundings, but also in the development and study of the elements of the own geometric design (Hassan, Easa, & Halim, 1998; Easa & Dabbour, 2005; Han et al., 2005; Figueira et al., 2014; Lopes et al., 2016).

However, each geometric design presents different parameter requirements and elements depending on the location and region to be executed. The software used for road geometric designs must take into account this local difference and present results compatible with the technical standards used (Dner, 1999; American Association of State Highway and Transportation Officials [Aashto], 2011).

Considering the large number of computer programs available on the market for the geometric design of highways, and the several characteristics regarding the geometric parameters presented by them, this study aims to compare the results of the geometric design of a road stretch using three different computer programs, which provided information about the main differences for results obtained with respect to the geometric parameters.

Material and methods

For the present study, was used an area of approximately 13 hectares in the province of Malaga, located in the Southern Autonomous Community of Andalusia, Southern Spain. The area was selected because of the existence of a road geometric design performed through a software called *TCP-MDT* widely used in Spain and in other European countries, provided by *Aplitop Surveying and Civil Engineering Solutions*. This area is close to the municipality of Ardales, next to the A-357 Highway, whose central coordinates are 36° 53' 30" N and 04° 51' 00" W, located between a paved highway and an unpaved road, as shown in Figure 1. The region is classified as mountainous terrain, with sharp longitudinal and transverse variations in elevation.

Digital elevation model and computer programs used

A Digital Elevation Model (MDE) was used in DWG (Autodesk's Design Web Format), provided by the company *Aplitop Surveying and Civil Engineering Solutions*. The computer programs used were the following: *TCP-MDT*, developed by *Aplitop S.L.*; T*opoGRAPH 98 SE*, developed by *Char*Pointer*; and *AutoCAD*

CIVIL 3D version 2016 developed by *Autodesk*. These computer programs were selected because they present differentiated attributes of engineering for the geometric design of roads and are used in different regions.

Methods

The technical parameters for simulation of the geometric design followed the original design made available by Aplitop Surveying and *Civil Engineering Solutions*, performed in Spain. In all the aforementioned computer programs, the technical characteristics and parameters were the same, as shown in Table 1, 2, 3 and 4.
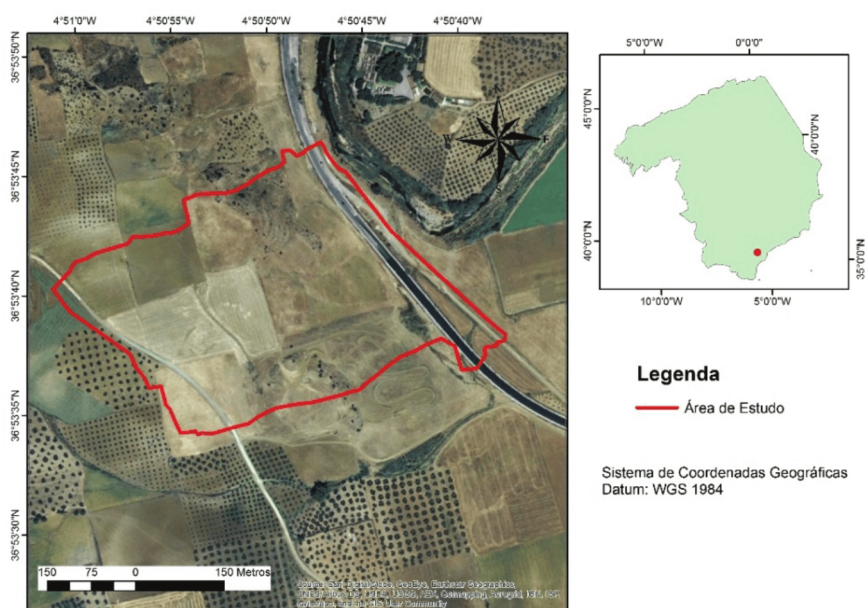

FIGURE 1.
Study area.

TABLE 1.
Technical parameters used in road geometric design.

Design parameters	
Parameters	Rigid, non-articulated commercial vehicles (CO)
Design speed	40.00 km hour^{-1}
Maximum superelevation	4.00%
Maximum ramp	8.00%
Stopping sight distance	42.00 m
Minimum tangent	40.00 m

TABLE 2.
Parameters of horizontal curves.

Horizontal curves	Notable points	Type	Azimuth	Radius (m)	Development (m)
P_i	Beginning	Straight	88° 46' 01,000"	-	25.00
C_1	PC	Circular Curve	88° 46' 01,000"	111.25	51.284
	PT	Straight	115° 10' 43,194"	-	55.00
C_2	TS – SC	Spiral	115° 10' 43,194"	variable	20
	SC – CS	Circular Curve	102° 43' 23,014"	46.00	48.00
	CS – ST	Spiral	42° 56' 10,172"	variable	20.00
	ST – PC_3	Straight	30° 28' 50,002"	-	90.00
C_3	PC_3	Circular Curve	30° 28' 50,002"	56.00	47.00
	PT_3	Straight	78° 34' 05,108"	-	46.970
P_f	End	-	78° 34' 05,108"	-	-

TABLE 3.
Parameters of vertical curves.

Stakes	Notable point	Quota (m)	Radius (m)	Ramp (%)
0 + 0.00	Beginning	365.999	-	0.432
0 + 14.987	PCV_1	366.064	744.109	-
3 + 12.028	PTV_1	364.121	-	-7.252
4 + 12.028	PCV_2	362.671	604.742	-
7 + 00.840	PTV_2	361.107	-	0.837
7 + 10.840	PCV_3	361.191	616.841	-
10 + 01.297	PTV_3	359.548	-	-7.362
14 + 16.398	PCV_4	352.547	1076.64	-
20 + 03.254	End or PTV_4	350.000	-	2.583

TABLE 4.
Technical parameters of the type section used in the
geometric designs of the road section under analysis.

Type section	
Rolling track width	7.00 m
Traffic band bulging	2.00%
Sidewalk width	2.00 m
Curb height	0.20 m
Ditch	0.40 m in horizontal direction (X)
	0.15 m in vertical direction (Y)
Landfill slope	3/2 [3 in horizontal direction (X) and 2 in vertical direction (Y)]
Cutting slope	2/3 [2 in horizontal direction (X) and 3 in vertical direction (Y)]
Berm height and width	2.00 m

Table 2 and 3 show, respectively, parameters of horizontal and vertical curves.

The type section of the designed road presented the characteristics, illustrated in Figure 2 and detailed in Table 4.

Steps for geometric design

The elaboration of the geometric design of the road proposed and analyzed consisted of the following steps:
- horizontal layout;
- vertical layout;
- superwidth and superelevation; and
- earth movement volume.

Finally, from the results obtained with the analyzed computer programs, they were compared to each other, in function of the standards contained in the technical specifications for road geometric design of the National Department of Transportation Infrastructure, previously represented by the National Department of Roads (Dner, 1999). In view of the above, it was possible to analyze the differences between the softwares in dimensioning the main geometric elements of the proposed road.

Results and discussion

For definition of the geometric elements of the projects developed by the softwares analyzed, it was noticed that the triangulations of the altimetric points of the relief in the study area did not coincide, although the Delaunay triangulation method (TIN) was used for the three computer programs (Figure 3).

The differences may be in the algorithms used to implement this method of triangulation and, consequently, in the interpolation used on this triangulation, since this can insert an uncertainty at the estimated point. Therefore, it is important to know the algorithms implemented in these interpolators that induce to the least error, and consequently, to a better result for calculations of the design elements and a better projection of earth movement volumes of cut and fill (Mazzini & Schettini, 2009; Lopes et al., 2016). According to Botsch, Kobbelt, Pauly, Alliez, and Levy (2010), the algorithms in the different softwares can generate models with badly sampled, redundant vertices or triangles with incoherent shapes, providing contours that do not reproduce the field reality. However, it was observed by Burrough and Mcdonnell (1998), when there is much field information, most interpolation methods produce similar results. In the computer programs analyzed, as a result of the triangulation, coherent contours were generated, except in some places in the horizontal plane, as shown in Figure 4.

In order to construct the horizontal layout of the proposed and analyzed road, the results were similar for the three softwares, that is, the results of stakes, angles and tangents were similar. By analyzing the profiles generated in the three computer programs through an overlap, a small difference (highlighted by an arrow in Figure 5) was observed, possibly caused by differences in triangulations (interpolation method) used in terrain modeling.

The vertical concordances did not present significant differences, with a mean of 0.05 m separation between the results of the analyzed softwares, without variations that could compromise the proposed geometric designs.

In the calculation of superwidth, the computer programs *TopoGRAPH* and *TCP-MDT* approached the values recommended by Dner (1999). The *AutoCAD Civil 3D* software presented values lower than those recommended in 20 cm, considering the recommendations prescribed by Aashto (2011). The designer should be aware of these values, because the analyzed softwares use different references, implying different results for the same parameter examined, as presented in Table 5.
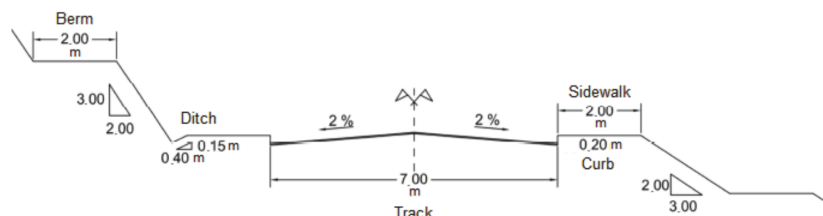

FIGURE 2.
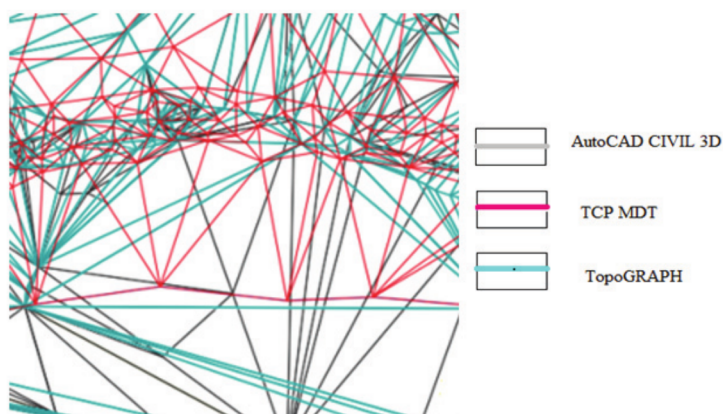Components of the cross section of the proposed track.

FIGURE 3.
Overlap of triangulations generated by the analyzed computer programs.
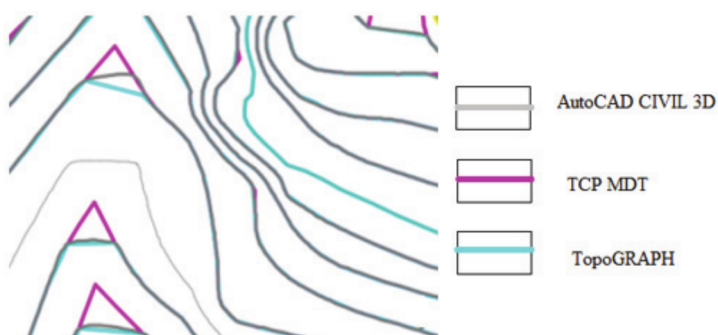

FIGURE 4.
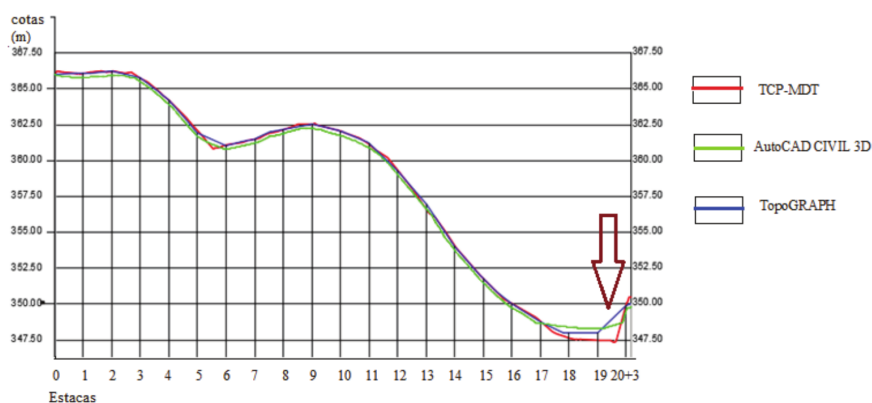Overlap of contours resulting from triangulations performed in the analyzed computer programs.

FIGURE 5.
Visualization of the overlap of the longitudinal profiles generated by the analyzed computer programs.

TABLE 5.
Values of superwidth determined by the analyzed computer
programs and the reference value of Dner (1999) .

Horizontal curves	Dner	Computer programs		
		TopoGRAPH	AutoCAD Civil 3D	TCP-MDT
C_1	0.80 m	0.80 m	0.60 m	0.80 m
C_2	1.60 m	1.50 m	1.40 m	1.76 m
C_3	1.40 m	1.30 m	1.20 m	1.40 m

According to Dner (1999), the values of superwidth to be considered in geometric design should be rounded to multiples of 0.20 m and limited to the minimum value of 0.40 m. The current Brazilian technical standards consider that values of superwidth smaller than this limit do not result in relevant practical effects, and may be disregarded. Nevertheless, Aashto (2011) adopts a minimum threshold of 0.60 m, and suggests the exemption of the parameter superwidth for horizontal concordances with radii of curves superior to 250.00 m, in geometric designs with normal width of traffic band of 3.60 m.

In the calculations to obtain values of superelevation, there was no significant difference for the distribution in plan. In the analyzed softwares, was adopted the Dner (1999) distribution criterion, which was also used by Aashto (2011). This consists of stipulating a value proportional to the transition length of the superelevation, so as to maintain the same superelevation ramp from the beginning with bulging up to where the maximum design superelevation is reached.

However, for the calculation of the maximum design superelevation adopted in the circular sections, the computer program *TopoGRAPH* did not consider the parabolic distribution recommended by Dner (1999), in the horizontal curve C_1. This function considers the minimum radius, the superelevation rate, and the transverse friction coefficients that decrease gradually and simultaneously, up to the radius value of the adopted design (Pontes Filho, 1998; Dner, 1999; Aashto, 2011). This leads to overestimated transverse slopes in the track, compromising the safety and comfort of users in the curve of the designed roadway. For the other two softwares analyzed, the values obtained were close to those recommended by Dner (1999). The difference occurred as a function of the determination of the minimum design radius adopted by each computer program, which depends on the values of the design speed, maximum superelevation and the coefficient of transverse friction (Pontes Filho, 1998; Dner, 1999; Pimenta & Oliveira, 2004; Aashto, 2011). Values of superelevation calculated by the analyzed computer programs, as well as the reference values of Dner (1999) are listed in Table 6.

In the analysis of earthmoving projects, according to the volume values of material to be moved in the geometric designs of the route proposed and analyzed, the computer program *TopoGRAPH* generated a greater cumulative volume of cut. The *TCP-MDT* software generated a larger cumulative volume of fill. The explanation for this difference is in the terrain modeling. Although the three computer programs analyzed used a TIN model, there is a difference in the triangulation criterion, as shown in Figure 3. This difference may overestimate or underestimate the values of land movement due to altimetric values of the model that are not associated with the actual surface of the terrain (Lopes et al., 2016). Table 7 presents the volumes of cut and fill obtained in the earthmoving projects of the proposed road stretch using the three computer programs analyzed.

The differences in values of cumulative volume of cut and fill presented in Table 7 can be even more significant with the increase in the extension of the paving work of the projected road section. In the values presented in Table 7, the length used for this comparative analysis was approximately 400 m. To minimize this problem, Burrough and Mcdonnell (1998) recommend that, regardless of the computer program used for topographic data processing, the collection of such data should contain as much information as possible about the terrain, reducing differences with respect to the interpolators used by the softwares, making the results more coherent with the field reality

Conclusion

The comparative analysis of the geometric designs developed by *TCP-MDT*, *AutoCAD Civil 3D* and *TopoGRAPH* allowed to conclude that:
- There was no significant difference in the values found for the horizontal and vertical concordances;
- The *TopoGRAPH* and *TCP-MDT* were those that approached the values of the superwidth;
- There was no significant difference in the distribution of superwidth between softwares;

- The *TopoGRAPH* did not consider the distribution of the maximum parabolic superelevation as a function of the radius;
- There were small differences in the cumulative volumes of earth moving, which can become larger with the increase of the longitudinal length of the work.

TABLE 6.
Values of superelevation determined for circular curves by the
analyzed computer programs and the reference value of Dner (1999).

Horizontal curves	Dner (1999)	Computer programs		
		TopoGRAPH	*AutoCAD Civil 3D*	*TCP-MDT*
C_1	3.00%	4.00%	3.20%	3.20%
C_2	4.00%	4.00%	4.00%	4.00%
C_3	3.80%	4.00%	4.00%	3.80%

TABLE 7.
Estimated cut and fill volumes for the proposed earthworks projects
of the proposed road, based on the computer programs analyzed.

Computer programs	Cut volume (m³)	Fill volume (m³)
TopoGRAPH	4646.22	2130.47
TCP-MDT	4330.01	2392.76
AutoCAD Civil 3D	4340.06	2118.96

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