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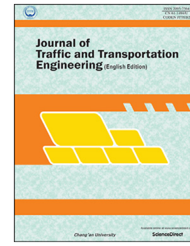

Original Research Paper

Guidelines for roundabout circulatory and entry widths based on vehicle dynamics

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HIGHLIGHTS

- A universal articulated vehicle's 2D steerability dynamic model is developed.
- The speed mode of long-wheelbase vehicle affects the swept path on a roundabout.
- The entry roadway width is estimated using vehicle dynamics simulation model.

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ABSTRACT

Current guidelines for roundabout circulatory roadway width are based on a static method that does not consider circulatory speed. In addition, the roundabout entry width is based on practical experience. This paper presents a method for determining the circulatory and entry widths based on a two-dimensional vehicle dynamics model that involves a system of differential equations of curvilinear motion. The method considers the interactions between a vehicle and road geometric elements, including tire sideslip, vehicle weight, vehicle speed, and vehicle stability. Three design vehicles are considered: intermediate semitrailer (WB-12), interstate semitrailer (WB-20), and city transit bus (CITY-BUS). Design guidelines for the required circulatory width are established for different circulatory speeds (0–60 km/h) and different inscribed circle diameters (30–80 m). To simplify the guidelines, for each design vehicle and for each inscribed circle diameter (ICD) the regression model of circulatory roadway width as a power function of circulatory speed was fitted. Guidelines for entry width were also established for typical conditions. The results show the efficiency of the proposed method which provides smaller values of circulatory roadway widths than those of current methods. The difference ranges from 0.4 to 0.6 m for CITY-BUS, 0.7–1.0 m for WB-12, and 1.3–2.0 m for WB-20. The proposed guidelines would be useful in case of spatial restrictions.

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1. Introduction

Geometric parameters of roundabouts are governed by the maneuvering requirements of the largest vehicles expected to travel through the roundabout. At roundabouts, the circulatory roadway width should accommodate the design vehicle (Rodegerdts et al., 2010). Roundabout circulatory and entry widths are also important inputs for sight distance analysis (Easa, 2017a; b). Appropriate vehicle-turning templates or computer-aided design (CAD)-based computer programs are normally used to determine the swept path of a design vehicle throughout the turning movements. Usually the left-turn movement is the critical path for determining the circulatory roadway width. According to the AASHTO (2011), a minimum clearance of 0.6 m (2 ft) should be provided between the outside edge of the vehicle's tire track and the curb line. Gingrich and Waddell (2008) presented the required circulatory width for various ICDs for different design vehicles. In some cases, particularly where the ICD is small or the design vehicle is large, the turning requirements of a design vehicle may result in unsafely constricted circulatory roadway for passenger vehicles that move behind on minimum radius. In such cases, the circulatory roadway width can be reduced and a truck apron provided outside of the central island mountable curb can be used to accommodate larger vehicles.

The best known approach for swept path determination is that of the society of automotive engineers (SAE) (Kizas, 1997). Using this approach, the parameters of circular movements for single and multiple unit vehicles have been established. This approach is static in nature and based mainly on geometric relations for a vehicle traveling along the curve path without considering the effect of vehicle speed. Thus, currently the circulatory width is determined using vehicle geometric interpretation either by the trigonometric functions of SAE method or using CAD procedures. The effect of vehicle dynamics behavior on the swept path at roundabouts has not been considered in previous research.

The purpose of this paper is to develop guidelines for roundabout circulatory and entry widths based on vehicle dynamics that consider vehicle speed at the steady–steady motion. The next sections describe the design vehicles and the vehicle dynamics-based model. Model validation and design guidelines for circulatory and entry widths are then presented, followed by the conclusions.

2. Design vehicles

An important factor in roundabout design is the need to accommodate the largest motorized vehicle likely to use the roundabout. The turning path requirements of this vehicle, termed design vehicle, dictate the circulatory and entry widths of roundabouts. The choice of design vehicle varies depending on the approach roadway types and the surrounding land use characteristics (Mills et al., 2011). In general, larger roundabouts are expected to accommodate large vehicles. However, in some cases, land constraints may limit the ability to accommodate large trailer semi-trailer combinations, while achieving adequate deflection for small vehicles (FHWA, 2010). In such cases, a truck apron may be used to provide additional traversable area around the central island. However, truck aprons provide a lower level of operation than standard non-mountable islands and are used only when there is no other means of providing adequate deflection for the design vehicle.

Three design vehicles with long wheelbase are considered in this study: (1) light two-unit truck (WB-12), (2) heavy tractor-semitrailer truck (WB-20), and (3) standard single-unit bus (CITY-BUS). The basic proportions and overall dimensions of the vehicles are governed by AASHTO (2011) and are shown in Fig. 1. Obviously, WB-12 and CITY-BUS are most typical for urban roundabouts, while WB-20 is more critical for rural roundabouts. According to the North American standards the vehicles' gross weights are taken as: 32.1 t for WB-12, 40 t for WB-20, and 18 t for CITY-BUS (Infrastructure and Transportation Motor Carrier Division, 2016). Other information needed for simulation includes gross weight (Ontario Ministry of Transportation, 2013), gross weight distribution among axles, curb weight (Wikipedia, 2016), and axle distribution (American Public Transportation Association, 2014). The weight is regulated by the vehicle weights and dimensions guide (Saskatchewan Regulations, 2010; Road Safety Authority, 2013), which establishes the requirements for vehicle axle-load limits (FHWA, 2000).

3. Vehicle dynamics-based model

The circulatory roadway width is determined using vehicle swept path. To understand the phenomenon of swept path, it is essential to appreciate the significance of various parameters affecting the turning behavior of a vehicle. The amount of swept path varies directly with the wheelbase length of a unit and inversely with a radius of the turn through which the vehicle travels. The magnitude of swept path is also affected by the number and location of the articulation points on a vehicle, the length of the arc negotiated during the turn, and the speed of the vehicle.

The following assumptions are acceptable for vehicle dynamics models: (a) a vehicle is assumed as plane dynamics model, (b) the redistribution of longitudinal and transversal vertical reactions on vehicle wheels is neglected, and (c) the modeling of contact forces between the tire and the road is based on the simplified Pasejka's magic formula for pure tire's slip (Bakker et al., 1989; Pacejka, 2002).

3.1. *Model description*

Consider briefly the integration of motion equations, where an articulated vehicle is represented by two-dimensional (2D) dynamics model (Fig. 2). This dynamics model is different from the traditional system equations used in the state-space of the bicycle model for multiple unit vehicles. The basic idea of this dynamics model is to account of the total number of tires' contact points with a road surface and the use of the matrix technique to represent model components. The model uses a minimum amount of necessary