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Capacity-based calculation of passenger car equivalents using traffic simulation at double-lane roundabouts

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ABSTRACT

Calculation of passenger car equivalents for heavy vehicles represents the starting point for the operational analysis of road facilities and other traffic management applications. This paper introduces a criterion to find the passenger car equivalents that reflect traffic conditions at double-lane roundabouts, where the capacity is typically estimated for each entry lane. Based on the equivalence defined by the proportion of capacity used by vehicles of different classes, the criterion implies a comparison between the capacity that would occur with a traffic demand of passenger cars only and the capacity reached beginning from a demand with a certain percentage of heavy vehicles. A preliminary activity consisted of the comparison of the empirical capacity functions based on a meta-analytical estimation of critical and follow up headways, and simulation output data derived for a double-lane roundabout built in AIMSUN. The formulation of the calibration process as an optimisation problem enabled to minimize an objective function using the genetic algorithm tool in MATLAB®. A subroutine in Python implemented the automatic interaction with AIMSUN. Differently from methods that propose constant values for the passenger car equivalents, the results highlighted that the passenger car equivalents at double-lane roundabouts increased when the circulating flow increased, while a higher effect was expected when the traffic streams included a higher number of heavy vehicles.

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1. Introduction

1.1. Background on roundabouts

The geometric design of a modern roundabout is an iterative process which searches for a balance among design objectives including safety, capacity, accommodation of design vehicles, costs of construction, maintenance requirements, impacts and aesthetics. As product of a good design, the geometric features of the roundabouts have to provide speed control for the effects on traffic calming and injury prevention, and ensure consistency in the relative speeds among the conflicting traffic streams. Based on size and number of entry and circulating lanes, three categories of roundabouts are usually

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distinguished: mini roundabouts, single-lane roundabouts and multi-lane roundabouts. Due to smaller design vehicles and greater constraints of the built environment, the mini roundabouts require smaller outer diameters than single-lane and multi-lane roundabouts. Standards and guidelines used worldwide distinguish further roundabout categories within the single-lane and multi-lane roundabouts based on the key dimensions of geometric design; for instance, within the multi-lane roundabouts one can identify the double-lane roundabouts having a circulatory roadway that can accommodate two vehicles travelling side-by-side and double-lane entries and exits. However, geometric design and operations at double-lane roundabouts are more complex than single-lane roundabouts [1,2]. According to [3] traffic patterns and gap acceptance behaviour can influence capacity mechanisms and determine the efficiency of whatever roundabout. Design principles and best practices suggest that the number of entry, circulating and exit lanes of roundabouts should be limited to the minimum number that achieves the desired capacity, as well as safety and operating requirements for the projected future traffic volumes. To maximise the level of efficiency and safety during the early years of traffic operations, a single-lane roundabout may be the interim configuration, initially built to serve the near-term traffic volumes; the circulatory roadway and entries can be cost-effectively expanded within a horizon of 10 to 15 years from the present to accommodate the future traffic volumes [2]. In this regard, two alternative approaches have been proposed to convert an initial single-lane layout to a future double-lane roundabout [4]: one alternative requires building the full outside footprint and widening inward; in turn, the other alternative involves building the central island and splitter islands in the ultimate configuration and widening outward. Expansion from a single-lane roundabout to a double-lane roundabout can be driven by needs of higher capacity and improved traffic performances especially for urban roads and arterials [5]. It is noteworthy that the roundabouts that operate within their capacity may represent a favourable alternative to signalised control for closely spaced intersections, since they provide better operational performance in terms of stops, delays, vehicle queues between successive intersections, safety and pollutant emissions than signalised intersections. Roundabouts also offer significant safety benefits since remove some of the most serious conflict points [2,6]. Improved capacity at double-lane roundabouts is due to the continuously flowing nature of yielding only until a gap is available, versus waiting turns at a red light. However, the double-lane design produces patterns of conflict at entries with one or two conflicting traffic streams; this should be taken into consideration when analysts have to calculate entry capacity especially under heterogeneous traffic conditions and assess the different degrees of traffic functionality through level-of-service determinations.

1.2. Assumptions, objectives and paper structure

Despite the calculation of passenger car equivalents (PCEs) for heavy vehicles represents the starting point for the operational analysis of roads and intersections and other traffic management applications, very few studies have looked at the effect of heavy vehicles on traffic operations at double-lane roundabouts.

The paper aims to attain the following goals:

- introduction of a capacity-based criterion to assess the passenger cars equivalents that reflect the traffic conditions at double-lane roundabouts, where capacity is typically estimated for each entry lane;
- use of a traffic microsimulation model for calculation of the capacity functions at double-lane roundabout entries;
- calibration of microsimulation traffic model as an optimisation problem using genetic algorithm approach;
- calculation of the passenger car equivalents for the left and the right lanes at entries.

The research starts from the assumption that the highly curvilinear nature of the roundabout design has significant effects on the paths that heavy vehicles would travel; as a consequence, the interaction between the physical and performance characteristics of the heavy vehicles and the geometric features of the double-lane roundabouts produce higher impacts on traffic operations than other at-grade intersections. It is well known that the static and dynamic characteristics of heavy vehicles on various road entities make their impact on traffic performances quite different than the passenger cars: heavy vehicles can occupy more roadway space due to their size, take longer to accelerate and/or decelerate due to their horsepower and weight, and maintain greater spacing from a lead vehicle than a passenger car especially on grades; heavy vehicles can limit the forward field of vision of the drivers behind and they can affect in some way the driving abilities of drivers in front of them and/or in the adjacent lanes, and so on [7]. Differently from single-lane roundabouts - where vehicles coming from a one-lane entry face vehicles travelling anticlockwise on the one-lane circulatory roadway around the central island - a different scheme of conflict may occur at each entry lane of the double-lane roundabouts: entering vehicles may be accommodated on two lanes (i.e. the left entry lane and the right entry lane) and must give way to two circulating streams of vehicles travelling side-by-side on the circulatory roadway; but it is also true that, depending on traffic conditions, entering vehicles must give way to at least one of the two traffic streams travelling on the outer or the inner circulating lane of the circulatory roadway. Considering that the gap acceptance behaviour of drivers is strongly related to the possible schemes of conflict in front of the subject entry, a further assumption is typically done when entry capacity should be calculated [3,8,9]:

- the capacity of the right entry lane opposed by one circulating lane is calculated based on the traffic stream in the outer circulatory lane;
- the capacity of the left entry lane opposed by two conflicting lanes is calculated based on the two traffic streams that move through the roundabout side-by-side.

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