CETRA 2014

3rd International Conference on Road and Rail Infrastructure
28–30 April 2014, Split, Croatia

Road and Rail Infrastructure III

Stjepan Lakušić – **EDITOR**

Organizer
University of Zagreb
Faculty of Civil Engineering
Department of Transportation

CETRA[2014]
3rd International Conference on Road and Rail Infrastructure
28–30 April 2014, Split, Croatia

TITLE
Road and Rail Infrastructure III, Proceedings of the Conference CETRA 2014

EDITED BY
Stjepan Lakušić

ISSN
1848-9850

PUBLISHED BY
Department of Transportation
Faculty of Civil Engineering
University of Zagreb
Kačićeva 26, 10000 Zagreb, Croatia

DESIGN, LAYOUT & COVER PAGE
minimum d.o.o.
Marko Uremović · Matej Korlaet

PRINTED IN ZAGREB, CROATIA BY
"Tiskara Zelina", April 2014

COPIES
400

Zagreb, April 2014.

Proceedings of the
3rd International Conference on Road and Rail Infrastructures – CETRA 2014
28–30 April 2014, Split, Croatia

Road and Rail Infrastructure III

EDITOR
Stjepan Lakušić
Department of Transportation
Faculty of Civil Engineering
University of Zagreb
Zagreb, Croatia

ORGANISATION

CHAIRMEN

Prof. Stjepan Lakušić, University of Zagreb, Faculty of Civil Engineering
Prof. Željko Korlaet, University of Zagreb, Faculty of Civil Engineering

ORGANIZING COMMITTEE

Prof. Stjepan Lakušić
Prof. Željko Korlaet
Prof. Vesna Dragčević
Prof. Tatjana Rukavina
Assist. Prof. Ivica Stančerić
dr. Maja Ahac
Ivo Haladin
dr. Saša Ahac
Josipa Domitrović
Tamara Džambas

All members of CETRA 2014 Conference Organizing Committee are professors and assistants of the Department of Transportation, Faculty of Civil Engineering at University of Zagreb.

INTERNATIONAL ACADEMIC SCIENTIFIC COMMITTEE

Prof. Vesna Dragčević, University of Zagreb
Prof. Isfendiyar Egeli, Izmir Institute of Technology
Prof. Rudolf Eger, RheinMain University
Prof. Ešref Gačanin, Univeristy of Sarajevo
Prof. Nenad Gucunski, Rutgers University
Prof. Libor Izvolt, University of Zilina
Prof. Lajos Kisgyörgy, Budapest University of Technology and Economics
Prof. Željko Korlaet, University of Zagreb
Prof. Zoran Krakutovski, University of Skopje
Prof. Stjepan Lakušić, University of Zagreb
Prof. Dirk Lauwers, Ghent University
Prof. Zili Li, Delft University of Technology
Prof. Janusz Madejski, Silesian University of Technology
Prof. Goran Mladenović, University of Belgrade
Prof. Otto Plašek, Brno University of Technology
Prof. Vassilios A. Profillidis, Democritus University of Thrace
Prof. Carmen Racanel, Technical University of Civil Engineering Bucharest
Prof. Tatjana Rukavina, University of Zagreb
Prof. Andreas Schoebel, Vienna University of Technology
Prof. Mirjana Tomičić-Torlaković, University of Belgrade
Prof. Audrius Vaitkus, Vilnius Gediminas Technical University
Prof. Nencho Nenov, University of Transport in Sofia
Prof. Marijan Žura, University of Ljubljana

CETRA[2014] 28–30 April 2014, Split, Croatia
3rd International Conference on Road and Rail Infrastructure

PERFORMANCE CHECKS AS PREREQUISITES FOR ENVIRONMENTAL BENEFITS OF ROUNDABOUTS

Saša Ahac, Tamara Džambas, Ivica Stančerić, Vesna Dragčević
University of Zagreb, Faculty of Civil Engineering,
Department for Transportation Engineering, Croatia

Abstract

Environmental benefits of roundabouts are well known: roundabouts help reduce fuel consumption and vehicle emissions and also require less maintenance than traditional intersections with traffic signals, providing a reduction in energy use and costs. The prerequisite for these assets is smooth speed profile through the roundabout, which is achieved by ensuring the clarity of the situation for approaching drivers, visibility between road users, comprehensibility of traffic operations and appropriate accommodation of the design vehicles. These requirements are met through quality roundabout design. Roundabout design is an iterative process that consists of identification of initial design elements, performance checks (definition of fastest path, offtracking geometry and visibility tests) and final design details. The development of reliable software for vehicle movement simulations simplified these performance checks, and led to the exploration of new possibilities for roundabout design, which represents a logical step in the area of road traffic engineering research.
In Croatia the positive aspects of roundabouts are often annulled due to their inappropriate design. Namely, performance checks that should ensure proper speed profile and required intersection visibility are usually ignored. The main reason for this stems from the fact that there are no official national guidelines or regulations for the roundabout design. In this paper key elements for successful roundabout design will be shown, based on performance checks conducted by vehicle movement simulation software. Proposed instructions could be used for the development of national guidelines for roundabout design.

Keywords: roundabout design, offtracking control, fastest path, visibility

1 Introduction

In the past two decades roundabouts became one of the most popular choices for intersections in suburban and urban areas in Croatia: according to the available data, in the year 2008 there were more than 130 roundabouts, 85 of which were located in urban and suburban areas [1]. Their application can result in a number of benefits, which include not only the improved intersection capacity and safety, but also lower maintenance costs and less air pollution. Numerous studies showed that application of modern roundabouts can help reduce the excessive emissions and fuel consumption associated with idling time, acceleration and deceleration of vehicles that usually occur on traditional intersections with traffic signals, as well as noise pollution in the vicinity of road intersections Reported average reductions varied from 21 to 42% in emissions of carbon monoxide, 16-59% in emissions of carbon dioxide, 20–48% in emissions of oxides of nitrogen, 18–65% in emissions of hydrocarbons and 4 dB(A) in noise emission [2, 3].

Environmental benefits of modern roundabouts are directly linked to the quality of their design. Namely, in order to achieve the required reduction in vehicular emissions, the speed profile through the roundabout must be as smooth as possible [4, 5, 6] This can be ensured in the roundabout's designing phase by conducting performance checks that include offtracking geometry, definition of fastest path, and visibility tests.
Unfortunately, in Croatia the positive environmental aspects of roundabouts are often annulled due to their inappropriate design. Namely, performance checks that should ensure proper speed profile and required intersection visibility are usually overlooked. The main reason for this stems from the fact that there are no official national regulations for the roundabout design. Because of that, in this paper focus is set to display the key elements of roundabout performance checks described in several design guidelines that are applied in countries with lasting tradition of roundabout design and construction.

2 Roundabout performance checks

Roundabout design is an iterative process that consists of identification of initial design elements, performance checks (which include definition of fastest path, offtracking geometry and visibility tests), and final design details. Roundabout design in Croatia is, due to the lack of official guidelines, usually carried out according to the guidelines of the Institute of Transport and Communications [7], German guidelines [8], Austrian guidelines [9] and/or Swiss norms [10]. These guidelines and norms do not include detailed instructions for all performance checks, particularly for the speed checks, i.e. definition of fastest path, which is essential for safe and functional roundabout design. Because of that, the key elements of roundabout performance checks represented in documents that are not commonly referred to by Croatian designers, namely FHWA's Roundabouts: An Informational Guide [11], and Serbian regulations on road and intersection design [12], are also described.

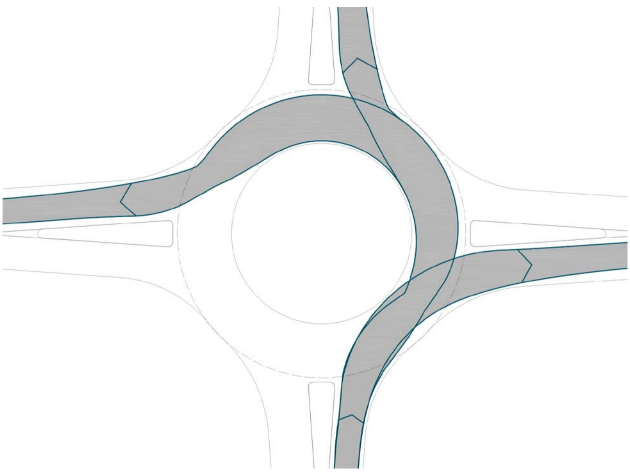

Figure 1 Offtracking control at roundabouts

2.1 Offtracking control

In order to secure safe and unobstructed traffic flow on any type of intersection, it is crucial to investigate the design vehicle's ability of passing through the intersection. This in ensured by means of offtracking control. In accordance with [8, 9, 10, 12], a drivable roundabout offtracking control should meet the following requirements:

· design vehicle selected for this performance check must correspond to the intersection position in the road network,
· offtracking control must be conducted for all approaches on roundabout and for all three directions (straight, right and left, as shown in Figure 1.),
· the safety lateral width of at least 0.25 m must be ensured along all elevated curbs.

In the past, offtracking control was usually conducted by means of design vehicle's templates. Issues concerning the usability of these templates for the said performance check on modern roundabouts include following limitations. Templates are given for limited number of design vehicles, turning radii, scales and steering angles and can be applied only for offtracking control on right turns. Because of that, offtracking control on modern roundabouts should be conducted by means of verified swept path analysis software.

2.2 Speed analysis

Another key performance check of a roundabout concept is speed analysis. According to [11, 12], this analysis is composed from following steps:
· construction of the fastest path through the roundabout for each approach,
· definition of five critical path radii for each approach (Figure 2) and
· vehicle speed estimation based on speed-radius relationship (Figure 3).

Fastest path is defined as the smoothest, flattest path possible for a single vehicle, in the absence of other traffic and ignoring all lane markings. The fastest path is drawn for a vehicle traversing through the entry, around the central island, and out the relevant exit [11, 12]. It can be drawn by hand, or constructed by means of CAD software, using 3rd degree splines (piecewise polynomials of 3rd degree with function values and 2nd derivatives that agree at the points where they join). For the purpose of speed analysis on roundabouts, fastest path is drawn with safety lateral width of 1.5 m along all elevated curbs.

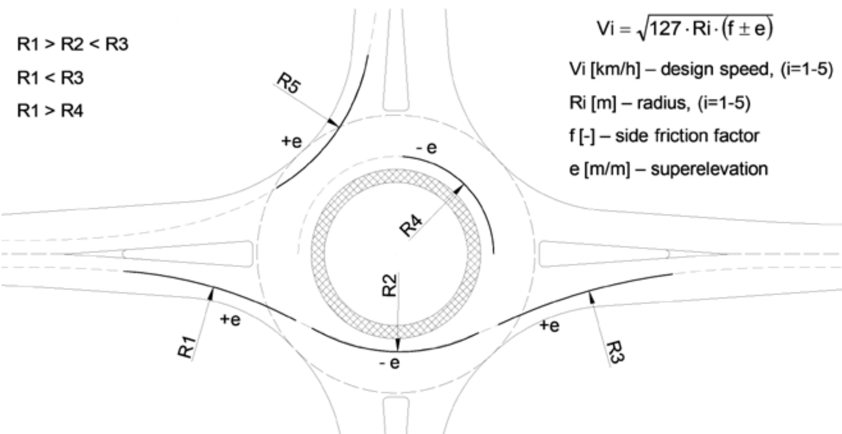

Figure 2 Fastest path and five critical path radii

After sketching the fastest path, the minimum radii are measured using suitable curve templates or by replicating the path in CAD and using it to determine the radii. Vehicle speed estimation is based on speed-radius relationship, which is described in [11, 12 13] and shown on Figure 2.
In order to achieve required entry (V1, V5), circulating (V2, V4), and exit speeds (V3), appropriate critical radii relationships for each approach must be achieved. Entry path radius (R1)

must be larger than circulating path radii (R2 and R4), but at the same time smaller than exit path radius (R3); also, circulating path radius (R2) must be smaller than exit path radius (R3). In addition to appropriate (maximum) speeds, speed checks should consider the speed differential between conflicting traffic movements. According to [11], in order for vehicles to safely negotiate the roundabout, the maximum speed differential between movements should be approximately 15 to 25 km/h, while according to [12] this value should be approximately 10 to 20 km/h. The predicted speed values are used to assess a roundabout's safety performance and are used in the intersection and stopping sight distance computations.

2.3 Visibility

An important aspect of roundabout design is the provision of adequate sight distance for all approaches. To safely negotiate the roundabout the driver must clearly perceive and understand the permitted manoeuvres before reaching the intersection – drivers approaching the roundabout should be able to recognize the main canalization features of the roundabout (the central island, raised splitter islands) and slow down to the appropriate speed [14].

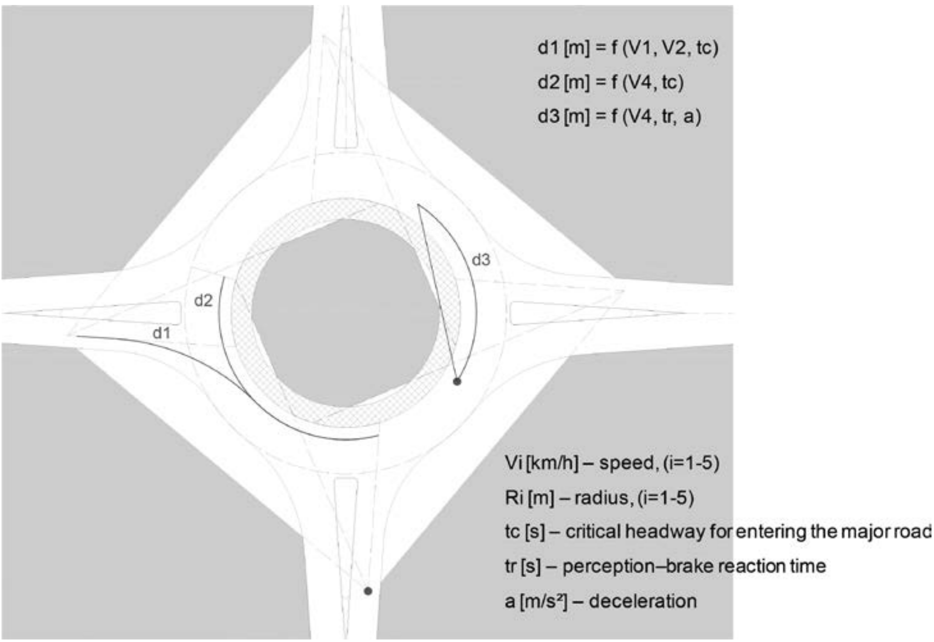

Figure 3 Fields of vision on roundabouts

In order to provide the adequate sight distance, visibility checks (that include investigation of stopping sight distance on every approach and on circulatory roadway, and also intersection sight distance for each approach) should be conducted during the roundabout design. Required sight distances on the approaches are directly related to predicted speed values on fastest paths through the analysed roundabout (V1, V2 and V4), critical headway for entering the major road (tc), while sight distance on circulatory roadway is related to predicted speed on circulatory roadway (V4), perception-brake reaction time (tr) and deceleration (a) [11, 13]. Visibility checks result in sight lines that should be overlaid onto a single drawing, as shown in Figure 3. This graphic presentation of fields of vision on roundabouts can be used as guidance on the appropriate locations for various types of visual obstructions. Namely, excessive intersection sight distance can lead to higher speeds that reduce intersection safety, so in

order to restrict sight distance to the (recommended) minimum landscaping or other visual obstructions are used [11].
The white zones in Figure 3 are areas that should be clear of large obstructions that may impede driver's line of sight. In the areas with grey solid shading, especially within the central island, visual obstructions may be used to break the forward view for through vehicles, which should contribute to speed reductions and reduction of oncoming headlight glare [11].

3 Speed profiles on roundabouts

Numerous studies have shown that all roundabouts have an influence zone over which they exert a significant speed effect, forcing the driver to decelerate from cruise (free flow) speed to circulating speed and to accelerate back to cruise speed when leaving the intersection. This influence zone usually extends from the centre of the intersection to each intersection leg for about 80 to 100 m in total [15, 16].
Based on the extensive empirical measurements, three distinct speed profiles for a vehicle moving through a single lane roundabout were identified, which cover all combinations of traffic flow conditions [4]:

- an unstopped vehicle that approaches the roundabout, decelerates to negotiate the roundabout circular roadway and then accelerates as it exits the roundabout,
- a vehicle experiencing a single stop, in which there is a full deceleration to a stop at the yield line, while waiting for an acceptable gap in the circulating lane, then accelerating to the circulating and cruise speeds, and
- a vehicle that experiences multiple stops on the approach as it moves up the queue.

It was also found that high speed differential between circulating and cruising speed will result in excessive accelerations and decelerations, with accompanying inconsistent driver behaviour, increase in emissions and fuel consumption [4, 16].
It was established that the emissions increase in following situations:

- when queuing conditions prevail as conflicting traffic increases,
- at low conflicting traffic volumes, when the acceleration rate back to cruise speed is high, and
- at larger differences between the cruise and circulating speeds [4].

Critical sections on a single lane roundabout in terms of their relative impact on total emissions is the section on which vehicles experience short stop and go cycles (in front of circulating traffic yield line) and the section on which vehicles accelerate back to cruise speed [4]. Because of that, it is important to ensure the appropriate speed differential between consecutive geometric elements through quality roundabout design. As mentioned earlier, speed checks should ensure that relative speeds between conflicting traffic streams and between consecutive geometric elements are minimized to 20 (25) km/h. Speed checks must also ensure that relationships between predicted speeds on fastest paths through the roundabout are as follows:

- entry speed (V1) must be smaller than exiting speed (V3),
- circulating speed (V2, V4) must be smaller than entry speed (V1),
- maximum entry speed (V1, V5) should be smaller or equal to 40 km/h.

4 Conclusions

Environmental benefits of modern roundabouts are directly linked to the quality of their design. In order to achieve the required reduction in vehicular emissions, the speed profile through the roundabout must be as smooth as possible, which can be ensured in the roundabout's designing phase by conducting performance checks (analysis of offtracking geometry, definition of fastest path, and visibility tests).

In Croatia the positive environmental aspects of roundabouts are often annulled due to their inappropriate design: performance checks that should ensure proper speed profile and required intersection visibility are usually overlooked. The main reasons for that are the facts that there are no official national regulations for the roundabout design, and that design is usually carried out according to the guidelines and/or norms which do not include instructions for all required performance checks.
Apart from roundabout design guidelines and norms that are usually referred to by Croatian designers, future official national regulations on roundabout design should include performance checks described in FHWA's Roundabouts: An Informational Guide and/or Serbian regulations on road and intersection design, which are presented in this paper. Also, in order to ensure the required environmental benefits of roundabouts, described performance checks should result in smooth speed profiles and minimized relative speeds between conflicting traffic streams and between consecutive geometric elements (to maximum 25 km/h).

References

[1] Legac, I., Pilko, H. & Šubić, N.: Introduction on roundabouts in Croatia – preliminary experiences, 16th IRF World Congress, Lisboa, 2010

[2] Hydén, C., Várhelyi, A.: The effects on safety, time consumption and environment of large scale use of roundabouts in an urban area: a case study, Accident Analysis and Pre6ention 32, 11–23, 2000

[3] Mandavilli, S., Russell, E.R., Rys, M.J.: Impact of Modern Roundabouts on Vehicular Emissions, Proceedings of the 2003 Mid-Continent Transportation Research Symposium, Ames, Iowa, USA, 2003

[4] Coelho, M.C., Farias, T.L., Rouphail, N.M.: Effect of roundabout operations on pollutant emissions, Transportation Research Part D: Transport and Environment, Volume 11, Issue 5, 2006

[5] Chamberlin, R., Swanson, B., Talbot, E., Dumont, J., Pesci S.: Analysis of MOVES and CMEM for evaluating the emissions impacts of an intersection control change, paper presented at TRB 90th Annual Meeting: Current Environmental Issues in Transportation, Washington, D.C., USA, 2011

[6] Ahn, K., Kronprasert, N., Rakha, H.: Energy and Environmental Assessment of High-Speed Roundabouts. Transportation Research Record No. 2123

[7] Dadić, I., Tollazzi, T., Legac, I., Čičak, M., Marić, V., Kos, G., Brlek, P.: Smjernice za projektiranje i opremanje raskrižja kružnog oblika – rotora, Institut prometa i veza, Zagreb, 2002

[8] Merkblatt für die Anlage von Kreisverkehren, K 10000, FGSV (Forschungsgesellschaft für Strassen- und Verkehrswesen), Köln, 2006

[9] Plangleiche Knoten – Kreisverkehre, Österreichische Forschungsgesellschaft Straße-Schiene-Verkehr (FSV), (RVS 03.05.14), Wien, 2010

[10] SN 640 263 – Schweizer Norm, Knoten mit Kreisverkehr, VSS, Zürich, 2000

[11] ROUNDABOUTS: An Informational Guide, Second Edition, Transportation research Board, Washington, D.C., USA, 2010

[12] Pravilnik o uslovima koje sa aspekta bezbednosti saobraćaja moraju da ispunjavaju putni objekti i drugi elementi javnog puta, Službeni glasnik RS, br. 50/2011

[13] AASHTO Green Book – A Policy on Geometric Design of Highways and Streets, AASHTO, Washington, D.C., USA, 2004

[14] Pratelli, A., Souleyrette, R. R., Harding, C.: Roundabout perception: review of standards and guidelines for advanced warning, WIT Transactions on The Built Environment, Vol 111, WIT Press, 2010

[15] Taylor, M.A.P. , Rutherford, L.M.: Speed profiles at slow points on residential streets, Proceedings of the 13th ARRB/5th REAAA Conference, Vermont South, Victoria, Australia, 1986

[16] Brindle, R.E.: Speed-Based Design of Traffic Calming Schemes, Proceedings of the ITE 2005 Annual Meeting and Exhibit Compendium of Technical Papers, Melbourne, Australia, 2005