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17–19 May 2018, Zadar, Croatia

# Road and Rail Infrastructure V

Stjepan Lakušić – EDITOR

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Organizer
University of Zagreb
Faculty of Civil Engineering
Department of Transportation

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

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# SPEED MODELS AT ENTRIES TO SIGNALISED RURAL INTERSECTIONS

**Chodur Janusz, Ostrowski Krzysztof**
*Cracow University of Technology, Poland*

## Abstract

Intersection design takes into account various groups of criteria that are common for intersections regardless of their location. However, road intersections located in urban areas are designed somewhat differently from those in rural areas, with greater emphasis at rural intersections placed on the issue of traffic dynamics, while service efficiency for various road users features high in the design of urban intersections. A particular problem in rural areas characterized by high vehicle speeds and a different traffic structure is posed by traffic control at the intersection by means of signals which would ensure consistency of geometric features, traffic organization and control at the intersection. In the absence of specific regulations, stakeholders increasingly ask whether the principles of control typically used in cities [5] can be applied at rural intersections. The answer to the above question required pre-tests to determine what specific features of geometry, traffic organization and traffic flows determine the quality of signalised intersection operation on high speed roads in rural areas [3]. Detailed empirical research at 38 intersections focused on vehicular traffic by group of light and heavy vehicles at individual entry lanes of rural intersections [1]. As a result, the authors were able to determine specification of the functioning of rural intersections and the impact of selected entry and intersection geometrical features, traffic features and road surroundings on the speed of vehicles approaching signalised rural intersections. The variability of the analysed factors allowed to examine the significance of the impact of individual quantitative and qualitative variables on vehicle speed and the creation of speed regression models. Proper speed modelling at intersection entries enables proper shaping of entry's geometry and configuration of detector systems and related control parameters (e.g. jednostkowe extension of the green signal). The main objective of the study work and empirical research was to create the basis for rationalization of the design of signalised intersections from the point of view of traffic performance and safety.

*Keywords: signalised intersection, speed on entries, regression models, determining factors*

## 1 Introduction

Chiefly due to safety considerations, rural intersections increasingly see the use of signals which control traffic flows. These are usually deployed at existing intersections prone to traffic accidents and/or where traffic performance has deteriorated. Frequently, the geometry of the intersection and the organization of traffic are adjusted to the new control method, but there are also intersections where existing solutions are retained. In rural areas, the speeds at intersections are much higher than in urban areas [6]. This translates into the geometric design of these intersections differing to some extent from that of urban intersections [2]. During the design of rural intersections, more emphasis is laid on traffic dynamics, whereas at urban intersections service efficiency of various users is at a premium. Analysis and comparison of similar urban and rural intersections indeed revealed some differences in geometry and equipment (pedestrian crossings, bus stops) [4]. There are significant differences in the area of traffic characteristics – in addition to differences in speed, there also exists significant differences in the directional structure of traffic and types of vehicles at entries to these two types of intersections. Usually at rural intersections, the location of detectors, and consequently the traffic control system itself, are different. In 2010-12, under a project designated "Problems of signalised intersection operation at high speed rural roads" funded by the National Science Centre, a series of empirical studies were carried out in Poland at selected entries to 38 signalised intersections. Research has been undertaken in the following areas:

a) identification of specific features of the functioning of the engineering object, i.e. of a signalised intersection in a high-speed rural area,
b) defining the interrelations among object features, i.e. intersection's geometry, traffic organization and traffic control during the object's design process,
c) specification of safety and performance related traffic control features at rural intersections with a view to designing principles for the creation of a traffic control algorithm,
d) identification of speed management options during the approach to anddeparture from intersections.

The paper presents findings on the specificity of rural intersections and selected results of speed tests on the approach to the intersection and its characteristics.

## 2 Shape and functioning specificity of signalised rural intersections

Signalised rural intersections have their own specificity involving the following characteristics:

- high speed on the main road, significantly exceeding the permissible speed in built-up areas,
- large disparity between traffic load generated by the primary direction (national road) and the suburban road,
- small pedestrian traffic, mostly generated by public transport stops, requiring provision of a phase enabling safe crossing of the main road, which has a significant share in the signal cycle, not always proportionate to traffic volume on the minor road,
- significant share of heavy vehicles in traffic flows on the main road, including lorries with trailers,
- lack of intensive development surrounding the intersection, which allows the geometry of entries to be adapted to the needs of flow and control.

Frequently, rural intersections are fitted with traffic lights, without however offering necessary accompanying solutions affecting road users' behaviour, especially those that control the speed of a vehicle's approach to departure from the intersection. With regard to the geometry of intersections, the following specificity can be indicated:

- way of entry canalization and geometry of centre islands, especially on subordinated entries,
- factors determining the length of additional lanes for left or right directions; in rural areas the key role is assigned to operating speed, while in urban areas the range of the back of queue plays the main role,
- one-lane subordinated entries are much more frequent at rural intersections,
- absence of or a much smaller scope of infrastructural development for pedestrian and bicycle traffic,
- markedly smaller surface of the intersection,
- smaller lengths of escape routes and approach to the collision zone,
- visibility less reduced than in urban areas,
- visibility requirements for stopping at the end of the queue and the traffic signals when approaching the intersection.

## 3 Speed measurements and database

Vehicles' speed measurements were carried out on selected entries to 38 rural signalised intersections in five Polish provinces. The intersections selected for the tests are located on two-way national roads with one (1x2) or two roadways (2x2). Detailed criteria were followed [1, 2] during the choice of intersections. In the course of speed measurements, the technique of video recording of vehicles passing through predefined sections of the intersection entry was used (Fig. 1). Each measurement lasted for 6 hours and was carried out in the morning or afternoon. As a result, approximately 12,000 signal cycles and 140,000 vehicles were recorded. Apart from a record of the speed of light and heavy vehicles entering the intersection without stopping, the database contains data on a given intersection's entry's cross-section and longitudinal cross-section, type of roadside, existence of pedestrian crossing, speed limit, signals program's parameters, signals' location, existence of acoustic screens and degree of urbanization.

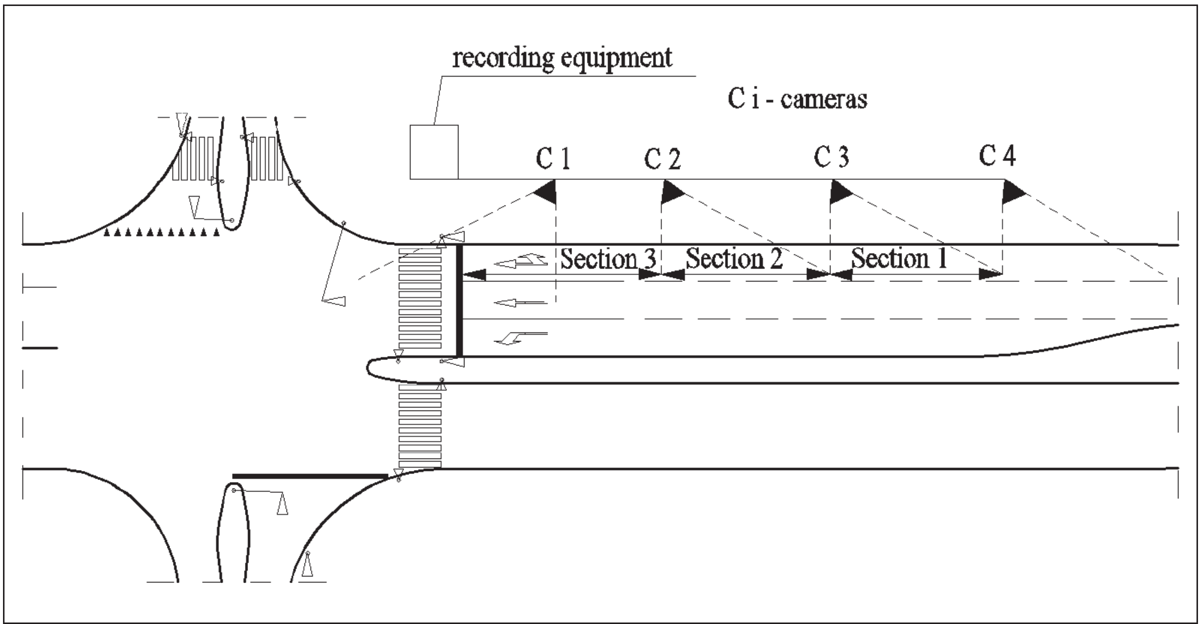


**Figure 1** Diagram with location of video cameras Ki and location of measuring sections alongside entry to a signalised intersection

## 4 Speed characteristics at entries to intersections

Analysis of the speed at the entry to the intersection involved vehicles that entered the intersection after decongesting of a queue of vehicles. Vehicles approaching the intersection adjust their speed to the speed of vehicles that have previously stopped in a queue when the last vehicle in the queue has not yet crossed the stop line. Although they enter the intersection on the green signal, these approaching vehicles are somewhat affected by the presence of the queue. The magnitude of this impact depends on the queue's length. This affects the range of vehicle speed variation at the entry to the intersection. That explains why the speed set features fairly low values. The method of speed measurement and the geometry features of the entry and traffic, as well as of the surroundings, included in the database allowed, among others, characterisation of the speed of two vehicle groups (Fig. 2.a and Fig. 3)) and of speed variations along the approach to the intersection and their distribution (Fig. 2.b). The authors limited themselves in the paper to the presentation of vehicular speeds at entries with one lane for straight-on traffic. The variations and speed distributions of vehicles shown in Figures 2 to 4 indicate that:

- light vehicles' speeds (l) are slightly higher than those of heavy vehicles (h); $v_{85,l}$ = 64,4 km/h, $v_{85,h}$ = 62,4 km/h. This small difference results from the presence of just one lane for straight-on traffic. Light vehicles must adapt their speed to that of the preceding vehicle. The greater the share of heavy vehicles in traffic, the lower the vehicle speeds;
- about 85 % of both light and heavy vehicles' drivers did not exceed the speed limit of 70 km/h;
- when vehicles approach the stop line, their average speed is reduced by 4 km/h in the group of light vehicles and by 2.5 km/h in the group of heavy vehicles. This is caused by the very fact of passing an intersection as well as anticipation of the possibility of signal change.

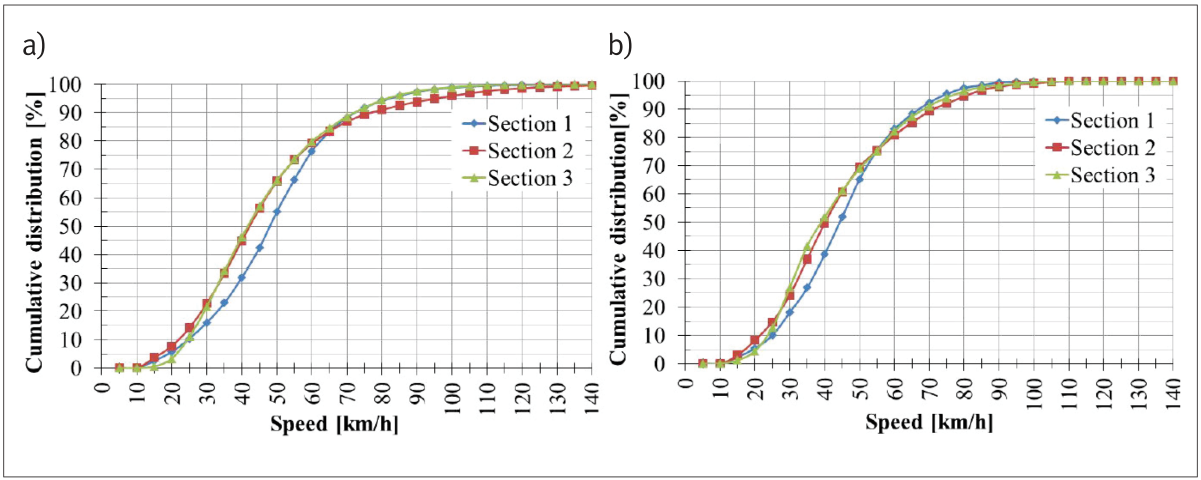


**Figure 2** Cumulative distribution function of average speed (a) and speed reduction during the approach to the stop line (b) of light and heavy vehicles at an entry with a single lane for straight-on traffic (cross-section 1x2)

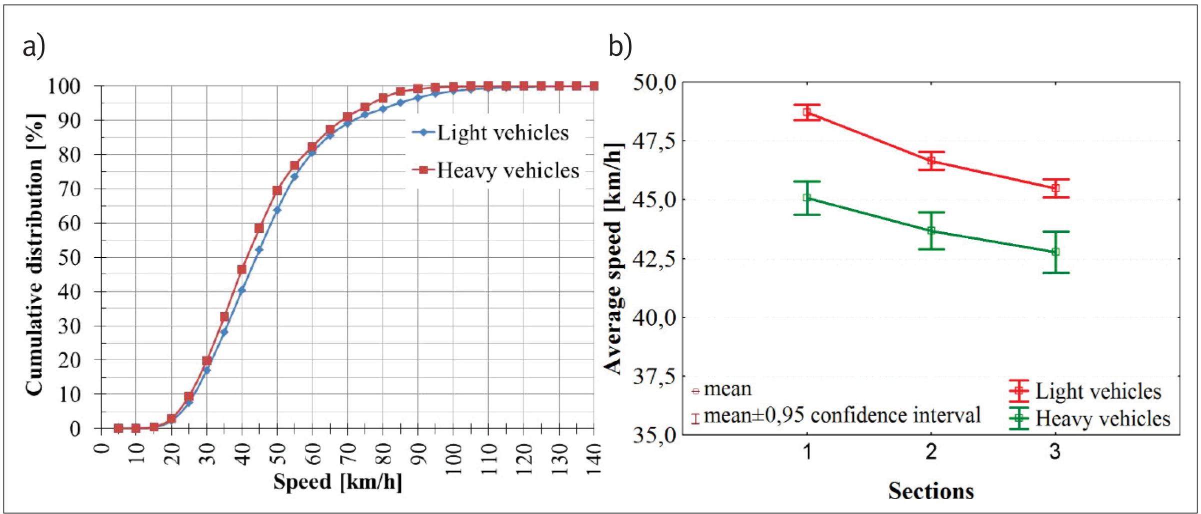


**Figure 3** Cumulative distribution functions of average vehicular speed at entries with a single lane for straight-on traffic (cross-section 1x2) in the successive measurement sections: a) light vehicles, b) heavy vehicles

Due to variations in the development of the surroundings of intersections covered by the tests and in the related pedestrian infrastructure and traffic, three groups of intersection's urbanization were distinguished (Table 1). The influence of the degree of the intersection's urbanization on vehicular speed at the entry is illustrated in Fig. 4. As expected, the lowest vehicle speeds were recorded at research sites from the urbanization group 3, and the highest at those from the urbanization group 1. Activities in the intersection's surroundings can affect vehicles' speeds when these approach and cross an intersection.

**Table 1** Characteristics of intersection's urbanization group

| Urbanization characteristics | group 1 | group 2 | group 3 |
|---|---|---|---|
| buildings in the surroundings of the intersections | 0 or sparse distant | sparse distant | group of buildings nearby |
| pedestrian crossings | 0 or 1 crossing | 1 or 2 crossings | 3 or 4 crossings |
| distance from nearest signalised intersections or roundabouts | > 13 km | 4 – 13 km | < 4 km |
| speed limit | 70 –90 km/h | min 70 km/h | min 70 km/h |
| traffic intensity | ≤ 400 P/h | ≤ 650 P/h | > 650 P/h |

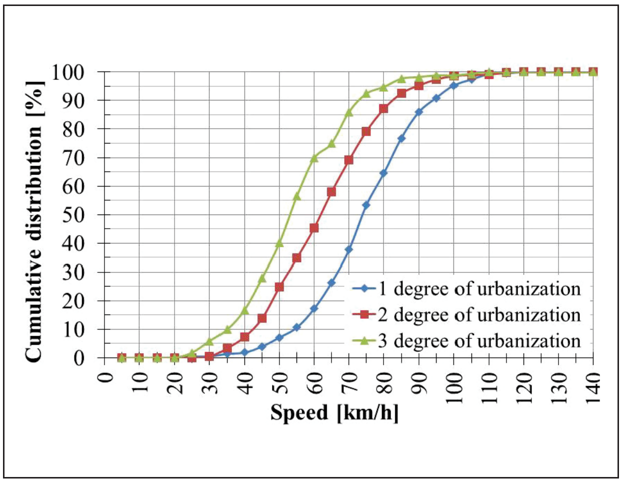


**Figure 4** Cumulative distribution functions of vehicular speed at entries with one lane for straight-on traffic, grouped according do degree of urbanization

## 5 Speed models at entries to intersections

Factors characterizing entry geometry, nature of traffic, traffic control and the intersection's surroundings potentially determining vehicle speeds at entry to intersections are divided into quantitative and qualitative ones. The authors conducted preliminary statistical analyses of the dependent variable and independent variables to verify if they confirm assumptions of the least squares method. As a result, the linear multiple regression model was selected, since it was initially shown that the linearity requirements of the independent variables relationship with the dependent variable are met, the number of observations is sufficient, there exist independent variables non-linear with other independent variables and further that the random components have a normal distribution. The linear multiple regression model for an n-element theoretical sample is as follows:

$$y_i = \beta_0 + \beta_1 \cdot x_{1i} + \beta_{2i} + \ldots + \beta_k \cdot x_{ki} + \varepsilon_i \quad \text{for } i = 1, 2, \ldots, n \tag{1}$$

Where:
$\beta_j$ – model's parameters,
$\varepsilon$ – random element.

Below, the authors present speed models which were developed on the basis of segmented regression in the Statistica application.

Section 1: $$V_1 = \begin{cases} 61,45 - 0,011 \cdot f_1 - 7,15 \cdot f_3 & \text{dla } V_1 \leq 65,0 \text{ vph} \\ 78,83 - 3,24 \cdot f_2 - 9,77 \cdot f_3 & \text{dla } V_1 > 65,0 \text{vph} \end{cases} \quad (2)$$

$$R = 0,86, R^2 = 0,74$$

Section 2: $$V_2 = \begin{cases} 23,27 + 0,71 \cdot V_1 - 4,73 \cdot f_4 + 15,41 \cdot (f_5 \cdot f_6) & \text{dla } V_2 \leq 70,5 \text{ vph} \\ 39,66 + 0,65 \cdot V_1 - 4,66 \cdot f_4 + 11,21 \cdot (f_5 \cdot f_6) & \text{dla } V_2 > 70,5 \text{vph} \end{cases} \quad (3)$$

$$R = 0,93, R^2 = 0,87$$

Section 3: $$V_3 = \begin{cases} 15,64 + 0,51 \cdot V_2 + 0011 \cdot f_7 & \text{dla } V_3 \leq 67,0 \text{ vph} \\ 28,39 + 0,57 \cdot V_2 + 0,084 \cdot f_7 & \text{dla } V_3 > 67,0 \text{vph} \end{cases} \quad (4)$$

$$R = 0,90, R^2 = 0,81$$

Where:
$f_1$ – traffic intensity (vph),
$f_2$ – binary variable; 0 – only passenger cars in the flow, 1 – heavy goods vehicles in the flow,
$f_3$ – binary variable describing existence in section 1 of the entry of an elevated island demarcated with a kerb; 0 – lack, 1 – existence,
$f_4$ – number of lanes at entry,
$f_5$ – binary variable describing existence in section 2 of the entry of an elevated island demarcated with a kerb; 0 – lack, 1 – existence,
$f_6$ – binary variable describing the deflection of the course of traffic in the initial part of section 2 due to the shape of the island; 0 – lack, 1 – existence
$f_7$ – entry surface (product of entry width, inclusive of the hard shoulder, and the length of the widened entry).

Traffic intensity occurring in the model along section 1 has a significant impact on the estimated speed at the entry. The impact is transferred to the successive sections by variable $V_i$ from the previous section. The value of traffic intensity is also related to the degree of urbanization of the intersection and its surroundings. It can be roughly assumed that in section 1, the model for $V_1 \leq 65,0$ vph corresponds to urbanization level 3, and the model for $V_1 > 65,0$ vph corresponds to levels 1 and 2.
The above models show that the introduction of traffic canalization islands, traffic calming horizontal deflections and of short lanes for left and right turns (length of the widened entry), reduces the speed of vehicles approaching the entry. Additionally, it transpired that the control parameters can also have a significant impact on the speed of vehicles passing the stop line (models with this impact are not included in the paper).

## 6 Conclusions

Significant differences in the shape and traffic characteristics of urban and rural intersections indicate the advisability of separate approaches to the design of the geometric shape and control of intersections in the two different locations. Knowledge of speed characteristics at the entries to rural intersections allows for reliable and traffic-related:
- designing of intersection geometry: tapers of widened entries and canalization islands, lengths of slowing sections,
- determination of inter-green intervals for collisional traffic flows,
- selection of the detector system at the intersection and control parameters related to the system,

- implementation of special control systems reducing the problem of the so-called dilemma zone,
- assessment of the rationale for and effectiveness of the use of speed management measures (speed cameras, variable message signs) or other solutions from the field of geometry and traffic organization to reduce the speed of the vehicle flows.

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