

Capacity of Unsignalized Urban Junctions

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ABSTRACT

New comprehensive empirical and simulation studies of traffic operation of major/minor priority junctions gave the basis for development of capacity estimation models including specificity of operation in urban areas. Obtained results allowed construction of a new capacity calculation method and gave the basis for its practical implementation. Presented in the paper are selected results of identification of critical gaps and capacities of lower rank movements and capacities of major road approaches at various traffic lane configurations.

1. INTRODUCTION

There were two main aims of a recently completed research project, sponsored by the Polish Scientific Research Committee:

- collection of field data and development of theoretical basis for estimation of capacity of minor movements and measures of traffic performance at approaches to urban major/minor priority junctions, and
- development of a capacity calculation procedure for practical applications in designing.

As well known methods are mainly oriented on rural junctions (Brilon et al. 1997; Kyte 1997) the author's investigations were focused on special features of urban junction layouts and their traffic characteristics.

Special features of the urban junction layouts, when comparing with rural junction layouts, include: different cross-sections of roads (streets), presence of pedestrian facilities and urban transport stops, frequent presence of adjacent traffic signals and different environment of a junction (buildings and other elements limiting visibility). Urban traffic also differs from characteristics of traffic flows in rural areas for its fluctuations, speed distribution, for presence of urban transport vehicles and pedestrians in traffic flows and frequently due to filtering of traffic streams by traffic signal control. In order to identify factors affecting capacity of the minor street approaches and to determine the potential capacities of lower rank movements, field measurements at urban priority-type junctions and simulation studies were conducted. Results of measurements and simulation calculation were a basis for further calculations of approach capacities in prevailing traffic and roadway conditions. In traffic analyses various locations of priority type junctions in a street network (isolated or situated near-by signalised intersections) affecting a performance of the subject junctions were investigated (Gaca et al. 1998; Gaca and Chodur 1998).

Presented in the paper are results of field measurements conducted at 28 urban junctions and results of simulation calculations of capacities of lower rank movements—including models of critical gap estimation and estimation of potential capacities. Major street capacity

for various lane assignments with and without separate traffic lanes for left turns is also considered.

2. OBSERVED CAPACITIES OF MINOR STREET LANES

In order to determine capacities of lower rank movements in a direct way, recording of traffic situations including gap acceptance in short time intervals was applied. Such intervals had to satisfy a condition of minor approach saturation, i.e., presence of the queue of minor movement vehicles during the short (one-minute) intervals of recording. Altogether about 3 hours of recorded traffic situations from each of 28 junctions were included in the analysis. Specific features of each of those junctions reflecting the drivers behavior were taken into account.

For the investigated minor street movements the relationships between recorded capacities of the individual movement C_m and the conflicting flow volumes V_c were analyzed. In cases justified by a junction layout and a behavior of drivers, to a conflicting volume added were also volumes of other major road movements, which do not conflict directly with a minor street movement but have a visible impact on its capacity. In case of shared traffic lanes with mixed directional composition, in determining conflicting traffic volume, rates of individual minor road movements using the lane were determined. The relationships $C_m = f(V_c)$ characterized different power. Values of the correlation coefficient R for these relationships ranged, depending on a junction and minor street movements, from 0.10 to 0.74 (for 1-minute intervals) and for groups of junctions from 0.47 to 0.81. An example of the relationship between capacity of the minor street left turning movement and the conflicting flow volume is presented in Figure 1. Figure 2 shows average hourly capacities recorded at individual junctions for the separate left turning lanes L (13 junctions) or for shared lanes carrying two movements: left turning and straight through movements L/T (6 junctions). Uniting of these two cases was assumed as permitted due to a small difference in the number of major conflicting movements. In Figure 2 each point represents relationship between average volume of the conflicting major movements and capacities from all of the analysed (saturated) 1-minute intervals for a considered lane (L , L/T) from the minor road approach. It should be noticed that, empirical capacities presented in Figures 1 and 2 were received in prevailing roadway and traffic conditions at the studied junctions — including also impacts of an impedance and traffic composition.

Correlation analyses have showed that for junctions situated in towns (30,000 – 50,000 inhabitants) correlation coefficients between capacities of lower rank movements C_m and conflicting volumes V_c reached higher average values than for junctions situated in large cities (>100,000 inhabitants). Greater values of capacities are characteristic to large cities (Figure 3).

The conducted regression analyses showed lack of relationships between capacities of the minor street movements and type of sign posted at minor road approach (Yield or STOP) (Figure 4). This result was rather unexpected and differs from the results reported earlier (more than 10 years ago) in references and also used in the Polish capacity calculation method for the rural road junctions. Impact of the type of posted sign essentially effected

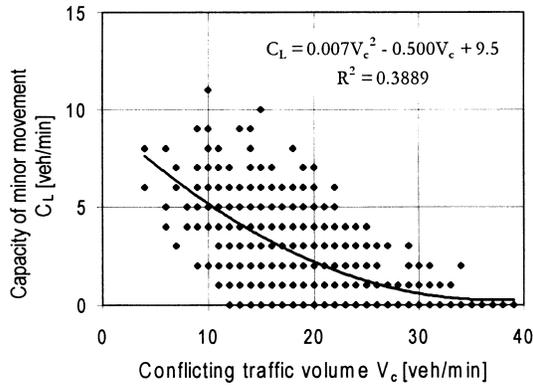


FIGURE 1 Relationship between capacity of the minor street left turning movement and conflicting traffic volume (data from 13 junctions).

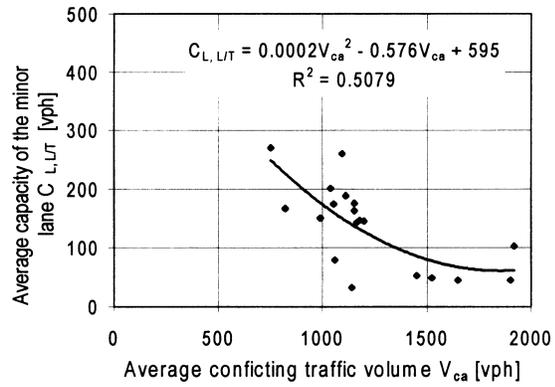


FIGURE 2 Relationship between average capacities of the minor lane and the average volume of the conflicting traffic lanes L and L/T.

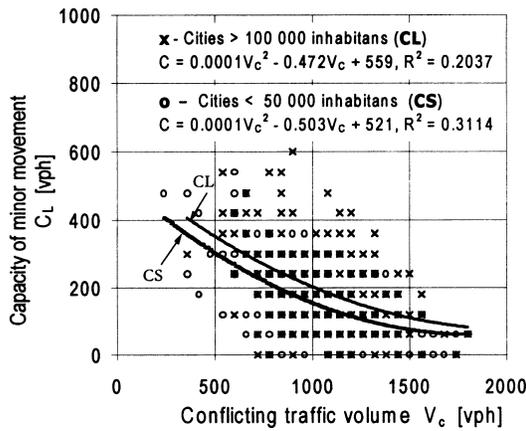


FIGURE 3 Capacities of the minor left turning movement recorded at 7 junctions in towns and cities with different numbers of inhabitants.

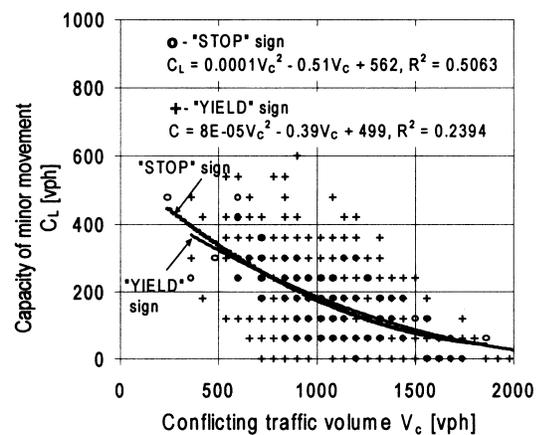


FIGURE 4 Impact of the type of posted sign (Yield or STOP) on capacity of the minor left turning lane (3-arm junctions).

the values of calculated capacities. It is not possible to explain if this result reflects behavior of the Polish drivers at the STOP sign.

The detailed analyses of factors determining capacities of minor street approaches were conducted in relation to the critical gap values determined with use of the maximum likelihood procedure (Gaca et al. 1998). In this case much larger sample than in capacity analysis were available from measurements. In Table 1 are presented models of critical values estimation together with the levels of significance of the describing variables and levels of determination R^2 determined for minor movements.

3. SIMULATION STUDIES OF CAPACITIES OF THE MINOR MOVEMENTS

Graphs of potential capacities of the individual minor movements were derived on the basis of simulation studies and empirical results under the following assumptions:

- lack of queues of vehicles arriving from adjacent signalized intersections, interfering random traffic flow arrivals to the considered junction;
- traffic flow demands at the considered junction approaches are characterized by the average restrictions of traffic flow freedom (some vehicles can move in platoons) and irregular traffic flow variations;
- lack of impacts of traffic signals installed at adjacent junctions or pedestrian crossings and therefore a distribution of headways between major road vehicles can be assumed as random;
- the major conflicting flow consists of the 1st rank movements (major road through movements);
- lower rank traffic movements have their own separate lanes.

Very important for deriving of the potential capacities was determination of characteristics of traffic flow demands at junction. Studies of short-term variability of traffic flow intensities have showed that in the urban conditions they have an irregular character or similar to the sinusoidal function. Less frequently recorded was variability that can be represented by a parabolic function. In the last case amplitude of traffic flow rates variability, described as the ratio of maximum value (after smoothing of flow rate time series) to an average flow rate were in a majority of cases 1.20–1.30. For deriving potential capacities of lower rank movements assumed was an irregular pattern of flow rate variations in time. Such solution requires conducting individual analyses, when specific demand flow rates profiles are identified.

The potential capacities were calculated in conditions of saturation—identified by a percent of stopped vehicles (close to or equal 100%) and by average delays (greater than 180 sec/veh). In each simulation run, determined were critical gaps and these values were used next in regression analyses conducted to derive functional relationships of capacities, conflicting flow volumes and critical gaps.

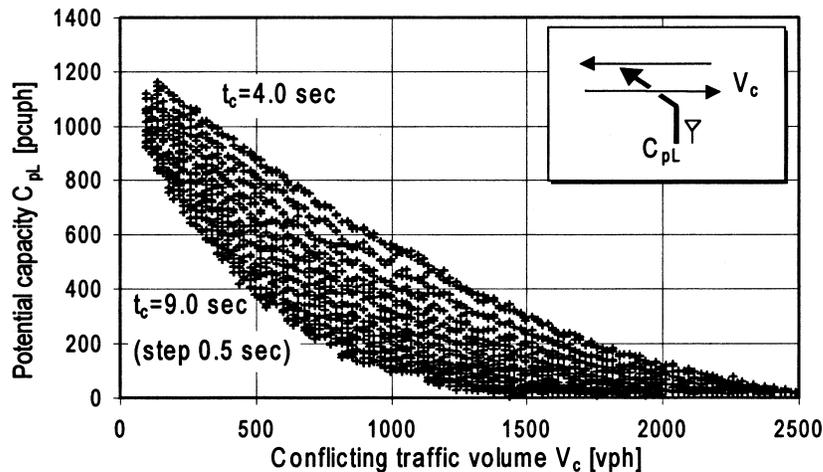
For each of the subject movements the regression model was determined under assumption that the following variables are independent: the conflicting traffic volume V_c , the critical gap t_c and the follow-up time t_f . The follow-up time is the time headway between departures of the following vehicles using the same major street gap, under a condition of continuous queuing on the minor street. In Table 2 presented is a model of potential capacity C_p for minor left turn movement. In Figure 5 presented are potential capacities of the minor road left turning movement in a function of a conflicting volume V_c and critical gaps t_c .

4. CALIBRATING OF CAPACITY MODELS ON THE BASIS OF FIELD RESULTS

The determined field capacities were mainly used for a calibration of the simulation model and for simulation runs. They were also used for validation of the potential capacities for

TABLE 2 Model of Potential Capacity C_p (pcuph)

Variables	$e^{\frac{-V_c \cdot t_c}{3600}}$	V_c	$\frac{3600}{t_f}$	Constant
Minor street left turn L				
Regression coefficient	1061.12	- 0.143	0.644	- 532
Statistics	$R^2 = 0.996, SE = 20.1, MAE = 16.3, n = 2140$			
Range of traffic parameters	$V_c = 100 \div 2400$ vph, $t_c = 5.0 \div 8.0$ sec and $t_f = 0.03 \cdot t_c + 2.89$ sec			

**FIGURE 5 Potential capacities of the minor road left turning movement obtained from simulation.**

individual minor movements derived in this way. It was particularly related to the intervals with high values of the conflicting volumes V_c , as in these intervals the capacity curves obtained from simulation (based on the acceptance of gaps in the conflicting flow) go to zero. In practice entering of some minor street vehicles can be observed, even at the major street congestion. It is an effect of changes of drivers' behavior; major street drivers give way to minor street vehicles and minor street drivers force their way into or through the conflicting flow in congested traffic conditions. A set of adjusted graphs of potential capacities for the right turning movement from the minor road is shown in Figure 6.

Similar sets of adjusted curves of potential capacities were derived also for other lower rank movements, i.e., left turns of the major road, straight through movement and left turns from the minor road. Obtained sets of curves are recommended to the new Polish method for capacity calculation of urban junctions.

5. CAPACITY OF THE MAJOR ROAD APPROACH

If the shared major road lane carries traffic streams of rank 1 and rank 2 (left turning movement), vehicles turning left can block through or turning movements and in a critical

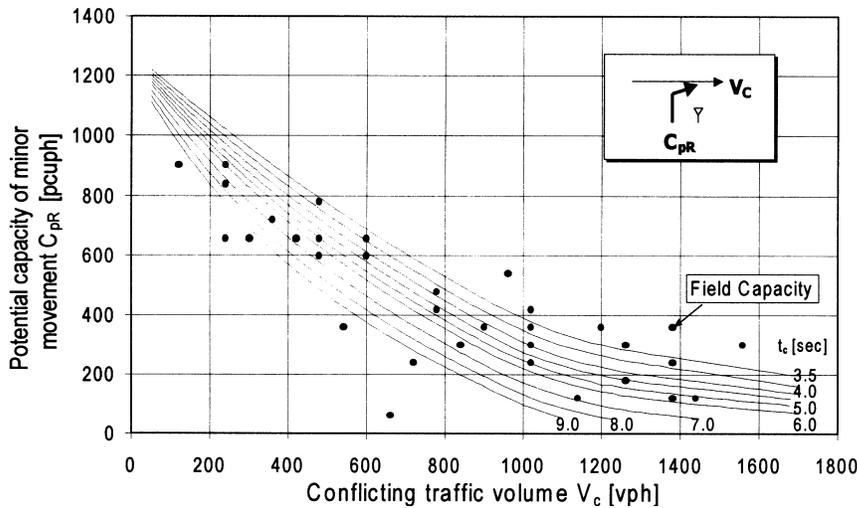


FIGURE 6 Adjusted potential capacities for minor road right turn movement R.

state they can even cause their total stoppage. Capacity of such a shared major road lane is determined by the share of left turning vehicles in the total traffic flow (assigned to a lane) and their critical gap and by the volume of the conflicting opposed traffic flow. Impact of a major road lane assignment is also essential. There might be three cases of the lane assignment on the major road (Figure 7).

For all of the considered lane assignment configurations, computations were made using simulation. Simulation was conducted for variable shares of the left turning movement r_L from 0.10 to 0.40, conflicting traffic volume of rank 1 and 2 V_c from 100 to 1500 vph, and three values of critical gap t_c , i.e., 4.5, 5.5 and 6.5 seconds.

For the considered lane *assignment (a)* one stated that the smaller share of left turning movement, the higher capacity of the major road approach (Figure 8). In the extreme case of lack of left turning movement on the lane, its capacity depends on the straight through movement. The critical capacity of the considered shared lane is approximately 1450 pcuph, resulting from the queue service (departure) time t_f of vehicles entering a junction from the approach B. Of course, capacity of the lane carrying only the straight through movement would be higher as vehicles which do not stop at approach can move in platoons in smaller time gaps than value t_f (i.e., the parameter describing queue departure process). The general model which enables estimation of capacity of the considered major road lane C_B determined by parameters $V_c (=V_A)$, r_{LB} , t_{cLB} and by capacity of the left turning movement C_{LB} (derived in such a way as if it came from separate lane) is presented below in Equation (2):

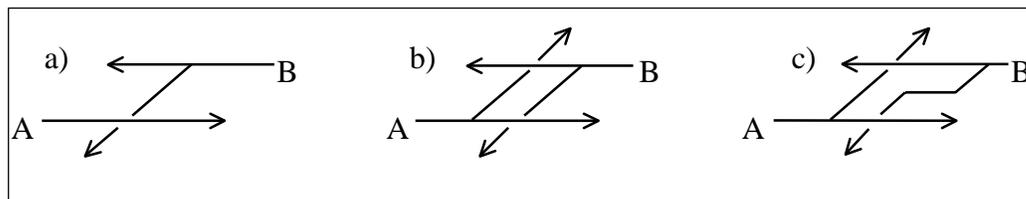


FIGURE 7 Three configurations of shared lane assignment on the major road.

$$\begin{aligned}
 C_B = & 1.07 \cdot C_{LB} + 2.09 \cdot V_c \cdot e^{\frac{-V_c \cdot t_{cLB}}{3600}} - 5578.7 \cdot e^{\frac{-3600}{V_c}} + 9915.0 \cdot \left(\frac{V_c}{3600}\right)^3 \cdot (r_{LB})^2 \\
 & - 1.46 \cdot \frac{V_c \cdot C_{LB} \cdot t_{cLB} \cdot r_{LB}}{3600} - 131.8 \cdot \frac{C_{LB}}{3600} \cdot r_{LB} + 89.32 \cdot t_{cLB} \cdot r_{LB} - 16.24 \cdot t_{cLB} \\
 & + 1872.1 \cdot r_{LB} - 3282.8 \cdot \sqrt{r_{LB}} + 1264.3
 \end{aligned}$$

(pcuph) (2)

$R^2 = 0.994, SE = 29.6, MAE = 21.5, n = 1127$

The set of capacity curves for the three analyzed critical gaps is shown in Figure 9. Taking under consideration complexity of the model (2) used in computations, for the purpose of manual applications, a set of simple individual equations was prepared for every critical gap and for the left turning movement share in the analyzed lane. There are also graphs derived on the basis of these equations (example in Figure 8).

In *case (b)* of the lane assignment, there is mutual interaction between traffic streams from the opposing major road approaches. Vehicles turning left from the approach give way to the straight through vehicles from the approach B using the shared lane together with the left turning vehicles. The left turning vehicles from approach B have to give way to the straight through vehicles from the approach A. This movement shares the lane with the left turning movement. It is determined by the situation at the approach B. In this case there is an essential change (in relation to the *case a*) in the distribution of gaps in the major stream caused by the increase of vehicles moving straight through in platoons, in the periods of queue departure. This situation reduces capacity of the major road left turning movement. On the other hand vehicles turning left from the opposing approach block the straight through movement (as one assumes that there is no possibility to omit them) but at the same time they make the left turn from the analyzed approach easier and that leads to an increase of capacity.

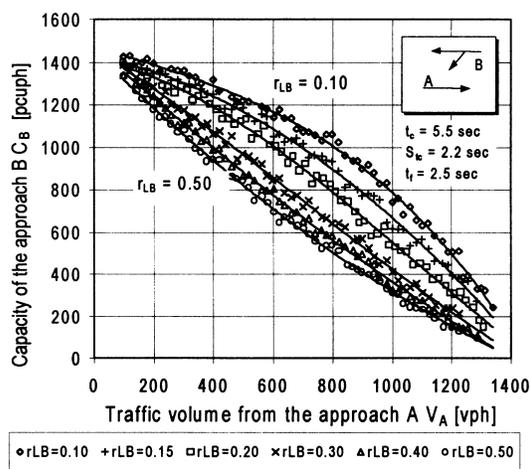


FIGURE 8 Capacity of the shared lane at approach B (regression curves in the graph are adjusted individually for every particular values r_{LB}).

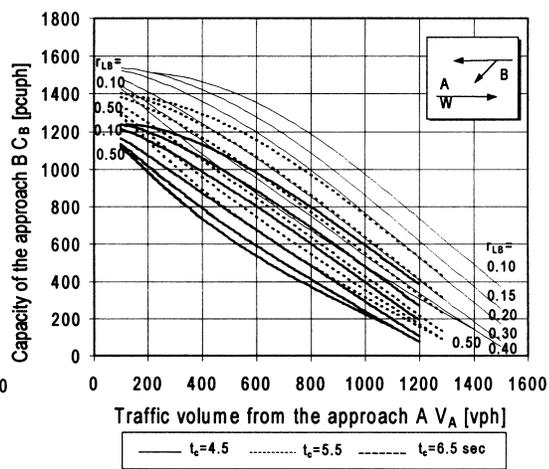


FIGURE 9 The set of capacity curves of the shared lane at the approach B (*case a*) from the model (2).

Resulting impact on capacity depends on the shares of the left turning movement at both opposing approaches and on traffic volumes (Figure 10), determining probability of a collision of vehicles turning left from the opposing approaches. In case of the analyzed lane assignment, along with increase of the traffic at the main road opposing approaches it might reach the state of the critical capacity at the both approaches simultaneously (bolded line in Figure 10). As the study showed in case of a small proportion of the left turning movement at the analyzed approach (in the study it was the approach B), i.e., $r_{LB} < 20\%$ impact of the left turning movement is insignificant (Fig. 10a). When the value r_{LB} is higher, i.e., 30 and 40%, its influence is noticeable (Fig. 10b). This impact grows together with increase of the major road traffic volume V_A .

The regressive model for the major road capacity at the *case b* of the lane assignment is represented by the following equation (3):

$$C_B = 16320.0 \cdot e^{-\frac{(V_A - V_{LA})}{3600}} + 63958.6 \cdot e^{-\frac{V_{LA}}{3600}} - 608.5 \cdot e^{-\frac{V_A \cdot t_c}{3600}} + 2.456 \cdot V_A + 14.332 \cdot V_{LA} - 251.2 \cdot r_{LA} - 151.0 \cdot r_{LB} - 144.5 \cdot t_c - 77293 \tag{3}$$

(pcuph)

$$R^2 = 0.921, SE = 80.1, MAE = 61.5.7, n = 2439$$

Critical states in which both major road approaches reach the maximum volume (volume equals capacity) has been also analyzed in details. Critical capacities determine the range for using relationships described by the model (3). The knowledge of these relationships is also very important in practice since it allows defining the maximum increase of the major road traffic knowing r_{LB} and r_{LA} and defining the critical capacity for both major road approaches. The model of mutual relationships between capacities of major road approaches (for $t_c = 5.5$ sec) is presented in Figure 11.

The presented analysis leads to the conclusion that there is a relationship between capacity of shared lane approaches (*case b*) and shares of the left turning movement at these approaches. This relationship is presented below:

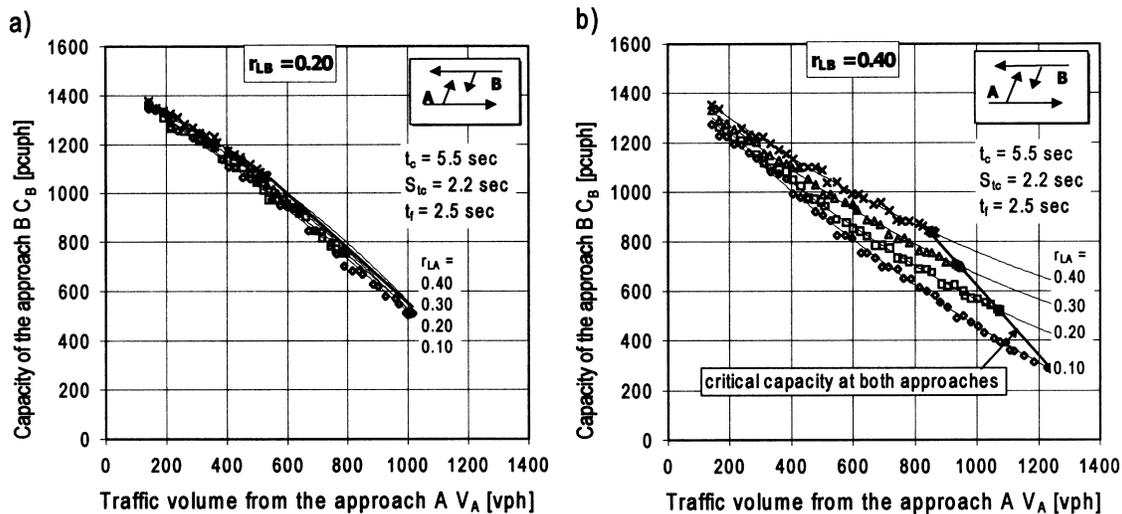


FIGURE 10 Capacity of the shared major road lane (*case b*) with various shares of the left turning movement.

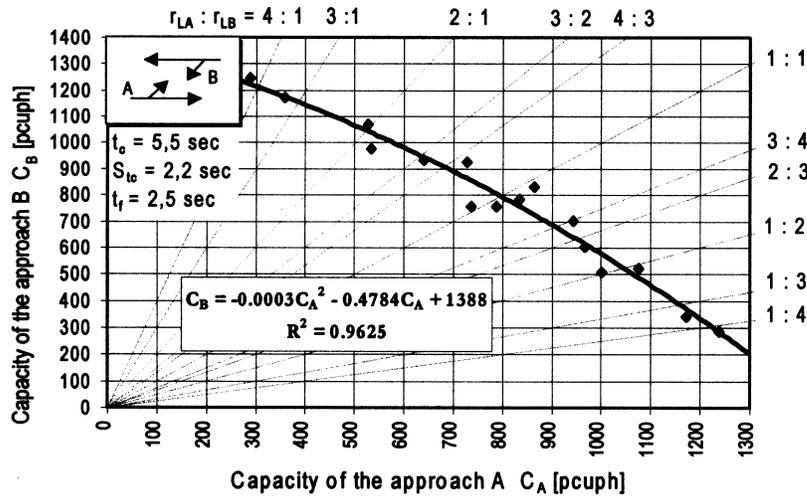


FIGURE 11 Critical states of capacity of shared lanes at the major road opposing approaches (*case b*) for $t_c = 5.5$ sec.

$$\frac{C_B}{C_A} = \frac{r_{LA}}{r_{LB}} \tag{4}$$

The resulting relationship (for $t_c = 5.5$ sec) is presented in Figure 11. According to this relationship it is possible to determine the capacity value C_A and C_B for the given proportion $r_{LA}:r_{LB}$ (relationship is valid for the following range of variability of $r_{LA}:r_{LB} = 0.10:0.40 \div 0.40:0.10$)

Case c refers to the situation when at one of the major road approaches (B) there is an additional lane for the left turning movement and at the opposing approach (A) there is a shared lane. Departures of vehicles turning left from the approach (B) with the separate lane are determined by gaps in the flow from the opposing approach (A) influenced by vehicles turning left from this approach. The movement of these left turning vehicles depends on the straight through stream from the approach B. Therefore one of factors affecting capacity of the left turning movement from the separate lane of the approach B is the straight through stream from the same approach V_{TB} . Impacts of the conflicting traffic volume, proportion of left turning movement in this volume and the straight through traffic volume from the analyzed approach are presented in Figure 12.

The capacity model of the separate lane for the left turning movement at the lane assignment *case c* is represented by the Equation (5):

$$C_{LB} = -122.5 \cdot e^{\frac{V_{HB} \cdot t_c}{3600}} + 866.4 \cdot e^{\frac{(V_A - V_{LA}) \cdot t_c}{3600}} - 0.308 \cdot V_A + 0.812 \cdot Q_A \cdot \frac{r_{LA}}{r_{LB}} + 0.315 \cdot \frac{3600}{t_f} \tag{5}$$

$R^2 = 0.998, SE = 30.1, MAE = 22.6, n = 1878$

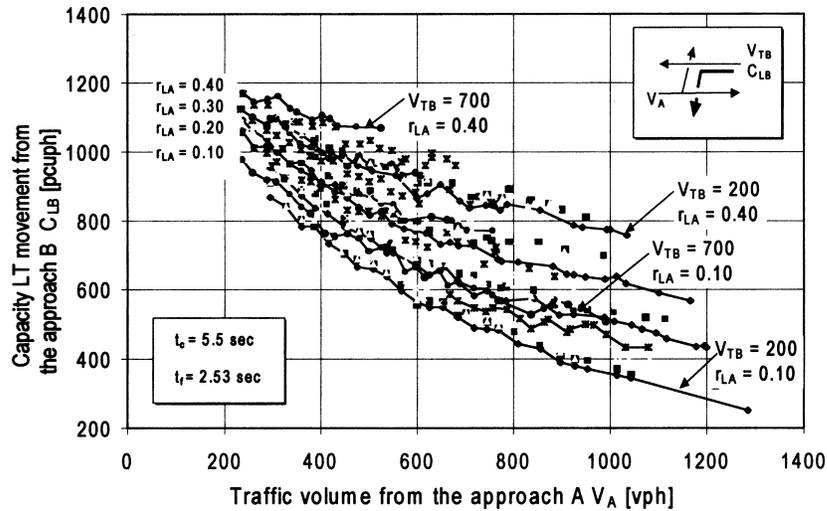


FIGURE 12 Capacity of the left turning movement from the approach B depending on the traffic volume at the approach A, shares of the left turning movement from the approach A and straight through traffic volumes from the approach B.

Like in the *case b*, one can determine equations of critical traffic states in which on both major road opposing approaches capacity can be reached simultaneously (in case of the approach B it refers to the lane LB) at certain volumes of straight through traffic from the approach B. In practice, for known V_{TB} it is possible to determine capacity of the approach A according to the procedure described as *case a* and next from the relationship between capacity of approaches A and B (*case c* of the lane assignment) to determine capacity of the rate LB.

6. CONCLUDING REMARKS

In traffic through unsignalized junction, mutual interactions and relationships between traffic streams determine its performance characterized by traffic conditions of the low rank movements. The basic factor in this evaluation is capacity of lower rank movements.

In the practical method of capacity calculation developed in Poland for urban major-minor priority junctions (Tracz 1997, 1998), common procedure of capacity calculation starting from determining of potential capacities of 2nd, 3rd and 4th rank movements for a given conflicting traffic volume is used. Empirical and simulation results gave the basis for construction of the method. From empirical measurements real capacities of lower rank movements were determined and factors determining capacity were identified. These capacity factors are included in the capacity calculation method in determining of values of critical gaps for given roadway and traffic conditions. Empirical values of capacities were used for calibration of capacity models determined on the basis of simulation results.

The method, that has been worked up enables estimation of capacity of the major road approaches for three described manners of lane assignment on the major road with shared and separated lanes for the left turning movement. Models of capacity include

critical states in which both major road approaches can simultaneously reach maximum volumes. Obtained results widen findings referred to capacity of the major road approaches described in the paper (Gaca and Chodur 1988).

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