TRANSPORT
ISSN 1648-4142 print / ISSN 1648-3480 online
2012 Volume 27(1): 67–72
doi:10.3846/16484142.2012.666764

INCREASING THE CAPACITY OF INTERSECTIONS BY SHORT TRAFFIC LANES

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Submitted 27 June 2011; accepted 11 November 2011

Abstract. When during peak hours intersections are loaded with 5000÷8000 veh/h, installation of short traffic lanes – one or two in each direction – is one of the most economical solutions for their reconstruction. Technical Construction Regulations (STR 2.06.01:1999) of Lithuania do not provide specific recommendations for calculation of the capacity of short traffic lanes. During 2005–2010, the authors of the article performed on-site tests of transport flows in the city of Vilnius and devised the methodology for modelling and calculation of short traffic lane capacity considering the size of the traffic flows. The article presents recommendations on calculation of lost time and vehicle queue lengths considering the size of traffic flows.

Keywords: short traffic lanes at intersections, lost time, degree of saturation.

1. Introduction

One-level intersections have a big influence on the capacity of urban streets as well as the existence of dedicated lanes. Although there are other reasons for a reduced street capacity – such as stops of the public transport within the carriageway and cars parked on the side of a street – that have to be resolved, the increase of the street network capacity should, however, start with the increase in the capacity of intersections.

Traffic control improvements could increase the capacity of street intersections. Such improvements could be achieved with the help of appropriate road surface markings at non-signalised intersections, changes in the traffic-light cycle at signalised intersections and a coordinated traffic control at all intersections (Highway Capacity Manual… 2000; Steierwald *et al.* 2005; Weiterentwicklung des Verfahrens… 2008; RiLSA 2010; Lazda, Smirnovs 2011).

In the Old Town of Vilnius, additional traffic lanes could be used to resolve oversaturated traffic issues at approaches to intersections controlled by traffic-lights. As buildings are situated at a different distances from street boundaries, streets have a limited width, which makes it impossible to build an additional lane along the entire length of the street between two intersections. Such situation suggests the use of short traffic lanes that can contain a limited number of vehicles.

Technical Construction Regulations (STR 2.06.01:1999) of Lithuania recommends that a short traffic lane should be $L_{tj} > 40$ m long. However, this is not possible under the conditions of the Old Town of Vilnius (Burinskienė 2003). The members of the Dept of Urban Engineering of Vilnius Gediminas Technical University analysed transport flows on short traffic lanes to find out how the length of a short traffic lane and its position on the plan of the intersection affect the capacity of the dedicated traffic lane.

The research object: short traffic lanes at intersections controlled by traffic-lights.

The research goal: to construct the methodology for calculation and modelling of traffic lane capacity considering the length of a short traffic lane. To estimate the impact of the distribution of transport flows that move straight from the short traffic lane and turn right (mixed flow lanes) across individual movement directions on the capacity of a short traffic lane.

2. Reconstruction of Intersections with the Help of Short Traffic Lanes

As the period 1980–2010 saw increase in the traffic load in the majority of urban areas of Lithuania, the analysis of ten intersections situated in the central part and the Old Town of Vilnius was carried out. The analysis was carried out in corporation with Vilnius City Municipal

Enterprise 'Vilniaus planas' (*http://vilniausplanas.lt*). According to the results, the change ranges by 1.96÷3.45 times in the Old Town of Vilnius and 1.07÷2.75 times in the central part of the city due to traffic restrictions (Table 1).

Short traffic lanes were introduced in 1970. At the time, the increase in the transport flow capacity with the help of short traffic lanes was not substantiated. In the Old Town of Vilnius, streets have only one traffic direction and buildings are situated very close to streets. Only one short traffic lane – amounting to 24÷27 metres in length – could be installed under these conditions (Technical Construction Regulations (STR 2.06.01:1999) of Lithuania).

In situations with heavy pedestrian flows (q_{ped} > 240 ped/h), dedicated left-turn and right-turn phases could be set for respective short traffic lanes within the general traffic-light cycle. Such short traffic lanes are illustrated in Figs 1 b, d. Figs 1 a, c illustrate the situation when capacity of the right-turn on the short traffic lane is limited by pedestrians crossing the street at green light (Sidra Intersections… 2008).

As illustrated in Fig. 2, two or three additional short traffic lanes may be built in the central part of a town, provided space is available (Traffic and Transport… 2008).

When green light is given to both traffic lanes (TLs) at the same time, then the capacity of both lanes is calculated in the following sequence (Brilon *et al.* 1994; Weiser *et al.* 2006).

The theoretical capacity, C_1 (veh/h), of the main lane is calculated as follows:

$$C_1 = f \cdot q_{s1}, \tag{1}$$

where: f – duration of the green interval for the analysed street (when $f = \frac{t_f}{t_u}$, where t_f – duration of the green interval, s; t_u – duration of the entire traffic-light cycle, s); and q_{s1} – saturation flow on the first traffic lane, veh/h.

Table 1. Transport flow dynamics at typical intersections of the Old Town and the central part of Vilnius (veh/h during rush hours)

Title of intersection	1980	1990	2000	2010	Increase in magnitude, times	Degree of saturation before	Degree of saturation after	Number of short traffic lanes
The central part								
Kalvarijų g. – Ozo g. – Kareivių g.	2220	3450	4930	5210*	2.27	1.15	0.88	5
Kalvarijų g. – Žalgirio g.	1830	3080	3760	3960	2.05	1.06	0.74	4
Kalvarijų g. – Konstitucijos pr.	2570	4860	4000	5040	1.80	1.09	0.72	4
Kudirkos g. – Pamėnkalnio g.	1580	3095	3770	3860*	2.34	0.97	0.82	2
Ukmergės g. – Geležinio Vilko g.	2455	4280	6810	8460*	3.45	0.91	0.72	1
The Old Town								
Vrublevskio g. – Arsenalo g.	1685	3590	2660	4640*	2.75	1.12	0.68	3
Aušros Vartų g. – Liepkalnio g.	1470	1990	1250	3260	1.26	1.14	0.62	3
Pylimo g. – Trakų g.	1930	2140	2280	2460*	0.97	1.02	0.54	1
Pylimo g. – Pamėnkalnio g.	1750	2330	2750	1880	0.87	0.88	0.72	1
Goštauto g. – Vilniaus g.	2990	2865	3490	3890*	1.14	1.09	0.78	2

Note: *oversaturated – g_{sat} > 0.90

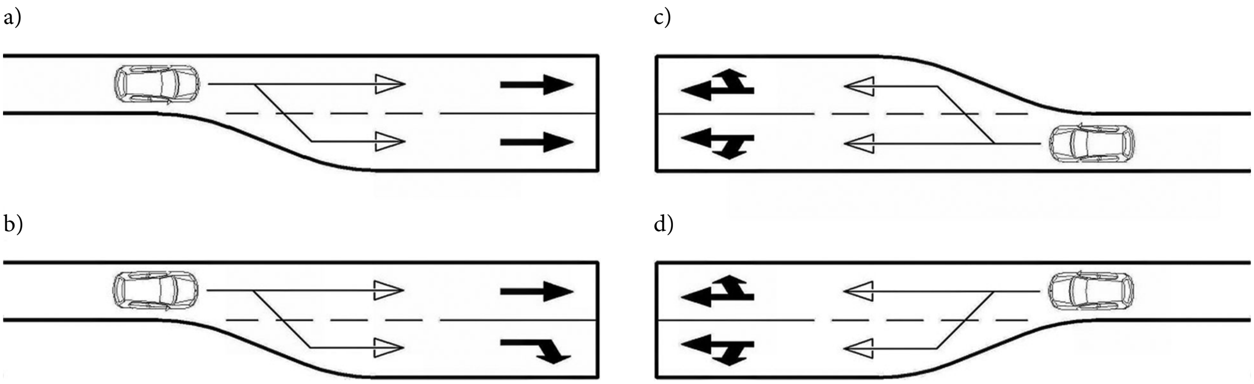

Fig. 1. Schemes of short traffic lanes commonly used in old towns of major cities

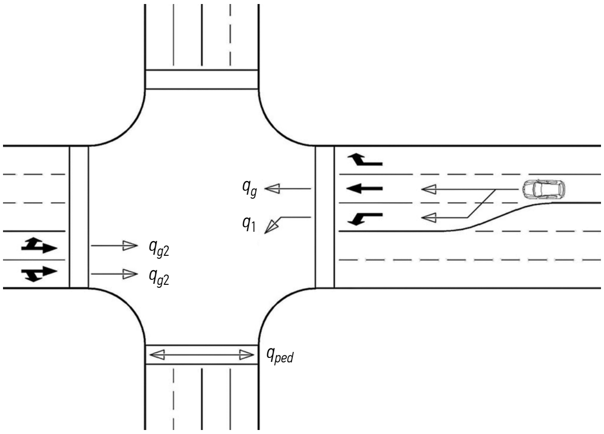

Fig. 2. Schemes of short traffic lanes commonly used in old towns of major cities: q_g – transport that flows straight; q_l – transport flow that turns left from the short traffic lane; q_{g2} – opposite transport that flows straight; q_{ped} – pedestrian flow in both directions (ped/h)

The theoretical capacity, C_2, of a short traffic lane depends on the number of vehicles, N_k, that can be contained by the lane and the number of cycles of traffic-lights, U:

$$C_2 = N_k \cdot U, \tag{2}$$

where: N_k – number of vehicles contained by the short traffic lane; U – number of cycles per hour.

The total capacity, C, of both lanes:

$$C = C_1 + C_2. \tag{3}$$

Situations when vehicles benefitting from short traffic lanes have to take a different direction from one traffic lane are illustrated in Fig. 3. In this case, the flow distribution between T_{L1} and T_{L2} lanes is continued (Handbuch für die… 2001).

Once data is available from on-site tests (straight q_g, right-turn q_r, *t* left-turn q_l), it is possible to calculate the distribution of the flow of an individual street within an intersection. Then, by the degree of the same saturation flows g_{sat} (formula 4), the size of the flow q_{g1} and q_{g2} moving straight from each traffic lane can be calculated (Tian *et al.* 2004; Tian, Wu 2006):

$$g_{sat} = \frac{q_1}{q_{s1}} \cong \frac{q_2}{q_{s2}} = \text{const.} \tag{4}$$

These flows are calculated by using formulas 6 and 7, on the supposition that entrances to individual short traffic lanes will not be blocked by long vehicles (trolleybuses and buses) (Sidra Intersections… 2008):

$$q_1 = q_r + q_{g1};$$

$$q_2 = q_1 + q_{g2};$$

$$q_g = q_{g1} + q_{g2}.$$

$$\frac{q_r + q_{g1}}{q_{s1}} = \frac{q_1 + q_g - q_{g1}}{q_{s2}}; \tag{5}$$

$$q_{g1} = \frac{\left(q_1 + q_g\right) \cdot q_{s1} - q_r \cdot q_{s1}}{q_{s1} + q_{s2}}; \tag{6}$$

$$q_{g2} = q_g - q_{g1}. \tag{7}$$

The saturation degree of T_L with mixed movement directions is calculated with the help of the following formula (8):

$$q_{sm} = \frac{1}{\sum_i \frac{a_i}{q_{si}}}. \tag{8}$$

Calculation of the length of vehicle queues on short traffic lanes depends on their position in the general scheme. If a short traffic lane is organised as illustrated in Fig. 1 b, the length of the vehicle queue on the short traffic lane at the end of the red light interval will be calculated as follows (Brilon *et al.* 1994; Weiser *et al.* 2006):

$$N_{res} = \left(e^{\left(0.022 \cdot (S-50)-1\right)} \cdot \sqrt{\left(m_r + N_{ge}\right)} + \left(m_r + N_{ge}\right)\right), \tag{9}$$

where: N_{res} – length of the queue during the red light interval, veh.; S – probability of a long queue (usually taken as 90%); m_r – number of vehicles arriving during the red light interval, veh.; N_{ge} – the pending queue at the end of the green light interval when flows are oversaturated, veh.

$$m_r = \frac{q_r \cdot t_f}{3600}, \tag{10}$$

where: q_r – flow of vehicles entering the traffic lane, veh/h; t_f – duration of the green interval for the T_L.

In a particular situation, when the right-turn flow from a short traffic lane is q_r = 360 veh/h, the saturation flow on the first traffic lane is q_{sl} = 1766 veh/h, cycle duration is t_u = 120 s, duration of the green light interval is t_f = 31 s, number of cycles per hour is U = 30 cycles, and flow saturation degree is g_{sat} = 0.798, then the vehicle queue formed (N_{res} = 15 veh) and the length of the short traffic lane should be L_{tj} > 90 m. If it is impossible to build a short traffic lane of the necessary length due to the existing situation, it is recommended to build two shorter L_{tj} = 45 m lanes, provided the width of the street allows it (Fig. 2) (Dorsch 2009),

$$C_2' = 1.88 \cdot C_2. \tag{11}$$

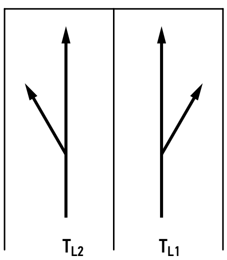

Fig. 3. Scheme for calculation of the capacity of mixed traffic lanes

Both a short traffic lane and a mixed traffic lane correspond to the theoretical throughput capacity, when installed at intersections located in a suburban area, as calculated by using formulas (3) and (8). Short traffic lane capacity at junctions, which are located in the Old Town, the actual appearance of lower throughput

(Richtlinien… 2003). This has an effect on pedestrian flows. Taking a roundabout as an example, where the pedestrian flow at the intersection of short traffic lanes q_{ped} > 120 pedestrians per hour in both directions, the practical short traffic lane permeability C_{1p} calculated using the formula (Klibavičius 2008):

$$C_{1p} = C_1 \cdot k_{ps}, \tag{12}$$

where: C_{1p} – practical short traffic lane capacity, veh/h; C_1 – theoretical short traffic lane capacity, veh/h; k_{ps} – factor for assessing pedestrian traffic impact; k_{ps} = 0.72÷0.98. The factor depends on discipline of drivers in different cities. The average value in Vilnius and Kaunas is given in Table 2.

Table 2. Factor for assessing pedestrian traffic impact

Pedestrian flow q, ped/h	Factor k_{ps}
120	1.00
240	0.98
360	0.95
420	0.92
480	0.88
540	0.81
600	0.72

Different calculations of the length of the vehicle queue at signalised intersections with short traffic lanes is provided in literature of different countries. As the queue length is calculated using various types of methodology, results often differ from the on-site test results. According to results of the test regarding transport flows on short traffic lanes, which was carried out in towns of Lithuania (Vilnius and Klaipėda), the saturation of transport flow on the main lane at the intersections with short traffic lanes is reached very quickly and the classical methodology for calculation of the queue length, which is used in situations with unsaturated flows, gives great errors (up to 60%) (Klibavičius 2008).

The advantage of the capacity of short traffic lanes is often unconsidered, because the entrance to the short traffic lane is blocked by the vehicle flow from the main traffic lane (see the situation in Fig. 2). Therefore, choosing the duration of the cycle and calculating presumable lengths of vehicle queues, it is important to know the number of possible cycles per hour with unsaturated and saturated flows. The number of such cycles, depending on the cycle duration, can be taken from Table 3 (Schnabel, Lohse 1997).

The general capacity of entrance to the intersection (Figs 1 a, b) depends on the capacity of the main traffic lane and on the length of the short traffic lane. When the length of a short traffic lane ranges from 36 m to 90 m, the capacity at the entrance to the intersection increases by 30÷75%. More detailed influence of the length of a short traffic lane and the difference in cycle duration is given in Table 4.

The main indicator that measures performance of short traffic lanes is the average vehicle idle time t_w, which is calculated with the help of the following formula:

$$t_w = \frac{t_u\left(1-f\right)^2}{2\left(1-\dfrac{q}{q_s}\right)} + \frac{3600 \cdot N_{ge}}{f \cdot q_s}, \tag{12}$$

where: t_w – the average idle time of a vehicle (transport time losses), s; t_u – cycle duration, s; f – share of the green signal in the total cycle; q – the flow on the short traffic lane, veh/h; q_s – saturation flow of the short traffic lane, veh/h; N_{ge} – number of vehicles that remain in the lane at the end of the green interval, veh.

Some additional tests were performed to find out if the formula 12 may be used for calculating the time loss of vehicles on short traffic lanes. The situation when the length of the short traffic lane exceeds the max permitted queue length and there are no vehicles left at the end of the green light interval, i.e. N_{ge} = 0, then average idle time on the short traffic lane is t_w = 44 s, which corresponds to the level of service (LOS) C, which is required in order to initiate the reconstruction of an intersection, i.e. the short traffic lane installation. But in the situation when one or more vehicles are left on the short traffic lane at the end of the green light interval (N_{ge} = 1), then t_w=63 s, which only corresponds to the lower than recommended LOS D (Klibavičius 2008) (Table 5).

Table 3. Number of saturated and unsaturated cycles per hour under different duration of cycle

Cycle duration, s	72	80	90	100	110	120
Number of cycles per hour, U	50	45	40	36	33	30
Probability, S, that the vehicle lane will not be longer than the one being considered:	Number of under-saturated cycles					
95%	47	43	38	34	31	28
90%	45	41	36	32	30	27
80%	40	36	32	29	27	24
	Number of over-saturated cycles					
95%	3	2	2	2	2	2
90%	5	5	4	4	4	3
80%	10	9	8	7	6	6

Table 4. Dependence of the total capacity of the main traffic lane and the short traffic lane on the length of the short traffic lane

Number of cycles per hour, U		50	45	40	36	33	30
Cycle duration, s		72	80	90	100	110	120
Duration of the green interval, s		40	40	40	50	50	50
Share of the green interval in the cycle, f		0.555	0.500	0.444	0.500	0.454	0.417
Capacity of the main traffic lane, $C_1 = f \cdot q_{s1}$, veh/h		1000	900	800	900	818	750
	Length of short traffic lane, L_{tj}, m	Capacity of the short traffic lane, C_2, with different lengths of short traffic lanes, veh/h					
$C_2 = N_k \cdot U$	36	300	270	240	216	198	180
$C_2 = N_k \cdot U$	60	500	450	400	360	330	300
$C_2 = N_k \cdot U$	90	750	675	600	540	495	450
		Total capacity of the main lane and the short traffic lane, veh/h					
$C = C_1 + C_2$	36	1300	1170	1040	1116	1016	930
	60	1500	1350	1200	1260	1148	1050
	90	1750	1575	1400	1440	1313	1200
Saturation flow, q_{s1}, veh/h		1800					

Table 5. Quality assessment of a short traffic lane performance depending on the vehicle idle time t_w (Holz-Rau, Brandt 2009)

Level of service (LOS)	A	B	C	D	E	F
Average idle time of a vehicle t_w, sec	< 15	< 30	< 45	< 60	< 90	91÷120

3. Conclusions and Remarks

The needed length of short traffic lanes L_{tj} depends on the flow distribution along movement directions (to the left, to the right and straight through).

The required length of short traffic lanes L_{tj} depends on the saturation level of the short traffic lanes g_{sat} and the length of max possible vehicle queue on the short traffic lane.

Prior to calculating the vehicle queue, the least number of unsaturated cycles on mixed and short traffic lanes per hour should be defined.

It is recommended to consider a longer cycle duration for the intersections with short traffic lanes (t_u = 100÷120 s).

If there is no possibility to build the lane of a sufficient length because of buildings situated too close to the street, the capacity of the short traffic lane C_2 would only partially reduce transport queues on mixed traffic lanes.

If there is no possibility to build one short traffic lane of the sufficient length, then two parallel traffic lanes of the same direction may be built.

When reconstructing intersections and installing short traffic lanes, it is recommended to make sure the idle time on short traffic lanes is $t_w < 60$ s and the LOS C is reached.

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