METHODOLOGY FOR ANALYZING CAPACITY AND LEVEL OF SERVICE USING HCM 2000

Ivona Nedevska
MSc, Teaching Assistant
University "Ss. Cyril and Methodius"
Faculty of Civil Engineering – Skopje
nedevska@gf.ukim.edu.mk

Zlatko Zafirovski
PhD, Assistant Professor
University "Ss. Cyril and Methodius"
Faculty of Civil Engineering – Skopje
zafirovski@gf.ukim.edu.mk

Slobodan Ognjenovic
PhD, Assistant Professor
University "Ss. Cyril and Methodius"
Faculty of Civil Engineering – Skopje
ognjenovic@gf.ukim.edu.mk

Riste Ristov
MSc, Teaching Assistant
University "Ss. Cyril and Methodius"
Faculty of Civil Engineering – Skopje
ristov@gf.ukim.edu.mk

Vasko Gacevski
MSc, Teaching Associate
Ss. Cyril and Methodius University
Faculty of Civil Engineering – Skopje
gacevski@gf.ukim.edu.mk

The augmentation of motorization level leads us to the need for mobility and demands better infrastructure, in urban and suburban areas. The complexity of this problem is especially notable in urban areas where the space delimitations, functional characteristics and different transportation must be considered.

The intersection between boulevard Krste Petkov Misirkov and boulevard Goce Delcev, in Skopje, has been analysed with the methodology for capacity and level of service, according to Highway Capacity Manual. Both boulevards are with three lanes before the intersection, and two additional lanes for left and right turns in the intersection area, and this is one of the most frequent intersections in Skopje. Number of vehicles is determined by measuring the traffic, and those inputs are used to analyse three solutions: The current solution (signalized intersection), Roundabout and interchange (levelled roundabout).

Calculations are based on custom measurements within a week.

Keywords: intersection, analysis, roundabout, capacity, level of service, Highway Capacity Manual

1. INTRODUCTION

City development affects all the movements and need for transportation. In urban areas, besides the motor traffic, bicycles and pedestrians are important part of city traffic. Part of the motor traffic in cities are buses, city railways, subway and trolleybus. These vehicles must be considered in each analysis, because of their influence [1].

The choice of the type of intersection and thus the applied design elements depend on the category of the road and its function in the network, as well as the ratio of the forecasted intensities and throughput [2]. Traffic conditions at the intersection must be regulated in such a way as to ensure maximum safety of all traffic participants and the required traffic flow. When choosing the type of intersection, one should strive for uniform solutions, which contributes to

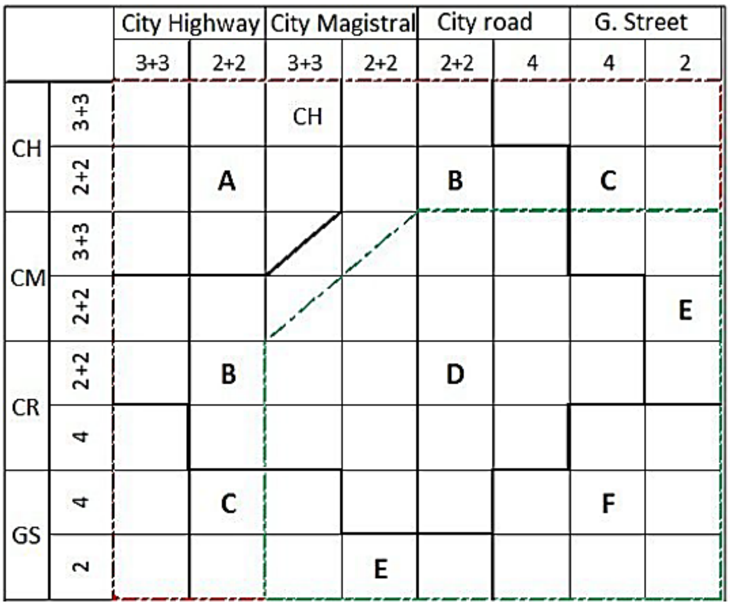

Figure 1. Functional level of intersection

the driver creating a "picture of the expected situation" and recognizability of the road category, which positively affects the driver's behaviour and thus the level of safety.

Intersection type is important and depends on many factors. For instance, if both roads are with similar traffic load, roundabout is recommendable. In case of different traffic load, signalized or unsignalized intersection is better solution. If the roads have more than 4 lanes, classical intersection is the best solution, or intersection with required signalization [3].

There are six types of intersection levels with defined connections and moving regime, according to the roads that are crossing (Fig.1) [4]:

- Functional level A means a interchange where there is no current intersection of the flows.
- Functional level B is applied to CM and CR, the intersection is levelled by cutting the traffic streams of lower rank.
- Levelled intersection with reduced outflow and intrusion is applied at the functional level C (inherent in the intersection of CH with lower rank roads).
- Complete traffic channelling and traffic lights are applied at functional level D. It is applied at city roads.
- Functional level E is applied when connecting gathering streets with streets of higher rank and implies the application of a surface intersections without sewerage of the traffic is applied in the assembly streets - functional level F. They can be signalized or unsignalized.

The Highway capacity manual is used for analyzing capacity and level of service for many various facilities [5]. The analyzed flows are classified as interrupted or uninterrupted flows. Uninterrupted flows are all the flows with no fixed elements (like traffic signals). Traffic flows depends on vehicles interactions and geometric and environmental characteristics.

Interrupted flows, on the other hand, have controlled and uncontrolled access points that interrupt the flow. This includes signals, stop-signs and any type of control that interrupts or slows the traffic. City roads are classified as interrupted because of the signs, signalization and bicycle and pedestrian presence.

The question is how to choose an appropriate traffic solution in the area of intersections and what is the correct choice of solution for intersection?

Such a complex question can be answered only with appropriate traffic analysis in order to check the capacity and level of service for the considered intersection. One way to make such a big decision is by applying the HCM methodology. Depending on how much traffic loads are involved and what spatial constraints occur. There are appropriate methods according to HCM that provide the level of service and capacity for signalized intersection, unsignalized classical or roundabout intersection and interchange.

With these methods, an analysis was made of the intersection of Boulevard Krste Petkov Misirkov and Boulevard Goce Delchev, and the obtained results are demonstrated in the reports.

Calculations have been made for different solutions at the indicated intersection, in order to determine which solution is most favorable.

2. REVIEW OF THE PREVIOUS RELATED STUDIES

In process of planning and design of road intersections the common question is whether to apply a roundabouts or a traditional type of intersection. Numerous studies have been conducted that consider the choice of the type of intersection, mostly for the choice between classical signalized and unsignalized intersection and roundabout [6].

Parameters that are commonly considered in the analysis are: effective intersection capacity, main road capacity, minor road capacity, major road average delay, minor road average delay, major road, 95% queue length, minor road 95% queue length [7].

From the results of the intersection capacity analysis studies based on HCM 2000, it is evident that the application of a roundabout scenario shows higher performance at the intersections than the intersection having a secondary signal [8]. In general, it was found that the two-way stop controlled intersection performed best for relatively low major road one-way volumes, the pretimed signal performed best for relatively high major road one-way volumes, and the roundabout performed best for a mid-range volume between the two.

For the specific case, intersection at Boulevard Krste Petkov Misirkov and Boulevard Goce Delcev, there are no similar studies.

3. CAPACITY ANALYSIS OF INTERSECTION AT BOULEVARD KRSTE PETKOV MISIRKOV AND BOULEVARD GOCE DELCEV

The purpose of the research is the analysis of the capacity and the level of service for the crossroads. In urban areas, there are intermittent flows, either due to the presence of signalization, crossing of pedestrians and cyclists. Such interruptions limit the movement time of the participants in the part of the intersection. The capacity of the roundabout, on the other hand, depends on one side of the surface and on the other side of the time constraints. This paper covers the methodologies for analysis of traffic light and non-traffic light intersection (roundabout), which lists the necessary input data, the procedure for analysis and comparison of the obtained solutions.

For start, it is necessary to know the geometric characteristics of the analyzed intersection (number and width of lanes, longitudinal slopes, etc.) and to provide traffic data. By knowing this data, we can categorize the bands according to the movements they distribute. Further calculations and analyzes are performed for each group of lanes respectively, and the results are summarized at the intersection level.

Taking into account the input data for traffic and geometry, the flow saturation is calculated, through which the capacity of the groups of lanes and the retention is obtained. The level of service is related to the size of delays (the greater delays the lower level of service).

The subject of research is a crossroad between Boulevard Krste Petkov Misirkov and Boulevard Goce Delcev in the city of Skopje.

Boulevard Krste Petkov Misirkov spans in line North - South, while boulevard Goce Delcev spans in line East -West. Both boulevards have three lanes before the intersection and two additional lanes for left and right turns. In the intersection area there are five lanes in total per leg (Figure 2) (Figure 3).

Figure 2. Current solution of intersection - blvd. Goce Delcev (East – West line), Skopje

Figure 3. Current solution of intersection - blvd. Krste Petkov Misirkov (Blvd. K. P. Misirkov - North - Blvd. K. P. Misirkov - South line), Skopje

For the needs of this analysis traffic measuring is made during a week (15.02.2016 - 21.02.2016) in the morning hours, 07:30 - 09:30 from Monday to Friday and 08:30 - 10:30 during the weekend.

The traffic was measured for each approach accordingly, dividing the vehicles according to the type, and then arranging them in the lanes for right movement, left and right turning.

Since measurements were made in a duration of 1 hour, it is necessary to convert this traffic into average daily annual traffic (ADAT).

From these measurements for the traffic, we can calculate average daily traffic (ADT 1) and average daily annual traffic (ADAT 2).

$$ADT = \frac{CO}{FNC} * 100 \qquad (1)$$

CO - Load per hour
FNC - n-hour factor (8-10, in this case it's 9)

$$AADT = \frac{ADT}{Ks} \qquad (2)$$

Ks - Factor of annual variability (Ks = 1.09 in this case)

The Origin - Destination matrix is presented for 15 minutes traffic for the analyzed intersection (Table 1).

	BGD - E	BGD - W	BKM - N	BKM - S	
BGD - E	0	270	59	81	**410**
BGD - W	173	0	61	23	**257**
BKM - N	167	48	0	91	**306**
BKM - S	173	49	135	0	**357**
	513	**367**	**255**	**195**	**1330**

Table 1. Origin - Destination matrix for the analyzed intersection

It is important to note that these data were obtained on the basis of own measurements over a period of one week, and they can not be used for analysis of the intersection in the future, because there is no data on traffic growth.

For Origin - Destination matrix a cartogram was made, in which the movements in the part of the intersection are presented (Figure 4).

Calculations have been made for different solutions at the indicated intersection, in order to determine which solution is most favorable:

- Four legged signalized intersection
- Roundabout - unsignalized intersection
- Interchange (roundabout) - unsignalized intersection

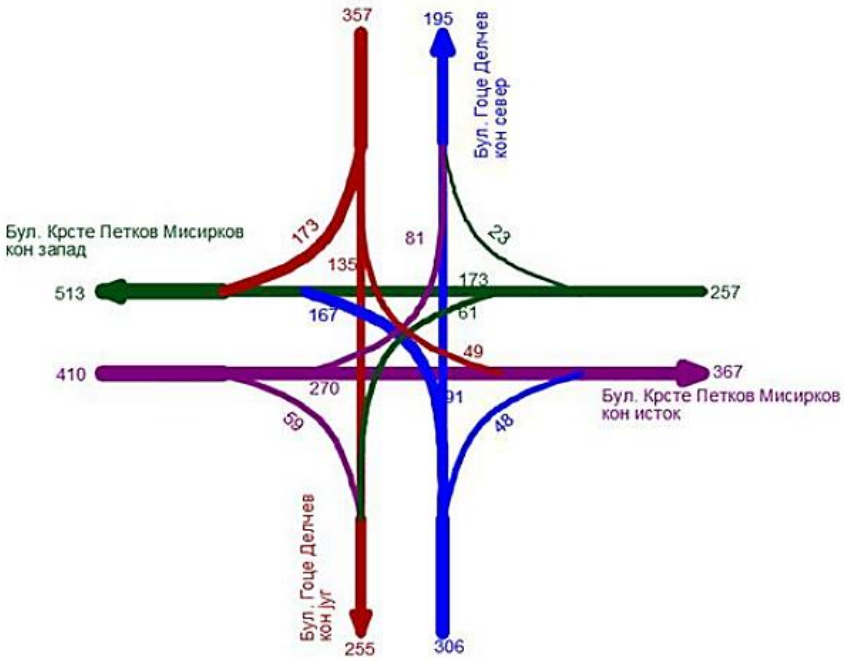

Figure 4. Cartogram of the analyzed intersection (Source: Own research)

3.1. FOUR LEGGED SIGNALIZED INTERSECTION

The intersection between blvd. Krste Petkov Misirkov and blvd. Goce Delcev is four legged signalized intersection. With personal counting of vehicles, the current traffic is obtained. Considering the influence of traffic, geometric and signalization conditions, appropriate correctional factors are used in order to calculate the saturation flow rate.

First step in the calculation is grouping the lanes, so that the capacity and level of service can be calculated for each group [9]. For this research lanes are grouped in 3 groups:

• Left turns and through
• Through
• Right turns

The left turns and through movements are actuated because they depend on the signalization, but the right turns as independent are classified as pretimed.

After grouping the lanes, volume adjustment is made by considering the percentage of heavy vehicles and peak hour factor. Next step is calculation of saturation flow rate, by knowing the number of lanes and appropriate adjustment factor (for lane width, HV, grade, area type, lane utilization...).

Now that both, adjusted flow rate in lane group and adjusted saturation flow are familiar, the capacity analysis can be done. For each group of lanes on each leg, critical lane group or phase is determined by the biggest flow ratio (v/s). Since all of the lane groups have flow ratio smaller than 1, except for the lane for right turns in the leg of Blvd. K. P. Misirkov - South the results for level of service are acceptable. Only the leg of Blvd. K. P. Misirkov - South has level of service F, while the other three have level of service A.

Another indicator of unsatisfying solution for the leg with LOS F is the delay.

In the calculations, the number of buses for some groups of lane is adjusted according to the HCM, it is given as 250 buses (max number given by the manual), even though the number is bigger than this. Also, each lane for right turns is analyzed as two lanes from 2.75m (2x2.75=5.50), because by the manual is not allowed to have lane wider than 4.8m.

With computation of total delay for each lane group, LOS can be determined, for each group lane and for each approach as well (Table 2).

Three of the approaches have LOS "A", while the approach of Blvd. K. P. Misirkov - South has LOS "F", because of the right turns, where the flow is bigger than the capacity.

Lane group capacity, Control delay and LOS determination				
	BGD - E	BGD - W	BKM - N	BKM - W
LOS by approach	A	A	A	F
Approach flow rate $v_a(veh/h)$	3958.06	2476.77	2960.61	3450.37
Intersection delay d_I	5.07	0.27	9.45	129.00

Table 2. Final results for signalized four-legged intersection

3.2. ROUNDABOUT – UNSIGNALIZESD INTERSECTION

Roundabout analysis is divided in two parts, computation of approach flows and computation of circular flow. In order to obtain more realistic results for each lane group, methodology for unsignalized four-legged intersection is used. First step is defining circulating traffic for each entry stream. (For example, for streams 7, 8 and 9 circulating flow is 1, 2 and 10).

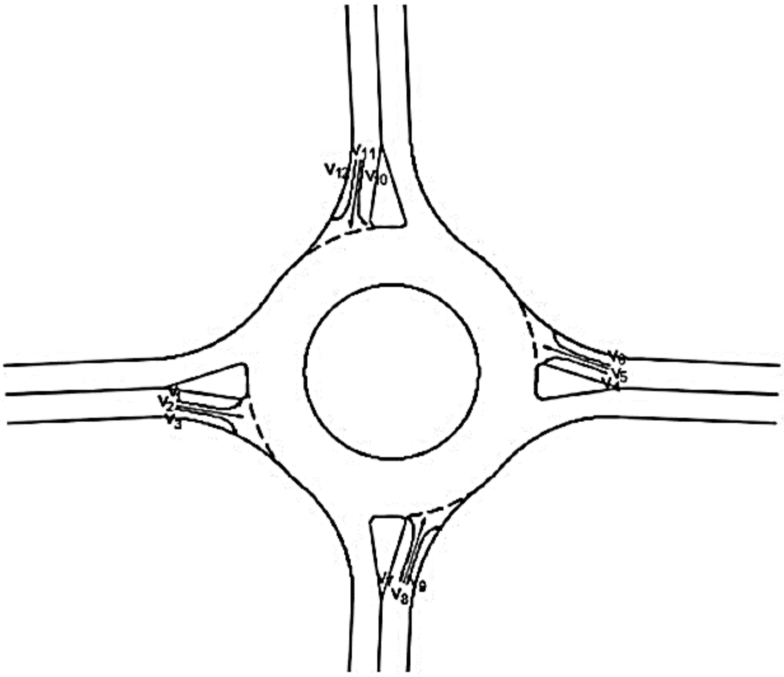

Figure 5. Flow stream definition

Because HCM 2000 only gives solution for roundabout with one circular lane, HCM 2010 methodology for two circular lanes is used in order to compute the capacity and obtain LOS. According to this methodology, the right lane is defined as dominant and the left lane as subdominant lane.

Since v/c ratio is bigger than 1,0 in two approaches (Blvd. G. Delcev - West and Blvd. K. P. Misirkov - North), the delays are bigger and LOS is lower. For these approaches LOS is "F", while for the approach of Blvd. G. Delcev - East LOS is "B" and of Blvd. K. P. Misirkov - South is "C" (Table 3).

Two - lanes roundabout				
	BGD - E	BGD - W	BKM - N	BKM - S
Entry lane capacity (right lane)	425	276	749	1059
Entry lane capacity (left lane)	716	561	500	515
Total capacity	1141	836	1248	1574
v/c	0.69	1.31	1.03	0.82
Control delay	14.89	164.19	52.11	16.68
LOS	B	F	F	C

Table 3. Final results for roundabout with two circular lanes

This results are expected, considering the fact that approaches with 3 lanes before, and 5 lanes in the intersection area are reduced to two-lane approaches and two-lane circular flow. Another anomaly in this concept is the lack of adjustment factors (only factors for heavy vehicles, pedestrians and bicycles are used). Anyway, utilization of roundabout with more than two lanes is insecure solution, considering the number of conflicting points.

3.3. INTERCHANGE (ROUNDABOUT) – UNSIGNALIZED INTERSECTION

Since neither of the previously mentioned solutions is acceptable, another possibility is analysed. By using diamond junction, delays would still remain big, and LOS would be low, so deleveled roundabout is proposed as more acceptable solution. The through movements from the main road are segregated in one level, while all the other movements are lead on another level, with circular flow. The same calculations as in two-lane roundabout is used, just the TH movements from Blvd. Goce Delcev are removed.

From the table is obvious that both approaches of blvd. Krste Petkov Misirkov have acceptable delays and LOS "A", while the approach of Blvd. G. Delcev - East has LOS "B" (which is acceptable) but the approach of Blvd. G. Delcev - West has LOS "F" (Table 4).

This solution is proposed strictly from visual and traffic aspect, with no information for installations, possibility for developing ramps or length of ramps.

Deleveled Two - lanes roundabout				
	BGD - E	BGD - W	BKM - N	BKM - S
Entry lane capacity (right lane)	425	276	1300	1510
Entry lane capacity (left lane)	716	561	903	753
Total capacity	1141	836	2203	2264
v/c	0.69	1.31	0.19	0.32
Control delay	14.89	164.19	52.11	16.68
LOS	B	F	A	A

Table 4. Final results for deleveled roundabout with two circular lanes

4. RESULTS AND DISCUSSIONS

Achieving the required capacity and level of service on any road and intersection as a whole, urban or suburban, is correlated with traffic load and geometric features [10]. In the years to come, with the development of technology and industry, as well as with social changes, traffic planning will become even more complex.

With the help of HCM methods that provide the level of service and capacity for signalized intersection, unsignalized classic or circular intersection and for deleveled roundabout, an analysis was made of the intersection of Boulevard Krste Petkov Misirkov and Boulevard Goce Delchev.

The aim is to achive satisfactory level of service and capacity.

4.1. REVIEW OF THE PROPOSED SOLUTIONS FOR THE INTERSECTION

Each of the proposed solutions has advantages and disadvantages. The solution with signalized intersection has relatively small delay, except for the approach of Blvd. K. P. Misirkov - South. The results are less acceptable for two-lane roundabout, while the deleveled roundabout has similar results as signalized intersection.

If the actual solution is accepted as more favorable, some corrections must be done, so that the problem with low level of service can be solved. One way to solve this problem is by directing the traffic on other existing roads.

Also, special lane for public transport vehicles would also help, because buses have big influence in capacity and level of service.

The bad results for both roundabouts can be because of the reduction of lanes in the intersection area. Anyway, this results are based on personal counting of traffic in short period, without previous information in order to obtain traffic increment, so they should be observed with backup.

4.2. INTERSECTION SAFETY

Studies have shown that roundabouts are safer than traditional stop sign or signal-controlled intersections [11].

Roundabouts reduced injury crashes by 75 percent at intersections where stop signs or signals were previously used for traffic control, according to a study by the Insurance Institute for Highway Safety (IIHS). Studies by the IIHS and Federal Highway Administration have shown that roundabouts typically achieve:

- A 37 percent reduction in overall collisions.
- A 75 percent reduction in injury collisions.
- A 90 percent reduction in fatality collisions.
- A 40 percent reduction in pedestrian collisions [12].

Increased safety of modern roundabouts occurs as a consequence of reducing the number of points of conflict compared to classic intersections, as well as reducing vehicle speed both when entering and while driving through the intersection, which is conditioned by the geometric shape of the intersection.

The reduction of the number of conflict points refers to both conflict points between vehicles and conflict points between vehicles and pedestrians (Figure 6) [13].

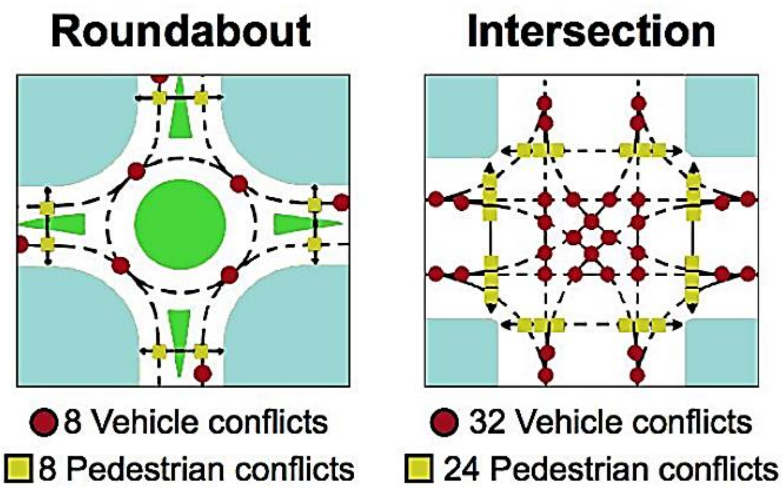

Figure 6. Points of conflict between the traditional intersection and the roundabout

4.3. WAYS TO IMPROVE THE LEVEL OF SERVICES

With the performed analyzes, results can be obtained where the level of service for any of these solutions is not satisfied. In this case, it is necessary to make changes in the existing solution and direction of traffic.

One of the ways to improve the level of service at a given intersection is to redirect part of the traffic on the existing road network, which would relieve this intersection. The possibility to expand the existing road network is not the most favourable solution, because by increasing the number of lanes, the capacity of the leg can be increased, but in the part of the intersection, large delays can occur, which would make it non-functional.

As public transport vehicles play a major role in the functionality of the intersection, it is possible to introduce a special lane for these vehicles, which would not interfere with other road users.

In developed countries, a commonly used way to solve the problem of capacity and throughput in the central urban areas is by introducing a ban on the movement of motor vehicles, restricting the movement in the central areas or charging for the movement of motor vehicles in these areas.

5. CONCLUSION

At the moment when the existing intersection, due to overload or a large number of registered accidents, no longer functions as planned, the question arises whether there is a better solution, another type of intersection that works better. When introducing a new intersection into the traffic network, there is often a dilemma as to which type of intersection to apply. The path to a solution to these problems is not easy. The choice of the most favourable solution when choosing the type of intersection is influenced by aspects such as traffic safety and the quality of traffic flow determined by the capacity, waiting time and the degree of saturation. Other aspects that may influence the choice are the integration of the solution into the environment (surface and aesthetic) and of course the costs.

From the results obtained from the HCM model, due to the heavy traffic load, the most acceptable solution was a interchange (deleveled roundabout) where the movements in the main direction are separated.

The previous results are important because they can determine level of service and capacity for different solutions and improve the traffic performance of them in the future.

Finally, future research should be conducted to extend all aspects of this research using comprehensive field data and traffic measuring. For each major and significant intersection in urban areas it is necessary to make an analysis of capacity and level of service, in order to solve the problem of traffic jams.

It is necessary to make measurements of traffic on a time interval to get a realistic picture of the growth of traffic, which would perform a satisfying capacity in the future.

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