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DIMENSIONING OF SIGNALIZED INTERSECTIONS IN REALISTIC URBAN ENVIRONMENT

ABSTRACT

It is very complex to assure the dynamics of traffic network in urban environment because of the intensity of traffic flows and the limited space in the urban area. Signalized intersections are undoubtedly very important and frequent element in road traffic network in urban regions, which greatly influences the traffic flow dynamics on each section as in the whole traffic network. The time (delay) a vehicle needs to drive through an intersection directly influences the travel comfort, fuel consumption, traffic pollution and so on. There are many methods for dimensioning signalized intersections in the world literature. One of the most applied methods is the HIGHWAY CAPACITY MANUAL (HCM) 2000 which is based on competent input traffic flows and other characteristics of traffic signal regulations. The intention of this paper is to establish whether we can use the HCM 2000 method directly in the Slovenian real environment. Based on the established methodology of research and limited number of delay measurement in real environment intersections, there have been some deviations. The completion of the level of service criterion for signalized intersections has been proposed, with the intention for more suitability estimation in the realistic environment.

KEYWORDS

signalized intersection, control delay measurement, level of service

1. INTRODUCTON

Speed and time needed to travel a defined distance in traffic network and traffic consumers' level of demand realization are factors which define quality of residence in the urban area. Traffic literature (too) often deals with traffic flow theory without usable relations to real traffic space researching. The effect of signalized intersections is closely connected with stopping the traffic flow. Every stopped vehicle means waiting on the spot and that is contrary to its fundamental purpose. Duration of vehicle delay in intersection area directly determinates the level of service (LOS). Higher delay means lower LOS. Delay value calculations by the used methods must be examined in real environment to ensure objectivity.

HCM 2000 methodology for signalized intersections deals with many factors which estimate (describe) the intersection as a whole and/or in its elements (arrival and driving lane). Elementary input parameters describe real conditions of a study intersection. They contain geometrical, traffic and signal conditions which appear in real environment and define the (in)adequacy of a treated intersection element. Control delay per vehicle in signalized intersection is established on the basis of output parameters and represents the decisive factor to determinate LOS.

This paper is based on incontestable connection of traffic flow theory and its research in real traffic space. The foundation of research is represented by the connection between the results based on HCM methodology and the results measured in real environment.

2. METHODOLOGY

2.1. Object and problem of research

Urban road systems are ultimately controlled by the function of the major intersections. Intersection failure directly reduces the number of vehicles that can be accommodated during the peak hours that have the highest demand and the total daily capacity of a corridor. As a result of this strong impact on corridor function intersection improvements can be a very cost-effective means of increasing a corridor's traffic volume capacity. With that in mind, it is important to determine how well the signalized intersections (especially the major ones) function by determining their LOS. The object of this research is to provide exploratory analysis of variability in signalized control delay using real-world measurement on sample intersections. Specifically, analyses were performed of the distribution of control delay, the relationships between LOS criteria and deviation of control delay in real-world.

The problem of research can be defined as: to prove the use of HCM methodology for signalized intersections in real (Slovenian) environment and to propose the necessary methodology correction. Interdependence and legality between results of HCM methodology and real environment must be analysed.

The delay measures are used for signalized intersections to evaluate the benefits of operational improvements and to estimate the cost-effectiveness, so that fundamental scientific hypothesis would be: the scientifically founded factors and methods for estimating the signalised intersection functioning can greatly influence the optimal dynamics of traffic urban network. By the context of signalized intersection dimensions, the HCM methodology can be directly assumed on account of its universal character. To directly assume the HCM methodology uniformity of theoretical origin and real traffic space parameters must be defined. The dependence of theoretical and realistic aspect of the used methodology should be analysed and guidelines for eventual correction should be proposed.

2.2. Data analysis

LOS is a qualitative measure developed by the transportation professions and represents the best available measure. It provides a means for identifying intersections that experience operation difficulties, as well as providing a scale to compare intersections with each other. The procedures used in HCM to evaluate the signalised intersections use detailed information on all the important parameters. Using these techniques and the data collected in the realistic environment, comparative criteria should be used. Feasibility of the used methodology with concrete realistic examples must be established with experimental field measurement. On that foundation the potential adjustment of the used methods is performed to establish real environment LOS (Diagram 1).

3. DIMENSION OF SIGNALIZED INTERSECTIONS BY HCM 2000

The represented and the used methodology in this paper are the latest tools and criteria from the Highway Capacity Manual 2000 by which the dimension of signalized intersections in the realistic environment is performed. The HCM contains concepts, guidelines, and computational procedures for computing the capacity and quality of service of various highway facilities, including freeways, signalized and unsignalized intersections, rural highways, and the effects of transit, pedestrians, and bicycles on the performance of these systems. HCM 2000 is a completely revised, updated, and expanded edition that reflects the results of a multiyear research.

With usage of adequate tools and methods, the dimensioning of the signalized intersection, arrival lane and/or drive lane is performed to establish the degree of suitability above all from the point of fluent traffic distribution. These procedures enable us to define and provide problematic element(s) of traffic network on the basis of real traffic distribution parameters. With the continuity of the present and long-run traffic flow situation, the usage of the analysed signalized intersection at present signal regulation with this method can be forecast. Also the steps of adaptation in the future can be indicated.

The data needed for HCM methodology are detailed (varied) and fall into three main categories: **geometric, traffic and signalisation.** All the needed input data must be observed in the field and must be determined as accurately as possible. On their basis the delay estimates and LOS are determined. The control delay and LOS, like capacity, are complex variables influenced by a wide range of traffic, roadway and signalization conditions. That is why we must accede to the methodology accurately and objectively (Diagram 2).

Intersection LOS is directly related to the average control delay per vehicle. Once delays have been esti-

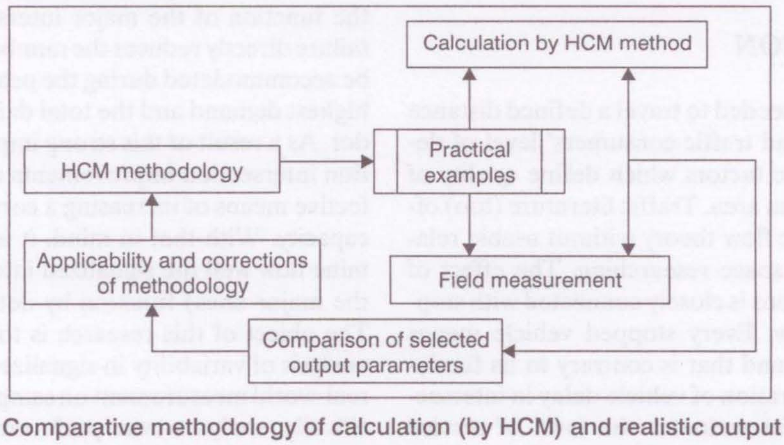

Diagram 1 - Comparative methodology of calculation (by HCM) and realistic output parameters

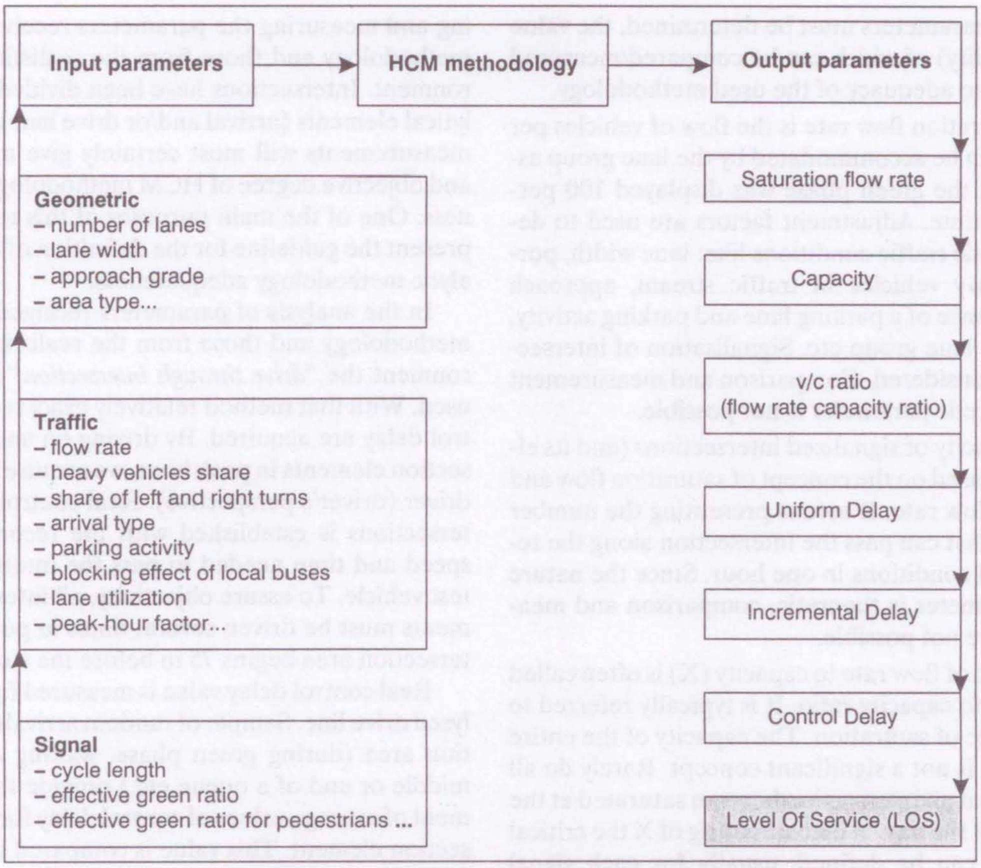

Diagram 2 - HCM 2000 methodology for signalized intersections

mated for each lane group and aggregated for each approach and the intersection as a whole, Table 1 is consulted, and appropriate LOS determined. Generally, the closer traffic volumes are to being above capacity, the lower the LOS. LOS provides an indication of how well the transportation supply serves the transportation demand and qualitatively measures the operational conditions within a traffic stream and their perception by motorists and/or passengers. It also provides an index of quality based on the factors such as speed, travel time, freedom to manoeuvre, traffic interruptions, comfort, convenience and safety.

Table 1 - LOS criteria for signalized intersections

Control delay per vehicle (s/veh)	LOS
< 10	A
10-20	B
20-35	C
35-55	D
55-80	E
> 80	F

Source: HIGHWAY CAPACITY MANUAL, Transportation Research Board, Washington, 2000

LOS range from A to F. LOS A represents the best operations, LOS F represents the worst, but does not mean failure. Rather, acceptable LOS can vary widely. In a rural area, transportation facilities may be designed to provide LOS B or C. In a large urban area, LOS E or F operations during peak hours may be tolerated. A facility that operates at LOS F during one hour of the day may operate at LOS C or better the other 23 hours. Some transportation systems have major seasonal changes in traffic flows that could, for example, result in peak hour LOS F for 10 weeks of the year and LOS B for most of the other 42 weeks. LOS must be interpreted carefully because some locations with low calculated LOS exhibit higher LOS when observed in the field.

4. REAL ENVIRONMENT RESEARCH

4.1. Measurement methodology in real traffic space

In purpose of defining adequateness of the used HCM 2000 methodology for signalized intersections in real environment the comparative parameters must be established. By that we mean parameters received with HCM methodology and those from realistic local environment.

Output parameters must be determined, the value (and suitability) of which can be compared/measured to analyse the adequacy of the used methodology.

The saturation flow rate is the flow of vehicles per hour that can be accommodated by the lane group assuming that the green phase was displayed 100 percent of the time. Adjustment factors are used to describe realistic traffic conditions like: lane width, portion of heavy vehicles in traffic stream, approach grade, existence of a parking lane and parking activity, left turns in lane group etc. Signalisation of intersection is not considered. Comparison and measurement of this theoretic parameter is not possible.

The capacity of signalized intersections (and its elements) is based on the concept of saturation flow and saturation flow rate. It means presenting the number of vehicles that can pass the intersection along the realistic signal conditions in one hour. Since the nature of this parameter is theoretic, comparison and measurement are not possible.

The ratio of flow rate to capacity (X) is often called the volume to capacity ratio. It is typically referred to as the degree of saturation. The capacity of the entire intersection is not a significant concept. Rarely do all movements at an intersection become saturated at the same time of the day. With computing of X the critical lane group can be defined, usually for each signal phase. It also cannot be compared or measured in the realistic environment.

The values derived from delay calculation represent the average control delay experienced by all vehicles that arrive in the analysis period. Control delay includes movements at slower speeds and stops on intersection approaches as vehicles move up in queue position or slow down upstream of an intersection. The majority of control delay is composed of uniform and incremental delay. Uniform delay is based on the first term of delay formulation and is accepted as an accurate depiction of delay for the idealized case of uniform arrivals. Assuming uniform arrivals, stable flow and no initial queue are estimate of delay. The incremental delay accounts for non-uniform arrivals and temporary cycle failures (random delay) as well as delay caused by sustained periods of oversaturation (oversaturation delay). It is sensitive to the degree of saturation of the lane group (X), the duration of the analysis period, the capacity of the lane group and the type of signal control. Comparison and measurement of delays is not only possible but also necessary to establish the degree of adequateness of HCM methodology and possibly corrections for the realistic environment.

Adequate methodology for delay analysis purposes in realistic traffic space must be developed to insure objectiveness. The method of acquiring realistic data must be defined precisely. Two signalized intersections have been analysed with the aim of comparing and measuring the parameters received by HCM methodology and those from the realistic local environment. Intersections have been divided in ten analytical elements (arrival and/or drive lane). More field measurements will most certainly give more precise and objective degree of HCM methodology adequateness. One of the main purposes of this research is to present the guideline for the definition of the used analytic methodology adequateness.

In the analysis of parameters received with HCM methodology and those from the realistic local environment the *"drive through intersection" method* was used. With that method relatively exact results of control delay are acquired. By driving on analysed intersection elements in peak hour, we acquire the role of a driver (driver's perspective). Real control delay in intersections is established with the recorded vehicle speed and time needed to pass the intersection with test vehicle. To assure objectivity, all intersection elements must be driven several times in peak hour. Intersection area begins 75 m before the stop line.

Real control delay value is measured for every analysed drive line. Sample of random arrivals in intersection area (during green phase, waiting at the start, middle or end of a queue etc.) provide the establishment of average values of control delay for every intersection element. This value is compared with the one calculated by HCM methodology. More test drives must be accomplished on the less loaded intersections (not oversaturated) like at the more loaded ones. Because of greater possibility of driving through intersection in the green phase, the delay value has a wider span (instant drive through or waiting the entire signal cycle). If drive line does not allow driving through the intersection in the first green phase (green time does not provide vehicle queue), values of real environment control delay are within a narrower span. Therefore, the less the intersection is loaded (saturated), the more test drives must be performed.

The measures in real environment are in some cases of oversaturated traffic conditions inaccurate.

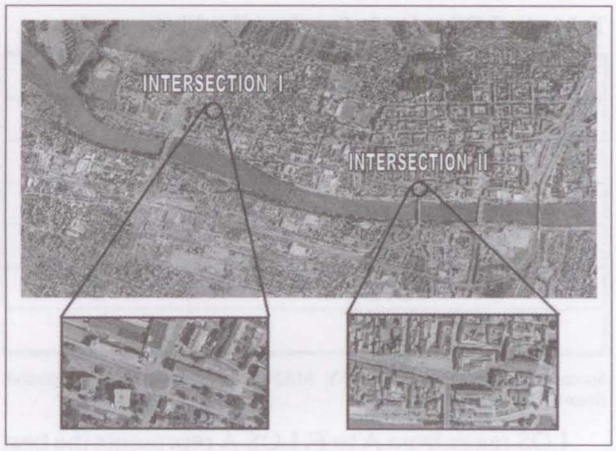

Figure 1 - Intersection locations in Maribor

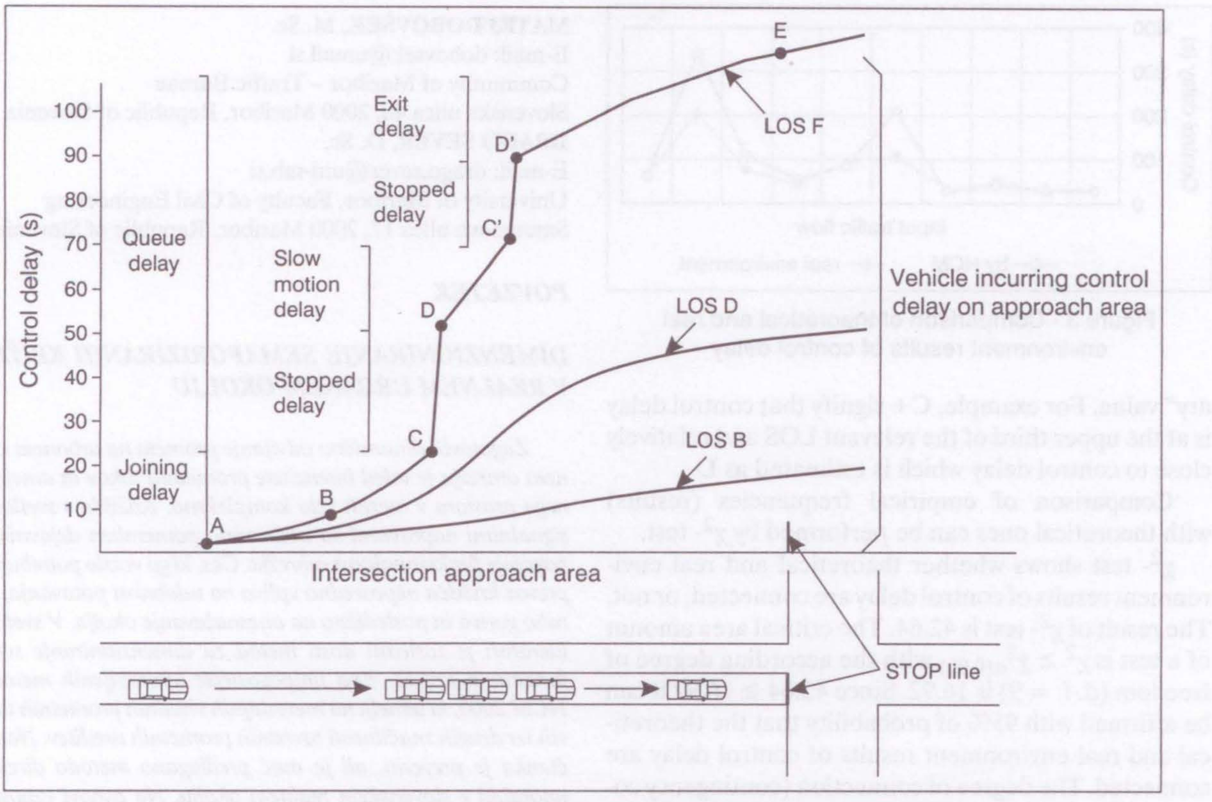

Figure 2 - Time-space relationship for vehicle in signalized intersection

Identifying the points when the vehicle enters and exits the delay "area" can be a difficult task for a number of reasons. Vehicle speeds are often less than the desired speed due to general street congestion or a slow lead vehicle in a platoon. Such conditions must be carefully analysed before attributed to intersection delay. It is also difficult to measure upstream delay during over-capacity conditions because of the stop-and-go actions experienced during queue move-up times. For example, an overcapacity intersection may create deceleration, idling and acceleration during queue move-up, then another deceleration, and a final acceleration through the intersection. Closely spaced intersections cause more potential difficulties in estimating control delay because long queues can extend the next upstream intersection. The HCM calculates intersection control delay assuming isolated conditions.

The intersection delay can be characterized by the stopped delay, time in queue delay, and approach delay. Figure 2 depicts the time-space trace of a vehicle that comes to a stop several times on the same signalized intersection approach. This trace might occur at a congested location during peak volumes when a queue of stopped vehicles is not completely discharged during one green phase. It also represents a situation where there is considerable compression of the queue during the red phase, or where a lane carries both through and left-turn movements, or there are stop-and-go conditions.

4.2. Data analysis

Figure 3 shows comparison of the results by HCM methodology and from real environment. Differences are greater in oversaturated intersection elements. In these intersection elements vehicles are waiting to drive through the intersection two or more signal cycles. Value differences arise on account of theoretical and practical proceedings of research themes. Theoretical HCM methodology is based on average value of control delay on analysed intersection element, which is used as origin to determinate LOS. However, values from realistic local environment represents average of delays in several drives through analysed intersection element at different traffic conditions (start, middle and end of green or red signal phase). Comparison of theoretical and real environment results of control delay must be performed by LOS criteria (A, B, C, D, E, and F). Deviations of the calculated and the measured values should not be analysed by time value, because LOS represents the estimation of the signalized intersection and/or its elements.

For the sake of objectivity to estimate LOS, it is necessary to expose the so-called "boundary" values, that is, values that are near two levels of service (for example 77s = LOS E, LOS F > 80s). It is reasonable to initiate (classify) levels of service on separate sub-levels. With sub-levels it could be determined "at first sight" if LOS is close to the adjacent LOS. If a sign (+ or –) is affix next to LOS estimation, that signifies the "bound-

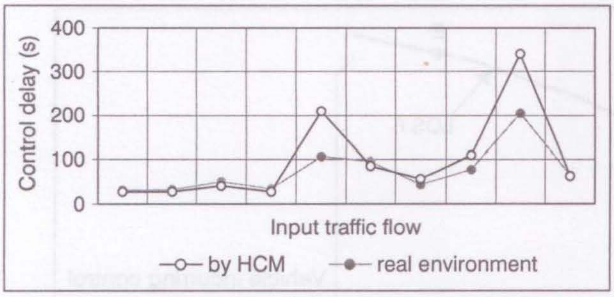

Figure 3 - Comparison of theoretical and real environment results of control delay

ary" value. For example, C+ signify that control delay is at the upper third of the relevant LOS and relatively close to control delay which is estimated as D-.

Comparison of empirical frequencies (results) with theoretical ones can be performed by χ^2- test.

χ^2- test shows whether theoretical and real environment results of control delay are connected, or not. The result of χ^2- test is 42.64. The critical area amount of a test is $\chi^2 \geq \chi^2{}_{\alpha(0.05)}$ with the according degree of freedom (d. f. = 9) is 16.92. Since 42.64 ≥ 16.92 it can be affirmed with 95% of probability that the theoretical and real environment results of control delay are connected. The degree of connection (contingency coefficient) is 0.18, which is good but not the strongest. This statistical result is conditional with limited extent of research in real local environment and with a specificity of a research area (indeterminate system).

5. CONCLUSION

In order to determine LOS for signalized intersections, average control delay is the best available measure in the functioning of the estimated urban traffic network. When estimating signalized intersection we must always accede carefully and bear in mind that every intersection is unique (especially with the results of interpretation). The results of control delay analysis in real environment give causes of critical intersection elements. These indicators enable fast and effective solution for traffic congestion. Permanent analysis of dynamics, structure of traffic flows and adaptations of analytical methodologies must be performed to assure dynamic traffic course. Let the principle *"dynamic of traffic flows must form organization of traffic network, not the other way round"* be the guidance.

More field measurements on the largest number of signalized intersections would give more precise adequateness of the HCM methodology. Despite the limited number of the analysed intersections, it could be established that HCM methodology is adequate for the usage in the Slovenian environment. That is based on relatively high share of compliance between theoretical and practical analyses, which create objective estimation of the used methodology.

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POVZETEK

DIMENZIONIRANJE SEMAFORIZIRANIH KRIŽIŠČ V REALNEM URBANEM OKOLJU

Zagotoviti dinamično odvijanje prometa na urbanem cestnem omrežja je vsled intenzitete prometnih tokov in omejenenega prostora v mestih zelo kompleksno. Križišča s svetlobno signalnimi napravami so nedvomno pomemben dejavnik, ki pogojuje funkcionalnost omrežja. Čas, ki ga vozilo potrebuje za prevoz križišča neposredno vpliva na udobnost potovanja, porabo goriva in posledično na onesnaževanje okolja. V svetovni literaturi je zaslediti dosti metod za dimenzioniranje semaforiziranih križišč. Ena najpogostejše uporabljenih metod je HCM 2000, ki temelji na merodajnih vhodnih prometnih tokovih ter drugih značilnosti tovrstnih prometnih ureditev. Namen članka je preveriti, ali je moč predlagano metodo direktno uporabiti v slovenskem realnem okolju. Na osnovi vzpostavljene metodologije raziskovanja in omejenemu številu meritev zamud vsled signalnih naprav v križišču, so bila ugotovljena določena odstopanja. Predlagane so dopolnitve kriterija za določitev nivoja usluge za križišča s svetlobno signalnimi napravami, ki ustrezneje opredeljujejo dejansko stanje v realnem prometnem prostoru.

KLJUČNE BESEDE

signalizirana križišča, merjenje kontrolne zamude, nivo usluge

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