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ASSESSMENT OF TRAFFIC EFFICIENCY INDICATORS FOR TWO-WAY, TWO-LANE RURAL HIGHWAYS THROUGH DIFFERENT HCM METHODOLOGIES

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Abstract

More than 90% of the Croatian road network consists of two-lane, two-way highways. These roads play a crucial role in intercity, regional, and local connectivity. The level of service they provide directly affects traffic efficiency, travel costs, and overall mobility. According to national regulations, their functional efficiency must be evaluated during the design phase using the Highway Capacity Manual (HCM) methodology. This paper compares the results obtained by applying the methods outlined in the HCM2000 and HCM2022 editions. The objective was to demonstrate, using a conceptual design for a two-lane, two-way, 7.6-kilometre bypass of the Janjina settlement, the differences between the older and newer methodologies and to contribute to a better understanding of their practical application. The review and comparison of the methodologies showed that HCM2022 incorporates road curvature directly into speed estimation, whereas HCM2000 uses simpler terrain-based adjustments. HCM2022 also introduces a unified service measure, replacing the previous approach that relied on multiple measures linked to highway classifications. On the other hand, it requires more precise design data and is more labour-intensive. The results of applying both methods to the highway section showed no significant difference in estimated travel speed. However, the HCM2000 methodology yields a lower level of service. It was concluded that the HCM2000 methodology is more appropriate when a robust, faster, simpler, and less parameter-intensive estimate for a two-lane, two-way highway is required.

Keywords: two-lane two-way highway, level of service, comparison, HCM2000, HCM2022

1 Introduction

As in most countries, two-way two-lane highways form the core road network in the Republic of Croatia, serving as a crucial link between urban and rural areas. According to the national regulations [1], public two-way two-lane highways are classified into five categories based on the average annual daily traffic (AADT) anticipated at the end of the planning period, and their function in the road network, depending on the average journey length. During the design process, the required road category is essential data for determining the design speed. This, in turn, influences the fundamental elements of road geometric design, including the horizontal alignment, vertical alignment, and cross-section. Ultimately, road design must be validated through capacity calculations based on forecasted traffic volume and structure, ensuring the required level of service (LOS) by the end of the road planning period. A road must be designed to maintain a specified LOS along its entire length, or at least within sections with similar traffic volumes and structures, which correspond to the designated road category. This LOS estimation should be conducted by the Highway Capacity Manual (HCM) procedures.

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The HCM, published by the Transportation Research Board, has undergone several significant revisions since its first edition in 1950. Major updates were issued in 1965, 1985, 2000, 2010, 2016, and 2022. The advancement of modern technologies for collecting traffic data has greatly enhanced LOS analysis by providing more accurate and continuous empirical data on traffic flows. Consequently, increasingly precise and efficient analytical methods for assessing traffic flow quality continue to be developed, as indicated by the numerous new editions and updates to the HCM since 2000, which have systematically integrated new scientific insights and methods.
The objectives of this investigation are to: (1) provide a brief overview of the basic concepts of LOS estimation based on the HCM editions from 2000 and 2022, (2) apply both methodologies to analyse the effectiveness of a two-way two-lane rural highway design, and (3) compare the results of these analyses to assess the extent to which the improvements in the HCM2022 methodology influence the evaluation process and the final assessment of the highway project's quality.

2 Basic concepts

According to the HCM2000 [2], two performance measures describe service quality on two-lane highways: (1) percent time-spent-following (PTSF), and (2) average travel speed (ATS). PTSF represents the freedom to manoeuvre and the comfort and convenience of travel. It is the average percentage of travel time during which vehicles platoon, not managing to pass slower vehicles. ATS reflects the mobility. It is the length of the highway divided by the average travel time of all vehicles traversing in both directions during a designated interval. The HCM2022 [3] introduces three performance measures: (1) average speed (AS), (2) percent followers (PF), and (3) follower density (FD). PF is the percentage of vehicles passing a given point in a follower state, at a headway of 2.5 s or less. FD is the number of vehicles in a follower state per length unit (mile) per lane, and it is used as a primary service measure.
According to the HCM2000, two-lane highways are categorised into two classes based on expected travel speed, distance, and road function. Class I corresponds to national road categories 1 and 2, and Class II corresponds to categories 4 and 5. A Category 3 road can be classified as Class I or Class II, depending on its design or limit speed. On Class I highways, both PTSF and ATS define LOS. On Class II highways, LOS is defined only in terms of PTSF. Although HCM2022 does not explicitly define highway classification, it provides different FD thresholds for a given LOS depending on the expected speed: higher than or equal to 80 km/h and lower than 80 km/h.
The first step in both methodologies is to divide the analysed two-lane highway into segments with homogeneous vertical grade, lane and shoulder width, number of lanes, design speed, and traffic demand and composition. The results from each segment analysis are then combined into results for the whole highway. The HCM2000 methodology differs for (1) two-way segments on which the analysis is performed in both directions together, (2) directional segments on which the analysis is performed for each direction separately due to higher vertical grade values, and (3) directional segments with passing lanes (an additional lane for slow vehicles or an overtaking lane). The percentage of no-passing zones, i.e., the percentage of each segment length along which passing is prohibited, must be defined for each segment. On the other hand, the HCM2022 incorporates this ability to pass directly into segmentation process, as its methodology differs for (1) passing constrained segments in which passing in the oncoming lane is either prohibited or is effectively negligible due to geometric or sight distance limitations, (2) passing zone segments which permit passing in the oncoming lane, and (3) passing lane segments which provide an additional lane in the same travel direction for a relatively short time.

Along highways with homogeneous traffic and cross-section geometry, the segmentation process for the HCM2000 ends once vertical alignment changes are located. The designed vertical grade, length, and direction (upgrade or downgrade) define the segment's terrain type (HCM2000) or vertical class (HCM2022). These are the main parameters that affect calculation steps, default values, and results. Additionally, HCM2022 requires identification of the subsegments, based on segments' horizontal alignment (tangents and horizontal curves defined by their length, radii, and superelevation).

3 Investigation

3.1 Case example and input data

The analysed section of a planned category 3 two-lane, two-way highway is planned in a rural area of the Municipality of Janjina, bypassing the southern side of the settlement (marked by a dotted red line in figure 1) [4]. The planned section was designed for a speed of 80 km/h [5-7]. Horizontal alignment consists of 14 tangents and 18 curves, with a minimum radius of 250 m, while the largest applied vertical grade is 6%. The total length of the section is 7.56 km. The roadway consists of two 3.3-m-wide lanes and 1.3-m-wide shoulders or berms. Planned at-grade intersection connects the designed bypass with the local road network.
According to [1], Category 3 roads are designed for an AADT at the end of the planning period of up to 7, 000 vehicles per day in both directions. This value was the basic input for further analysis of traffic flow volumes and flow rates. Current traffic flow composition and peak hourly traffic data were obtained from [8], for traffic counting station 6502 on state road D-414, from which traffic is to be redirected to the analysed planned section.

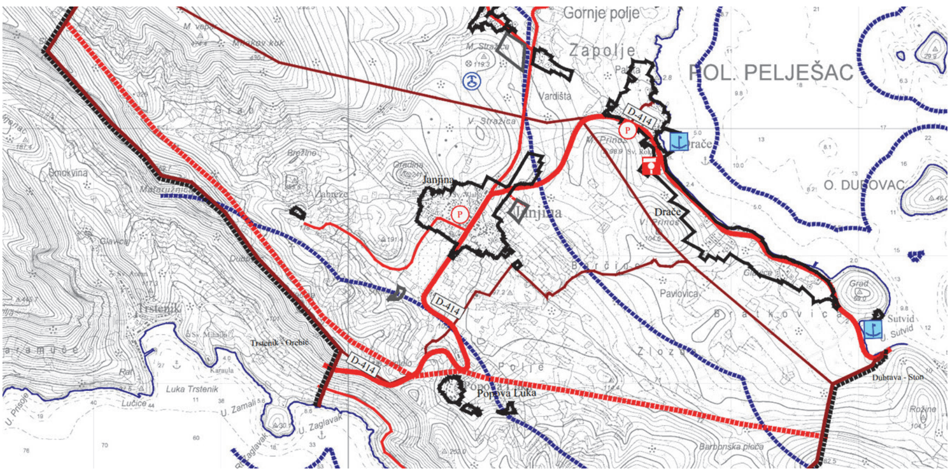

Figure 1 Excerpt from the cartographic representation of the Spatial Plan of the Janjina Municipality [4]

The percentage of various vehicle types was obtained from records of a stationary meter for continuous traffic counting. Vehicle groups other than passenger car (pc) were defined and their percentages aggregated as: (1) 3% of recreational vehicles (RVs) comprising of vans with or without trailers, small and medium-sized trucks (vehicle groups A3, B1 and B3) and (2) 14% of heavy vehicles (HVs) comprising of groups heavy goods vehicles with or without trailers, tractors and buses (vehicle groups B3, B4, B5 and C1). The HCM2000 methodology considers the impact of HVs and RVs separately. HCM2022 considers the total effect of all vehicles other than passenger cars; therefore, 17% of HVs was considered in this estimation [9].

Demand traffic volume at the end of the planning period was determined based on the peak 100th-hour-traffic (K-factor), which, according to [8], amounts to 9.5% of AADT. The directional distribution of traffic (D) and the peak-hour factor (PHF) were defined for both analyses according to the HCM2000 recommendations, as D = 60:40 and PHF = 0.88 [9].
According to this input data, the hourly demand traffic flow in the analysed direction, estimated for the end of the planning period, was 454 pc/h/lane - significantly less than the highway lane capacity envisaged by HCM of 1, 700 pc/h/lane [2, 3].

3.2 Computational steps

The first three steps of the analysis were identical for both methodologies [9]. In the first step, the planned highway section was divided into six analytical segments of homogeneous design and traffic characteristics, according to the changes in vertical grade (figure 2). The lengths of individual segments ranged from 0.4 km to 2.3 km, while the vertical grades ranged from 1.2% to 6%. Since the analysis was conducted for the planned AADT of 7, 000 vehicles per day, any potential changes in traffic volume before and after the planned at-grade intersection located on segment 3 were deemed irrelevant. Therefore, this intersection was considered as an approach in both analyses, rather than a point marking the end or beginning of the segment. In the second step, the access point density was calculated for segment 3. Each segment was then classified according to vertical grade value and direction.

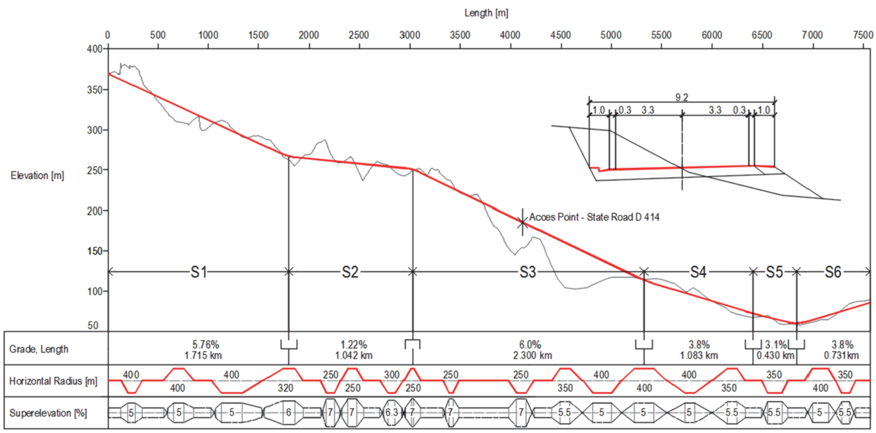

Figure 2 Designed two-lane, two-way highway section - horizontal, vertical and cross-section elements and analytical segments [9]

The LOS estimation based on the HCM2000 was conducted using the methodology for the Class I highway directional segments. The LOS estimation based on HCM2022 was conducted by the methodology defined for the passing zone segment, which allows for passing in the oncoming lane. Figures 3 and 4 summarise the further analysis steps.

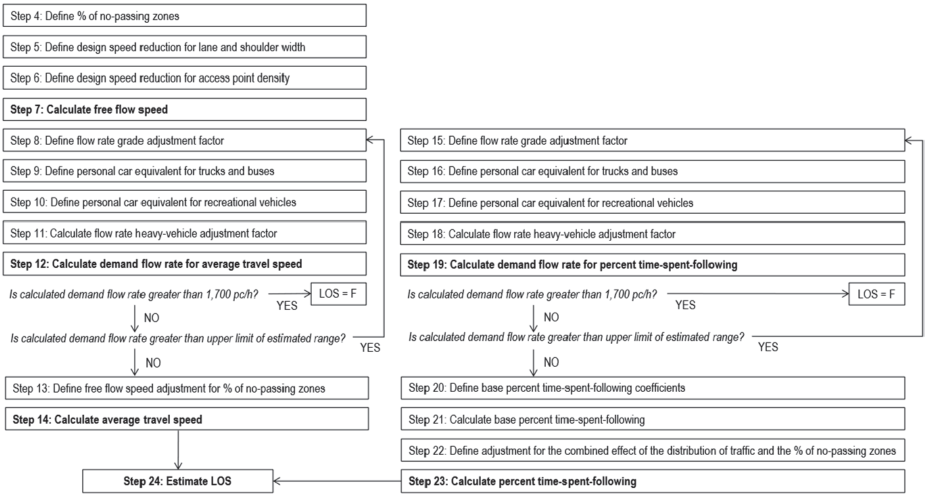

Figure 3 Flowchart of the HCM2000 methodology for LOS estimation

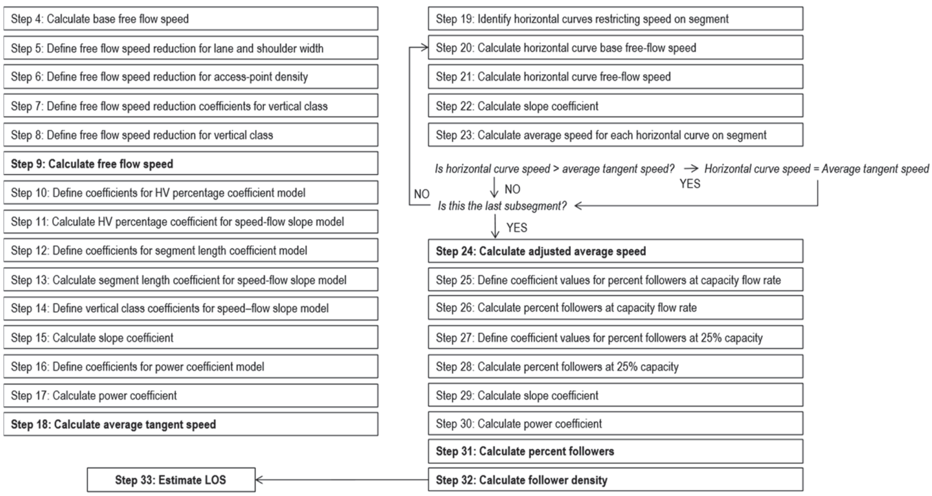

Figure 4 Flowchart of the HCM2022 methodology for LOS estimation

The LOS estimations were performed for each segment in both directions of travel. Finally, the results of each segment were aggregated for the entire road section.

4 Results and discussion

Figure 5 summarises the results of the individual segment and entire section evaluations, in both directions of travel [9]. Comparable results of the two methodologies concern the average speeds ATS and AS, and the percentages PTSF and PFcap, since the same parameters are used for their estimation.

		Direction 0 km → 7,6 km							Direction 0 km ← 7,6 km						
Alignment	Segment	1	2	3	4	5	6	Av.	1	2	3	4	5	6	Av.
	Lenght [km]	1,7	1,0	2,3	1,1	0,4	0,7	1,22	1,7	1,0	2,3	1,1	0,4	0,7	1,22
	Vertical Grade [%]	5,8	1,2	6,0	3,8	3,1	3,8	4,5	5,8	1,2	6,0	3,8	3,1	3,8	4,5
	Curvature 1000/R [10^3/m]	1,9	2,6	1,9	2,4	1,8	1,8	2,07	1,9	2,6	1,9	2,4	1,8	1,8	2,07
HCM2000	BFFS [km/h]	80,0	80,0	80,0	80,0	80,0	80,0	80,0	80,0	80,0	80,0	80,0	80,0	80,0	80,0
	FFS [km/h]	77,2	77,2	76,9	77,2	77,2	77,2	77,1	77,2	77,2	76,9	77,2	77,2	77,2	77,1
	ATS [km/h]	62,2	66,2	62,0	64,6	64,1	64,1	63,4	61,2	66,2	60,6	63,9	64,1	64,1	62,6
	PTSF [%]	95,2	77,5	95,2	86,2	88,0	88,0	90,2	96,0	77,1	96,0	87,3	87,6	87,6	90,7
	LOS	E	D	E	E	E	E	E	E	D	E	E	E	E	E
HCM2022	BFFS [km/h]	91,2	91,2	91,2	91,2	91,2	91,2	91,2	91,2	91,2	91,2	91,2	91,2	91,2	91,2
	FFS [km/h]	69,4	82,1	68,7	77,4	82,1	77,5	73,7	69,4	82,1	68,7	76,1	77,5	77,5	73,3
	ASG	53,4	79,3	48,4	72,4	79,3	72,9	61,8	53,4	79,3	48,4	69,9	73,4	72,9	61,1
	ASC	50,2	65,2	45,0	67,1	70,7	64,6	55,8	50,2	65,2	45,0	65,5	66,7	64,6	55,4
	PFcap [%]	90,7	81,5	91,7	81,9	82,5	82,4	87,1	90,7	81,5	91,7	84,6	83,4	82,4	87,1
	PF [%]	50,9	23,3	50,9	48,1	23,4	48,1	44,7	50,9	23,3	50,9	72,7	48,2	48,1	49,8
	FD [followers/km/lane]	4,6	1,6	5,1	3,3	1,5	3,4	3,8	4,6	1,6	5,1	5,0	3,3	3,4	4,2
	LOS	C	B	D	C	B	C	C	C	B	D	C	B	C	C

Figure 5 Overview of evaluation results

The base free-flow speed (BFFS) served as the primary input data for assessments in both methodologies. However, HCM2000 used the design speed or speed limit as BFFS, while HCM2022 increased the design speed or speed limit by 14% to estimate BFFS. In HCM2000, the free-flow speed (FFS) on a segment was calculated by adjusting the BFFS to account for lane and shoulder width, as well as approach density. Consequently, the average FFS for the entire highway section according to HCM2000 was 3 km/h lower than the BFFS. HCM2022 also considered the impact of opposing flow, the percentage of heavy vehicles, and the segment length. As a result, the estimated FFS for the section was 3 km/h lower than that calculated by the HCM2000 methodology.
According to HCM2000, ATS was estimated by reducing the FFS, considering the opposite flow rate and the percentage of no-pass zones along the segment. According to HCM2022, AS was first estimated as a reduction in FFS due to segment length, percentage of HVs, and the opposing flow. This procedure determined the average speed on the segment influenced by the vertical grade (ASG). Considering the vertical grade, a significant difference was observed between ATS and ASG. As expected, the speed decreased with increasing grade, but ATS varied much less than ASG. The change in ATS was of the order of 10 km/h for grades from 1% to 6%. For the same grade range, the change in ASG was of the order of 30 km/h. If the average speeds for the entire section were compared, ATS was up to 2 km/h higher than ASG. In addition, HCM2022 estimated the influence of horizontal curve length and radius, and the superelevation value on the reduction in average speed (ASC). Depending on the segment, this additional speed reduction ranged from 5 to 15 km/h. Overall, the section ASC was 8 km/h lower than the ATS.
PTSF and PFcap were comparable because they both considered the combined effect of longitudinal slope, percentage of HVs, opposing flow, and segment length. The HCM2022 estimate yielded better results by about 5%, except for the smallest vertical grade. Considering the grade, a difference of approximately 10% was noticed in the estimated PTSF and PFcap values at grades under and above 3%. The estimated PTSF of the entire section was only 3% higher than PFcap, but considering section LOS, HCM 2022 estimated that the section will meet the higher LOS C at the end of the planning period.

5 Conclusion

The investigation results show that HCM2000 provides a larger set of default values that can be utilised as input data when observed, measured, or designed data is missing. In contrast, the HCM2022 methodology mandates that most data is gathered from design documents or field measurements. Additionally, it requires accounting for horizontal curves and superelevation data. According to HCM2000, the estimation of segments' LOS indicators consists of 24 steps. In principle, estimation of segments' LOS indicator according to HCM2022 consists of 33 steps. However, the number of steps increases by five for every subsequent horizontal curve along the segment. An additional step in the HCM2022 methodology is the conversion of units. The HCM2000 was produced in two editions, one using U.S. customary units and the other using metric units. At that time, U.S. states were moving toward compliance with federal requirements to use metric units in road design. Because the federal metrication requirements were later dropped, HCM2022 is using only U.S. customary units. This requires additional processing of input data. A comparison of the results showed that HCM2022 estimates a lower average speed, greater average speed variation along the section (depending on the value and direction of the segment grade), and smaller percent followers' values. On the other hand, if the values of HCM2000 and HCM2022 LOS indicators for the entire section are compared, their differences are minimal. Differences occur only in the final assessment - when assigning a LOS, HCM2022 assigns a higher LOS C to the analysed two-way two-lane road section for the same input parameters.

In conclusion, the HCM2000 methodology is more suitable for those who want to quickly and simply estimate the LOS of a planned two-way, two-lane highway. It requires fewer detailed input parameters and relies on a larger number of default or assumed data, making it useful for comparing different design options. On the other hand, the HCM2022 procedure demands more precise input data and is more time-consuming. However, it estimates higher LOS, making it preferable for situations where a more detailed road design is available.

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ADVANCED ASSESSMENT AND MONITORING OF BRIDGES