Lane keeping behavior on urban two-lane roads

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***Abstract*—Road design parameters, especially the layout of cross-sections and their elements are influencing the lateral position of vehicles. From another perspective, the actual lateral behavior of vehicles could have an impact on the optimal design of cross-sections, including their geometry and pavement structure. There are several research papers about the behavior of drivers concerning their lateral position in traffic lanes on rural roads. However, there is less information about drivers' lateral position in urban traffic lanes with different lane widths. In this paper results of own field measurements will be shown about human drivers' lateral positions on urban roads with elevated curbs and various lane widths. Mean values and distributions of the lateral position near elevated curbs will be shown. Impacts of lane width and speed will be also presented. Results of this research will be later used to consider safe curb distances for autonomous vehicles.**

Keywords— traffic lane, lateral position, urban road, road curbs

I. INTRODUCTION

In previous studies it was found that vehicle lane position varied depending on road type and lane width. Several studies investigating lateral position of vehicles were conducted to assess the impact of heavy vehicles on road pavements. In Sweden, for example, position surveys were carried out at fifteen locations, resulting data on approximately 271,000 vehicles [1]. Factors such as lane type, lane width, verge width, total width, and close proximity of guardrail all had some influence on vehicle position and amount of lateral wander. The extent of lateral wander varied quite considerably. Values associated with light vehicles varied between 455 millimeters and 190 millimeters. Commercial traffic values were lower and ranged between 430 millimeters and 140 millimeters.

Other studies like [2] found that these variations will have a direct effect on the rate of surface wear and will influence where stresses and strains are distributed in the pavement structure. Human-driven trucks have known to follow a normal distribution of wandering within a lane. On the other hand, autonomous trucks would navigate the lane with zero wander, which would require less lane width but due to zero wander, channelized loading will come into effect which will accelerate pavement rutting and fatigue cracking.

From another perspective, it is well known that inappropriate lateral position is one of the primary factors leading to accidents [3]. Therefore, another group of papers surveyed lateral positions of vehicles from the safety point of view. In a US study, the researchers collected speed and lateral position data for three rural two-lane curves. The relationship between lateral position and speed was assessed by comparing the odds of a near-lane crossing for vehicles traveling 5 or more mph over the advisory speed to those for vehicles traveling below that threshold [4].

Lateral positions were investigated by [5] for pavement marking treatments at transition zones from 120 to 100 km/h and 100 to 80 km/h zones, respectively. Regarding the variations in drivers' lateral position, the results showed that the proposed pavement markings did not negatively influence drivers' lateral control on the road as the maximum observed standard deviation of lateral position was around 0.065 m. Another study about traffic calming measures at entries in built-up areas [6] has found similar results.

Another stream of papers deals with the right lateral positioning of autonomous vehicles (AVs). Here the problem is that traditional positioning sensor such as the Global Positioning System (GPS) may fail to obtain satisfactory performance, the lateral position error will be increased. Among many related papers [7] proposes a novel methodology to achieve lane-level lateral positioning based on the integrated deep neural network (IDNet).

The research papers cited are dealing with the lateral position of vehicles on rural roads or in transition areas. However, there is less information about drivers' lateral position in urban traffic lanes with different lane widths. In this paper results of own field measurements will be shown about human drivers' lateral positions on urban roads with elevated curbs and various lane widths. Mean values and distributions of the lateral position near elevated curbs will be shown. Impacts of lane width and speed will be also presented. Results of this research will be later used to consider safe curb distances for autonomous vehicles.

II. METHOD OF MEASUREMENTS

The goal was to measure the vehicles' lateral position in the lane and their speed. For this, two views of the same car were needed. A video camera was placed next to the road, perpendicular to the road axis, about 2-3 m from the curb to measure the speed of the cars. To measure the lateral position, a photo camera was placed parallel to the road axis, next to the road edge, behind a bush or object to hide it, about 10 m ahead from the spot.

Before the main measurement series, a test measurement was made at three sites and 200 cars to determine the expected mean and standard deviation data, as well as the required sample size.

Car speeds were determined from the video recordings, based on the video camera setting and the marked reference distance. Speed of the vehicles was calculated from the number of the frames, needed for the vehicle to pass the reference distance [8].

The lateral position of cars was determined from the photos, taken as the vehicles were in the reference distance. AutoCad program was used to process the measurement. The edge and the axis of the lane was marked on the inserted photo. Traffic lane width and the distance between the car's axis and the road axis was measured in the program. The principle of direct proportionality was used to determine the distances.

III. Measurement Sites

Measurement sites were selected in built-up areas in the southern part of Budapest, and in a town adjacent to the city. All sites were along tangent sections, with 2x1 traffic lane road cross-section designs, with 10-12 cm high vertical curbs, with same speed limits (50 km/h) and different lane widths. Sites were marked for easier identification, ranked according to the width of the lanes. The widest lane (3.90 m) is at the K1 site, and the narrowest lane (2.75 m) is at the K8 site (Table 1).

TABLE 1 PARAMETERS OF THE MEASUREMENT SITES

Site	Lane width [m]	Speed limit [km/h]	Inlet grates [Y/N]	Pavement marking [Y/N]	Road type
K1	3.90	50	Y	Y	Arterial
K2	3.60	50	Y	Y	Arterial
K3	3.50	50	N	Y	Collector
K4	3.50	50	Y	Y	Collector
K5	3.00	50	Y	Y	Collector
K6	3.00	50	N	N	Collector
K7	3.00	50	Y	Barely	Collector
K8	2.75	50	N	N	Collector

IV. Results

Lateral positions of cars at the eight locations are shown in Table 2. Distances between the car edge and the centerline of the road, as well as between the car edge and the curb were calculated using the width of the cars and the measured lateral positions.

A. Lane width and speed

Mean speeds at the eight locations were between 39.9 and 51.4 km/h. It was expected that the mean speed is lower at the narrower lane sites, but on contrary, the lowest speed was found at the K2 site, where the lane width is 3.60 m.

TABLE 2 THE RESULT OF THE MEASEREMENT

Site	Lane width [m]	Average distance [m] between			STD [m]	Speed	
		Car axis and lane axis	Car left edge and road centerline	Car right edge and curb		Mean [km/h]	STD [km/h]
K1	3.90	0.47	0.58	1.51	0.21	51.14	6.84
K2	3.60	0.23	0.66	1.12	0.17	39.91	10.12
K3	3.50	0.14	0.71	0.99	0.27	51.36	6.62
K4	3.50	0.32	0.52	1.16	0.19	40.63	4.39
K5	3.00	0.13	0.49	0.75	0.16	40.43	8.68
K6	3.00	0.12	0.47	0.72	0.21	44.28	5.80
K7	3.00	0.25	0.33	0.83	0.25	42.16	6.10
K8	2.75	0.33	0.14	0.79	0.19	41.18	4.66

According to these measurements, the width of the lane and the mean speed results do not show a relationship, which is the opposite of the several studies [9], [10], [11]. These says the narrower road indicate lower free-flow speed. However, it has to be mentioned that the cited studies are dealing with higher speed roads, outside urban areas.

Based on the results so far, the impact of the lane width on speed cannot be confirmed on normal urban roads with 50 km/h speed limits.

B. Lateral position and speed

It would be a straightforward idea that within one site the speed of individual vehicles and their lateral position have some relationship. However, the measurements showed, that there is almost no correlation between these parameters.

C. Lane width and lateral position

In order to get a clearer and simpler overview, sites were merged in two groups, Group K1-K4 with the wider lanes, Group K5-K8 with the narrower lanes. Minimum and maximum values of means and standard deviations were collected in Table 3.

TABLE 3 GROUPED MEASUREMENT RESUTS – WIDE VERSUS NARROW LANES

Site	Lane width [m]	Average distance [m] between			Standard deviation [m]
		Car axis and lane axis	Car left edge and road centerline	Car right edge and curb	
K1-K4	3.50-3.90	0.14 - 0.47	0.52 - 0.71	0.99 - 1.51	0.17-0.27
K5-K8	2.75–3.00	0.12–0.33	0.14 – 0.49	0.72 – 0.83	0.16-0.25
Difference	0.75–0.90	0.02– 0.14	0.38 – 0.22	0.27 – 0.68	0.01-0.02

Table 3 contains the three reference distances and reference points used throughout the measurements, which are in obvious relationship with each other, with the car width, as well as with the lane width. These are the

- distance between car axis and lane axis

- distance between car (left) edge and road centerline,
- distance between car (right) edge and curb

Drivers should perceive and obey each of these reference points: they must

- keep in lane,
- not to cross the centerline and
- not to climb the curb.

Table 4 shows that for narrow lanes cars have a closer distance to each of the three reference points than for wider lanes. This observation seems obvious. It is more interesting that comparing the three reference points, lane axis comes first, average distances from the lane axis are very similar for both wide and narrow lanes. At each site, the average position of vehicles is left of the lane axis, i.e. a larger distance is held from the curb than from the road centerline.

Comparing distances from the curb, it is visible that for wide lanes the curb distance can go up to 1.50 m, while it does not go below 0.70 m even for narrower lanes.

The standard deviation of lateral position at one site - by definition - is the same value, irrespective of the reference point. It is the most stable indicator in Table 4, its value varies by sites between 0.16 and 0.27 m, and it does not depend on lane width. The lower figures correspond well to the lower Swedish results in [1].

D. *Effect of oncoming cars*

Measurement data at each site were divided in two groups, depending on whether another vehicle in the opposing direction was registered on the video recording, while the car measured passed the reference distance. The results are shown in Table 4. Site 4 was deleted from this table, as due to the high traffic volume, very few cases were found without oncoming car.

TABLE 4 LATERAL POSITIONS WHEN COMING CAR FROM THE FRONT

Site	Lane width [m]	Coming car from the front - avg. Δ lane axis.				
		NO [m]	Standard deviation	YES [m]	Standard deviation	Δ dist. [m]
K1	3.90	0.46	0.22	0.48	0.19	-0.02
K2	3.60	0.21	0.18	0.29	0.15	-0.08
K3	3.50	0.17	0.25	0.01	0.34	+0.16
K5	3.00	0.17	0.16	0.06	0.17	+0.11
K6	3.00	0.31	0.23	0.04	0.19	+0.27
K7	3.00	0.17	0.21	0.00	0.19	+0.17
K8	2.75	0.37	0.19	0.17	0.11	+0.20

The average distances between the car axis and the lane axis for individual sites are shown in Table 4, divided to oncoming car YES/NO situations. The differences between the YES/NO cases are shown in the last column. A positive sign means that in the YES case (oncoming vehicle) the observed vehicle was to the right from the position in the without case, i.e. further from the centerline.

From Table 4 it is visible that with lane widths 3.50 m and below, when meeting an oncoming vehicle, the observed car moves 11-27 cm away from the centerline. This result confirms expectations. For lane widths larger than 3.50 m, an oncoming vehicle does not mean a significant change in the position of the observed vehicle.

Figures 1 and 2 show the deviations of the lateral positions at sites with wide lanes. The boxes indicate the ±1 standard deviation from the mean position, while the lines the ±2 standard deviation.

According to Table 4, due to the wide lanes, there is only a small difference in positions between meeting another car or not. Further it is remarkable that drivers keep a relatively large distance from the curb. In most cases this is at least 50 cm, which is in the design guidelines of many countries the usual distance not considered as part of the traffic lane.

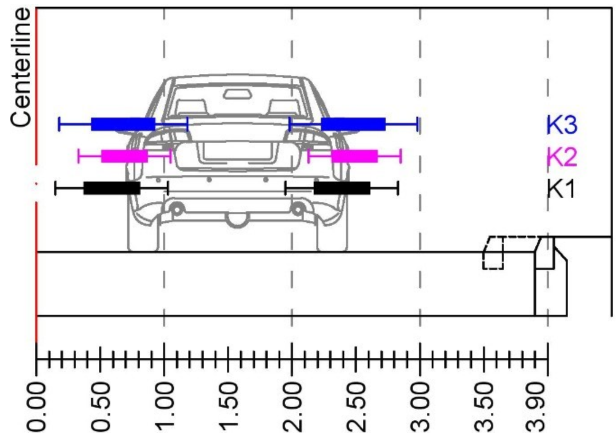

Fig. 1 Positions in wide lanes (no oncoming car)

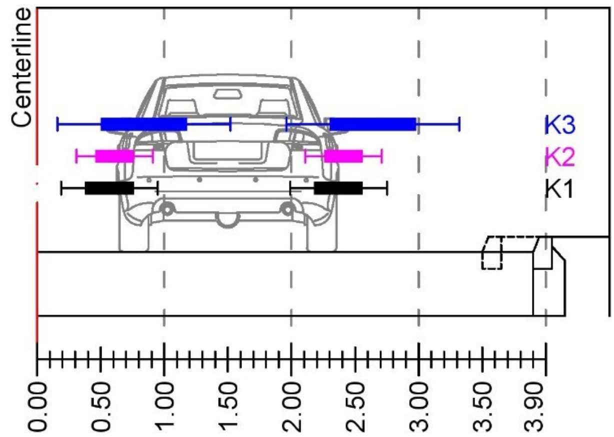

Fig. 2 Positions in wide lanes (oncoming car)

In Figures 3 and 4 the observed positions in 3.00 m wide lanes are shown. Surprisingly, the lateral deviations are not smaller than for wide lanes, although one would think a narrower lane means also more exact lane-keeping.

As expected, distances from the curb are less than for wide lanes. However, if there are no oncoming vehicles, the 50 cm value mentioned above is kept and even for meeting situations it does not fall under 30 cm.

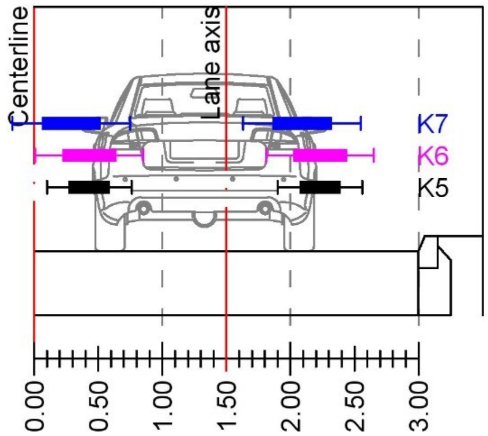

Fig. 3 Positions in 3.00 m wide lanes (no coming car from the front)

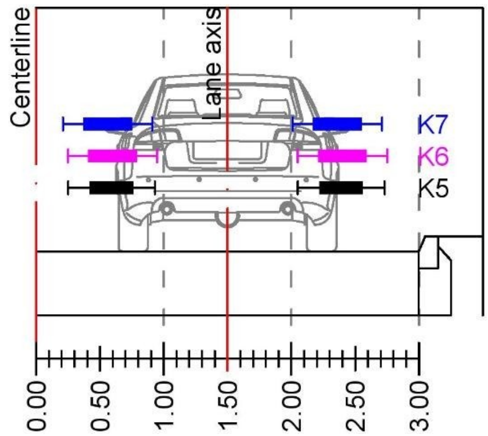

Fig. 4 Positions in 3.00 m wide lanes (coming car from the front)

Due to the relatively small number of sites, the effect of pavement markings and the presence of inlet grates near the curb was not investigated. However, these factors may have an impact an optical effect of the driver behavior [13] [14].

V. Conclusions, relations to autonomous vehicles

Based on the results so far, the impact of the lane width on speed cannot be confirmed on normal urban roads with 50 km/h speed limits. Measurements also showed that within one site there is no correlation between the speed of individual vehicles and their lateral position.

In traffic lanes with different widths, from among three reference points (lane axis, road centerline and curb), lane axis was found to be the one followed by vehicles.

The standard deviation of vehicles' lateral position was found as the most stable indicator describing positions in traffic lanes with different widths.

Results of the measurements indicate lateral positions, distances from the curb and from oncoming vehicles, kept and possibly felt safe by drivers.

The research described above could be extended to laboratory/simulation tests, using virtual driving environment [15], [16].

Autonomous vehicles may have better capabilities than humans, e.g. in terms of lane keeping. However, we have to bear in mind that in autonomous vehicles humans are sitting, who have an in-built feeling about safe behavior of vehicles. Therefore, a trajectory too close to a curb (or a tree) may be frightening for them. The same is valid for human drivers meeting an oncoming autonomous vehicle. Therefore, results of this research with more data and details might be later useful in designing driving strategies of autonomous vehicles.

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