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CIVIL ENGINEERING

A driver perspective-based investigation for lane line visibility of pavements on drivers' lane utilization behaviors

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ABSTRACT. There have been significant advances in vehicle safety and road construction in all over the world and driver misbehaviours are still shown as one of the most important reasons of traffic accidents. When the current traffic accidents are examined, the negative effect of lane line quality and level of visibility related on the accidents comes to the forefront in underdeveloped and developing countries. In this study, the effect of lane line visibility level on drivers' lane utilization was investigated in detail. For this aim, a total of 17 different points in Türkiye were selected and the lateral positions of the vehicles on the road surface at these points were determined with the help of the screen scaling technique. In order to determine the level of lane line quality for an expert group and driver perspective, a face-to-face survey was conducted. From the analysis results, the lane line quality was determined low in urban and intercity roads, and the average maximum evaluation score was determined as 4.7 and the lowest score was determined as 1.42 where the best line quality was 5. This result showed that the level of lane line quality had significant differences at different points. Although, it was observed that the lateral position distributions in the examined points fit the normal distribution, the distribution of both the right/left wheels and their gravity center skewed to the right or left and deviated from the ideal conditions on road surfaces. It showed that the vehicles do not center the lanes exactly, but usually move close to the right or left edge of the lane. This situation also clearly revealed that the lane utilization disciplines of drivers are quite weak with the effect of the low lane line quality on road surfaces.

Keywords: Lane line quality; lateral position; line visibility; driver characteristics; lane discipline.

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Introduction

In many countries around the world, urban and intercity road pavements' surface markings (lane and pavement markings) are made and opened for the service in a very short time after the construction. The low-quality marking material utilization and unplanned maintenance on intercity roads result the disappear of road surface signs in a short time after a road opened to operation. On urban roads, road surface lane lines are also disappeared in a short time due to unplanned infrastructure works, constructions on the roadside, polluted water flowing onto the road surface and environmental effects of pollution on road surfaces. When urban and intercity roads are considered as a whole, failure to planned maintain the road surface signs and the use of low-quality materials cause the erase of signs particularly/completely. These markings on the road surfaces have a vital importance to prevent accidents because of their visual guide properties on drivers' lane selection and utilization discipline. In recent years, road authorities paid attention to renew road surface markings, regularly. However, current observations show that these improvements are not entirely sufficient and needs more renew process especially in urban roads. In particular, the rapid visibility loss of the lane lines shows that the existing surface markings are made with cheap and non-permanent materials in the majority of the roads (Aydın, 2017). The rapid disappearance of lane markings or road surface markings can create difficulties for drivers in deciding how to move on a road platform. Therefore, drivers may use two lanes on a three-lane road or three lanes on a four-lane road and it may cause traffic congestion, regularly. This lane utilization indiscipline, which occurs as a result of the rapid visibility loss of the lane lines, can cause confusion on the roads and result many traffic accidents (Ma, Zheng, Easa, Wong, & El-Basyouny, 2022). On the other hand, situations such as no lane line availability, low visibility of lane lines or completely disappear of lane lines can cause arbitrarily move of vehicles at the desired point of the road surface on urban and intercity roads. Thus, it may cause undisciplined behaviors for the other drivers (Choudhury, Ramanujam, &

Ben-Akiva, 2009; Aydin & Topal, 2016). Therefore, undisciplined driving may cause losses in traffic flow capacity and safety issues on roads. Whereas, quality and long-lasting road surface markings are used in developed countries and it provides long-term guide to drivers (Ben-Edigbe, Mashros, & Minhans, 2011). This result clearly reveals the importance of the effect of lane markings on drivers' lane utilization discipline and highlights the examination of this issue (Aydin, 2021).

Figure 1. Indiscipline due to weak or no lane line visibility on urban and intercity roads.

In developing countries such as Türkiye, Azerbaijan, Albania etc. the encountered problems due to weak lane line visibility and the consequent indiscipline of drivers in lane utilization have persisted for years due to factors such as deficiencies in painting the lines properly on time, or the inability to allocate supply necessary budget. Because of this problem, drivers began to disobey the lane utilization rules and show irregular behaviors that cause traffic accidents as a habit. Unfortunately, it may cause negative driver behaviors. For this reason, it is very important to examine the perception of the drivers on lane line quality and to conduct the necessary measures for the solution of the problem both in the design and post-construction stages.

In the study, it has been tried to examine how the visibility (quality) of lane lines affects the behavior of drivers. For this purpose, firstly, road types with different characteristics were determined by examining the relation between lane utilization and lane line quality. Then, the lane line quality of the examined roads was asked to an expert group and drivers who have different characteristics. Thus, the importance of the lane line quality for the participants were tried to be understand. Using the obtained results, it has been tried to show the effect the lane line quality on traffic safety for drivers. Therefore, it has been aimed to attract the attention of road authorities and researchers to importance of this issue.

Literature review

In the literature, the number of lanes, road surface coating quality, driver characteristics, traffic flow, environmental factors and surface signs, etc. shows variations depending on many sub-parameters (Ben-Edigbe et al., 2011; Aydin, 2021; Lee & Park, 2012; Munigety & Mathew, 2016; Aydin & Topal, 2018; Shirke, Sumanth, Arkatkar, Bhaskar, & Joshi, 2019; Yildirim, Aydin, & Gökkuş, 2022; Mutu & Yakar, 2022). Among these factors, the effect of road pavement and marking quality on drivers' lane selection and utilization behavior has been the subject of many different studies (Bangarraju, Ravishankar, & Mathew, 2016; Aydin, 2021). When these factors are examined in detail, road surface deformations, lane line quality and visibility, and driver characteristics are the most observed issues (Asaithambi & Shravani, 2017). For example, in the study of Aydın and Topal (2016), they investigated the effects of deformation on drivers' lane choice, utilization and movement tendency in traffic flow by examining the driver behavior in the longitudinal and lateral direction on a deformed road section with two lanes. In the study, they determined that the larger area and less depth of the deformation zone had less effect on the tendency of vehicles to use lanes on lateral direction. From the results, it was concluded that the variation in other parameters such as deformation type, depth and height was related to the drivers' lateral lane utilization, and they concluded that the drivers' characteristics such as perception and aggression are the most important factors affecting the longitudinal vehicle driving behavior while passing through the deformation zones. In their study, Aydin, Yildirim, Karpuz, and Ghasemlou (2014) tried to model the relation between the lane selection behavior of drivers and lane line quality on deformed road sections. They also investigated the negative effects of line visibility and deformation effects on drivers' vehicle utilization behaviors using artificial neural networks (ANN) and linear regression (LR) analysis, and they concluded that lane changing behavior is negatively correlated with approach speed, and if a vehicle has a higher approach speed, the driver will be less likely to change lane due to surface deformation. In another study, Saplioglu, Unal, and Bocek (2022) examined the effect of the pavement surface quality on the driver behavior at signalized intersection approaches on urban roads. They determined that road surface deformations and surface line features have a significant effect on driver behaviors and traffic accidents.

When the studies were examined related on examining the effects of road surface and driver characteristics on lane utilization discipline, it was seen that there are many conducted studies related on this issue. In his study, Gunay (2003) concluded that lane-based driving discipline in multi-lane traffic flow is quite weak in Türkiye as in many developing countries. It has been shown that the main reasons for this situation are different driving behaviors, insufficient maintained lane markings and low lane line quality. In a similar study, Gunay (2008) reported that drivers have different lane utilization behaviors. From his field observations and analyzes, he stated that low lane line visibility, insufficient lane width, and low lane-based driving discipline of drivers are effective among the main reasons for these behaviors. On the other hand, Aydin (2020) examined the drivers' current lane utilization behaviors in five-point level ranging from 'Level-1: Very Poor' to 'Level-5: Very Good' in order to develop a new method to examine the drivers' lane keeping discipline. As a result of the study, it was determined that the traffic volume and lane width had a positive effect on the lane utilization discipline, while the increase in the lane width and the number of lanes had a negative effect, and drew attention to the importance of lane line quality in this subject. In another similar study, Aydin (2021) examined the lane-based driving disciplines of drivers along the road platform and proposed a model. As a result of the model, it was concluded that lane width and traffic volume cause an increase on lane selection and utilization discipline. Additionally, it was found that heavy vehicle ratio, vehicle width, speed and lane numbers have a positive effect on undisciplined driver behaviors. He also drew attention to the importance of lane line quality in addition to the above parameters and he stated that lane line quality is an important parameter that can be added to the model.

With the development of vehicle technology and autonomous vehicle concept in recent years, many researchers around the world have focused on road and lane detection research and focused on the importance of lane lines on this subject. Ma et al. (2022) examined the visibility of urban roads by using mobile laser scanning and deep learning method and they founded autonomous vehicles will be actively used in the future with the help of the effective vision systems. For this purpose, they determined the road sections with low visibility in the city where they made a pilot application and created an infrastructure by processing this on the map. In another study, Zhang, Li, Gao, Jin, and Li (2021) tried to perform lane detection with lidar cameras in order to improve the lane detection and tracking performance of autonomous vehicles through the lane lines and they concluded that their proposed method detects lane lines with 80.75% accuracy. In a similar study, Haris, Hou, and Wang (2021) worked on lane line detection with a multi-scale spatial convolution algorithm and they succeeded in lane detection with 85.6% accuracy. Zeybek (2021) worked on the detection of all road surface markings by the mobile lidar device and he concluded that the system gave accurate results with the standard deviation varying between 1.2 and 1.7 cm from the measurements, extracting and mapping the positions of the markings on the road surface. In another study, Li, Qu, Wang, Wang, and Chen (2019) proposed a robust lane detection method based on the hyperbolic model, and they performed lane detection with 97% accuracy using the density-based spatial clustering applications and the weighted hyperbolic model. In a similar study, Liu, Li, and Huang (2014) determined the extraction of all signs on the lane with 92% accuracy by using routing and escape point constraints in stuck road scenes as a different method. Almotairi (2022) also used a hybrid adaptive method for lane detection of degraded road surface condition and found that the proposed method was the best in missed detection ratio with 2.54%. Similarly, Oğuz, Küçükmanisa, Duvar, and Urhan (2022) studied a deep learning based fast lane detection. They proposed a deep learning based novel approach to solve this challenging problem. Study results showed that the proposed method is able to detect lanes even in the challenging conditions with low computational complexity which makes it suitable for real-time applications. All these results clearly reveal that latest studies may cause a major transformation in the automotive industry. Especially, they could contribute positively to the lane keeping performance of autonomous vehicles.

When the existing literature is examined, it is clearly seen that the current studies generally focus directly or indirectly on the effects of road surface deformation, driver characteristics and lane line quality on driving discipline. In addition, it has been observed that some studies focus on the development of road and lane detection systems for semi-autonomous and autonomous vehicles, along with technological development.

When the existing studies are examined in detailed, it is seen that there is no study that directly examines the effect of lane line quality on driver lane utilization behavior and driver-based lateral placement (position) of the vehicles. In this scope, it is thought that a study on the evaluation of the quality of the lane lines from the point of view of the drivers and the examination of their driving performance according to this situation will help to fill this important gap in the literature. Therefore, in the study, drivers' lane utilization was examined depending on lane line quality and their evaluations were tried to be modeled according to different driver characteristics. Thus, this gap in the literature has been tried to be filled as long as fully autonomous vehicles will be implemented by evaluating the driving characteristics and the adequacy of the line quality in terms of the driver, depending on the line quality in the selected road sections. In addition, it was concluded that the study will be important research to determine the threshold value of lane line quality required for the drivers' effective lane utilization and semi-autonomous vehicles in the future.

Material and method

Determination of pilot cities and road sections

In the study, three different metropolitan cities (Antalya, İzmir and Trabzon) located in different regions were selected as pilot cities in order to examine the effect of lane line quality and visibility problems on the lane utilization performance of drivers on urban and intercity roads in Türkiye (Figure 2). Thus, lane utilization characteristics have been tried to be examined according to driver characteristics in different regions. The following boundary conditions were used to determine the selected road sections to be examined in the study:

- Divided roads on the main arterials,
- A multi-lane road section with uninterrupted flow (the traffic flow at the observation point is not affected by signals, intersections, etc.),
- Presence of different vehicle types in the flow and speed limits should be the same with city speed limits,
- Availability for field observations under normal weather conditions and on working days,
- Typical parking on the side of the road and no illegal additional lanes,
- Absence of road surface deformations which directly affect lane selection and utilization behaviors of drivers,
- Proper locations to collect field data via video cameras.

Figure 2. The locations of 17 different selected points and example visuals from the field.

In the study, a total of 17 different observation points (12 from Antalya, 3 from Izmir and 2 from Trabzon) were determined to be used which fit the parameters specified above. Then, these selected road sections are numbered as ANT-1,2,3,..,12 for Antalya city; İZ-1,2,3 for İzmir city and as TRAB-1,2 for Trabzon city. After the selection of the pilot city and road sections, the geometric and structural features (lane width, total lane width, lateral clearance and platform width) of the examined road sections were determined in order to clarify the lane utilization characteristics depending on the lane line quality and the lateral positions of the vehicles (Table 1).

Table 1. Obtained geometric and structural features of selected road sections.

City Name	Obs. Point No	Lane No	Lane Width (m)	Total Width of Lanes (m)	Lateral Clearance (Right – Left) (m)	Platform Width (m)
Antalya	ANT-1	1	3.10	9.50	0.80 – 0.40	10.70
		2	3.15			
		3	3.25			
	ANT-2	1	3.10	9.40	0.25 – 0.35	10.00
		2	3.10			
		3	3.20			
	ANT-3	1	3.10	9.50	0.25 – 0.30	10.05
		2	3.20			
		3	3.20			
	ANT-4	1	3.10	9.50	0.25 – 0.30	10.05
		2	3.20			
		3	3.20			
	ANT-5	1	3.10	9.55	0.25 – 0.35	10.05
		2	3.20			
		3	3.25			
	ANT-6	1	3.10	9.55	0.25 – 0.30	10.10
		2	3.20			
		3	3.25			
	ANT-7	1	3.10	9.55	0.25 – 0.30	10.10
		2	3.25			
		3	3.20			
	ANT-8	1	3.10	9.55	0.60 – 0.35	10.50
		2	3.25			
		3	3.20			
	ANT-9	1	3.00	9.30	0.35 – 0.30	9.95
		2	3.10			
		3	3.20			
	ANT-10	1	3.10	9.60	0.60 – 0.35	10.55
		2	3.20			
		3	3.30			
	ANT-11	1	3.10	9.55	0.25 – 0.35	10.15
		2	3.20			
		3	3.25			
	ANT-12	1	3.05	9.45	0.25 – 0.35	10.05
		2	3.20			
		3	3.20			
İzmir	İZ-1	1	4.20	12.60	2.10 – 1.0	15.70
		2	4.20			
		3	4.20			
	İZ-2	1	3.10	6.20	0.20 – 0.20	6.60
		2	3.10			
	İZ-3	1	3.10	6.20	0.20 – 0.20	6.60
		2	3.10			
Trabzon	TRAB-1	1	3.10	6.30	0.60 – 0.30	7.20
		2	3.20			
	TRAB-2	1	3.20	6.30	0.40 – 0.30	7.10
		2	3,20			

Note: According to the direction of the vehicles, the rightmost lane is defined as the 1st lane, and the lane numbers are increased to the left, (m): meters.

Collection, extraction and digitization of field data

Field traffic observations are made on the road sections at multi-lane and uninterrupted flow on the determined main arterials to reflect the traffic flow and driver characteristics of the region. For this purpose, data belonging to 17 different points in three different pilot cities were obtained with the help of video cameras, under normal weather conditions during working days. Due to bad weather conditions cause negative effects on traffic flow, clear days were selected for observations. In order for the data to be used in the study, the situation where there was no excessive traffic congestion on the road and a sufficient saturated traffic flow conditions were selected during the observation. Lane and platform widths were measured using a steel-tape meters during the low traffic hours. The normal driving behaviors of the drivers were observed by placing the digital cameras where they would see the road from the opposite side and would not be noticed by the drivers (Figure 3).

Figure 3. Data collection from the examined regions with the help of video recordings.

In the next step, the images recorded from the field were via video recordings and they transferred to the computer environment. Then, they analyzed with the help of image analysis and converted to digital data. During the digitization of the data, the screen scaling technique was used for the detailed analysis of all vehicle movement and lane utilization on the selected road sections, and all lanes were examined as lane-based at this step. The screen scaling technique process was carried out with the help of a special program as seen in Figure 4. From the video analysis, the lateral positions of a total of 4090 vehicles (including all vehicle types) on the road surface for 17 different points were examined from field observations. They were obtained for each observation point and recorded as digital data. Thus, numerical data regarding the type of vehicle (car, minibus, truck, etc.), the lateral positions of the right and left wheels of the vehicle on the road lane (m), and the vehicle width (m) were obtained to use in the analysis.

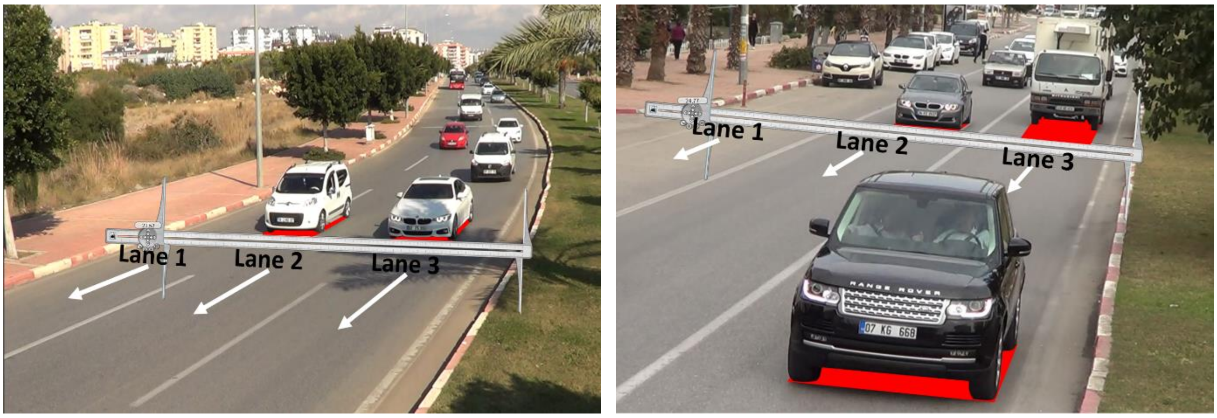

Figure 4. Determination of the lateral vehicle positions on the road by screen scaling technique.

According to the used screen scaling technique, firstly, the widths of the vehicles, the positions of the right and left wheels, and the lateral positions of vehicles' gravity centers on the road surface (meters) were determined. Then, observed vehicle types were defined in seven different classes (1-Car, 2-Minibus, 3-Van/Minibus, 4-Midibus, 5-Truck, 6-Bus, 7-Lorry) to use in the scaling process. In the data extraction and the scaling process, the closest lane to the roadside pavement was defined as Lane-1 (closest lane to shoulder) and the lane number towards the refuge was increased as Lane-2,3…n. After the complete of data extraction and examination process, the obtained statistical results are given in Table 2 regarding to the vehicle widths and the gravity centers.

When Table 2 is examined, it is clearly seen that the vehicle width values, which vary according to the vehicle types, coincide with the values defined by the vehicle brands. For the analysis, the most observations were made in ANT-1 (628 vehicles) and the least observations were made in IZ-2 (72 vehicles) because the hourly lane-based volume values of these points were taken into the account while determining the number of observations. Similarly, it is determined in Table 2 that Type-1: Passenger Car (3443 vehicles) is the most observed vehicle type, and Type-7: Truck (20 vehicles) is the least observed vehicle type according to observed vehicle types. Also, the distribution of vehicle types in the traffic at the observed points was taken into consideration while determining the ratio of vehicle types to examine in the study.

Table 2. Statistical information for the examined vehicles' widths and gravity centers (meters).

Obs. Point No	Vehicle Types																												$\sum_N$
	1				2				3				4				5				6				7				
	Vehicle Width		Gravity Center		Vehicle Width		Gravity Center		Vehicle Width		Gravity Center		Vehicle Width		Gravity Center		Vehicle Width		Gravity Center		Vehicle Width		Gravity Center		Vehicle Width		Gravity Center		
	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	
ANT-1	1.9	0.1	6.5	1.7	2.1	0.0	5.8	1.6	2.2	0.1	5.5	1.5	2.4	0.1	5.1	1.1	2.5	0.2	4.9	0.9	2.5	0.0	4.6	0.2	2.5	0.0	4.5	0.1	628
ANT-2	1.8	0.1	5.6	2.0	2.1	0.0	4.1	2.1	2.2	0.0	5.0	1.2	2.4	0.0	2.6	2.5	0.0	0.0	0.0	0.0	2.5	0.0	2.5	1.2	0.0	0.0	0.0	0.0	379
ANT-3	1.9	0.1	6.1	1.7	2.1	0.1	5.9	1.7	2.2	0.1	4.6	0.2	2.4	0.1	4.6	0.2	0.0	0.0	0.0	0.0	2.5	0.0	4.9	1.0	0.0	0.0	0.0	0.0	346
ANT-4	1.8	0.1	6.3	1.5	2.2	0.0	6.5	1.7	2.1	0.1	6.0	1.5	2.4	0.0	4.9	1.1	2.4	0.1	8.1	0.0	2.5	0.0	4.5	0.2	2.5	0.0	6.3	1.7	170
ANT-5	1.8	0.1	6.0	1.5	2.1	0.2	5.9	1.5	2.1	0.1	6.0	1.6	2.4	0.1	5.6	1.4	0.0	0.0	0.0	0.0	2.5	0.0	3.9	1.1	2.5	0.0	4.6	0.1	559
ANT-6	1.9	0.1	5.5	2.1	2.2	0.1	4.5	0.1	2.2	0.1	5.2	1.4	2.4	0.1	4.5	0.2	2.6	0.1	1.7	0.0	2.5	0.0	2.5	1.4	0.0	0.0	0.0	0.0	181
ANT-7	1.8	0.1	6.2	1.6	2.2	0.0	5.1	1.1	2.2	0.0	5.6	1.4	2.4	0.0	3.7	1.5	0.0	0.0	0.0	0.0	2.5	0.0	3.3	1.6	0.0	0.0	0.0	0.0	305
ANT-8	1.9	0.1	6.2	1.7	2.2	0.1	5.0	1.4	2.3	0.1	3.0	1.8	2.4	0.0	2.9	1.6	0.0	0.0	0.0	0.0	2.5	0.1	2.5	1.6	0.0	0.0	0.0	0.0	92
ANT-9	1.9	0.1	5.9	2.1	2.1	0.0	4.8	2.6	2.1	0.0	3.9	2.2	2.4	0.0	3.3	1.5	0.0	0.0	0.0	0.0	2.5	0.0	4.7	2.1	0.0	0.0	0.0	0.0	104
ANT-10	1.8	0.1	6.2	1.7	2.2	0.1	4.9	0.9	2.2	0.1	6.0	1.5	2.4	0.0	3.5	1.5	0.0	0.0	0.0	0.0	2.5	0.0	3.3	1.5	0.0	0.0	0.0	0.0	313
ANT-11	1.9	0.1	5.8	2.0	2.2	0.1	4.8	1.5	2.1	0.1	4.4	0.1	2.4	0.0	4.3	0.0	0.0	0.0	0.0	0.0	2.5	0.0	5.8	1.6	2.5	0.0	4.5	0.0	169
ANT-12	1.9	0.1	5.9	1.8	2.1	0.0	7.7	0.0	2.2	0.0	3.8	1.4	2.4	0.0	4.7	0.2	2.5	0.0	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	95
İZ-1	1.8	0.1	5.8	3.1	2.1	0.1	7.1	3.1	0.0	0.0	0.0	0.0	2.4	0.0	1.5	0.0	2.6	0.1	1.4	0.0	2.5	0.0	5.6	0.1	0.0	0.0	0.0	0.0	100
İZ-2	1.8	0.1	3.0	1.6	2.1	0.0	3.2	1.5	2.2	0.1	2.4	1.4	2.4	0.0	1.4	0.1	0.0	0.0	0.0	0.0	2.5	0.0	1.4	0.0	0.0	0.0	0.0	0.0	72
İZ-3	1.8	0.1	2.2	1.4	2.1	0.0	2.1	0.0	2.2	0.0	2.0	1.0	2.4	0.1	2.2	1.4	2.5	0.1	1.5	0.2	2.5	0.0	1.6	0.2	0.0	0.0	0.0	0.0	175
TRAB-1	1.8	0.1	3.7	1.6	2.1	0.0	4.2	1.3	2.1	0.1	4.9	0.3	0.0	0.0	0.0	0.0	2.6	0.0	1.8	0.0	2.6	0.0	2.6	1.3	0.0	0.0	0.0	0.0	211
TRAB-2	1.8	0.1	2.9	1.7	2.1	0.1	2.0	1.0	2.2	0.1	2.1	0.9	2.4	0.0	1.5	0.0	2.5	0.0	1.8	0.7	2.5	0.0	1.5	0.3	2.6	0.1	2.0	1.0	191

$\sum_N$= Total observation number; μ=Average; σ= Standard deviation.

Determination of the lane line quality

In order to determine the lane line quality of the of the road sections at 17 different points, total nine expert from academicians and road authority staff were selected as an expert group that 9-15 people recommended in the literature (Aksoy, Kader, & Çetin, 2020). This selected expert group examined the real visuals of 17 determined road sections in detail and they scored the quality (visibility) of the lane lines at 5 different levels (1-Very Bad, 2-Bad, 3- Fair, 4-Good, 5- Very Good). The demographic characteristics of this expert group and the determined scoring results for line quality are given in Table 3.

Table 3. Statistical results of lane line quality evaluation scores of the expert group.

Parameter	Expert Number									Average Age (μ)
	E-1	E-2	E-3	E-4	E-5	E-6	E-7	E-8	E-9	
Gender	0	1	1	0	0	0	0	0	0	
Age	57	50	52	47	48	40	48	45	47	48.22
Obs. Point No	E-1	E-2	E-3	E-4	E-5	E-6	E-7	E-8	E-9	Average Rate (μ)
ANT-1	3	2	3	3	2	2	2	3	3	2.56
ANT-2	4	3	4	3	3	3	3	4	4	3.44
ANT-3	4	4	4	3	3	4	4	4	4	3.78
ANT-4	3	2	3	3	3	3	2	3	3	2.78
ANT-5	4	3	3	3	3	3	3	3	4	3.22
ANT-6	4	3	4	3	3	3	3	4	4	3.44
ANT-7	3	2	4	3	3	2	3	2	2	2.67
ANT-8	3	3	3	3	3	3	3	2	3	2.89
ANT-9	3	3	4	3	3	3	2	2	3	2.89
ANT-10	2	3	3	3	3	2	3	2	2	2.56
ANT-11	4	3	4	3	3	3	3	4	4	3.44
ANT-12	3	3	3	3	3	3	3	3	3	3.00
İZ-1	4	3	3	4	3	3	4	3	4	3.44
İZ-2	1	1	2	1	1	2	1	1	1	1.22
İZ-3	2	2	2	1	2	1	2	1	1	1.56
TRAB-1	3	4	4	3	3	4	4	4	3	3.56
TRAB-2	5	4	5	5	5	5	5	5	5	4.89

Note: for the gender parameter Female: 1 and Male: 0.

When the average values were examined in detail, the expert group determined that the highest quality (visible) lane line was at TRAB-2 and the least quality line (visible) was at İZ-2. The fitness (similarity) between the responses of the expert group was subjected to Kendall's W coefficient of agreement analysis.

Kendall's W was obtained as 0.184; P:0.103>0.05. According to this result, it was determined that there was no significant difference between the answers given by the experts and the answers had similar statistical results with each other. After the similar results between the answers, a survey was conducted with drivers who had different characteristics to determine the lane line quality. Due to the total number of drivers in the three different cities examined within the scope of the study is not known exactly, the required sample size for the survey was determined using Equation 1.

$$n = \frac{t^2 * p * q}{d^2} \quad (1)$$

n: Number of examples,
t: Theoretical value in the t-chart at a given degree of freedom for a determined mention level (α = 0.05 and ∞ is 1.96 for degree of freedom),
p: Frequency of the event under investigation (probability),
q: Frequency of absence of the investigated event (probability),
d^2: The amount of deviation desired to be made according to the incidence of the event.

Due to the number of drivers in the examined pilot cities was quite high, the value of P=0.5 (maximum variability) was used as the probability value in order to avoid inaccuracy while estimating (Baltagi, 2008; Saplioğlu & Aydin, 2018). The minimum survey value from the sampling amount was determined as 385 people. For this purpose, a face-to-face survey study was conducted with 390 people. First of all, all the characteristics of the drivers (socio-demographic and economic, vehicle utilization characteristics, driver profile, etc.) were determined with the survey study, and the summary results are given in Figure 5.

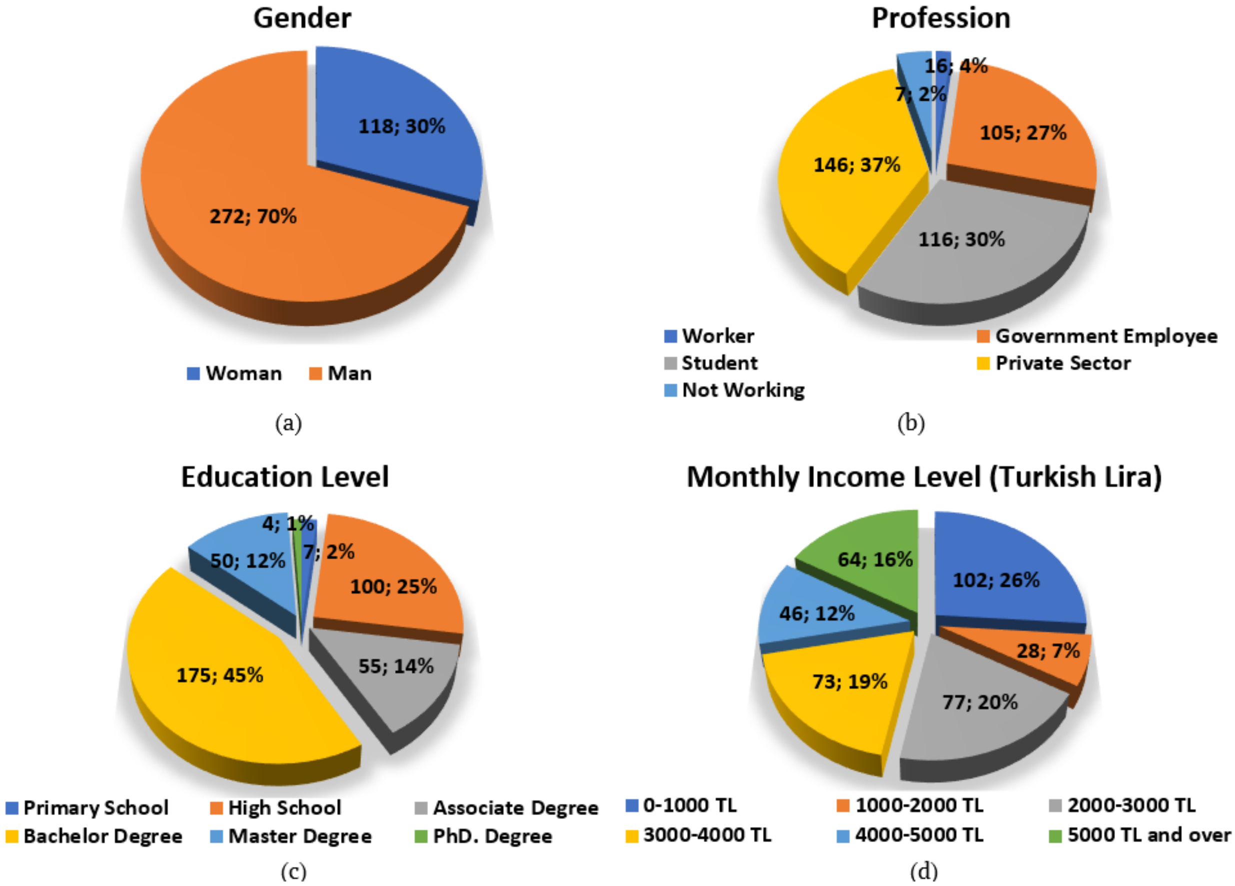

Figure 5. Socio-demographic and socio-economic characteristics of the drivers who attended to conducted survey.

In Figure 5, it is concluded that the gender percentages of the participants almost reflect the driver profile (75% male and 25% female driver) in terms of gender for 2020 in Turkey (TÜİK, 2021). In addition, driver profile variation was supplied in the study by conducting surveys from different demographic and economic levels. Profile and vehicle utilization characteristics of all participated drivers who attended to the survey are given in Figure 6.

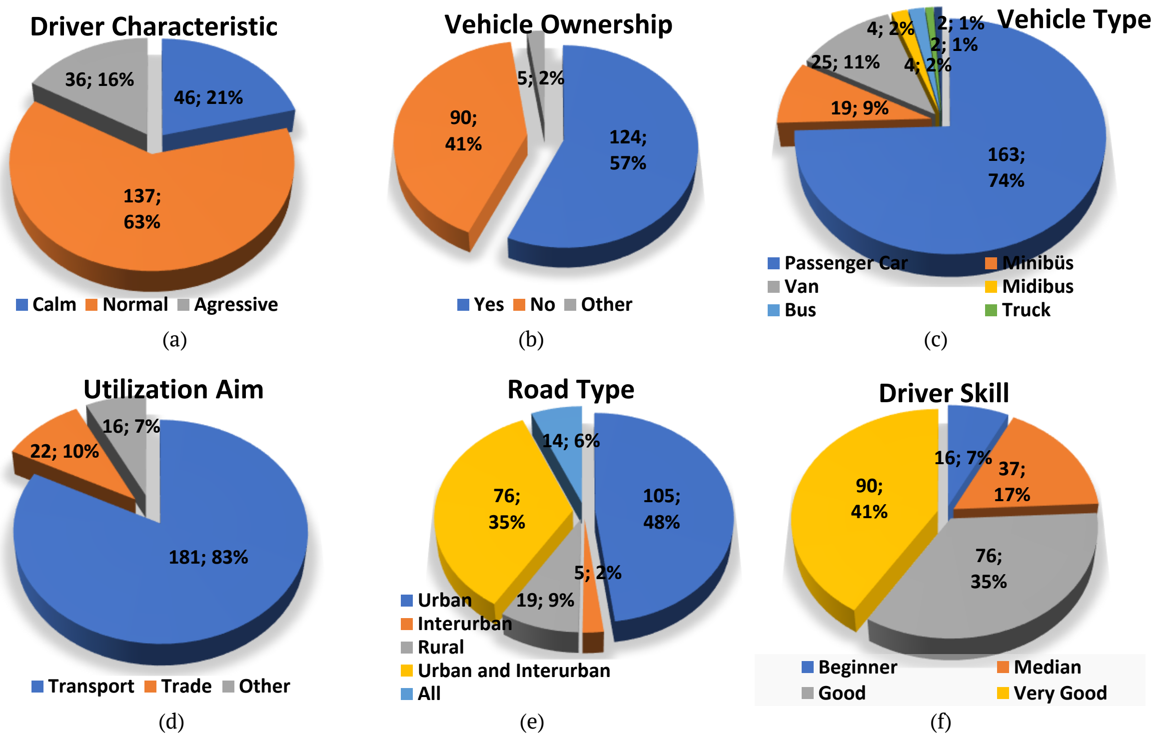

Figure 6. Driver properties and vehicle utilization characteristics of the participants.

According to the results in Figure 6, it is concluded that the majority of the participants (63%) define themselves as a normal driver profile, nearly half (41%) of them see their own driving skills at a very good level. The statistical results of the answers to the quantitative questions were obtained as given in Table 4 in order to determine the vehicle utilization characteristics in traffic in more detail.

Table 4. Statistics for the participants' thoughts on vehicle properties and life of lane lines.

No	Variables	Average (μ)	Std. Deviation (σ)
1	Age (Year)	33,48	11.98
2	Frequency of Vehicle Utilization (Once-Day)	3.09	2.44
3	Frequency of Vehicle Utilization (Hours per Day)	2.05	1.75
4	Frequency of Vehicle Utilization (Km/Day)	50.44	67.09
5	Vehicle Utilization Experience (Years)	12.35	9.63
6	Average Speed (Urban)	63.12	15.01
7	Average Speed (Intercity)	99.72	16.53
8	Estimated Lane Line Life	249.71	178.34

The average age of the participated drivers was calculated as approximately 33.5 years. These people drive an average of 3.09 times a day in traffic, and the average of these travels is 125 minutes. It was determined that they drove an average of 50.44 km in this period and they had an average of more than 12 years of driving experience. When examining drivers' opinions about lane markings effective visibility life, they estimated the average approximately 250 days (a little over eight months). This result, which the drivers make estimations based on field observations and experiences, clearly shows that the lane lines lose their effectiveness before lasting a year and must be renewed on an annual basis. The results of the drivers' opinions about the visibility of lane markings and their perspectives on the effect of lane markings on driver behavior were summarized as given in Figure 7.

According to Figure 7, more than 80% of the participants think that lane line quality is very important for safer driving in traffic, and nearly 2/3 of the participants think that it has an important effect on vehicle speed. On the other hand, 3% of participant stated that they had an accident due to insufficient line visibility, and concluded that line quality is an indirect factor as well as an important factor which causes traffic accidents. The participants attribute the deletion of lane lines to two main reasons with their answers. The most effective reason for this negative situation is the opening of the road to traffic immediately after painting, and the utilization of low-quality paint materials as a secondary reason. Again, according to the responses of the participants, the majority (more than 2/3) thinks that the lane line quality directly affects the drivers' lane changing, overtaking, actions etc., negatively. In addition, 57% of the participants defined the current intercity roads as good and very good, and this response value was obtained as approximately 32% for urban roads. These two views clearly reveal that the quality of the lane lines on intercity roads is much better than the urban roads. On the other hand, none of the participants gave the answer "very good" to the line quality of urban roads. This shows that the drivers cannot score the lane line quality on urban roads as perfect. It means that they do not find current urban lane line quality as very good quality, and they draw attention to another important point. In order to examine the participants' thoughts on line quality (visibility level) on urban and intercity roads in more detail, 17 opinions which are given in Table 5. Participants' opinions on the importance of lane line quality were tried to determine using their responses (1- Strongly Disagree; 2- Disagree; 3- Undecided; 4- Agree; 5- Strongly Agree) on lane line quality.

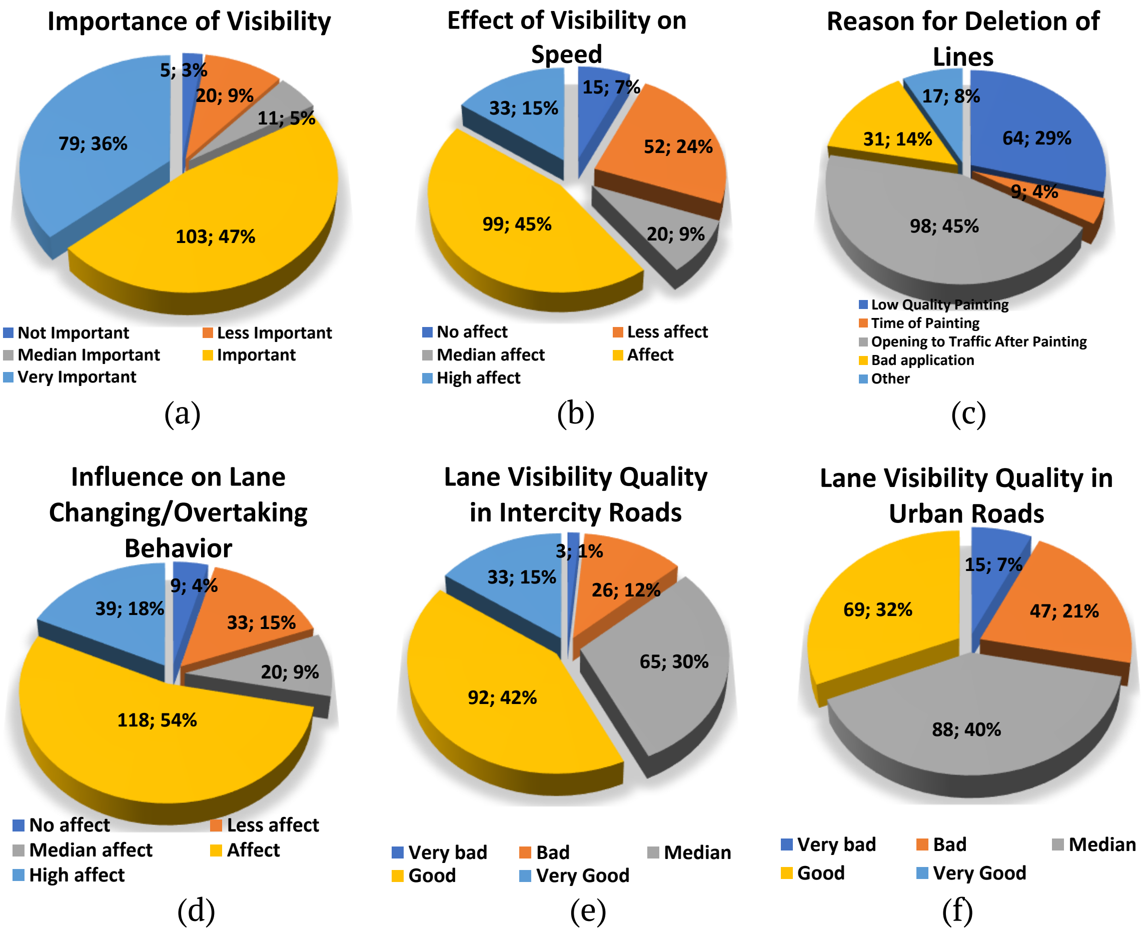

Figure 7. Participants' thoughts on lane line quality (lane visibility).

Table 5. Asked opinions to drivers for measuring their thoughts on lane line quality.

Question No	Driver Thoughts
Q1	Lane markings on the road is important for me.
Q2	Visibility (quality) of lane lines is important for me.
Q3	The presence of lane lines makes the road safer and gives me confidence.
Q4	The visibility of the lane lines positively affects my driving by centering the lane lines.
Q5	If the visibility of the lane lines is good, I obey the lane lines.
Q6	Visible (high quality) lane lines give me confidence in traffic.
Q7	The main reason for the confusion on urban roads is the absence of lane lines or their low quality.
Q8	The quality of the lane line has no effect on the occurrence of the accident.
Q9	Drivers pay attention to the lines and follow the rules when the lane lines are of good quality.
Q10	I think that the lane lines on urban roads are made according to a road standard.
Q11	I think that lane lines on intercity roads are made according to a road standard.
Q12	I think, it is important that the lane lines are visible at night.
Q13	The visibility of lane lines on urban roads is sufficient at night.

Q14	The visibility of lane lines on intercity roads is sufficient at night.
Q15	I think that the controls of the deleted lane lines were made on time by the road authorities.
Q16	Although the lane markings are visible, there are still drivers who act undisciplined in the traffic.
Q17	The penalty sanction imposed on drivers who act undisciplined in traffic even though road lines are visible.

The responses of the participants to the opinions which is asked to the drivers are given in Figure 8. It has been determined that the drivers are not completely satisfied with the lane lines on the existing urban and intercity roads. It is more clearly seen that the line quality in the lanes has low quality for many different reasons, which negatively affects the behavior of the drivers.

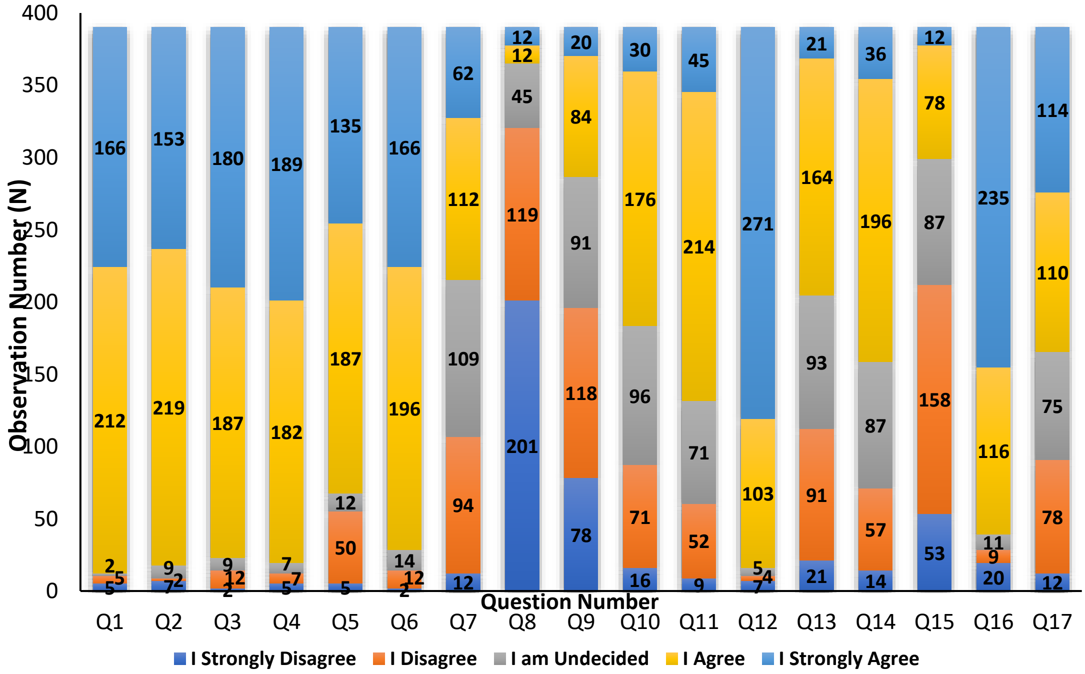

Figure 8. Participants' thoughts on lane line quality.

In the survey, drivers who had different socio-demographic, socio-economic and characteristic features, were also asked to score the quality of the lane lines on the examined road sections for 5 different levels. The lane line quality of the 17 points was examined according to the average of the scoring results which ranked from 1 (best) to 17 (worst) (Table 6).

Table 6. Summary statistics of 390 participants' lane line quality scoring for 17 points.

Obs. City No	Score of Lane Line Quality		*Ranking (R)
	Average (μ)	Std. Deviation (σ)	
ANT-1	2.95	0.67	12
ANT-2	3.49	0.53	5
ANT-3	3.75	0.57	2
ANT-4	2.96	0.77	11
ANT-5	3.46	0.85	6
ANT-6	3.56	0.57	4
ANT-7	2.92	0.84	13
ANT-8	2.99	0.70	10
ANT-9	2.76	0.71	14
ANT-10	2.55	0.64	15
ANT-11	3.31	0.49	7
ANT-12	3.02	0.51	9
İZ-1	3.30	0.89	8
İZ-2	1.42	0.61	17 (the worst)
İZ-3	1.68	0.69	16
TRAB-1	3.69	0.58	3
TRAB-2	4.70	0.46	1 (the best)

*Ranking (R) is made from the highest quality:1 to the lowest quality: 17.

According to the Table 6, the participants stated that the best (the most visible) quality are at the TRAB-2 point on the road located in the city center of Trabzon, and the worst (the least visible) quality lane line is at the İZ-2 point at the number 2 in İzmir. Again, the compatibility (similarity) analysis between the expert group and 390 participants' answers was made and Kendall's W coefficient of agreement was calculated as W:0.204; P:0.066>0.05. According to this result, it was determined that there is no significant difference between the responses of the participants (drivers) and expert group for the lane line quality.

One-Way Analysis of Variance (One-Way ANOVA) was performed to determine the equality of the average lane line quality responses at each observed observation point. Before proceeding to this test, it was checked whether the two assumptions required for the test were met. The first assumption is that 390 participants' line quality scores for 17 points (from 1 to 5) fit the normal distribution; The second is the assumption of homogeneity of the masses. It is known that these two assumptions must be supplied absolutely in order to apply the One-Way Analysis of Variance. If any of them are not provided, the Kruskal-Wallis W test which is one of the non-parametric tests, is required. Within the scope of One-Way Analysis of Variance, it was first investigated whether the lane line quality data conformed to the normal distribution with the Shapiro-Wilk W test (Table 7) and then the hypotheses of this test were established as follows:

H_0= The line quality classification of each point is distributed normally.

H_1= The line quality classification of each point is not distributed normally.

According to Table 7, it was seen that all of the values at 17 observation points were normally distributed. In order to test whether the variances of the obtained lane line quality values are equal, the Homogeneity test was performed. In order to investigate whether the quality values of 17 observation points are homogeneous, the following hypotheses (Equation 2-3) were established.

$$H_0 = \sigma_{K_1}^2 = \sigma_{K_2}^2 = \sigma_{K_3}^2 = \cdots = \sigma_{K_{12}}^2 \quad (2)$$

$$H_1 = \text{At least one } \sigma_{i_j}^2 \text{ is different} \quad (3)$$

According to Bartlett test, chi-square (χ2) test statistic was calculated as χ2=208.7272 and P value (p > χ2)=0.000.

Due to p = 0.000 < 0.01, the H_0 hypothesis implying homogeneity of variances was rejected. It was determined that there were significant differences at 0.01 error level between the variances of the average line quality values of 17 points, and the masses were determined as heterogeneous. Thus, it was seen that the homogeneity condition was not supply in order to perform the One-Way Analysis of Variance. Therefore, the Kruskal-Wallis W test, which is the non-parametric equivalent of the One-Way Variance test, was used to determine the equality of the variances of the average scores (Table 7)

Table 7. Shapiro-Wilk and Kruskal-Wallis W test results of lane line quality scoring of 390 drivers.

Obs. Point No	Shapiro-Wilk Normality Test				Kruskal-Wallis W Test			
					Score of Lane Line Quality			
	w	v	z	P	Average (μ)	Std. Deviation (σ)	KW	P
ANT-1	0.84	16.10	6.24	0.000*	2.95	0.67		
ANT-2	0.93	9.83	5.28	0.000*	3.49	0.53		
ANT-3	0.91	8.80	4.88	0.000*	3.75	0.57		
ANT-4	0.92	7.57	4.54	0.000*	2.96	0.77		
ANT-5	0.99	2.16	1.77	0.038**	3.46	0.85		
ANT-6	0.97	5.03	3.74	0.000*	3.56	0.57		
ANT-7	0.96	6.32	4.26	0.000*	2.92	0.84		
ANT-8	0.98	3.84	3.11	0.001*	2.99	0.70		
ANT-9	0.95	4.53	3.39	0.000*	2.76	0.71	9.794	0.007
ANT-10	0.98	3.49	2.89	0.002*	2.55	0.64		
ANT-11	0.98	3.59	2.95	0.002*	3.31	0.49		
ANT-12	0.98	3.18	2.68	0.004*	3.02	0.51		
İZ-1	0.98	1.96	1.51	0.061***	3.30	0.89		
İZ-2	0.92	13.29	5.98	0.000*	1.42	0.61		
İZ-3	0.98	1.79	1.34	0.089***	1.68	0.69		
TRAB-1	0.98	2.96	2.51	0.006*	3.69	0.58		
TRAB-2	0.92	8.19	4.72	0.000*	4.70	0.46		

Notes: *Significant at 0.01 level; **Significant at 0.05 level, ***Significant at 0.10 level. According to the Bartlett test, the groups are not homogeneous at a significance level of 0.05. KW: Kruskal-Wallis W test statistic.

From the Table 7, it was concluded that there were significant differences between the average lane line quality values according to the observation points (p = 0.007 < 0.01) and thus the participant responses were obtained as reasonable.

Modeling of driver evaluations for lane line quality

Determination of variables and model development

In order to model the average lane line quality (visibility) scores, the following obtained parameters were used for the Least Squares (LS) regression model. In the predicted LS regression model, the independent variables consist of both qualitative and continuous variables (covariates) (Baltagi, 2008; Aydın, Akgöl, & Günay, 2019). The average of the lane line quality scores given by the participants for all points was used as the dependent variable in the modeling analyses. From the observation data of 390 participants, the following variables were determined to be used in the LS regression analysis. The obtained model estimation results are given in Table 8.

Continuous independent variables: Duration of driving licence (T_E), Age (Y)

Discrete independent variables: Gender (C), Profession (M), Education Level (E_S), Monthly Income Level (AG_D), Driver Characteristic (S_P), Vehicle Ownership (A_S) Driving Skill (AK_B), Overview of Line Importance (CO_B).

Table 8. LS regression model estimation results for the lane line quality values.

Variable Type	Notation	Dependent Variable: Average Lane Line Quality	Coeff.	Std. Error	t	P
Continuous	T_E	Duration of driving licence (Year)	0.247	0.152	1.67	0.098***
	Y	Age (Year)	0.002	0.003	0.62	0.537
Discrete	C	Gender (If gender is female: 1; otherwise: 0)	0.009	0.050	0.18	0.859
	M_{-2}	Profession 2 (If profession is government employee:1; otherwise: 0)	-0.016	0.098	-0.17	0.868
	M_{-3}	Profession 3 (If profession is student:1; otherwise: 0)	-0.106	0.081	-1.30	0.196
	M_{-4}	Profession 4 (If profession is private sector:1; otherwise: 0)	-0.171	0.177	-0.97	0.336
	M_{-5}	Profession 5 (If profession is unemployed:1; otherwise: 0)	0.056	0.166	0.34	0.732
	E_{S-2}	Education Level 2 (If education level is high school:1; otherwise: 0)	0.156	0.151	1.03	0.304
	E_{S-3}	Education Level 3 (If education level is associate degree:1; otherwise: 0)	0.045	0.153	0.30	0.766
	E_{S-4}	Education Level 4 (If education level is bachelor degree:1; otherwise: 0)	0.164	0.150	1.09	0.277
	E_{S-5}	Education Level 5 (If education level is master degree:1; otherwise: 0)	0.240	0.157	1.53	0.128
	E_{S-6}	Education Level 6 (If education level is Phd. degree:1; otherwise: 0)	0.152	0.247	0.62	0.538
	AG_{D-2}	Monthly Income Level 2 (If monthly income level 1000-2000 TL: 1; otherwise: 0)	0.027	0.083	0.33	0.745
	AG_{D-3}	Monthly Income Level 3 (If monthly income level 2000-3000 TL: 1; otherwise: 0)	0.450	0.719	0.62	0.528
	AG_{D-4}	Monthly Income Level 4 (If monthly income level 3000-4000 TL: 1; otherwise: 0)	0.086	0.599	0.14	0.885
	AG_{D-5}	Monthly Income Level 4 (If monthly income level 4000-5000 TL: 1; otherwise: 0)	0.156	0.19	0.84	0.400
	AG_{D-6}	Monthly Income Level 6 (If monthly income level 5000 TL and over: 1; otherwise: 0)	0.086	0.106	0.82	0.414
	S_{P-2}	Driver Characteristic 2 (If driver characteristic is normal:1; otherwise: 0)	0.086	0.049	1.74	0.084***
	S_{P-3}	Driver Characteristic 3 (If driver characteristic is aggressive:1; otherwise: 0)	0.089	0.067	1.33	0.186
	A_{S-2}	Vehicle Ownership 2 (If Vehicle Ownership:1; otherwise: 0)	0.075	0.066	1.14	0.256
	AK_{B-2}	Driving Skill 2 (If driving skill median: 1; otherwise: 0)	0.247	0.152	1.67	0.098***
	AK_{B-3}	Driving Skill 3 (If driving skill is good: 1; otherwise: 0)	-0.112	0.085	-1.32	0.189
	AK_{B-4}	Driving Skill 4 (If driving skill is very good: 1; otherwise: 0)	-0.046	0.091	-0.51	0.610
	CO_{B-2}	Overview of Line Importance 2 (If it has less importance: 1; otherwise: 0)	-0.156	0.185	-0.84	0.400
	CO_{B-3}	Overview of Line Importance 3 (If it has median importance: 1; otherwise: 0)	0.901	0.524	1.72	0.088***
	CO_{B-4}	Overview of Line Importance 4 (If it has good importance: 1; otherwise: 0)	0.821	0.459	1.79	0.077***
	CO_{B-5}	Overview of Line Importance 5 (If it has very good importance: 1; otherwise: 0)	0.812	0.454	1.79	0.076***
		Const. Coeff.	3.556	0.361	9.83	0.000*

Notes: *Significant at 0.01 level; **Significant at 0.05 level, ***Significant at 0.10 level.

It was concluded that the model estimated from the LS regression analysis was a statistically significant model (F=5.13, p = 0.000 < 0.01). The coefficient of the age variable was found to be insignificant (p = 0.537 > 0.10) and it was determined that driver age had no effect on the score. The coefficient of the driver's license duration variable (p = 0.098 < 0.10) was found significant and it had a positive effect. It was also concluded that the coefficient of the first discrete variable and gender (female) did not have an effect on the model that means it was a meaningless variable (p = 0.859 > 0.10). This result was an important finding to show that gender was statistically insignificant in scoring process of lane line quality. Profession type, education level and monthly income level variables were also found as statistically insignificant. Again, it has been revealed that this situation does not have a statistically significant effect on the score of average lane line quality, regardless of the profession, education level or income level of the drivers. It has been determined that the "Normal" driver characteristic has a significant effect at the 0.10 error level (p = 0.084 < 0.10), and the "Aggressive" driver profile does not have a statistically significant effect on the score of lane line quality. Similarly, it was concluded that the vehicle ownership (vehicle does not belong to him/her) variable was also statistically insignificant at the 0.10 error level (p = 0.256 > 0.10). When the variables of driving skills were examined, it was found as statistically significant (p < 0.1) for driving skill was "median" level, and insignificant for the "Good and Very Good" levels. This result may show that drivers, who define themselves as "Good" and "Very Good", do not care lane line quality. When the drivers' view of the importance of line quality was examined, the answers of the drivers, who found the quality of the lane line has "median importance" and above (good and very good importance), were found as statistically significant (p < 0.10). However, the other drivers' view of the importance who declared lane line quality has "less importance", were found as statistically insignificant. As a result of the analysis, the equation for the proposed model was obtained as given in Equation 4.

$$\begin{aligned} \text{LLQ} = 3.56 + 0.25 * \text{duration of driving license} + 0.09 * \text{driver characteristic type } 2 + 0.25 * \text{driving skill } 2 + 0.9 \\ * \text{overview of line importance } 3 + 0.82 * \text{overview of line importance } 4 + 0.81 \\ * \text{overview of line importance } 5 \end{aligned} \quad (4)$$

In order to prove that the obtained model is a reliable and usable, it was first examined whether there was a multicollinearity problem in the model. For this purpose, variance inflation factors (VIF) were calculated. The maximum value (max VIF) was obtained as 5.9 and it was seen that there was no multicollinearity problem in the model. Secondly, it was examined whether there was a heteroskedasticity problem in the model and the variable variance test was performed. The test hypothesis was formed as "H_0 = There is no varying variance" and "H_1 = There is varying variance". From the test result (p = 0.768 > 0.10), the null hypothesis, which expresses the homogeneity of the variances, was accepted. Thus, it was seen that there was no problem of varying variance in the model. Third, the linear relationship between independent variables and quantitative dependent variables was examined. Due to the regression analysis predicts a linear model, the non-linear relationships of the independent variables with the dependent variable will invalidate the established model (Gujrati, 2003; Ardahan & Mert, 2013). In order to show that each quantitative independent variable in the model is linear, it has been seen from the ACPR (Augmented Component Plus Residual) graph that the independent variable and the dependent variable are in a linear relationship. Fourthly, it is examined whether there is a model specification error or not and Ramsey Reset test was performed to control the specification error (Mert, 2016). The test hypothesis was established as "H_0 = A necessary variable was not left out in the model" and "H_1 = A variable that should be in the model was not left out". Due to p = 0.135 > 0.10, the null hypothesis was accepted and it was seen that there was no specification error in the model. Finally, the condition that the residuals of the predicted model come from a normally distributed population is examined. For this purpose, Shapiro-Wilk W test was performed to investigate whether the residues were normally distributed. As p = 0.143 > 0.10 from the results, it was seen that the residues were normally distributed and it means dependent variable was normally distributed.

Examination of drivers' lane utilization behaviors

The lane utilization behaviors of the drivers on the selected road sections were examined by determining the lateral positions of the vehicles in the lanes. For this purpose, the positions of the wheels and gravity center of the vehicles on the road surface for the examined points in three different cities were determined with the help of screen scaling technique. Sample images of the right/left wheel position and gravity center distribution obtained after the examination on the three-lane and two-lane road sections ANT-9 and İZ-3 and TRAB-2 points are given in Figure 9-11.

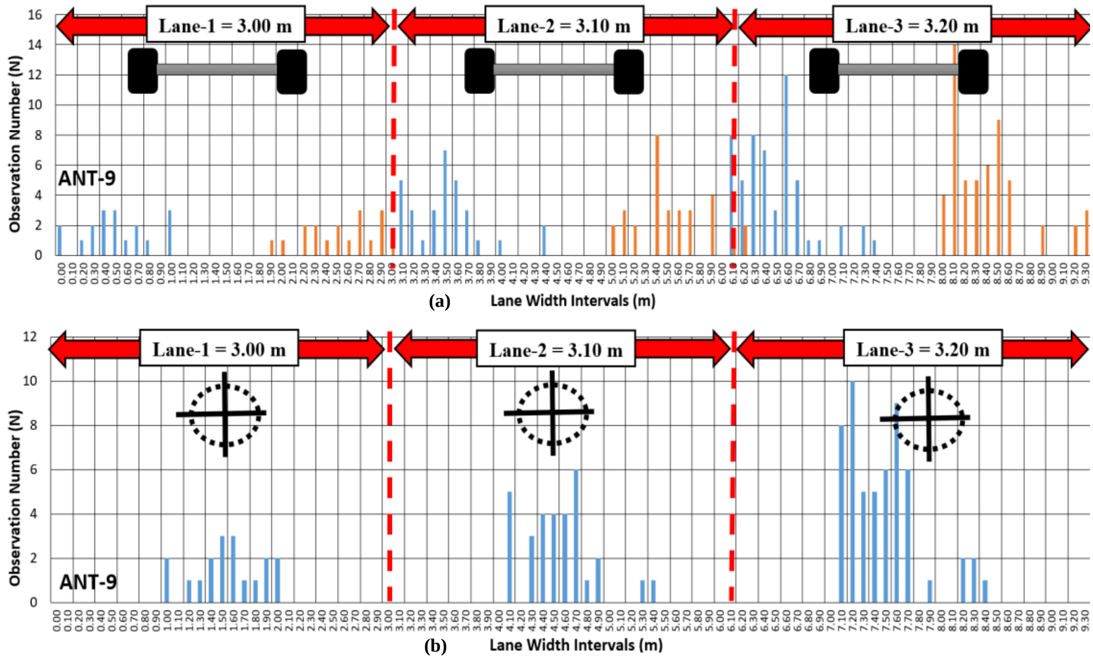

Figure 9. Positions of (a) right and left wheels and (b) gravity center of the vehicles on the road surface for ANT-9 as an example from Antalya city.

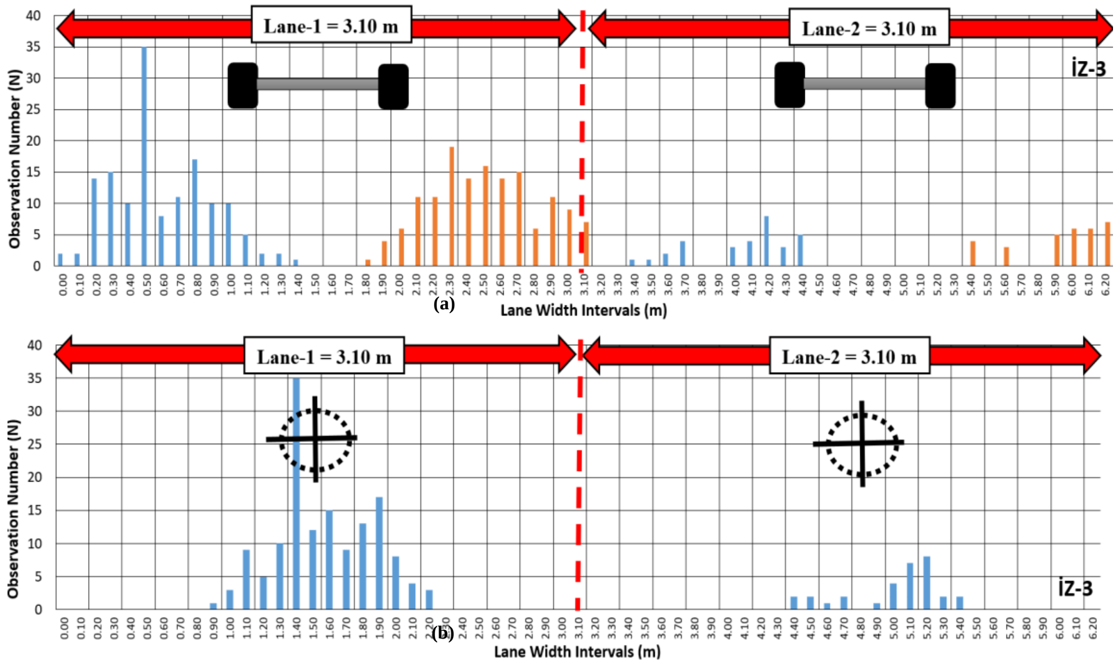

Figure 10. Positions of (a) right and left wheels and (b) gravity center of the vehicles on the road surface for İZ-3 chosen as an example from İzmir city.

From the lateral position and gravity center measurements for three different points in three pilot cities in Figure 9-11 and the results for all points in Table 2; no vehicles use Lane 1 (right lane) due to roadside parking at points ANT-1, 3 and 4. It was concluded that very few vehicles use Lane 1 at ANT-2,5,6,7,8,9,10,11 and 12 points. This result shows that roadside parking causes lane blockage and a lane was not used effectively by drivers on three-lane roads. Thus, the traffic density in the other two lanes increases as expected. Thus, it causes capacity losses in operating performance and have a negative effect on lane utilization discipline and road safety. Table 2 is examined in detail; it is seen that the vehicles in each lane move closer to the lane line on the right wheel side. Among the most important factors on this situation, it can be said that roadside parking and roadside lateral clearance trigger vehicles to go further to the right of the lane. When the two-lane roads are examined, if there is no roadside parking, it is seen that the vehicles tend to use Lane-1 (İZ-2, 3 and TRAB-2), This result shows that drivers mostly tend to use Lane 1 on two-lane divided roads with no roadside parking due to geometric constraint. When the distribution of vehicles on the divided three-lane roads is evaluated according to their gravity centers, it is seen that the drivers mostly use (at ANT-1, 2, 3, 4, 6, 11, 12 and İZ-1 points) Lane 2 (middle lane) and the rest use Lane 3 (left lane) (ANT-5, 7, 8, 9 and 10) at divided three-lanes roads. When the distribution of vehicle gravity centers on the divided three-lane roads was examined by the Shapiro Wilk Normality test, a normal distribution was observed in all lanes except ANT-5 Lane-1 (Table 10). It shows that the distribution did not comply with the normal distribution because the less vehicles use Lane-1 on the roads with roadside parking.

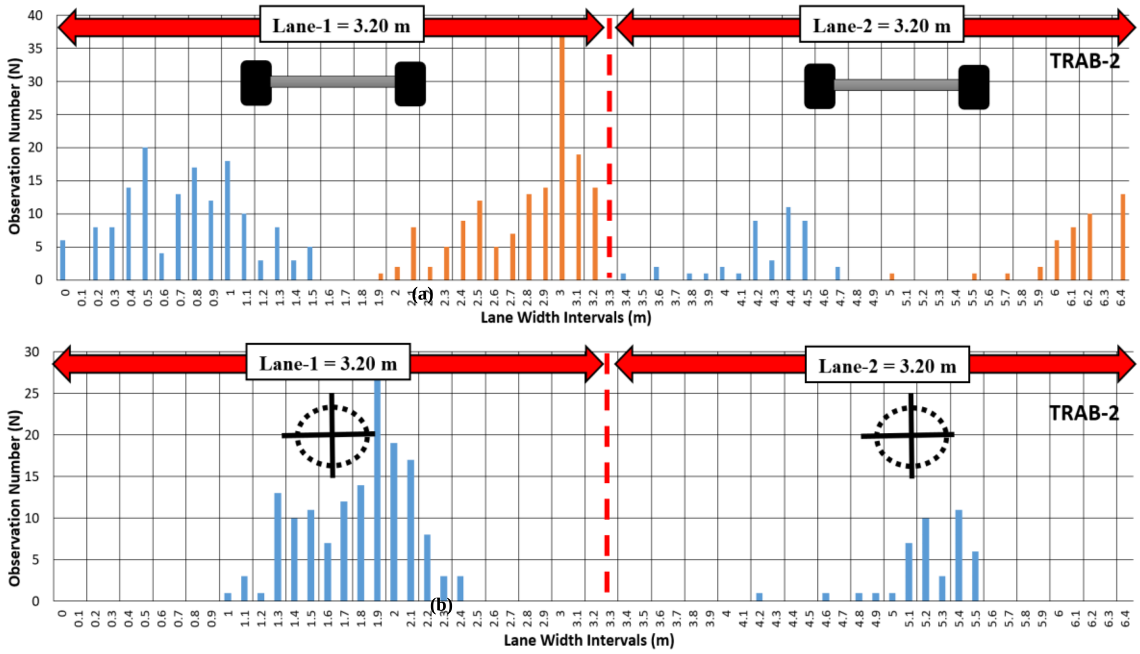

Figure 11. Positions of (a) right and left wheels and (b) gravity center of the vehicles on the road surface for TRAB-2 chosen as an example from Trabzon city.

Table 10. Normal distribution analysis of the vehicle gravity centers according to Shapiro Wilk Normality test.

Obs. Point No	Road Type	Lane No	Lane Width (m)	Vehicle Number	Total (∑)	W	V	z	P	Normal Distribution?
		1	3.1	0					No Vehicle	
ANT-1	Urban	2	3.15	339	628	0.795	6.68	3.93	0.000*	Yes
		3	3.25	289		0.766	8.17	4.38	0.000*	Yes
		1	3.1	51		0.720	9.35	4.64	0.000*	Yes
ANT-2	Urban	2	3.1	178	379	0.834	5.42	3.50	0.000*	Yes
		3	3.2	150		0.838	5.41	3.51	0.000*	Yes
		1	3.1	0					No Vehicle	
ANT-3	Urban	2	3.2	184	346	0.759	8.03	4.33	0.000*	Yes
		3	3.2	162		0.809	6.39	3.85	0.000*	Yes
		1	3.1	0					No Vehicle	
ANT-4	Urban	2	3.2	87	170	0.730	9.01	4.56	0.000*	Yes
		3	3.2	83		0.708	9.74	4.73	0.000*	Yes
		1	3.1	11		0.999	0.04	-6.93	0.990	No
ANT-5	Urban	2	3.2	270	559	0.747	8.24	4.37	0.000*	Yes
		3	3.25	278		0.727	9.32	4.64	0.000*	Yes
		1	3.1	23		0.697	10.09	4.80	0.000*	Yes
ANT-6	Urban	2	3.2	90	181	0.592	13.62	5.42	0.000*	Yes
		3	3.25	68		0.645	12.11	5.19	0.000*	Yes
		1	3.1	6		0.621	12.66	5.27	0.000*	Yes
ANT-7	Urban	2	3.25	147	305	0.731	9.20	4.62	0.000*	Yes
		3	3.2	152		0.698	10.08	4.80	0.000*	Yes
		1	3.1	6		0.680	10.68	4.92	0.000*	Yes
ANT-8	Urban	2	3.25	41	92	0.697	10.10	4.80	0.000*	Yes
		3	3.2	45		0.667	11.38	5.06	0.000*	Yes
		1	3	18		0.804	6.39	3.84	0.000*	Yes
ANT-9	Urban	2	3.1	31	104	0.752	8.09	4.33	0.000*	Yes
		3	3.2	55		0.750	8.35	4.41	0.000*	Yes
ANT-10	Urban	1	3.1	8	313	0.672	10.95	4.97	0.000*	Yes

		2	3.2	150		0.752	8.28	4.39	0.000*	Yes
		3	3.3	155		0.712	9.82	4.75	0.000*	Yes
ANT-11	Urban	1	3.1	9	169	0.611	12.97	5.32	0.000*	Yes
		2	3.2	91		0.652	11.60	5.09	0.000*	Yes
		3	3.25	69		0.812	6.41	3.87	0.000*	Yes
ANT-12	Urban	1	3.05	5	95	0.569	14.37	5.53	0.000*	Yes
		2	3.2	49		0.647	11.78	5.12	0.000*	Yes
		3	3.2	41		0.683	10.56	4.89	0.000*	Yes
İZ-1	Intercity	1	4.2	24	100	0.650	14.63	5.67	0.000*	Yes
		2	4.2	44		0.655	14.17	5.60	0.000*	Yes
		3	4.2	32		0.628	15.28	5.76	0.000*	Yes
İZ-2	Urban	1	3.1	38	72	0.635	12.19	5.19	0.000*	Yes
		2	3.1	34		0.796	6.65	3.93	0.000*	Yes
İZ-3	Urban	1	3.1	144	175	0.734	8.86	4.53	0.000*	Yes
		2	3.1	31		0.698	9.84	4.74	0.000*	Yes
TRAB-1	Intercity	1	3.1	67	211	0.840	5.34	3.48	0.000*	Yes
		2	3.2	144		0.682	10.62	4.91	0.000*	Yes
TRAB-2	Urban	1	3.2	149	191	0.783	7.40	4.16	0.000*	Yes
		2	3.2	42		0.638	12.07	5.17	0.000*	Yes

Notes: *Significant at 0.01 level.

When the lateral positions of the vehicles in all lanes are examined, it is seen that the distribution of both the right/left wheels and their gravity center are skewed to the right or left although their gravity centers are in a normal distribution. In ideal conditions, it is expected that the right/left wheel positions and the distribution of vehicles' gravity center are not skewed to the right or left. According to the results, it is seen that the vehicles do not center the lanes exactly, and they usually move close to the right or left edge of the lane. When the surveys are re-examined, the majority of the participants stated that they care about the quality of the lane lines and insufficient quality affects their lane utilization behavior negatively Therefore, it supports the fact that the vehicles do not use the lanes precisely. When the lateral positions of the vehicles on the two-lane divided roads are examined, it is seen that the lateral positions (right/left wheel) of the vehicles on these roads are less skewed to the right or left than those on the three-lane roads. The main reason for this situation is the narrowness of the road platform rather than the quality of the lane lines.

Conclusion and suggestions

In the study, the driver thoughts on the lane utilization characteristics and lane line quality relation were aimed to examine by evaluating the difference in line quality in three different cities. The data were collected from a total of 17 points in three cities. Using the field data, nine different experts were asked to score the line quality and it was seen that there was a concordance between the scores given by the experts from the compatibility analyzes (Kendall's W: 0.184; p: 0.103 > 0.05). Then, a face-to-face survey was conducted with a total of 390 drivers. According to answers, lane markings' visibility (lifetime) loss duration was declared approximately 250 days. This result clearly showed that the lane lines lost their visibility in a very short time and needed to be renewed on an annual basis. More than 80% of drivers stated that lane line quality has a great importance for the safe driving in traffic, and nearly 2/3 of them state that vehicle speeds, overtaking, lane selection, lane change etc. has a significant impact on driver behavior. 57% of the participants think that the lane line quality is good and above in intercity roads and 32% of the participants gave the answer as good or above for urban roads. Thus, these two results showed that the line quality on intercity roads were better than the urban roads, and unfortunately, the drivers were not satisfied with the line visibility (quality) on urban and intercity roads. From the statistical analysis, this situation does not have a statistically significant effect on scoring the line quality regardless of the profession, education level or income level of the drivers ($p > 0.10$). On the other hand, it was concluded that drivers did not care the lane line quality and did not pay much attention to this issue while driving. They mostly prefer to drive Lane-2 on three-lane roads, if a roadside parking is available in Lane-1.

It has also been determined that the lateral position distribution of the gravity centers does not comply with the normal distribution. Two main reasons observed for this issue: 1-Drivers do not use that lane at all, 2-They do not comply with the lane utilization discipline. Although, it is seen that the lateral position distributions of both right and left wheels comply with the normal distribution in almost all of the examined points, it was clearly observed that the distribution of gravity centers skewed to the right or left. However, under ideal conditions, it is expected that the right-left wheel positions and the distribution of the gravity centers should not be skewed to the right or left. According to the lateral position results, it was measured that the vehicles did not center the lanes exactly, and they generally moved close to the right or left edge of the lane where the lane utilization discipline is quite weak. When the positions of the vehicles on the two-lane divided roads are examined, the lateral positions of the vehicles (right and left wheels) on the two-lane roads are less skewed to the right or left rather than the three-lane roads. On this situation, lane line quality and the narrowness of the road platform can be shown as the main reason why drivers tend to average their lanes to stay on the safe side.

In summary, all the results clearly show that the quality of the lane line has a significant effect on the lane selection and utilization behavior of the drivers. It is very important to state that drivers are not satisfied with the line quality on both roads in Turkey, and it negatively affects lane selection and utilization behaviors. The participants declared the main reasons on this issue as low-quality material utilization, opening of the roads to traffic after painting, or not constructing the lane line paintings on time. The field data analysis also confirmed these thoughts and clearly drew attention to this problem. It is also thought from the results that lane tracking systems of new technology vehicles will not work on roads which have not sufficient lane line quality. In the study, the importance of lane line quality to increase the traffic safety and flow performance has been revealed as an undeniable fact. In addition, an important gap has been tried to be filled until the fully autonomous vehicles will be implemented by evaluating the driving characteristics and the lane line quality. Thus, the study aims to be an important study to determine the threshold for lane line quality requirements for the effective lane utilization of drivers, fully and semi-autonomous vehicles for the near future.

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