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Banihan Gunay
Lecturer in Transport,
University of Ulster, Faculty of Engineering, Northern Ireland

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An investigation of lane utilisation on Turkish highways

B. Gunay

This paper, being the first report on 'lane utilisation on Turkish highways', explores some of the unconventional characteristics of multilane traffic flows. As in many developing countries, the discipline of lane-based driving in Turkey is fairly weak. Possible reasons for this problem are different driving attitudes, poor road surface, poorly maintained lane markings, and the non-existence of studs on lane lines. The possible consequences of the problem, thus, could be loss of safety, difficult traffic management, inapplicability of conventional lane-based models, etc. Findings revealed that lateral positions of vehicles within the lane were more disorderly when compared with developed countries, where a normal distribution can be used. Regarding the distribution of vehicles over the lanes, the results in general were significantly different from the existing diagrams of some European highways. The proportion of traffic exhibited totally opposite trends for the median and shoulder lanes in Turkey, especially with wider shoulders. Whereas using the shoulder provided some extra capacity, along with some disadvantages, highways with no shoulders discharged less traffic than their counterparts from the developed world. Therefore, the present paper is thought to be the first step of the research into the problem of untidiness.

1. INTRODUCTION

'Lane utilisation', also known as lane split, can be defined by the percentage distribution of the total traffic flow to the individual lanes of multilane carriageways.[1] 'Lane-based-driving discipline' is the tendency to drive within a lane by keeping to the centre as closely as possible unless lane changing,[2] and should not be confused with a similar term 'lane discipline', meaning the tendency to choose the most appropriate lane with respect to the current speed of the vehicle, or in short, keeping to the slower lane unless overtaking.[3] Some researchers may prefer to use 'lateral position discipline' for the second definition and 'lane choice' for the third one. All of these three definitions can be grouped under the heading of 'lateral discipline'. To bring the concept to life, two photographs are shown in Fig. 1, as an example of two different levels of lane-based-driving discipline. Regarding the lane terminology, throughout the paper it should be noted that 'shoulder lane', 'middle lane' and 'median lane', will refer to nearside, middle and offside lanes, respectively.

As summarised in the following, investigation of lane utilisation has been an important issue for some researchers. Mahalel and Hakkret[4] revealed that, in a multi-lane unidirectional highway, the arrival pattern of vehicles in one lane is dependent on the arrival patterns of vehicles in the other lanes, and this feature necessitates the use of models that simultaneously describe vehicle arrivals on the roadway. Since the arrival pattern of vehicles in a cross-section of a multi-lane roadway is not random, the assumption of independent vehicle arrivals may lead to inaccuracies in traffic flow analyses. Concerning highway safety, Mahalel and Hakkret stated that relatively high usage of the median lane as well as a transfer of vehicles from the shoulder lane to the median lane, as traffic flow increases, may have a significant negative impact. Chang and Kao[5] carried out a macroscopic investigation of lane-changing characteristics in the USA, indicating the need for more understanding of the phenomena for better use of limited resources. Heidemann[6] argued that if a more balanced lane utilisation were to be achieved, for large traffic flows, the increase in capacity and the decrease in traffic congestion would be considerable. Later, Golias and Tsamboulas[7] scrutinised the problem from the aspects of macrolevel estimation of lane usage on highways. They stated that the heterogeneous distribution of vehicles over the lanes is a critical factor in designing highway intersections, as merging, diverging and transit traffic volumes in each lane need to be known.

Most important of all, it has also become clear that no coherent consensus exists on lane utilisation in general. The US Highway Capacity Manual,[8] for instance, does not specify a typical lane usage that could be applicable to any type of roadway, probably because it may depend on a variety of factors, such as driver attitude, traffic flow, type and proximity of intersections, and the quality of road surface and road markings. Not many studies were conducted after this manual (*ibid.*), and hence the problem still deserves more attention. The findings of this paper broadened the scale of uncertainty in lane utilisation even further, and hence the question certainly remains unsolved, especially for developing countries.

2. OPERATION OF MULTILANE TRAFFIC IN TURKEY AND NEED FOR RESEARCH

Direct observations of traffic flow, as a user of Turkish roadways, was the first motive of the research, leading to the supposition that lateral characteristics of traffic flow may be different in developing countries. As a matter of fact, a number



Fig. 1. The effect of carriageway width on the discipline of lane-based-driving

of researchers, such as Sutomo[9] and Hoque and McDonald,[10] took a low discipline of lane-based-driving into consideration in their traffic flow models in Indonesia and Bangladesh, respectively. However, since these studies scrutinised urban traffic by focusing on intersections, utilisation of lanes over the cross-section for uninterrupted traffic was a missing concept.

Gunay[11] analysed the lateral positions of vehicles in two- and three-lane roadways in England and Germany, respectively. His study revealed that the normal distribution could be used to represent the lateral locations of vehicles within a lane at certain sites in these countries. However, in most of the developing countries, reasons such as poor roadway surface, inefficient maintenance of road markings, impatient driver attitudes, and disorderly travelling vehicles gave rise to the difficulty of representing the lateral positions by a statistical distribution. It was also reported (*ibid.*) that not only was the shape of the lateral distribution of traffic was irregular, but also this shape took various forms with respect to the prevailing traffic flow conditions.

Possible discipline scenarios for multilane unidirectional traffic flows can be outlined as seen in Table 1, where the term 'discipline of lane-based-driving' represents lateral distribution of vehicles within a lane, and the term 'lane discipline' refers to the choice of the lane in which to travel. While the traffic flow in European highways takes the middle row of the matrix, the bottom right cell is a typical description of traffic in developing countries in general. Practical examples for the first row are, however, difficult to find. The KLUO (Keep Left Unless Overtaking) system, used in the table, refers to the situation where the proportion of traffic in each lane follows a common and 'international' pattern, such as a decrease in the percentage of the shoulder lane and an increase in the percentage of the median lane with increasing total flow (see also Figs 9 and 10).

As a result of disorderliness in traffic flow, a number of negative consequences are expected. Irregular positions of vehicles across the carriageway may cause density or speed drops and hence some capacity loss may be inevitable. Extensive usage of the shoulder (Fig. 2), especially at high densities, is a potential source of bottleneck or lack of safety as far as the emergency cases are concerned. Furthermore, poor discipline of lane-based-driving will result in extra wear on lane markings, which are already hardly visible in many developing countries. In regard to the traffic engineering issues, the unavailability of a suitable model that takes into account the disorderly lateral characteristics of traffic flow may lead to some accuracy loss in analyses, as the assumptions of existing models become cumbersome in such places. Therefore, an important issue that needs to be focused on is the provision of a better understanding of the lane utilisation in developing countries. These problems may be the subject of future research and the present paper is expected to form a basis.

3. DATA COLLECTION AND EXTRACTION

The traffic flow observations were carried out in Istanbul, the north-west of Turkey, taking place at nine different sites in



Fig. 2. Using the hard shoulder as a traffic lane with increased density

Discipline of lane-based-driving	Lane discipline	
	Good	Weak
Ideally tidy	KLUO system is practised. Every vehicle travels in the centre of the lane.	KLUO system is not practised. Every vehicle travels in the centre of the lane.
Tidy	KLUO system is practised. Lateral distribution of vehicles within the lane is very similar to a normal distribution.	KLUO system is not practised. Lateral distribution of vehicles within the lane is very similar to a normal distribution.
Untidy	KLUO system is practised. It is very difficult to represent the lateral distribution of vehicles within the lane by a statistical distribution.	KLUO system is not practised. It is very difficult to represent the lateral distribution of vehicles within a lane by a statistical distribution.

Table 1. Discipline matrix (driving on the left)

order to meet the objectives of a broader piece of research. Only the data from five of these sites were appropriate to be included in the paper, and these are listed in Table 2. While Sites 2 and 3 formed the main data collection places to serve the majority of the research objectives, the rest of the sites provided additional data to investigate whether the findings are similar in various places.

The data collection sites were selected in such a way that the most important requirements of the research are met and the number of external effects are kept to a minimum, in order to concentrate on lateral characteristics. These sites were straight and zero gradient sections of multilane uninterrupted highways, away from entrance and exit ramps. They all had suitable vantage points: either a pedestrian or roadway bridge passing over the carriageway being considered.

The data were collected using a camcorder. A small tripod was used to hold the camera on site. The guard rails of the bridges were used to position the equipment. Because the whole equipment was not very large compared with a normal-sized tripod, it was difficult to be seen by the drivers. Most of the time, the observer sat on the floor of the bridge so that his presence was not detected, and so the driving patterns were not affected. The total filming duration in these sites was about 17 hours.

Analysis of the data was carried out at the Traffic Laboratories of the Transport Operations and Research Group, University of Newcastle. Although there is no fixed rule for selecting the time interval in the processing of traffic flow data, TRB[8] suggests 15-min intervals, while some others used 5-min intervals. Thirty-minute intervals were also used in more aggregate measurements, such as in establishing the maximum sustainable throughput. The present research, however, used 1-min intervals for the analyses, since it was assumed that the degree of untidiness changes frequently, depending on the instantaneous local conditions of the flow. While these short intervals increased the time consumed during the processing of the data, this decision was justified in terms of better accuracy of the findings. As an ongoing part of this research, the same data will be re-grouped into longer sampler intervals to obtain a different picture of the relationship. The current analysis, presented in the following chapter, assumes that flow is the explanatory variable and lane encroachments the response variable. To see whether there are any lagged correlations indicating the direction of cause and effect, the future work will analyse the findings as a time series, and this will be discussed elsewhere.

4. THE FINDINGS

Figure 3 is the frequency distribution of vehicles over 54 strips, each of which is 25 cm wide. Unlike tidy flows in western highways, the presence of vehicles occupying two lanes results in a dispersed lateral distribution especially on the shoulder lane. The case in a similar highway of a developed country, however, according to Gunay,[11] exhibits much tidier distribution, where a normal fit could be used to represent the lateral distribution of vehicles in each lane (Fig. 4). The non-existence of frequency bars on or around lane lines is clearly observed in Fig. 4, when compared with Fig. 3, where a considerable amount of traffic is travelling, occupying two lanes simultaneously. This fact was the same as in other nine

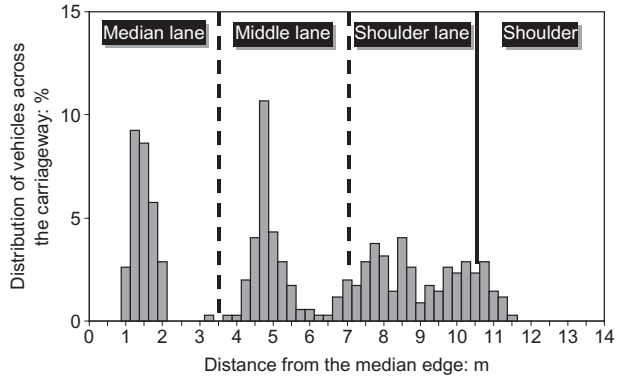


Fig. 3. Frequency distribution of lateral position of 347 vehicles across the carriageway, Site 4A.

Site no.	Location	Roadway type	No. of lanes	Lane width	Description	Heavy vehicles	Duration
2	Buyukdere Street near Otosanayi	Urban carriageway, no shoulder	3	3·0 m	Visible lane markings	3·8%	5 h 30 min
3	Londra Asfalti, near Atakoy	Urban carriageway, 2·25 m wide shoulder	3	3·5 m	Visible lane markings	4·4%	6 h
4A	Londra Asfalti, near Merter	Urban carriageway, 3·0 m wide shoulder	3	3·5 m	Visible lane markings	6·2%	1 h 30 min
4B	Site 4A, West bound	Urban carriageway, 3·9 m wide shoulder	3	3·5 m	Hardly visible lane markings	5·9%	2 h
5	Ankara Asfalti, near Kucukyali	Urban carriageway, 3·0 m wide shoulder	2	3·5 m	Hardly visible lane markings	12·7%	1 h 30 min

Table 2. Data collection sites and characteristics

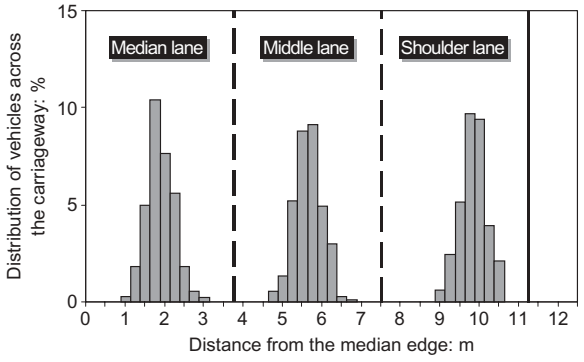


Fig. 4. Frequency distribution of lateral position of 1050 vehicles in Germany, from Gunay[11]

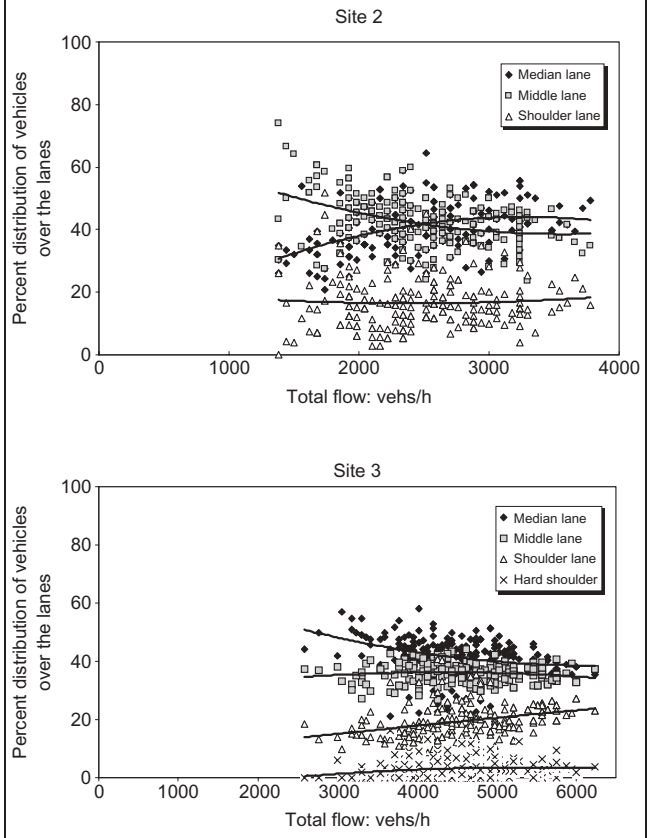


Fig. 5. Distribution of traffic over the lanes on three lane carriageways without and with shoulders, respectively

sites of his study, suggesting that untidiness in exercised on many (especially non-motorway) roads in Turkey.

Therefore, in untidy traffic flows, it is not very easy to count the number of vehicles in each lane, as some drivers located astride both lanes. For simplicity, it was decided that when more than half of a vehicle happens to be in a particular lane, that vehicle was counted in that lane. Analyses were carried out on five different sites with different characteristics, such as various shoulder widths. Then the numbers of vehicles in each lane was transferred to percentages with respect to the total number of vehicles in the carriageway in each minute.

The relationship between the total flow, on the x-axis, and the percentage distribution of vehicles in each lane, on the y-axis, for various data collection sites are given in the next three figures. More interpretation on these diagrams will be made in section 5 where the case is compared with developed countries. Brief descriptions of the diagrams are given here. Computer fitted curves to the plots are also shown. Equations and R^2 values of the curves are given separately in the Appendix.

Figure 5 demonstrates this relationship for Sites 2 and 3 where 10 248 and 16 425 vehicles are counted lane-by-lane, respectively. Similarly, Fig. 6 shows the effect of the shoulder width on the lane split for Sites 4A and 4B, where 10353 and 6919 vehicles are categorized over the lanes. The amount of traffic on the shoulder increases with increasing shoulder width. At around capacity operation, it nearly carries as much traffic as normal traffic lanes.

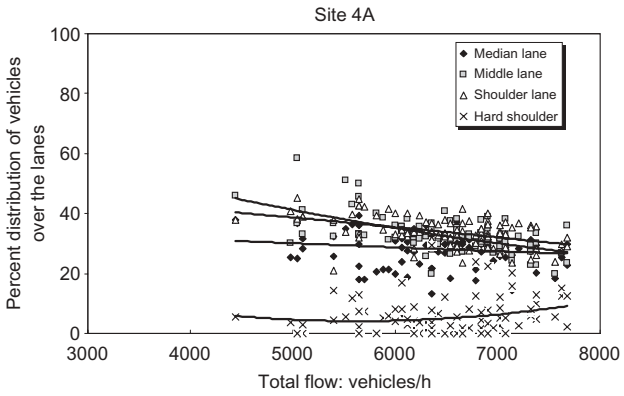
Finally, Fig. 7 gives the lane distribution of 6458 vehicles on Site 5. The contribution of the shoulder is again noticeable especially with increasing total flow.

In addition, as a different way of presentation, the relationship between the total density and the percentage distribution of vehicles in each lane could also be used to show the concerned relationship of lane split. For instance Fig. 8 is drawn for Site 3, which is generally consistent with the second diagram of Fig. 5, where the total flow rate rather than density was the criterion.

5. LANE UTILISATION IN COMPARISON WITH DEVELOPED COUNTRIES

According to the best knowledge of the author, there has been a small number of studies on lane split, leading to a limited comparison. Although it is impossible to find identical highways from various countries, straight sections of multilane carriageways were thought to be sufficient to make some general comparisons regarding the lane utilisation characteristics. Besides, since the observations of the present research concentrated on around capacity operations, the findings for the free flow regions were not provided. The term 'other countries' in Figs 7 and 8 refer to Germany (Heidemann[6]), Italy (Gattuso [12]), Britain (Yousif and Hunt[1]), and Greece (Golias and Tsamboulas[7]).

In these countries, the common trend of the relationship was that the amount of traffic carried by the shoulder lane decreased with increasing flow and the proportion of traffic in the median lane increased with increasing flow. The ratio in the middle lane remained almost the same in these countries except Italy, where the trend was a steady decline. In Turkey, however, for a typical three-lane carriageway with shoulder, with increasing flow, a decrease in the median lane and an increase in the shoulder lane was the most striking finding. This was exactly the opposite behaviour to that found in the countries above. Another important finding from the untidy flow data was the considerable amount of traffic carried by the shoulder. At high total flow rates, the portion was around 10–30% depending on the width of the shoulder. The data



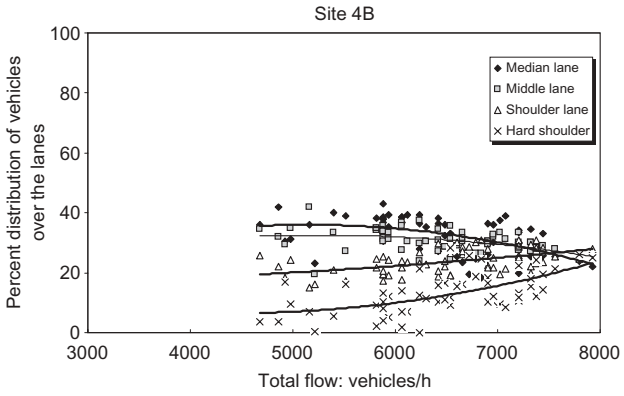


Fig. 6. Distribution of traffic over the lanes on two similar carriageways with 3·0 and 3·9 metre-wide shoulders, respectively

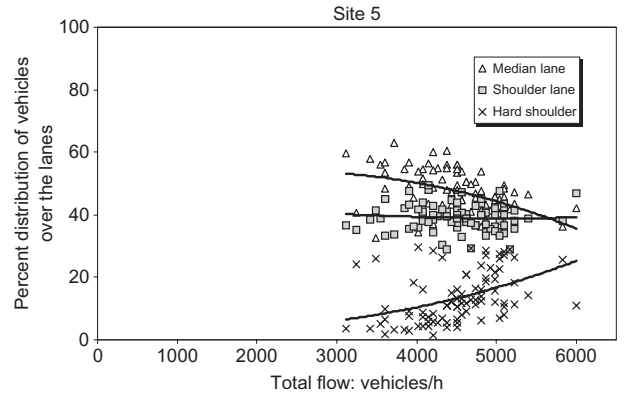


Fig. 7. Distribution of traffic over the lanes on a two-lane carriageway with a shoulder

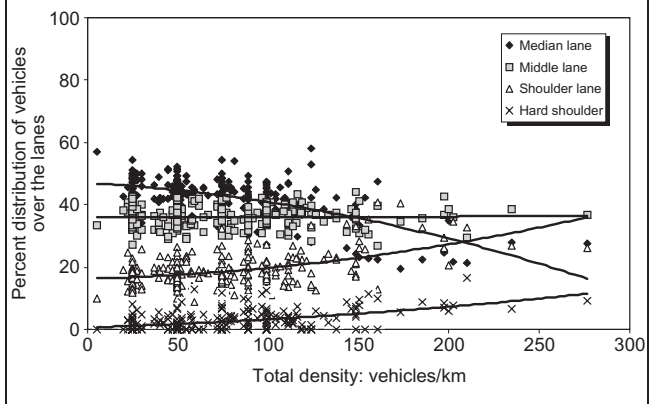


Fig. 8. Distribution of traffic over the lanes with respect to various density levels in Site 3

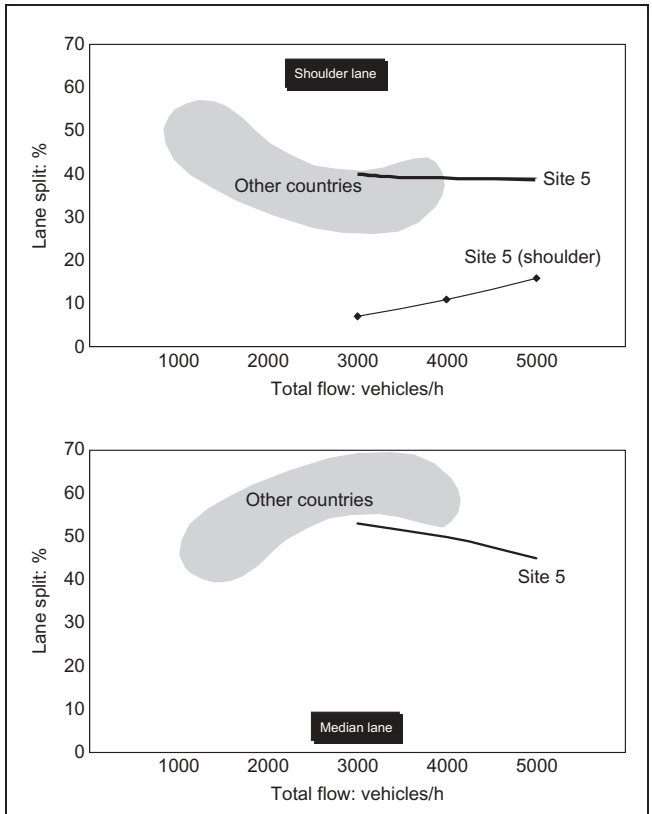


Fig. 9. Comparison of lane utilisation on two-lane carriageways with other countries

revealed that, except for the congested state, in general the median lane is the main carrier, whereas in tidy flows the shoulder and middle lanes carry the majority of traffic. From these observations, it can also be concluded that lane discipline (i.e. keep to the slower lane unless overtaking) is not practised in untidy traffic, while it is followed much better in tidy flows. Furthermore, the availability of a shoulder might be the main source of lack of carriageway discipline. While the curve representing Site 2 (no shoulder) was similar to the others, Site 3 exhibited a totally different trend.

6. CONCLUDING REMARKS AND FUTURE WORK

Observations of lateral position of traffic revealed that distribution of vehicles within a lane is less tidy in Turkey than in developed countries and the degree of untidiness may vary from one highway to another.[11] Various factors influence the shape of this distribution. The width of the shoulder has a significant effect on the utilisation of the lanes. In sites with no

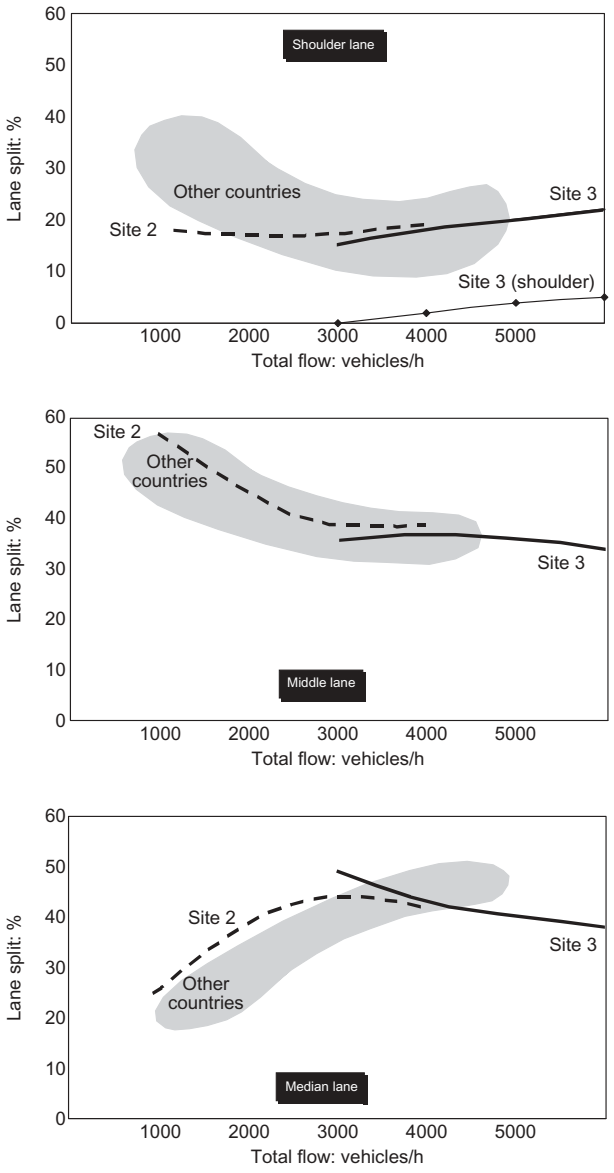


Fig. 10. Comparison of lane utilisation on three-lane carriageways with other countries. Remember that Site 2 does not have a shoulder

shoulder, the findings resulted in similar lane split curves to the results obtained from developed countries. When the shoulder was available to be travelled in, the shape of the lane utilisation curves exhibited a totally opposite pattern to similar highways of developed countries. It should be remembered that no previous research had been undertaken in Turkey to investigate lane utilisation. Therefore, some of the unconventional lateral characteristics discovered in the paper might be worth taking into consideration by the responsible authorities in the planning, design and operation of highways. The following points are some examples of this kind.

Traffic flow in the slower lanes of the multilane highways in Turkey is less tidy and requires more skilful driving than in faster lanes. This sometimes might result in totally different operational characteristics between the left- and the right-hand sides of the same carriageway. In addition, in free flow conditions, the proportion of traffic in the median lane is significant. As the flow approaches capacity, a considerable amount of lane changes from the median lane to the middle and shoulder lanes takes place. Therefore, this might be one of the reasons behind the instability in traffic during the maximum flow operations. A supportive argument was made earlier by Gedizlioglu and Akad [13] stating that in the flow-speed-density observations in Turkey, generally, scarcity of data around the capacity is noted, leading to a jump from the stable flow to the unstable flow regions. First, in the design of intersections, the estimation of lane flows and the proportion of transit and merging/diverging vehicles is important. Application of conventional values, established by western traffic analysts, may not be accurate in Turkey. Second, the investigation of a potential increase in the maximum reachable flows with more balanced lane utilisation gives scope for further research. A simulation study is being carried out in order to estimate the effects of untidiness on the flow characteristics for given various operation scenarios. Third, ongoing work on the same data will classify the vehicle types to see which types are most likely to breach lateral discipline. This will be useful in helping to target remedial measures. Fourth, the hard shoulder can be made bumpy, but the fact that emergency vehicles will also experience discomfort is a disadvantage. And finally, safety issues, perhaps as equally important as the congestion and capacity problems arising from poor discipline, will form a new dimension to the author's future research.

7. ACKNOWLEDGEMENT

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REFERENCES

1. YOUSIF S. and HUNT J. Modelling lane utilisation on British dual-carriageway roads: effects of lane changing. *Traffic Engineering and Control*, 1995, **36**, No. 12, 680–687.
2. GUNAY B. Methods to quantify the discipline of lane-based-driving. *Traffic Engineering and Control*, 2003, **44**, No. 1, 22–27.
3. MCDONALD M., HALL R. D., ROLLS G. and RICHARDS A. Motorway lane discipline – a literature review and video analysis. *University of Southampton technical report*, 1992.
4. MAHALEL D. and HAKKERT A. S. Traffic arrival patterns on a cross-section of a multilane highway. *Transportation Research*, 1983, **17A**, No. 4, 263–270.
5. CHANG G.-L. and KAO Y.-M. An empirical investigation of macroscopic lane-changing characteristics on uncongested multilane freeways. *Transportation Research*, 1991, **25A**, No. 6, 375–389.
6. HEIDEMANN D. Distribution of traffic of the individual lanes on multilane unidirectional roadways. *The Second International Symposium on Highway Capacity, Sydney, Australia*, Australian Road Research Board Ltd.: Transportation Research Board, 1994, 265–276.
7. GOLIAS J. and TSAMBOULAS D., Macrolevel estimation of highway lane usage. *Journal of Transportation Engineering*, 1995, **121**, No. 1, 40–49.
8. TRB HIGHWAY CAPACITY MANUAL. 2000, Transportation Research Board National Research Council.

9. SUTOMO H. S. Appropriate Saturation Flow at Traffic Signals in Javanese Cities. *PhD Thesis*, 1992, University of Leeds.
10. HOQUE S. and MCDONALD M. MIXSIM: A microscopic model of signalized intersections in developing countries. *Modelling and Simulation ESM1995, Istanbul, Turkey*, Society for Computing Simulation International, 1995, 321–325.
11. GUNAY B. Modelling lane discipline on multilane uninterrupted traffic flow. *Traffic Engineering and Control*, 1999, **41**, No. 9, 440–447.
12. GATTUSO D. Some characteristics of traffic flow on motorway studied with support automatic image processing. *Euro XIII Conference on Operations Research Designing Practical Solutions*, *Glasgow*, 1994.
13. GEDIZLIOGLU E. and AKAD M. Utilisation of capacity at urban bottleneck sections; the Bosphorus Bridge example (in Turkish). *The Second Congregate on Istanbul's Urban Transport*, Ed. TMMOB, Istanbul, 1992.

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APPENDIX

Statistical characteristics of the best fitted curves

		Second-order polynomial equation*	R^2
Site 2	Shoulder lane	$S = 2 \times 10^{-6}\ TF^2 - 0{\cdot}01\ TF + 28{\cdot}31$	0·005
	Middle lane	$S = 2 \times 10^{-06}\ TF^2 - 0{\cdot}013\ TF + 64{\cdot}32$	0·119
	Median lane	$S = -4 \times 10^{-06}\ TF^2 + 0{\cdot}023\ TF + 7{\cdot}37$	0·130
Site 3	Shoulder	$S = -8 \times 10^{-07}\ TF^2 + 0{\cdot}008\ TF - 16{\cdot}03$	0·056
	Shoulder lane	$S = -2 \times 10^{-06}\ TF^2 + 0{\cdot}017\ TF - 22{\cdot}04$	0·097
	Middle lane	$S = -1 \times 10^{-06}\ TF^2 + 0{\cdot}008\ TF + 19{\cdot}02$	0·027
	Median lane	$S = 4 \times 10^{-06}\ TF^2 - 0{\cdot}034\ TF + 119{\cdot}05$	0·147
Site 4A	Shoulder	$S = 2 \times 10^{-06}\ TF^2 - 0{\cdot}023\ TF + 74{\cdot}38$	0·040
	Shoulder lane	$S = -9 \times 10^{-08}\ TF^2 - 0{\cdot}002\ TF + 52{\cdot}04$	0·215
	Middle lane	$S = 5 \times 10^{-07}\ TF^2 - 0{\cdot}012\ TF + 86{\cdot}38$	0·350
	Median lane	$S = 6 \times 10^{-08}\ TF^2 - 0{\cdot}002\ TF + 38{\cdot}6$	0·026
Site 4B	Shoulder	$S = 2 \times 10^{-06}\ TF^2 - 0{\cdot}027\ TF + 87{\cdot}25$	0·203
	Shoulder lane	$S = 3 \times 10^{-07}\ TF^2 - 0{\cdot}001\ TF + 16{\cdot}63$	0·254
	Middle lane	$S = -1 \times 10^{-06}\ TF^2 + 0{\cdot}010\ TF + 5{\cdot}32$	0·220
	Median lane	$S = -2 \times 10^{-06}\ TF^2 + 0{\cdot}018\ TF - 9{\cdot}20$	0·303
Site 5	Shoulder	$S = 1 \times 10^{-06}\ TF^2 - 0{\cdot}003\ TF + 6{\cdot}53$	0·181
	Shoulder lane	$S = 3 \times 10^{-07}\ TF^2 - 0{\cdot}003\ TF + 47{\cdot}49$	0·004
	Median lane	$S = -1 \times 10^{-06}\ TF^2 + 0{\cdot}007\ TF + 45{\cdot}98$	0·223

* Where S is the percentage split in the corresponding lane, and TF is the total flow. It should also be noted that the analyses were carried out over 1-min intervals, and hence the plots of the figures were dispersed over a wide range. If the presentation had been based on longer time intervals, the R^2 values would have improved with smoother fluctuations of the plots. However, representation of the plots by the best-fitted curves is not the primary objective of the paper.