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Area-wide ANPR coverage with a small number of instrumented vehicles

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***Abstract*—The paper investigates the applicability of an area-wide coverage of speed enforcement by a non-stationary Automatic Number Plate Recognition (ANPR) system. Two instrumented cars, each fitted with an ANPR camera and related equipment, were facilitated in the surveys. These cars were parked systematically according to a schedule during the day within a large university campus in Turkey on 11 corridors over a four-month period. The work was carried out at two stages to be able to compare the effectiveness of the application. During the first two months, the application was disguised from the drivers. In the next two-month period the public were informed of the scheme by various publicity means and were told to obey the speed limits. Since the tests were carried out within a closed area, in both stages more or less the same profile of drivers were studied, hence the findings are expected to reflect directly the effects of the application. It was found that in most corridors the average speeds were lower in the second stage. For the two month period after the announcement of the scheme, no evidence was found to show that the impact was diminishing, suggesting the effectiveness of the system. However, the study revealed the problem of posting unsuitable speed limits in the campus which requires further attention.**

Keywords*—*ANPR; average speed limit; speed enforcement

I. INTRODUCTION

One of the main reasons behind traffic accidents is speeding [1]. In Turkey, among other infringements types of traffic rules and regulations, speeding has the highest amount of penalty paid by drivers in total [2]. Speeding related accidents account for up to 30% of all accidents [3]. As known, there is a direct relationship between the speeds of vehicles involved in a crash and the severity of the accident [4]. For speed limit enforcement, many countries widely employ police radar (gun) [5], and the same applies to Turkey. However, the main drawback is that if the drivers know the location of the radar check point, they obey the limits locally around that point, but in advance (upstream) as well as downstream of this point higher speeds are recorded. Hence the improvement is only achieved around the radar check points, leaving the rest of the road sections unattended. Another disadvantage is that they require a large amount of scarce and valuable police sources. Various traffic calming techniques can be argued as alternatives, such as the speed humps; however they have their own disadvantages, i.e. driving discomfort, environmental disturbance, etc. [6]. For a longer (in distance) coverage of road sections (in corridors), automatic number plate recognition (ANPR) systems are now in practice in many countries and gaining popularity every day. The concept of average speed limit works as follows: two ANPR cameras are located on a corridor with a distance of d apart from each other. Each time a vehicle passes, these cameras record the times of passage (t_1, t_2) and the registration number of this vehicle. The average speed of the vehicle is calculated using the $\frac{d}{t_2 - t_1}$ formula. In practice, the d distance ranges from a few hundred metres to a few kilometres. The spot (instantaneous) speed of the vehicle can fluctuate along the corridor between these two ends. But it is the average value that this system is interested in, not the fluctuating (dashboard) speed values. For a more detailed description of these systems and their applications, refer to [7-14]. Various authorities such as the Police and the General Highways Directorate in Turkey have recently adapted such systems on a limited number of urban as well as rural corridors [15, 16]. It should however be noted that all of the above examples [7-14] are based on corridor coverage rather than network-wide enforcement. The present paper will demonstrate a special application of the system for the purpose of a wider coverage by a limited number of cameras as will be discussed in the following sections.

II. Data Collection

The Akdeniz University campus was selected as the pilot area. This kind of closed area has the advantage of providing quite consistent driver population. This feature gives the opportunity that the same vehicle can be captured more than once during the study period, compared to open areas such as urban streets where this rate is expected to be much lower. This, hence, allows more robust "before and after" studies. The work was carried out on 11 routes within the campus (Fig 1.), one of the largest campuses in the country with around 5.9 km^2. These routes had speed limits ranging from 20 to 50 km/h. The Northeast corner of the campus (where the Medical School and its hospital buildings are situated) has its own borders and is separated from the main campus. The administration and the parking rules, etc. are different from the main campus The gardens in the Northwest corner belongs to the Faculty of Agriculture and has no public traffic. Similarly the Southeast corner is mainly the student accommodations again with no traffic of interest. Hence these parts of the campus were excluded in the survey.

The data collection infrastructure contained a limited number of system components with reasonable cost implications. These were

- two ANPR cameras,
- two vehicles,
- plate recognition hardware and software,
- data transfer (3G) routers and the SIM cards,
- two uninterrupted power units (UPS),
- a global positioning system (GPS) device, and
- a laptop.

The two vehicles were hired for the study period of four months and the rest of the equipment were purchased for the traffic laboratory of the university.

In order to achieve good viewing angle, the cameras had to be positioned at a certain height. Therefore they were mounted at the top of the vehicles for better viewing angle. Although it is not normally required in practice, in order to test the accuracy level of the readings, all of the registration plate readings (around 250 thousand) were manually checked by a one of the authors after the data collection and before the analyses commenced. It was found that the accuracy level was more than 90% throughout the survey, a very acceptable figure when compared with various other ANPR studies from different countries around the world [17].

The work was carried out in two stages (as can also be called as before and after). During the first stage the speed measurements were disguised from the public by hiding the cameras inside large loud speakers (Fig. 2) placed on top of the two vehicles as seen in Fig. 3. "Traffic Noise Measurement" signs were displayed on these vehicles (Fig. 3) so that people noticing these vehicles had the impression that the survey was about traffic noise.

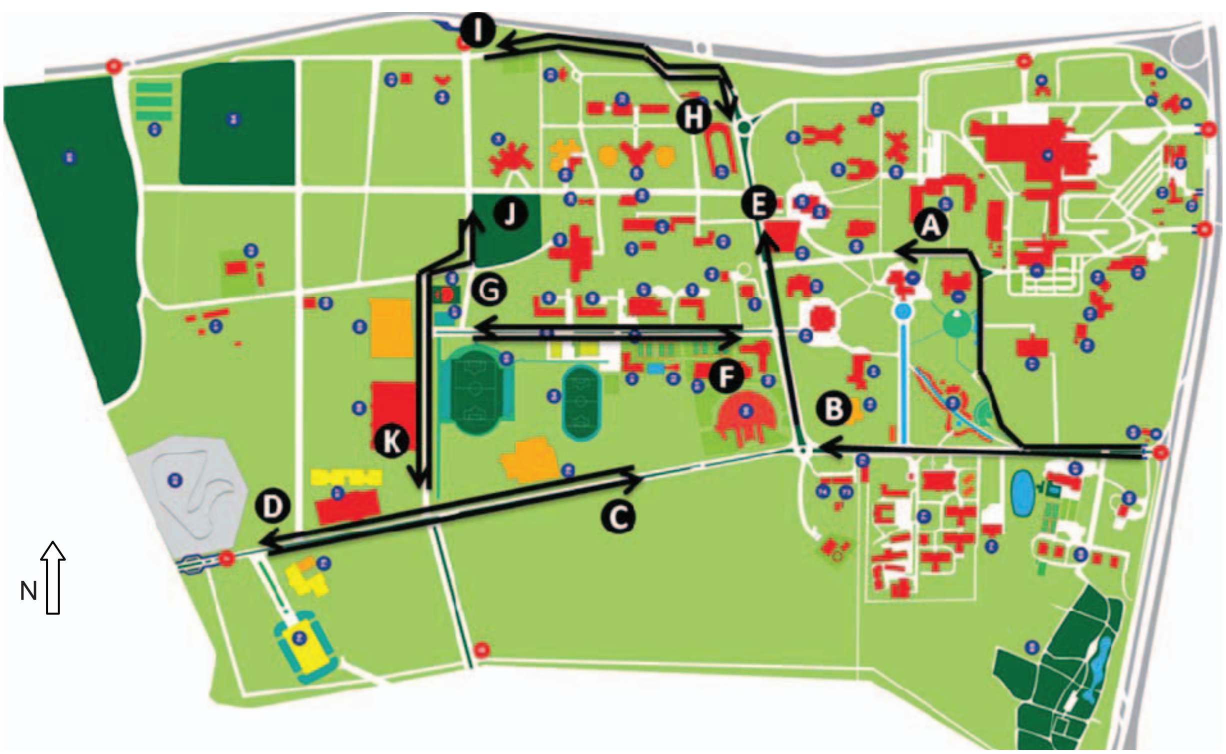

Fig. 1. The campus map and the routes studied

Fig. 2. One of the ANPR cameras hidden inside a loudspeaker.

Fig. 3. One of the instrumented vehicles.

Fig. 4. The 'noise survey' sign for deception.

The surveys were conducted between 08:00-18:00 hours every weekday. The cameras and the routers in the vehicles were powered by the UPS during these times. At night the UPSs were recharged from the 220 Volts mains (Fig. 5).

At the end of the first stage and before the start of the second stage, a number of announcements were made to the public that there would be speed checks (based on the average speed limit concept) at the campus from a specific date onwards. These announcements were implemented by (a) distributing around 5000 leaflets to the motorists when entering the campus, (b) by sending official email messages from the university management about the speed enforcement, (c) by passing website/Twitter messages, and (d) by displaying three large banners (200 x 70 cm) at the main gates of the campus. None of these announcements mentioned any sort of penalty for speeding. Some of the route characteristics and the number of observation days for each stage can be seen in Table I. It should also be noted that normally no speed checks are carried out by local police within the campus. Therefore the differences in the speeds before and after are the direct outcomes of the announcements about the new application of the average speed limit concept.

TABLE I. CORRIDOR CHARACTERISTICS AND SURVEY DURATIONS

Route Code		Route Length (m)	No of observation days	
Before*	**After***		**Before***	**After***
A1	A2	908	6	7
B1	B2	717	6	8
C1	C2	890	7	5
D1	D2	890	7	5
E1	E2	425	6	5
F1	F2	600	5	5
G1	G2	600	5	4
H1	H2	615	8	6
I1	I2	594	7	6
J1	J2	695	9	5
K1	K2	695	6	4

* *Before and after the announcement of the speed checks*

As one of the unique features of the particular system employed in the surveys, the image recognition and processing took place in the camera unit as opposed to many other systems where the photos are first transferred to the central computer and then processed. The main advantage here therefore is that the sizes of the capture files were very small as they were only text files. In addition to the transfer of the registration plate readings, the transfer of the photographs of the vehicles was also possible and optional.

During the surveys, on the 11 routes, each instrumented vehicle was carefully parked at certain locations first determined on a map of the university campus and later these locations were double checked by a GPS device. The distances between these locations were then calculated accurately to find the route lengths. The whole survey lasted around four months (around two months for each stage). The parking of the vehicles was conducted according to a schedule for a uniform coverage as much as possible in time and space during the survey. The weather conditions were taken into account so that each corridor is surveyed at least 4 days (Table I). In the present paper only the dry days are included in the analyses.

III. The Findings

First of all, the data collected were arranged in the form of frequency distributions of speeds where the horizontal axis is speed and the vertical axis is percent frequencies. All observations were aggregated route by route. In other words, each row in Table II represents all speed measurements at a particular route (over a number of days) for each stage (both before and after). See Table I for the other characteristics of these routes. Means and standard deviations are averaged over all observation days for each route and for each stage to be able to see the whole picture as a first step.

Secondly, the differences between the mean values of speeds were statistically compared for both stages. Although the effect of light rain on the speed distribution diagrams was invisible by naked eye, to be able to eliminate variations in the readings (due to this and any other possible reason), rather than using the grouped averages of the routes (shown in Table II), only selected single days were compared. In order to do this, for each route a typical dry day was selected to represent a typical week day on that route during the first and the second stages. Then the histograms are produced where the x-axis is the speed classes and the y-axis is the frequencies (see the Appendix).

TABLE II. A Summary Of Before And After Comparisons (All Days)

Route Code	Speed Limit (km/h)	Average Means and (Average Std. Deviations)	
		Before	After
A	30	28.2 (6.4)	28.5 (5.9)
B	30	31.7 (6.9)	31.8 (7.1)
C	50	54.3 (10.9)	49.4 (10.0)
D	50	51.9 (8.4)	49.3 (9.7)
E	30	33.4 (8.5)	31.0 (7.8)
F	20	48.0 (12.2)	46.0 (12.3)
G	20	44.8 (11.2)	44.5 (10.7)
H	30	37.1 (8.0)	35.9 (7.4)
I	30	42.8 (7.5)	41.9 (8.0)
J	30	45.1 (7.1)	42.3 (7.4)
K	30	41.8 (6.7)	39.8 (6.7)

Table III summarizes the shift in the modes (the speed class which has the highest frequency) between the two stages for each route. It can be concluded that for most routes, the modes were lower in the second stage at least by 5 km/h.

For these bell-shaped distributions, a normal fit is sought using the chi-square test. For example, for Route A in the Appendix, the 27th of March 2013 is selected from the first stage (before the announcement) and the 10th of April 2013 is selected to represent a typical day in the second stage (after the announcement). Based on 78 and 96 speed readings, respectively, six speed classes are arranged (for Route A) for both histograms and the total Chi-square values are computed for the both. To make sure that each class has at least 5 values, class combinations are practiced at the tales of the histograms if necessary. The degrees of freedom were then calculated by subtracting 3 from the final (combined) number of classes. Using the statistical tables, the Chi-square values were compared to decide whether the null-hypothesis of a normal fit can be rejected or not.

After the goodness-of-fit tests for each route, it was possible to conclude that Routes A1, A2, C1, C2, D1, D2, F2, G1, G2, H1, H2, I1, I2, J1, J2, K1, K2 had good fit (Table IV). The rest of the routes however still exhibited bell-shape histograms implying some sort of normality in the distributions (See Appendix). Therefore t-tests, to compare the means, were still carried out for all the routes. Equation (1) is used in the "1.96 x S" formula, which is compared with the numeric difference between the two means (μ_1 - μ_2). If (μ_1 - μ_2) is bigger than (1.96 x S), then the difference is said to be significant.

TABLE III. Shifts In Mode Values

Route Code	Speed Limit (km/h)	Observation Dates (no rain)		Class of the mode (km/h)	
		Before	After	Before	After
A	30	27/03	10/04	35	30
B	30	26/03	09/04	40	35
C	50	05/03	11/04	60	50
D	50	05/03	11/04	N/A	N/A
E	30	07/03	17/04	40	35
F	20	28/02	07/05	55	50
G	20	28/02	07/05	55	45
H	30	06/03	25/04	40	35
I	30	06/03	25/04	45	45
J	30	27/02	08/05	45	45
K	30	27/02	08/05	40-45	40

$$S = \sqrt{\frac{SD_1^2}{n_1} + \frac{SD_2^2}{n_2}} \qquad (1)$$

As a result, except F and I, the rest of the (nine) routes proved that the means for the first and the second stages are significantly different from each other implying the positive effect of the announcement almost everywhere of the campus studied. It is worth mentioning that the amount of drivers who exceeded the set speed limits deserves special attention. As the diagrams in the Appendix show, in the majority of the cases the means were greater than the speed limits especially in the second stage.

Finally, it was interesting to find that among various routes, whose speed limits are the same, the distribution histograms of speeds were so wide ranging. This problem implies a number of issues that requires further scrutiny and will be the subject of ongoing work.

TABLE IV. THE SUMMARY OF THE CHI SQUARE AND T-TESTS

Route Code	Date	Number of observations	Means ($\mu_{1,2}$)	Standard Deviation	No of Classes	Class range (km/h)	Calculated Chi-square	Degrees of Freedom	Table value of Chi-square	**Normal Fit?**	S (Eq. 1)	1.96 x S	μ_1 - μ_1	**Significant Difference?**
A1	27/03	78	30.6	5.36	6	15-45	0.48	1	3.84	**Yes**	0.798	1.56	3.20	**Yes**
A2	10/04	96	27.4	5.08	6	10-40	2.52	2	5.99	**Yes**				
B1	26/03	820	32.9	7.43	9	10-55	70.3	6	12.6	**No**	0.343	0.67	1.50	**Yes**
B2	09/04	985	31.4	7.03	9	10-55	39	5	11.1	**No**				
C1	05/03	583	54.5	8.21	9	35-80	8.07	5	11.1	**Yes**	0.454	0.89	5.50	**Yes**
C2	11/04	823	49	8.65	11	20-75	14	7	14.1	**Yes**				
D1	05/03	268	52.9	8.08	11	25-80	4.61	4	9.49	**Yes**	0.765	1.50	3.40	**Yes**
D2	11/04	242	49.5	9.09	10	25-75	8.14	5	11.1	**Yes**				
E1	07/03	1109	32.3	8.35	10	10-60	89	6	12.6	**No**	0.336	0.66	1.60	**Yes**
E2	17/04	1148	30.7	7.55	9	10-55	33.3	6	12.6	**No**				
F1	28/02	193	46.9	13.9	13	10-75	46.9	8	15.5	**No**	1.362	2.67	2.40	**No**
F2	07/05	177	44.5	12.3	12	15-75	9.42	7	14.1	**Yes**				
G1	28/02	44	49	6.78	7	30-65	1.94	1	3.84	**Yes**	1.44	2.82	4.20	**Yes**
G2	07/05	62	44.8	8.08	8	25-65	0.914	3	7.8	**Yes**				
H1	06/03	165	37.3	6.83	9	15-60	1.79	4	9.49	**Yes**	0.883	1.73	3.70	**Yes**
H2	25/04	73	33.6	6.02	7	15-50	3.99	2	5.99	**Yes**				
I1	06/03	103	42.5	7.05	9	20-65	2.08	2	5.99	**Yes**	1.14	2.23	0.90	**No**
I2	25/04	51	41.6	6.46	7	25-60	0.154	1	3.84	**Yes**				
J1	27/02	367	44.6	6.16	8	20-65	4.87	3	8.82	**Yes**	0.471	0.92	3.70	**Yes**
J2	08/05	455	40.9	7.34	11	5-65	8.17	5	11.1	**Yes**				
K1	27/02	79	41.6	5.47	6	20-55	2.02	1	3.84	**Yes**	0.934	1.83	2.90	**Yes**
K2	08/05	78	38.7	6.2	6	20-55	0.7	2	5.99	**Yes**				

IV. CONCLUSION

Speed limit enforcement on roadways have long been implemented by spot speed measurements over the years. However the fact that the location of the radar is usually known by drivers gives rise to lack of compliance on other sections of the same road. For this reason in many countries the concept of average speed limit has been developed. By means of automatic number plate recognition (ANPR) technology, a corridor is monitored usually by fixed cameras. This too means improvements only on that corridor leaving the neighbouring roads uncontrolled. Based on the initial findings of the work, it can clearly be stated that, although no penalties were issued to the speeding drivers during the second stage, the amount of reductions in average speeds and the shift of the mode values were noticeable. The statistical tests on selected dates proved this. Therefore it can be concluded that the method tried in the study was quite effective and can easily be employed by authorities. Both the police services and other bodies with enforcement rights, such as campus security, can purchase a similar set of equipment and cover a wide area with a small amount of human resource. Since in many countries university campuses are specially governed areas, police presence cannot be practiced so easily. Special invitations by the university management may be required on certain conditions. However, the campus security itself can implement the system introduced in this paper and may consider certain discouraging instruments to control speeding such as penalties of freezing temporarily or cancelling permanently the entry permits to the campus. Although the primary aim of the paper was not to investigate the suitability of the speed limits in the campus, the findings revealed that despite the reductions in speeds in the second stage, the majority of the readings were far higher than the set speed limits. The anecdotal evidence in the campus was toward the public opinion that the speed limits need to be changed as they are too low. This highlights the fact that posting the correct speed limit is very important and in many developing countries this is not handled professionally. The gap between the posted speed limits, the design speeds and the operating speeds are thought to be much smaller in the developed countries than in the developing world. This problem deserves special attention by researchers.

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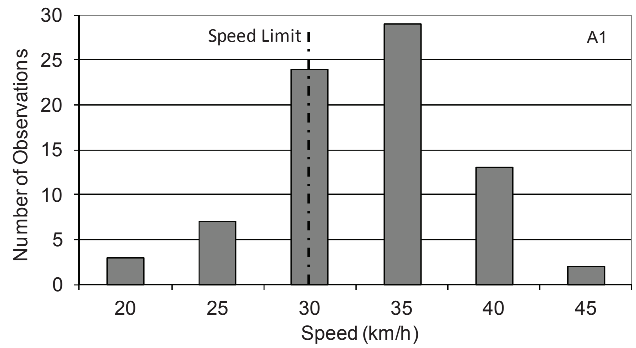
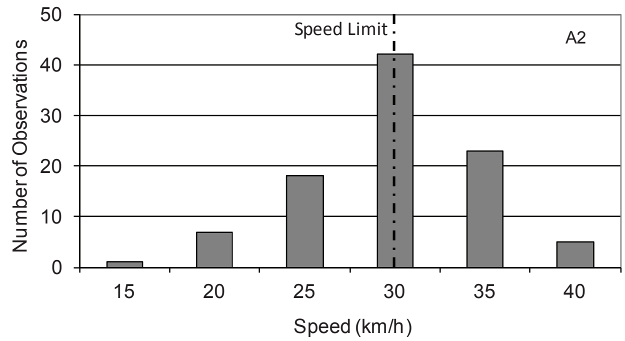
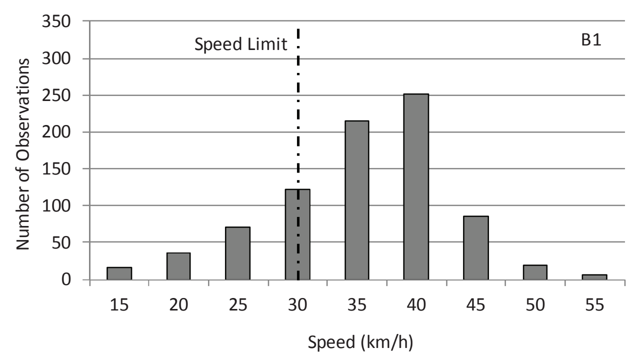
REFERENCES

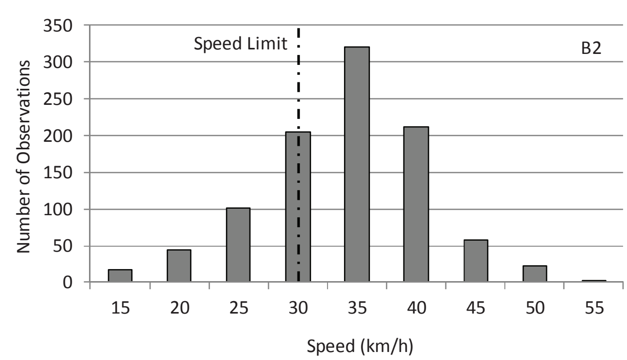
[1] L. Aarts and I. Schagen, "Driving speed and the risk of road crashes: A review", Accident Analysis and Prevention, vol. 38, pp. 215–224, 2006.
[2] Z. Karagöz, "Development of an intelligent speed bump system in highway traffic", Yildiz Technical University, MSc Thesis, Istanbul, 2009.
[3] Accident Statistics, 2014, www.tuik.gov.tr.
[4] J. Jun, R. Guensler, and J. Ogle, "Differences in observed speed patterns between crash-involved and crash-not-involved drivers: Application of in-vehicle monitoring technology", Transportation Research Part C, 19(4), pp. 569-578, 2010,
[5] C. Goldenbeld and I. Schagen, "The effects of speed enforcement with mobile radar on speed and accidents. An evaluation study on rural roads in the Dutch province Friesland", Accident Analysis and Prevention, vol. 37, pp. 1135–1144, 2005.
[6] M. Pau and S. Angius, "Do speed bumps really decrease traffic speed? An Italian experience", Accident Analysis and Prevention, vol. 33, pp. 585–597, 2001.
[7] C. Stefan, "Section Control – Automatic Speed Enforcement In The Kaisermühlen Tunnel", Austrian Road Safety Board (Kfv), 2006.
[8] R. Kolbl, M. McDonald, G. Fisher, and M. Brackstone, "Probe Vehicle: A Comparison of Motorway Performance Measure with Other Motorway Flow Detection Techniques", Road Transport Information and Control, 11th International Conference, 2002.
[9] J. Heidstra, C. Goldenbeld, T. Mäkinen, G. Nilsson, and F. Sagberg, "New concepts in automatic enforcement", The “Escape” Project Contract Nº: RO-98-RS.3047, 2000.
[10] G. Garibotto, P. Castello, E. Ninno, P. Pedrazzi, and G. Zan, "Speed-Vision: Speed Measurement by License Plate Reading and Tracking", IEEE Intelligent Transportation Systems Conference Proceedings, 2001.
[11] B. Gunay, "Using Automatic Number Plate Recognition technology to observe drivers’ headway preferences", Journal of Advanced Transportation, 46(4), pp. 305-317, 2012.
[12] C. J. Lakshmi, , A. J. Rani, K. S. Ramakrishna, and M. KantiKiran, "A Novel Approach for Indian License Plate Recognition System", International Journal of Advanced Engineering Sciences and Technologies, vol. 6, Issue 1, pp. 010 - 014, 2011.
[13] I. J. Faulks, M. Lane, and J. D. Irwin, "Safety and Policy Analysis International. Traffic policing and road safety for individuals and for populations", Australasian College of Road Safety Conference, Sydney, 2012.
[14] D. W. Soole, B. C. Watson, and J. J. Fleiter, "Effects of average speed enforcement on speed compliance and crashes: A review of the literature", Accident Analysis and Prevention, Elsevier, 2013.
[15] Turkish National Police, www.egm.gov.tr/en, 2014.
[16] General Directorate of Highways, www.kgm.gov.tr, 2013.
[17] M. Rhead, R. Gurney, S. Ramalingam, N. Cohen, "Accuracy of automatic number plate recognition (ANPR) and real world UK number plate problems", Security Technology (ICCST), IEEE International Carnahan Conference, Boston, 2010.

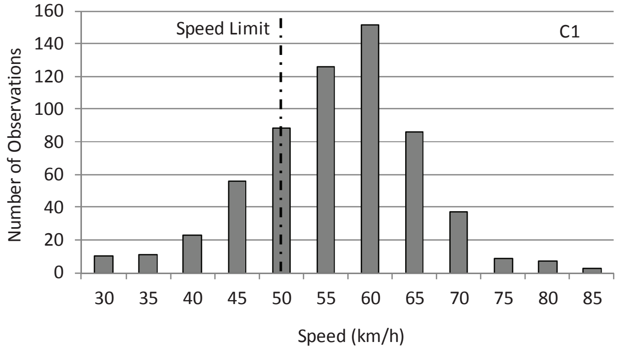
APPENDIX: THE FREQUENCY DIAGRAMS OF SPEEDS IN ASSOCIATION WITH TABLE IV

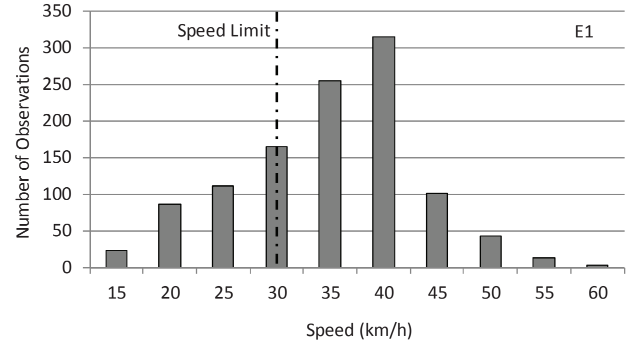


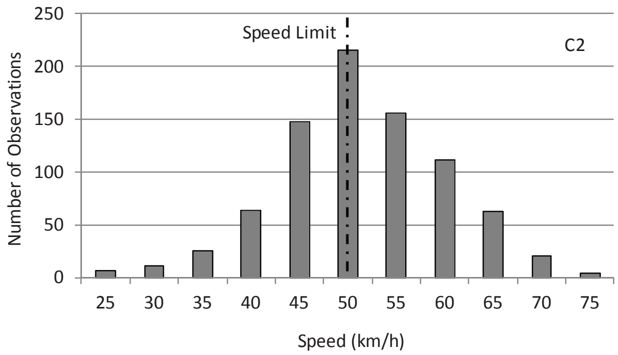


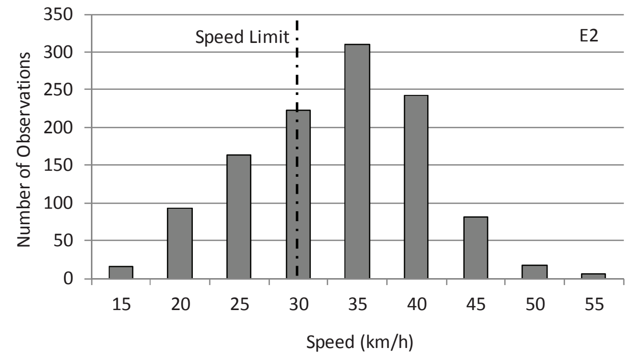





C1
Speed Limit
Number of Observations
0 20 40 60 80 100 120 140 160
30 35 40 45 50 55 60 65 70 75 80 85
Speed (km/h)


E1
Speed Limit
Number of Observations
0 50 100 150 200 250 300 350
15 20 25 30 35 40 45 50 55 60
Speed (km/h)


C2
Speed Limit
Number of Observations
0 50 100 150 200 250
25 30 35 40 45 50 55 60 65 70 75
Speed (km/h)


E2
Speed Limit
Number of Observations
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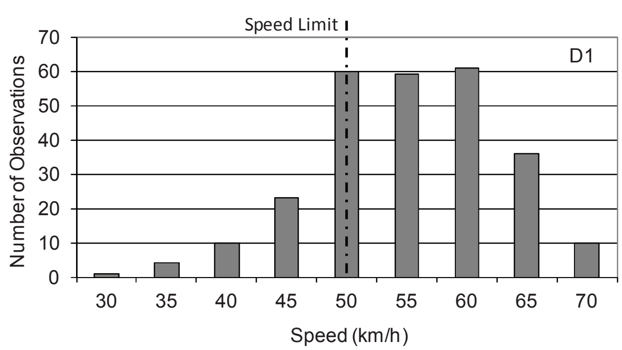
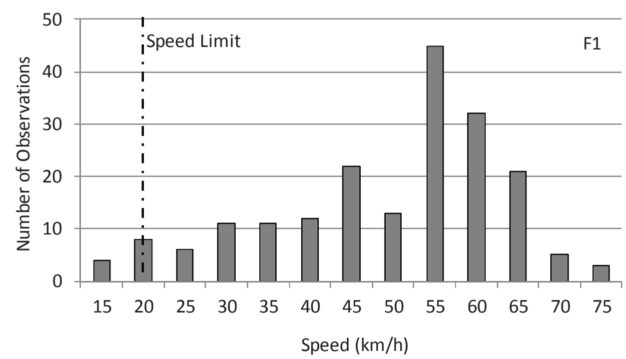
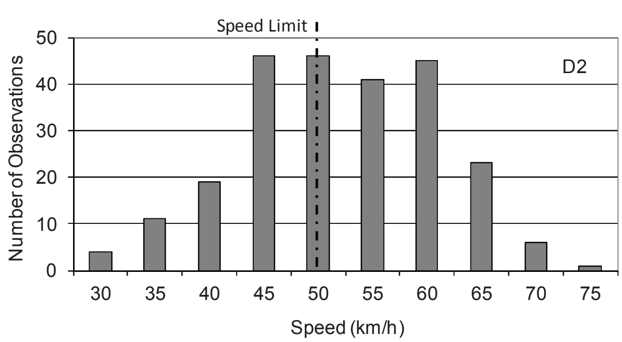
15 20 25 30 35 40 45 50 55
Speed (km/h)


D1
Speed Limit
Number of Observations
0 10 20 30 40 50 60 70
30 35 40 45 50 55 60 65 70
Speed (km/h)


F1
Speed Limit
Number of Observations
0 10 20 30 40 50
15 20 25 30 35 40 45 50 55 60 65 70 75
Speed (km/h)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Speed Limit
Number of Observations
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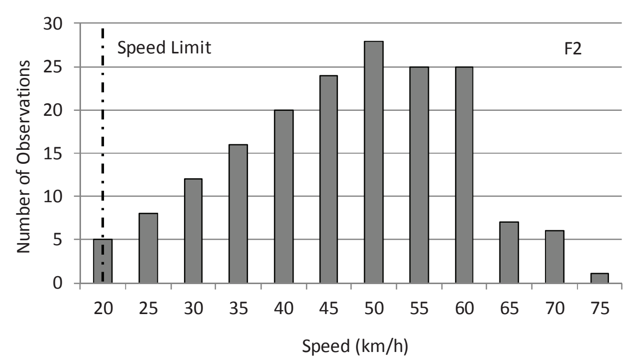
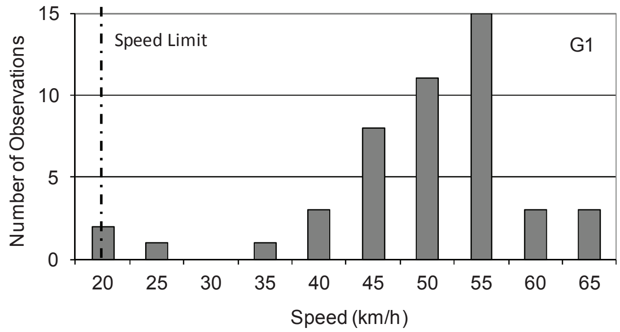
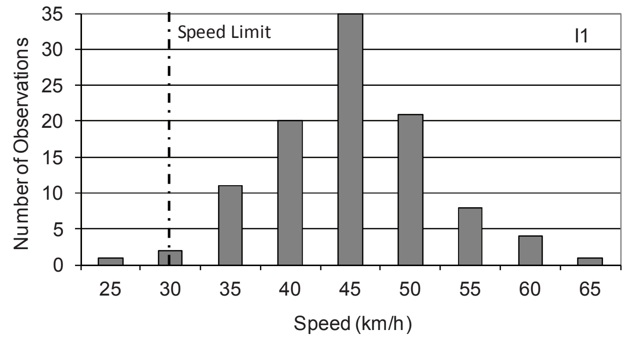
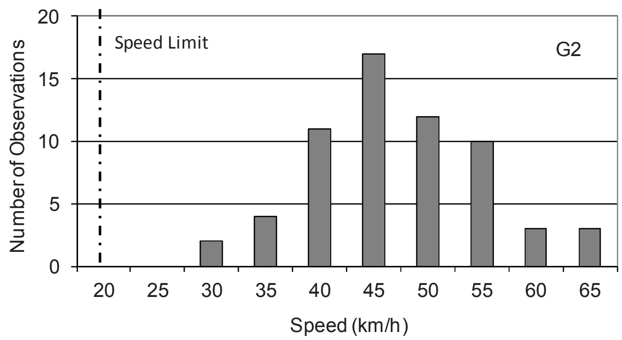
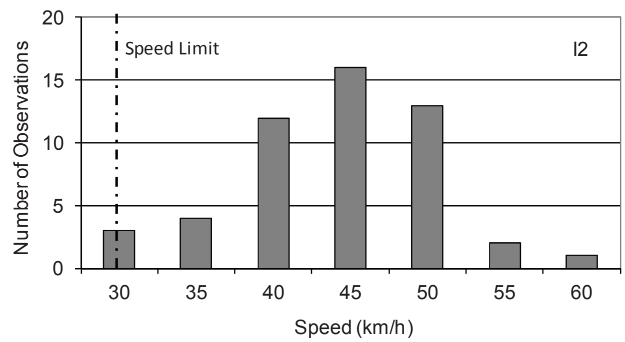
30 35 40 45 50 55 60 65 70 75
Speed (km/h)

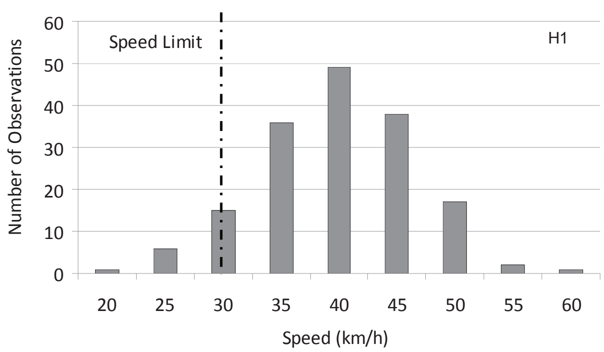

F2
Speed Limit
Number of Observations
0 5 10 15 20 25 30
20 25 30 35 40 45 50 55 60 65 70 75
Speed (km/h)

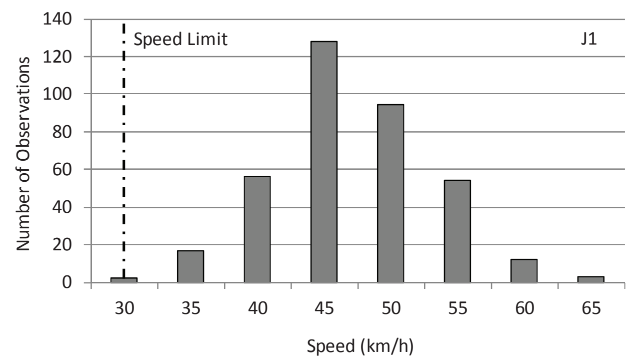

G1
Speed Limit
Number of Observations
Speed (km/h)
0
5
10
15
20
25
30
35
40
45
50
55
60
65

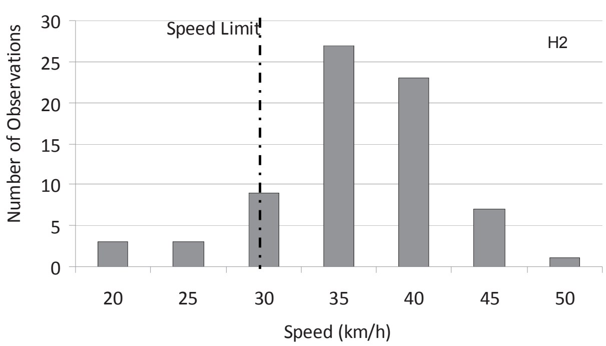

I1
Speed Limit
Number of Observations
Speed (km/h)
0
5
10
15
20
25
30
35
25
30
35
40
45
50
55
60
65

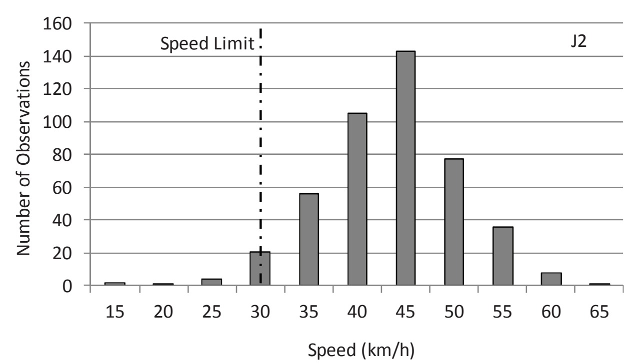

G2
Speed Limit
Number of Observations
Speed (km/h)
0
5
10
15
20
20
25
30
35
40
45
50
55
60
65


I2
Speed Limit
Number of Observations
Speed (km/h)
0
5
10
15
20
30
35
40
45
50
55
60


H1
Speed Limit
Number of Observations
Speed (km/h)
0
10
20
30
40
50
60
20
25
30
35
40
45
50
55
60


J1
Speed Limit
Number of Observations
Speed (km/h)
0
20
40
60
80
100
120
140
30
35
40
45
50
55
60
65


H2
Speed Limit
Number of Observations
Speed (km/h)
0
5
10
15
20
25
30
20
25
30
35
40
45
50


J2
Speed Limit
Number of Observations
Speed (km/h)
0
20
40
60
80
100
120
140
160
15
20
25
30
35
40
45
50
55
60
65