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IMPACT OF RAINFALL CONDITIONS ON DRIVER SPEED: A CASE STUDY IN ANTALYA

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Abstract

Weather and climate factors are environmental factors known to have an impact on section safety performance in the road transportation sector and they also affect the demand in transportation services. In this study, data acquired from 11 sections inside a university campus with speed limits of 20 km/h, 30 km/hand 50 km/h were used for examining the impact of rain conditions on the average speeds of drivers. Traffic data were analyzed by taking into consideration the average speed data recorded by average speed cameras for a period of two months in average with an evaluation based on dry weather and rainy weather conditions. Only weekday work hour data were used in the study. There were statistically significant decreases in average speed results in rain condition in comparison with dry condition at rates varying between 4-8%. Average speeds increased in 2 sections and no statistically significant changes occurred in the others. The article puts forth that drivers do not consider the speed limits for these sections as reasonable. The article also provides suggestions for directing driver speed behaviors in dry and rainy weather conditions.

Keys Words: Speed, rainfall, ANOVA test

YAĞIŞ KOŞULLARININ SÜRÜCÜ HIZI ÜZERİNDEKİ ETKİSİ: ANTALYA'DA BİR VAKA ÇALIŞMASI

Özet

Hava ve iklim faktörleri, kara ulaşım sektöründe yol güvenliğinin performansını etkilediği bilinen çevresel faktörlerdir ve taşımacılık hizmetlerine olan talebi de etkilemektedir. Bu makalede, bir üniversite kampüsü içindeki 20 km/s, 30 km/s ve 50 km/s hız limitine sahip 11 adet güzergâhta toplanan veriler kullanılarak, yağmur yağış koşullarının sürücü ortalama hızları üzerindeki etkisi araştırılmıştır. Trafik verileri, yaklaşık iki ay ortalama hız kameraları tarafından kaydedilen ortalama hız bilgileri alınarak, kuru hava ve yağmur yağışlı hava koşullarına göre değerlendirilerek analiz edilmiştir. Çalışmada yalnızca hafta içi mesai saatleri içindeki veriler kullanılmıştır. Sonuçlar, yağış koşullarında, kuru şartlardakilere kıyasla, 4 adet güzergâhta ortalama hızlar %4-8 arasında istatistiksel olarak anlamlı düşüşler göstermiştir. 2 adet güzergâhta ortalama hızlar artış göstermiş, diğerlerinde ise anlamlı bir değişiklik olmamıştır. Makale, bu güzergâhlardaki hız limitlerinin sürücüler açısından makul görülmediğini belirtmektedir. Makale, kuru hava ve yağmur yağış koşullarında bu sürücü hız davranışlarını yönetmek için tavsiyede bulunmaktadır.

Anahtar Kelimeler: Hız, yağış, ANOVA testi

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1. Introduction

Studies for decreasing traffic accidents which are among the most important problems for all countries in the world have become somewhat successful in various countries as a result of the technical, administrative and legal precautions taken thereby minimizing traffic accidents. However, less developed or developing countries still grapple with this problem (Coşkun, 1999).

Traffic accidents with significant losses of life and goods may occur when safe driving conditions are not attained. Factors affecting traffic accidents may be listed as follows: (1) humans (2) vehicles (3) roads and (4) environment. It has been determined in recent examinations carried out in Turkey that accidents due to driver mistakes make up 90.5% of the total number of accidents which is a very high ratio (Table 1.). "Failing to adopt the vehicle speed to road, weather and traffic conditions" which is among the driver mistakes makes up about 40% of all driver mistake related accidents (Table 2.) (KGM, 2016). Traffic safety depends technically on the structure and characteristics of the roads as well as meteorological and environmental factors (Pampal and Ercan, 2009). Weather conditions have an impact of 4 % on traffic accidents and rain is among the climate parameters which affect vehicles, drivers and highways (Coşkun, 1999; Pampal and Ercan, 2009).

Table1. Yearly rates of mistakes in accidents involving deaths and injuries (KGM, 2017)

	Human Factor					
Years	**Driver %**	**Pedestrian %**	**Passenger %**	**Total %**	**Vehicle %**	**Road %**
2008	90.5	8.4	0.4	99.3	0.3	0.4
2009	89.6	9.1	0.4	99.1	0.3	0.6
2010	89.7	9.0	0.4	99.1	0.3	0.6
2011	90.2	8.5	0.4	99.1	0.3	0.6
2012	88.9	9.8	0.4	99.1	0.3	0.6
2013	89.0	8.9	0.4	98.3	0.9	0.8
2014	89.1	9.2	0.5	98.8	0.6	0.6
2015	89.8	8.7	0.5	98.9	0.6	0.5
2016	90.0	8.6	0.4	99.0	0.5	0.5

Table 2. Driver mistakes which cause accidents involving deaths and injuries (KGM, 2017)

Driver Mistakes	**Residential Area**		**Non-Residential Area**		**Total**	
	Number of Defect	**%**	**Number of Defect**	**%**	**Number of Defect**	**%**
Failing to adopt the vehicle speed to road, weather and traffic conditions	53046	37.23	26625	50.44	79671	40.80
Other	89441	62.77	26160	49.56	115601	59.20
Total	**142487**	**100**	**52785**	**100**	**195272**	**100**

Rain has significant impact on traffic due to its temporal nature. Hence, it is not unusual for drivers to be anxious at the beginning of, during and even after the rain (Mashros et.al, 2014). Relationships between meteorology and traffic safety gain importance especially during winter months since the range of vision of drivers decreases rapidly during sudden hail and downpour. Drivers who are not accustomed to driving in rainy weather conditions are affected

more from a limited range of vision. Driver speed decreases in parallel to the decrease in the range of vision during rainy weather (Coşkun, 1999; Gürer and Gürer, 2004). Dust particles on the road surface get wet and become as slippery as ice especially when the rain has first started .The dust layer that gets wet and turns into mud slides between the tread strips thus filling the empty spaces. In the meantime, the friction between the tire and the road decreases (Coşkun, 1999; Andrey et.al., 2001; Rowland et.al.,2007; Pampal and Ercan, 2009; Yayla, 2011; Hassan et.al, 2016). The thickness of the water layer accumulating on the road increases as the rain continues thus resulting in aquaplaning between the tire and the road. Excessive rain fall decreases the range of vision thus blocking the vehicles coming from the opposite lane. These problems make traffic even worse. The impact of these issues on traffic are; reduced range of vision, increased braking distance, decreased vehicle handling, delays in giving decisions when faced with a dangerous situation resulting in hesitant actions, decreased vehicle speeds and loss of relative trip time. Such instances are among important factors that reduce driving safety thereby increasing the risk of accidents (Coşkun, 1999; Pampal and Ercan, 2009; Yayla, 2011; Mashros et.al, 2014 Andersen and Torp, 2016; Hassan et.al, 2016). Table 3. summarizes the potential weather impacts on roads, traffic and driver / vehicle safety.

Table 3. Impacts of Weather on Roads, Traffic and the Driver/Vehicle, (Rowland et.al.,2007)

Weather	**Roads**	**Traffic**	**Driver / Vehicle**
Effects of Rain	Range of vision Friction on the road Congestion	Road capacity Traffic Change of speed Delays Accident risk	Vehicle performance Driver characteristics Driver behavior

Ensuring the safety of road/vehicle/bicycle/pedestrian traffic interaction in education areas such as university campuses is among the most important objectives of university administrations. Pedestrians, bicycles and vehicles mostly use the same areas at the Antalya Akdeniz University campus. Drivers should be more understanding when faced with the more reckless, anxious and hasty behaviors of bicycle riders in rainy weather. Even though there are traffic signs indicating speed limits of “20, 30 and 50 km/h” inside the university campus, the number of recorded and unrecorded accidents is about 20-30 annually. Road traffic safety is closely related with the climate conditions as well as meteorological conditions especially during the winter season (Mukhlas et.al., 2016). Sudden local downpours of rain that take place in the city of Antalya during the winter season have adverse impacts on the drivers inside the campus and thus campus traffic safety. This study evaluates driver behavior according to dry and rainy weather conditions. The focus of this study has been road transportation in only one university campus. In addition, the term ‘vehicle’ covers only car and pickup truck type vehicles (heavy vehicles rarely enter the campus). Studies examining the impacts of rain on driver behavior are very limited. Thus, the objective of the study was to measure the impact of rain on driver speeds. This study is also important for managing traffic under rainy weather conditions.

In this study, average speed values of vehicles under dry and rainy weather conditions have been calculated by mobile license plate recognition average speed cameras placed along 11 different sections in the Akdeniz University campus. Since speed was measured along a longer distance on sections where the cameras were placed, it can be defined to be a more fair application in comparison with spot speed application. In addition, data from 11 sections are detected using only 2 cameras since the average speed cameras are mounted on vehicles thereby reducing investment cost. In this manner, the data can be acquired at the desired spot at the desired time.

2. Background

The impact of weather conditions on road network operation has been realized since the 1950's due to various driver behaviors (Mashros et.al, 2014; Mukhlas et.al., 2016).The role played by climate change can be relatively low when compared with many political, economic and technological factors that play a role on transportation systems and road safety; however it still has significant impacts (Andrey et.al., 2001; Rowland et.al.,2007).

A properly dimensioned, safe and reliable road is a must for safe traffic. Various drainage systems should be installed along the section for eliminating the impacts of water that has harmful effects on the lifetime and durability of roads, removing water from the road in the shortest amount of time possible as well as eliminating traffic holdups resulting from excessive rainfall (Gürer and Gürer, 2004; Pampal and Ercan, 2009).Roads in Turkey are generally asphalt covered and since asphalt is deformed quickly under adverse weather conditions, these roads need regular maintenance and repair (Pampal and Ercan, 2009).Even though road construction techniques and safety precautions, road operation services along with developments in vehicle technology have made it possible to build roads and vehicles that can be used safely in all weather conditions, driving safety is still dependent mostly on the driver. Thus, the driver has to learn the impacts of different weather conditions on humans, vehicles and roads in addition to the precautions that should be taken (Coşkun, 1999). Vehicle related precautions that the drivers should take for minimizing dangers associated with rainy weather conditions may be listed as follows: it is an important safety precaution to regularly replace every autumn the wipers that determine the range of vision in rainy weather. It is of great importance to turn on the headlights in order to see the road clearly and to show yourself. Tire care should be given importance since overused tires with decreased tread depth increase braking distance and cause accident risks. Maintenance and control of braking system is important since braking distance increases on wet surface. The periodical maintenance of the vehicles listed in their respective catalogues should be completed in a timely manner (Coşkun, 1999; Gürer and Gürer, 2004; Pampal and Ercan, 2009).

Rain may have significant impact on travel demand, driving behavior, traffic characteristics and safety. Rain results in a tighter time schedule for drivers thereby impacting driver behavior since the driver tries to change his/her driving style in order to adopt to the new situation (Mashros et.al, 2014). According to the findings of a study using traffic and weather data acquired at theVirginia Road Hampton region; light rain (0.01 – 0.25 inch / hour intensity) decreases highway capacity by 4-10 %, heavy rain (0.25 inch / hour or higher intensity) decreases highway capacity by 25-30 % and rain causes a decrease of about 5.0-6.5 % regardless of its intensity (Smith et.al., 2004).According to a study carried out by the Federal Highway Administration at three large metropolitan regions in the USA, free flow

speed was determined to decrease by 2-3.6 % and 6-9 % respectively in light rain (<0.01 cm/h) and heavy rain (~1.6 cm/h) (FHWA., 2006). Data acquired from the double lane highway at Terengganu and Johor were used to examine the impact of various rain conditions on traffic and speed. The results indicate that capacity decreases by 2-32 % in comparison with dry weather conditions on selected highways. The speed generally reduces under rainfall condition with mean speed, free-flow speed and speed at capacity have drop about 3-14%, 1-14% and 3-17%, respectively (Mashros et.al, 2014).

3. Method

3.1. Selection of Measurement Period According to Rain Conditions and Data Acquisition

Rainfall is an important weather factor for the city of Antalya in Turkey. When the climate diagram of Antalya is examined (Figure 1.), it can easily be understood that the summer months are hot and dry and that the winter months are warm and rainy. Average annual total rainfall is 725.9 mm most of which takes place in winter time (December, January and February) (Klimatoloji Şubesi, 2004).

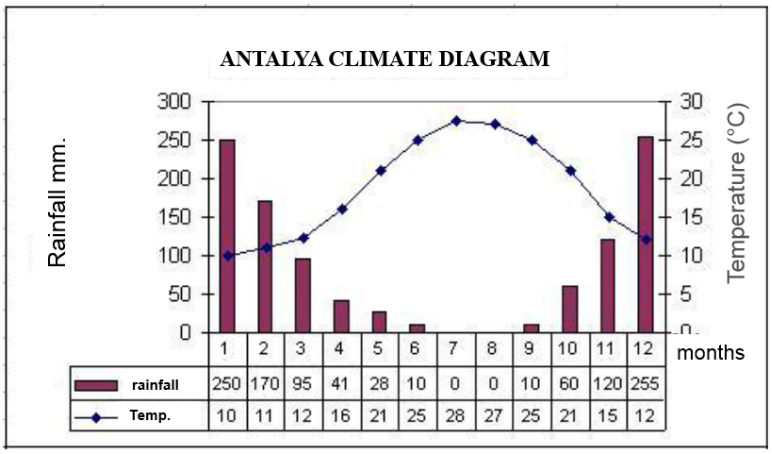

Figure 1. Antalya Climate Diagram (Eken et.al, 2008)

A study period encompassing the months of February and March 2013 in Antalya has been selected in this study. This is a period during which measurement devices can be procured and installed in full by us and when speed data can be measured in both rainy and dry weather conditions. In addition, it is also important for data sufficiency that the selected period covers the spring semester of the university during which there were no holidays. Two different rain intensity classes (light for a rainfall of 1-5 mm/hour of rainfall, heavy for a rainfall of 6 mm/hour of rainfall) (MGM, 2013).Road surface in dry weather is defined as “dry”, road surface in rainy weather is defined as “moist”, whereas road surface in heavy rain is defined as “slippery”.

A total of 11 sections with 2 or single lanes and speed limits of 20, 30 and 50 km/h were selected inside the campus (section characteristics can be seen in Table 4.).Typical installation of the 2 mobile average speed enforcement systems installed on the data acquisition area has

been shown below in Figure 2. Two average speed cameras were installed inside the camera housings (blue colored) on the vehicles for protection against the rain which were then placed along the roadside. Two average speed cameras with distances known between them record the time of passage of vehicles and calculates their average speeds. “Calculated average speed = distance/time of passage” (Figure 3. and Figure 4.) (Soole et.al, 2012; Montella et.al, 2015). Average speed detection was carried out with this installed system for a period of 2 months for 5 weekdays during the hours of 08:00-18:00 (because this is the time interval that covers the working hours of the staff and students).Data included in the analyses were comprised only of light vehicle (passenger vehicles and pickup trucks) data.

Table 4. Characteristics of the selected sections

Section	**Length (m)**	**Speed limit (km/h)**	**Number of lanes** 1 st spot	2 st spot	**1 Lane width (m)** 1st spot	2 st spot
A	908	30	2	1	3.50	3.50
B	717	30	2	2	3.50	3.50
C	890	50	2	2	3.50	3.50
D	890	50	2	2	3.50	3.50
E	425	30	2	2	3.50	3.50
F	600	20	2	2	3.00	3.00
G	600	20	2	2	3.00	3.00
H	615	30	1	2	3.50	3.50
I	594	30	2	1	3.50	3.50
J	695	30	2	1	3.50	3.50
K	695	30	1	2	3.50	3.50

Figure 2. Typical installation of mobile average speed enforcement system (Ilgaz and Saltan, 2017)

Figure 3. The location of the test routes on campus plan

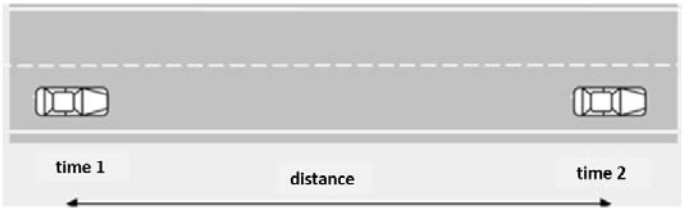

Figure 4. Mobile average speed system diagram

4. Results

4.1. Analysis of average speed data according to road surface condition

Table 5. gives the average speed results according to “dry, moist and slippery” road surface states measured at 11 different sections depending on rain conditions. ANOVA (Analysis of Variance) tests have been carried out in the light of these findings. Decreases of about 8% and 7% respectively were observed in the A, B sections for the moist road surface in comparison with the dry road surface whereas an increase in average speed was observed in section E for the moist road surface in comparison with the dry road surface. When the P values were evaluated for sections A, B, E, it can be observed that there is a statistically significant difference between the averages of the average speeds of drivers with regard to dry and moist road surfaces since all calculated values were below the significance level of 0.05. Decreases of about 4 % and 3% were observed respectively on moist and slippery road surfaces for the J sections, while an increase in average speed was observed in sections F for the moist road surface in comparison with the dry road surface. When the P values were evaluated for

sections F, J, it can be observed that there is a statistically significant difference between the averages of the average speeds of drivers with regard to dry, moist and slippery road surfaces since all calculated values were below the significance level of 0.05. When the P values were evaluated for sections H, K, it can be observed that there is no statistically significant difference between the averages of the average speeds of drivers with regard to dry and moist road surfaces since all calculated values were above the significance level of 0.05. This is an indication that the speed increase in section H and the speed decrease in section K are not statistically significant. Since the P values for sections C and G were above the significance level of 0.05, it can be observed that there is no statistically significant difference between the averages of the average speeds of drivers with regard to slippery and dry road surfaces. This is an indication that the decreases in speed on sections with slippery surfaces were not statistically significant. There was a decrease by 4% in average speed for the slippery road surface on section D in comparison with dry road surface and a statistically significant difference was observed between the averages of the average speeds of drivers on this section with regard to slippery and dry road surface since the P value was below the significance level of 0.05. This is an indication that the speed decrease on slippery road was statistically significant. In addition, different traffic conditions occur during rainy and dry weather conditions. Whereas traffic flow is 0-600 vehicles/hour per lane in dry weather conditions, this was 0-60 vehicles/hour in rainy weather conditions.

Table 5. Speed results according to road surface condition and ANOVA tests

Road Surface	Section	Speed limit (km/h)	Number of vehicles	Average speed (km/h)	Standard Deviation	F	P
Dry	A	30	569	28.46	6.51	9.18	0.0025
Moist			90	26.23	6.37		
Dry	B	30	4103	32.02	7.10	70.00	<.0001
Moist			859	29.81	6.69		
Dry	C	50	3681	54.33	10.79	3.13	0.0768
Slippery			139	52.69	9.31		
Dry	D	50	1154	53.69	8.95	6.96	0.0084
Slippery			145	51.61	8.94		
Dry	E	30	5743	33.29	8.45	7.18	0.0074
Moist			460	34.39	8.70		
Dry	F	20	600	46.72	12.85	11.25	<.0001
Moist			79	53.37	10.12		
Slippery			127	49.31	11.21		
Dry	G	20	208	48.10	11.08	0.24	0.6250
Slippery			65	47.31	12.13		
Dry	H	30	1073	37.18	8.04	1.49	0.2222
Moist			50	38.60	8.27		
Dry	I	30	539	42.81	7.62	-	-
Dry	J	30	2665	45.10	7.06	4.59	0.0103
Moist			132	43.17	7.49		
Slippery			167	44.98	7.85		
Dry	K	30	343	41.97	6.82	1.14	0.2860
Moist			69	41.01	6.74		

5. Conclusions

Drivers in the study responded to the rainy weather conditions on sections A, B, D and J by decreasing their speeds. Statistically significant decreases of 8% and 7% in average speed were observed in sections A and B on moist road surface in comparison with dry road surface, statistically significant decreases in average speed of 4% and 0.3% were observed in sections J on moist and slippery road surfaces in comparison with dry surface, whereas a statistically significant decrease of 4% was observed in section D on slippery road surface in comparison with dry road surface. Drivers changed their driving styles to try and adapt to the new situation. It is thought that the decrease in the average speeds of drivers is due to decreased range of vision and reduced road surface traction. On the other hand, an increase was observed in the average speed for sections E and F on moist and slippery road surfaces in comparison with dry surface. According to these results, it is thought that the speed limits of these 2 sections are not considered by the drivers as reasonable and that they neglect this speed limit even in rainy weather conditions. No statistically significant difference was observed between the average speeds of drivers for C, G, H and K with regard to dry moist and slippery road surfaces. Rain had no impact on driver behavior for these sections, which have different speed limits, lengths, geometric and physical properties. It is also assumed that the speed limits in these sections are detected by the driver unreasonably and that optimal speed limit regulation is required for these sections.

Neither the vehicle nor the road or weather conditions can be a reason for accidents by themselves. Hence, driving safety and protection from accidents may only be attained by obeying in accordance with the prohibitions and limitations as indicated by traffic rules and traffic signs. Driving safety can be ensured by way of precautions taken by drivers and thus accidents may be prevented. The method for reducing traffic speeds in rainy weather conditions and to ensure a safe interaction between road/vehicle/bicycle/pedestrian traffic is to announce the weather-road conditions via changing signs and to warn the drivers using variable speed limit signs in rainy weather conditions as well as by reducing the speed limits. In addition, a speed limit inspection strategy should also be determined which will direct the drivers to obey the speed limits. The reason for making traffic controls in areas such as education campuses is not to punish the drivers but to prevent and reduce traffic accidents as well as the deaths and injuries involved.

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