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Modelling the Effects of Environmental Factors on Traffic Flow Parameters

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Abstract

Weather conditions, as some sort of environmental factors, influence traffic parameters. Although this topic was examined by many researcher's around the globe, few studies were conducted in Jordan to address the impact of weather on traffic conditions. The objectives of this study look into the relationship between weather conditions and traffic operating conditions on the 6-lane divided arterial streets in suburban area in the vicinity of Amman, Jordan. The posted speed limits vary from 80 to 100 km/h. The study looked into the impact of environmental conditions including lighting conditions, timing (day of the week and time of the day) on traffic conditions and to develop related models. Traffic data and weather data were collected including temperature, rainfall, wind speed and humidity for two months (November and December). Traffic data on traffic volume and traffic speed are collected. The statistical analysis includes descriptive statistics and inferential statistics and generalized models were used.

Traffic speed on wet conditions is higher than when it is dry, the difference in speeds increase as speed limits increase. As rain precipitation depth increases the speed decreases. The strength of the association between traffic flow indicators (speed and volume) differ by the depth of rain precipitation. Air temperature and wind speed influence negatively the relationship between speed and volumes. The impact of temperature seems more influential on traffic volumes. Speed at night is higher than day time and it found is statistically different. The developed general linear models provides results that in confirm with the study findings.

KeyWords: Weather and Lighting Conditions; Speed and Traffic Volume.

INTRODUCTION

Number of factors influence the road user behaviour which accordingly impact the utilization of roadway capacity. These factors are related to legislation, regulation, weather conditions and many others. This paper addresses the impact of weather conditions on traffic streams parameters that reflects the roadway use pattern and capacity. Several studies looked into how weather conditions influence traffic parameters. This would help in setting the principles for traffic management under adverse weather conditions that often lead to excessive traffic delay and the associated fuel consumption and economic losses. For example, road network capacity reduced by 10% to 20% in heavy rain conditions [De Palma and Rochat, 1999]. On the other hand, the severity of accidents maybe decreases as a result of reduction in traffic speed and traffic flow. Still, this is not the case for accidents on slippery roads that increase their severity and frequency. The effect of weather conditions on traffic movements have become a growing concern for all roadway agencies. Many authors have studied the effects of a variety of weather-related environmental factors on traffic volume, driver speeds, and road service [Hoogendoorn et al., 2010]

The effect of weather conditions on daily traffic intensities (the number of cars passing a specific segment of a road) was investigated in Belgium. The effects of weather conditions on traffic intensities at three count locations (upstream and downstream of specific location) along a specific route were reported according to the type of road usage. The results showed that snowfall, rainfall, and wind speed reduce traffic intensity, and high temperatures increase traffic intensity [Cools et al., 2009]. The impact of weather intensities (rain, snow, and pavement surface conditions) on traffic flow for the metro freeway region around the Twin Cities in Iowa State were assessed. Traffic flow parameters include speed, headways, and capacity of roadways. The results indicate that severe rain (more than 0.25 inch/hour), snow (more than 0.5 inch/hour), and low visibility (less than 0.25 mile) cause significant reductions in capacities of 10%–17%,19%–27%, and 12 % and reduction of operating speeds of 4%–7%, 11%–15%, and 10%–12%, respectively [Agarwal, 2005].

The relationship between the inclement weather and hourly traffic volumes on freeways in Buffalo, New York was investigated. The study looks into the impact of weather factors such as visibility, temperature, weather type, precipitation and wind speed. Weather and traffic data were collected and analysed. The results show that traffic volumes during inclement weather condition were significantly lower than dry weather volumes. The difference was larger during peak hours (7:00 AM to 9:00 AM, and 3:00 PM to 5:00 PM), with the volume reductions ranging from 13.3 to 33.9 percent. The study indicated that wind speed and temperature have a lower impact on traffic reduction when compared to the other weather factors [Bartlett, 2012].

Average vehicle speed of rural highways in Iowa, US was investigated in relation to winter weather and road surface conditions. Detailed data on weather, road surface conditions, and traffic over three winter seasons from two two-lane and two four-lane rural highways are used for this study. A multivariate linear regression, artificial neural network, and time series analysis were used. The finding confirmed the statistically strong relationship between traffic speed and road surface conditions. The speed is also related to several weather variables including precipitation, temperature and wind speed

[Luchao et al.. (2013]. Lastly, the time series model could be used for predicting real-time traffic conditions based weather forecast and planned maintenance operations.

The adverse weather impact on traffic speed and travel time were also investigated in the city of Shenzhen, Guangdong Province (China). The aim of this study is to investigate the impact of rainfall intensity on traffic speed during the summer season (July and August). The data was analyzed for five one-hour periods on weekdays during the morning periods (6:00 AM – 11:00 AM). A taxi equipped with GPS was utilized for data collection to track speed data. The average speed of nine weekdays under clear weather was used as the basic condition of the urban road speed. The difference between the rainstorm and clear weather was calculated. The main findings of this study indicated that nearly half of the roads within the urban area are affected by the rainstorm. For each stormy day, at least 35% of urban roads showed that traffic speed variation rates are significantly affected by the rainstorm but the impact of the rainstorm on traffic speed is not homogeneous [Qiuping, 2017].

The relation between the free flow speed and weather and environment conditions were also examined in Nigeria. The study considers traffic characteristics including pedestrian and traffic streams. The study area was an arterial streets in a medium - sized urban settlement. Instantaneous speeds of forty test vehicles were observed during the periods that precedes the storm on the 7.1km –road divided into four uniform sections. Simultaneous data collection involves drivers' and vehicle ages, passenger occupancy, roadside parked vehicles and businesses, roadside parked vehicles and businesses. The statistical analysis showed that the environment, pedestrian and roadway geometry have negative influences on the free flow speed. However, the relationships between free flow speed and these factors were poor, with R2 values of 14.9 - 55%. The average free flow speed of commercial saloon cars on wet pavement is lower than on dry pavement by 12% [Yusuf1, 2016].

The effect of some weather hazardous factors on driving conditions was studied by installing visibility and road sensors to achieve the objectives of their study [Kyte et al.,2000]. The relationships between traffic speed and various road weather and surface condition factors were modelled [Luchao et al., 2013]. They applied multivariate linear regression, artificial neural network and time series analysis. The authors concluded that the time series model could be used as a tool for predicting real-time traffic conditions as function of weather conditions forecasting to plan maintenance operations, whereas multi-layer logistic regression classification tree model could be applied for estimating road surface condition based both the average traffic speed and weather conditions.

Lu et al. [2019] address means to increase traffic efficiency and road safety by modifying the pre-timed traffic signal control parameters under adverse weather conditions. The parameters include saturation flow rate, start-up lost time, and free flow speed. Traffic conditions based on two case studies were modelled using Synchro and VISSIM and the results indicated that signal plans is most beneficial for intersection with a medium level of traffic demand and the benefit of implementing weather-responsive plans was more compelling at a coordinated corridor level compared to the non-coordinated-intersection level.

Means to improve road safety in Abu Dhabi when drivers face poor visibility caused by dense fog were investigated. All drivers, who are about to enter poor visibility sections of the highway, received early real-time warning signals to warn them of the dangers ahead. Radio signals or cell phone voice-based short messages were used as well as variable message signs [Oualid et al.,2013]. A study showed that as the rainfall becomes heavier, the average travel speed becomes significantly lower. In the case of heavy rain, the average travel speed decreases 6.03 km/h when compared to the case of no rain [Wang et al., 2006]

The effect of weather conditions on drivers' behaviour and its impact on traffic congestions were investigated in many studies Traffic performance due to different factors such as type of vehicle road type, road characteristics etc. For example, the speed and the driver behavior varied according to different types of winter conditions and type of vehicles [Goodwin, 2002 and Wallman, 2005]. Other studies investigated the effect of weather conditions on traffic road safey [Maze et al., 2002 and Nookala, 2006]

Mahmassani H. et al. [2009] showed that drivers must take care on wet or icy driveway, while the manual of highway capacity manual [HCM, 2000] reported that the free-flow speed is reduced by 10 Km/h in light rain and by 19 Km/h in heavy rain while the capacity is not specified. On the other hand, the impacts of weather on speed, volume and densities, was investigated and it is found that the mean speed reduced by 8 % to 12% and the capacity between 7% and 8% while in the snowy weather the traffic volume reduced by 65% with an increase in speed by 4% while the fog has no effect [Akin et al., 2011]. Hranac, et al. [2006] in their studies in Minneapolis area found that rain reduces the free flow speed and capacity around 3% and 9% while during snow the reduction is around 5% in FFS and 16% on capacity. Other studies showed that the adverse weather has no effect on speed while the wind and snow have a negative effect on speed by 2% and 7% respectively [Sabir et al., 2011] More recent study addressed to what extent does the weather variables (rain, snowfall, temperature and visibility) have an impact on the vehicles parameters, their results shows negative effect on speed and speed's variability [Rondon, 2014}

Jordan climate is characterized by long, hot, dry summers and short, cool winters. January is the coldest month, with temperatures range from 5°C to 10°C, and August is the hottest month at 20°C to 35°C. Jordan can be divided into three main geographic and climatic areas: continental climate in the inner regions, arid climate in the south-east area and Mediterranean climate in the west coast area. During winter, Jordan's weather is relatively rainy with occasionally snow-capped mountain ranges between November and April. Summer in Jordan is characterized by prolonged droughts and high temperatures between May and October. In Amman, the temperature varies between 12° C during winter and 32° C during summer while the rest of the country has an average between 18° C during summer and 4° C during winter. The effect of weather on traffic conditions concentrate mainly on road accidents. Al-Khateeb [2010] refers to the impact of weather conditions and other related factor including pavement surface conditions on road accidents in Jordan, He concluded that these factors are not considered major causes of traffic accidents in Jordan.

The objectives of this study look into the relationship between weather conditions and traffic operating conditions on main arterial streets in the vicinity of Amman, the capital city of Jordan. The study also looks into the impact of other environmental conditions including lighting conditions, and the timing in term of the day of the week, period of analysis on traffic conditions. Models that relates environmental parameters to traffic conditions are developed.

METHODOLOGY

Four stations were selected on the main streets that connect the capital city of Jordan "Amman" with the nearby governorates. They are classified as 6-lane divided arterial streets. The posted speed limits vary from 80 to 100 km/h. The slope of the selected sites is level. Lane width of all sites are not less than 3.6 m. The selected streets are located in sub-urban area with very low population density,

Description of each station is shown in Table 1 and visualized in Figure 1. The sites selection took into consideration the existing of nearby permanent weather stations.

Two types of data are needed to address the study questions, traffic data and weather data. Traffic data on traffic volume and traffic speed were measured and considered as traffic flow parameters that will be related to weather conditions. Data from selected sites nearby weather stations were collected that includes temperature (C°), rainfall (mm/15 min), wind speed (km/h) and humidity (%). The average annual weather parameters for the selected sites are presented in Table 2. Detailed data on monthly weather parameters from Amman Civil Airport for two periods (1975-2006) and (1985-2014) indicates that the climate tends to be warmer with less rain (Table 3). This station is expected to reflects the weather conditions in Amman city, although it is located on the eastern side of the city, which is more arid than western or northern side.

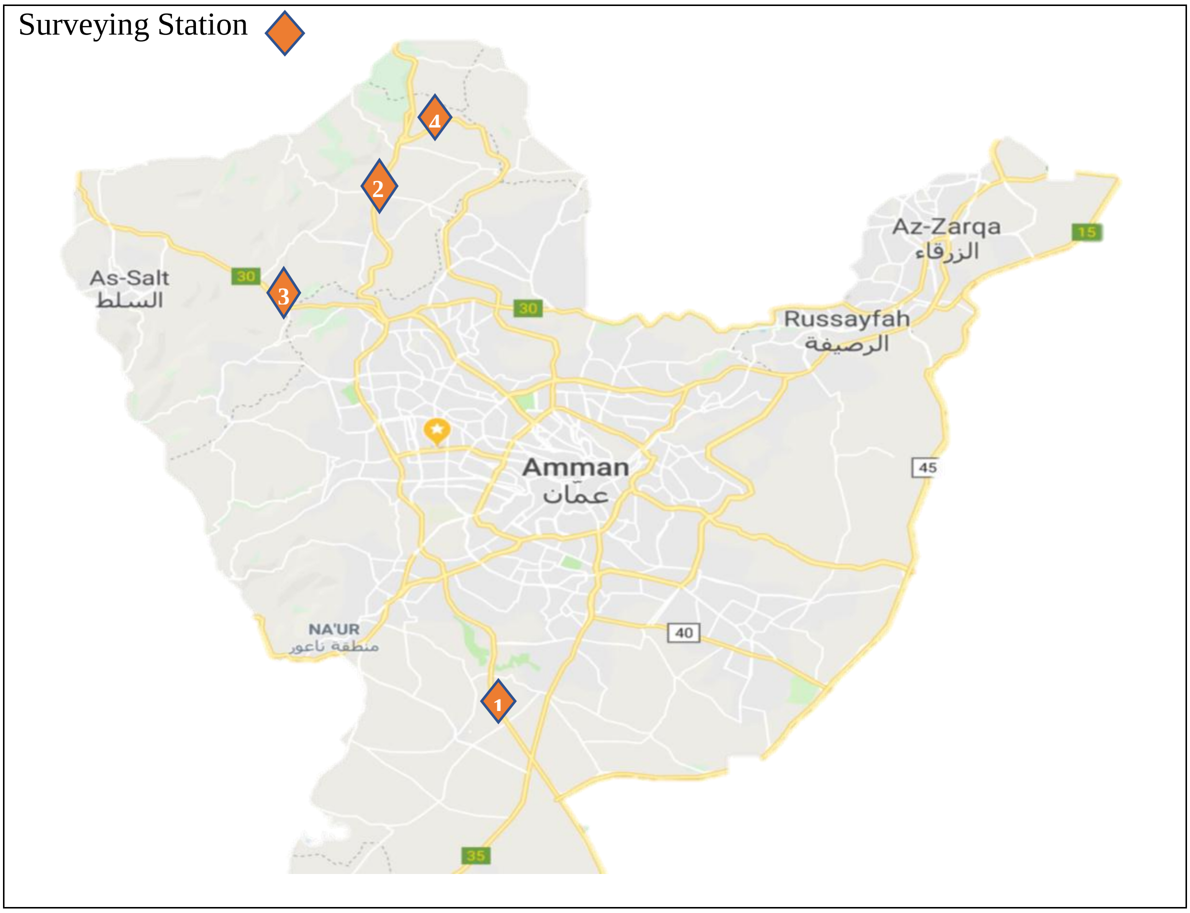


Figure 1 Location of the Selected Stations

Table 1: Description of the Selected Stations

Site	Road/Street	Distance from Amman city center (km)	Speed Limit (km/h)	Cross section	Division type
1	Road 35-South	20	100	6-lane divided highway with 4 lane service road	Concrete barrier
2	Road 35-North	15	90	6-lane divided highway	Narrow raised median with no safety barrier
3	Road 30-West	18	80	6-lane divided highway	Wide planted median with safety guard rail
4	Al-Urdon Street-North	16	80	6-lane divided highway	Wide raised median with no safety barrier

Table 2 Average Annual Weather Parameter for the Selected sites

Station	Nearby Station	Relative Humidity (%)	wind Speed Rate Km/hr (knot)	Rainfall (mm)	Average Temp C°	Maximum Temp C°	Minimum Temp C°	Rainfall (mm)
Q. A. I. Airport	1: Road 35-South	6.6	55.5	141	17	25.4	8.6	154.7
Sweileh	2: Road 35-North	4.8	56.6	475.6				
As-Salt	3: Road 30-West	2.9	59.6	514.8	17.7	22	13.4	651.5
Jordan University	4: Al-Urdon Street-North				17.1	21.6	12.6	521.8
Amman Civil Airport		4.6	51.2	245.6	19.0	24.4	13.6	272.7

Environment Statistics Bulletin 2012- Department of Statistics (2015)

For the purpose of this study, weather data were collected from Arabia weather records for the city of Amman. The collected data covers the survey period that continues for two months (November and December). According to Table 3, the average annual number of rainy days is 2.8 mm which is slightly lower than wet days in November and December. If dry months are excluded, the average wet days is 4.25, slightly higher than November (4 days) and less than December (5 days). The average temperature in November is 15 C° while it is 10.2 C° for December.

Traffic data were collected for the middle lane to reflect the average condition as traffic on the left lane is often associated with high speed and on-contrary the traffic on right lane tends to be slow. The selected segments have a level terrain. The survey period started at 7:00 and ended at 20:00 to cover day time and early evening hour. The sun set during these two months between 16:30 and 16:45 while sun rise between 5:53 and 6:35. For the purpose of this study, week-days traffic conditions were only collected and analyzed. Automatic traffic counters were installed during the survey period. The device programmed to provide data on 15 minutes interval. A passenger car equivalency factor of 2 was used to convert heavy traffic to passenger car. Speed measurements were completed using radar speed gun. Speed measurement sample size varies between 20-25%.

Table 3 Changing of the Average Monthly Weather Parameters for the Selected sites over Years

	1975-2006[1]						1985-2014 [2]			
Month	**Average Minimum Daily Temp C°**	**Average Maximum Daily Temp C°**	**Relative Humidity am**	**Relative Humidity pm**	**Rainfall (mm)**	**Average Wet Days (+0.25mm)**	**Average Maximum Daily Temp C°**	**Average Minimum Daily Temp C°**	**Rainfall (mm)**	**Humidity (%)**
January	4.0	12.0	80.0	56.0	69.0	8.0	12.7	4.2	60.6	74.1
February	4.0	13.0	78.0	52.0	74.0	8.0	13.9	4.8	62.8	71.9
March	6.0	16.0	57.0	44.0	31.0	4.0	17.6	7.2	34.1	64.0
April	9.0	23.0	53.0	34.0	15.0	3.0	23.3	10.9	7.1	51.0
May	14.0	28.0	39.0	28.0	5.0	0.8	27.9	14.8	3.2	43.3
June	16.0	31.0	40.0	28.0	0.0	0.0	30.9	18.3	0.0	42.9
July	18.0	32.0	41.0	30.0	0.0	0.0	32.5	20.5	0.0	45.1
August	18.0	32.0	45.0	30.0	0.0	0.0	32.7	20.4	0.0	50.0
September	17.0	31.0	53.0	31.0	0.0	0.0	30.8	18.3	0.1	54.4
October	14.0	27.0	53.0	31.0	5.0	1.0	26.8	15.1	7.1	57.0
November	10.0	21.0	66.0	40.0	33.0	4.0	20.1	9.8	23.7	62.3
December	6.0	15.0	77.0	53.0	46.0	5.0	14.6	5.8	46.3	71.4
Average	11.3	23.4	56.8	38.1	278.0	2.8	23.7	12.5	245.0	57.3

1. Potter et al. (2007) 2. Jordan Department of Metrology Statistics (2019)

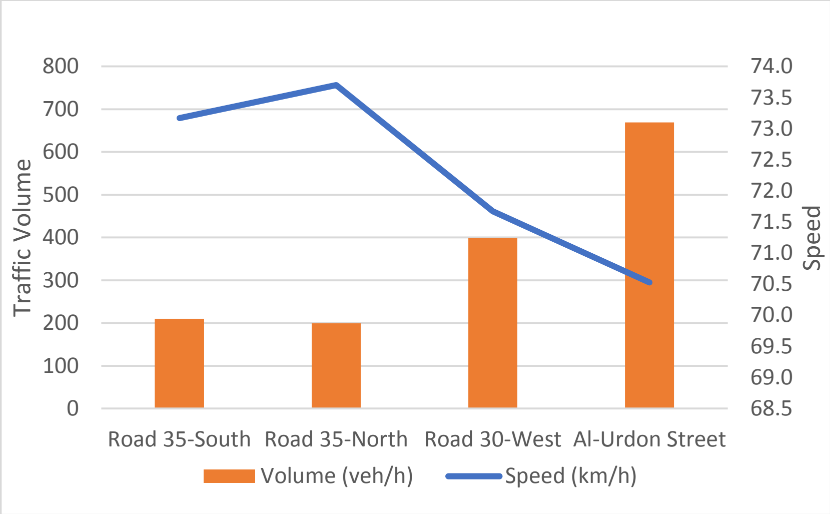
Data were analyzed using IBM SPSS statistics version 23. The analysis includes descriptive statistics and inferential statistics. The tested variables are average speed, traffic volumes, density and capacity. The factors that were considered are day of the week (Sunday through Thursday), time of the day (day or night), surface condition (wet or dry) and period of analysis (am and pm peak). The covariates are rain fall, temperature, and wind speed. Depending on the subject variable, the traffic covariate differs. For instance, the covariates such as density and volume or volume to capacity ratio can be considered when the speed is the dependent variable.

Results of Analysis

Collected data were categorized into two categories weather and traffic. The data were described by central tendency indicator as presented by the mean of each indicator and the dispersion indicators that includes the standard deviation together with minimum and maximum values (Table 4). The average traffic speed on the selected locations ranges between 70.53 to 73.7 km/h while the 85th percentile traffic speeds where in the range of 75 to 83 km/h . The speed limits ranges between 80 to 100 km/h, which means that the average speed as well as the 85th percentiles are below the posted speed limits. Traffic volumes, on average are moderate (199-669 veh/h) while the maximum reported were in the range of 400 to 2106 veh/h. Traffic volume on some occasions exceeds the capacity in Al Urdon street whereas maximum traffic on other locations considered to be low to medium, which permits free traffic flow conditions. On average, the rain precipitation is considered low (0.16-14.79 mm/h). The temperature at this time of the year in considered to be moderate (13.24 to 14.78 C°). Weather conditions for the selected locations more or less look similar with some variation related to the maximum reported rain precipitation depth. Analysis of variance analysis showed that there are significant difference variations in traffic volume (F=1127, p=0.000) and speed (F= 21.09, p = 0.000) that can be attributed to the location. Figure 2 shows that with one exception as traffic volume increases the speed decreases. Pearson correlation coefficient for all sites, although significant (p=0.000), indicates poor negative correlation (-0.107). For site-based analysis, there was significant relationship except for site 3 (Road 30-west) with r=0.174 and p=0.000.

Table 4 Descriptive Analysis Results of Collected Data

Site Location	Data Type	Indicators	Sample Size	Minimum	Maximum	Mean	85th percentile	Std. Deviation
Road 35-South 100	Weather	Rain (mm/h)	503	0.00	44.00	0.16	00.00	02.16
		Humidity (%)	503	07.00	112.00	50.20	79.00	23.76
		Temperature C°	501	02.00	32.00	14.54	21.00	05.74
		Wind (km/h)	502	0.00	14.00	04.68	08.00	02.64
	Traffic	Speed (km/h)	492	51.00	123.00	73.17	82.00	08.49
		Volume (veh/h)	492	90.00	638.00	210.00	292.00	79.49
Road 35-North 90	Weather	Rain (mm/h)	504	0.00	118.80	07.72	10.69	19.26
		Humidity (%)	504	20.00	97.00	57.76	76.00	16.86
		Temperature C°	504	04.00	29.00	14.04	18.00	03.76
		Wind (km/h)	504	0.50	18.00	04.94	08.00	03.03
	Traffic	Speed (km/h)	504	53.00	105.00	73.70	83.00	07.73
		Volume (veh/h)	504	90.00	400.00	199.00	278.00	64.21
Road 30-West 80	Weather	Rain (mm/h)	492	0.00	237.60	14.79	19.88	39.01
		Humidity (%)	492	17.00	99.00	62.19	98.00	27.46
		Temperature C°	492	02.00	35.00	13.24	18.05	05.69
		Wind (km/h)	492	01.00	32.00	06.13	10.00	04.49
	Traffic	Speed (km/h)	492	63.00	90.00	71.67	78.00	06.12
		Volume (veh/h)	492	175.00	837.00	399.00	526.00	116.41
Al-Urdon Street-North 80	Weather	Rain (mm/h)	503	0.00	61.20	01.00	02.46	04.63
		Humidity (%)	503	14.00	95.00	53.71	79.00	22.54
		Temperature C°	503	06.00	28.00	14.78	20.40	04.91
		Wind (km/h)	503	0.00	19.20	03.70	07.34	03.85
	Traffic	Speed (km/h)	492	60.00	91.00	70.53	75.00	05.17
		Volume (veh/h)	492	241.00	2106.00	669.00	760.00	247.43

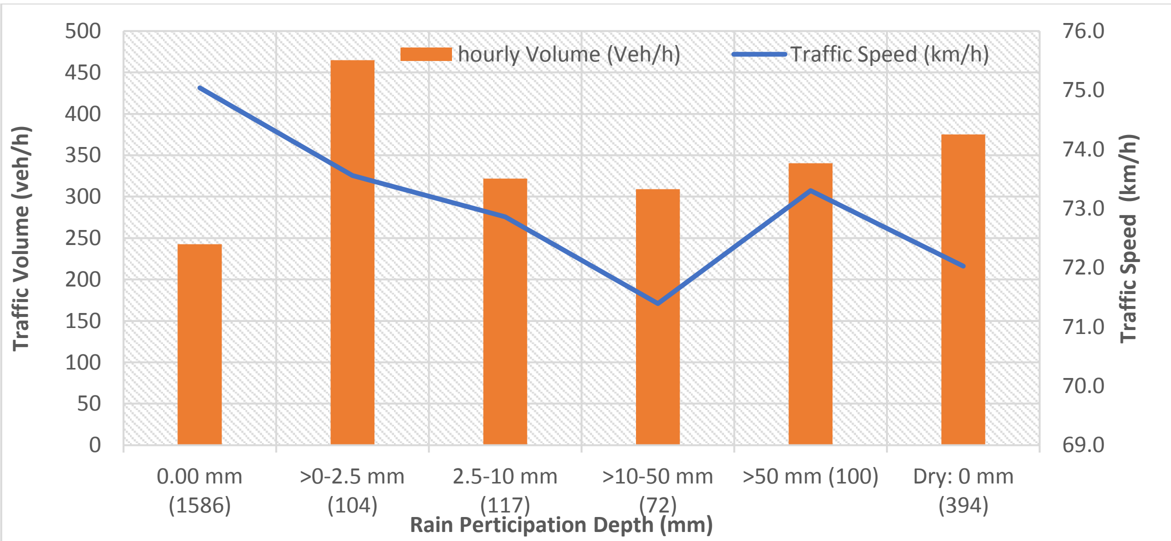


Traffic Parameter	F	Sig.
Speed	21.089	0.000
Volume	1127.044	0.000

Figure 2 Traffic Flow Parameters by Site Location

The analysis showed that there is a significant negative relationship between traffic speed and hourly volume when the road surface is dry (r=-0.101, p=0.000) and it slightly increase when the surface becomes wet (r=-0.116, p=0.021). Figure 3 illustrates that traffic speed in dry condition (72 km/h) is lower than that of wet surface condition (73.3 km/h). The opposite is valid for traffic volume that were 340 and 375 for wet and dry surface conditions respectively.

Figure 3 also shows that as rain precipitation depth (RPD) increases the speed decreases. The association between the two traffic flow indicators (speed and volume) differ by the depth of rain precipitation. The highest, only significant, correlation is reported (r=-0.236, p=0.01) for moderate rain fall (2.5-10.0 mm). The second highest correlation is related to violent rain fall (>50 mm), which was insignificant (r=-0.111, p=0.273). The lowest insignificant relation is reported for heavy rain category (10-50 mm), which is the only positive relationship (r=0.031, p=0.799). ANOVA test was used to test if there is difference in traffic speed or traffic volume that can be attributed to depth of rain precipitation. The results showed that the speed differs according to the rain depth category (F=5.927, p=0.000). The same applies to traffic volume (F=14.843, p=0.000). The impact of temperature seems more signficant on traffic volumes. Traffic increase significantly when the rain is light and drop significantly (30%) when it turns heavy. Traffic is less when it is dry, on average, it composes 52% of traffic volume when it starts to rain.

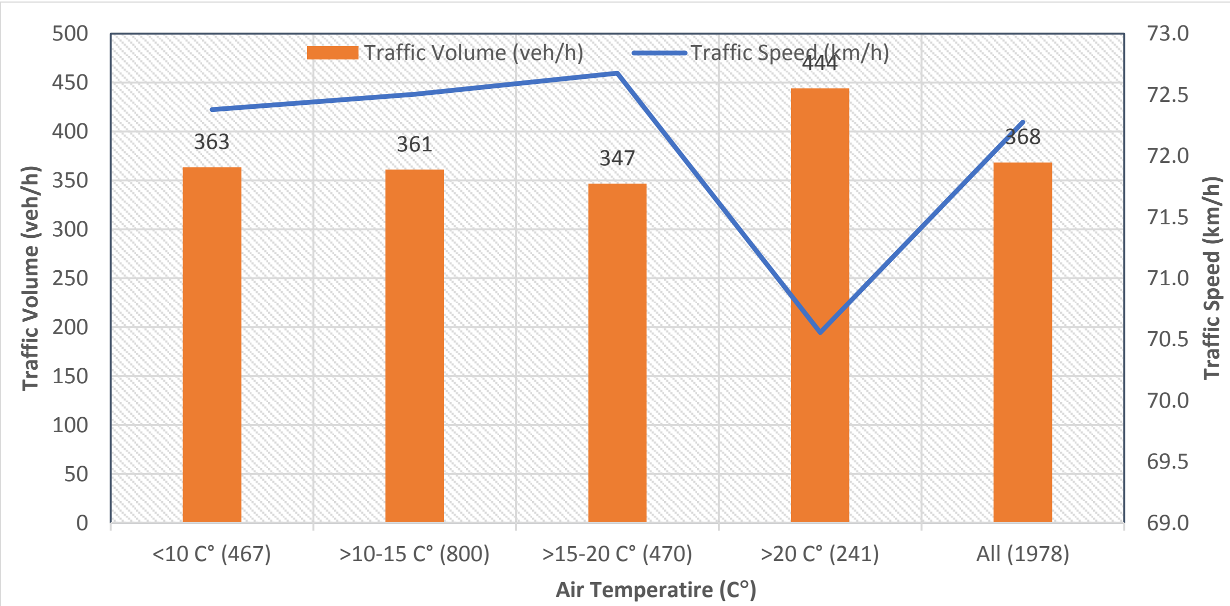


Number in parenthesis refers to number of observations

Figure 3 Relationship between Traffic Flow Indicators and Rain Participation Depth

Air temperature seems to have some influence on traffic parameters. Negative relationship between traffic speed and volume is illustrated in Figure 4. As temperature increases, traffic volume slightly decreases while speed increases. When the traffic volumes start to increase due at high temperature, speed dcreases. The correlation magnitude and significance differ according to temperature category. Poor significant relationships were found for cold (<10 C°) and mild temperature (>10-15 C°) in this time of the year. The correlation coefficients were -0.104 (p=0.025) and -0.108 (p=0.002) for cold and mild weather conditions respectively. Similar correlation coefficients, but not significant, were reported for warm (>15-20 C°) and relatively hot weather conditions in this time of the year (>20 C°). The correlation coefficients were -0.082 (p=0.076) and -0.093 (p=0.15) for warm and hot weather conditions respectively. ANOVA test result showed that the speed differs according to the temperature category (F=5.444, p=0.001). The same applies to traffic volume (F=9.758, p=0.000). The impact of temperature seems more pronounced on traffic volumes, particularly at high temperature.

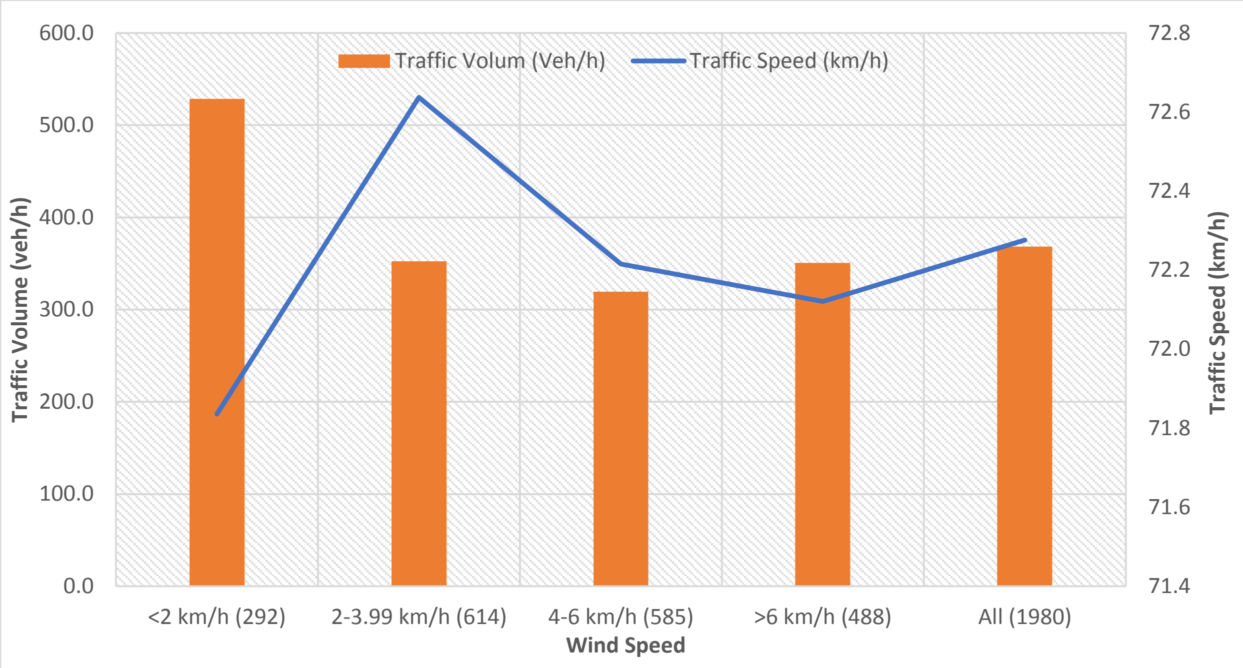
Wind Speed influences on traffic parameters. A negative relationship between traffic speed and volume is illustrated. The correlation magnitude and significance differ according to wind speed category (Figure 5). Traffic speed is the lowest when the wind is calm while traffic volume is the highest. As wind speed increases the traffic speed decreases while traffic volume fluctuates. Significant relationships between traffic volume and speed were found for calm wind (<2 km/h) and light air (2-3.99 km/h). The correlation coefficients were -0.266 (p=0.00) and -0.093 (p=0.021) for calm and light breeze conditions respectively. Poor correlation coefficients and not significant are related to light air/ breeze (>4-6 km/h) and light breeze (>6 km/h). The correlation coefficients were -0.045 (p=0.277) and -0.072 (p=0.111) light air/breeze and light breeze respectively. ANOVA test result showed that the speed differs according to wind speed category (F=2.305, p=0.056). The level of significance is rather poor and exceeds the two-side test limit (0.025). On the other hand, traffic volume differs significantly due to the wind speed (F=43.49, p=0.000).



Number in parenthesis refers to number of observations

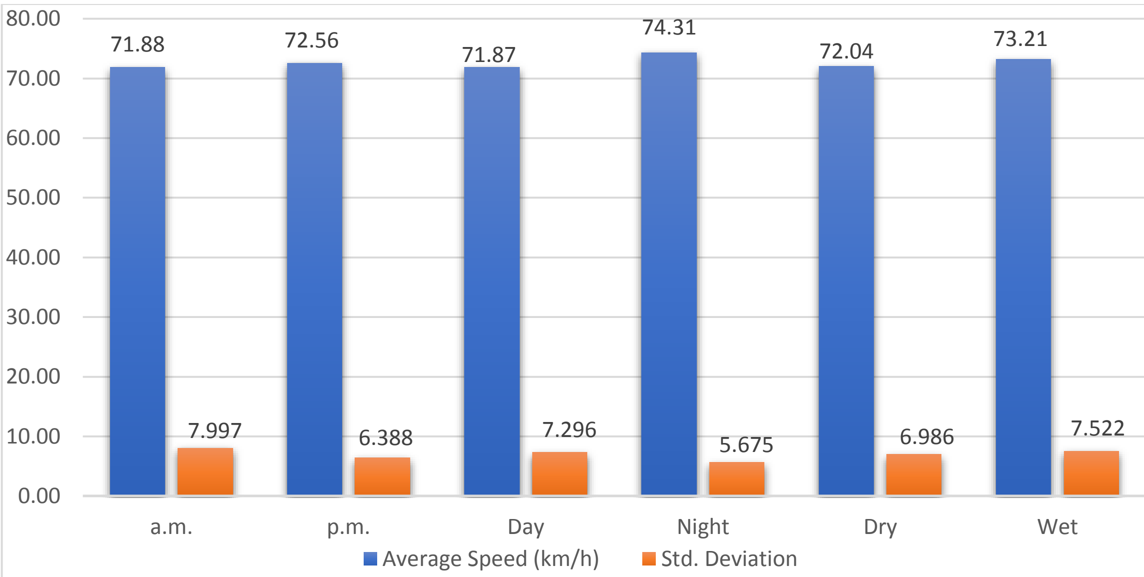
Figure 4 Relationship between Traffic Flow Indicators and Air Temperature

The influence of other factors that are related to time of day (day versus night) and the period of the day (morning "am" and afternoon "pm") on speed and its variation was further investigated as shown in Figure 6. The speed in the morning period is lower than the afternoon but the variation in the afternoon is less. The difference in speed variation due to the period is significant (F=11.607, p=0.00) but the difference in the average speed between the two periods is marginally insignificant (t=-2.001, p=0.046). Surprisingly, the speed at night (74.31 km/h) is higher than the average speed at day time (71.87) and the difference in the speed due to this factor is significant (t=-6.782, p=0.000). Traffic at night is more uniform as indicated by the standard deviation, which is 5.675 at night compared to 7.296 in day time. F-test results showed the difference in speed variation due to day of time is significant (F=15.286, p=0.00). The variation in speed when the road surface is wet (s=7.522 km/h) is higher than when the surface is dry (6.986 km/h) and the difference is significant (F=7.47, p=0.006).



Number in parenthesis refers to number of observations

Figure 5 Relationship between Traffic Flow Indicators and Wind Speed



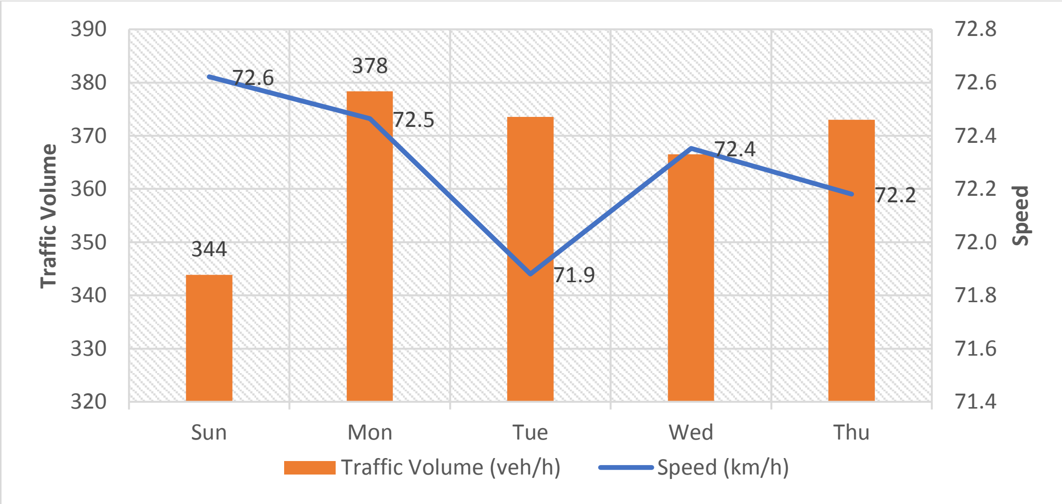
Statistical Parameter	Period of the Day	Time of the Day	Surface Condition
F-test	11.607	15.286	7.470
Sig.	.001	.000	.006
t-test	-2.001	-6.782	-2.792
Sig. (2-tailed)	.046	.000	.005

F-Test used for testing difference in variation while t-test is used to test difference in means

Figure 6 Variation in Traffic Speeds due to Time of the Day and Period of the Day

Variation in traffic parameters by day of the week shown in Figure 7 illustrates that the highest average peak traffic volumes on the selected sites occurs on Monday (378 veh/h) while the lowest happened to be on Sunday (344 veh/h), which indicates a narrow margin of variation in traffic (34.5 veh/h, the difference between the highest and lowest peak). The average speed also does not vary by the day of the week.

The highest average speed (72.6 km/h) is reported on Sunday, which has relatively the lowest traffic peak volume while the lowest speed is on Tuesday (71.9 km/h). Average speed fluctuates in narrow margin that does not exceed 0.74 km/h. ANOVA analysis showed that there is no significant difference in traffic speed nor traffic volumes that can be explained by day of the week (F=0.618, p=0,649 for speed) and (F= 1.079, p=0.365).



Traffic Parameter	F	Sig.
Speed	0.618	0.649
Volume	1.079	0.365

Figure 7 Traffic Flow Parameters Variation by Day of the week

The average speed fluctuates in narrow range (71.1 to 73.7 km/h) that composed 73.2%, 81.9 and 88.9% of posted speed limits of 100, 90 and 80 km/h respectively (Figure 8).

The average speed on the selected locations differ due to speed limit (F=28.27, p=0.000). The association between speed limit and operating speed proven to be significant (r=0.137, p=0.000).

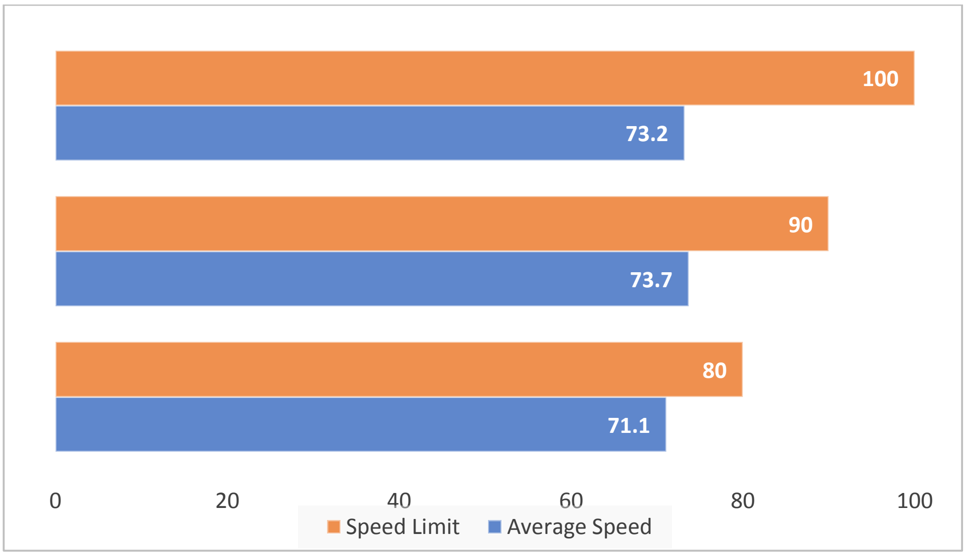
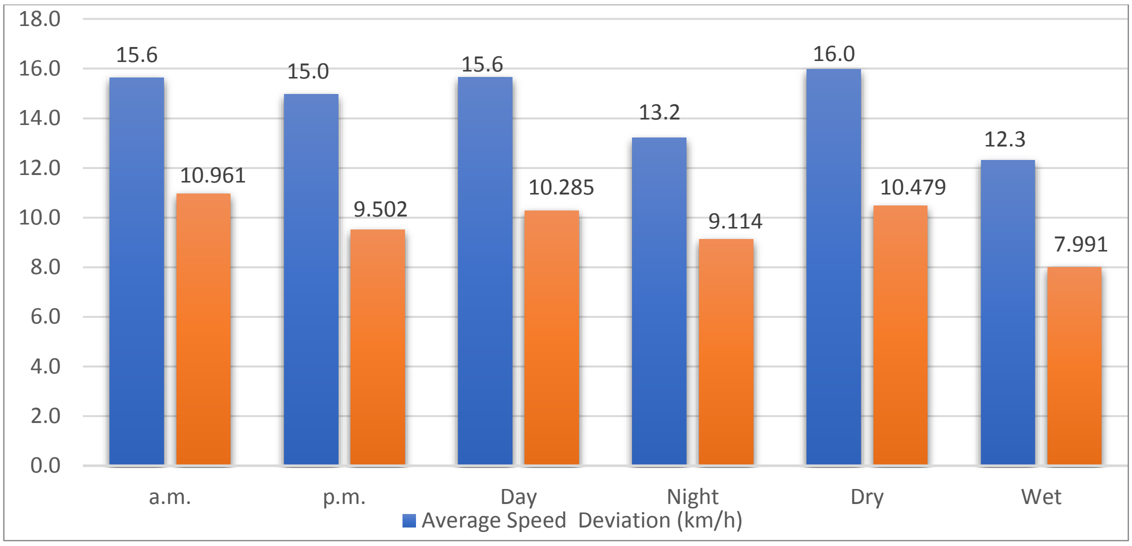


Figure 8 Relation between Speed Limit and Average Operating Speed on the Selected Sites.

Further, the analysis covered the speed deviation from the posted speed limit as shown in Figure 9. The speed deviation in the morning period is higher than the afternoon peak (15.6 and 15.0 km/h respectively), which is not found statistically significant (t=1.421, p=0.156). This is not the case for the variation as the speed variation in the morning (s=9.502 km/h) is less than the afternoon (s=10.961 km/h), which is significantly different (F=14.211, p=0.000). Further, the average deviation of speed at night is 13.2 km/h is lower than the daytime deviation (15.6 km/h), which is a reflection of the fact that the speed at night were higher the daytime. The average speed deviation is significantly different due to time of the day (t=4.012, p=0.000) while the variation where insignificantly different (F=1.609, p=0.205).



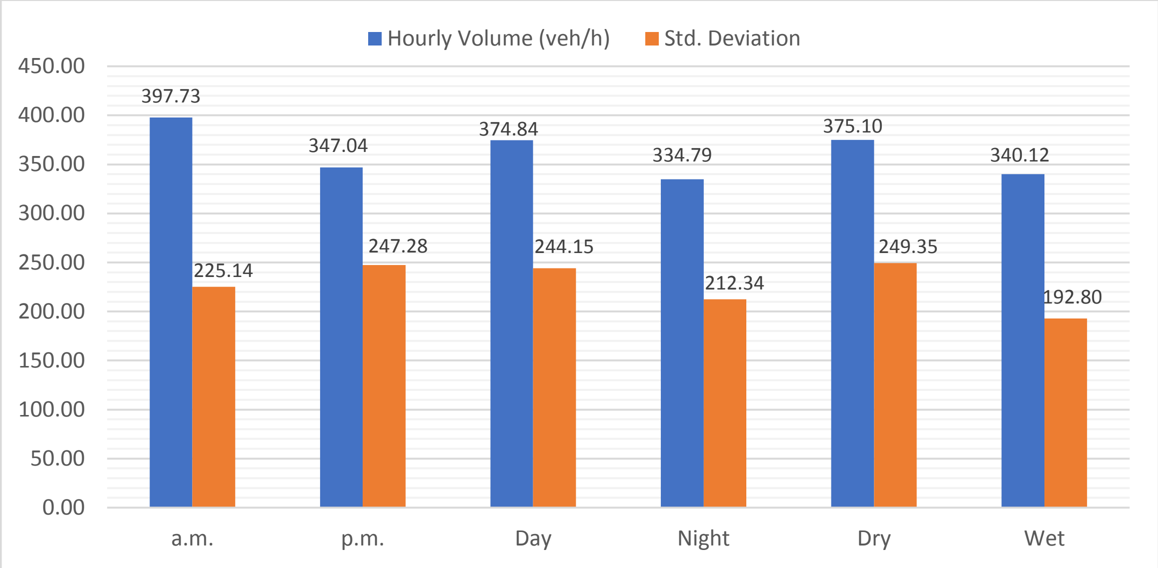
Statistical Parameter	Period of the Day	Time of the Day	Surface Condition
F-test	14.211	1.609	45.542
Sig.	.000	.205	.000
t-test	1.421	4.012	7.592
Sig. (2-tailed)	0.156	0.000	0.000

F-Test used for testing difference in variation while t-test is used to test difference in means

Figure 9 Speed Deviation from Speed Limit due to Time of the Day and Peak period Time

Further, the variation of speed deviation as expressed in standard deviation is lower if the surface is wet (7.99 km/h) compared to 10.479, if the surface is dry. The difference in speed variation due to surface conditions was statistically significant (F=45.542, p=0.000). The average speed deviation when the surface is dry is 16 km/h while it is only 12.3 km/h on wet surface. The difference in speed is also statistically significant (t=7.592, p=0.000).

Average hourly volume in the morning (398 veh/h) is higher than the afternoon (347 veh/h) and there is significant difference in average hourly traffi volume due to period of the day (t=4.739, p=0.000) while the variation is not statistically significant (F=1.59, p=0.208). The coefficient of variations were 0.57 and 0.71 for morning and afternoon respectively. Similar results were reported for difference in traffic volume due to time of the day. There is significance difference in average speed (t=3.047, p=0.002) but not the variation (F=0.656, p=0.418). Traffic on wet surface does not vary to the extent that of the dry surface (Figure 10). The coefficient variations are 0.56 and 0.66 for wet and dry surface respectively. There is a significant difference in the average traffic volumes due to surface type (t=3.025, p=0.003) and this also applies for difference in variation, which was proven to be significant (F=13.195, p=0.000).



Statistical Parameter	Period of the day	Time of the Day	Surface Condition
F-test	1.590	.656	13.195
Sig.	.208	0.418	.000
t-test	4.739	3.047	3.025
Sig. (2-tailed)	.000	0.002	.003

F-Test used for testing difference in variation while t-test is used to test difference in means

Figure 10 Contributing Factors of Traffic Volume Variations

Generalized linear models were used to develop the relation between speed and the contributing factors. The likelihood chi-square ratio was used to test the goodness of fit of the model. Different models were developed. The response variables were traffic speed or traffic volumes. The predictors differ according the response variables. The results presented below are the models that were significant including their coefficients.

Two models were developed to predict the speed; the first one does not include interaction term (interaction of traffic volume as covariate with the time of the day) while the second model includes interaction term. The likelihood chi-square ratios were 61.218 and 69.214 for the models with no interaction and with interaction respectively. Both were proven to be significant (p=0.000). The models involved two factors that were treated as dummy variables. The time of the day factor has two values 1 for day and 0 for night, surface condition which is reflecting the raining status is assumed to be zero while it is 1 if it was dry.

The noninteraction model suggests that as traffic volume increases (model 1), the speed decreases. It also shows that traffic at night is 2.38 km/h higher than the day traffic. The speed tends to be slightly higher (1.162 km/h) when it rains and the surface becomes wet.

Traffic Speed= 76.195 – 0.003 x Traffic Volume -2.338 x Time of Day -1.162 x Surface Condition……..(1)

(χ^2 =18.37, p=0.000) χ^2 =30.56, p=0.000) (χ^2 =8.672, p=0.003)

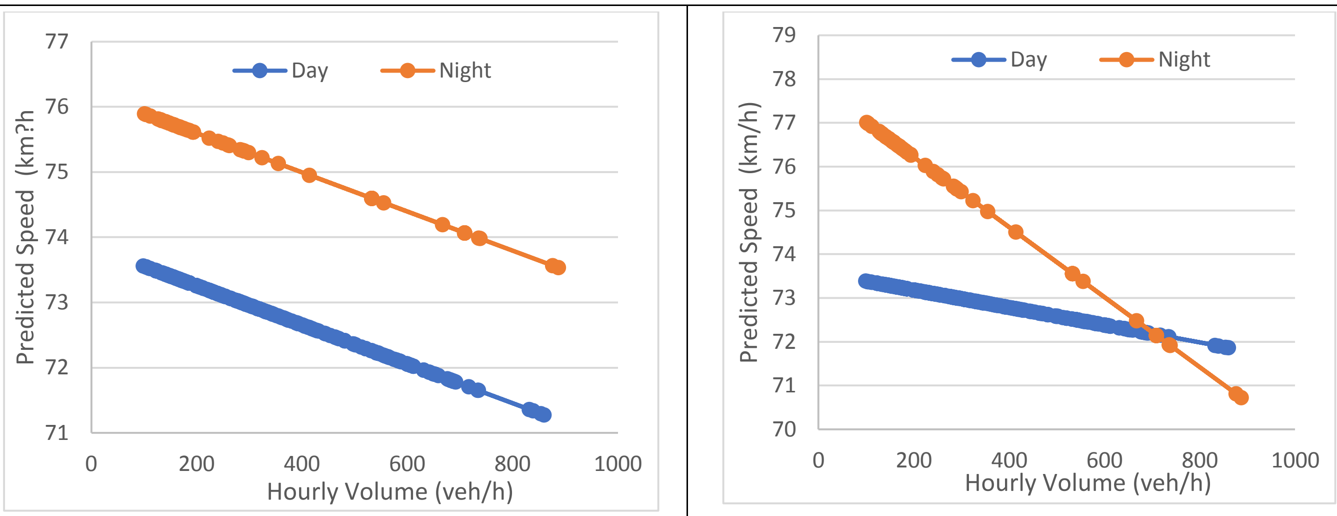
The interaction model suggests that as traffic volume increases (model 2), the speed decreases. However, impact of volume size is lessened when the period of day is considered, particularly at day time (Figure 11). It also shows that traffic at night is 4.235 km/h higher than the day traffic. The speed tends to be slightly higher (1.158 km/h) when it rains and the surface becomes wet.

Traffic Speed= 77.818 – 0.008 x Traffic Volume-4.235 x Time of Day -1.158 x Surface Condition

(χ^2 =17.94, p=0.000) (χ^2 =29.09, p=0.000) (χ^2 =8.618, p=0.003)

+ 0,006 x Traffic Volume x Time of Day …………………………………………..(2)

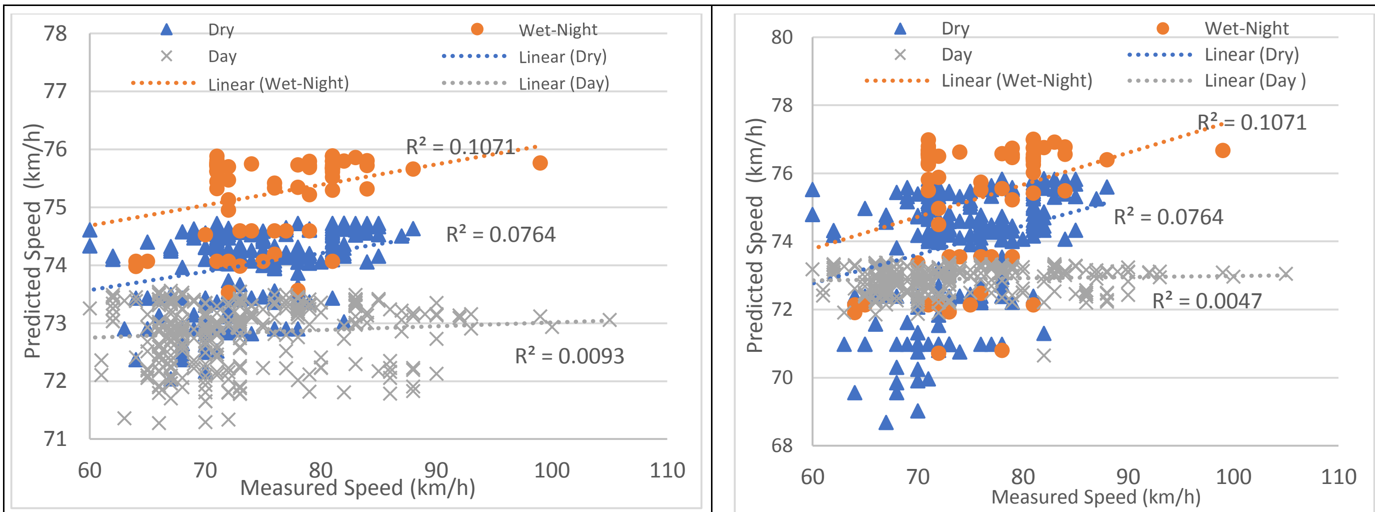
(χ^2 =8.237, p=0.004)



Noninteraction Model	Interaction Model

Figure 11 The Impact of Introducing Interaction Term (Volume with Time of the Day) to Speed Prediction Model

The predicted speed values are related to the measured values as shown in Figure 12. The relationships although significant but do not show high correlation coefficients. The highest person correlation coefficient was reported for wet surface conditions during night (r=0.33). The lowest value reported for wet surface during day time (r=0.069), which refers to the interaction model. Figure 12 shows correlation coefficient of the interaction model (0.069) is lower than the non-interaction model coefficient (0.096) by 28%.



Noninteraction Model	Interaction Model

Figure 12 Correlation between the Predicted Speed and the Measured Speed for both Models (Interaction and Noninteraction)

The application of the developed models for predicted speeds during daytime on dry surface conditions as shown in Figure 13 suggest that the two the models provide the same prediction of speed for low traffic volume (<500 veh/h). The prediction begins to deviate after this level and the interaction model gives higher estimate compared to the non-interaction. Both models failed to indicate high correlation coefficient between the predicted speed and the actual speed (r=0.072).

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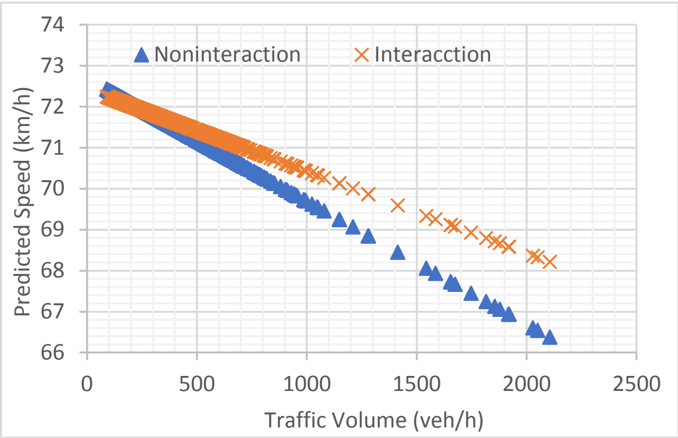
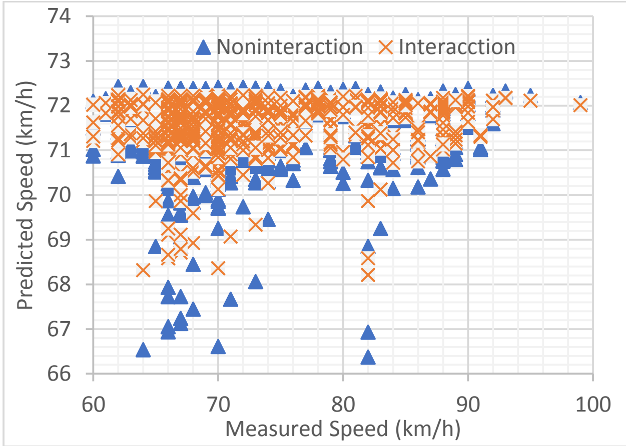


Predicted Speed Function of Traffic Volume



Correlation between Predicted & Measured Speed

Figure 13 Speed Prediction during Day time on Dry Surface Conditions

A model was developed to predict traffic volume as function of environment conditions as shown below,

Traffic Volume= 276.975 + 2.718 x Air Temperature + 36.271 x Time of Day +28.396 x Surface Condition

(χ^2 =6.39, p=0.011) (χ^2 =6.28, p=0.012) (χ^2 =4.29, p=0.038)

The model indicates that traffic on daytime is higher than daytime by 32.7 vehicle per hour and it is also higher if the surface condition is dry by 31.323 compared to wet surface conditions. The correlation coefficient between the predicted volumes and actual count sis 0.105. The relationship is slightly stronger if the prediction is used to determine traffic on dry surface conditions (r=0.154). The correlation between the predicted and the counted traffic volume is low if the prediction is related to wet surface conditions (r=0.0557). Although a model that includes speed to predict traffic volume was developed and found to be valid for the estimation as indicated by the high likelihood chi-square (χ2 =33.124, p=0.000). However, it will not be discussed hereby because it might be illogical to predict the traffic as function of speed because traffic volume has impact on the speed but the opposite might not be justified.

CONCLUSION

The results of analysis showed that both average speed and the 85th percentile traffic speeds are below the posted speed limit. The average speed fluctuates in narrow range (71.1 to 73.7 km/h) that composed 73.2%, 81.9 and 88.9% of posted speed limits of 100, 90 and 80 km/h respectively. The average speed on the selected locations differ due to speed limit (F=28.27, p=0.000). The association between speed limit and operating speed proven to be significant (r=0.137, p=0.000). Table 5 indicate that traffic speed on wet conditions is higher than when it is dry. The difference in speeds increase as speed limit increases. Raining seems to influence the speed more than it influences traffic volume. Table 5 does not show clear relationship between change in traffic volumes due to surface and speed limit. As surface became wet, traffic volume decreases for roads with speed limits less than or equal 90 km/h while it increases for 100 km/h speed limit. For all sites and irrespective of the speed limit, the statistical analysis showed that there is a difference in average speed (t=-2.96, p=0.003) and its variation (F=9.486, p =0.002) due to road surface conditions.

Table 5 Traffic Parameters Function of Speed Limit and Surface Condition

Speed Limit	Surface Condition	Average Speed (km/h)	85th Speed (km/h)	Average Hourly Volume (veh/h)
80.00	Dry	71.1	76.0	543
	Wet	71.3	77.8	495
	All	71.1	76.0	534
90.00	Dry	73.0	81.0	200
	Wet	74.7	83.0	197
	All	73.7	83.0	199
100.00	Dry	73.0	82.0	209
	Wet	81.5	92.2	255
	All	73.2	82.0	210
All	Dry	72.0	79.0	375
	Wet	73.3	82.0	340
	All	72.3	81.0	368

The same applies for the traffic volumes, the data showed that there is a difference in average traffic volume (t=3.06, p=0.002) and the variation (F=13.446, p=0.000). The situation is different when the data is classified by speed limit, the difference in speed due to surface conditions was only significant for road with speed limits 90 km/h (t=-2.329, p=0.02) and 100 km/h (t=-3.306, p=0.001). Traffic volumes, on the other hand, was significant for road with speed limit 80 km/h (t=2.53, p=0.012). The analysis suggests that there is specificity for each site and both speed (F= 21.09, p = 0.000) and traffic volumes (F=1127, p=0.000) are significantly different from one site to another.

The impact of weather conditions on traffic parameters appears to be significant for depth of rain precipitation. Average speed differs according to the rain depth category (F=5.927, p=0.000) as well as the traffic volume (F=14.843, p=0.000). As rain precipitation depth (RPD) increases the speed decreases. The strength of association between traffic flow indicators (speed and volume) differ by the depth of rain precipitation. The highest, significant, correlations are reported (r=-0.236, p=0.01) for moderate rain fall (2.5-10.0 mm). Air temperature influences the relationship between speed and volumes with a negative trend. Traffic volume decreases as temperature increase but not when the temperature increased beyond 20 C°. The highest correlation between traffic indicators was related - mild temperature (>10-15 C°) (r=-0.108, p=0.002) while the lowest was reported for warm weather condition (>15-20 C°) (r=-0.082, p=0.076). In general, speed (F=5.444, p=0.001) and traffic volume (F=9.758, p=0.000) differ significantly due to the temperature category. The impact of temperature has more influence on traffic volumes, particularly at high temperature. Further, as wind speed increases the traffic speed decreases while traffic volume fluctuates. Significant negative relationships between traffic volume and speed were found for calm wind (<2 km/h) (r=-0.266, p=0.00) and light air (2-3.99 km/h) (r=-0.093, p=0.021). Poor correlation coefficients and not significant are related to light air/ breeze (>4-6 km/h) (r=-0.045, p=0.277) and light breeze (>6 km/h) (r=-0.072, p=0.111). Poor association between traffic speed and wind speed categories (F=2.305, p=0.056) while the association is significant for traffic volume (F=43.49, p=0.000).

The study also showed that the average speed fluctuates over the day of the week in narrow margin that does not exceed 0.74 km/h, but the difference is not significant (F=0.618, p=0,649). Traffic volumes differ slightly over the day of the week with the significant evidence (F= 1.079, p=0.365). Speed at night (74.31 km/h) is higher than the average speed day time (71.87), the difference is statistically significant (t=-6.782, p=0.000). for the period of the day, speed in the morning is lower than the afternoon but the variation in the afternoon is less with significant variation (F=11.607, p=0.00). However, average speed between the two periods is marginally insignificant (t=-2.001, p=0.046). further, the speed deviation from the posted speed limit in the morning peak is higher than the afternoon peak (15.6 and 15.0 km/h respectively), the difference was not found statistically significant (t=1.421, p=0.156) whereas, the variation as the speed variation in the morning (s=9.502 km/h) is less the afternoon period (s=10.961 km/h), which is significantly different (F=14.211, p=0.000). Average hourly volume in the morning (398 veh/h) is higher than the afternoon (347 veh/h) and there is significant difference in average traffic volume due to peak hour time (t=4.739, p=0.000) while the variation is not statistically significant (F=1.59, p=0.208).

Generalized linear models were used to develop the relation between speed and the contributing factors. Two models were developed, non-interaction and interaction (Interaction of traffic volume with the time of the day. The non-interaction model suggests that as traffic volume increases, the speed decreases. It also shows that traffic speed at night is 2.38 km/h higher than the day traffic. The speed tends to be slightly higher (1.162 km/h) when it rains and the surface becomes wet. The interaction model also suggests that as traffic volume increases, the speed decreases. However, impact of volume size is lessened when the time of the day is considered, particularly at day time. It also shows that traffic speed at night is 4.235 km/h higher than the day traffic. The speed tends to be slightly higher (1.158 km/h) when it rains and the surface becomes wet. The predicted speed values were correlated to the measured values and it was found significant but do not show high correlation coefficients. The highest person correlation coefficient was reported for wet surface conditions during night (r=0.33). The lowest value reported for wet surface during day time (r=0.069), which refers to the interaction model. The developed models were used for predicted speeds during daytime on dry surface conditions. The two the models provide the same prediction of speed for low traffic volume (<500 veh/h). The prediction begins to deviate after this level of volume. The interaction model gives higher estimate compared to the non-interaction. Both models failed to indicate high correlation coefficient between the predicted speed and the actual speed (r=0.072). It is true that the correlation coefficient is significant but that is maybe due to the large size of the sample. In addition, a model was developed to predict traffic volume as function of environment conditions. The model indicates that traffic on daytime is higher than daytime by 32.7 vehicle per hour and it is also higher if the surface condition is dry by 31.323 compared to wet surface conditions. The correlation coefficient between the predicted volumes and actual count sis 0.105. The relationship seems slightly stronger if the prediction is used to determine traffic on dry surface conditions (r=0.154). The authors, although developed model that includes speed to predict traffic volume and found to be valid for the estimation, would not consider for prediction, because it may not be logical to predict the traffic as function of speed. As traffic volume has impact on the speed but the opposite might not be debatable. Some believes, if the speed is high on one road segment, then it will invite more traffic, while others would not consider this is a valid assumption.

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