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The Impact of Rainfall and Temperature on Peak and Off-Peak Urban Traffic

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Abstract. This paper focuses on quantifying the effect of rainfall and temperature intensities on urban traffic characteristics in peak and off-peak respectively hours using traffic data from Greater Manchester, UK, as a case study. Three broader issues are addressed: (1) the impact of rainfall on urban traffic; (2) the impact of rainfall intensity on traffic flow parameters at both peak and off-peak periods; (3) the impact of atmospheric temperature level on peak and off-peak urban traffic. Our contribution arises both from the combination of data sources included in the study as well as the separate analyses of peak and off-peak weather effects on traffic. This is the first study undertaken in a real urban environment with reduced operating speed (30mph). This research can provide urban traffic policymakers with crucial information that can be used to modify or develop traffic planning decisions in order to maximize the traffic network utilization.

Keywords: Traffic Analytics, Traffic Flow Analysis, Data Science.

1 Introduction

Over the years, it has been identified that harsh weather can considerably affect traffic flow parameters by influencing driving behaviour, travel demand, travel mode, safety, as well as traffic flow characteristics [1-5]. In terms of traffic operation, rain conditions reduce traffic capacity and operating speeds, thereby increasing congestion and road network productivity loss. The incorporation of weather-related data for traffic management enables a clear understanding of the dynamics of traffic flow modeling, especially in geographical locations with the tendency of severe weather conditions. Despite the vastness of studies investigating whether weather affects traffic, there is still a dire need to quantify the impact of weather conditions on traffic operation within urban road networks. The limitations in understanding the direct impact on traffic by weather conditions minimizes the potential for transportation policymakers to capitalize on additional intelligence provided by weather-related data sources in order to develop improved traffic management strategies. This leaves the presence of a number of gaps or opportunities for new and exciting research within this area.

One of the main limitations addressed by this study is the fact that only few studies have investigated the impact of weather conditions on urban traffic. This is possibly because urban links are shorter in length, usually have lower speed limits, and have more interrupted traffic [6]. Secondly, peak and off-peak periods should be analyzed separately during weather-traffic analyses. Policymakers can benefit from a deeper understanding of the effects of weather conditions on peak and off-peak periods leading to better planning decisions or traffic control modifications that will be applied to effectively control traffic congestion. This research differs from existing studies by focusing on weather impact on urban traffic rather than freeway/motorway/highway traffic. The remainder of this paper is organised as follows. Section 2 presents related studies, while the Methodology and Data are presented in Section 3. The results are presented and discussed in Section 4. The final section presents the conclusion and future research opportunities.

2 Related Work

Many studies have attempted to investigate the relationship between weather and traffic. For instance, Jones and Goolsby [7] reported a 14% reduction in operating speed during rainfall. Smith, Byrne [8] observed that light rain decreased capacity by 4% to 10%, while heavy rain caused a reduction in the range of 25% to 30%. Ibrahim and Hall [9] performed a regression analysis on weather data and found out that light rain caused a reduction of about 1.1*mph* in operating speeds during free-flowing conditions and 4 to 8*mph* in congested conditions. In heavy rain, they observed a reduction of 8*mph* to 10*mph* during capacity conditions. Mahmassani, Dong [10] showed that adverse weather can affect traffic by increasing demand, as well as shifting the peak-hour demand. Similarly, Wang, Yamamoto [11] observed a reduction in operating speeds to about 6% to 8% during heavy rainfall and that the magnitude of the weather impact was dependent on road network characteristics, such as number of lanes, and the size of road. Other studies claim that changes in rainfall intensity is what affects the traffic speed negatively [2, 6, 8, 12].

A step in the right direction would be the analysis and quantification of the impact of weather on traffic data within an urban setting (reduced operating speed - 30*mph*), as opposed to the vast majority of studies that consider freeway traffic [3, 9, 13-16]. Moreover, identifying how traffic is impacted at peak and off-peak times can provide additional information to policymakers for developing improved traffic management policies.

3 Methodology and Data

The traffic data used within this study was provided by Transport for Greater Manchester (TfGM) and comprised observations of average speed, flow, density, and travel time. The data was collected using a combination of Inductive Loop Devices (ILD) and Bluetooth sensors on an urban road (Chester Road - A56) in Stretford, Greater Manchester, UK, as depicted in Fig. 1. This represents an ideal characteristic of serving as a conduit from a residential area to the city centre. Landmark locations around are the Old Trafford Stadium (Manchester United) in addition to other leisure points like shopping malls, clubs, restaurants, etc. The study period spans from 1 January 2014 to 31 December 2014. The study area has a speed limit of 30mph.

Fig. 1. Map of Study Area (source: Google Maps)

The weather data obtained during the study period comprised hourly observations of temperature ($^{\circ}\text{C}$) and precipitation (mm). The rainfall was categorized as *Light* ($< 0.5\text{mm}$), *Moderate* ($0.5\text{mm} < r < 4.0\text{mm}$), and *Heavy* ($r > 4.0\text{mm}$) as stated in the SYNOP FM-12 weather equipment. Weather data was obtained from the Centre for Atmospheric Studies (CAS), University of Manchester. The weather stations are located within a 3-mile radius of the study area. Holidays and weekends were excluded from the analysis, as these would present significantly differing traffic patterns to the daily peak and off-peak patterns used within this study. The workdays were further sub-categorized into peak and off-peak hours. The peak hours were identified by performing analysis and descriptive statistics on the data, which revealed the peak hours (excluding outliers) to be 08:00 to 10:00, 17:00 to 19:00.

4 Results

The first step in the process of this analysis was the visualization of the provided traffic dataset by producing speed-density-volume (V-K-Q) plots for peak and off-peak hours, which are presented in Fig. 2. This was compared to existing traffic stream models in the literature [17] and agreed with the Greenshields traffic stream model. Table 1 presents the descriptive statistical analysis for the traffic dataset. All the tables

also present the Standard Deviation (SD), Standard Error (SE), Degree of Freedom (*df*) and Mean Square (MS) for the respective groups. As shown in Table 1, all p-values are statistically significant at the 0.05 level, implying that the null hypothesis cannot be rejected. Also, the average speed at off-peak periods is higher than that of the peak periods, which makes sense and shows the level of traffic congestion during peak hours.

Summarily, there is a 35% reduction in average speed during peak periods, an increase of 157.5% and 154% for volume and density respectively. This represents a significant increase in traffic congestion during peak periods.

Fig. 2. V-K-Q Relationships for Peak and Off-Peak period

4.1 Precipitation

Table 2 displays the descriptive statistics and single factor ANOVA for the groups of rainfall intensities during peak periods. As can be seen from the table, there is a significant difference ($p < 0.05$) between all the rainfall intensities and the traffic flow characteristics (i.e. speed, volume, and density). What stands out in the table is that heavy rainfall negatively impacted average operating speeds by 9.74%, equivalent to a 2-3mph average speed reduction. More specifically, average speeds were reduced by 2.61% and 9.74% during moderate and heavy rainfall respectively.

4.2 Temperature

The temperature observations were classified as Freezing (below 5°C), Cold (between 5°C and 10°C), Normal (from 10 to 15°C), Warm (between 15°C and 20°C), and Hot (above 20°C). Tables 3 and 4 present the descriptive statistics for the respective groups, at off-peak and peak periods respectively. In Table 4, there is a clear trend of increase in volume with temperature at peak periods. However, average speed is reduced by 36.5% at hot temperatures, which translates to a speed reduction of 5-6mph.

Table 1. Speed-Volume-Density descriptive statistics at Peak and off-peak periods

Section	N	DESCRIPTIVES				Comparison	df	ANOVA			
		Mean	SD	SE	Max			MS	F	p-value	F crit
Speed (Off Peak)	4301	26.8	4.18	0.06	35.6	Between Groups	1	110143.26	5961.16	0	3.84
Speed (Peak)	1771	17.4	4.57	0.11	34.8	Within Groups	6070	18.48			
Total	6072	17.5	4.59	0.26	35.6	Total	6071				
Volume (Off Peak)	4301	431	349	5.32	1209	Between Groups	1	5781615.28	6063.47	0	3.84
Volume (Peak)	1771	1110	177	4.22	1762	Within Groups	6070	95351.66			
Total	6072	628	396	4.23	1762	Total	6071				
Density (Off Peak)	4301	26.8	24.6	0.38	193.7	Between Groups	1	2294876	3554.32	0	3.84
Density (Peak)	1771	69.6	24.6	0.65	262	Within Groups	6070	645.66			
Total	6072	35.4	29.2	0.31	262	Total	6071				

Table 2. V-K-Q descriptive statistics by rainfall intensity for peak periods

Section	Intensity	N	DESCRIPTIVES				Comparison	df	ANOVA			
			Mean	SD	SE	Max			MS	F	p-value	F crit
Speed (mph)	None	1276	17.25	4.61	0.13	34.8	Between Groups	3	71.362	3.36	0.02	2.6
	Light	399	17.98	4.45	0.21	34.7	Within Groups	1514	21.254			
	Moderate	89	16.8	4.24	0.8	25.2						
	Heavy	7	15.57	2.55	0.96	17.8						
	Total	1771	17.06	4.6	0.26	34.8	Total	1770				
Volume (veh/hr)	None	1276	1117	179.5	5.02	1762	Between Groups	3	84426.30	2.69	0.05	2.6
	Light	399	1089	173.9	8.70	1558	Within Groups	1767	31388.54			
	Moderate	89	1102	156.7	16.55	1453						
	Heavy	7	1059	193.9	73.29	1283						
	Total	1771	1005	264.3	6.78	1762	Total	1770				
Density (veh/mi)	None	1276	70.62	27.5	0.77	262	Between Groups	3	2027.3	2.74	0.04	2.6
	Light	399	67.22	28.04	1.4	220	Within Groups	1767	741.12			
	Moderate	89	65.54	19.03	2.02	146						
	Heavy	7	57.41	9.62	364	72.9						
	Total	1771	63.08	28.76	0.74	262	Total	1770				

Table 3. V-K-Q descriptive statistics by rainfall intensity for off-peak periods

Section	Intensity	N	DESCRIPTIVES				Comparison	df	ANOVA			
			Mean	SD	SE	Max			MS	F	p-value	F crit.
Speed (mph)	None	3176	27.12	4.03	0.07	35.6	Between Groups	3	532.86	31.11	7E-20*	2.6
	Light	901	25.79	4.53	0.15	35.1	Within Groups	4295	17.13			
	Moderate	217	25.64	4.33	0.29	31.3						
	Heavy	5	30.22	2.41	1.08	30.7						
	Total	4299	27.14	3.85	0.05	35.6	Total	4298				
Volume (veh/hr)	None	3176	434	350.4	6.22	1204	Between Groups	3	81358.3	0.67	0.571	2.6
	Light	901	427	351.6	11.71	1209	Within Groups	4295	121659			
	Moderate	217	406	310.9	21.11	1057						
	Heavy	5	313	334.5	149.5	707						
	Total	4299	403	409.7	6.07	1209	Total	4298				
Density (veh/mi)	None	3176	27.48	25.31	0.45	194	Between Groups	3	1987.61	3.288	0.02*	2.6
	Light	901	25	22.64	0.75	117	Within Groups	4295	604.425			
	Moderate	217	24.21	21.51	1.46	146						
	Heavy	5	21.48	18.39	8.22	42						
	Total	4299	24.5	28.93	0.43	194	Total	4298				

Higher temperatures also resulted in 6.6% more traffic volume. Additionally, at peak hours, higher temperatures produced a corresponding increase in density and volumes, and a significant reduction in traffic speed. Table 3 shows that higher temperatures

consistently drove down the traffic volume and density, while hot temperatures exceeding 20°C resulting in a 36.8% reduction in volume. Conversely, higher temperatures resulted in greater average speeds to the tune of 15.7% at hot temperatures. As shown in Table 5, all traffic flow parameters are statistically significant at the 0.05 level, implying that there is a relationship between temperature and traffic flow parameters.

Table 4. V-K-Q descriptive statistics by temperature intensity for off-peak periods

Section	Intensity	N	DESCRIPTIVES				Comparison	df	ANOVA			
			Mean	SD	SE	Max			MS	F	p-value	F crit
Speed (mph)	Freezing	416	24.09	4.09	0.20	33.5	Between Groups	4	2664.81	177.6	6E-141*	2.4
	Cold	1366	25.32	4.33	0.12	35.6	Within Groups	4300	15.008			
	Normal	1411	27.46	3.96	0.11	31.3						
	Warm	905	28.72	3.00	0.10	30.2						
	Hot	207	28.59	2.92	0.20	28.9						
Total		4305	26.77	4.6	0.26	35.6	Total	4304				
Volume (veh/hr)	Freezing	416	1117	179.5	5.02	1762	Between Groups	4	84426.3	2.69	0.045*	2.4
	Cold	1366	1089	173.9	8.70	1558	Within Groups	4300	3138.5			
	Normal	1411	1102	156.2	16.55	1453						
	Warm	905	1059	193.9	73.29	1283						
	Hot	207	706	297.5	20.68	1115						
Total		4305	1005	264.3	6.78	1762	Total	4304				
Density (veh/mi)	Freezing	416	70.62	27.5	0.77	262	Between Groups	3	2027.3	2.74	0.042*	2.4
	Cold	1366	67.22	28.04	1.4	220	Within Groups	4300	741.12			
	Normal	1411	65.54	19.03	2.02	146						
	Warm	905	57.41	9.62	364	72.9						
	Hot	207	48	23.64	1.64	119						
Total		4305	63.08	28.76	0.74	262	Total	4304				

4.3 Comparison and discussion with respect to other studies

Over the past decades, many studies have investigated speed-flow-density relationships under rainy conditions and such studies also revealed that rainfall intensities have differing impacts on traffic flow parameters [8, 13, 17, 18]. Table 6 presents a comparison of the findings from these studies. A total of ten studies were compared in terms of the results obtained. A quick look at Table 6 shows a vast variation in the reduction of speeds across the studies, which is attributable to the differences in the weather, traffic speeds, driving behavior, etc. Most studies report that light rain has the smallest impact on traffic, which supports the notion that intensity matters when considering the impact of rainfall on traffic. In addition, studies reported that temperature had a near negligible impact on traffic speed [6, 13], although the reverse was the case in this study. This is arguably attributed to the fact that the studies compared in Table 6 were all freeways/motorways, and thereby would be affected differently by temperature levels. However, as Tables 4 and 5 show, there are significant relationships between temperature levels and traffic flow parameters and these effects vary at peak and off-peak periods. As previously stated, this is the first study that considers urban city traffic (i.e. speeds at 30mph), as opposed to other studies analyzing freeway, highway or urban freeway traffic. For instance, although [6] claim the study to be carried out in urban traffic, in reality it has been conducted on an urban motorway. Furthermore, this study also categorized the traffic into peak and off-peak periods, enabling a proper understanding and appreciation of the traffic state.

Table 5. V-K-Q descriptive statistics by temperature intensity for peak periods

Section	Intensity	DESCRIPTIVES					Compar- ison	df	ANOVA			
		N	Mean	SD	SE	Max			MS	F	p-value	F crit.
Speed (mph)	Freezing	150	20.6	3.95	0.32	32.9	Between Groups	4	2041.18	125	5E-94*	2.4
	Cold	534	19.75	4.52	0.20	34.8	Within Groups	1766	16.33			
	Normal	540	16.75	4.23	0.18	31.8						
	Warm	388	14.80	3.53	0.18	27.9						
	Hot	159	15.09	2.67	0.21	22.0						
Total		1771	17.40	4.57	0.11	34.8	Total	1770				
Volume (veh/hr)	Freezing	150	1053	264.7	21.61	1541	Between Groups	4	231290	7.45	6E-06*	2.4
	Cold	534	1094	187	8.09	1596	Within Groups	1766	31025.9			
	Normal	540	1132	153.2	6.59	1625						
	Warm	388	1117	160.4	8.15	1762						
	Hot	159	1127	140.1	11.11	1444						
Total		1771	1110	177.4	4.22	1762	Total	1770				
Density (veh/mi)	Freezing	150	54.05	23.48	1.92	200	Between Groups	3	40291.5	61.63	8E-49*	2.4
	Cold	534	59.37	22.62	0.98	203	Within Groups	1766	653.72			
	Normal	540	73.16	26.75	1.15	237						
	Warm	388	81.00	28.69	1.46	230						
	Hot	159	78.16	24.56	1.95	262						
Total		1771	69.55	27.26	0.65	262	Total	1770				

Table 6. Comparison of changes in operating speeds from several studies

Source (year)	Road Type	Location	Speed Limit (mph)	Intensity	Impact on Speed %					
					Rainfall			Temperature		
					Peak	O-Peak	N/S	Peak	O-Peak	N/S
Ibrahim and Hall (1994)	Freeway	Mississauga, Ontario, USA	62	Light			-12.9			N/A
				Heavy			-9.7			N/A
Kyte et al., (2001)	Freeway	Idaho, USA	70	Light			-13.6			N/A
				Heavy			-13.6			N/A
Smith et al., (2004)	Freeway	Virginia, USA	62	Light			-6.5			N/A
				Heavy			-6.5			N/A
Maze et al., (2005)	Freeway	Iowa, USA	70	Light			-2			-1
				Medium			-4			-1
				Heavy			-6			-2
Agarwal et al., (2006)	Freeway	Minnesota, USA	70	Light/Warm			-2.5			-1.5
				Heavy/Cold			-7			-3.6
Unrau and Andrey (2006)	Urban Expressway		55	Light			-10			N/A
				Medium			-10			N/A
				Heavy			-10			N/A
Rakha et al., (2008)	Freeway	Multiple, USA	87	Light			-3.6			N/A
				Heavy			-9			N/A
Billiot et al., (2009)	Motorway	France	80	Light			-8			N/A
				Heavy			-12.6			N/A
Tsapakis et al., (2013)	Urban	London, UK	70	Light			-2.1			-1.9
				Medium			-3.8			-3.2
				Heavy			-6			-3.2
This study (2018)	Urban Arterial	Manchester, UK	30	Light/Cold	+4.2	-4.9		-4.12	+5.1	
				Moderate/Normal	-2.6	-5.5		-18.7	+14	
				Heavy/Warm	-9.7	+11.4		-28.2	+19.2	
				Hot Temp	N/A	N/A		-26.7	+18.7	

5 Conclusion

This study has quantified the effect of weather conditions on traffic flow characteristics. It contributes to understanding of how differing rainfall and temperature intensities affect urban traffic. The key insights derived from this study is that rainfall affects urban traffic, but is dependent on the intensity, and peak/off-peak hours. Light rainfall had no impact on peak traffic (Table 2). However, average speed reduces with Moderate and Heavy rainfall by 2.6% and 9.7% respectively. The results are however different for off-peak periods, as can be seen from Table 3. Tables 4 and 5 present the off-peak/peak descriptive statistics respectively. This research provides policymakers with additional information towards developing effective traffic management solutions

to improve congestion. Further research work will investigate the effect of weather-related data on weekends and holidays, and use of a larger dataset spanning 4 or more years that guarantee an even distribution of rainfall and temperature values enabling increases in results accuracy.

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