EFFECT OF FOG ON FREEWAY PERFORMANCE: INITIAL RESULTS

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ABSTRACT

The main objective of this research is to use the well-known micro-simulation model VISSIM to evaluate the effect of the fog on freeway performance. To achieve this research objective, a micro-simulation model for a freeway section connected Dubai and Abu Dhabi was developed. The experimental design for this research includes two variables, namely; the traffic volume, represented by the Volume-to-Capacity (V/C) ratio and the percentage of speed reduction. Based on local experience and approved practice in the local planning agencies, the assumed capacity for the considered freeway is assumed as 2,000 passenger cars/hour/lane, and the enforcement speed as 140 km/hr. In addition to that, the percentage of aggressive drivers in the area is 40% (drivers going above the maximum speed).

This paper presents an initial assessment of the fog effect on the performance. The simulation results indicated that the delay was increasing substantially against the reduction of speed, and/or the increase of the V/C ratio. Furthermore, the results indicated a reduction in the desired mean and maximum speeds with the increase of the traffic volume. Finally, the changes in the total number of vehicles in the network due to changes in the percentage of speed reduction were very small.

The results of this study will be considered as a major component of a fog detection and warning system in Abu Dhabi. The final conclusions of this research will help Abu Dhabi Police Department to decide on the speed limit, to be suggested to the road users in case of fog.

Keywords: Freeway Performance, Microsimulation, Freeway Traffic Management

INTRODUCTION

The United Arab Emirates (UAE) is a country that is situated in the Arabian Gulf. The country is a federation of seven emirates. UAE had faced a rapid growth in the past few decades due to oil discovery, leading the country to be one of the most developed countries in the Middle-East region. Abu Dhabi is the largest among the other emirates and it is the capital of the country. However, it has limited residential availability; leading the rental prices to exceed the affordable level for many people. On the other hand, Dubai, which is the financial hub in the country, is about one hour away from Abu Dhabi, and with the economic crisis affects, the rental prices had dropped significantly relative to Abu Dhabi ones. Therefore, a substantial number of people are now residing in Dubai and commuting daily to their work in Abu Dhabi leading the Abu Dhabi - Dubai Highway (the main connection for passenger cars) to be extremely busy inbound to Abu Dhabi during the morning peak hours, and outbound from Abu Dhabi during the evening peak hours.

Abu Dhabi - Dubai Highway (E10) faced two world record accidents in both March 2008 and April 2011. In the March's accident, around 25 vehicles were caught on fire out of 60 vehicles that were involved in the accident. About 127 vehicles were involved in April's accident. These two accidents, and several other small ones, were due to the high density of fog. This problem has been considered seriously by Abu Dhabi Police Department and it has been decided to develop a fog detection and warning system. For this system to work efficiently, the impact of fog on road safety and performance has to be evaluated. (Gulf News 2008, 2011)

This paper presents the effect of fog on freeway performance. It should be noted that there is another research project considering the development of a fog detection system.

BACKGROUND REVIEW

The effect of fog has been considered since the 1970's as indicated in the literature. Heiss (1976) appears to be one of the first few researchers who studied this problem and estimated the critical densities of fog that may lead to significant impact on freeway safety and performance. Several researchers considered the visibility during fog conditions, where some (Paulmier et al, 1992) aimed at estimating the visibility distance during fog conditions based on analytical models. Also, Al-Ghamdi (2004) estimated that drivers' behavior is impacted by the fog when the visibility is less than 50 m. Finally, Kang et al (2008) investigated the traffic accidents during fog conditions and concluded that the main reason for such accidents can be due to the lack of visual landmarks during fog times.

The driver perception during foggy times was studied by Gavallo (2002), who used a fog chamber and a driving simulator, and concluded that the risk of accidents is doubled during fog conditions. In his conclusion, he indicated that the effect of fog on the perception of speed is negligible, while there is a significant impact on the estimation of the headway.

MacCarley et al (2006) evaluated the drivers' response to Variable Message Sign (VMS) cautioning of foggy conditions and providing advisory speeds. It was concluded that the mean speed will decrease when VMS is activated.

In China, some research work investigated the impact of fog on road performance and safety. Qi et al (2007) developed a traffic safety management system during foggy weather through the utilization of Geographic Information Systems (GIS) technologies. Using real life data, the system was tested and proved to have significant potential to improve traffic safety on highways during fog periods. Wang et al (2004) evaluated the influence of fog on traffic safety and calculated the risk level and the period of fog's for different regions in China. The areas that showed the highest risk level are Beijing, Shanghai, and Tianjin.

In Australia, Brisbane and Hons (1993) examined the possibility of using an 'intelligent' sign for fog warning on Australian roads. The system was implemented on one of the major roads in Australia, which suffers from heavy fog intensities for about 250 hours every year. It was concluded that there is limited research in that considers the environmental factors'

impact on road safety and performance, based on a comprehensive review of previous research (Rowland et al, 2007).
In the United States, Abdel-Aty et al (2011) indicated that most of the limited research that considered the impact of environmental conditions on freeway performance and safety has focused on the crashed caused by snow or rain. In their paper, they conducted a detailed study on Florida's crash data between 2003 and 2007 with emphasis on crashes caused by fog or smoke. Head-on and rear-end crashes are the two most common crash types in terms of crash risk and severity. The highest rate and severity of accidents caused by fog or smoke were detected during night time in the absence of public street lighting. Furthermore, a study in Iowa estimated a speed and traffic volume reduction of about 16% and 29%, respectively, due to winter storms. Also, Pisano et al (2002) estimated the impact of weather conditions on traffic delays based on data from two metropolitan areas. It was determined that weather conditions are the cause of about 12% of the traffic delays. The Federal HighWay Administration (FHWA) sponsored some research that determined that weather effects are the cause for roughly 12% of travel time delay in two metropolitan areas.
In a recent study, the use of image processing technologies for detecting the existence of night fog was examined. Two approaches were developed that are based on analyzing images obtained from in-vehicle cameras. The first approach considered the fog detection for the scenario where there is no exterior street lighting. The other approach considered the scenario when there is street lighting (Gallen et al, 2011).
Maoh et al (2008) developed a simulation tool to evaluate the impact of different climate conditions on transportation and the economy in Canada.

In conclusion, the literature review clearly indicated that there is a lack of significant research that investigates the influence of fog on drivers' behavior, road safety and performance. The majority of the research in the literature did not focus on areas in the Gulf region. Therefore, this research is considering the impact of fog on freeway performance in Abu Dhabi, UAE.

RESEARCH OBJECTIVE

Abu Dhabi Police Department is concerned about the serious impacts of fog on freeway performance and safety. Therefore, the ADPD has initiated research efforts to develop a fog detection and speed advisory system to reduce the negative impacts of fog on freeway performance and safety. This paper is one of the research efforts to evaluate the impacts of fog on freeways. The other research elements include the development of a fog detection system that will estimate the intensity of fog and determine the proposed speed reduction on the freeway.
For this system to work efficiently, the impact of fog on road safety and performance has to be evaluated. The main objective of this research is to use the well-known micro-simulation model VISSIM to evaluate the effect of the fog on both freeway performance and safety. However, the current paper presents the initial results of the simulation experiments related to highway performance only. The traffic safety results will be discussed in coming papers.

METHODOLOGY

To achieve the research objective, a micro-simulation model was developed for a section of E10 (Abu Dhabi – Dubai Freeway), where the April 2011 accident happened. The experimental design for this research includes two variables, namely; Volume-to-Capacity (V/C) ratio and the percentage speed reduction. The paper considers the following conditions for the two variables: (a) different traffic volumes that corresponding to V/C ratios of 40%, 60%, 80%, 100% & 120%, which represent different traffic demand levels during the fog times and (b) for the speed reduction, the values are: 0%, 30%, 50% & 70%, which represent different speed reduction levels. These speed reductions represent the possible enforcement speeds during fog time. In addition to that, the paper adopted the existing number of lanes in the road, which are four lanes. Table 1 lists the different simulation scenarios considered in this study. The impact of fog is considered in one of the simulation parameters that is named “look ahead distance” (PTV VISION, 2011), which is the visibility limit for the drivers.

Table I – Simulation Scenarios

V/C	Volume (veh/hr)	Percentage Speed Reduction	Equivalent Enforcement Speed
120%	9,600	0%	140
		30%	98
		50%	70
		70%	42
100%	8,000	0%	140
		30%	98
		50%	70
		70%	42
80%	6,400	0%	140
		30%	98
		50%	70
		70%	42
60%	4,800	0%	140
		30%	98
		50%	70
		70%	42
40%	3,200	0%	140
		30%	98
		50%	70
		70%	42

Based on local experience and approved practice in the local planning agencies, the capacity for the considered freeway is assumed as 2,000 passenger car/hour/lane, and the enforcement speed as 140 km/hr. In addition to that, the percentage of aggressive drivers in the area is 40% (drivers going above the radar’s speed). The reduction in the speed is implemented by reducing the enforcement speed; however, maintaining the same aggressive drivers' percentage, which allows the aggressive drivers to drive above the enforcement speed.

Each one of the scenarios shown in Table 1 is simulated for five times using different random seed numbers. The reported results represent the trimmed average of the five runs for each scenario. The highest and lowest result runs are excluded and the average of the remaining three runs is reported.

DATA COLLECTION

The main factor that is affected by the changes of the fog intensities is the driving speed. Therefore, this paper considered collecting the speed information in the Emirate of Abu Dhabi. The authors contacted both the Department of Transport and the Traffic Police Department in Abu Dhabi to collect such data. Several count locations' data were provided. However, the authors focused mainly on freeway data; represented by freeway E12, due to the similarity in the characteristic to the considered freeway. E12 serves a considerable percentage of the traffic that is driving between the Emirates of Abu Dhabi and Dubai. The posted speed on E12 is 100 km/hr, while the enforcement speed is limited at the 120 km/hr speed.

The provided data is for 2011 for both directions of the E12 and in three different locations, in which the first one is located in the section between Yas and Sadiyaat Islands, while the second is immediately before Sadiyaat Island and the third location is before the last bridge to Mina Zayed. The traffic data was collected for three days; Saturday, Monday and Tuesday. After summarizing the data, it was noticed that the daily traffic volumes is almost balanced for both directions, as shown in Figure 1. In addition to that, 40% of the drivers were driving above the radar speed limit, and around 34% are driving between the posted and the radar speed, while around 26% are driving below the posted speed, as shown in Figure 2. This paper had considered these percentages in the model's speed calibrations.

In addition to the traffic speed data, the geometric features of the considered section of E12 were made available to the research team.

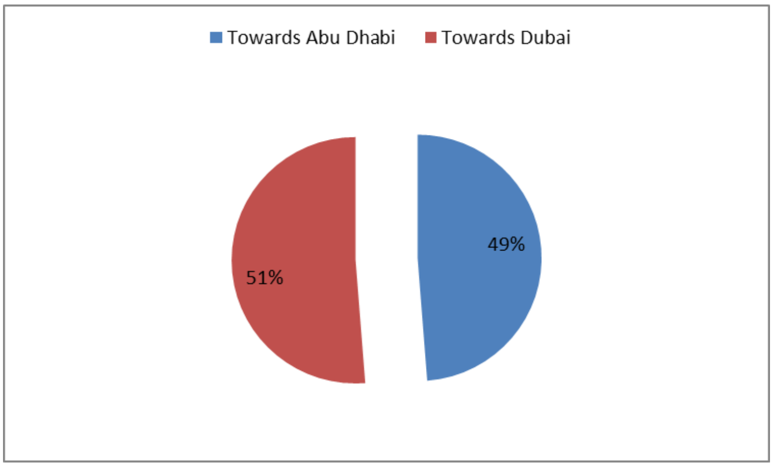

Figure 1 – Traffic Percentages on E12 Freeway

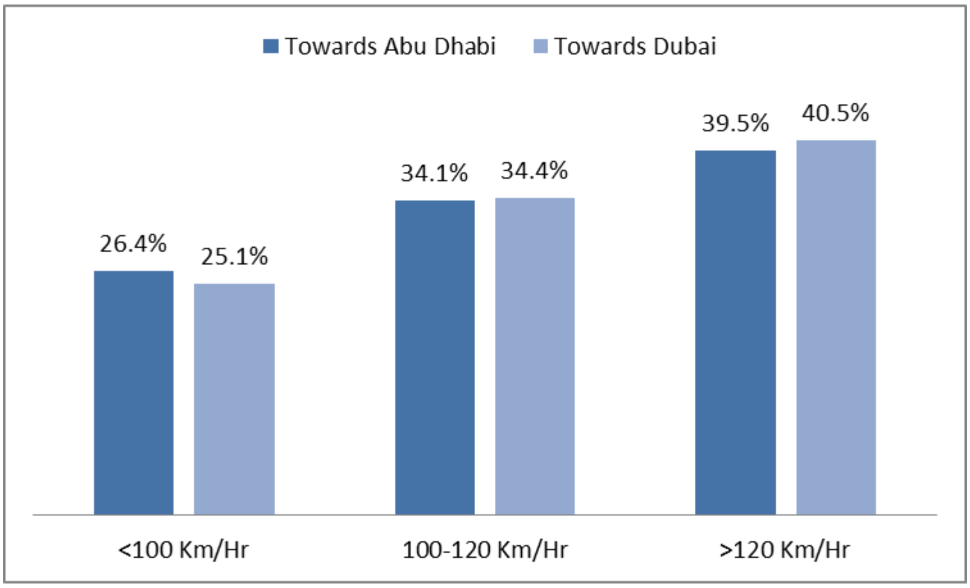

Figure 2 – Speed Distribution on E12 Freeway

MODEL BUILDING

In order to test the effect of fog, the authors had built a micro-simulation model adopting VISSIM software, as shown in Figure 3.The standard AutoCAD software is used for drafting . The word CAD is abbreviated for Computer-Aided Design. An AutoCAD drawing of the section that witnessed the year 2011 accident was loaded as a background in the VISSIM Model. This step facilitated coding the road network to scale and to world's coordinates. The authors calibrated the speed to follow the same percentages that was collected in the existing traffic surveys. In addition to that, there was no allowance for temporary lacking of attention; as it was assumed that all the drivers should be relatively more alert while driving in foggy weather and as the paper is not studying the impact of temporary lack of attention on the road safety. Furthermore, the minimum safety distance between two cars was allowed to be as small as zero. This assumption would allow the authors to count the number of times that the distance is reduced to the unsafe distance (potential accident).

The model had kept at the default values except when needed. For example, the speed distributions was obtained from a city in the Gulf region that has the same characteristic as our concerned study area. In addition to that, a 15-minutes warm-up period was used in the concerned highway section. In addition to that, the “look ahead distance” and the observed number of vehicles were changed to replicate the fog condition. It should be noted that the maximum speed based on actual data was 200 km/hr, which was applied in all the scenarios.

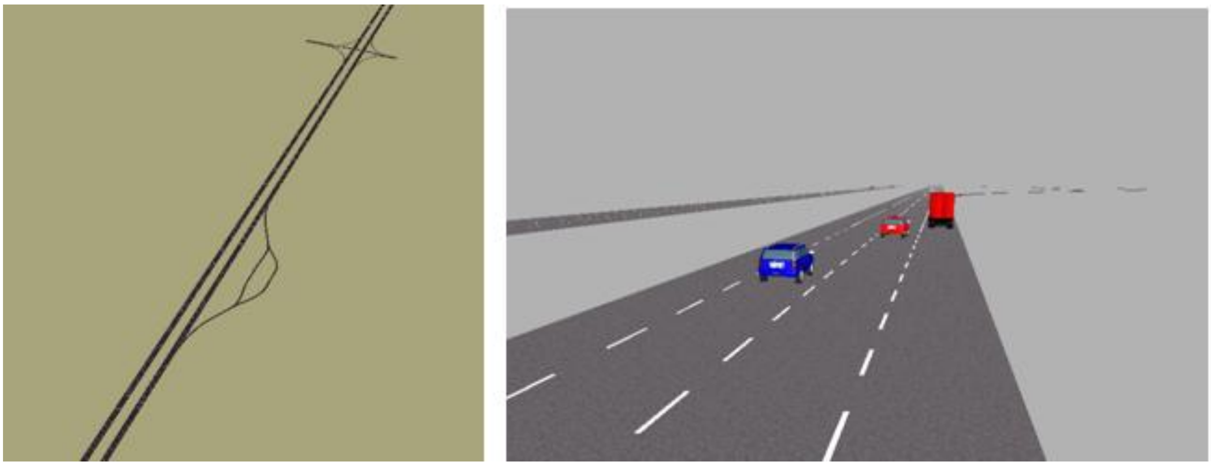

Figure 3 – Snapshots of the VISSIM Model

PERFORMANCE RESULTS

This section provides the initial results for the impact of fog on freeway performance. The following subsections provide brief discussion on different performance parameters. It should be noted that the available data from the site were not enough to validate the model; however, the only verification done is that on low traffic volumes, the speed and traffic volumes are matching the input data.

Average Speed

The first result that was studied is the average speed. It was intended to observe the impact of changing speed or V/C on the average driving speed on the road. It was noticed that the average speed was around 115 km/hr for the non-impacted scenario (no speed reduction and 40% V/C). However, this speed was reasonably reduced by the increase of the V/C. It can be noted that at the speed reduction of 70%, the average speed would have a very limited impact for any V/C higher than 80%, as illustrated in Table 2. In addition to that, it was also observed that the average speed would experience very limited changes when the V/C reaches or exceeds 100% regardless of speed reduction, in which the average speed is about two-thirds of the average speed at 40% V/C.

Table 2 – Average Speed (km/hr) for Different Simulation Results

Speed Reduction \ V/C	40% 3,200	60% 4,800	80% 6,400	100% 8,000	120% 9,600
0% (Average Speed = 140)	115	108	99	75	71
30% (Average Speed = 98)	100	90	79	62	61
50% (Average Speed = 70)	81	73	65	53	54
70% (Average Speed = 42)	60	51	40	40	40

Minimum Speed

The minimum speed that is observed in the simulated network can be reached due to traffic congestion, incident, or vehicle type. It should be noted that the minimum speed was around 54km/hr for the non-impacted scenario (no speed reduction and 40% V/C). However, this speed was considerably reduced due to the increase of the V/C and/or the speed reduction.

Table 3 – Minimum Speed (km/hr) for Different Simulation Results

Speed Reduction \ V/C	40% 3,200	60% 4,800	80% 6,400	100% 8,000	120% 9,600
0% (Average Speed = 140)	54	21	7	2	1
30% (Average Speed = 98)	32	18	7.07	3	3
50% (Average Speed = 70)	29	12	4	2	2
70% (Average Speed = 42)	15	7	2	1	1

Maximum Speed

The maximum speed that will ever happen in the network by any single vehicle was recorded. This speed is a good indication of the driver behavior on the tested freeway. It was noted that the maximum speed was around 200 km/hr for the non-impacted scenario (no speed reduction and 40% V/C). The significantly high speed is a result of the high percentage of aggressive drivers. Considering the data in Table 4, it can be concluded that the maximum speed is reasonably reduced due to the increase of the V/C and/or the speed reduction. It should be noted that the values in this table represent the highest speed achieved during the whole simulation period.

Table 4 – Maximum Speed (km/hr) for Different Simulation Results

Speed Reduction \ V/C	40% 3,200	60% 4,800	80% 6,400	100% 8,000	120% 9,600
0% (Average Speed = 140)	200	190	174	135	119
30% (Average Speed = 98)	189	156	132	107	107
50% (Average Speed = 70)	163	121	95	83	82
70% (Average Speed = 42)	109	71	59	59	58

Average Delay

In addition to the speed measure, the average delay of the vehicles within the network was examined. It was intended to observe the impact of reducing speed (due to fog) under different traffic congestion levels (V/C) on the average delay on the road. The average delay was around 10 seconds for the non-impacted scenario (no speed reduction and 40% V/C). However, the delay value was significantly increased because of the increase in the V/C and/or the speed reduction. At the highest speed reduction of 70%, the average delay would show a negligible change for V/C value that are equal to or higher than 80%, as shown in Table 5. In addition to that, it is also observed that the average delay would have very limited variation when the V/C reaches or exceeds 100% regardless of the speed reduction. It should be noted that the delay in this case represents the slowing down of the vehicles below the average speed. This explains the existence of some delay values for v/c ratios that are less than one, as the vehicles may reduce their speeds during lane change maneuvers.

Table 5 – Average Delay (seconds) for Different Simulation Results

Speed Reduction \ V/C	40% 3,200	60% 4,800	80% 6,400	100% 8,000	120% 9,600
0% (Average Speed = 140)	10	16	25	60	67
30% (Average Speed = 98)	14	23	38	75	76
50% (Average Speed = 70)	20	29	44	77	76
70% (Average Speed = 42)	40	60	110	111	111

Total Travel Time

The total travel time of the vehicles within the network was examined. It was noted that the travel time was around 3 minutes for the non-impacted scenario (no speed reduction and 40% V/C). The pattern for the total travel times exhibits a trend that is similar to that for the delay values, as depicted in Table 6.

Table 6 – Total Travel Time (seconds) for Different Simulation Results

Speed Reduction \ V/C	40% 3,200	60% 4,800	80% 6,400	100% 8,000	120% 9,600
0% (Average Speed = 140)	182	240	313	475	496
30% (Average Speed = 98)	209	287	393	547	553
50% (Average Speed = 70)	257	353	478	617	609
70% (Average Speed = 42)	350	512	731	730	731

Actual Traffic Volume

The last performance measure examined is the actual number of vehicles that entered and leaved the network within the concerned traffic hour. From the data in Table 7, it was observed that the number of vehicles was always similar within the same V/C group, except when the speed reduction reached 70% and the V/C reached or exceeded the 80% limit, in which the number of vehicles that were able to enter and leave the network started to reduce. Moreover, the maximum number of vehicles will ever be able to pass through the network in a given hour is around 7,900 vehicles/hour, which is around the 100% /VC limit that the paper is considering (8,000 vehicle/hour). The maximum reduction observed was at the 70% speed reduction and 120% VC scenario, in which the reduction was around 25%. It can also is observed that if the speed reduction was below 50%, the number of vehicles will not be impacted.

Table 7 – Actual Traffic Volume (pc/hr) for Different Simulation Results

Speed Reduction \ V/C	40% 3,200	60% 4,800	80% 6,400	100% 8,000	120% 9,600
0% (Average Speed = 140)	3,283	4,885	6,493	7,843	7,813
30% (Average Speed = 98)	3,283	4,887	6,489	7,386	7,376
50% (Average Speed = 70)	3,284	4,887	6,488	7,139	7,128
70% (Average Speed = 42)	3,286	4,887	5,890	5,831	5,843

CONCLUSIONS

The paper presented an effort to evaluate the impact of fog on freeway performance. The experimental design includes four values of speed reduction level (0%, 30%, 50%, and 70%) and five different congestion levels represented by V/C ratios of 40%, 60%, 80%, 100% and 120%. Based on the simulation results, it is recommended to limit the speed reduction to 50% or less for V/C ratios of 80% or more. At low values of V/C, the speed can be reduced to any value without significant impact on the freeway performance. It was estimated that the maximum speed on the freeway is significantly higher than the allowed speed on the freeway. Therefore, it is recommended to Abu Dhabi Police Department to increase the speed enforcement devices (speed radars) in order to reduce the percentage of aggressive drivers on Abu Dhabi freeways, especially during fog conditions.

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