Full Paper

REVIEW OF TRAFFIC DATA COLLECTION METHODS FOR DRIVERS' CAR – FOLLOWING BEHAVIOUR UNDER VARIOUS WEATHER CONDITIONS

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Graphical abstract

Abstract

Adverse weather conditions have considerable impact on traffic operation and safety as it affects drivers' car-following behaviour. However, the quality of traffic data and its related methodologies to address these effects are under continuous enhancement. This paper intends to provide an overview of various empirical traffic data collection methodologies widely used to investigate drivers car-following behaviour under various weather conditions. These methodologies include video cameras, pneumatic tubes, floating car data, instrumented vehicle and driving simulator. Moreover, the advantages and disadvantages related to methodologies have been discussed with emphasis on their suitability to work under adverse weather conditions. Furthermore, conclusion also comprises on table format of comparative review of facilities concerned with the methodologies.

Keywords: Adverse weather; car-following behaviour; traffic data

1.0 INTRODUCTION

Understanding drivers' behaviour response is considered important to assess the performance and ways concerned to transportation system enhancement. In this regard, one of on-road drivers behaviour is car-following, that's refers to the process of drivers' adjustment according to the leading vehicle on the same lane under high density conditions [1]. Car-following behaviour models which predicts the interaction of the adjacent vehicles in traffic stream plays a remarkable role in road traffic safety analysis, microscopic traffic simulation and advanced driving assistance systems [2].

Keeping in view, road safety analysis concerning the cause of accidents as well as the preventive measure has been done by various approaches. However, these approaches depends on the amount of car-following behaviour data under various conditions[3-4]. Furthermore, the realism of microscopic traffic simulation programs such as AIMSUN, MITSIM, PARAMICS and VISSIM mainly depends on the

accuracy of car-following behaviour algorithm in its core [5]. Recently, car-following is considered as one of behavioural models which constitute the functional definitions of advanced vehicle control and highway system (AVHS) and autonomous cruise control (ACC). These system plays an important role for driver safety by using mimic driver behaviour [6].

The available car-following models constitute on speed of the leading and following vehicles, leading vehicle acceleration, following vehicle reaction time and spacing /relative speed [3, 7]. However, all these parameters are highly dependent on the drivers' response towards surrounding environment specifically adverse weather conditions [8]. Adverse weather conditions such as fog, snow and rainfall have substantial effect on traffic flow operations and safety due to its effect on drivers behaviour[9]. However, these effects are characterized by spatiotemporal incidence and degradation of roadway environment via decrease in pavement surface friction, vehicles stability and maneuverability. Regardless, they impact drivers by reduced sight span and objects recognition as clear

visibility is considered a vital element for comfortable and safe driving [10].

Reduced visibility due to fog, rainfall or snow precipitation resulted in adaptive driver behaviour due to feeling of risk factor [11]. Individual drivers' response towards driving risk control under adverse weather at the microscopic traffic level has been maintained via reduced speeds, long headways and overtaking maneuvers avoidance on single carriageway roads [12]. However, adaptive drivers behaviors' during adverse weather is insufficient and still it affects roadway safety by crash frequency and severity [13, 14]. Hence, evidences relating to fatal crashes and multiple vehicles involvement are increasing day by day due to weather effects specifically [15-16].

In this regard, traffic engineers and planners are trying to maintain traffic operation and safety under adverse weather through drivers' behaviour enhancement. However, drivers' orientation via traffic management strategies plays a significant role in alleviating the adverse weather impacts on traffic flow and car-following behaviour is still under stress [15, 17]. US Federal Highway Administration (FHWA) [18-19]introduced the application of Road Weather Information Systems (RWIS) and weather/traffic data collection and forecasting technologies in order to enhance mobility and travelling safety during adverse weather. However, this can be achieved by understanding of individual drivers' behaviour during adverse weather and how their decisions collectively impact traffic flow.

In this way, these applications supports the weather-responsive traffic management strategies such as real-time modification of traffic signal and ramp meter timings, automated de-icing systems and variable speed limits[20]. According to Federal Highway Administration, effectiveness of weather related to traffic management strategies are primarily reliant on collected data, outcomes and recommendations of previous researches. Moreover, implementation of traffic management strategies and programs requires the information and data sets regarding weather impact on microscopic drivers' behaviour parameters and car-following behaviour too [3, 19].

Keeping in view, it is difficult to analyse and model individual vehicles trajectories during fine weather apart from being modelled during adverse weather conditions due to traffic heterogeneity and complexity of human behaviour on one hand and high cost of microscopic data collection process on the other hand [21]. Practically, analysing car-following behaviour response to adverse weather conditions requires precise comparison regarding changes in drivers' speeds and gap distribution among successive vehicles as the variability comes only due to various weather events, with controlling other factors may have the similar impacts on drivers behaviour [12, 22].

Researches highlight that various data collection techniques have been adopted in order to study drivers' car following behaviour during fine and adverse weather conditions. These methodologies include questionnaire, surveys, network monitoring and driving simulator experiments [8, 23]. However, it seems few researches address the suitability of aforementioned methodologies during adverse weather conditions. This paper is intended to give an overview of existing data collection technologies related to detection and analysis of drivers' car-following behaviour with special emphasis on their suitability for their application in various weather conditions. The comparison of previous researches result is not being discussed in this paper due to variation of their objectives.

2.0 LITERATURE REVIEW

The first car-following behaviour model has been introduced by Reuschel and Pipes [24] which has been extended by Herman et al. [25]. However, it has been refined continuously up to date via various approaches and under various situations in order to describe the interaction between the leading and the following vehicles on bases of reality. However, effect of reduced visibility and pavement friction caused by precipitation (rain, snow and fog) on drivers' behaviour, traffic safety and operation has been widely explored since 1950s[26-30] and it is still needed to enhance the traffic safety through drivers' behaviour improvement [18]. Federal Highway Administration's Road Management Program [31] explains the effect of adverse weather on traffic and reported that precipitation of light rain or snow resulted as 3-13% reduction in average speed, 2-13% decrease in free-flow speed, 5–10 % decrease in volume and a 4–11% decrease in capacity. Furthermore, heavy rain leads up to 3- 16% reduction in average speed, 6-17% decrease in free-flow speed, 14 % decrease in volume and 10–30% decrease in capacity. Moreover, heavy snow effects reached the percentage of 5-40% reduction in average speed, 5-64% decrease in free-flow speed, 30- 44% decrease in volume and 12–27% reduction in capacity.

In view of this, various studies have been conducted to investigate the effect of weather on car-following behaviour, in order to fulfill various objectives such as traffic safety and operation by adopting various research methodologies [22, 32-34]. In regard to roadway safety analysis, Unrau et al., [35] investigated drivers acceleration, deceleration behaviour and collision avoidance under foggy weather. Results reported that reduced visibility leads to reduced perception for unexpected events which resulted as long reaction time. According to the study conducted by Muller et al., [32] on drivers car-following behaviour among experienced and inexperienced drivers during foggy weather conditions results shows that experienced drivers control the speed successfully with sufficient reaction time for collisions avoidance.

However, other studies debate on the effect of weather on traffic operations, adaptive drivers' behaviour and car-following models performance during adverse weather. Hoogendoorn et al., [36] conducted a driving simulator study on longitudinal drivers behaviour under adverse weather. Results shows

that fog has considerable adaptation effects in longitudinal driving behaviour as the mean acceleration and deceleration values under fog are less than fine weather as the drivers being more cautious under foggy weather conditions. Moreover, performance of investigated car-following behaviour model decreases with the start of adverse weather. Zhu et al., [30] studied drivers speed during various weather conditions. Results highlighted when visibility approaches to 50 m in case of rainy and foggy weather the speed drops to 52km/h which is equalivent to 45% of speed in case of clear weather.

However, Saberi et al., [37] found the speed reduction of 3.2 km/h, 6.4 km/h, and 16 km/h caused by very light rain as 0.25 mm/h, light rain as 0.25–1 mm/h, moderate rain as 1–4.05 mm/ h respectively. Whereas Agarwal et al., [38] analysed the airport weather data and freeway speed data in USA at segment of freeway road network of the Twin Cities that is managed by the Traffic Management Centre. Results shows that, heavy rains more than 6.35 mm/hour and heavy snow more than 12.mm/hour leads to speed reductions of 4%–7% and 11%–15%, respectively.

Hoogendoorn [39] investigated car-flowing behaviour under normal and foggy weather with 150m visibility. Results highlighted that speed was reduced from 75km/h in normal weather to 63km/h in foggy weather. In contrast to previous results reported by Hawkins, [28] in which few drivers kept a high speed in light foggy weather as drivers did not slow down until the visibility dropped to 150m. However, when visibility drops to 100m, drivers reduce their speed up to 30% in normal weather condition. Steeghs et al., [40] reported that drivers tend to increase their speed in case of fog more as compared to normal weather condition. This is due to less recognition of road features with reduced visibility.

3.0 DISCUSSION ON METHODOLOGIES ADOPTED TO INVESTIGATE CAR-FOLLOWING BEHAVIOUR

Investigating car-following behaviour requires naturalistic observation of driving behaviour in order to obtain microscopic traffic data for single vehicles (vehicles speed, spacing and acceleration) at point level on a roadway segment, either short or long roadway segment [41]. In this regard, variety of traffic data collection technologies –along with their advantage and disadvantage have been adopted in order to investigate the car-following behaviour during fine and adverse weather situation[23, 39]. Car-following behaviour experiments with the available data collection techniques shows that each method can provide some useful results for model development, calibration and validation purposes.

However, still there is a need to obtain dataset regarding continuous speed, space and acceleration profiles of vehicles platoons traveling on rural highway and urban road segments under various traffic and

weather conditions by placing the self-evident trade-off between collection cost, network coverage and data accuracy. This lack of suitable data to develop, validate and calibrate car-following behaviour is confirmed by the fact that several recent results are still based on more than twenty-years old sources[42]. Kim et al., [23] investigated important limitations of previous experimental studies and models on car-following behaviour to improve the reality of previous car-following models. These limitations of earlier researches and models on car-following behaviour shows inconsistency with real driving experience as precedent models treats the car-following as memory less process. Hence, new data collection methods that could overcome the shortcomings of previous methods should consider following (1) need to observe and analyse the car-following behaviour of subjects who do not know they are part of an "experiment," (2) should be able to capture the following behaviour of a diverse population of drivers to identify and distinguish the variability in car-following behaviour across and within drivers, (3) should designed to capture various critical factors such as human characteristics, traffic, road characteristics and environmental characteristics that affects the driving behaviour of the following vehicles, (4) need to identify and investigate the driving manoeuvres (or scenarios) that unfold over an interval of time which are common in congested traffic followed by vehicles as it might respond in unique ways, (5) need to be easy to collect a sufficient quality and quantity of data.

However, in order to investigate and model car-following behaviour response towards adverse weather conditions; the general concept is to build dataset which comprises of both roadway individual traffic data and local weather information in order to seek causation between weather and traffic [43]. Anund [44] explains the relationship between validity and controllability of the independent variables pertaining to common methodologies. In this regard, validity is considered as the limit that the method measures what it claims to measure whereas controllability refers to the degree of confusing variables reduction in the experiment as shown in Figure 1.
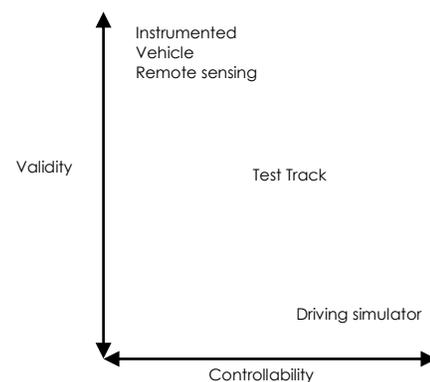

Figure 1 External validity and controllability measures of empirical longitudinal drivers' behaviour [40].

3.1 Video cameras

Traffic data can be collected via video cameras that are enables the identification, tracking and recoding of vehicles trajectories via video image processing [4]. This technology was employed since 2000's in Next Generation Simulation Program (NGSIM) as directed by Federal Highway Administration (FHWA) to develop core behavioural algorithms that supports the traffic simulation. In this regard, program focused on collection of high quality traffic data and microscopic modeling along with private sector engagement (traffic simulation vendors) to include the improved algorithms in the form of new commercial models [42]. Furthermore, NGSIM data is being available for all researchers for investigation, calibration and validation of microscopic behavioural sub-model and car-following behaviour is also included [3, 45]. However, few studies shows constraints regarding NGSIM data accuracy such as [46, 47].

Traffic video camera can be fitted at sideway of the roads, high viewpoint or a helicopter. However, in all of these fixing methods the system is sensitive to metrological conditions [48]. Keeping in view there are other limitation factors which refer to the way of camera fixing or the investigated roadway segment.

Figure 2 Camera fitted to a high place by Next Generation Simulation Program (NGSIM) data collection site [49].

3.1.1 Camera Fitted To A High Place

Video camera used to be fixed at a high place such as high buildings and bridges in order to get an overview of road traffic movement as showed in figure 2. Yeung et al., [50] conducted research to understand how the road tunnel environment affects drivers' car-following behaviour. In this regard, video footages of in Singapore acquired 15,325 car following headways for both tunnel and open expressway. However, open expressway video footage has been recorded via overhead pedestrian bridge arching during fine weather entire observation period.

Moreover, video footage for the tunnel has been requested from Land Transport Authority which monitor

the traffic through 24-h cameras with good external weather and "away" view is also preferred. Ahmed [51] used a standard video equipment for the collection of car-following data from observed section at length of 150 to 200 meters in accordance to zoom levels. In this regard, video data has been processed via image processing software, while the drivers were not aware about their participation in car-following experiments. However, Kim et al., [23] described this type of data collection as complicated and monotonous work. Moreover, the inclusion of large experimental errors because of inaccurate measured values of spacing and distance within each small frame of video, thus regeneration of calculation errors in drivers' responses such as acceleration or deceleration.

3.1.2 Camera Fitted To A Helicopter

Hoogendoorn, [41] introduced the data collection system prototype via remote sensing technology in order to gain more insight by drivers behaviour during congestion. The study aims to determine the individual vehicle trajectories from sequences of digital aerial camera. In this regard, camera fitted to helicopter covered 280 m of a Dutch motorway with high-resolution monochrome images. Moreover, personal computer attached to the camera in order to ensure real-time storage of the digital images.

However, the system comprises of software program which was able to detect and track the vehicles along with provision of longitudinal and lateral positions as a function of time. Furthermore, it determines the vehicle lengths and widths also. Due to limited stability of the helicopter only 210 m of the detected segment has been used to detect and track vehicles. Researcher highlighted that; adverse weather conditions during data collection time have a significant effect on accuracy and reliability of the collected data.

Moreover, thick clouds leads to reduce visibility to road, while winds makes difficult to keep the helicopter stable at fixed specific location. This resulted as instability of the helicopter itself and reduction in the observed road segment from 280m to 200m. Hence, for this purpose camera attached with manned or unmanned helicopter in the sky has been used to examine the traffic situations on the ground as shown in Figure 3. The collected data includes vehicle counts, vehicle speed and traffic density [49].

Figure 3 Unmanned helicopter as traffic sensor[49].

3.1.3 Camera Fitted To The Roadside

Che Puan [7] examined the distance separation between impeded vehicles on single carriageway roads during fine weather conditions. In this regard, data which defines the headway and speed for more than 8000 vehicles were collected by the use of video cameras attached to time device in order to record traffic data at four sites in Malaysia. At study location two video cameras were mounted by the roadside unobtrusively at a distance ranging from 100 m to 200 m apart to record the vehicles passage. Figure 4 illustrates video camera arrangement at the road side. Furthermore, author mentioned complexity in this method regarding seeking a suitable vantage point with good visibility in order to acquire the data. Research highlighted that complexity as a problem which is affecting the type of data. Moreover, the exact location of cameras at each site was influenced by logistics such as vegetation, visibility etc.
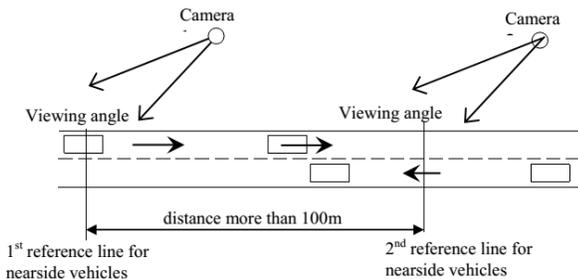

Figure 4 Arrangement of cameras for video recording process at roadside position [7].

Regardless of this, Yet [52] has explained the use of video image Processor (VIP) of rainfall impact on surface traffic and drivers' deceleration behaviour on Malaysian freeway. This research addresses the effect of rain in the flow-density relationship and deceleration behaviour. Moreover, the same data has been utilized for car-following model calibration. This study has significant importance towards WRTM as it used video-image processor to collect data on drivers' deceleration behaviour under rainy conditions [18].

In general, video camera records provides considerable amount of vehicles trajectories and traffic based on time series of platoons' movement thus, enables to investigate car-following behaviour along a selected road section. Furthermore, advantages of this method are : data can be collected from large numbers of vehicles and has no influence on drivers; therefore the collected data can be considered unbiased [51]. In this regard, it is noteworthy that limited studies have been conducted utilizing this technology in order to investigate the effect of adverse weather on car-following behaviour, may be due to the effect of the adverse weather on the camera itself. The limitations of the methods mentioned above can be summarised as follows:

i. Observation covers limited road segment due to the limited view of the camera and the accuracy requirements, thus drivers can observe only for few seconds. Moreover, driving manoeuvres which have been unfold over a greater distances can be captured by the camera which has not been presented properly[4].

ii. It is difficult to find suitable high vantage points with good visibility to be fitted with the camera in order to observe the required segment[7].

iii. Difficulty of data analysis for each recorded vehicle (calculation of vehicle position, speed and acceleration) unless the automated image processing methods can be used [23].

iv. It does not allow the controllability and observation regarding drivers' personal characteristics like age, gender and driving experience etc[41].

v. Vulnerability to visual obstruction e.g. adverse weather, shadows, poor-lighting conditions and strong winds during data collection leads to affect the accuracy and reliability of the collected data [48].

3.2 Inductive-Loop Detectors

Inductive-Loop Detectors (in a double loop formation) are on-road traffic sensors considered as tools to obtain the individual vehicle traffic data at a point of roadway segment. It consists of one or more turns of insulated wire embedded in the surface of the road pavement, through which an electric current is passed creating an electromagnetic field as shown in Figure 5. Vehicle movements are recorded by measuring the change in inductance induced by a motor vehicle passing through the electromagnetic field [53]. This technology has been adopted by the Motorway Incident Detection and Automatic Signaling (MIDAS) project in order to build a network of traffic sensors installed on several (highly congested) UK motorways [4].
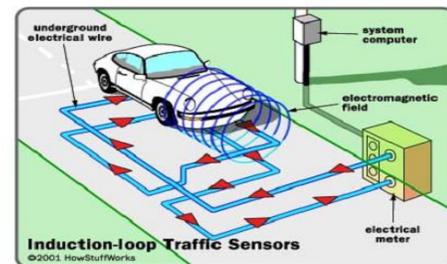

Figure 5 An inductive-loop detection system [49].

Noteworthy, aforementioned methodology has been adopted by Billiot et al., [49, 50] to investigate the impact of rainy weather on drivers' behaviour and traffic operation. Furthermore, in an effort to enhance roadway safety and speed-flow-occupancy relationship during suboptimal weather, this method has been used to model the effect of light rainfall on urban freeway operations [33]. Moreover, double-loop

deductors has been used to quantify the impact of adverse weather (rain and snow) on freeway traffic flow[38]. However, even though the methodology provides timed roadway individual vehicle traffic data, it seems not popular in car-following behaviour studies during fine and adverse weather both. This may be due to few or all of the following disadvantages summarised from previous studies.

i.   Traffic observation can be maintained only on limited coverage at the instrumented site [4].
ii. It does not allow controllability or even the observation regarding drivers' personal characteristics like age, gender, driving experience etc [4].
iii. Interruption of traffic to install the loop under pavement along with installation and maintenance cost [54].
iv. The inductive sensor can be affected by bad weather conditions. However, they may have complexity in differentiation of closely spaced vehicles [48].

3.3 Pneumatic Tubes

Pneumatic tubes are hollow rubber tubes which lay across the road lanes in order to detect the vehicles from pressure changes that are produced when a vehicle tyre passes over the tube as shown in Figure 6. However, one end of the tube is attached to a traffic counter/classifier. As vehicle tyres passes over the tube, it compressed the tube triggering and the air pressure inducer on the counter. The system is able to provide classification of vehicles (number of axles), instantaneous speed, flow direction and volume via computer software program[55].

Figure 6 Road tubes on two-lane highway[55].

Moreover, this methodology is suitable for short-term studies of traffic operation and drivers' behaviour due to its reasonable cost, portable, easy installation and possibility to reuse the system at many locations [56].Furthermore, in order to investigate car-following behaviour during fine and adverse weather conditions, this methodology has been used [22].In this regard, speed data is obtained directly by the traffic counter software. Moreover, software also record the vehicles time gap in a second while following the distance, as it has been calculated by multiplication of time gap by

following the vehicle speed. Furthermore, the methodology has been applied in Johor Bahru Malaysia for two months, in order to analyse the effect of wet weather in headway behaviour. Results revealed the headways reduction between no-rain and rainy conditions as more reduction has been observed towards increase of rainfall intensity [57]. The main limitations of this technology are as follows:

i. This methodology has limited lane coverage for limited time. Moreover, system may be intrusive to traffic and nearby properties [48, 56].
ii. The system can be damaged in high traffic volumes or maintenance on roadways causing inaccurate data collection [48, 56].

3.4 Floating Car Data

Traffic data collection can be maintained via Floating Car Data (FCD), particularly Global Positioning System (GPS) and Cellular-based systems. It is satellite-based navigation system and it records timely vehicles trajectories. Moreover, it ensures the provision of vehicle dynamic driving behaviour. Furthermore, FCD works on the collection of real-time traffic data by locating the vehicle via mobile phones or GPS over the network as illustrated in Figure 7 and 8.
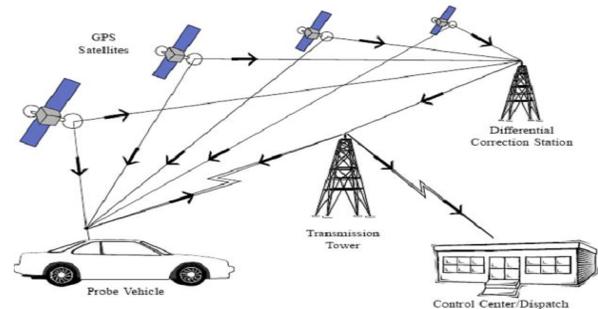
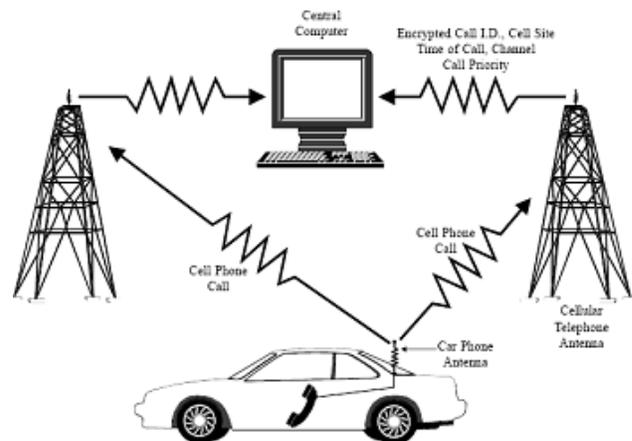

Figure 7 Communication from GPS[48]

Figure 8 Communications from cellular phones[48]

This means that every vehicle that is equipped with mobile phone or GPS can act as road network traffic sensor and provide the real time traffic data such as car location, travel speed direction and road operating conditions [58, 59].In this regard, this technology has been widely used for traffic data collection in order to prove and model the microscopic free flow speed changes due to change in weather. Moreover, in order to investigate hazardous road surfaces with dynamic variations within the short roadway segment. In this context, GPS now becomes an affordable technology to study car-following behaviour under all weather and lighting conditions in order to provide real time traffic data over a large network [20]. In this view, Hidas et al., [42] conducted an experiment by using a differential GPS (DGPS) fitted with two passenger cars on urban roads in Sydney city following each other in order to study car-following behaviour and characteristics of vehicle progression.

However, this technology is able to provide traffic data for the same individual drivers under various weather conditions over long roadway and given a chance for more detailed analysis of individual driver behaviour. Research highlights the data analysis process in this methodology as faster than in video recording methodology as the vehicle positions, speed and acceleration can be calculated automatically from the GPS data. The advantages of this technology refers towards the large coverage of the detected areas at lower cost as there is no need of infrastructure investment as compared to conventional methodologies. Moreover, it is reliable to work under various weather situations depending on communication/network used in covered area [48]. The main limitations of this technology are as follows:

i. GPS receivers only provide vehicle-specific data whereas the traffic information has to be obtained from all vehicles in the traffic stream [42].
ii. GPS signals can be obstructed by obstacles such as tall buildings and trees[42].
iii. Signals may lost due to poor road-network coverage in congested zones, highways, tunnels and bridges [48].

3.5 Instrumented Vehicle

Instrumented vehicle is equipped in order to obtain complete data coverage regarding drivers' behaviour, vehicle kinematics, and vehicle surroundings. For this aim, the system may be equipped with number of detectors including infrared radar sensor in order to detect the distance headway and relative speed. Beside that it is composed of global positioning system (GPS) to get vehicle location, and set of cameras which are required to monitor the driving behaviour of the adjacent vehicle along with information such as approximate age, gender. Furthermore it consist of internal vehicle kinematics sensors in order to measure wheel speeds and acceleration [60] as shown in Figure 9.
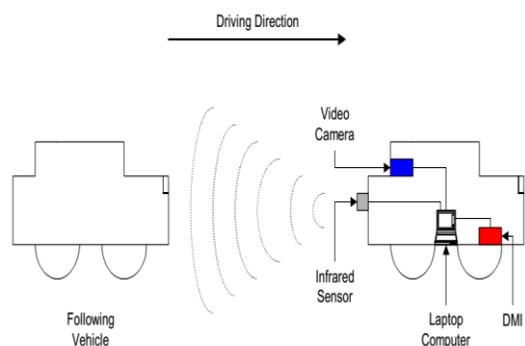

Figure 9 Example of car-following data collection apparatus [23]

This technology enables longer observations under flexible experimental conditions, thus several research projects based on IVs aimed towards analysing and modeling of driving behaviour. The ability to collect and record the traffic data by IV in accordance to vehicles ahead or behind is prerequisite for studies and observation regarding car-following condition [61]. Noteworthy, observations can be done both in active and passive mode in accordance to location as a follower or a leader. Active mode refers to the situation that IV is the follower and obtained data relative to the leading vehicle, while in passive mode IV is the leader and obtained data relative to the following vehicle [62]. Moreover, drivers car-following behaviour studies with objectives related to driving style dispersion in accordance to various driver characteristics have been based on IV data [63].

Kim et al., [23] stated that most of studies conducted based on this methodology focused mainly on issues related to performance like auto cruise control (ACC), human factors and safety concerns. However, in UK a study on three-lane motorway has been conducted on car-following using Instrumented vehicle to provide on road observation regarding driving behaviour under various experimental conditions [42]. However, this method has various complexities and limitations as shown below:

i. Instrumented vehicle provides useful datasets regards to car-following behaviour. However, the influence of the instrumented vehicle is considered as a limiting factor [42].
ii. Synchronization of the large amount of data recorded via different sensors is not easy. It needs data acquisition system design that utilise the separate system for each sensor[64].
iii. Moreover, the radar sensors record any object that produces a radar echo, confusing between roadside objects and following/leading vehicles [42].
iv. Detected trajectories of following vehicles are less than to provide adequate data on the consistency of car following behaviour (As in the case of video recording from fixed vantage points [42].

v.   The performance of camera and infra-red sensor may be affected during bad weather [48].

3.6 Driving Simulator

Driving simulation has been introduced since 1960s. Yen et al., [65] describes the driving simulators as mock-ups of automobile with surrounding screens and simulated driving environments are displayed on it while drivers' vehicle control is maintained via actuators as making them able to drive through the virtual environment.

Although driving simulator is becoming popular as research tool in driving behaviour arena, it constitutes great importance to be confident that the results are relevant to real road traffic behaviour. In this way, the choice to adopt driving simulator as research methodology should be based on whether the simulator is sufficiently valid for the specific test or behaviour that is under investigation [66].

Regardless of this, it plays an important role in traffic engineering as a research tool to investigate the car-following behaviour for traffic safety analysis as well as to validate the models performance or to calibrate models parameters under specific risky conditions. Muller et al., [32] explain that driving simulator experiments plays a remarkable role in traffic safety and accident analysis studies. A study was conducted on drivers' car-following behaviour between experience/inexperience drivers during foggy weather conditions in order to investigate the adjustments of drivers regarding safety with reduced visibility. Results indicate that experience drivers controlled the speed successfully with sufficient reaction time in order to avoid the collision.

Moreover, driving simulator study with repeated measures design has been conducted to assess the effect of fog on drivers' adjustments as well as to assess Helly model and Intelligent Driver Model performance under foggy weather conditions. In this regard, a result shows reduced speed and acceleration while distance headway has increased and the performance of the assessed models decreases with the start of adverse weather. While keeping in view these results, researcher highlighted the need to develop new car-following models that incorporates weather related adaption effects and longitudinal driving behaviour under adverse weather conditions [39].

Driving simulators technology has various advantages in order to investigate car-following behaviour under adverse weather conditions. It is an easy methodology in order to collect traffic data with high controllability along with reproducibility of virtual traffic, road layout, weather conditions and participants to be manipulated as a function of research objectives. Moreover, it is capable enough to provide the possibilities to encounter dangerous driving conditions without physical risk along with provision of feedback and instructions such as to freeze, reset, or replay a scenario[44, 67].

However, the main drawback is that driving simulators provides only a depiction of reality and not reality itself and the high degree of controllability is linked with reduced validity. However, a validation study in accordance to empirical car-following behaviour under adverse conditions by using the advanced driving simulator has not been performed yet [28].

4.0 CONCLUSION

Variety of traffic data collection methodologies have been adopted to investigate, analyse and model drivers' car-following behaviour during various weather conditions. In this regard, this paper highlights traffic data collection methodologies like video cameras, pneumatic tubes, floating car data, instrumented vehicle and driving simulator. However, double-loop detectors are widely used in traffic data collection. Even though this methodology provide timed roadway individual vehicle traffic data. The interesting fact is that a double loop traffic detector seems uncommon in car following behavior literature, during fine or adverse weather both.

Few researches address the suitability of traffic data collection methodologies to investigate driver's car-following behavior under adverse weather conditions. Moreover, the effect of adverse weather on traffic data collection methodologies always considered as one package such as rain, snow, fog and wind. It has been rarely divided in to adverse weather related elements like humidity, poor visibility and drainage system.

Noteworthy, traffic engineering researchers have to investigate car-following behaviour via alternative facilities concerned with traffic data collection methodologies. However, researchers should focus on validity/controllability degree, capability of coverage area, suitability to work under the required weather and reasonable cost of installation. While keeping in view the above mentioned facilities concerned with the methodologies, methodology selection should match the objective of car-following behaviour studies. Hence, comparative review of available data collection facilities concerned with methodologies has been illustrated in Table 1.

Table 1 Comparative review of traffic data collection facilities concerned with methodologies used for car-following behaviour
Note: Yes = ✓ and No = ✗.

Traffic detector	Network coverage			Drivers observation and bias				Effect of weather			
	point measurement	limited roadway stretch	increasing network coverage	Observation of many drivers simultaneously	Observation of drivers characteristics	Control over drivers characteristics	Drivers bias (awareness of being monitored)	Wind	poor-visibility	Humidity and precipitation	Drainage system
Traffic video camera	✓	✓	✗	✓	✗	✗	✗	✓	✓	✓	–
Inductive-Loop	✓	✓	✗	✗	✗	✗	✗	–	–	✓	–
Pneumatic Tubes	✓	✓	✗	✗	✗	✗	✗	–	–	–	–
Floating Car Data	✓	✓	✓	✗	✗	✓	✓	✗	✗	✗	✗
Instrumented vehicle (active mode)	✓	✓	✓	✗	✓	✓	✓	✗	✗	✓	–
Instrumented vehicle (passive mode)	✓	✓	✗	✗	✓	✓	✗	✗	✗	✓	–
Driving Simulator	✓	✓	✓	✗	✓	✓	✓	–	–	–	–

Acknowledgement

References

[1] Brackstone, M., Sultan, B. and McDonald, M. 2002. Motorway Driver Behaviour: Studies On Car Following. *Transportation Research Part F: Traffic Psychology and Behaviour*. 5(1):31-46.

[2] Brackstone, M. and McDonald, M. 1999. Car-following: a historical review. *Transportation Research Part F: Traffic Psychology and Behaviour*. 2(4):181-196.

[3] Bevrani, K. and Chung, E. 2011. Car Following Model Improvement For Traffic Safety Metrics Reproduction. Australasian Transport Research Forum 2011 Proceedings 28 - 30 September 2011, Adelaide, Australia Publication website: http://www.patrec.org/atrf.aspx

[4] Bifulco G.N., Galante, F., Pariota L., Russo Spena M., Del Gais, P. 2014. Data Collection for Traffic and Drivers' Behaviour Studies: a large-scale survey. *Procedia-Social and Behavioral Sciences.* 111:721-730.

[5] Panwai, S. and Dia, H. 2005. Comparative Evaluation Of Microscopic Car-Following Behavior. *Intelligent Transportation Systems, IEEE Transactions.* 6(3): 314-325.

[6] Chang, K. and Chon, K. 2005. A Car-Following Model Applied Reaction Times Distribution And Perceptual Threshold. *Journal of the Eastern Asia Society for Transportation Studies.* 6:1888-1903.

[7] Che Puan, O. 2004. Driver's Car Following Headway On Single Carriageway Roads. *Jurnal Kejuruteraan Awam*. 16(2): 15-27.

[8] Soria, I., Elefteriadou, L. and Kondyli, A. 2014. Assessment Of Car-Following Models By Driver Type And Under Different Traffic, Weather Conditions Using Data From An Instrumented Vehicle. *Simulation Modelling Practice and Theory*. 40:208-220.

[9] El Faouzi, Romain Billot, Pertti Nurmi, Bernhard Nowotny. 2010. Effects Of Adverse Weather On Traffic And Safety: State-Of-The-Art And A European Initiative. *In 15th International Road Weather Conference*.

[10] Cai, X.N., Jian John Lu, Yingying Xing, Chenming Jiang and Weijie LuAnalyzing. 2013. Analysing Driving Risks of Roadway Traffic under Adverse Weather Conditions: In Case of Rain Day. *Intelligent and Integrated Sustainable Multimodal Transportation Systems Proceedings from the 13th Cota International Conference of Transportation Professionals (Cictp2013)*. 96: 2563-2571.

[11] Chakrabarty, N. and Gupta, K. 2013. Analysis Of Driver Behaviour And Crash Characteristics During Adverse Weather Conditions. *2nd Conference of Transportation Research Group of India (2nd Ctrg)*. 104:1048-1057.

[12] Allain, Fabrice Gamboa, Philippe Goudal and Jean-Noel Kien. 2012. Modeling Weather Conditions Consequences on Road Trafficking Behaviors. *arXiv preprint arXiv:1210.2294*.

[13] Jung, S., Qin, X. and Noyce, D.A. 2011. Modeling Highway Safety and Simulation in Rainy Weather. *Transportation Research Record. 2237(2237):*134-143.

[14] Jung, S.Y., Qin, X. and Noyce, D.A. 2010. Rainfall Effect On Single-Vehicle Crash Severities Using Polychotomous Response Models. *Accident Analysis and Prevention*. 42(1):213-224.

[15] Hassan, H.M. and Abdel-Aty, M.A. 2011. Analysis of Drivers' Behavior under Reduced Visibility Conditions Using a Structural Equation Modeling Approach. *Transportation Research Part f: Traffic Psychology and Behaviour*. 14(6):614-625.

[16] Zhibin Li, Pan Liu, Ye Li, Changchang Xu, Hao Yu and Yuanyuan Zhang. 2014. Development of a Variable Speed Limit Strategy to Reduce Secondary Collision Risks During Inclement Weathers. *Accid Anal Prev*. 72: 134-45.

[17] Perrin, H.J., Martin, P.T. and Hansen, B.G. 2001. Modifying Signal Timing During Inclement Weather. *Advanced Traffic Management Systems and Vehicle-Highway Automation*. 1748(1748): 66-71.

[18] Krechmer, D., Hesham Rakha, Mark Howard, Weimin Huang and Ismail Zohdy. 2010. *Data Mining and Gap Analysis for Weather Responsive Traffic Management Studies.*

[19] Goodwin, L.C. and Pisano, P. 2003. *Best practices for road weather management.*

[20] Rakha, Daniel Krechmer, Gustave Cordahi, Ismail Zohdy, Shereef Sadek, and Mazen Arafeh. 2010. *Microscopic Analysis of Traffic Flow in Inclement Weather-Part 2.*

[21] Rakha, Mohamadreza Farzaneh, Mazen Arafeh, Robert Hranac, Emily Sterzin, and Daniel Krechmer. 2007. *Empirical studies on traffic flow in inclement weather.*

[22] Rahman, A. and Lownes, N.E. 2012. Analysis Of Rainfall Impacts On Platooned Vehicle Spacing And Speed. *Transportation Research Part F-Traffic Psychology and Behaviour*. 15(4): 395-403.

[23] Kim, T., Lovell, D.J. And Park, Y. 2003. Limitations Of Previous Models On Car-Following Behavior And Research Needs. *in 82nd Annual Meeting of the Transportation Research Board, Washington, DC.*

[24] Reuschel, A. 1950. Vehicle Movements In A Platoon With Uniform Acceleration Or Deceleration Of The Lead Vehicle. *Zeitschrift des Oesterreichischen Ingenieur-und Architekten-Vereines*. 95: 50-62.

[25] Herman, R. 1959. Traffic Dynamics: Analysis Of Stability In Car Following. *Operations research*. 7(1): 86-106.

[26] Tanner, J. 1952. *Effect Of Weather On Traffic Flow.*

[27] Sumner, R., Baguley, C. and Burton, J.1977. Driving in fog on the M4.

[28] Hawkins, R.K. 1988. Motorway traffic behaviour in reduced visibility conditions. *II. Second International Conference on Vision in Vehicles.*

[29] Snowden, R.J., Stimpson, N. And Ruddle, R.A.1998. Speed Perception Fogs Up As Visibility Drops. *Nature, 1998*: 392: 450.

[30] Zhu, Z., Rong, J. and Zhou, W. 2010. Driver Behaves in Bad Weathers. *Journal of Wuhan University of Technology(Transportation Science & Engineering)*. 34(5).

[31] Program, F.R.W.M., How Do Weather Events Impact Roads, 2009:http://www.ops.fhwa.dot.gov/Weather/q1_roadimpact.htm Lastmodified 11.04.2015. Last accessed 8.05.15.

[32] Mueller, A.S. and Trick, L. M. 2012. Driving In Fog: The Effects Of Driving Experience And Visibility On Speed Compensation And Hazard Avoidance. *Accid Anal Prev*. 48: 472-9.

[33] Unrau, D. and Andrey, J. 2006. Driver Response To Rainfall On Urban Expressways. *Driver Behavior, Older Drivers, Simulation, User Information Systems, and Visualization*. 1980(1980): 24-30.

[34] Broughton, K. L., Switzer, F. and Scott, D. 2007. Car Following Decisions Under Three Visibility Conditions And Two Speeds Tested With A Driving Simulator. *Accident Analysis & Prevention*. 39(1): 106-116.

[35] Hogema, J. and Van der Horst, R. 1994. Driving Behaviour Under Adverse Visibility Conditions. In Towards An Intelligent Transport System. Proceedings of The First World Congress On Applications Of Transport Telematics And Intelligent Vehicle-Highway System, November 30-3RD December 1994, Paris. 4. 1994.

[36] Hoogendoorn, G. Tamminga, S.P. Hoogendoorn and Daamen, W. 2010. Longitudinal driving behavior under adverse weather conditions: Adaptation Effects, Model Performance and Freeway Capacity In Case Of Fog. *in Intelligent Transportation Systems (ITSC) 13th International IEEE Conference on.*

[37] Saberi, M. and Bertini, R.L. 2010. Empirical Analysis of The Effects Of Rain On Measured Freeway Traffic Parameters. *in Transportation Research Board 89th Annual Meeting.*

[38] Agarwal, M., Maze, T.H. and Souleyrette, R. 2005. Impacts Of Weather On Urban Freeway Traffic Flow Characteristics And Facility Capacity. *in Proceedings Of The 2005 Mid-Continent Transportation Research Symposium.*

[39] Hoogendoorn, R.G. 2012. Empirical Research and Modeling of Longitudinal Driving Behavior Under Adverse Conditions. *2012: TU Delft, Delft University of Technology.*

[40] Snowden, Robert J, Stimpson, Nicola Ruddle and Roy A.1998. Speed Perception Fogs Up As Visibility Drops. *Nature, 1998*. 392:2.

[41] Hoogendoorn, S. P., Van Zuylen, H. J., Schreuder, M., Gorte, B. and Vosselman, G. 2003. Microscopic Traffic Data Collection by Remote Sensing. *Transportation Research Record: Journal of the Transportation Research Board*. 1855(1): 121-128.

[42] Hidas, P. and Wagner, P. 2004. Review of Data Collection Methods for Microscopic Traffic Simulation. *World Conference on Transport Research Istanbul,* Turkey.

[43] Portaankorva, P. 2002. Road Weather and Traffic Data in Traffic Management. *Finnish Road Administration, SIRWEC*.

[44] Anund, A. and Kircher, K. Advantages And Disadvantages Of Different Methods To Evaluate Sleepiness Warning Systems. *VTI*.

[45] Zhang, X. and Bham, G. H. 2007. Estimation of Driver Reaction Time from Detailed Vehicle Trajectory Data. *MOAS*. 7:574-579.

[46] Hamdar, S. H. and Mahmassani, H. S. 2008. Driver Car-Following Behavior: From Discrete Event Process to Continuous Set of Episodes. *in Transportation Research Board 87th Annual Meeting.*

[47] Punzo, V., Borzacchiello, M.T. and Ciuffo, B. 2011. On the Assessment of Vehicle Trajectory Data Accuracy and Application to the Next Generation SIMulation (NGSIM) program data. *Transportation Research Part C: Emerging Technologies*. 19(6):1243-1262.

[48] Leduc, G. 2008. Road Traffic Data: Collection Methods and Applications. *Working Papers on Energy, Transport and Climate Change*. 1:55.

[49] Klein, L. A., Mills, M. K. and Gibson, D. R. 2006. *Traffic Detector Handbook*. Volume II.

[50] Yeung, J.S. and Y.D. Wong. 2014. The Effect Of Road Tunnel Environment On Car Following Behaviour. *Accident Analysis & Prevention*. 70: 100-109.

[51] Ahmed, K.I. 1999. Modeling Drivers' Acceleration and Lane Changing Behavior. *Massachusetts Institute of Technology*.

[52] Yet, T. H. 2005. Impact of Rain to Highway Traffic and Drivers' Deceleration Behavior. Master of Science Thesis, Transportation and Logistics Department, Malaysia University of Science and Technology, Malaysia University of Science and Technology.

[53] Wilson, R.E. 2008. Mechanisms for Spatio-Temporal Pattern Formation in Highway Traffic Models. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*. 366(1872): 2017-2032.

[54] Klein, L.A. 2001. *Sensor Technologies and Data Requirements for ITS*.

[55] McGowen, P. and Sanderson, M. 2011. Accuracy of pneumatic road tube counters. i*n Proceedings of the 2011 Western District Annual Meeting, Anchorage, AK, USA*.

[56] B.A. 2014. New Traffic Data Sources – An Overview. *Paper Prepared In Support Of Proposed Bitre/Ipa Joint Workshop: 'Exploring New Sources of Traffic Data*, Sydney.

[57] Ben-Edigbe, J., Mashros, N. and Rahman, R. 2013. Extent of Sight Distance Reductions Caused by Rainfall on Single Carriageway Roads. *International Journal for Traffic and Transport Engineering*. 3(3): 291-301

[58] de Boer, G. and Krootjes, P. 2012. The Quality of Floating Car Data Benchmarked: An Alternative to Roadside Equipment? *in 19th ITS World Congress*.

[59] Huber, W., Lädke, M. and Ogger, R. 1999. Extended floating-car data for the acquisition of traffic information. *in Proceedings of the 6th World congress on intelligent transport systems*.

[60] Wang, Chenfeng Xiong, Meng Lu, Keqiang Li. 2014. Longitudinal Driving Behaviour on Different Roadway Categories: An Instrumented-Vehicle Experiment, Data Collection and Case Study in China. *IET Intelligent Transport Systems*.

[61] Yan, X., Abdel-Aty, Mohamed Radwan, Essam,Wang, Xuesong Chilakapati, Praveen. 2008. Validating a driving

simulator using surrogate safety measures. *Accident Analysis & Prevention*. 40(1): 274-288.

[62] Brackstone, M., Waterson, B. and McDonald, M. 2009. Determinants of Following Headway In Congested Traffic. *Transportation Research Part F-Traffic Psychology and Behaviour*. 12(2): 131-142.

[63] Ranjitkar, P., Nakatsuji, T. and Kawamua, A. 2005. Car-following models: an experiment based benchmarking. *Journal of the Eastern Asia Society for Transportation Studies*. 6:1582-1596.

[64] Azli, A., Azad, A. and Abdullah, S. 2010. Challenges and progress: Transforming an Ordinary Vehicle Into An Extraordinary Research Instrument. *in MIROS Road Safety Conference, Kuala Lumpur*.

[65] Yan, X., Yang Liu and Jia Zhao. 2014. Effects of Foggy Conditions On Drivers' Speed Control Behaviors At Different Risk Levels. *Safety Science*. 68: 275-287.

[66] Rudin-Brown, C., Williamson, A. and Lenné, M. 2009. Can Driving Simulation Be Used To Predict Changes in Real-World Crash Risk. *Rapport Technique, Monash University, Accident Research Centre*.

[67] Vlakveld, W. P. 2005. The Use Of Simulators In Basic Driver Training. *in Humanist TFG Workshop on the Application of New Technologies to Driver Training, Brno, Czech Republic. Available at: www. escope. info/download/research_and_development/HUMANISTA_1 3Use. pdf*.