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Car following behaviours on multilane highways in Kuwait: a case study on 6th ring road

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Car following behaviours on multilane highways in Kuwait: a case study on 6th ring road

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Abstract. Reckless driving causes around 35% of all the road accidents in Kuwait. This study aims to evaluate the relationship between speed and headway of traffic for highways in Kuwait. The data were collected at 6th ring road in Kuwait for a week. The data were classified and analysed to estimate the behaviour of small, medium and large cars in addition to trucks. The analysis shows that the 33.68% of the cars are flowing in a speed between 70 and 80 km/hr. The effect of classified car (small, medium, large and truck) to the car-following pattern were determined based on the average headway of the cars. It was found that the Small – Small following pattern has the minimum average headway in all lanes with headway of 1.62 s. Also, the maximum average headway is for Medium – Medium car following pattern with headway of 8.01 s. It was found that there is no relationship between the type of following pattern and the headway in which it supports the previous studies conclusion that only the driver behaviour, weather conditions and road quality affect the headway. Finally, a linear regression for data was plotted to estimate relationship of the average headway as a function of speed for 16 different following patterns. It was found that the accuracy of linear regression for small and medium cars is larger than the accuracy for large cars and trucks.

1. Introduction

Road accident is considered to be the 9th leading factor for killing people around the world [1]. According to studies, road accidents result in death of 1.2 million people per year globally. Approximately 20-50 million people are either injured or are disabled every year due to these road accidents. The situation in Kuwait is worst among all Gulf countries with astoundingly high number of road accidents occurring every year [2]. The traffic fatalities per 100,000 cars for Kuwait are 28.8, the highest among selected countries in the Middle East that were recorded in Hajeeh's study [2].

Driver behaviour is identified to be a key factor behind these accidents. Risk can be controlled by drivers at many levels, but it can be useful if hierarchal organization is considered to be characteristic of driver behaviour [3]. Operations in traffic flow are substantially impacted due to poor weather conditions that are usually characterized by fog, black ice and snow, and heavy rain. Freeway capacities for instance are shown to have decreased by 14 -19%, visibility impairment are shown to have been caused due to fog by 10 – 12%, and similar findings from important but limited research sources [4].

Addressing the uncertainty of driver characteristics is a big challenge while modelling and analysing car-following behaviour. Analysis that considers multi-lane driving has varied findings of driver behaviour than that of single-lane analysis [5]. Multi-lane analysis is thereby important to better explore driver behaviour under real driving conditions, while accounting for the weather conditions. When weather conditions are adverse, driver behaviour is significantly impacted in terms of traffic operation and safety. Car-following is one of the notable driver behaviours on road, which is normally adjusted within the same lane based on traffic density. Driver behaviour needs to be measurable while focusing on their cognitive discourse, and is done by modelling driver behaviour using various methodologies, car-following models in particular [5,6]. In car-following models, measurable parameters include leading car speed, following car speed, leading car acceleration, following car acceleration, following car reaction time, and relative speed or spacing.

In Kuwait, there are various reasons behind the road accidents, such as, driver's behaviour, road conditions, driving speed, and climate conditions. The available data has shown that reckless driving is the prime factor that causes road accidents. It causes around 35% of all the road accidents. The next major factor that contributes to higher number of accidents is speeding, causing 13% of all the road accidents. Tailgating is the third most common factor that causes approximately 6.4% of road accidents [2]. In year 2013, the total numbers of traffic violations were found to be around 3.4 million which increased in 2014 to 6.5 million [7]. This increasing number of traffic violations poses a serious threat. Climate conditions such as dust storms, results in low visibility on roads and hence contribute to occurrence of road accidents [5].

Traffic congestion and road safety therefore have turned to attain increased importance among issues in Kuwait. Young drivers – primarily male – are the demographic largely responsible for road crashes that are recorded with high rate. This has been observed repeatedly through several studies involving patterns of accidents and driving habits in Kuwait. Driving behaviour has to be related to or influenced by other factors such as traffic law enforcement, education, life style, and external factors pertaining to the environment, road infrastructure, traffic flow, car characteristics, and weather conditions. This study focusses on traffic flow speed and drivers' car-following behaviour.

Solutions for this problem at the outset include developing suitable data collection techniques for studying car following behaviours of drivers across different demographics during adverse as well as fine weather conditions.

2. Literature review
Various models have been proposed and developed for studying car-following behaviour, some using computer simulations for the purpose. One such model by Markkula [8] predicted a general time-headway value to be beyond 2 seconds with determining factors being speed, visibility, and braking capacity [8]. Driving manuals in many countries usually prescribe a safe 3 second time-headway, although many researchers found most drivers maintaining only 1 – 2 second distance or even below [8]. The time-headway of 1-2 second range as posited by researches in different countries seems appropriate for the host demographic and region. This may vary for drivers in the Arabian Gulf countries, Kuwait in particular, as they have their own set of socio-economic, cultural, geographical, and other factors governing their driving behaviour.

2.1. Accidents causes and effects in Kuwait
Based on Al-Matawah [7], the driver's behaviour has high influence on the perception, distractions, situation of all-round traffic (or traffic flow), distance misjudgement, inappropriate overtaking or turning, passing red traffic lights, failing to give way, and following too closely [7]. The last factor is also popularly known as tailgating, which pertains to car-following behaviour of drivers – a concept that is central to the Al-Matawah's study. Apart from user errors, car defects and deficiencies in road and environment are other factors that contribute to accidents, although not as much as the first category Tailgating is a form of driving aggressively that often leads to rear-end car collisions. About 5.9 thousands police reports during the period between 2010 and 2016 showed accidents involving rear-end crashes in Kuwait to be the top cause with over 1.8 thousands cases i.e. 30.4% of total accidents. Every year over 220 fatal accidents and 1500 injuries occur due to rear-end crashes. Along with tailgating, intention was also identified for such crashes [7]. Studies carried out in Kuwait show that tailgating is a major cause of accidents in Kuwait [8].

2.2. Headway characteristics and constraints
Song and Wang discussed the 2-second rule as the recommended time-headway distance between the leading and following car [9]. Car headway lower than 2 seconds is identified to be tailgating and thus

is not considered safe driving behaviour [9]. Song and Wang discussed counter-tailgating measures to help drivers maintain sufficient car headway and to reduce car crashes associated with tailgating [10].

2.3. Conditions effect on headway of cars

Goodwin reviewed research works addressing the effect of weather on traffic flow, focussing on arterial roadways with signals [11]. Driver headway or inter-car spacing was found to increase with inclement weather conditions, along with reduced speeds and acceleration rates. The effectiveness of timing plans of traffic signals can be impacted by adverse weather conditions. The different weather events that can impact the headway on roads are Rain, snow, sleet, hail and flooding, High winds, Fog, smog, and smoke and Lighting extreme temperatures [9, 10 &11].

Goodwin found that the travel time was raised up to 50 percent when weather events were extreme. The number of car stops was higher by 14 percent during adverse weather conditions as compared to normal conditions. Implementing signal timing plans related to weather was suggested so as to facilitate driver response, and was found to increase traffic speeds by 12 percent [11].

A relevant paper was by Rama and Kulmala who studied the effect of Dynamic Message Signs (DMS) or Variable Message Signs (VMS) on car-following behaviour of drivers. It was used to warn drivers about slippery road conditions and also to display a recommended value for minimum distance of more than 30% between cars. Results showed reduction of car mean speed by 1 to 2 km/hour, and also lowered proportion of tailgating. Besides car speed and car-following, the DMS implementation other behavioural changes among drivers. It led drivers to refocus their attention to be on the lookout for cues for hazards they're likely to encounter. Potential hazards in this case would include how slippery the roads are, and thus they will be more cautious while passing. Similar studies involving experimental implementations of advisory signs have shown improvement in headway distance, followed by reduced tailgating, and thereby lowered rear-car crash accidents [12].

Kong and Guo worked on identifying car headway characteristics for multi-lane freeways. It was for interaction between cars and trucks for lane management in China's freeways. Two queries were addressed in particular [13]:

1. If headway is impacted by car-truck interaction (as headway depends on leading and following car types)
2. The best-fitted distribution model for the specific type of headway under lane management.

Appropriate statistical methods were used for analysing the car headway, including maximum likelihood estimation, chi-square test, and Kolmogorov-Smirnov test. For car-car and truck-truck headway types, lognormal model was found appropriate, whereas for car-truck headway type the inverse Gaussian model was found fitting [13]. In addition to developing suitable distribution models for various headway types, their impact on traffic flow rate as well as traffic density was examined in this study [13]. Useful inferences on research approach can thus be adopted for present purpose.

2.4. Relevant studies – GCC and Kuwait

Research focusing on weather condition in Kuwait will be worth following, particularly how the locally relevant dust storms impacts traffic flow and driver response. Abdullah studied the phenomena of dust storms and their impact on the environment in Kuwait [14]. Sand storms and dust storms are common occurrence in Kuwait owing to its arid location, especially during the dry summer season. The absence of vegetation in the region combined with the strong winds play primary roles behind the occurrence of dust and sand storms. Among other things these storms impact visibility, usually reported to be less than 1000 meters, which in turn have adverse effect on transportation safety in Kuwait. June and July are the months when dust storms are encountered most frequently with 15.7 percent and 14.4 percent days per month of respective occurrence rates. A lowest visibility of only 0.05 km was recorded during rising dust; rising dust is observed to be concentrated along the months of summer. Traffic safety is compromised not only because of poor horizontal visibility conditions, but also because roads – particularly non-urban roads – get buried during dust storms or sand storms. Abdullah addressed the use of Dust Warning System that was reported to have been introduced in 1975, in order to warn drivers and commuters against dust storms. The effectiveness of dust storm alert system was also discussed in terms of a survey outcome. Most of the road users (79%) were reported to lower their car speed while driving on the road when they notice dust alert signage. Some (4%) were even reported to leave the freeway using exit ramp, and some (4%) exited the roadway, and certain drivers (9%) were reported to continue driving without any response [14].

Besides dust storms, other weather conditions are also to be considered in the study. Fog is a second major weather condition in Kuwait that affects the visibility. Fog and dust storms both effect visibility conditions during the winter months, while only dust storms do it during the summer months. The typical visibility condition ranging is below 500 meters along a roadway in Kuwait owing to dust storms. During such an event, the sky is not seen clearly and looks reddish instead. Drivers have to use their car headlights to warn other drivers and avoid crashing [14].

Abdullah found a strong correlation between dust storms and visibility range below or equal to 500 meters. The visibility range is sometimes reported to drop to very small distance in presence of a dust cloud. Driving during such conditions is obviously perilous; conventional suggestions to drivers are therefore to stop by the side of the road and remain there until there's improvement in visibility conditions. No accident data in relation to dust storm induced visibility conditions were accessible for this research, although impact on driver behaviour and traffic flow is understood [14].

3. Methodology

3.1. Case study

The case study in this research is the 6th ring road in Kuwait. This road is considered very important road as many governmental, urban and industrial regions are connected together by this road. Figure 1 shows the location of this road in Google map.

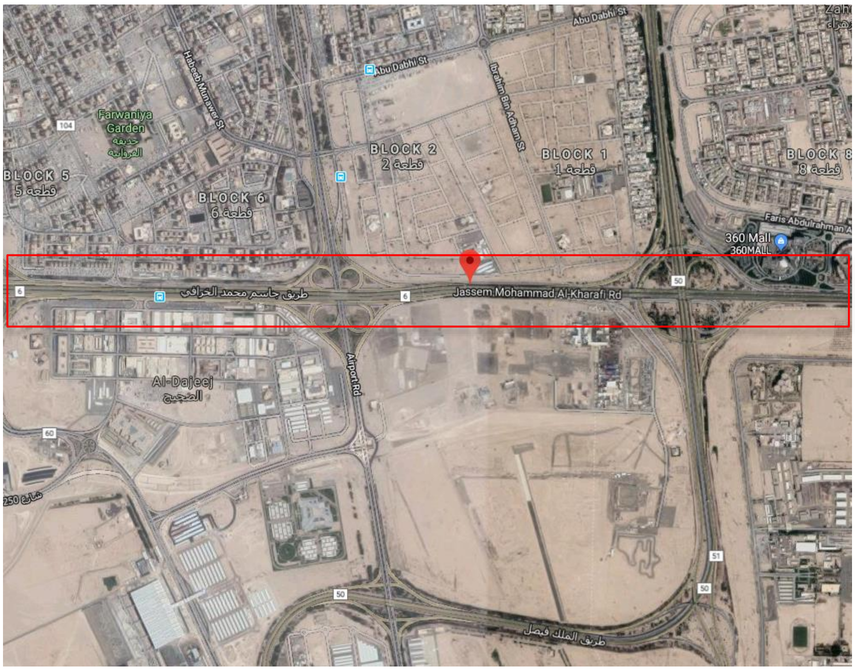

Figure 1. Studied case study: 6th ring road – Kuwait (Google map).

The road is 2 directions with 6 lanes on each side and the lower and upper speed limits are 80 km/hr and 120 km/hr respectively. Figure 2 shows top view of the road showing the studied lanes.

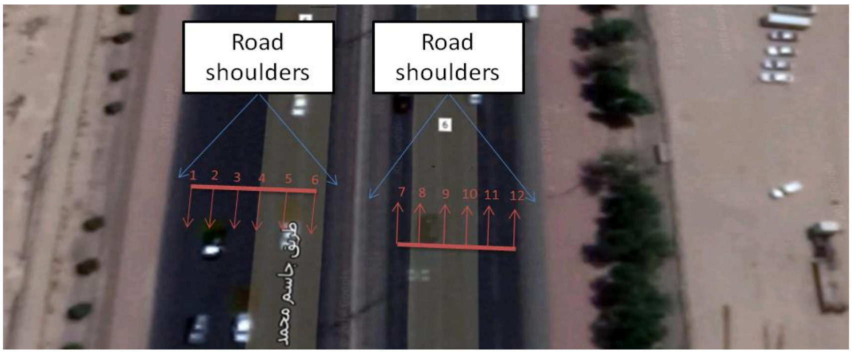

Figure 2. Top view of 6th ring road – Kuwait (google map).

3.2. Data collection
The data were collected at the studied road using RTMS Sx-300 device which is a radar device used for traffic monitoring. The data were collected between 23rd of August 2018 and 30th of August 2018 which is within the hot summer period in Kuwait. Figure 3 shows the schematic diagram for the measuring methodology of the device.

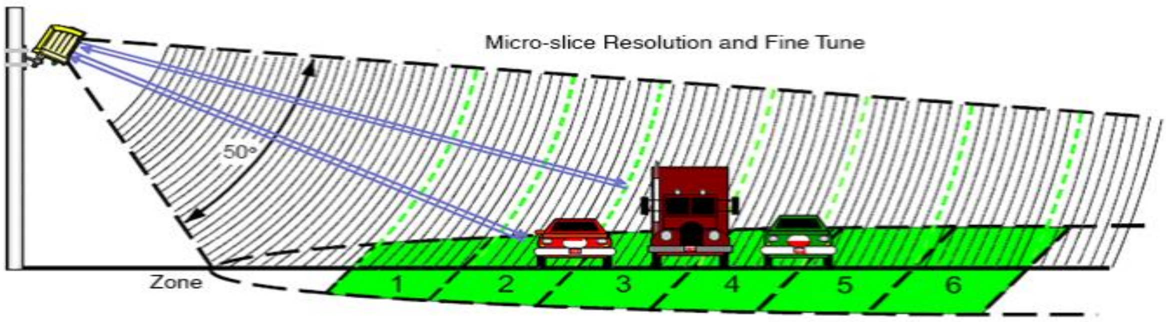

Figure 3. Beam Range and Micro-Slices for RTMS Sx-300 (6 lanes monitoring setting) [14].

The device shown in Figure 3 is a measuring device Remote Traffic Microwave Sensor (RTMS). It measures the speed, time and length of cars. The device classified car type based on the length of the car. The device is all-weather accurate and virtually maintenance-free. It is suitable for any road and pole type, with various built-in communications options, including contact pairs. Using the device, the headway was calculated for each following pattern in seconds. Also, the number of car collected for 1-week duration was greater than 380,000 records. The maximum and minimum temperature during the studied period is 48℃ (day) and 36 ℃ (night) respectively. The relative humidity during the studied period was between 85% and 94%.

3.3. Data classification and analysis
The collected data were classified and analysed based on the following types:
1. Percentage of cars for each speed interval (<20 – >120 km/hr)
2. Speed of cars at day time (each 30 minutes)
3. Average headway versus speed intervals (<20 – >120 km/hr)
4. Average headway versus car following pattern for combined lane
5. Average headway versus speed for each following pattern
6. Vehicle class

Based on average headway versus speed for each following pattern analysis, a model was derived for car following pattern considering the linear regression.

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4. Results and discussion

4.1. Percentage of cars for each speed interval

Figure 4 shows the traffic composition of the studied road.

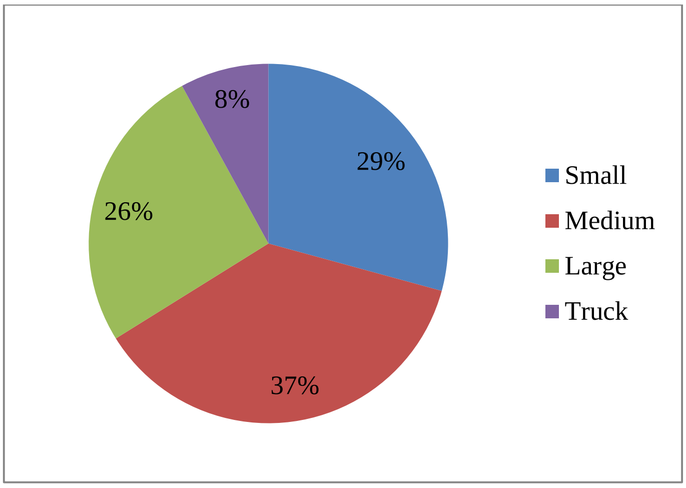


Figure 4. Traffic composition of collected data.

As seen in Figure 4, the traffic volume on the road consists of high volume of medium vehicles (37%), followed by small vehicles (29%), large vehicles (26%) and trucks (8%). Figure 5 shows the percentage of cars based on speed of the car during day and night time. The flowing pattern depends on the average car speed on the road as mentioned in many researches [12].

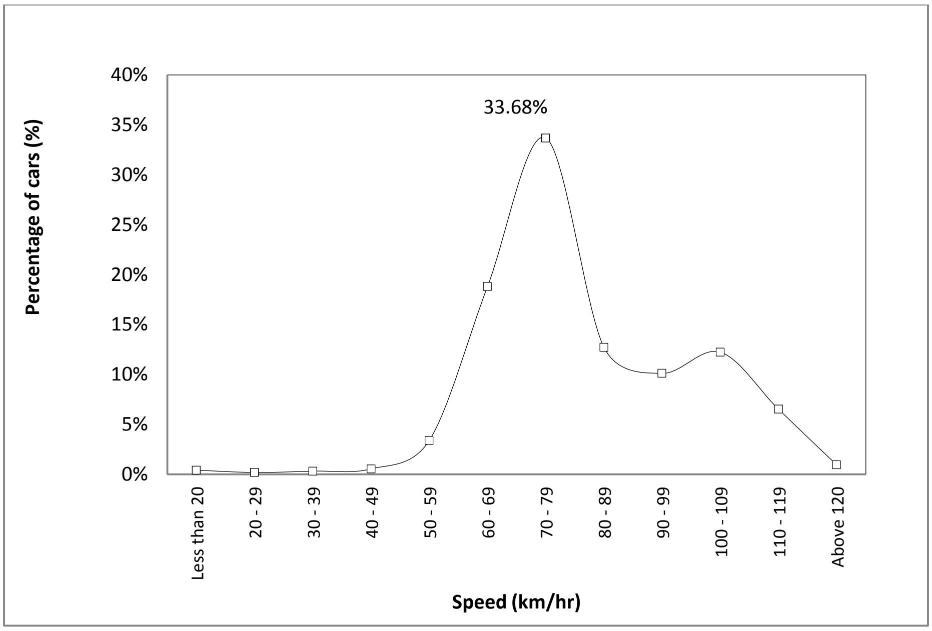


Figure 5. Normal distribution of cars on studied road for speed intervals (20 – 120 km/hr).

Figure 5 shows that the 33.68% of cars on this road flows between 70 and 80 km/hr and 97.52% of cars flow between 50 and 120 km/hr. The analysis shows that most of vehicles did not exceed speed limit 120 km/hr. Also, it was found that only 0.95% of cars exceed the maximum speed limit of the road (120 km/hr).

4.2. Speed of cars at day time

The speed of cars changes with day time for many reasons such as congestion. Figure 6 shows the average speed of car on the studied road for 30-minute interval at all day and night time.

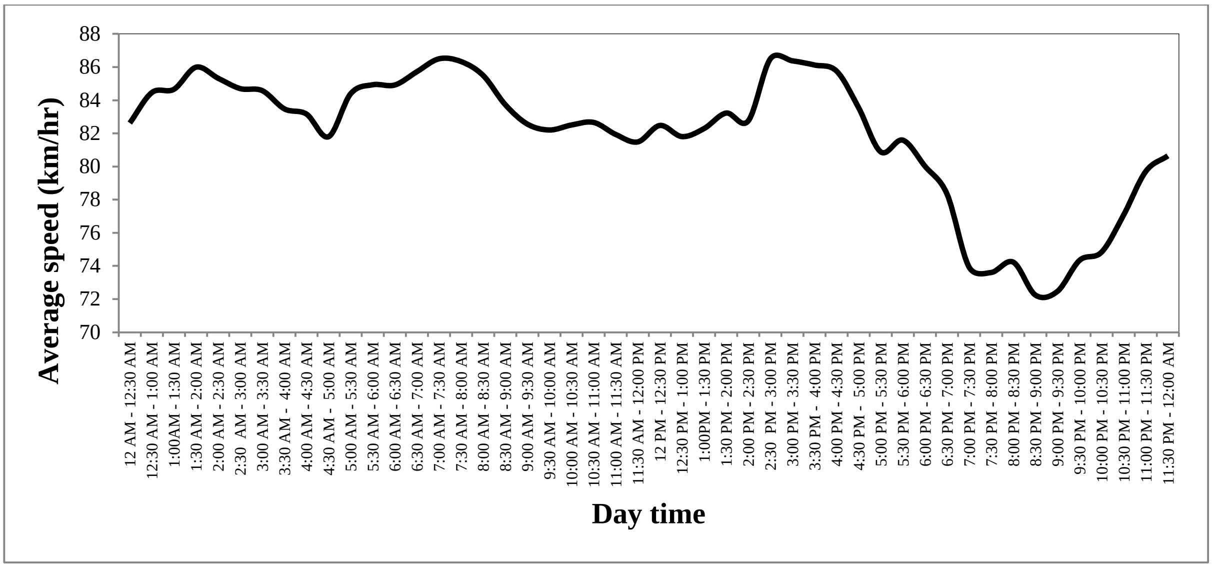


Figure 6. Change of average car speed with different day time for studied road.

As shown in Figure 6, the speed of cars changes between 72 km/hr to 87 km/hr approximately. It can be noted that the speed of cars is significantly decreased between 3:00 pm to 10:00 pm due to congestion in Kuwait at this period.

4.3. Average headway versus speed intervals

The most references concluded that there is a significant relationship between average speed of car and recorded headway. The expected behaviour was that drivers should increase the distance between their car and other cars at high speed to avoid accidents. Figure 7 shows the average headway for various speed intervals.

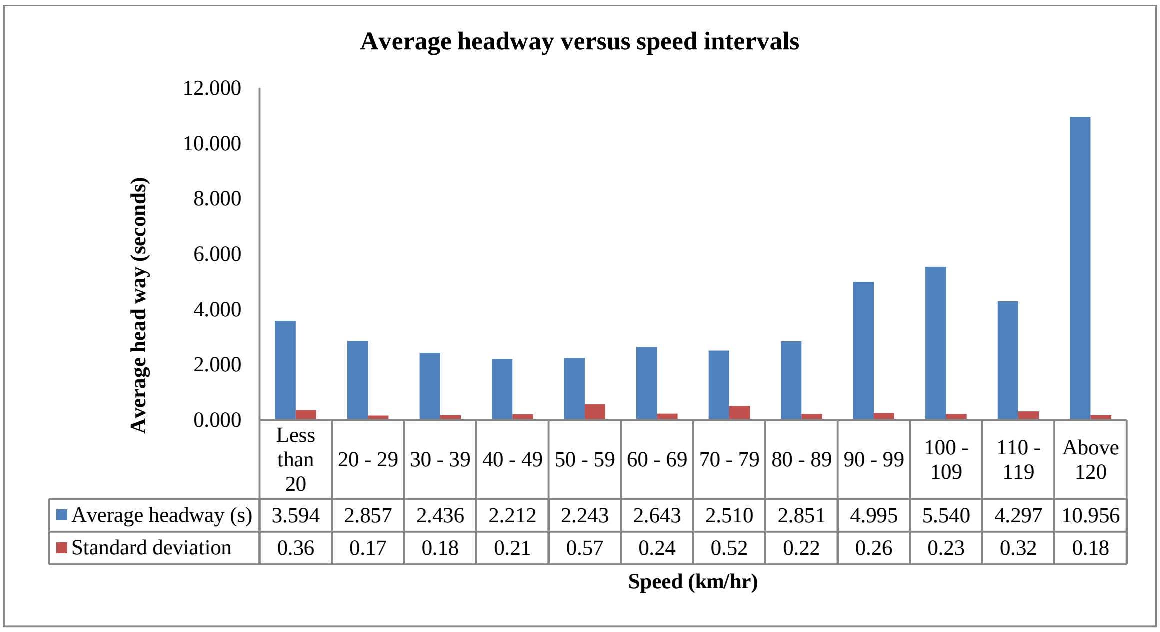


Figure 7. Average headway at different car speed intervals (seconds).

As shown in Figure 7, cars of high speed (greater than 120 km/hr) have high headway time (approximately 11 seconds) which met the expected findings by other researchers [3, 5, 6]. It can be noted that all cars in other speed intervals have safe headway (above 2 seconds). According to standards, the risky headway between cars is 2 seconds [8]. Headway greater than 2 seconds is critical to achieve safe environment for road's users. The case in this study contradicts to the previous study that indicated the tailgating is a major reason of accidents with headway less than 2 seconds. This indicates that future study in this field is needed in Kuwait.

4.4. Average headway versus car following pattern for each lane

Cars were classified into 4 types:

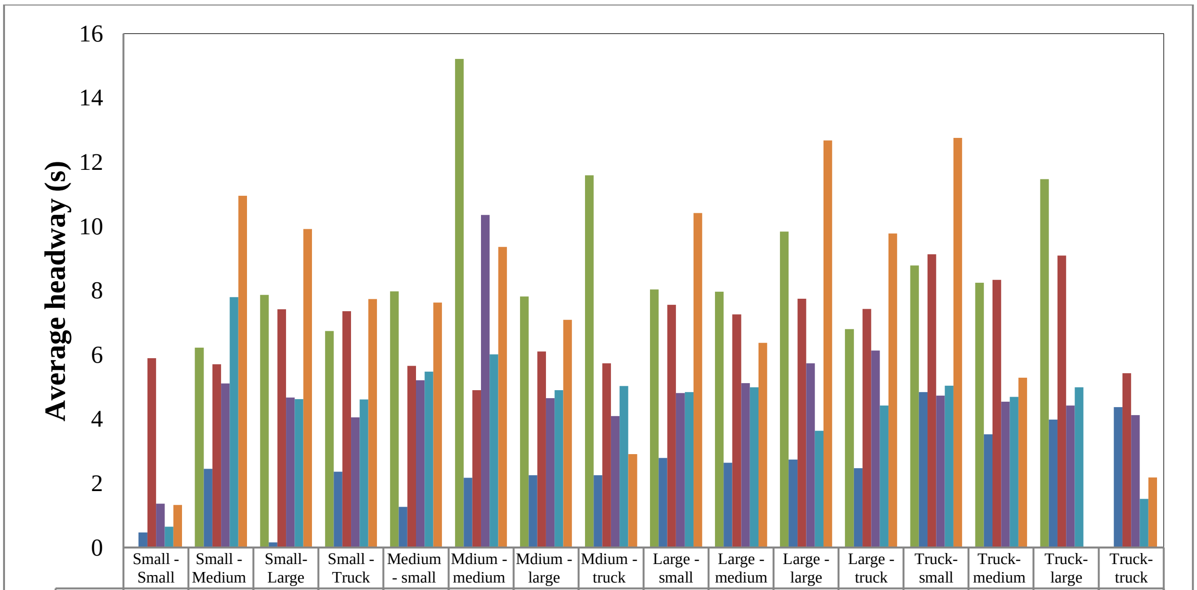
i. Small cars (0 – 6 m long)
ii. Medium cars (6 – 10 m long)
iii. Large cars (10 – 20 m long)
iv. Trucks (above 20 m)

Based on this classification of data, 16 following patterns are possible for the data as shown in Table 1.

Table 1. Type of studied car following pattern on studied road.

Car Type	Followed by			
Small	Small	Medium	Large	Truck
Medium	Small	Medium	Large	Truck
Large	Small	Medium	Large	Truck
Truck	Small	Medium	Large	Truck

The average headway estimated for each flow pattern per lane is shown in Figures 8.



	Small - Small	Small - Medium	Small- Large	Small - Truck	Medium - small	Mdium - medium	Mdium - large	Mdium - truck	Large - small	Large - medium	Large - large	Large - truck	Truck- small	Truck- medium	Truck- large	Truck- truck
Lane 3	0.02	6.22	7.87	6.74	7.98	15.22	7.82	11.59	8.04	7.96	9.84	6.80	8.79	8.25	11.47	0.00
Lane 1	0.47	2.45	0.16	2.36	1.27	2.17	2.25	2.25	2.79	2.64	2.74	2.47	4.84	3.52	3.99	4.37
Lane 2	5.90	5.71	7.42	7.36	5.66	4.90	6.11	5.74	7.56	7.26	7.75	7.43	9.14	8.34	9.09	5.43
Lane 4	1.36	5.11	4.67	4.06	5.21	10.36	4.65	4.09	4.81	5.12	5.74	6.13	4.73	4.55	4.42	4.12
Lane 5	0.65	7.80	4.62	4.61	5.48	6.02	4.90	5.03	4.84	4.99	3.63	4.42	5.04	4.69	4.99	1.52
Lane 6	1.33	10.96	9.92	7.74	7.63	9.36	7.09	2.91	10.42	6.37	12.68	9.78	12.76	5.29	0.00	2.18

Figure 8. Average headway at different car following pattern per lanes (second/car).[a]

[a] **Small – Small*:*** Small car *followed by small car.* **Small – Medium*:*** Small car *followed by small car.* ***Small – Large:*** Small car *followed by large car.* **Small – Truck*:*** Small car *followed by Truck.* ***Medium* – Small*:*** *Medium* car *followed by small car.* ***Medium* – Medium*:*** *Medium* car *followed by small car.* ***Medium – Large:*** *Medium* car *followed by large car.* ***Medium* – Truck*:*** *Medium* car *followed by Truck.* ***Large* – Small*:*** *Large* car *followed by small car.* ***Large* – Medium*:*** *Large* car *followed by small car.* ***Large – Large:*** *Large* car *followed by large car.* ***Large* – Truck*:*** *Large* car *followed by Truck.* ***Truck* – Small*:*** *Truck followed by small car.* ***Truck* – Medium*:*** *Truck followed by small car.* ***Truck – Large:*** *Truck followed by large car.* ***Truck* – Truck*:*** *Truck followed by Truck.*

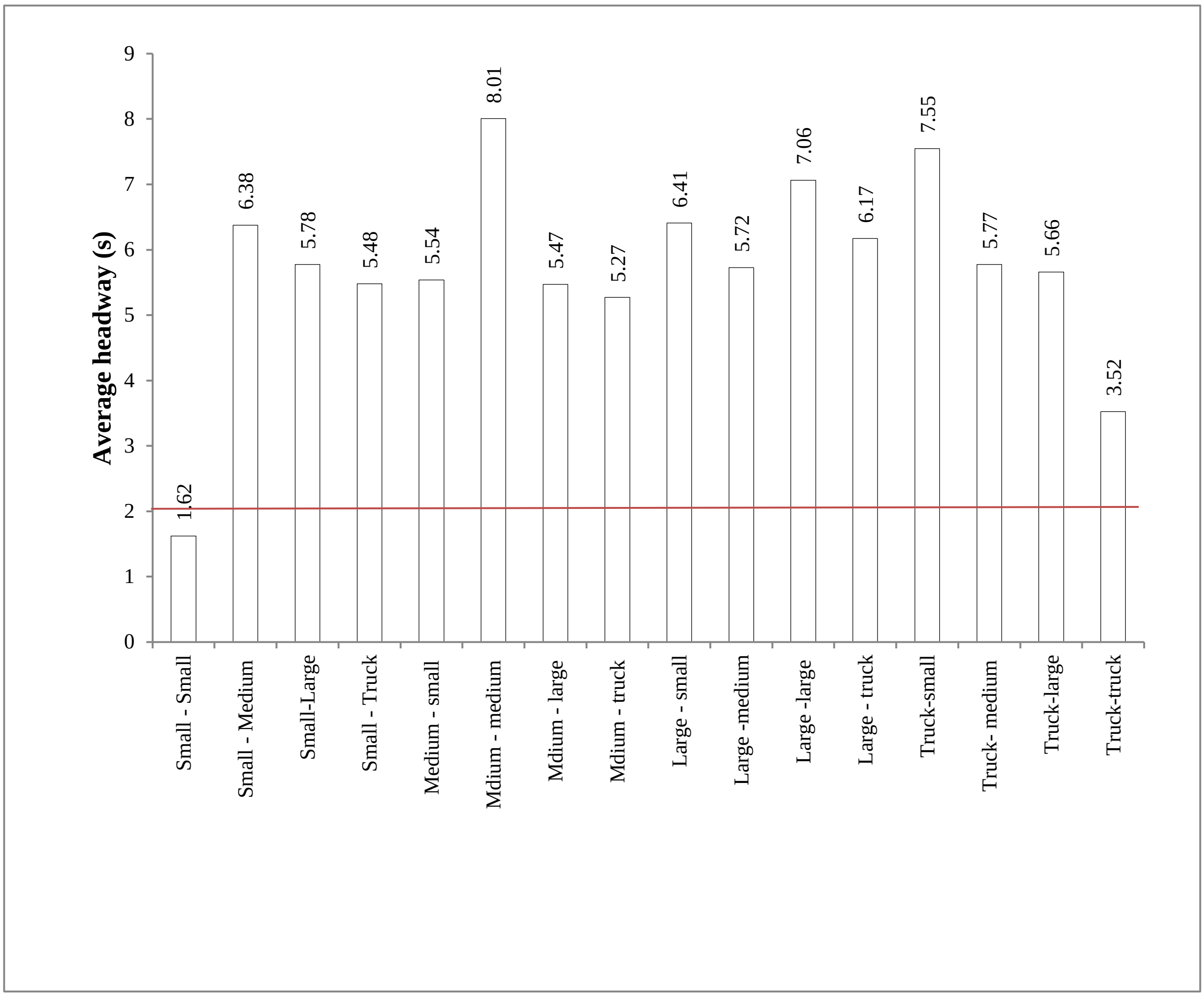


Figure 9. Average headway at different car following pattern for combined lanes (seconds/car).

As shown in Figures 8 and 9, the Small – Small following pattern has the minimum average headway in all lanes with average headway of 1.62 s. Also, the maximum average headway is observed for Medium – Medium car following pattern with average headway of 8.01 s. Figure 8 and 9 show fluctuation pattern of average headway for different vehicle types. This pattern shows that there is no relationship between the type of following pattern and the headway in which it supports the previous studies conclusion that only the driver behaviour, weather conditions and the road quality effect on the headway [7 – 10].

4.5. Average headway versus average speed of cars for each car following pattern (all models for cars with speed >15 km/hr)

4.5.1 Small car. Figure 10 shows a scatterplot of average headway versus vehicle's speed for small car following pattern.

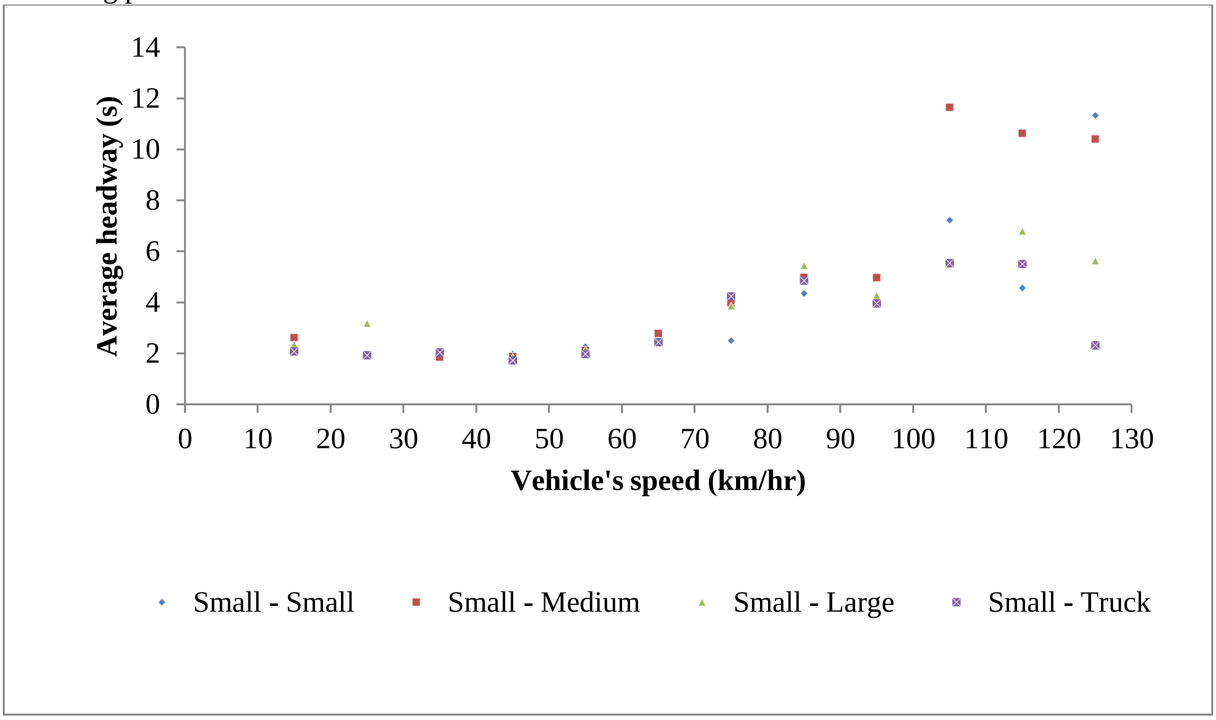


Figure 10. Average headway in seconds at different car following pattern for combined lanes for small car.

To find a linear relationship for each following pattern of small car, a linear fitting of data was created as shown in Figure 10. The summary of relationships for following pattern headway in seconds for small car at different speed (km/hr) can be seen as in Table 2.

Table 2. Summary of relationships for following pattern headway in seconds for small car at different speed (km/hr).

Type of following	Linear relationship	R^2 (%)
Small – Small		56.6
Small – Medium	$t_h = 0.0902\,V - 0.4292$	75.4
Small – Large	$t_h = 0.0405\,V - 0.9684$	73.7
Small – Truck	$t_h = 0.0629\,V - 0.2719$	75.4

Where; t_h is the headway in seconds and V is the average speed of car in kilometres per hour.

4.5.2 Medium car. Figure 11 shows a scatterplot of average headway versus vehicle's speed for medium car following pattern.

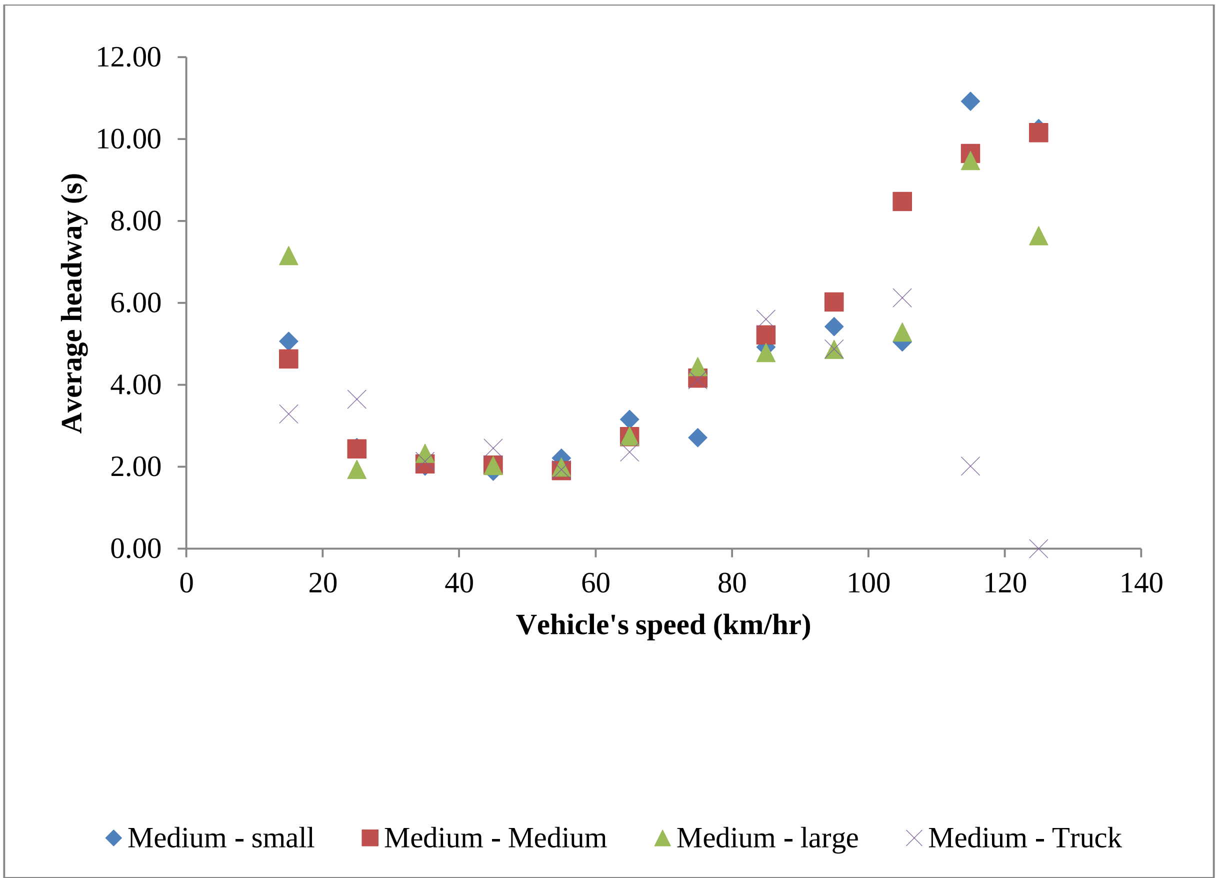


Figure 11. Average headway in seconds at different car following pattern for combined lanes for medium car.

The summary of relationships for following pattern headway in seconds for medium car at different speed (km/hr) can be seen as in Table 3.

Table 3. Summary of relationships for following pattern headway in seconds for medium car at different speed (km/hr).

Type of following	Linear relationship	R^2 (%)
Medium – Small	$t_h = 0.0629\,V - 0.2719$	54.8
Medium – Medium	$t_h = 0.0706\,V - 0.0158$	75.4
Medium – Large	$t_h = 0.0413\,V - 1.6654$	35.2
Medium – Truck	No relation	-

Where; t_h is the headway in seconds and V is the average speed of car in kilometres per hour.

4.5.3 Large car. Figure 12 shows a scatterplot of average headway versus vehicle's speed for large car following pattern.

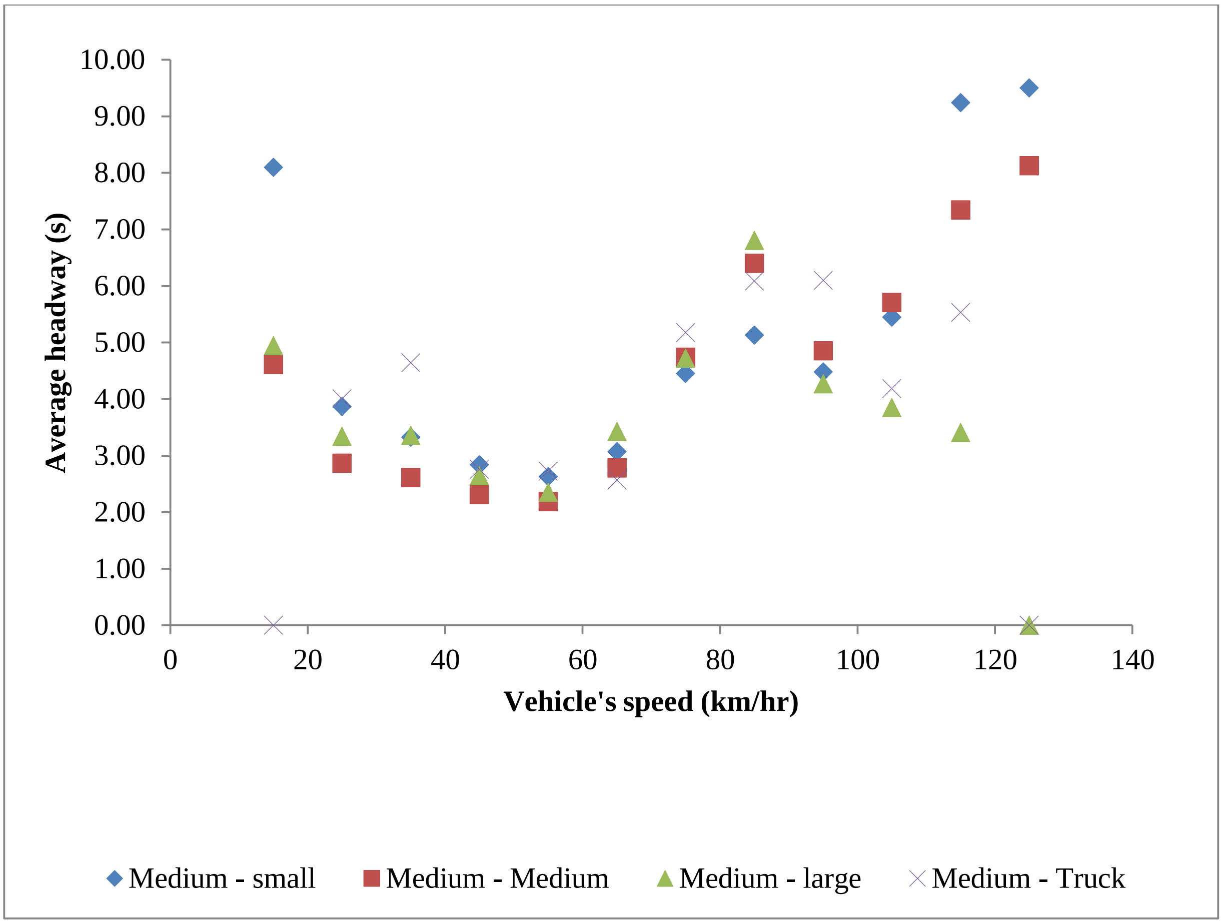


Figure 12. Average headway in seconds at different car following pattern for combined lanes for large car.

The summary of relationships for following pattern headway in seconds for large car at different speed (km/hr) can be seen as in Table 4.

Table 4. Summary of relationships for following pattern headway in seconds for large car at different speed (km/hr).

Type of following	Linear relationship	R^2 (%)
Large – Small	$t_h = 0.03335\,V - 2.8308$	24.16
Large – Medium	$t_h = 0.0448V + 1.4112$	62.53
Large – Large	No relation	-
Large – Truck	No relation	-

Where; t_h is the headway in seconds and V is the average speed of car in kilometres per hour.

4.5.4 Trucks. The average headway versus average speed of cars for large car following patterns can be seen in Figure 1 Figure 10 shows a scatterplot of average headway versus vehicle's speed for truck following pattern.

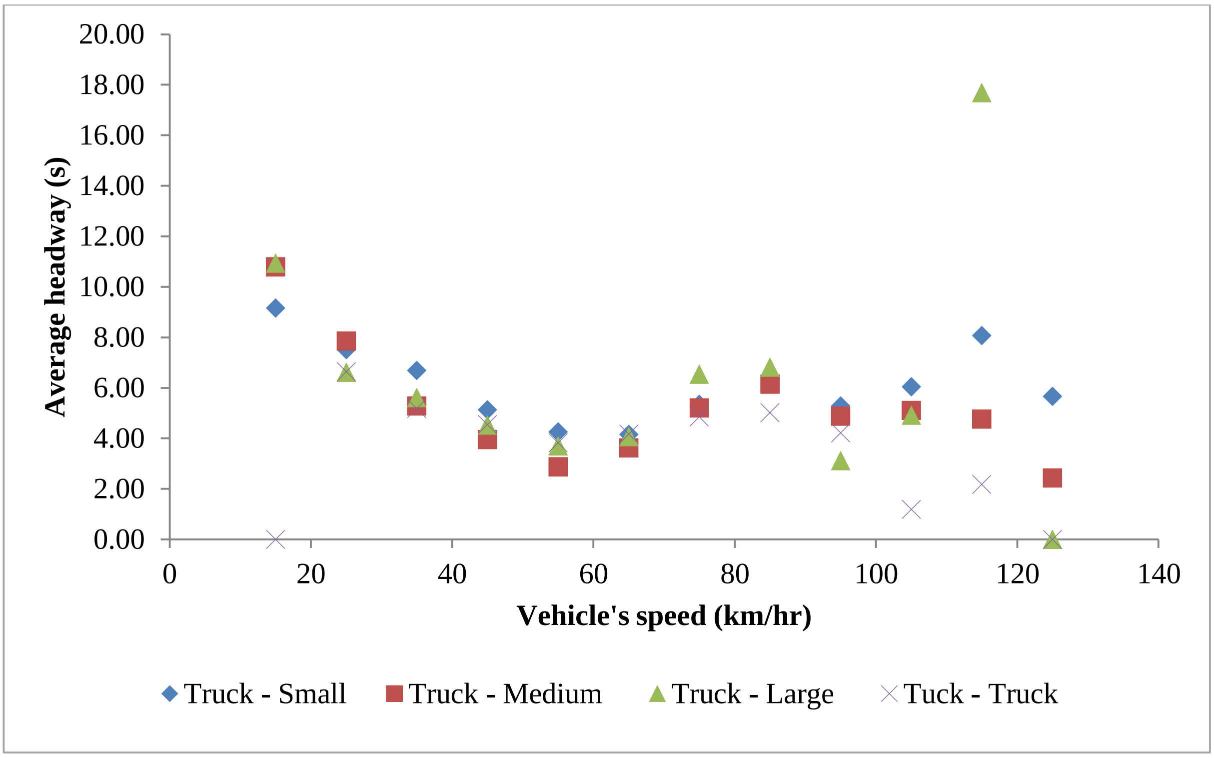


Figure 13. Average headway in seconds at different car following pattern for combined lanes for large car.

It was noted during the analysis that there is no relationship can be obtained for trucks as the accuracy percentage is very low.

5. Conclusion

Driver behaviour is identified to be a key factor behind road accidents. Risk can be controlled by drivers at many levels, but it can be useful if collected data will be analysed to be characteristic of driver behaviour in Kuwait. The purpose of this study is to find the relationship between speed and headway of traffic on multi-lane highway in Kuwait. The analysis shows that the 33.68% of the cars are flowing in a speed between 70 and 80 km/hr. Moreover the cars were classified based on type (small, medium, large and truck) to determine the effect of following pattern to the average of cars. It was found that the Small – Small following pattern has the minimum average headway in all lanes with headway of 1.62 s. Also, the maximum average headway is for Medium – Medium car following pattern with headway of 8.01 s. It is noted that there is no relationship between the type of following pattern and the headway (as shown in Figure 8 and 9 where the data is scattered). This observation supports the previous studies conclusions that only the driver behaviour, weather conditions and the road quality effect on the headway. Finally, a linear regression for data was made to estimate a liner equation describes the average headway as a function of speed for 16 different following patterns. It was found that the relationship could be assumed in small and medium cars. It was found that the average headway can be fitted in linear form for small, medium and large cars while the linear regression for trucks is difficult to be modelled. The trucks are little in size in comparison with other car types so the liner regression of them cannot be found. If the size of data is larger, the accuracy of the model can be expected to increase (i.e. the traffic composition in Figure 5 shows that truck percentage is only 8%).

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