Characteristics of the Driver Behaviour in Weaving Sections: Empirical Study

Hamid Al-Jameel [1]

[1] Lecturer in the University of Kufa, Najaf, Iraq

Abstract

Apart from the impacts of traffic accidents and lane drops, congestion on motorways may be attributed to merging and weaving sections. However, weaving sections receive less attention compared with other situations such as merging at motorways. This supports a real need for investigating some weaving characteristics. In the UK, Motorway Incident Detection and Automated Signalling (MIDAS) data have been used to obtain data on flow, speed, headways and occupancy. However, the MIDAS data is not capable of capturing some important details relating to weaving characteristics. Therefore, more than 50 hours of video recordings have been gathered from seven weaving sections throughout the Greater Manchester area in the UK. Different characteristics of weaving sections have been recorded, including the volume ratio, weaving ratio, merging/diverging points, segregation behaviour, effective length, courtesy yielding and the selection of the original gap by weaving vehicles. These characteristics have been studied to inform an understanding of driver behaviour at weaving sections and to calibrate and validate simulation models used for studying weaving sections.

Keywords: weaving sections, volume ratio, weaving ratio, merging/diverging points.

1. Background of weaving sections

Motorways represent an important part of the traffic system and provide through movements at high speed. However, in recent years, these facilities have suffered from congestion. In the absence of traffic accidents and lane drops, congestion may be attributed to the merging, diverging and weaving sections (Al-Kaisy, 1999).

The HCM (2000) stated that weaving areas can be classified by type according to the minimum number of lane changes as indicated in Table 1. The different configurations of weaving sections (i.e. Types A, B and C) are fully explained in the HCM. A weaving section entails intensive lane changing and this leads to high turbulence which is one of the major factors that cause congestion. Therefore, different methods have been developed throughout the years to design and analyse a weaving section because this section is considered as a critical section that strongly affects the capacity of a motorway (Zhang, 2005). These methods are mainly using mathematical and simulation models.

Mathematical models such as the HCM 1950 all the way through to HCM 2000, Polytechnic Institute of New York (PINY-1976) method, Leisch method-1979, JHK-1984 and Fazio and Rouphail-1986 have proven to be inadequate for weaving analysis (Leisch and Associates 1979 and 1984, Roess and Ulerio, 2000, Lertworawanich and Elefteriadou, 2003, Zhang, 2005 and Lee, 2008). Recently, the HCM 2010 has been released with the same limitations inherent in the previous versions even though there are some changes in some procedures. Recent studies have found that the most suitable method to estimate capacity and operational performance of weaving sections is by using simulation (Lertworawanich, 2003, Sun *et al.*, 2004 and Zhang, 2005). On the other hand, there is a lack of sufficient information about the quality and quantity of previous field data (Lee, 2008) to evaluate appropriate and more reliable calibration and validation of such models. Rudjanakanoknad and Akaravorakulchai (2011) reported that there is a real need for field data collected using video cameras because limited field data collected by loop detectors in previous studies fail to capture important data such as lane changing manoeuvres which are so important in describing weaving operational characteristics. An attempt has been made to collect data for two rush hours for two days, however the data was not giving specific information on lanes changes within weaving sections and distinguishing them from those for non-weaving ones.

Table 1 Configuration types based on the HCM, 2000.

Number of lane-changing required by minor movement (from on-ramp)	Number of lane-changing required by major movement (from motorway).		
	0	1	≥ 2
0	Type B	Type B	Type C
1	Type B	Type A	N/A
≥ 2	Type C	N/A	N/A

To overcome the shortcomings in the information of field data, this study tries to cover these limitations by collecting more than 50 hours of field data and the main factors affecting weaving behaviour have been identified.

2. Characteristics of weaving sections

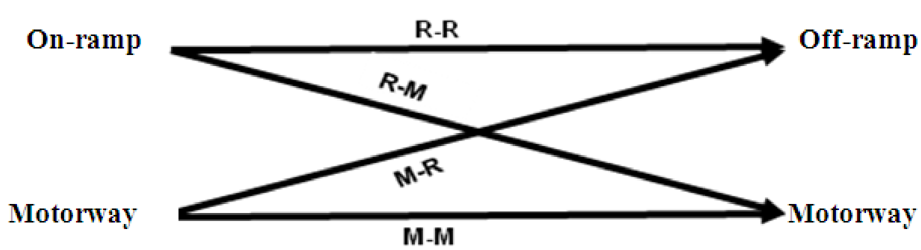
Several factors have been shown to affect the capacity of weaving sections. These include the type of weaving section, volume ratio, weaving ratio, length and width of a weaving section, weaving and non-weaving speeds (Lertworawanich and Elefteriadou, 2003, Zhang, 2005 and Lee, 2008).

2.1 Volume ratio (VR)

According to the Highway Capacity Manual – HCM (2000), volume ratio (VR) can be defined as the weaving volume (V_w) divided by the total volume (V) entering a weaving section. It can be calculated as shown in the following equations (see also Figure 1):

$$\mathbf{V_w = W_1 + W_2} \quad \textbf{(1)}$$
$$\mathbf{VR = V_w / V} \quad \textbf{(2)}$$

The HCM (2000) recommended that the value for VR should not exceed 0.45 and 0.35 for three and four lanes, respectively for Type A, whereas for Type C it should not exceed 0.5. For Type B, VR may reach 0.8 (Roess and Ulerio, 2000).



R-R is ramp to ramp flow (non-weaving flow).
R-M (either W_1 or W_2) is ramp to motorway flow (weaving flow), also called merging traffic.
M-M is motorway to motorway flow (non-weaving).
M-R (either W_1 or W_2) is motorway to ramp flow (weaving flow), also called diverging traffic.

Figure 1 Weaving and non-weaving movements within a weaving section.

2.2 Weaving ratio (R)

The weaving ratio (R) is the proportion of the minor weaving volume (W_1) from one direction to the total weaving volume (V_w) (HCM 2000), as indicated in Equation 3. If this value equals zero (i.e. if W_1=0), this means that the section operates either as an isolated merge or as an isolated diverge section. The maximum value for R is equal to 0.5 when the section operates at high turbulence (i.e. due to increased interactions between vehicles). This normally exists when flows are at or approaching capacity (Fazio and Rouphail, 1990).

$$R = W_1 / V_w \tag{3}$$

2.3 Traffic segregation

Traffic segregation refers to the manner in which weaving vehicles segregate themselves from through traffic and relocate to the lanes closer to the auxiliary lane before entering a weaving section (Cassidy, 1990). This phenomenon is described in Figure 2. The shaded area in this figure represents the zone where all segregations have to be implemented before entering the weaving section after the entrance point.

A few studies have tried to link traffic segregation with weaving characteristics. Pahl (1972) conducted a study on motorway merges and diverges and reported that traffic segregation is a function of flow conditions where segregation increases with an increase in traffic flow. Pignataro *et al*. (1975) found that nearly 98% of motorway to ramp traffic relocates to the lane adjacent to the auxiliary lane before entering a ramp weaving section. In the same way, 60 to 85% of motorway to motorway traffic change lanes before entering a ramp-weave section in order not to be impeded by weaving vehicles.

Kojima *et al*. (1995) developed a simulation model to analyse the behaviour of drivers for Type A weaving sections. Field data were used to calibrate the model and two strategies for traffic behaviour at the upstream section, one "with controls" and the other "without controls" were applied in the simulation model. The "with controls" could, for example, represent the use of traffic signs to direct drivers to get onto the correct lane depending on their destinations before entering the weaving section. Although the study suggested that the case of "with control" showed that drivers' behaviour is smoother than in the case of "without control" (which initially seemed logical), but a closer look at the results that they obtained from simulation revealed that the differences in behaviour were not very significant. Jinchuan *et al*. (2000) collected data from two weaving sections in China and they found that 95% of diverging traffic segregated before entering the weaving section.

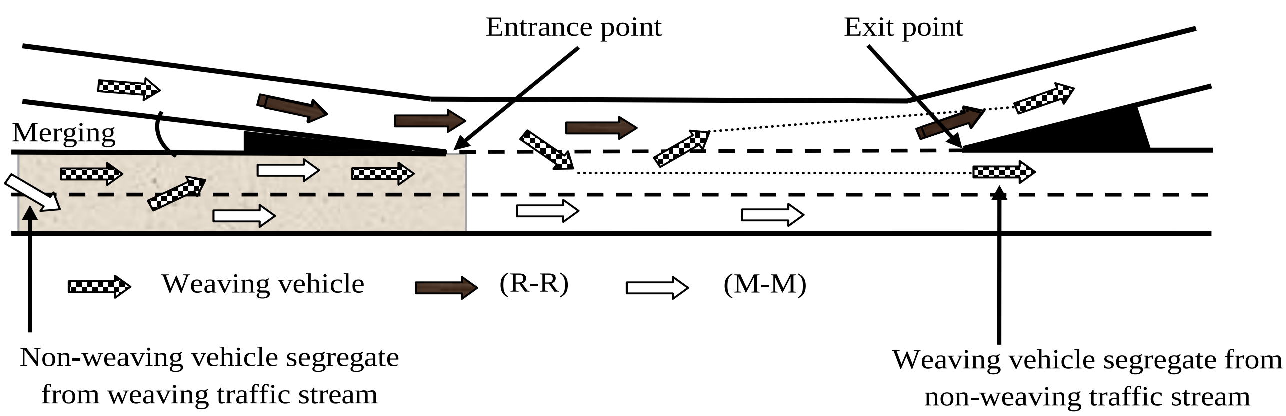


Figure 2 Segregation cases for weaving and non-weaving traffic.

In light of the above, it is evident that the segregation behaviour for different weaving sections in different countries has approximately the same behaviour as segregation from other traffic before the entrance point of the weaving section with a high percent of up to 95%.

2.4 Length of weaving sections

Knowing the length of weaving section will determine the nature of traffic operations at the section, whether it is a weaving or an isolated (merging or diverging) section. The 2000 version of the HCM sets the maximum length of weaving sections at 600m for Type A and at 750m for both Types B and C. Therefore, a weaving section with a length more than these limits is considered as a separate on-ramp followed by an off-ramp.

The majority of lane changes between the on-ramp and motorway occur within the first 150m of the weaving area (Cassidy and May, 1991 and Cassidy *et al.*, 1993). These results were extracted from analysing a large amount of empirical and simulated data from a number of sites throughout California, USA. Stewart *et al*. (1996) reported that if the spacing between the on and off-ramp is less than 300m, this causes more turbulence. However, if it is more than this the turbulence due to merging and diverging vehicles dissipates.

Wang *et al*. (2002) found that the weaving section length had different impacts on the capacity of general traffic under different weaving configurations. Whereas, Shoraka and Puan(2010) reported that the first 75m from the entrance point for the two lanes adjacent to the merge gore had the highest rate of lane changing activities and the highest concentration of flow.

From the above studies, it can be concluded that there are two types of weaving length: the actual length for which the section operates as a weaving section and the length by which all weaving vehicles complete all lane changes required to reach their destinations. The latter can be called the effective length. This term will be adopted in this study.

3. Data collection and analysis

As discussed above, there is a lack of weaving data in the UK. In order to cover this lack and to understand the operational characteristics of weaving sections, seven sites of weaving sections were selected within the Greater Manchester area as indicated in Table 2. Some of these sites could be considered to be part of urban motorway sections (such as the Mancunian Way Sites 1 and 2 and Northenden Sections), whereas others (such as the M60 sections) could be considered as part of non-built up sections. Figure 3 shows a map of these sites within the Manchester area, while Figure 4 shows the details of the geometric design of each of these selected sites.

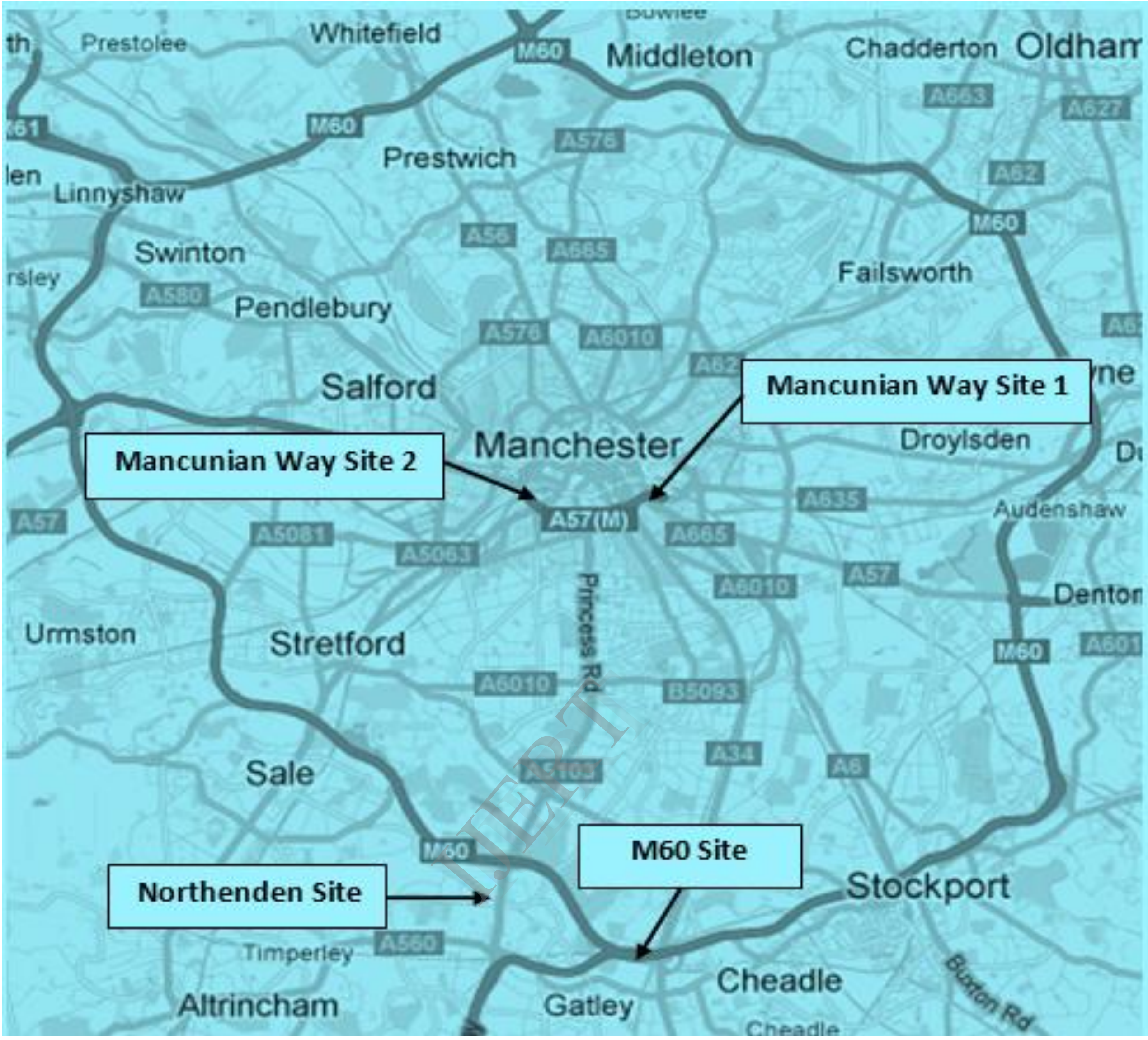


Figure 3 Locations of weaving sections within the Manchester area (Google Earth, 2010).

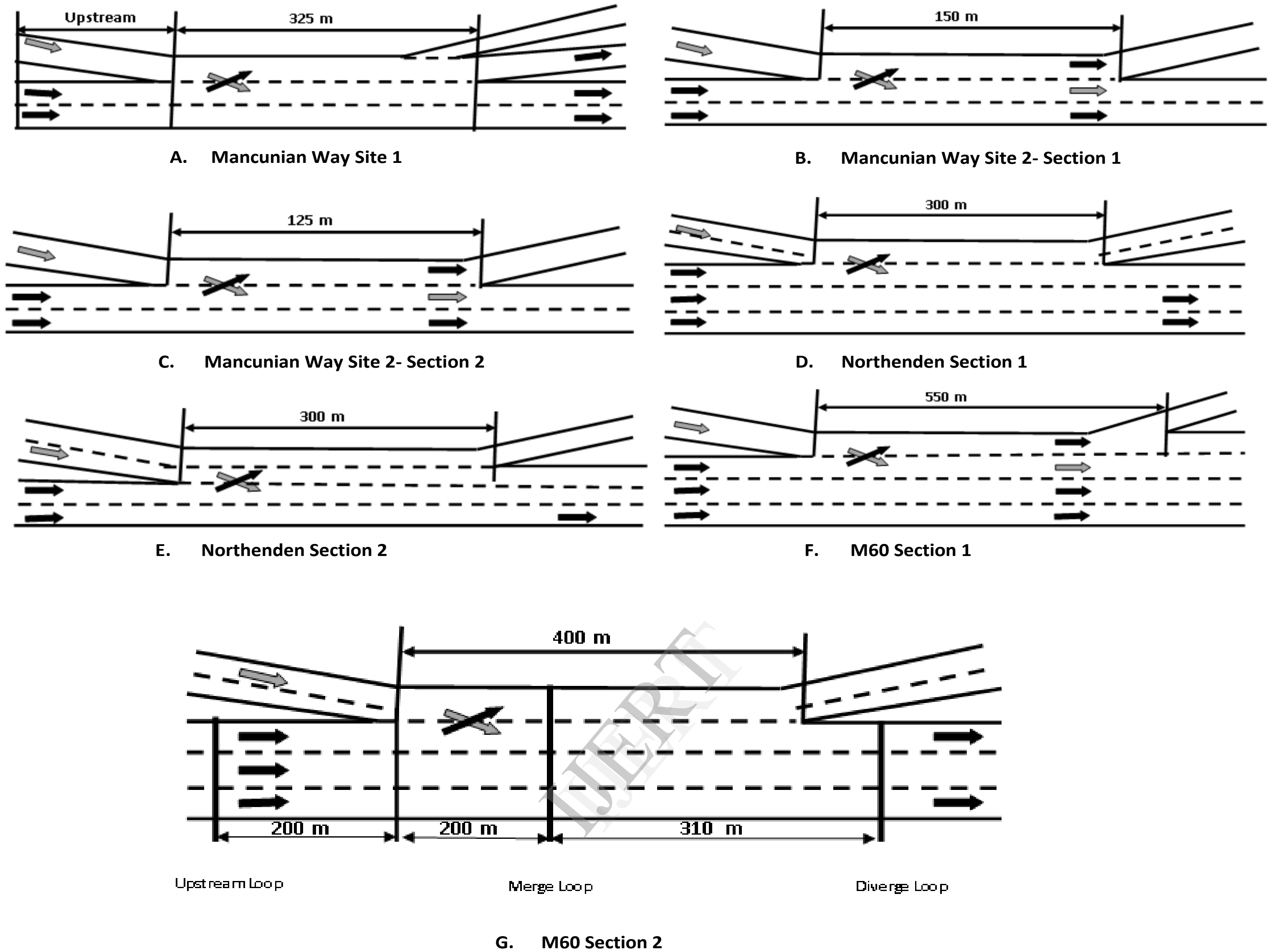


Figure 4 Layouts of the seven selected weaving sections sites.

The criteria for selecting these sites were:

- Coverage of a range of weaving section layouts.
- Coverage of a range of traffic flow conditions.
- Existence of a suitable vantage point close to the weaving sections (such as an over-bridge or multi-storey building).

For all of these sections, video cameras have been used since the MIDAS data alone cannot provide the fundamental characteristics of weaving sections such as volume ratio (VR) and weaving ratio I. In addition to using video cameras, MIDAS data has also been adopted to provide flow, speed and occupancy from motorway weaving sections.

Table 2 Details of the visits to weaving section sites.

No.	Site	Location	Dates	Description	Weaving Type
(A)	Mancunian Way Site 1	At the Eastern part of the Mancunian Way near Manchester Metropolitan University.	From July 2009 to November 2010.	A total of 12 visits covering 28 hours for different periods during the day (8 am to 5 pm) and for different days/months.	A
(B)	Mancunian Way Site 2 Section 1	At the Western part of the Mancunian Way	July 23, 2009	4 hours for evening peak	A
I	Mancunian Way Site 2 Section 2	At the Western part of the Mancunian Way	July 23, 2009	5 hours for evening peak	A
(D)	Northenden (A5108) Section 1	Within Northenden	June 28, 2010	4 hours for both morning and evening peaks	A
			July 2, 2010	4 hours for both morning and evening peaks	
(E)	Northenden (A5108) Section 2	Within Northenden	June 28, 2010	4 hours for both morning and evening peaks	C
			July 2, 2010	4 hours for both morning and evening peaks	
(F)	M60-J2 Section 1	Between Junctions 2 and 3	March 15, 2010	4 hours for morning and 2 hours evening peaks	A
			October 8, 2010	4 hours for morning and 2 hours evening	
(G)	M60-J2 Section 2	Between Junctions 2 and 3	March 15, 2010	2 hours for mornings	A
			October 8, 2010	3 hours evening peaks	
			October 29, 2010	4 hours evening peaks	
			May 11, 2011	6 hours from morning until evening	

3.1 Data extraction

Different characteristics of data were extracted from field observations such as flow, vehicle classification and number of lane changes. Video playbacks were shown on the computer monitor screen and a screen line was imposed to manually extract the necessary information using an event recorder (i.e. recording the time and counts when certain vehicles cross the screen line). The same procedure was used to determine the location of merging points (i.e. when a vehicle is changing lanes by crossing the longitudinal pavement marking that separates the lanes).

The proportion of non-segregation behaviour for those weaving vehicles within the weaving section (i.e. after the nose) is calculated by dividing the number of diverging vehicles from any motorway lane (except the shoulder lane) by the total number of those diverging vehicles as shown in Figure 2. The proportion of non-segregation behaviour for those non-weaving vehicles is determined by dividing the number of vehicles staying in the shoulder lane and not changing lanes to the auxiliary lane (i.e. M-M) by the total flow entering from the shoulder lane at the entrance point of the weaving section (after the nose) as shown in Figure 2. Google Earth as well as the standard distance between successive pavement markings as used in the Traffic Signs Manual (1985) was adopted to determine the length of each section under study.

Finally, the percentage of courtesy yielding has been determined by the number of drivers that used their headlights to facilitate the merging process to others. Flashing headlights is common practice amongst drivers in the UK when they try to cooperate and help others. These cases were taken just for the critical situations where merging vehicles need longer gaps in order to perform their manoeuvres.

3.2 Volume and weaving ratios

Determining the VR and R ratios for a weaving section is a difficult task. This is because it depends mainly on the frequency of lane changes (FLC) for a given time, say each 5 minutes. Table 3 gives the relationship between the maximum VR and maximum and minimum R under different ranges of recorded flow for the seven weaving sites.

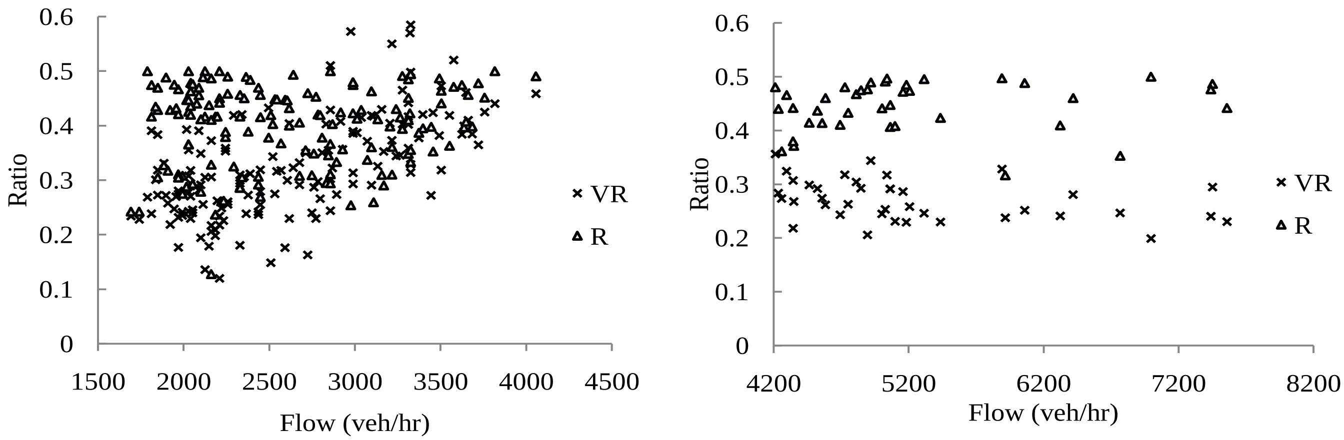
Table 3 Observed values of VR and R for different sites.

No.	**Sections**	**Flow range veh/hr**	**Max VR vs. Flow**		**Max R vs. Flow**		**Min R vs. Flow**	
			Max VR	**Flow**	**Max R**	**Flow**	**Min R**	**Flow**
(A)	Mancunian Way Site 1	1100-4050	0.58	3324	0.5	3816	0.3	2830
(B)	Mancunian Way Site 2-Section 1	2100-3350	0.48	3180	0.49	2724	0.3	3348
I	Mancunian Way Site 2-Section 2	2000-3000	0.55	2052	0.49	2052	0.41	2736
(D)	Northenden Section 1	2900-5000	0.58	3780	0.24	3624	0.11	4476
(E)	Northenden Section 2	4000-5600	0.51	4152	0.24	4632	0.09	4152
(F)	M60-J2 Section 1	5000-8000	0.25	7400	0.49	7300	0.3	7000
(G)	M60-J2 Section 2	4200-7260	0.27	7092	0.48	6768	0.33	6720

The highest observed values of VR were found for the Mancunian Way Site 1 and the Northenden Section 1, while the minimum values were recorded at the M60-J2 Section 1, as shown in Table 3. The high values of VR could be due to the high percentage of merging and diverging. However, this may also be due to the relatively lower flow levels (i.e. <5000 veh/hr) compared with those of the M60 sites (i.e. <8000 veh/hr). Figure 5 shows VR and R values for two selected cases taken from the Mancunian Way Site 1 (for flows <4200 veh/hr) and the M60 J2 Section 2 (for flows >4200 veh/hr). However, it seems hard to generalise the behaviour from these two chosen sites especially that they appear to show quite different characteristics.

In Table 3, the VR value of 0.27 for the M60 Section 2 represented the critical value that caused disruption in traffic (i.e. queues starting to form). However, this critical value is less than the 0.35 which is suggested by the HCM (2000).

For R, the maximum value of 0.5 was also found at the Mancunian Way Site 1 in spite of the relatively low flows. This suggests that the section operates under very critical conditions in terms of high interactions between vehicles.



A. Mancunian Way Site 1. G. M60 J2 Section 2.

Figure 5 Different values of VR and R under different levels of flow.

The minimum value of R was also investigated from these sites, as shown Table 3. This is due to the fact that not only has the maximum value of R been found to be critical in causing disruption to traffic but also the minimum value. For example the minimum R value of 0.11 for the Northenden Section 1 site has been accompanied by severe disruption in traffic movements for the case of ramp-weave section. This could be attributed to weaving drivers on the upstream section before the nose finding a relatively clear road ahead in the auxiliary lane (within the weaving section). This might motivate most drivers to change lanes very early and very close to the entrance point (i.e. nose). The process relating to these manoeuvres involves adjustment in speeds which may require deceleration. Consequently, this results in causing some turbulence within that section close to the merging point for such low values of R. Therefore, it is not always true to associate low R values with free flow conditions or with desirable operations.

3.3 Segregation characteristics

Segregation characteristics for the upstream sections have been found from this data. It was found that the proportion of weaving segregation vehicles (M-R) for Mancunian Way Site 1 was 95% and that for Northenden Section 2 was 85%. The difference between these values may be attributed to the fact that for the Northenden Section, the upstream distance between this section and the junction before it is only 350m, whereas that for the Mancunian Way Site 1 is about 900m. The proportion of non-weaving vehicles (i.e. M-M) in the shoulder lane which stayed in the same lane after entering the weaving section of the Mancunian Way Site 1 ranged between 40% and 60%. These proportions are lower than the 60% to 80% which were reported by Pignataro *et al.* (1975). These different percentages could be attributed to the different behaviours between drivers of the USA and those in the UK. More research is needed to investigate the reasons for these differences.

3.4 Bottleneck location

Knowing bottleneck locations in any part of a motorway was considered by different studies because of their influence on interpreting the causes of congestion and selecting suitable management techniques. Therefore, the location of a bottleneck in a weaving section has been investigated based on field observations and MIDAS data.

Data taken from the M60-J2 Section 2 has been used for this analysis. This data was taken from loop detectors located at 200m from both upstream and downstream of the entrance point as shown in Table 4. The data illustrates that there is a reduction in speed at the upstream sections compared with those of the downstream locations for all the selected dates. This reduction is generally more than 20 km/hr. This could be explained by the presence of a traffic bottleneck close to the entrance of the weaving section. Similar observations of bottleneck signs were reported by Hounsell and McDonald (1992).

Table 4 Flow and speed for upstream and downstream loop detectors for the M60-J2 Section 2.

Date	Time period	Duration	Upstream detector-flow and speed	Downstream detector-flow and speed
3/3/2010	6:15 p.m	(5:55-6:15)	5508 veh/hr (50.6 km/hr)	6732 veh/hr (69.75 km/hr)
5/3/2010	5:25 p.m	(5:15-5:40)	5244 veh/hr (46.5 km/hr)	6300 veh/hr (72.8 km/hr)
¼/2010	4:46 p.m	(4:21-5:16)	5124 veh/hr (44 km/hr)	6216 veh/hr (67.0 km/hr)
7/4/2010	4:43 p.m	(4:38-4:53)	5592 veh/hr (44 km/hr)	7044 veh/hr (71.12 km/hr)

In addition to the loop detector data, video recordings for the M60 J2 Site 2 during the evening peak hour on 29/10/2010 between 4:30 and 5:30 pm show that the location of the bottleneck is about 70m downstream of the entrance point (nose) as indicated by Figure 6.

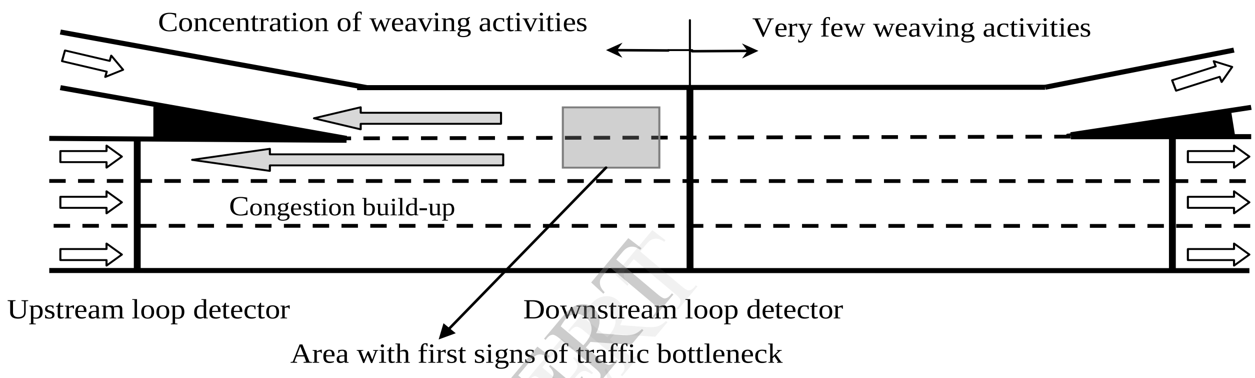


Figure 6 Bottleneck locations for the M60 J2 weaving section.

Observations from site show that in general, the location of bottleneck could start at about 70m and oscillate between this location and the entrance point of the merge section. However, the upstream section, especially the 250m from the entrance point, suffers from high turbulence and a queue dominates at this section.

3.5 Effective length

After gathering more than 50 hours of field observations for 7 weaving sections, a new factor was introduced in this study. This is referred to as the effective length. This length, which is part of the weaving section, starts from the entrance point and extends to a length at which the majority of weaving manoeuvres are completed.

The results of the analysis of field data suggest that the effective length for the Mancunian Way Site 2 represents the whole weaving length (i.e. 150 and 125m for Sections 1 and 2, respectively). The effective length of about 200m was observed for all other ramp weave sections where the actual weaving length was equal to or more than 300m. This value was less than that reported by Vermijs and Schuurman (1994) which suggested a value of 350m. For the observed Type C weaving sections (e.g. Northenden Section 2), the effective length was the whole weaving length.

3.6 Courtesy yielding and cooperative lane changing

Wang (2006) stated that the following vehicles on the main motorway sometimes help merging vehicles from on-ramp sections in the merging areas in order to avoid disturbance or delay. This help could be done either by decelerating to increase the gaps or shifting to adjacent lanes of motorways; the first behaviour is referred to as courtesy yielding and the second is the cooperative lane changing (LC).

In general, the behaviour of courtesy yielding is the same for on-ramp drivers in both isolated sections and weaving sections. In both situations, the driver on motorways or on the main road wants to let merging vehicles merge in the gap ahead by reducing his/her speed. This is also true for on-ramp vehicles to show courtesy behaviour to diverging vehicles from motorways. Empirical studies have indicated that there are different percentages of cooperative lane changing and courtesy yielding. The percentages of courtesy yielding were 20% according to Wang (2006) and 13% based on a study by Liu and Hyman (2008). However, it is quite difficult to accurately collect courtesy yielding data from the field because it is hard to know that a driver is cooperative (or not) unless one puts such a driver in a critical situation to highlight this behaviour and more importantly, it is not possible to accurately obtain acceleration/deceleration rates from video recordings.

In this study, the percentage of courtesy yielding was measured from video recordings. The main sign that was used to distinguish courteous drivers from the non-courteous ones was the use of flashing headlights (which is common practice amongst drivers in the UK when trying to help other drivers to merge in front of them). However, there are other cases of yielding behaviour which could not be detected easily from the video recordings (e.g. some drivers may reduce their speeds to allow others to merge in front of them without the use of flashing headlights).

Field data from the M60 J10 (which is an isolated merging section and therefore its details are not included in Table 2) over a period of 80 minutes have been analysed. Here, only 46 cases were considered where the flashing headlights were observed from the video recordings involving lag gaps (i.e. between the merger and the follower on the first lane of the motorway) which were below 3 sec (i.e. small lag gaps). The results suggest that 78% of drivers yield. For those which did not flash their lights (i.e. 10 cases), only 5 refused to yield. Therefore, the percentage of courtesy behaviour is expected to be about 90% for all cases. This percentage is significantly higher than that shown in other studies (such as Wang, 2006). This may be due to the fact that in this study, only those critical cases where the lag gaps were small have been considered.

Data from the M60 J2 weaving section indicates that the percentage of yielding motorway drivers is higher than that for isolated merging sections. It was about 80% for the two hours of field data (total cases were 60, 48 of these showed yielding). The high percentage of courtesy yielding could be attributed to the fact that in addition to the percentage of courtesy yielding from non-weaving drivers, most weaving drivers, as observed from the field, showed courtesy amongst themselves (i.e. diverging drivers show courtesy for merging and vice versa).

3.7 Merging and diverging points

3.7.1 Definition

In this study, a merging point represents the point at which a vehicle starts to cross over the longitudinal pavement marking from the on ramp (minor road) towards the motorway, as shown in Figure 7. For the other movement from the motorway to the ramp, this is referred to as the diverging point.

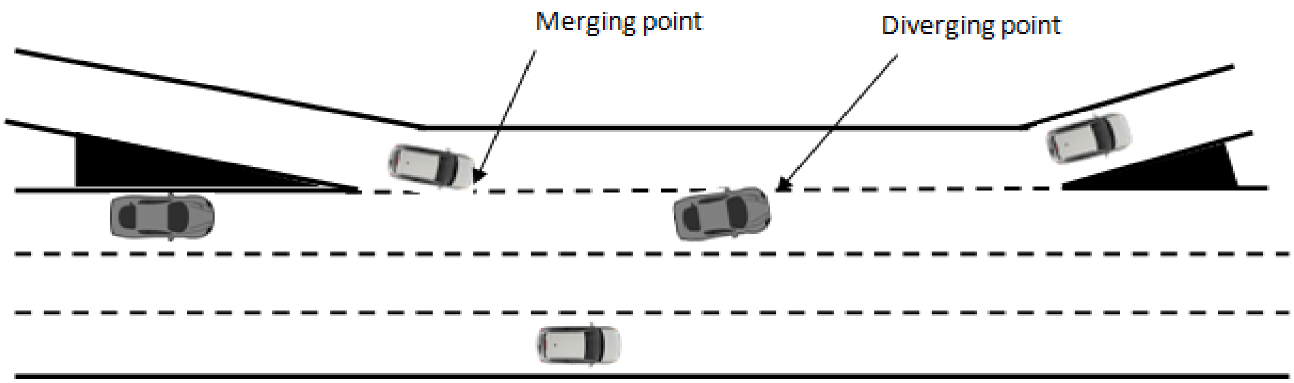


Figure 7 Merging and diverging points within a weaving section.

Regarding the behaviour of weaving drivers, certain questions have received different answers from previous studies. Some of these questions are the location where the majority of the lane changing is concentrated and the location of where the active bottleneck location is within the weaving segments.

In order to investigate merging/diverging points in this study, the M60-J2 weaving section was observed. To determine the number of vehicles that start manoeuvring in each zone of a weaving section, the video recordings have been displayed on the PC monitor. Several screen lines have been drawn on the monitor starting from the entrance point and ending at the end of the section as shown in Figure 8. The determination of merging/diverging vehicles was implemented by tracing each vehicle from the time of entering the boundaries of each zone until exiting from it.

Because the concentration of LC was in the first 200m of the whole section, it was decided to divide the 200m segment into four zones using screen lines. The first zone represented zero to 50m; the second ranged between 50 and 100m; the third was from 100m to 150m and the fourth was greater than 150m.

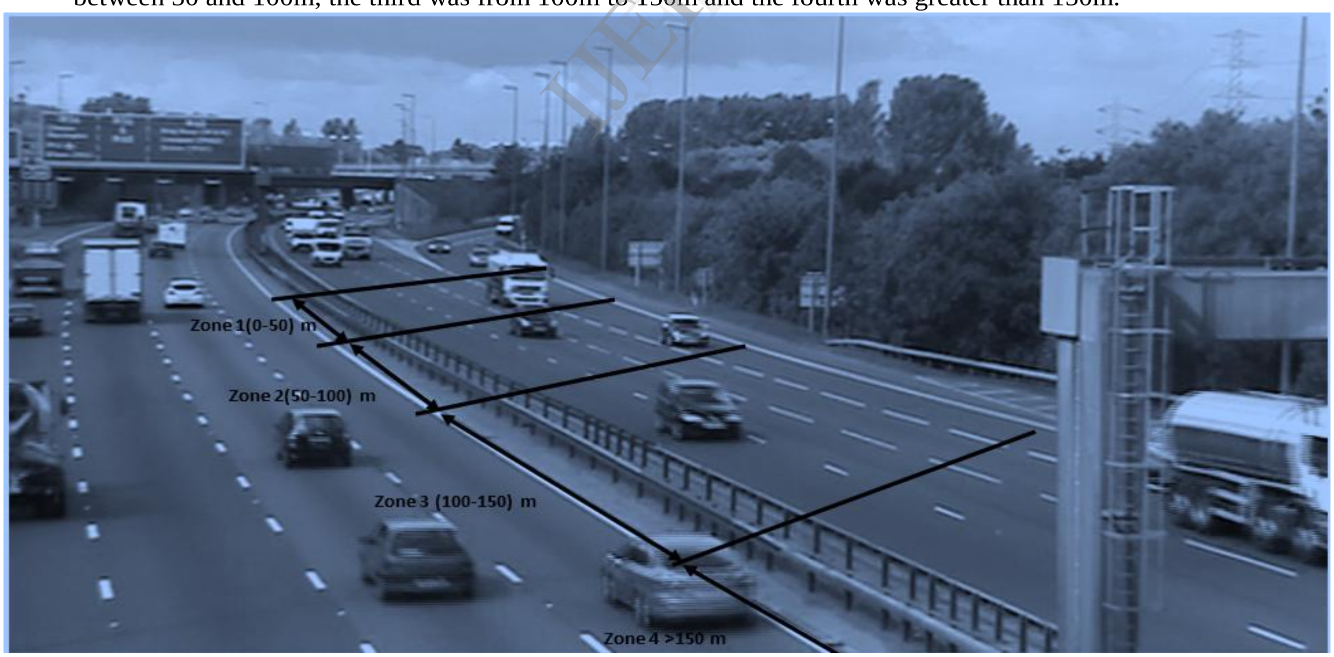


Figure 8 Division of the M60-J2 Section 2 weaving section into four zones (11 May, 2011).

In order to have a better view of driver's behaviour under different levels of flow, six hours and thirty minutes of observed data were collected under low flows up to congested flow conditions when speed limits were applied. The last hour of this data has been excluded from analysis because of the application of different speed limits during that period. Figure 9 shows the characteristics of this set of data in terms of total flow, total weaving flow, R-M and M-R. This figure indicates that the level of flow starts from low and extends to high flow levels and covers a wide range of traffic conditions.

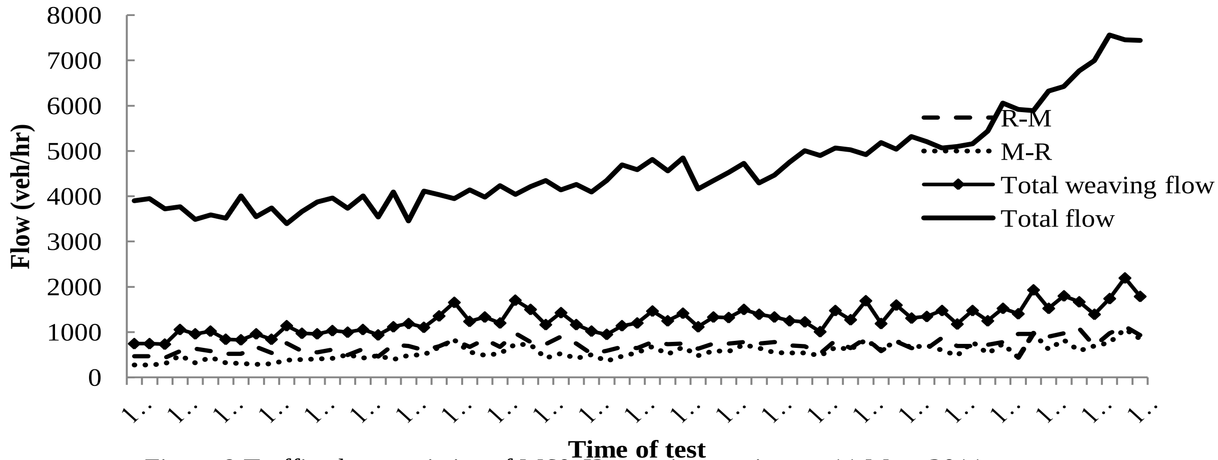


Figure 9 Traffic characteristics of M60-J2 weaving section on 11 May, 2011.

3.7.2 Percentage merging

For the merging section, Figure 10 shows that most merging vehicles try to merge in the first two zones (i.e. in the first 100m). The average percentage of merging vehicles in low to moderate flow is around 70%. This value reaches more than 90% at high flow, whereas for the third zone, i.e. (100-150m), the behaviour is different. According to the figure, under low to moderate flow, the percentage ranges from 10 to 30%, while under high flow, this percentage does not exceed 20% because most merging vehicles are concentrated in the first 100m. For the fourth zone, the percentage ranges from zero to 18%. However, in most cases this percentage does not exceed 10%.

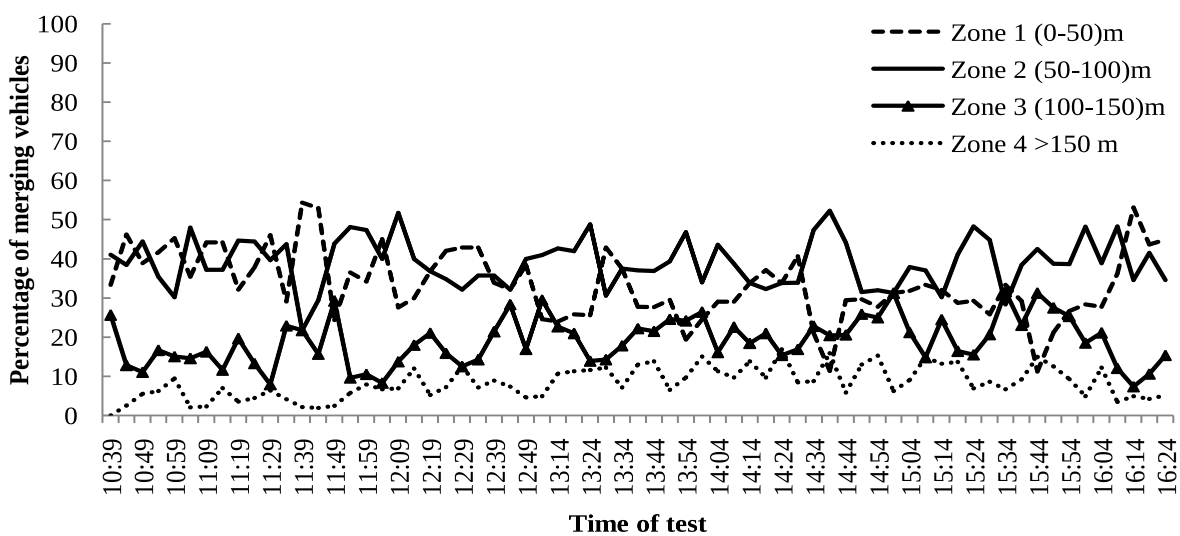


Figure 10 Percentage of merging vehicles at different zones of M60-J2 weaving section on 11 May, 2011.

3.7.3 Percentage diverging

Figure 11 shows the behaviour of diverging drivers in terms of percentages for each zone. For the first zone (0-50m), the behaviour mainly depends on the level of flow. For low flows, this percentage is very high and it reaches up to 90%. This percentage falls to around 45% under moderate flow levels. This reduction continues until it reaches 20% under high flow but when flow approaches capacity this percentage rises again to around 50%.

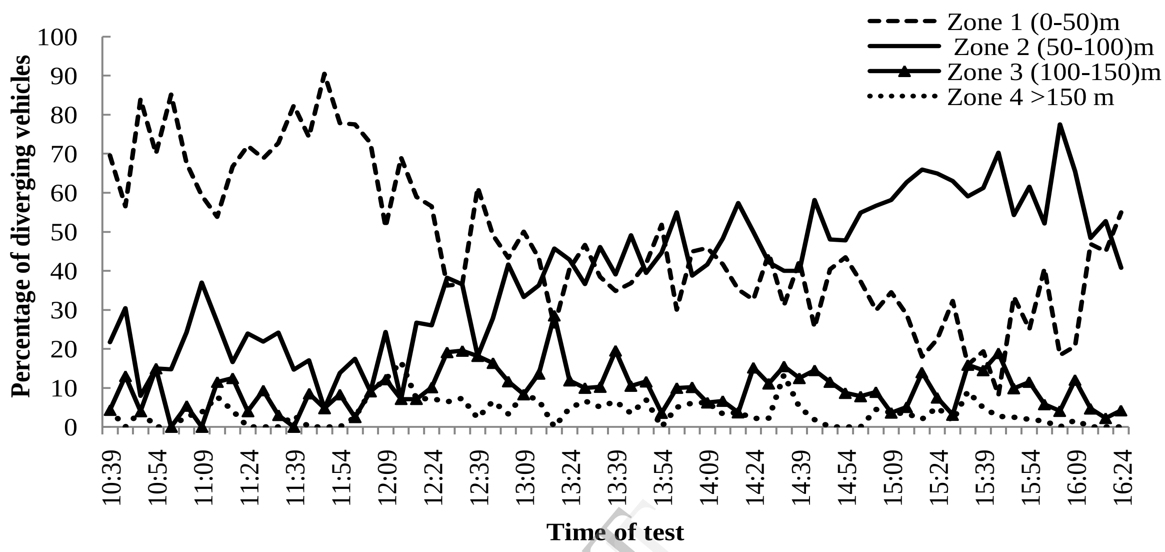


Figure 11 Percentage of diverging vehicles at different zones of M60-J2 weaving section on 11 May, 2011**.**

For the second zone (50-100m), the percentage of diverging increases proportionally with an increase in the level of flow. For the third zone (100-150m), this percentage does not show significant difference under different levels of flow but it fluctuates around 10%. For the fourth zone (>150m), the percentage is only about 5% which is very low compared with other zones under different levels of flow.

3.7.4 Lane changing and bottleneck locations for weaving sections

Generally, this set of data is characterised by a wide range of flow levels and it could give a comprehensive view about driver behaviour in a weaving section in terms of where the majority of interactions of merging and diverging vehicles could be expected.

According to the data, one can easily conclude that the location of a bottleneck is within the first 100m as observed in the field because of high interaction from both merging and diverging vehicles. Moreover, all lane changing manoeuvres in weaving sections may be implemented within the first 200m.

3.8 The selection of gap

The selection of gap means which gap a weaving driver (either merging or diverging) chooses to merge in. A sample of 300 cases was investigated under moderate flow levels at the M60-J2 Section 2 for merging cases and 300 samples for diverging cases as shown in Table 5. It was found from this analysis that 92% of merging vehicles selected the original gap whereas just 8% tried to merge into a gap either before or after the original one, whereas the percentage of diverging vehicles that selected the original gap was 90%. These results are slightly higher than those obtained from isolated merging as reported by Zheng (2003) and Wang (2006), as shown in Table 5. This difference is due to the fact that the percentage of the cooperative vehicles within the motorway for a weaving section is higher than for the motorway of an isolated merging section. Consequently, the opportunity for accepting the original gap is high. This behaviour could be used for the calibration or validation of simulation models.

Table 5 Selection of the original gap**.**

Weaving section		Isolated merging section	
Merging case	Diverging case	Zheng (2003)	Wang(2006)
92%	90%	87%	88%

4. Conclusions

The main findings and conclusions from this study can be summarised as follows:

1. The effective length, as defined in this study, was found to represent the whole of the weaving section length if the weaving section is less than 300m for ramp weave, whereas it is only 200m if the weaving section is greater than 300m.

2. The segregation behaviour for motorway drivers at the upstream of weaving sections showed that most of segregation occurred within the first 250m from the entrance point (e.g. 95% for the Mancunian Way Site 1 and 85% for the Northenden Section 2).

3. Based on field data, the bottleneck location in weaving sections was found to be at the first 70m from the first part of the weaving section and then propagated to the upstream section of the entrance area.

4. It was found, based on the field data from the investigated weaving sites, that a VR value of 0.27 (which is lower than what has been suggested by the HCM of 0.35), triggers a bottleneck in the ramp weaving section (Type A) with four lanes.

5. New weaving characteristics were investigated from field data called the merging and diverging points. These points show the locations for the concentration of merging/diverging vehicles along weaving sections. 80% of merging points are concentrated in the first 100m from the weaving length, whereas this percentage reaches up to 90% for diverging points for the same length. These points could be used as calibration or validation factors for simulation models.

6. The percentage of weaving drivers who selected the first gap was higher than the corresponding percentage of drivers in isolated merging sections. Moreover, this percentage for weaving drivers was higher for merging than diverging drivers. These percentages could be used to calibrate and validate the behaviour of simulation models.

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