Gap Acceptance Behaviour in Motorway Weaving Sections

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Abstract: Weaving sections are one of the most critical sections on the motorway network. Many vehicles change their lane in a weaving section according to their destination. These weaving movements create instability and affect the traffic performance. Safety is a significant issue, as the drivers share the time and space without any traffic control device during their movement. Each driver seeks the safest gap based on their preference, either to execute the weaving movement or not. This paper applies discrete choice to capture the gap acceptance behaviour among the traffic. The explanatory variables (i.e. speed, type of vehicle) in the model are based on traffic video extraction process. The study focuses on a four lanes dual carriageway in UK motorway network. The vehicle position and type of vehicle affect the gap-acceptance behaviour. The leading and heavy vehicles are more aggressive (accepting smaller gaps) compared to the following and small vehicles.

Keywords; Weaving movement, Gap acceptance, Discrete choice.

1. INTRODUCTION

Motorways form the main road traffic backbone to transport people and goods efficiently and safely. Due to economic growth; the amount of traffic has increased every year, in addition, the traffic becomes more congested especially during the morning and afternoon peak period since the traffic volume is higher than the design capacity.

The most critical sections in the motorway network are weaving sections. The weaving behaviour occurs when there are two vehicles, moving side by side, which plan to shift lane at the same time. HCM (2010) defines a weaving movement as *a situation where there are two or more traffic streams crossing each other without any aid of traffic control devices in order to adjust their lane position due to their destination lane or to seek a chance to pass a vehicle in front of them.* Each driver therefore seeks the gap event both in their current lane and target lane.

A high number of weaving movements and an aggressive driving movement can create traffic instability and shockwave effects. In terms of road safety issues, the movement contributes to a high accident risk considering that the traffic has to share the space at the same time without any assistance of traffic control.

There is a large number of researches on gap acceptance behaviour models. The models can be classified based on level of detail; macro and micro level. Most of the road design manuals (i.e. HCM, DMRB, Germany Highway standard) analyse the gap acceptance behaviour at the macro level. However a number of researchers (Skabardonis et al. (1988), Cassidy and May (1991), Vermijs (1998), Lertworanich and Elefteriadou (2001), Awad (2004), Al-Jameel (2011)) have applied micro-level modelling in an attempt to capture gap acceptance behaviour at a more detailed level.

This current paper presumes that each driver faces a discrete situation either to accept or reject the available gaps. Each driver has their own preferences in evaluating the available gaps. In fact, he or she accepts the gap that gives the highest utility for them. Moreover, the application of discrete choice modelling in this research is to evaluate the probability of accepting an available gap event. This method has been tested in many traffic cases such as, T junction, merging and diverging area. This paper extends the approach to weaving sections where three common driving tasks are involved, namely car-following, lane changing and weaving movement.

The modelling itself uses an empirical traffic data from a weaving section of UK motorway. The data is based on traffic video recording. Using this methodology shall help the researcher to identify the traffic and driver behaviour characteristics that affect the weaving movement.

2. BACKGROUND

The structure of the weaving model in this current research is based on the driver decision-making process, assuming that the weaving movement driver will face a discrete situation. The drivers are simply allowed to pick one set of alternatives, either to accept or reject the traffic situation around them. In order to make a decision, the drivers firstly observe and find a traffic condition that has the highest utility based on their preferences. Analysing the utility for each traffic condition cannot be done directly due to mathematical limitations. Hence, this research applies the discrete choice model as an analysis tool.

2.1 Weaving Section

Weaving movements on the motorway traffic occur in a section where the entry and exit slip roads are relatively close. DMRB (2006) defines the weaving section as *the distance between a successive merge or lane gain and diverge or lane drop (where vehicles) have to cross the paths of vehicles that have joined the mainline at the merge or lane gain*.

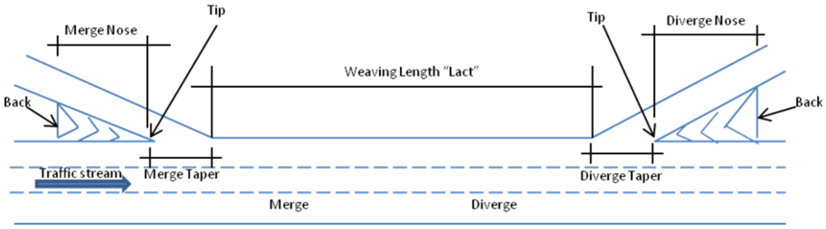

Figure 1. The UK weaving section layout (source: DMRB, 2006)

On the other hand, the HCM (2010) has different terms and approaches in measuring the weaving section length. The length in HCM is stated as *the distance (feet) between the merge and diverge that form the weaving section*.

The UK manual classifies the weaving section length based on types of road. There are three types of road, which are rural-motorways, rural all-purpose roads, and all-purpose roads. The manual states that the weaving section should be between 2 and 3 kilometres. Once the distance between the entry and exit slip road is longer than 3 kilometres, then it should be treated as two separate junctions.

Most traffic engineers and modellers agree that gap-acceptance behaviour is a parameter that can affect the road section capacity. This principle is applied as well in weaving section.

Cassidy and May (1991) define the weaving section capacity as the total number of vehicles passing through the section and crossing among the traffic along the weaving section length. They stated the maximum flow for through traffic is 2200 PCU/hr/ln and for cross traffic is between 1100 and 1200 per hour per 76 m of weaving section. Meanwhile, the weaving section capacity can also be defined as the maximum number of vehicles able to pass the weaving section during a specific period of time, under prevailing road, environment, traffic and traffic control conditions (Boekholt et al., 1996, Vermijs, 1992). There are several parameters that can affect the capacity e.g. road geometry, driving behaviour, and traffic management policy. Meantime, this current paper will focus only on the driving behaviour parameter.

Gap acceptance is one parameter that can represent the driving behaviour. This current paper presumes that each driver may face a discrete situation. They have to decide either to accept or reject each gap event that they face. To do so, the drivers each have their own preference to come to a decision considering the traffic condition.

2.2 Gap Acceptance Modelling

Briefly, gap acceptance is a significant factor in road capacity due to the fact that the driver may find the safest gap event based on their preference to change their lane, merge, diverge or weave. There are two approaches to measure the gap event which are distance and time based. However, this research applies the time based considering that it is very difficult to measure the exact gap in the distance based approach. In addition, most of the previous gap acceptance researches adopt this approach rather than distance based.

In terms of definition, headway is *the time interval between the passages of successive vehicles past a point on the road*. Meanwhile, a Gap event is *time interval or distance between the back tail of vehicle in front and the front tail of vehicle backward* (Al-Jameel, 2011).

Gap event is *the time event used to define the beginning and the ending of each major stream gap*. Further, the beginning of gap event is known as lag. In addition the observation starts at the time when the minor stream driver stops at the yielding point. Drivers with lower priority have to seek a gap that is generated by other streams with higher priorities. (Tian et al., 1999)

Furthermore, the Gap event is more common in driving behaviour analysis compared to the headway terms.

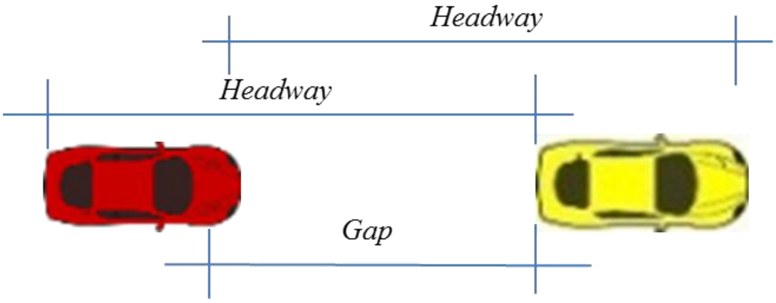

Figure 2. Headway and gap definition

Gap acceptance is the required gap for each vehicle to start a manoeuvre. In the case of a weaving movement, the gap acceptance is a gap when the weaving vehicles agree to shift their lane position. Once the vehicle fails to execute the manoeuvre, the available gap on the target lane is classified as a rejected gap. And then, a maximum rejected gap is the largest gap that has been rejected by each driver. Presumably that the driver faces a discrete situation for each provided gap event, either accept or reject it. In the reality, each driver has possibility to reject several gaps but only accept one gap event.

To capture the gap acceptance behaviour of drivers at the specific observed location, the gap acceptance model applies a probabilistic approach to evaluate the decision whether to accept or reject the current gap event. To do so, Brilon et al. (1999) presumed that drivers in a population were consistent and homogenous. That is to say that the drivers always behave in the same way every time for all similar situations.

The model of gap acceptance behaviour tries to capture the distribution of mean and variance for the population of drivers in a weaving section, considering that each driver has different preferences to evaluate a gap event. Daganzo (1981) introduced a critical gap acceptance behaviour considering that there were limitations in the gap acceptance approach. First, the gap acceptance model captures an individual average of the population. Second, the model considers only the first accepted gap. He adopts a probit model to estimate the parameters that represent the heterogeneity of driver behaviours. Mahmassani and Sheffi (1981) applied the probit as well to capture the behaviour at an unsignalised intersection. However, Ahmed et al. (1996) found that the probit model had a limitation in dynamic traffic modelling since the function has to be normalised.

The binary logit is another approach to represent the gap acceptance behaviour. Kita (1993) used a binary logit to capture the gap acceptance behaviour in the merging area. Cassidy et al. (1995) extended the binary logit to estimate the critical gap value which is mean value of the sample population. They assumed each gap event at a specific time (t) was an independent event. Their research, therefore, presumed a gap sequence where each driver may reject several gaps and only accept one gap event.

Discrete choice modelling is the latest approach in gap-acceptance behaviour. This approach is relatively well-known in transport research areas, especially in transport economics. Many researchers extend the used of discrete modelling to capture the driving behaviour. They presume that each driver faces a discrete situation while he or she decides either to accept or reject the available gap. Moreover, a number of studies have found that this approach is able to capture the heterogeneity of driving population during a specific observation period. This method has been applied in gap-acceptance modelling research i.e. (Toledo et al., 2009, Kusuma, 2009, Toledo, 2003, Ahmed, 1999, Ahmed et al., 1996).

The previous discrete choice application in driving behaviour captures gap-acceptance in several road sections i.e. merging and diverging area, junction, roundabout. Therefore, this research extends the use of discrete choice application to analysis of the gap acceptance behaviour in weaving section.

3. DISCRETE CHOICE MODEL OF GAP ACCEPTANCE

3.1. Overview of Discrete Choice Modelling

A discrete choice model assumes that the *probability of individuals choosing from a given set of alternatives is a function of their socioeconomic characteristics and the relative attractiveness of the alternatives. The model presumes that each individual/driver faces at least two sets of alternatives* (Ortuzar and Willumsen, 2007). However, the driver picks only the alternative that maximises their utility. The discrete choice in this proposed research represents the probabilistic function of each driver to choose a set alternative.

In short, each set alternative has three characteristics (Train, 2003); (i) the alternatives must be mutually exclusive, meaning that the driver chooses one alternative and disregards the others, (ii) the set of alternatives are exhaustive, assuming that all the related alternatives can be included. (iii) The number of alternative is finite. There are four common ways to manage the discrete choice, which are logit, General Extreme Value (GEV), probit and mixed logit. Most driving behaviour research applies the logit model , since it has good capability to capture the unobservable parameter that is uncorrelated over the alternatives and same variance for all alternatives (Train, 2003).

This paper applies a discrete choice model in order to represent the decision-making process during the weaving section. To do so, it is necessary to ensure that the unobservable parameters of one set alternative are not related with the other alternatives. The discrete choice model consists of two parts; (i) the explanatory variables $V_{nq}$and (ii) an unobservable parameter(ε_{nq}). The formula can be written as follows;

$$U_{nq} = V_{nq} + \varepsilon_{nq} \tag{1}$$

where,

U : utility function,
V : observable variables,
ε : error terms,
n : individual identification, and
q : decision identification.

There are two basic characteristics for the discrete choice model. First, the characteristic of choice probability is independent from irrelevant alternatives (IIA). Second, the error term (ε_{jq}) distribution is Independently, Identically Distributed value (IID). Moreover, the IIA characteristic in discrete choice model is a condition where each of set alternative has non-zero probability of being chosen, and the probability of being chosen an alternative does not depend on the presence or absence of any additional set of alternative for each driver (Train, 2003, Ortuzar and Willumsen, 2007). This characteristic leads the discrete choice modelling to maximise the utility of set alternative.

The utility function (1) assumes that all individuals are homogeneous and share the same set of alternatives and face the same constraints (Domencich and McFadden, 1975). In addition, $\boldsymbol{V_{nq}}$ is a function of the attribute q and this may differ from one individual to the other and assumes that the residual $\boldsymbol{\varepsilon}$ is a random variable with mean 0 and a specified probability distribution (Ortuzar and Willumsen, 2007).

There is a difficulty to observe the error terms, therefore, it is held at a certain level then the probability function. To derive the analysis, it is necessary to ensure that the residual ε follows a certain distribution. Therefore we can write the error term as a function$f(\varepsilon) = f(\varepsilon_1, \varepsilon_2, \dots., \varepsilon_n)$. Let the probability of utility function;

$$P_{nq} = \int_{Rn} f(\varepsilon)\, d\varepsilon \tag{2}$$

It is necessary to note that the random utility model is assumed to follow the independent and identically distributed (IID) residuals.

Then, the equation 2 can be moldered into;

$$f\left(\varepsilon_1,\varepsilon_2,...,\varepsilon_n\right)=\prod_n g\left(\varepsilon_n\right) \tag{3}$$

In this case, the $g\ (\varepsilon_n)$ relates to the set of alternatives $\boldsymbol{A_n}$, then the general expression for the probability of utility function in equation 3. The equation 4 can be written;

$$P_j=\int_{-\infty}^{\infty} g\left(\varepsilon_n\right)d\left(\varepsilon_n\right)\prod_{m\neq n}\int_{-\infty}^{V_n-V_m+\varepsilon_n} g\left(\varepsilon_m\right)d\varepsilon_m \tag{4}$$

A simplification of equation (4) with the G function (4) can be written;

$$G\left(x\right)=\int_{-\infty}^{X} g\left(x\right)dx \tag{5}$$

In other words, $G(x)$ is a total summation of all discrete situation that the driver has faced during a specific time t. it is important to keep in mind that the prerequisite of IID should be independent.

The discrete choice model in this research needs to be extended, considering that it shall capture the variation of time for one driver, and the variation among different drivers. In other words there are two types of error terms representing those two variations respectively.

3.1 Gap Acceptance Function

The application of discrete choice in gap-acceptance behaviour should capture the driver's preference and characteristics as random variables which are distributed across the specific time (t) period. To observe the heterogeneity of gap function among the drivers at time (t) period, we extend the equation 1 into;

$$G_n^{acc}\left(t\right)=G_n\left(t\right)+\varepsilon_n^{acc}\left(t\right) \tag{6}$$

where,

$G_n^{acc}(t)$: gap acceptance of *n* driver at the specific *t* time period,

$G_n^{cr}(t)$: components of critical gap that represent each driver characteristic, and

$\varepsilon_n^{cr}(t)$: random error term at the specific t time period.

And then, it is necessary to assume that $G_n^{cr}(t)$ and $\varepsilon_n^{cr}(t)$ are mutually Independent Identically Distributed (IID).

This current paper enhances the discrete choice model for representing the Gap acceptance behaviour in the weaving section of a motorway. The structure of the gap acceptance model shall follow the driver decision making process considering that each driver has only two alternatives either to accept or reject each gap event. In fact, there are four types of gaps that need to be considered since two vehicles at least are involved in the weaving movement. Each vehicle has to consider the gap event in their current lane and the target lane. More details of the gap event in weaving movement will be discussed in section 4.1

3.2 Likelihood Function

This research applies the likelihood function as a statistical estimation technique. The application of the likelihood function in this paper is to define the parameter value that maximises the summation of probability for choosing an alternative. This statistical approach is able to minimise the variance unbiased estimator for the actual parameter. Moreover, the likelihood function presumes that each choice is affected by previous experiences and decisions (Ahmed et al., 1996).

Considering the objective, the maximum-likelihood function can be written as follows;

$$\prod_i (P_{ni})^{y_{ni}} \tag{7}$$

where,

y_{ni} : the status of set of alternative. 1 = accepted the alternative, 0 = rejected the alternative,
P_{ni} : the probability function of the alternative,
n : driver ID, and
i : the sequence of gap-event for each driver.

Due to the IID characteristic of discrete choice modelling, each individual's decision is assumed to be independent from the other decisions makers. Moreover, each individual decision is also independent from his or her past decisions. The assumption transforms the likelihood function into;

$$L(\beta) = \prod_{n=1}^{N} \prod_i (P_{ni})^{y_{ni}} \tag{8}$$

Moreover, the likelihood function is the summation of logarithmic value of the probability for each individual decision. The maximum likelihood function is written as follows;

$$LL(\beta_j) = \sum_{n=1}^{N} \sum_i y_{ni} \ln(P_{ni}) \tag{9}$$

The research is only interested in the chosen set alternative (y_{ni}=1) and also average β_j parameters that maximise the likelihood function. To do so, we divide the summation of $\beta_j$parameters with the sample size (N). Then, equation 9 is written as;

$$LL(\beta_j) = \frac{\sum_{n=1}^{N} \ln P_n(\beta_j)}{N} \tag{10}$$

Analysing the average β_j parameters does not affect the maximum summation value of the probability, as well as N is fixed (Train, 2003). Additionally, All the procedures work identically whether the N parameter is applied or not.

The maximum summation of probability can be defined by increasing the β_j parameters of the likelihood function. The researcher shall specify the starting β_j parameters, which are well known as β_0 equal to 0. They iterate and increase the value of β_j parameters until the further maximum value of the log-likelihood cannot be found. The processes need a massive computation hence it is necessary to use mathematical programming.

Eventually, it is necessary to evaluate β_j parameters and the step size for each iteration process. The first derivative of $LL(\beta_j)$, which is known as the gradient, may show if the iteration direction either increases or decreases the β_j parameters. This is the first derivative condition;

$$g_t = \left(\frac{\partial LL(\beta_j)}{\partial(\beta_j)} \right)_{\beta jt} \tag{11}$$

If the gradient is positive, it tells the programming to increase the β_j parameters. On the other hand a negative sign indicates the programming to move the β_j parameters backward. The gradient is in K x 1 vector. The explanation of likelihood function is needed considering that this is a part of iteration process. This current research sets up the code and iterates the process in R.

4. APPLICATION OF DISCRETE CHOICE TO WEAVING BEHAVIOUR

4.1 Modelling Formulation

The weaving movement involves at least two vehicles or more considering that each vehicle needs to adjust its current lane to the target lane. During the weaving movement, those weaving vehicles shall interact to adjust their relative position among the other vehicles. The traffic interaction among the weaving traffic can be illustrated as;

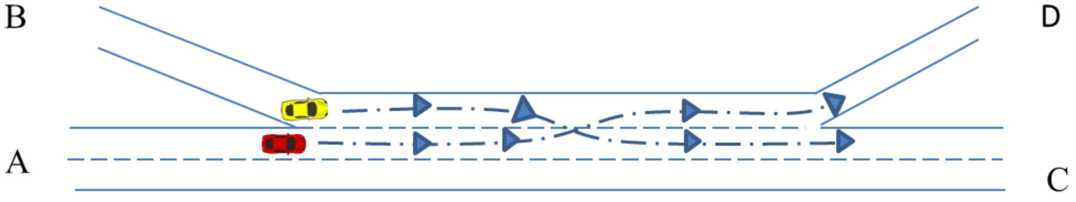

Figure 3. Weaving movement interaction

Figure 3 illustrates the interaction among the weaving vehicles. There are two vehicles planning to weave; one vehicle drives to exit slip road “C” meanwhile the other vehicle may join the through traffic. Those two vehicles interact with each other and the vehicles surrounding them in an attempt to find an optimum-weaving situation.

Moreover, this proposed research focuses only on the traffic that moves from the main-stream traffic to exit slip road (B to C) and from the enter slip road to the main stream of traffic (A to D). Each driver, who plans to weave, observes the traffic around him/her and the other vehicle that plans to cross or exchange the lane at the same time. During the interaction process, the driver considers all traffic information surround him/her such as type of vehicles, current speed, gap events, distance to exit ramp or to merge. The driver evaluates all the information and then decides either to accept or reject the traffic situations regarding to his/her preferences.

Referring to Figure 3, the driver decision making process can be derived in more detailed level as;

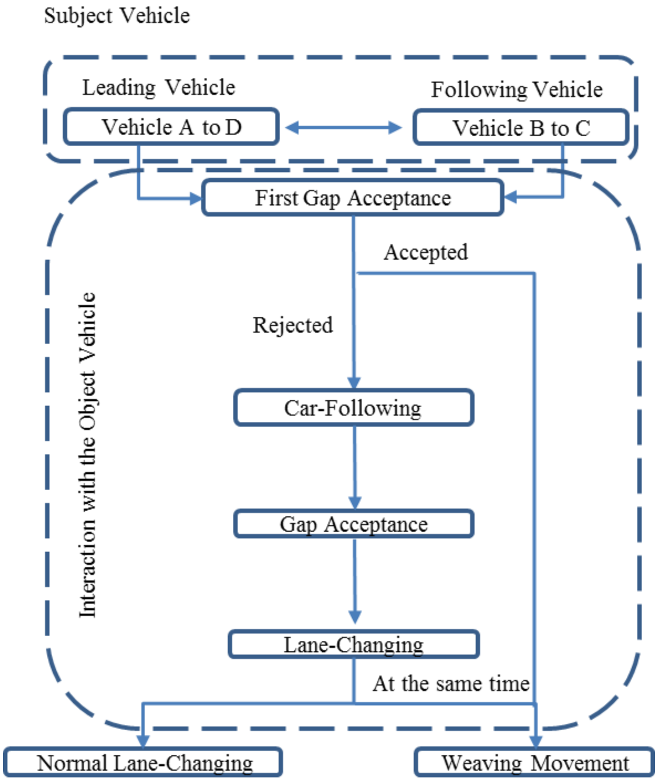

Figure 4. Weaving movement decision process

Figure 4 shows that there are two groups of vehicles: “Subject vehicles” and “Object vehicles”. The subject vehicles are two vehicles that plan to shift their lane without any traffic aid at the same time and in the same space; in other words those vehicles decide to weave at some point during the weaving section. Moreover, there two types of Subject Vehicle, which are the leading and following vehicle. The object vehicles are all the vehicles that affect the weaving movement decision-making process.

An interaction among the two subject vehicles and object vehicles occurs as soon as those two vehicles plan to weave and turn on their indicators. Those subject vehicles put their effort to find their first weaving opportunity. In other words, the drivers try to accept the first gap event that they face as soon as they come into the weaving section. This research models the situation as the “First Gap Acceptance” by using the discrete choice model. Moreover each subject vehicle has its own preference to accept or reject the first gap event. The weaving movement will take place if both of them accept the situation at the same time.

If one of the subject vehicles rejects the first gap opportunity then the drivers shall change their driving mode into car-following. The subject vehicles in this case need to adjust their current speed to follow and maintain a safe gap between the object vehicles, especially the frontward traffic in their current lane. The drivers under this mode drive in their current lane until they find the accepted gap in their target lane.

Similar to the first gap acceptance decision making process, the next weaving movement opportunity will be executed if those two subject vehicles accept the provided gap event. There is also a possibility that only one vehicle accepts the next gap event, and then the driving mode changes into lane-changing behaviour. This traffic situation is under lane-changing mode, such as merging, diverging or an overtake situation. And then, the other subject vehicles shall drive in car-following mode for several reasons; i.e. safety issues, change the destination etc.

4.2 Mathematical Formulation

This paper applies gap acceptance as a result of interaction of traffic and driving characteristics. It is assumed that each subject vehicle may seek a gap with an equal or higher utility as the accepted gap. There are three possibility modes in weaving movement model; (i) weaving movement; if those two drivers find their highest utility at the same time, (ii) car-following, if both of the drivers do not accept the traffic condition. (iii) lane- changing movement, if only one driver gets the highest utility. Table 1 represents those three utility conditions (symbols refers to equation 1)

Table 1. Driving mode conditions

Vehicle Id			Driving Mode
Leading Vehicle (n)		Following Vehicle (n+1)	
$U^{Gap}_{\mathrm{n,tar}} > U^{Gap}_{\mathrm{n,cur}}$	and	$U^{Gap}_{\mathrm{n+1,tar}} > U^{Gap}_{\mathrm{n+1,cur}}$	Weaving Movement
$U^{Gap}_{\mathrm{n,tar}} > U^{Gap}_{\mathrm{n,cur}}$	and	$U^{Gap}_{\mathrm{n+1,tar}} < U^{Gap}_{\mathrm{n+1,cur}}$	Lane-Changing*
$U^{Gap}_{\mathrm{n,tar}} < U^{Gap}_{\mathrm{n,cur}}$	and	$U^{Gap}_{\mathrm{n+1,tar}} < U^{Gap}_{\mathrm{n,cur}}$	Car-Following

*) the reverse condition is also possible

Referring to equation 1 and Figure 3, this paper modifies the utility function (U) so tah it shall cover the subject vehicle ID, the location of gap event. The weaving movement involves two subject vehicles, which are the leading and following vehicle respectively. They plan to weave and adjust their current lane where the leading vehicle is represented as n while the following vehicle is n+1. In this regards, both of them seek the safest gap situation at their current lane (cur) and target lane (tar). The vehicles will decide either to stay in their current lane or move to the target lane.

Therefore, Figure 5 illustrates the gap event that may occur inside the weaving section.

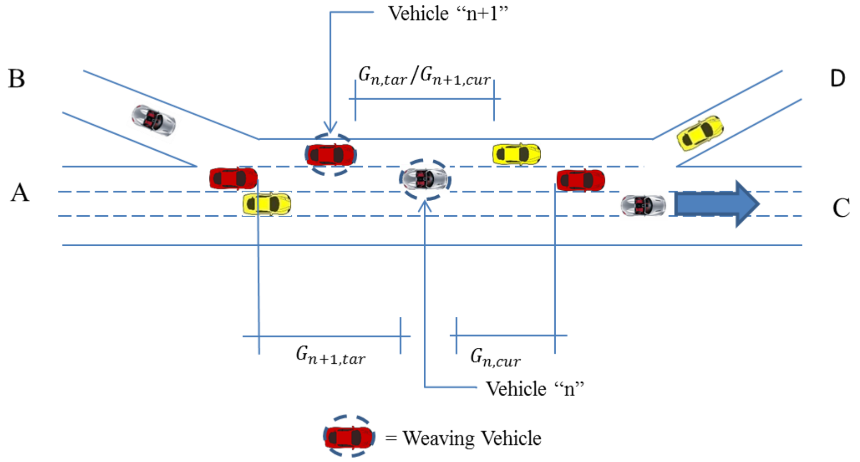

Figure 5. Gap event on weaving section

where,

$G_{n,q}$: available gap event,

n : leading vehicle in weaving,

$n+1$: following vehicle in weaving, and

q : the lane decision {cur (current lane) , and tar (target lane }.

Then, this current paper develops the gap acceptance utility function for weaving model based on equation 6, and Figure 5;

$$G_{n,q}^{weave} = X_{n,q,j}^{weave}(t).\beta_j + \varepsilon_{n,q,j}^{weave}(t) \tag{12}$$

Equation 12 is in the linear form. This may lead to negative sign result whereas in fact a negative value for the gap event is not possible. Transforming the equation into the exponential form helps the model to avoid negative values. The exponential form gives the positive result intended, then the equations becomes;

$$G_{n,q}^{weave} = \exp\left(x_{n,q,j}^{weave}(t).\beta_j + \varepsilon_{n,q,j}^{weave}(t)\right) \tag{13}$$

where,

$G_{n,q}^{weave}$: the utility function of observed gap event in target lane and current lane,
$x_{n,q,j}^{weave}$: explanatory variables (j: type of vehicle, distance to exit or length of weaving segment, speed and etc),
n : subject vehicle ID (n: leading vehicle, n+1: following vehicle),
q : the lane decision {tar (target lane), cur (current lane)},
j : number of explanatory variables,
β : constant,
$\varepsilon_{n,q,j}^{weave}$: error terms,
exp : the exponential value, and
t :specific time frame.

The weaving movement assumes that the driver must accept all the four gap event conditions (see Table.1). Applying equation 12, the probability function of accepting a gap can be written as;

$$\begin{aligned} &P(weave \mid t) = \\ &P(veh_n lane_{cur} gap_{acc} \mid t) * P(veh_n lane_{tar} gap_{acc} \mid t) * P(veh_{n+1} lane_{cur} gap_{acc} \mid t) \\ &* P(veh_{n+1} lane_{tar} gap_{acc} \mid t) \end{aligned} \tag{14}$$

$$\begin{aligned} &P(weave \mid t) = \\ &P\left(G_{n,cur}^{acc}(t) > G_{n,cur}^{weave}(t)\right) * P\left(G_{n,tar}^{acc}(t) > G_{n,tar}^{weave}(t)\right) * P\left(G_{n+1,cur}^{acc}(t) > G_{n+1,cur}^{weave}(t)\right) * \\ &P\left(G_{n+1,tar}^{acc}(t) > G_{n+1,tar}^{weave}(t)\right) \end{aligned} \tag{15}$$

Using equation 15, the probability that the gap is accepted gap could be written as follows;

$$P_t\left(G_{n,q}^{acc}(t) > G_{n,q}^{weave}(t)\right) = \phi\left(\frac{\ln\left(G_{n,q}^{weave}(t) - x_{n,q,j}^{weave}(t).\beta_j\right)}{\sigma_{\varepsilon_{n,q,j}}}\right) \tag{16}$$

Then, if the available gap is rejected than the formula for accepted gap is;

$$P_t\left(G^{acc}_{n,q}(t) > G^{weave}_{n,q}(t)\right) = 1-\phi\left(\frac{\ln\left(G^{weave}_{n,q}(t) - x^{weave}_{n,q,j}(t).\beta_j\right)}{\sigma_{\varepsilon_{n,q,j}}}\right) \tag{17}$$

4.3 Observation and Data Extraction

This research chooses a weaving section in A5103, which is a part of UK's motorway network, as the case study. The observed weaving section is a dual carriageway, and each carriageway has four lanes where three lanes are used for through traffic and one additional lane between the entry and exit slip road.

The data extraction for gap event and the explanatory variables are based on the raw video used in Al-Jameel's PhD theses (Al-Jameel, 2011). The video was recorded from two way traffic on the A5103 for 45 minutes period between 15:30 and 16:15 on 28th June 2010. The current extraction process is only for a 5 minute period, between 15:35 and 15:40. This current study focuses on one direction (north bound towards Manchester city centre).

The research applies computer software known as Semi-Automatic Video Analyser (SAVA) in order to handle the explanatory variables extraction process. This software was developed by Kungliga Tekniska Hogskolan (KTH), Sweden. SAVA records each vehicle passage time at specific locations during the observation time. In addition the researcher needs to define their own virtual measurement location. The current extraction process records the passage time in three virtual locations M, N, O, and P (see Figure 6). In this case the distance among the virtual locations is 50 metres. Each virtual location has four virtual lines based on the lane numbers in Figure 6.

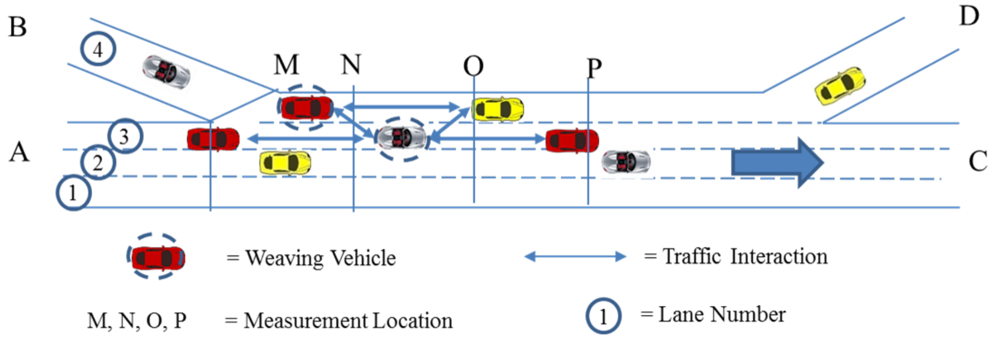

Figure 6. Data collection point

It is important to acquire a clear picture of the weaving section and a constant length between the measurement points in order to have better picture of traffic interaction. If A loop detector location exists, then it can be one of good location to put the virtual measurement location in SAVA. This approach may simplify the data validation process, considering that the research may validate directly the SAVA passage time with loop detector data.

An example of weaving movement in Figure 6 is a situation where the M records the passage time of a vehicle "n" in lane 3 and then the N records the vehicle "n" in lane 4. This example is categorised as lane changing situation. Furthermore, if vehicle "n" moves from zone M in lane 4 to zone N in lane 3 at the same time that vehicle "n+1" moves from lane 3 to lane 4, this situation is classified as a weaving movement.

5. RESULT

5.1 Traffic Characteristic

During the five minutes period, there are 524 vehicles passing through the A5103. The traffic consists of Car (79.8%), Multi-Purpose Vehicle (7.1%), Van (6.7%), Light-Goods Vehicle (3.1%), Heavy-Goods Vehicle (1.9%), Bus/Coaches (1%) and Motorcycle (0.6%).

The speed measurement is based on the passage time of each vehicle in three measurement points M, N, O, and P (see. Figure 6). The average speed between zone M and N is around 69.07 kph (42.83 mph), then the speed increases to 92.67 kph (54.45 mph) in second 50 metres section (N to O). The speed slightly drops to 54.23 kph (33.62 mph) between zone O and P. Furthermore, the 85th percentile speed is around 85.42 kph (52.95 mph), 109.17 kph (67.69 mph), 66.68 kph (41.36 mph) between zone M to N, zone N to O and zone O to P respectively. This finding illustrates that there are speed reductions due to the impact of lane changing or weaving movements.

The majority of the vehicles run on the left lane or lane 3 (45%) then by middle lane or lane 2 (22.1%), auxiliary lane or lane 4 (18.3%) and Right lane or lane 1 (14.3%). In addition, the researcher observed that there were 81 weaving and lane changing movements during the five minutes period.

Moreover, most of the weaving movement occur between left lane or lane 3 and auxiliary lane or lane 4. The lane changing traffic from lane 3 to 4 is around 34.5% of the total traffic. The preliminary result shows that most of the lane changing happens between the zones M and N. The simple gap acceptance analysis finds the driver accepts 3.44 sec and 5.88 sec in their current and their target lane respectively. This situation indicates that the vehicles seek a longer gap event in their target lane compared to their current lane.

The parameters extracted from the traffic video included: type of leading vehicle, type of following vehicle, type of vehicle in front of leading vehicle, type of backward vehicle of leading vehicle, type of vehicle in front of following vehicle at current lane, type of backward vehicle of following vehicle, gap event at current lane of leading vehicle, gap event at current lane of following vehicle, gap event at target lane of leading vehicle, gap event at target lane of following vehicle, travel time of leading vehicle, travel time of following vehicle, speed of leading vehicle, speed of following vehicle, distance to exit of leading vehicle, distance to exit of following vehicle, acceleration rate of leading vehicle, acceleration rate of following vehicle, and relative speed difference between the leading and following vehicle, status of weaving behaviour.

An application of a dummy variable in several parameters is needed to simplify the analysis of the weaving model. The following parameters adopted a dummy variable: type of leading vehicle, type of following vehicle, type of vehicle in front of leading vehicle, type of backward of leading vehicle, type of vehicle in front of following vehicle, type of backward of following vehicle, and status of weaving behaviour of each observed at time (t). This research classifies the type of subject and object vehicle into two types which are small (such as car; Multi-Purpose Vehicle, Van) and heavy vehicle (such as; Light-Goods Vehicle, Heavy-Goods Vehicle) by introducing dummy variables (0 = heavy vehicle) and (1= small vehicle). Moreover, the status of subject vehicle classifies in two types of movement either stay at current lane as 0 or move to the target lane as 1.

5.2 Gap Acceptance Analysis

The researcher iterates and presents the result for the 81 registered weaving and lane changing situations for the peak five minutes period, between 15:35 and 16:40. The data extraction result shows that the majority of weaving movement occurs between the left lane (3) and the exit slip road (4). The proportion of the weaving traffic between the lane 3 and 4 is around 47.9% of the total traffic. The data also illustrates that most of the lane changing movements happen from the left lane to exit slip road (26.0%) rather than the entry slip road to the left lane (15.1%).

The iteration process in "R" gives four utility models of gap acceptance behaviour in weaving section. The four utility models represent the gap acceptance for: the leading vehicle and the following in their current lane, lead vehicle and the object in target lane, following vehicle with the object vehicle in current lane, following vehicle with the object vehicle in target lane.

Table 2 Beta parameters result

Types of Variables	Beta value			
	Leading Vehicle		Following Vehicle	
	Current lane	Target lane	Current lane	Target Lane
Constant	-2.126 (-0.919)	1.238 (2.210)	-0.013 (-0.021)	1.756 (1.134)
Type of Vehicle	1.100 (1.141)		1.011 (1.402)	
Type of Following Vehicle		-0.920 (-1.576)		
Speed of Leading Vehicle	-0.028 (-0.902)			
Distance to Exit	0.011 (1.892)			0.001 (0.215)
Acceleration		-0.038 (-2.864)	-0.013 (-0.747)	
Relative Acceleration				-0.052 (-3.117)
Relative distance to lead				-0.042 (-2.952)
LL (β)	-172.427			
LL (0)	-209.213			
Chi-square test	73.572			
No. of Observation	81			
Likelihood ratio test	0.175			

The iteration process considers all extracted variables in section 5.1l. There are three types of statistical tool in this research which are t hypothesis, chi-square and likelihood ratio test. The application of those statistical approaches is to define the optimum model compare to other tested model.

5.3 Statistical Analysis

In the hypothesis test, it is necessary to ensure whether the parameter is not equal to zero. Moreover, this paper applies one-tail test with 90% level of confidence considering that the gap event must be in positive value. The t-test shows that most of the parameters have a significant effect. However, there are some of parameters that in significant since t-value is lower than the critical value such as; type of leading vehicle at target lane, speed of leading vehicle at current lane, acceleration rate at the current lane and two constant of the following vehicle at current lane and target lane as well. However, this research considers holding on those parameters considering that variables may affect the behaviour the gap acceptance behaviour.

Moreover, the paper applies the chi-square tests to capture the independency of among the variables in the model. The test shows that the chi-square value is large compare to the critical value. It means that all the type of variables in the modelling are independent.

The last statistical test is the McFadden Rho due to test the level of goodness of fit. This test illustrates the relative number to any null hypothesis, which helps the researcher to select the appropriate model. The McFadden Rho value in the modelling is relatively low goodness of fit where the value equals 0.175. Furthermore, it is the optimum McFadden Rho which the researcher can find after the number of iteration process.

Several indicators may affect the t values and the likelihood ratio in this research such as the coverage of recording area, data extraction process, consistency of the distance of measurement location and variation of vehicle types.

5.4 Modelling Interpretation

There are four mathematical models. Moreover, the first two models represent the gap acceptance behaviour of the leading vehicle on the current lane and target lane. Then, the other two models represent the gap acceptance behaviour of the following vehicle on their current and target lane respectively.

$$
\begin{aligned}
&G^{weave}_{n,cur} = \\
&\exp(-2.126 + 1.100 * Type\_of\_Leading\_Vehicle - 0.028 * Speed\_of\_ \\
&Leading\_Vehicle + 0.011 * Dis\tan ce\_to\_exit\_of\_Leading\_Vehicle)
\end{aligned} \tag{18}
$$

$$
\begin{aligned}
&G^{weave}_{n,tar} = \\
&\exp(1.238 - 0.920 * Type\_of\_Following\_Vehicle \\
&-0.038 * Acceleration\_Rate\_of\_Leading\_Vehicle)
\end{aligned} \tag{19}
$$

$$
\begin{aligned}
&G^{weave}_{n+1,cur} = \\
&\exp(-0.013 + 1.011 * Type\_of\_Following\_Vehicle - 0.013 * Acceleration\_Rate)
\end{aligned} \tag{20}
$$

$$G_{n+1,tar}^{weave} = \exp(1.756 + 0.001 * Distance\_to\_Exit\_of\_Following\_Vehicle - 0.052 * Relative\_Acceleration - 0.042 * Relative\_Distance\_to\_Lead\_Vehicle) \quad (21)$$

The model of leading vehicle's gap acceptance behaviour consist four parameters which are constant, type of vehicle, speed of leading vehicle and distance to exit slip road. The type of vehicle has positive sign. In the other words, the small vehicle (dummy variable=1) pretends to accept larger gap compare to the heavy vehicle (dummy variable =0). The leading vehicle speed parameter indicates to reduce the gap-acceptance time, since it has negative sign. That is to say that a faster vehicle is more aggressive compare to the slower vehicle. The last parameter in the model is distance to the exit slip road. The distance parameter indicates that a leading vehicle pretends to accept smaller gap in their current lane where he or she becomes closer to the exit-slip road.

The target lane modelling for the leading vehicle has three parameters which are constant, type of following vehicle and acceleration rate. The type of following vehicle has negative sign. Consequently, it reduces the target lane gap acceptance behaviour of the leading vehicle while they meet the small vehicle. This situation is in-line with a real traffic situation where a weaving vehicle shall become more aggressive, once they interact with the small vehicle (dummy variable =1). On the other hand, the leading vehicle tries to find a larger gap in target lane, if the following vehicle is heavy vehicle. Acceleration rate of the leading vehicle affects the gap-acceptance on the target lane. The model indicates that a leading vehicle with higher acceleration rate may reduce the gap-acceptance level compare to the vehicle with lower rate. That is to say that a leading vehicle with higher speed and acceleration rate intends to be aggressive and find small gap event for shifting to the target lane.

Then, the following vehicle's gap acceptance behaviour in the current lane has three parameters, which are constant, type of following vehicle and acceleration rate. The type of following vehicle has a positive sign, which is similar behaviour to the type of leading vehicle in the current lane. The modelling illustrates that the small vehicle is less aggressive compare to the heavy vehicle. The small vehicle may maintain to move in a larger gap with the vehicle in front of them. Nevertheless the heavy vehicle drives closer to the front vehicle. The model shows that a following vehicle considers the acceleration while the vehicle interacts with the current lane traffic. The vehicle in higher acceleration rate pretends to move in a smaller gap to the front vehicle compare the slow vehicle. In the other words, they are more aggressive and push the vehicle as much as closer to the vehicle in front.

The last mathematical model is the following vehicle's gap-acceptance behaviour on the target lane. The iteration process finds three parameters that affect the behaviour. The parameters are the constant, distance to exit and relative acceleration. The model shows that a vehicle tries to shift with a small gap in the target lane while they become near to exit slip road. The relative acceleration rate is the difference between the acceleration rate of following vehicle and leading vehicle. Moreover, the following vehicle finds smaller gap event in the target lane when the driver confidence that the vehicle moves in higher acceleration rate compares to the leading vehicle. The other explanatory variable in this model is relative distance to lead vehicle. The iteration result shows that the distance to lead vehicle has a negative effect to the model. In the other words, the following vehicle shall consider to accept a larger gap event in the target lane while the distance to the lead vehicle is relatively close. Moreover, the following vehicle pretends to decelerate and stay on their current lane until the driver finds an acceptable gap event.

5.5 Gap Acceptance Behaviour Based on Types of Vehicle

Using the beta parameters for each model, the overall data shows that the leading vehicles' critical gaps are 4.03 sec (current lane) and 1.36 sec (target lane) in average. And then the following vehicles critical gaps are 2.61 sec (current lane) and 4.88 sec (target lane). Moreover, the research shows the critical gap for each weaving vehicle type in their current and target lane. Due to lack of data for the interaction between the heavy vehicles, the predicted gap acceptance appears only for one vehicle data set

The modelling predicted that most of the weaving drivers require a larger gap in their current lane compared to their current lane. In other words, the weaving driver is in deceleration mode due to create a gap event between the frontward vehicles. Table 3 shows the predicted critical gap for each type of vehicles both on the current lane and target lane.

Table 3 Predicted critical gap (unit: seconds)

Leading Vehicle	Gap Event		Following Vehicle	Gap Event	
	Current Lane	Target Gap		Current Lane	Target Lane
Heavy	0.81	0.62	Heavy	4.62	15.33
Heavy	1.78	1.15	Small	2.60	7.44
Small	5.07	2.82	Heavy	1.01	5.97
Small	4.04	1.30	Small	2.67	4.03

Furthermore, Table 3 the vehicle shall to find an acceptable gap in the target lane before the vehicle start to weave or lane change. If the heavy vehicles act as the leading vehicle, the prediction shows that they are more aggressive in comparison to the small vehicle, since they accept smaller gap in their target lane. Acting as the following vehicle, the heavy vehicles need a longer gap event either to weave or in lane-changing. In this case, there is a possibility that their acceleration speed is slower than the small vehicle. On the other hand, the small vehicle accepts a larger gap compare to the heavy vehicle while it acts as the leading vehicle. The outcome indicates as well that the following vehicle is more conservative driver. Moreover the output indicates that the following vehicle seeks for the larger gap event in the target lane rather current lane. And they shift the lane immediately after the leading vehicle start to shift the lane.

6 CONCLUSION

This paper applies an algorithm of driver's decision-making process in order to capture the gap acceptance behaviour on the motorway. In practice, it was difficult to observe the behaviour directly from the field considering that each weaving driver has their own preferences in selecting the available gaps. The driver may choose an available gap based on their utility considering that the driver choose a highest utility. Applying the likelihood function, this paper finds a beta for the utility function that maximises the probability for choosing each available gap both in the current and target lane respectively. The model data comes from the traffic video recording on a weaving section on four lanes dual carriageway in UK Motorway road network.

This methodology gives more flexibility for the researcher to capture the gap acceptance behaviour and driving characteristic. Several researchers have successfully applied this methodology in junctions, roundabout, merging and diverging areas. Therefore, this paper extends the methodology for analysing the gap acceptance behaviour in weaving traffic. The paper finds number of parameters that affected the weaving behaviour of among the leading and following vehicle. Furthermore, the parameters consists such as; type of leading and following vehicle, speed of leading vehicle, distance to exit slip road, acceleration rate and relative acceleration rate between the following and leading vehicle. Those parameters fit to replicate the real traffic situation.

Moreover, the analysis indicates that the leading weaving vehicle considers smaller gaps compared to the following vehicle. The leading vehicle accepts a gap of 4.03 sec (current lane) and 1.36 sec in (target lane). Meanwhile the following vehicle requires a smaller gap to execute lane changing and weaving movement. The following vehicles critical gaps are 2.61 sec (current lane) and 4.88 sec (target lane). The model shows that the heavy vehicle is more aggressive compare to the small vehicle driver. However, in comparison to the small vehicle, the heavy vehicle as a following vehicle may find a large gap event since they have lower acceleration rate. Due to lack of data for the interaction between the heavy vehicles, the predicted gap acceptance appears only for one vehicle data set. Eventually, the result shows that the heavy vehicle is more aggressive than small vehicle considering they find larger gap.

This research methodology depends on the quality of data in order to produce and improve the accuracy of gap acceptance behaviour model. A good extraction process also gives an opportunity to introduce more parameters into the model, enabling it to describe the gap acceptance behaviour in more detail.

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