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Merging behaviour: Empirical comparison between two sites and new theory development ☆

Florian Marczak [a,1], Winnie Daamen [b,*], Christine Buisson [a,2]

[a] Université de Lyon, Laboratoire Ingénierie Circulation Transports LICIT (IFSTTAR/ENTPE), rue Maurice Audin, 69 518 Vaulx en Velin Cedex, France
[b] Department of Transport & Planning, Delft University of Technology, Stevinweg 1, 2628 CN Delft, The Netherlands

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ABSTRACT

This paper presents two empirical trajectory data sets focusing on the merging behaviour on a motorway, both in the Netherlands and in France. A careful review of the literature shows that the main theories explaining this behaviour rely on the hypothesis of gap acceptance, i.e. the fact that each driver has a certain threshold value depending on among other things the distance to the end of the acceleration lane, and when the offered gap is larger than this threshold the driver decides to merge.

We conducted a detailed comparative analysis of the two data sets examining the main variables identified in our conceptual model of merging behaviour. The contribution of this paper is that the analysis does not only focus on the accepted gaps, but it also takes into account the rejected gaps. The comparison of our observations with the critical gap formula in literature showed that this formula does not take into account the strong probability of rejecting a gap, even larger than the gap finally accepted.

Moreover, we created a logistic regression model that predicts the acceptance or rejection of a given gap, depending on the gap value and the speed difference between the merging vehicle and the putative follower. We have shown that two other factors impact the probability of rejecting or accepting a given gap, but these are significant for just one of the data sets: the distance to the end of the acceleration lane and the speed difference between the putative follower and the putative leader. This shows the impact of the local situation on the merging behaviour (e.g. traffic composition, road geometry, and traffic conditions).

1. Introduction

Research into motorway bottlenecks has shown that driver behaviour at merging sections affects traffic operations and is the cause of breakdowns (Elefteriadou et al., 1995; Kerner and Rehborn, 1997; Yi and Mulinazzi, 2007). The breakdown events appear to be associated with interaction between the flow on the main motorway and the flow on the acceleration lane (or the ramp), which compete for the same capacity downstream the merging point.

Many models have been developed to describe and predict this process, and some of these models have been implemented in microscopic simulation models to provide a more realistic representation of traffic operations. However, due

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* Corresponding author. Tel.: +31 15 2785927; fax: +31 15 2783179.
E-mail addresses: florian.marczak@entpe.fr (F. Marczak), w.daamen@tudelft.nl (W. Daamen), christine.buisson@entpe.fr (C. Buisson).
[1] Tel.: +33 4 72 04 70 50.
[2] Tel.: +33 4 72 04 77 13.

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to a lack of microscopic empirical data these models have not been validated nor have the underlying assumptions been evaluated. In addition, no insights have been presented on the variability in merging behaviour, neither to show the effect of the road configuration nor to identify the cultural effect in driver behaviour.

The aim of this paper is therefore threefold. First of all, we compare merging behaviour on a site in the Netherlands to a site in France using microscopic empirical data. Secondly, using these empirical data and the results of the behavioural comparison we evaluate the assumptions of gap acceptance theory (underlying most of the developed merging models). After having observed that the gap acceptance theory is not able to reproduce the observed rejection of large gaps, we propose a model for accepting or rejecting a gap during a merging manoeuvre. This model is based on a logistic regression. The predictive power of the model, assessed on the two datasets, is 98%.

The empirical data have been obtained using a camera mounted underneath a helicopter. Using dedicated software the images have been stabilized and the trajectories have been automatically derived. As the trajectories have been obtained in a similar way for both sites, the analyses errors are assumed to be comparable for both data sets. To analyse merging behaviour of both sites, both simple and composite statistics (e.g. joint regression analyses) have been performed.

This paper starts with an extensive literature overview on experimental analyses of merging behaviour and models on merging behaviour. Then, a description is given of the data collection for Bodegraven (the Netherlands) and Grenoble (France). In chapter 4 the empirical data analyses are presented, starting with a conceptual framework containing our hypotheses on the merging behaviour (Section 4.1), followed by the global descriptive analyses (Section 4.2). Then, some particular relationships are studied in more detail, such as the relation between lengths of accepted/rejected gaps and merging location (Section 4.3), the relation between accepted gap and headway versus merging speed (Section 4.4), and the relation between merging speed and merging location (Section 4.5). Chapter 5 provides strong empirical evidence to reject the gap acceptance theory. In chapter 6 we therefore propose a model to predict acceptance or rejection of gaps based on the longitudinal position, the length of the gap and the difference in speed of the three vehicles involved into a merge: the putative leader, the putative follower and the merger. The paper ends with conclusions and recommendations for future research.

2. Literature review on experimental analyses and models for merging behaviour

This chapter discusses the existent literature on merging behaviour. Here, we start with an indication of the importance of merging behaviour in traffic operations (Section 2.1), followed by an overview of the experimental analyses of merging behaviour (Section 2.2). In Section 2.3 an overview of the merging models has been given, while Section 2.4 gives an overview of the definitions of the critical gap as applied in the most frequently used theory, the gap acceptance theory. We end with conclusions on the literature review.

2.1. Importance of merging behaviour in traffic operations

It is well known, and reported in many papers, that merges are one of the causes of motorway bottlenecks. Various characteristics of merges can be studied. Some authors concentrate on capacity sharing modelling and observations between the two entrances (Daganzo, 1995; Bar-Gera and Ahn, 2010; Chevallier and Leclercq, 2007). Other authors focus on the capacity drop caused by the merge i.e. the fact that when a merge is an active bottleneck, the total capacity is lower than what is observed in free flow (for examples of observations of this phenomenon, see Elefteriadou et al., 1995, 2006; Hall and Agyemang-Duah, 1991; Chung et al., 2007). Others look at the impact lane changes, and especially those observed at merges, can have on stop and go waves (Laval, 2005; Oh and Yeo, 2012).

The fact that numerous queues occur in merges led traffic managers to propose ramp metering strategies, which are reported to be effective. The most recent on-site experimentation is reported in Bhouri et al. (2013) where they observed that the mean loss time is reduced by 3 min using control. Also the buffer time is significantly reduced.

All those researches convincingly show the importance of correct merge behaviour analyses.

2.2. Experimental analyses of merging behaviour

Fig. 1 illustrates the various variables characterising the merging process. We focus here on the merging vehicle and the vehicles surrounding him/her. We leave out the mainline drivers' lane choice modification i.e. courtesy lane changing. The merging behaviour cannot be correctly observed through point-located measurement devices such as electromagnetic loops. Therefore, authors of papers presenting phenomenological observations of the merging behaviour use trajectory measurement devices. A trajectory in our case is the set of positions occupied in the (x,y) plane over time. Two trajectory measurement methods exist: either measuring the trajectory of the merger with an equipped vehicle (using GPS) or measuring trajectories outside of the vehicle, from video camera recordings.

A few papers were published on experimental observation of lane changers' trajectories at merge locations. Tables 1a and 1b recall the main merging characteristics presented in these papers. Some papers use instrumented vehicles (Kondyli and Elefteriadou, 2010, 2011; Sarvi and Kuwahara, 2007) where the trajectory of the subject vehicle is estimated from GPS data. The GPS device is accompanied with a set of devices allowing to capture the position of the neighbouring vehicles. This