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Driving behaviour at motorway ramps and weaving segments based on empirical trajectory data

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A B S T R A C T

In the vicinity of ramps, drivers make route choices, change lanes and in most cases also adjust their speeds. This can trigger anticipatory behaviour by the surrounding vehicles, which are also reflected in lane changes and/or changes in speed. This phenomenon is called turbulence and is widely recognised by the scientific literature and various design guidelines. However the knowledge about the characteristics of turbulence is limited. This study investigates the microscopic characteristics of driving behaviour around 14 different on-ramps (3), off-ramps (3) and weaving segments (8) in The Netherlands, based on unique empirical trajectory data collected from a video camera mounted underneath a hovering helicopter. The data analysis reveals that lane changes caused by merging and diverging vehicles create most turbulence, that an increase in the amount of traffic results in a higher level of turbulence and that an increase in the available length for merging and diverging results in a lower level of turbulence. The results of this study are useful for improving the road design guidelines and for modelling driving behaviour more realistically.

1. Introduction

In the vicinity of motorway ramps, multiple manoeuvres are performed by drivers who enter the motorway, who exit the motorway, or who cooperate or anticipate on entering or exiting vehicles. These manoeuvres involve lane changes, changes in speed, and changes in headways. This results in changes in lane flow distribution (Knoop et al., 2010, Van Beinum et al., 2017), greater speed variability and changes in headway distribution of the different lanes, with presumably a greater share of small gaps on the outside lane. In the literature and in motorway design guidelines, this phenomenon is referred to as turbulence. According to the Highway Capacity Manual (HCM, 2010) turbulence is always present in traffic. A raised level of turbulence is expected around motorway ramps (Van Beinum et al., 2016; HCM, 2010) and has a negative influence on the motorway's capacity and traffic safety (Abdel-Aty et al., 2005; Golob et al., 2004; HCM, 2010; Kondyli and Elefteriadou, 2012; Lee et al., 2003b, 2003a; Chen and Ahn, 2018). In free flow conditions the level of turbulence is expected to increase a few hundred meters upstream of a ramp and to dissolve a few hundred meters downstream of the ramp (Van Beinum et al., 2016). This concept is shown in the theoretical framework in Fig. 1.

Both literature and freeway design guidelines agree that the level of turbulence is influenced by road design, traffic volume, and driver behaviour. Several researchers have tried to assess the impacts of different manoeuvres on traffic safety and traffic operations

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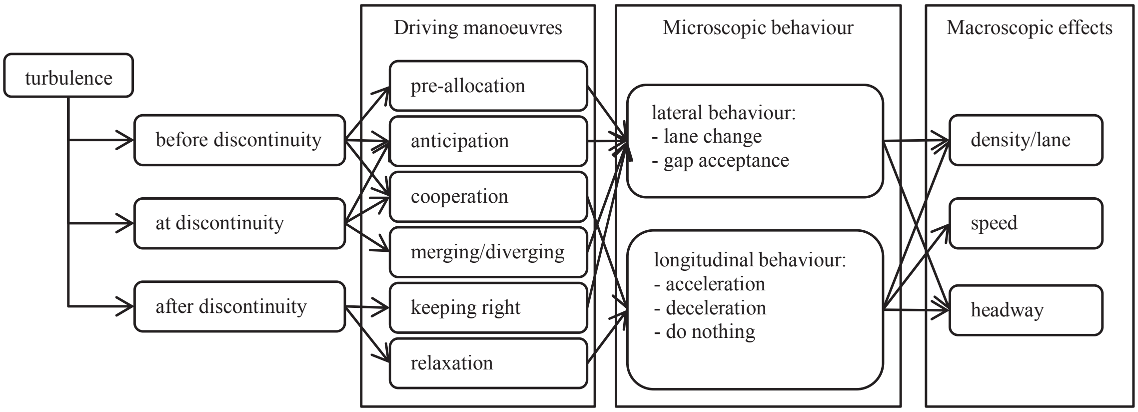

Fig. 1. Theoretical framework for turbulence (Van Beinum et al., 2016).

and the influence of design characteristics on these aspects. An overview of these studies is given in (Van Beinum et al., 2016). The available research on the characteristics of turbulence is limited and different values for the location where turbulence starts and ends are found in different studies (HCM, 2010, Kondyli and Elefteriadou, 2012, Van Beinum et al., 2017). Also the available research regarding the microscopic characteristics of the different manoeuvres is limited. To gain a better understanding of the different manoeuvres that contribute to turbulence more research is needed, preferably based on empirical data. Following this, the main research questions of this study are:

– How and to what extent do the different manoeuvers contribute to the raised level of turbulence?
– How is the raised level of turbulence affected by the amount of traffic and the motorway's design characteristics?
– Where does the raised level of turbulence start and end?

To answer these questions, the driving behaviour of the vehicles that perform the different manoeuvres was studied. For this study we have collected empirical trajectory data of individual vehicles at 14 different on-ramps (3), off-ramps (3) and weaving sections (8) in The Netherlands. The data was collected under free flow conditions, using a video camera mounted under a hovering helicopter.

The insights from this research can be used to improve microscopic simulation models and motorway design guidelines (Marczak et al., 2014; Daamen et al., 2010; Schakel et al., 2012; Hill et al., 2015; Marczak and Buisson, 2014).

This paper is structured as follows: Section 2 gives a summary of the currently available knowledge in the literature regarding turbulence related driving behaviours; Section 3 presents the method used to answer the research questions; Section 4 presents the results of the performed analysis; and Section 5 and 6 discuss and summarize the conclusions arising from the analysis.

2. Literature review

The goal of the literature review is to summarize the available knowledge regarding turbulence related driving manoeuvres around ramps and their impact on microscopic behaviour, corresponding to the theoretical framework as shown in Fig. 1. To this end, the literature study is structured as follows: first the different manoeuvres that contribute to turbulence are discussed in more detail, followed by the manoeuvre's microscopic aspects in terms of lateral and longitudinal behaviour. This section concludes by discussing the length of the ramp influence area on turbulence.

2.1. Manoeuvres

According to the theoretical framework displayed in Fig. 1, different manoeuvres are related to motorway turbulence. These different manoeuvres are graphically explained in Fig. 2.

A merge is performed by a vehicle that drives on the acceleration lane and changes lanes to enter the motorway. Studies on merging in the past 10 years show that merging is a complex combination of merging plan choice, gap acceptance, target gap selection, and acceleration decisions (Choudhury et al., 2009). Merging is also regarded to be a major cause for capacity drops at on-ramps (Leclercq et al., 2016, Chen and Ahn, 2018). Furthermore, a substantial proportion of crashes on motorways occur in the vicinity of ramps (Lee and Abdel-Aty, 2008, Lee and Abdel-Aty, 2009). Many researchers have studied the mechanisms of merging behaviour. Daamen et al. (2010) studied empirical trajectory data and found that at free flow most of the lane changes take place in the first half of the acceleration lane. Calvi and De Blasiis (2011) used a driving simulator and found that the merging length (distance between where a lane change starts and where it ends) increases as the traffic volume increases. The length of the acceleration lane did not show a significant effect on driving behaviour (Calvi and De Blasiis, 2011).

A diverging manoeuvre is performed by a vehicle driving on the outside lane and changes lanes to the deceleration lane to exit the motorway. This manoeuvre takes place at off-ramps and weaving segments. Muñoz and Daganzo (2002) found that motorway