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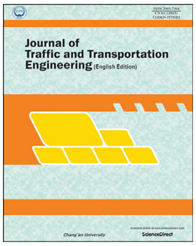

Original Research Paper

# Capacity drop through reaction times in heterogeneous traffic

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## HIGHLIGHTS

- Various causes for the capacity drop have been identified.
- Reaction times in macroscopic models have been insufficiently considered.
- A discrete approach for reaction time induced capacity drop is proposed.
- An experimental case demonstrates the validity of the approach.
- Further research on hybrid causation of capacity drop is recommended.

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## ABSTRACT

The capacity drop forms a major reason why the prevention of congestion is targeted by traffic management, as lower capacities are detrimental to traffic throughput. Various reasons describing the dynamics behind the capacity have been described, however one of these, reaction times, has had less explicit attention when modelling on a macroscopic flow level. In this contribution, a method to include the effect of reaction times for the capacity drop in heterogeneous traffic is proposed. The applied method further overcomes difficulties in including reaction times in a discrete time model through relaxation of the updating process in the discretization. This approach is novel for application in the considered first order approach, which is practise ready, contrary to many other models that propose similar approaches. The combination of the introduced method and the model form a solid development and method to apply the capacity drop based on this causation of the capacity drop. The results of the experiment case showed that the influence of traffic heterogeneity had a limited effect on the severity of the capacity drop, while it did influence the time of congestion onset. The influence of the reaction time on traffic showed greater capacity drop values for greater reaction time settings. The findings showed the method effective and valid, while the model application is also practise ready.

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## 1. Introduction

Macroscopic modelling has long been able to accurately model traffic flow and capture many traffic related phenomena. However, the capacity drop phenomenon in traffic flow is an important phenomenon that initially was not able to be reproduced in early first order traffic models. And still today, even with growing consensus on the causes of the capacity drop, there remains no one accepted cause or modelling method. This paper focuses on developing a yet limited investigated idea in modelling the capacity drop, which is caused, in part, by the reaction times of drivers to the movement of their predecessors (Kesting and Treiber, 2008). The idea that differences in acceleration and deceleration by drivers can cause the capacity drop is well known, but has not been widely investigated as a function of the reaction of drivers in congestion. This approach is further considered and developed in this paper and implemented in a state of the art first order macroscopic model with consideration of individual microscopic car following characteristics and stochastics. The model is practise ready and the difficulty of including stochastic reaction times in a discrete formulation is addressed.

The capacity drop is defined as the difference between the breakdown capacity and the discharge capacity on a section of road and can be frequently observed after traffic breakdown between observations in a critical under-saturated traffic state and an over-saturated traffic state. The occurrence of the capacity drop was originally signalled by Hall and Agyemang-Duah (1991) and Banks (1991) and was generally attributed to the so called hysteresis effect (Banks, 1991; Hall and Agyemang-Duah, 1991). The hysteresis effect occurs in part due to differing driving behaviour as vehicles enter and exit congested traffic states and is most commonly captured in macroscopic models in second order formulations. In these models, an additional equation is given that describes the dynamics of vehicle flow. There have also been attempts to include the capacity drop in first order model, such as by Laval (2004). The drop in capacity after a breakdown event is obviously detrimental to traffic flow and network performance as it reduces the potential throughput of traffic. For this reason, the prevention of the capacity drop or reduction of its effects is often targeted as an important method to improve traffic throughput within areas such as traffic management. From empirical research, it has become apparent that the capacity drop does not have a single value, but can vary from almost non-existent to values up to 30%, while values ranging from 3% to 15% appear to be most common (Zhang and Levinson, 2004). It has also been demonstrated and argued that the capacity drop, just as capacities themselves, do not hold to a static value, but are also stochastic entities (Calvert et al., 2015b; Lorenz and Elefteriadou, 2001).

Traditionally first order macroscopic models consider traffic flow based on principles laid in the LWR model, first described as a compressible fluid (Richards, 1956; Whitham, 1955), which allows general traffic flow features to be described. The LWR model has long been applied due it is the eloquent description and easy implementation in describing macroscopic traffic flow. Despite their popularity in traffic modelling, basic first order models, do not capture many of the detailed dynamics of traffic flow, such as the interaction between vehicles in various traffic states and therefore do not sufficiently describe phenomena such as kinematic waves (Kerner, 1999) and the capacity drop. This has previously been described in detail and led to the development of second order models (Aw and Rascle, 2000; Daganzo, 1995; Lebacque et al., 2007). Second order macroscopic models do allow the capacity drop to be captured, however often at a cost, such as higher calculation time, or with simplifications, such as presuming homogeneity in traffic flow. Daganzo (1995), among others, described certain flaws of second order models. Furthermore, the simplicity of first order models offers a major advantage over second order models, which has led to the proposal of many extensions for first order models to help capture more traffic dynamics while retaining much of their simplicity (Leclercq, 2007a).

In this contribution, an extension to a first order model is proposed that allows the capacity drop phenomenon to be modelled based on delays in driver reaction times in heterogeneous traffic. In heterogeneous traffic, the aggressiveness of a driver is considered by a drivers' willingness or ability to accelerate at different rates to maintain a headway, which is described in the FOMSA model, a Lagrangian kinematic wave model. In this contribution, we first give a description of the dynamics that lead to the capacity drop and the ways that this has been modelled. In Section 3, we describe the applied model and give a description of the capacity drop inducing components. In Section 4, a demonstration of the method is given, with a discussion and the conclusions given in Sections 5 and 6.

## 2. Capacity drop

### 2.1. Dynamics of the capacity drop

In traffic flow theory and modelling there are few variables that are as fundamental as road capacity. Road capacity is applied in modelling for the likes of infrastructure planning and the evaluation of traffic measures. Various interpretations of capacity exist; traditionally the capacity of a road is defined as “the maximum traffic flow on a section of road under fluent traffic conditions”. In more recent decades, capacity is seen increasingly in relation to the likelihood of a flow value being achieved as “the maximum flow rate that can reasonably be expected to traverse a uniform segment of road under prevailing roadway, traffic and control conditions”, as defined in the Highway Capacity Manual. It is well accepted that the capacity of a road can be stochastic and Lorenz and Elefteriadou (2001) define capacity as “the rate of flow along a uniform freeway segment corresponding to the expected probability of breakdown deemed acceptable under prevailing traffic and roadway conditions in a specific direction”. These definitions all relate to the breakdown capacity, often also referred to as the free-flow capacity, which indicates the traffic flow in under-saturated conditions. The discovery of a discharge capacity for over-saturated traffic flow by Hall and Agyemang-Duah (1991) and Banks (1991) and later consolidated by empirical evidence by Cassidy and Bertini (1999) among

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