Fundamental diagrams for heterogeneous traffic and their applications

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Abstract

This paper explores on how fundamental diagrams have evolved over a period of time. Fluid flow analogies are used to depict the differences and highlighting the behaviour of vehicles. The heterogeneity of vehicles is also discussed along with the underlying fundamental diagrams.

Keywords: fundamental diagrams, heterogeneity, traffic states.

1. INTRODUCTION

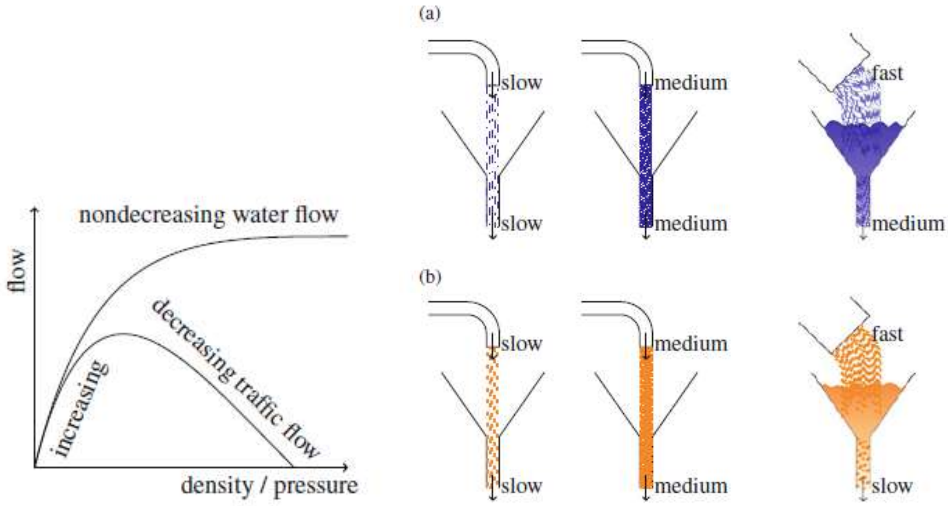
In traffic flow theory the representation of traffic state is done through the fundamental characteristics speed, flow and density. These characteristics however cannot describe the traffic state entirely, as these variables can vary greatly depending on the type of observations made. Typically the observations on the traffic variables are achieved through a variety of sensors. They can be categorized as point, mobile and space sensors. Point sensors yield the observations that are corresponding to the cross-sectional data, while space sensor gives those over a short or long stretch of a road. Mobile sensors could give the position of an individual vehicle over time. As indicated earlier the relationship among the traffic flow characteristics can give insights into the dynamics of the traffic state and its evolution over space and time. Thus the models and the associated graphical depiction of the pairwise relationships of the traffic flow characteristics can be referred to as the fundamental diagrams (Ni, 2016). In the vehicular traffic, Greenshields postulation of the pairwise relationship between speed and density can be considered as the first fundamental diagram (FD) (Greenshields, 1935).

Given the variety of the traffic states that exist in different types of environments that involve multiple vehicle types, infrastructure and driver population leads us to the need of exploring fundamental diagrams in these conditions. The multiple vehicle types can include motorized two-wheelers, trucks, buses and motorized three-wheelers besides cars, leading us to heterogeneous traffic. Also with the advent of the autonomous vehicles would necessitate the revisiting of the FDs of the conventional human-driven vehicles (HVs) and connected and autonomous vehicles (CAVs). Some studies show interesting insights into the scatter aspects of the FDs with the increased penetration of CAVs (Zhou and Zhu, 2020). This paper tries to explore the evolution of the FDs and their applications to heterogeneous traffic conditions.

2. FUNDAMENTAL DIAGARM AND ITS EVOLUTION

The flow-density diagrams with steady state equilibrium of identical driver units can be called as fundamental diagram. Here the steady state refers to the stationarity of traffic. FDs describe the theoretical relation between density and flow in these conditions (Trieber and Kesting, 2013). Thus the equilibrium relationships are theoretical and can be described by unimodal functions within certain limited range of independent variables. In the case of flow-density pair, flow as a unimodal function of density. Many researchers tried to define the properties of FDs both microscopic and macroscopic conditions. Kessels (2019) gives an excellent summary of the properties of the fundamental diagrams. Some of them are worth mentioning here. Before we plunge into these details it is important to understand the evolution of fundamental diagrams from the physical phenomenon such as flow of water through pipes and flow of granular media.

If one considers drivers choice of the speeds, the relationship between speed and density best describes this process. At low densities drivers have larger spacing and can choose speeds close to free flow, while during congested conditions the converse is true. Thus a non-decreasing function would fit this description very well. However, when this relationship is translated to flow versus density the relationship, it has an inflection point. Often the traffic flow draws heavily from fluid flow analogy, but here is the stark deviation from this analogy which is very well depicted in Figure 1.



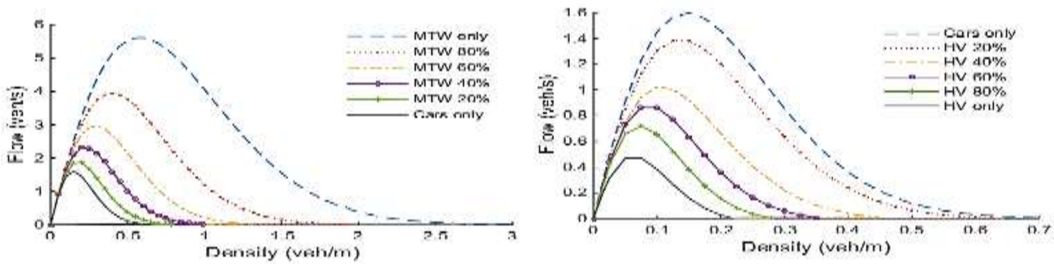
(a) (b)

Figure 1: Traffic and fluid (water) analogy (a) Flow-density curve (b) granular/agents vs. water flow through constrained exits (similar to bottlenecks) (Kessels, 2019)

The critical point that needs to be highlighted here is the inflection point, after increasing portion in Fig. 1(a). This is clearly depicted in Fig 1 (b) where granular media/agents passing through constriction as the flow goes past the peak, the throughput decreases which are in contrast to the flow of water which is non-decreasing after the peak. In the next section some idea of the multiple vehicle types and the related heterogeneity is discussed.

3. HETEROGENEITY

Heterogeneous traffic is a common sight in many Asian countries, which predominantly comprises of motorized two-wheelers (MTW), and some extent motorized three-wheelers (MThW, tuk-tuks or auto-rickshaws) besides cars and heavy vehicles (HVs). Understanding the FDs when such traffic mix is prevalent offers interesting insights into the evolution of the traffic phenomena over a range of densities (which are again defined in terms of passenger car equivalencies). In one of the recent studies by Gaddam and Rao (2020), the fundamental diagrams evolved show an interesting trend. It is observed that traffic flow and density increases with the increase of MTW proportion due to their smaller physical dimensions and shorter longitudinal headways maintained by them. In MTW only conditions, maximum flow values observed to be four times higher than that of cars only condition. However, if MTW proportion is less than 0.4, it has little effect on flow values when compared to that of cars only situation (where MTW proportion is zero). The concept of including the heterogeneity is also demonstrated by Chanut and Buisson (2003).



(a) (b)

Figure 2: Effect of (a) MTW and (b) Heavy vehicle proportion on capacity of traffic flow

4. SUMMARY

It is important to explore the FDs evolution for a variety of traffic situations. This can lead to an in depth understanding of the underlying evolution of dynamic traffic phenomena.

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