Traffic Grammar and Algorithmic Complexity in Urban Freeway Flow Patterns

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Abstract This paper uses techniques from formal language theory to describe the linear spatial patterns in urban freeway traffic flows in order to understand and analyze “hidden order” in such high volume systems. A method for measuring randomness based on algorithmic entropy is introduced and developed. These concepts are operationalized using Pincus’ approximate entropy formulation in an appropriate illustration. These measures, which may be viewed as counterintuitive, are believed to offer robust and rigorous guidance to enhance the overall understanding of efficiency in urban freeway traffic systems. Utilization of such measures should be facilitated by information generated by real time intelligent transportation systems (ITS) technologies and may prove helpful in real time traffic flow management.

Keywords Formal language theory · Algorithmic complexity · Intelligent transportation systems (ITS) · Approximate entropy
1 Introduction

Traffic flows, particularly congested ones, have patterns, which are often difficult to recognize. Even generally free-flow patterns appear to have random segments of congestion. Today many major road arteries carry two and three times their design capacities, even during off-peak periods. Although, urban vehicle miles traveled (VMTs) have increased commute times have either remained constant or shown relatively small increases (Gordon and Richardson 1994; BTS 2006). Further, even without accidents, urban traffic flows are usually operating at speeds above the posted limits. On the other hand, accident rates (per 100 million vehicle miles) are declining on many urban segments (BTS 2006). Traffic at high volume and high speeds on under designed roads should result in more accidents and slower travel times. This has not occurred. One explanation for this paradox is that high-volume congested traffic patterns may contain more orderly characteristics than otherwise appreciated.

If we could identify and understand the “hidden order” in these linear spatial flow patterns perhaps, the congested conditions on urban freeways may be classified more accurately. In turn highway design, law enforcement, and intelligent transportation system (ITS) intervention could be used more effectively to improved traffic flow.

2 Background

The dynamic nature of traffic flows on urban freeways is self-evident. The plots of workday traffic on segments of major roads against time of day display the familiar contours of lumpy, peaked curves. Over the years the peaks have become blunt and the valleys filled, suggesting nearly day long high-volume traffic. At the same time that the average travel speed on congested freeways has gone up, average commute time has either remained steady or increased marginally and the number of accidents per 100 million VMTs has gone down or remained constant (Gordon and Richardson 1994; BTS 2006). Congested traffic patterns suggest an inherent disorder or randomness. Such attributes would not be helpful in increasing the throughput of traffic systems. Could it be that there is a hidden order in the congested traffic patterns? It would be helpful to analyze and understand these linear spatial patterns to see the degree to which order/disorder associated with these patterns can be determined (Holland 1995).

Here we explore the possibility of using formal language theory to describe traffic patterns. Although we are attempting to model similarities between the formal languages and the traffic patterns, this paper does not deal with the aspects of natural languages in the tradition of Chomsky (1985) nor do we consider the universal grammars of natural languages (Cook and Newson 1996). The approach is to model the observed phenomena of traffic patterns using formal language structures (Harrison 1978; Woodcock and Loomes 1988). Once a formal language of traffic is described, we use concepts from the theory of algorithmic complexity (Chaitin 1975; Kolmogorov 1968) to study the randomness or the lack of it in the linear spatial segments of traffic flow/ patterns.

The continuing advances in ITS related technologies have greatly facilitated the acquisition and processing of real time information on urban freeway traffic conditions.