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On the distribution of urban road space for multimodal congested networks ☆

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ABSTRACT

Transport systems in real cities are complex with many modes of transport sharing and competing for limited road space. This work intends to understand how space distributions for modes and interactions among modes affect network traffic performance. While the connection between performance of transport systems and general land allocation is the subject of extensive research, space allocation for interacting modes of transport is an open research question. Quantifying the impact of road space distribution on the performance of a congested multimodal transport system with a dynamic aggregated model remains a challenge. In this paper, a multimodal macroscopic fundamental diagram (MFD) is developed to represent the traffic dynamics of a multimodal transport system. Optimization is performed with the objective of minimizing the total passenger hours traveled (PHT) to serve the total demand by redistributing road space among modes. Pricing strategies are also investigated to provide a higher demand shift to more efficient modes. We find by an application to a bi-modal two-region city that (i) the proposed model captures the operational characteristics of each mode, and (ii) optimal dynamic space distribution strategies can be developed. In practice, the approach can serve as a physical dynamic model to inform space distribution strategies for policy makers with different goals of mobility.

1. Introduction

As cities around the world grow rapidly and more people through different modes compete for limited urban road infrastructure to travel, it is important to understand how this space can be managed to improve accessibility for travelers. The ultimate goal of research towards this direction is to develop modeling and optimization tools, which will contribute on how to redistribute city space to multiple transportation modes and to understand what level of mobility cities of different structures and topologies can achieve.

Management strategies can be implemented to partition a city so that road space is deliberately allocated between competing modes. Although the allocation of this space is a policy-oriented decision, it should be informed by the correct physics and dynamics of the multimodal flows. This system can be treated as an interconnected network of regions (sub-networks) with one or more modes moving. In this extension, different parts of a city can be subject to different management strategies (see for example Fig. 1). Perhaps bus-only streets are allocated only in the central region while other parts of the city allow vehicles to operate in mixed traffic. Changes in infrastructure, demand, or operations in one region have impact on the behavior of adjoining regions. While recent findings in the macroscopic modeling and dynamics of traffic in cities have

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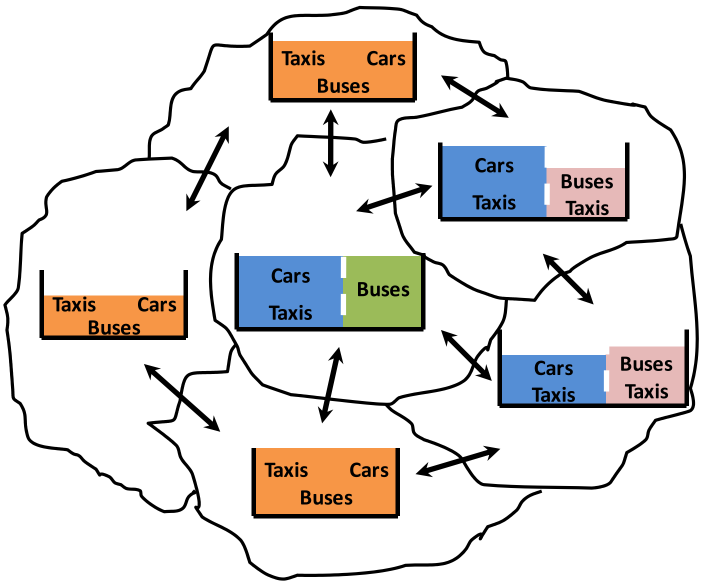

Fig. 1. A multi-region, multimodal system.

provided knowledge of single-mode/single-region cities and single-mode/multi-region cities, the understanding of multi-mode, multi-region cities is limited.

Under a multimodal environment, space should be allocated taking into account spatiotemporal differences in the demand, the topology, and the control characteristics. These spatiotemporal decisions are important because if they are made incorrectly, space could be wasted. If this wasted space could be productively used by low-occupancy vehicles without affecting the more productive modes, mobility is being restricted. For example, recent studies in Californian freeways, have questioned the effectiveness of high-occupancy vehicle (HOV) lanes and have shown that HOV lanes are underutilized and the passenger capacity of freeways has decreased, resulting in heavier congestion levels (Chen et al., 2005).

Operational characteristics should be considered as well. Despite the different features of modes in terms of occupancy (number of passengers), driving behavior (speeds, acceleration and deceleration profiles, length), duration of travel, scheduled vs. non-scheduled service, a common characteristic is the following: all of these vehicles when moving to an urban environment make stops related to traffic congestion (e.g. red phases at traffic signals) and *other* stops, which also cause delays to the transportation system as a whole, e.g. buses stop at bus stops to board/alight passengers, taxis stop frequently and randomly when they search/pick up/deliver passengers, cars may stop/maneuver when search/find a parking spot. While there is a good understanding and vast literature of the dynamics and the modeling of congestion for congestion-related stops, the effect of *service or general purpose* stops in the overall performance of a transportation system still remains a challenge. It is intuitive that the effect of these stops during light demand conditions in the network capacity is almost negligible, but nowadays city centers are experiencing high level of congestion and the frequency in time and space of the service stops is significantly high.

In this paper, we present a macroscopic approach for optimizing road space allocation for multimodal transport systems with focus on two modes of transport, cars and buses and two regions, the city center and the periphery. Extensions to more complex city structures are also discussed. This approach should not only deal with the problems mentioned above, but also will switch the interest from the currently inefficient vehicle throughput based optimization to the more efficient for networks and society, passenger throughput optimization. Congestion pricing strategies for cars are also considered to further facilitate the demand shift when preferential treatment to buses is offered.

2. Background

Existing literature on the physics of urban congestion can be divided generally into city-scale, street-scale, and car-to-car scale. City-scale investigations have thus far looked only at the behavior of *one* mode and the involved dynamics of traffic congestion. Studies of multiple modes, on the other hand, have only been made at the street-level scale for simplistic time-independent scenarios. Planning studies have looked at public transport on a city scale, particularly buses on idealized road networks. Making road space allocation decisions, however, requires consideration of interactions and dynamics between multiple modes. To date, such considerations have been made only at the much finer street scale and still in a time-independent and unrealistic environment. Thus, the existing body of work leaves a gap to be filled—a physically realistic time-dependent, city-scale model including multiple modes that interact with each other.