A bilevel model for public transport demand estimation

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Abstract

For the case of public transport, we consider the problem of demand estimation. Given an origin-destination matrix representing the public transport demand, the distribution of flow among different lines can be obtained assuming that it corresponds to a certain equilibrium characterized by an optimization problem. The knowledge of that matrix is expensive and sometimes unaffordable in practice. In this work, we explore its estimation through the numerical solution of a bilevel optimization problem.

\section{Introduction}

Transit assignment models have become an interesting research area because knowing the passenger behavior allows comparing different planning scenarios in terms of network performance, always assuming that the transport demand is known.

Many models for passenger behavior have been proposed. Most of them consider that when a passenger decides to travel between certain O-D pairs and is waiting for a vehicle at a stop, he must decide which transit line should he take to minimize his total expected travel time. Among the first models that considered congestion effects, we can cite (1) that work with the concept of hyperpath composed by ”strategies of attractive lines”, but failed to be realistic in cases of high demand.

De Cea and Fernandez (2) began to consider the congestion effects at bus stops and inside the bus. This model was improved in (3) formulating a transit equilibrium problem that uses effective frequencies functions that vanish if the in-vehicle flow exceeds its capacity. The main limitation of these methods is that the technical assumptions are very limiting in the first case and there no efficient algorithms to compute the solution in both cases.

Cepeda et al (4) decided to continue this idea and reformulated the equilibrium problem as the minimization of a nonconvex and nondifferentiable gap function. To solve this problem a heuristic method was proposed, using an adaptation of the Method of Successive Averages (MSA) and obtaining the lines flow vector. This method can

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be applied on high scale networks without computational drawbacks but can generate line flows that exceed the capacity when the demands are high. To improve this method, Codina and Rosell (5) presented an algorithm with strict capacities that find the solution of the fixed point inclusion formulation derived from the problem of variational inequality proposed by Codina (6). At each iteration an assignment problem is solved, using Lagrangian duality and the cutting-planes method.

The use of the previous models of transit assignment in any planning study requires the knowledge of the transport demand, commonly known as the origin-destination matrix. To obtain that matrix could be very expensive and sometimes unaffordable in practice. As has been made for the case of traffic assignment (see (7)), in this work we explore its estimation through some directly measurable quantities like the real frequencies of the buses. As we know how to compute, given the demand, the flows, and hence the frequencies, we pose a kind of inverse problem whose solution estimates the actual demand. Here we focus on correcting the given demand to comply with the observed frequencies. That is, given a nominal demand $\bar{g}$ and observed (measured) frequencies $\bar{f}$ over some observed arcs in $A_{obs} \subset A$, we look for the demand $g$ that minimizes

$$
\min_{g,v} \sum_{a \in A_{obs}} \left( \frac{f_a - f_a^*}{\bar{f}_a} \right)^2 + \gamma \sum_{a \in A} \left( \frac{g_a - \bar{g}_a}{\bar{g}_a} \right)^2
$$

subject to

$$
v \in V(g),
$$

$$G(v, g) = 0.
$$

As far as we know, there is no previous work about public transport demand estimation using this approach. Most of them are based on statistical or econometrical considerations, see (8; 9; 10; 11).

In the next section, we present a detailed description of the assignment model following the one presented in (4). In section 3 we pose the inverse problem used for demand estimation and in section 4 we present the numerical experiments made with the example given in (4).

References