



Estimation of population origin–interchange–destination flows on multimodal transit networks[☆]



Jason B. Gordon^{a,*}, Haris N. Koutsopoulos^b, Nigel H.M. Wilson^a

^a Massachusetts Institute of Technology, Cambridge, MA, USA

^b Northeastern University, Boston, MA, USA

ARTICLE INFO

Keywords:

Linked trip
OD matrix
ODX
AFC
AVL
Multimodal
Passenger journey
Transit

ABSTRACT

Previous research has combined automated fare-collection (AFC) and automated vehicle-location (AVL) data to infer the times and locations of passenger origins, interchanges (transfers), and destinations on multimodal transit networks. The resultant origin–interchange–destination flows (and the origin–destination (OD) matrices that comprise those flows), however, represent only a sample of total ridership, as they contain only those journeys made using the AFC payment method that have been successfully recorded or inferred. This paper presents a method for scaling passenger-journey flows (i.e., linked-trip flows) using additional information from passenger counts at each station gate and bus farebox, thereby estimating the flows of non-AFC passengers and of AFC passengers whose journeys were not successfully inferred.

The proposed method is applied to a hypothetical test network and to AFC and AVL data from London's multimodal public transit network. Because London requires AFC transactions upon both entry and exit for rail trips, a rail-only OD matrix is extracted from the estimated multimodal linked-trip flows, and is compared to a rail OD matrix generated using the iterative proportional fitting method.

1. Introduction

Public transit ridership has traditionally been measured by periodically counting riders entering or exiting stations or vehicles, and by supplementing these data with occasional surveys to relate sampled passengers' movements into journey origins, interchanges (transfers), and destinations (Ben Akiva et al., 1985; Simon and Furth, 1985; Mishalani et al., 2011). As survey response rates continue to decline and their cost and bias therefore rise (Stopher, 2008), automated fare-collection (AFC) data have been shown to provide similar origin–destination (OD) information at larger scales and with lower cost (Park et al., 2008).

AFC data have been used to measure OD flows on rail networks requiring both entry and exit transactions. Gordillo (2006) and Chan (2007), for example, use AFC data from Transport for London (TfL) to generate large samples of OD flows, and then estimate expansion (scaling) factors to increase those flows to match the total numbers of entries and exits recorded by each station's gates, which include both AFC and non-AFC travel.

Recent work has shown that linked passenger trips, or passenger journeys, can be inferred in an automated way for the majority of a transit system's riders using AFC and AVL (automated vehicle location) data. For example, TfL processes complete sets of data from their AFC and AVL systems on a nightly basis to infer bus boarding and alighting locations (rail entry and exit locations are already

[☆] This article belongs to the Virtual Special Issue on Smart Cards.

* Corresponding author at: 77 Massachusetts Avenue, Room 1–238, Cambridge, MA 02139, USA.

E-mail address: jay_g@mit.edu (J.B. Gordon).

recorded by the card), and to infer whether each bus or rail passenger trip, herein called a journey stage, was linked to the cardholder’s next through an interchange to form a multi-stage journey (Gordon et al., 2013). In this way TfL can observe the travel patterns of the majority of its customers (typically 75% of passenger journeys are inferred), but any analysis aimed at measuring passenger volumes—whether the passenger load of a single bus, the rush hour flow between two rail stations, or the number of passengers taking a distinct origin–interchange–destination path—must account for those passengers whose journeys were not inferred.

The problem of estimating population OD flows from sample OD flows is commonly solved using the iterative proportional fitting (IPF) method (Deming and Stephan, 1940). IPF and similar OD-scaling methods typically yield flows aggregated by origin and destination, regardless of the number or location of interchanges in between. The goal of this paper is to provide a methodology for estimating scaled passenger flows while preserving the intermediate interchange information. Doing so enables the estimates to (1) more closely match observed data, (2) provide journey flows without overcounting each journey’s constituent stages, and (3) be decomposed to constituent unlinked stages, for ridership analyses at the bus-route or rail-network level that are compatible across modes and services.

Section 2 of this paper elucidates the problem while Section 3 discusses previous research on OD matrix estimation; the inference of passenger origins, destinations, and interchanges (ODX); and the various applications of ODX data. Section 4 details the methodology, Section 5 illustrates and validates the methodology using a small sample network, and Section 6 describes the application of the methodology to London’s multimodal transit network. Section 7 discusses the method’s implications, applications, and suggestions for future research.

2. Problem definition

Flows of passengers are often presented in origin–destination (OD) matrices: contingency tables in which each row represents an origin and each column a destination, with each cell indicating the flow between a distinct OD pair during a given time period. This is useful for describing passenger flows between any two points, where the origins and destinations might be the entry and exit stations on a rail network, the boarding and alighting stops on a single bus route, or the geographic zones connected by a highway network. Passenger journeys can be included in OD matrices—for example, by counting the number of passengers who start at a given bus stop and end at a given rail station, regardless of their intermediate transfer locations—but the inclusion of interchange locations in addition to origin and destination locations necessitates a different analytic framework.

Rather than estimating a scaling factor for each OD pair, this work estimates a scaling factor for each passenger-journey itinerary, which is defined in this context as a unique sequence of fare-transaction nodes observed to have constituted at least one passenger’s journey during the time period being observed. The concept of transaction nodes and itineraries is illustrated with the hypothetical transit network shown in Fig. 1 (referred to hereafter as the test network).

In the context of journey scaling, a transaction node is defined as a node on the network at which a rider can tap an AFC (automated fare collection) card. If AFC data and control-total counts are available for each bus stop and rail station, each transaction node can be uniquely identified by a place (a station or stop) and a movement (a station entry or vehicle boarding, or a station exit or vehicle alighting). However, many agencies, such as TfL, require bus riders to tap only upon boarding, and bus control totals are available only at the vehicle-trip level. This study therefore defines rail nodes by station and movement (entry vs. exit) but generalizes bus nodes by route and direction (inbound vs. outbound). For example, the test network consists of the following twelve transaction nodes (inbound is considered northbound in Fig. 1):

- | | |
|-----------------|------------------|
| Station A entry | Station A exit |
| Station B entry | Station B exit |
| Station C entry | Station C exit |
| Route 1 inbound | Route 1 outbound |
| Route 2 inbound | Route 2 outbound |
| Route 3 inbound | Route 3 outbound |

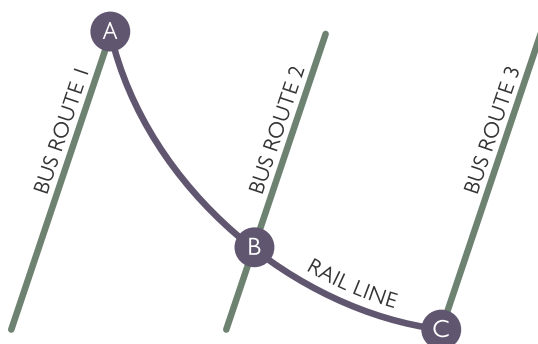


Fig. 1. The test network.

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