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Redesigning subway map to mitigate bottleneck congestion: An experiment in Washington DC using Mechanical Turk

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ABSTRACT

This paper explores the possibility of using subway maps as a planning tool to influence passenger route choice to mitigate congestion. Specifically, it tests whether extending the appearance of an overcrowded subway line on the Washington DC subway map would encourage passengers to use other underutilized lines. The experiment was conducted through the Mechanical Turk, a crowdsourcing platform, with 3056 participants, producing 21,240 route choice decisions on the official and six alternative maps. Results show that redesigned maps significantly affect participants' route choices. Depending on the specific design, a 20% length increase of the overcrowded line could move 1.9–5.7 percentage points of ridership to an alternative, underutilized line. The change could remove up to 10 passengers per car during the highest peak, reducing the number of highly congested half-hour periods (max load = 100–120 passengers per car) on the overcrowded line from 4 to 1, and the number of crush periods (max load > 120 passengers per car) from 3 to 1. This is done at minimal or zero cost. The paper calls for more attention from transit agencies to the planning potential of transit maps.

1. Introduction

A subway map is arguably the single most important information source for subway passengers. It displays the spatial information critical to passenger decisions, such as the alignment of subway routes, connecting points, and relative location of stations. However, such information is often distorted for the sake of legibility. For example, lines are streamlined to minimize curves; station spacing is often equalized; one angle (e.g. 45 degree) is frequently enforced for all turns (Ovendon, 2007); the center is often enlarged while the edge is often condensed (Jenny, 2006). As a result, a subway map may differ significantly from reality in terms of route length and directness.

Prior research demonstrated that such distortion could heavily influence passenger decisions in choosing the best route (Guo, 2011). The finding should concern transit planners, because if passengers rely on a distorted map over estimated travel time to plan their transit, traditional planning efforts based on timesaving might be less effective than expected. However, it also suggests utilizing a visual map as a planning tool to influence passenger behavior may bring surprisingly cost-effective outcomes. This paper tests the latter's possibility using the subway system in Washington DC as an example. Our experiment confirmed that a purposely redesigned map was able to switch passengers away from a bottleneck to an underutilized route, thus mitigating system congestion at minimal cost.

The research calls for more attention from transit agencies to the behavioral consequence of map design, and its plausibility as a planning tool.

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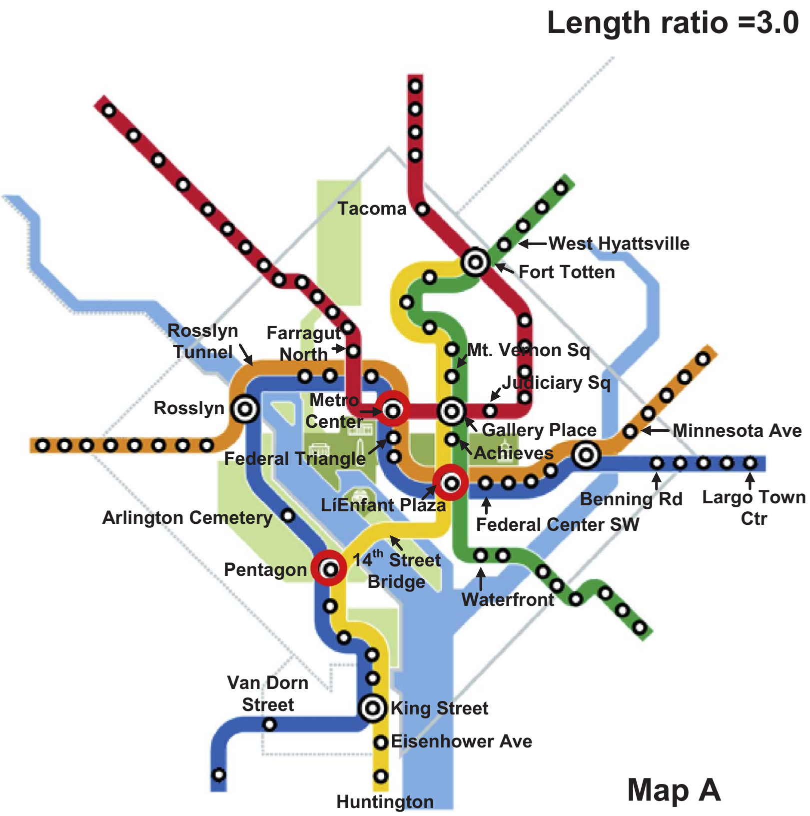

Fig. 1. Official subway map before 2014 (with 22 labeled stations).

2. Literature

Subway map design has been well-studied in the field of cartography (Berendt et al., 1998; Barkowsky et al., 2000; Wolff, 2007; Avelar, 2006, 2008; Bain, 2010). However, that literature did not focus on behavioral consequences until recent years.

One of the earliest studies was conducted by Garland et al. (1979), who examined whether color coding bus lines on a transit map in Fort Worth, TX, would affect the efficiency of trip planning. Through an experiment using 86 college students on four map designs, they found that with color coding, a transit map could enhance people's planning accuracy and confidence, and reduce perceived difficulty and frustration. However, this effect depended on the level of street network detail preserved in the bus map.

Hochmair (2009) compared two types of map designs for the Vienna subway system: one traditional schematic map and one real-scale map. Based on responses from 35 participants, he found that people follow different criteria on different maps in choosing the best route. For example, the number of transfers seems to play a less important role on the real-scale map than on the schematic map. Zegras et al. (2015) examined the impact of a schematic bus map on users' stated understanding, navigation and perceptions of the bus system in Dhaka, Bangladesh. They found the map filled a knowledge gap, provided useful information, and may stimulate 'exploration' of the city and its bus system. Roberts et al. (2013) asked 120 participants to plan their journey between five origin-destination station pairs on three different subway map designs in Paris. They found that an all-curves design that replaces straight lines and corners with gentle curves is easier to read than the map that follows the traditional rule of octolinearity with many zigzags. Although participants' route choices seem not to be affected by the two design principles, routes with many kinks (traditional design) and elongations (all-curves design) on maps tend to discourage passengers from choosing them regardless of their actual length in reality.

In a series of two papers, Raveau et al. (2011, 2014) developed a route choice model for the metro system in Santiago, Chile, using revealed route choices from 28,961 passengers over 1365 Origin-Destination pairs. They included several map attributes as independent variables, such as route directness and angular cost depicted by the schematic metro map. Both variables turned out to be statistically significant.

Guo (2011) investigated the famous tube map in London and its impact on passengers' route choice based on the actual decision of 18,894 trips over 2330 Origin-Destination pairs collected by the London Underground. He defined two variables for comparison: route map distance (length depicted on the map) and route actual distance (actual travel time along the route). The elasticity of the former is about twice that of the latter, even for those frequent users of the system. In other words, the tube map is twice as influential as travel time in affecting passenger route choice. People trust the map more than their own experience.

These studies improve the understanding of passenger travel behavior and map design, but do not directly focus on using new transit maps to improve system performance by purposely *changing* passenger behavior. This paper aims to fill that gap by answering