Mind the Map!
The Impact of Transit Maps on Travel Decisions in Public Transit

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Abstract

This paper investigates the impact of schematic transit maps on passengers' travel decisions. It does two things: First, it proposes an analysis framework that defines four types of information conferred from a transit map: distortion, restoration, codification, and cognition, and their potential impact on three types of travel decisions: location, mode, and path choices[1]. Second, it conducts an empirical analysis to explore the impact of the famous London tube map on passengers' path choice in the London Underground (LUL). Using data collected by LUL from 1998 to 2005, the paper develops a path choice model and compares the influence between the distorted tube map (map distance) and reality (travel time) on passengers' path choice behavior. Results suggest that passengers often trust the tube map more than their own travel experience on deciding the "best" travel path. This is true even for the most experienced passengers to the system. The codification of transfer connections on the tube map, either as a simple dot or as an extended link, could affect passengers' transfer decisions. The implications to transit operation and planning, such as trip assignments, overcrowding mitigation, and the deployment of Advanced Transit Information System (ATIS), are also discussed.

Keywords: Transit map; Travel information; Cognitive Map; Path choice; Tube map; London Underground

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[1] Path refers to a unique sequence of entry, transfer, and exit stations/stops in the public transit network. The author differentiates between path and route choices because the latter could refer to a situation among different service routes that follow the same physical path, which is not the purpose of this analysis.

1. Introduction

Traveling in a transit system often involves a greater degree of uncertainty than traveling on a road network due to the complexity of transit systems and the stochastic nature of services (Hickman and Wilson, 1995). Transit users often need more information in planning travel than road travelers, such as operating hours, fare and fare media, waiting and travel times, access and egress, transfers, station locations, and seat availability (Abdel-Aty et al., 1996; Cluet et al., 2003). Such information is critical to passengers' travel decisions (Khattak et al., 2003; Chorus, 2007), and the provision of information could be a powerful planning tool to guide individual decisions and to enhance the overall efficiency of the system (Polak and Jones, 1993; van der Horst, 2006).

While most studies in this field have focused on Advanced Traveler Information Systems (ATIS), this paper considers an alternative perspective and targets traditional information media. In particular, it focuses on the effect of schematic transit maps on travel decisions in public transit. The central argument is that a transit map has a tremendous impact on a passenger's perceptions and his or her usage of the transit system. If implemented appropriately, a transit map can be a valuable tool to solve planning and operation problems in a cost-effective way.

This paper first develops a conceptual framework of the impact of the map on transit travel and then focuses on a specific travel decision, path choice in public transit. The case study of the London Underground indicates that passengers often (mis)trust a transit map more than their actual experience; they often take a path that looks shorter on the system map but is longer in reality compared with alternative paths. They also try to avoid transfer stations when the coded connection on a map looks less convenient than it actually is. The implications of the map on transit planning and operations are also discussed.

2. Literature

The importance of maps to spatial behavior has been well documented (Woods, 1992; Hutchins, 1995; MacEachren, 2004). However, in the field of transportation, maps have attracted little attention. Little is known about the travel information conferred by a map to a traveler and the effect of a map on travel decisions. There have been few efforts to incorporate the map as an analytical tool for transportation planning (Jankowski et al., 2001). The author identifies only a few related studies. Garland et al. (1979) tested the effect of transit map design on the quality of trip planning. They found that when the street detail was high, color coding of transit lines led to greater trip planning accuracy, less perceived difficulty, less frustration, and higher confidence. When color coding was absent, greater street detail led to lower trip planning accuracy, greater perceived difficulty, greater frustration, and lower confidence. Hall (1983) investigated students' travel times by foot or bus from a university campus to a library 1.5 miles away. He found that those supplied with transit maps reached the destination significantly faster than those without maps did. However, students supplied with both schedules and maps were actually slower than those using maps alone. Dziekan (2008) found that a transit map is the primary source of information for passengers traveling to unfamiliar places.

Hochmair (2009) compares the effect of four different transit map designs on route choices in Vienna. He found that a transit map with headway information allowed planning for faster routes compared with a transit map lacking this information. Both map annotation and network geometry affect the selection of the fastest route.

Three other types of literature are also relevant to the topic. The wayfinding literature generally investigates the effect of a map on people's wayfinding behavior (Golledge, 1999; Devlin and Bernstein, 2002). Freska (1999) compared maps and verbal route descriptions based on their effectiveness in assisting wayfinding. She also discussed conceptually an optimal trade-off between competing design criteria as well as seeking an adequate compromise between a "faithful" and a schematic map. Soh and Smith-Jackson (2004) looked at the influence of map designs, individual differences, and on-site signs on wayfinding performance in terms of the total time for completion, time and accuracy of decision-making, and deviation from the route. Other studies in this literature examined the difference between a map and the actual experience in spatial orientation (Tversky 1981, Thorndyke and Hayes-Roth 1982, Richardson 1999, Uttal 2000).

The cognitive mapping literature occasionally looks at travel decisions (Golledge and Garling, 2004; Weston and Handy, 2004). However, most of them focus on the effect of travel behavior on cognitive maps, not vice versa. For example, Mondschein et al. (2007) investigated the influence of mode choices on the formation of different cognitive maps of Los Angeles. Chorus (2009) compared the actual and perceived cognitive maps of passive (e.g., car passengers) and active travelers (e.g., car drivers or pedestrians) in Eindhoven, Belgium. Because of the difficulty quantifying cognitive maps, studies on the effect of cognitive maps on travel are generally qualitative (Hannes et al. 2009) or use crudely simplified cognitive maps, such as perceived distances (Montello, 1997; Horning, 2008), a single spatial syntax value (Lee and Ryu, 2007), or frequency of travel (Arentze and Timmermans, 2005). This literature has not yet been applied to transportation planning (Golledge and Gärling, 2001).

The third type of literature is cartography and geo-visualization that focus on the quality of map design (Glasgow et al., 1995; Mijksenaar, 1999). Some studies looked specifically at travel maps, such as the rise and fall of strip format travel maps by MacEachren and Johnson (1988), the differences in transit maps of France, Germany, and Spain (Morrison, 1994), or automated drawings of transit maps (Wolff, 2007). Berendt et al. (1998) proposed suitable criteria to evaluate the accuracy or inaccuracy of map-like diagrammatic representations and applied the criteria to develop a diagrammatic transit map of Hamburg, Germany. Only a few studies in this literature have explored the effectiveness of graphic displays for exploratory data analysis, problem solving, and learning (Shah and Miyake, 2005). For example, Fabrikant et al. (2010) studied users' responses to different weather map designs in terms of eye movements and the time and accuracy of responses.

In summary, travel maps, in general, and transit maps, in particular, are still an unexplored multidisciplinary research topic. Particularly, we know little about the three critical questions on this topic:

1. What kind of information is delivered from a travel map to a traveler?
2. How could that information affect a traveler's decisions?

3. Could we use a travel map as a planning tool to improve individual's decision making and the performance of a transportation system? And how?

This paper covers the first two questions and leaves the third question for future research. Section 3 discusses the two issues conceptually and proposes a framework for the subsequent empirical analysis. Because bus and urban rail systems are distinct in terms of map design, embedded travel information, and the possible effect on travel behavior, this paper differentiates the two and focuses on the urban rail systems.

3. Transit Map, Travel Information, and Travel Decisions

3.1 Transit Map and Travel Information

A transit map is a topological map in the form of a schematic diagram that is used to illustrate the lines and stations within a public transit system. Its primary function is to help users navigate the labyrinth of transit networks. It depicts the locations, directions, and connections of stations and lines and normally does not include service information, such as travel time or crowding[2]. A transit map can deliver four types of travel information: distortion, restoration, codification, and cognition.

3.1.1 Distortion

Unlike conventional maps, transit maps are usually not geographically accurate; instead, they use straight lines and fixed angles and often illustrate a fixed distance between stations, compressing those in the outer area of the system and expanding those close to the center. Such distortion in a schematic map can lead the user's attention to decision points, and routes can be more easily derived from a schematic map than more general maps (Lakin and Simon,1987; Hochmair, 2009). Remaining to-scale would make the map difficult to read and unwieldy to carry. Passengers may not care exactly what streets they are traveling under when they use a subway system. For some large systems like those in Tokyo, it is simply impossible to retain geographical features for so many interwoven lines in such a compact area.

Distortion certainly changes the lengths and directions of transit lines and the locations and directions of stations. For example, in the London Underground, the Central and District lines between Paddington and Notting Hill Gate run east-west on the system map but physically run north-south. On the map, the Notting Hill Gate are west, not south, of Paddington (see Figure 1). Distortion prevails in urban rail transit maps. A test of the London Underground map indicates that it only represents about four percent of the variation of the actual spatial relationship.

3.1.2 Restoration

Restoration refers to the retaining of geographic features in this generally distorted environment. A few system maps remain largely geographical, such as those in New York City, San Francisco, and Chicago. Some remain hybrid, like those in Madrid,

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[2] One exception is the subway map in San Francisco in the late 1960s. For each station, it showed travel times from Embarcadero or 12th & Broadway. The number became the station marker of the line (Ovenden 2007).

Amsterdam, and Mexico City. Such variation depends on several factors: the structure of the system, i.e., an overground structure tends to be more geographical on a map than an underground one (Chicago), the spatial layout of the city, i.e., those with clearer geographic features tend to have more geographic maps (New York City and San Francisco), or the unique history of the transit map development, e.g., in Madrid and Paris (Ovenden 2007). Restoration also occurs because distortion has its limits; it is possible for passengers to find too much distortion unacceptable. The 1972 subway map in New York City was finally abandoned nine years later its introduction because of this particular reason (Ovenden 2007). For example, Central Park was drawn as a wide, west-east rectangle even though it is actually narrow and runs south-north; the 50th Street-Broadway station appeared west of 50th Street and 8th Avenue on the map even though in reality the station is east.

Restoration is normally done by including geographic features, such as major roads, green spaces, or mountains on the map. A prime example is New York City where the subway map overlaps with the street network with many stations named after street numbers. Some transit agencies provide geographic maps as an alternative to the schematic map to passengers. For example, in Paris, the transit maps on station walls remain fully geographic. In Sao Paulo, Brazil, a geographic map with all of the subway lines in the region is printed on the reverse side of the diagrammatic map (Ovenden 2007).

3.1.3 Codification

Codification refers to how lines, stations, and connections are coded as symbols on a schematic map. The effect of map coding on map use has been well documented in the cartography literature (Montello, 2002). Colors, visibility, and labels make some stations and lines more prominent in people's cognitive maps than others (Garland et al., 1979; Dziekan, 2008). Another good example is Mexico City, where each station on the subway map has its own emblem to help the illiterate (Ovenden 2007).

Codification, in general, is essential to denoting connections on a transit map. There are diverse ways to represent transfers, such as overlapped stations (most systems), semi-overlapped stations (Kiev, Ukraine), separate stations connected by a link (Moscow, Berlin, Tokyo), or no connection at all (Bilbao). Within the case of overlapped stations, the symbol could vary by size (Munich), color, or pattern, e.g., segmented dots (Moscow, Mexico City, Budapest), national flag symbol (Seoul), or a scheme too complicated to interpret (Miami).

Different codifications of connections could likely affect passengers' transfer decisions in public transit. For example, in the London Underground, the Piccadilly and Victoria lines intersect at two transfer stations: Green Park and King's Cross. Such a connection is represented as a simple, overlapped dot at Green Park compared with a long link between two separate stations at King's Cross although in reality, transferring at King's Cross is not comparable to Green Park. This may mislead transferring passengers to avoid King's Cross and to "over-transfer" at Green Park. The same "error" occurs at two other transfer stations, Charing Cross and Embankment, on the Bakerloo and Northern lines (see Figure 1).

3.1.4 Cognition

Cognition refers to the cognitive effect of a schematic transit map on the perception of the transit system and the whole urban space. Human psychology has proven that the diagrammatic type of visualization affects internal cognitive representations (Uttal, 2000; Hegarty, 2004). A transit map certainly affects the perception of the system: not only the simplicity or complexity of the system structure but also the overall image of the transit agency. Many transit agencies view transit maps as a valuable tool to establish a corporate identity.

However, the impact of the transit map likely goes well beyond the transit system. Transportation networks often act a backbone in people's cognitive map (Lynch, 1960). A transit network, the subway in particular, could potentially reshape the mental map of an urban space in at least two ways. First, underground travel substitutes surface travel and "deprives" the passenger of a chance to form a spatial cognition through one's own experience. Second, a transit map often offers alternative "assistance" with a clear, simplified, stable, and widely-published depiction of the urban structure. Deprivation and assistance, acting as push-and-pull forces, often occur at the same time and place, reinforcing the impact of the transit map on spatial cognition.

Specifically, a transit map may affect three elements of a cognitive map: boundary, landmark, and perceived distance. Subway lines often act as boundaries of different areas in a metropolitan region. A circumferential line might become the unofficial definition of a downtown or urban center (e.g., London, Chicago, Moscow, Berlin, Beijing). When different fare zones are adopted, they often become a proxy of different real estate markets. Major subway stations often become new or reinforce existing landmarks in a cognitive map. In some cases, the number of stations, rather than the number of miles or kilometers, is used by the public to measure distance. Some critics argue that schematic transit maps actually represent an ideal image of modern time and space: orderly, lucid, regular, efficient, and entirely functional for the era of capitalism (Hadlaw, 2003).

This cognitive effect of the transit map is mentioned by Hannes et al. (2006) with respect to naming subway lines after towns or neighborhoods and is well discussed by Vertesi (2008), using the London Underground as a case study.

3.2 Transit Map and Travel Decisions

The information delivered by a transit map through distortion, restoration, codification, and cognition might affect travel decisions in two ways. First, it influences the number of available opportunities and travel options perceived by travelers in terms of destination, mode, or path choices. Second, it affects the perceived attributes of these opportunities and travel options, such as the desirability of a place and travel time and cost (Chorus, 2007).

3.2.1 Location Choice

If a transit map could affect people's spatial cognition, it might change their location preferences and the desirability of certain locations. For example, it is believed that Harry Beck's famous design for the London Underground was accepted primarily for real estate development (Vertesi, 2008). The London Underground has owned a significant amount of land along the train lines outside Central London since 1933, the same time when they adopted the current transit map design. The map was ideal in promoting suburban developments as viable neighborhoods for London professionals, such as Golder's Green; it placed them 'on the map', made these suburban locations seem close to the city center, and encouraged regular use of the system for daily commutes (Garland, 1994; Halliday, 2001). Even today, the Underground map defines what is and what is not London; places marked on the map offer a sense of familiarity and security while those that are not present on the map often suggest "uncharted and perhaps dangerous territory" (Vertesi, 2008).

A transit map may affect location choices primarily through distortion and cognition. Although there have been no empirical analyses on this particular topic, studies have shown that spatial cognition, which can be influenced by a transit map, affects various location choices, such as residential preferences (Johnston, 1972; Pacione, 1982) and business locations (Pacione, 1978). The perceived distance, which is often distorted by a transit map, could affect store choices for shopping (Garling, 1989) and recreational and leisure destinations (Golledge and Timmermans, 1990).

3.2.2 Mode Choice

A transit map could potentially advance one mode while penalizing another because of the codification and cognition effects. For example, the transit map for an urban rail system is often straightforward, easy to understand, and beautifully drawn while the bus map is generally complex and confusing. It is difficult to determine the alignment of a bus route and the locations of stops and terminals. When each bus route is printed on a separate map or brochure, it is hard to go through all the printouts to identify the best bus route. In this context, transit maps may actually have "switched" customers from bus to rail, promoting one while hampering the other.

A transit map might also alter the "transaction cost" of a mode switch. For example, when the street network is excluded from a transit map, and transit stations are not shown on a street map, drivers and transit passengers may develop different knowledge sets or cognitive maps of the two transportation systems. This is likely to make mode switching between transit and automobile more difficult. A similar situation might occur with the bus and rail system. Although there are no empirical analyses on this topic, the studies by Fujii et al. (2003) on mode switch during a Freeway closure and by Chorus et al. (2007) on the mode-switch effect of transit information on car-drivers illustrate this possibility.

3.2.3 Path Choice

A transit map may affect a passenger's path choice through distortion, codification, and cognition. The path choice issue arises when a passenger has to select the "best" path over multiple options from an origin to a destination. Path attributes that are crucial to path choice decisions include path distance, path geometry, connection, and service quality.

Path distance or travel time has been proven to be the single most important factor in path choice decisions (Dijkstra, 1959; Gallo and Pallottino, 1988; Prato, 2009). Numerous studies have found that path geometry is also important. People generally prefer routes that are initially long and straight even if these routes are not the shortest in terms of Euclidean distance (Bailenson et al., 2000). They may follow a "least-angle" strategy to minimize the total length of the (perceived) initial street segment and the fictitious segment running from the endpoint of the initial segment to the distal target (Hochmair and Frank, 2002). People often prefer fewer directional turns along a path (Golledge, 1995) and tend to conserve linearity along their paths (Dalton, 2003). A path with better spatial cognition, as represented by a higher score on spatial syntax, is more likely to be chosen (Lee and Ryu, 2007). Transfer is always a major concern for public transit passengers because of the inconvenience and uncertainty involved (Guo and Wilson, 2004).

A schematic transit map is able to change all these path attributes through distortion, codification, and cognition, and unavoidably alter the relative attractiveness of available paths.

In summary, a transit map can deliver multiple layers of information to travelers, and the information can have a strong and lasting effect on various travel decisions. To test the assumption, a large-scale empirical analysis was conducted for one of the largest urban rail systems in the world, the London Underground. It focused on passengers' path choices because the map was more likely to impact path choice than mode or location choices. Path choice also tends to involve less external "noises" and therefore is more likely to capture the pure effect of a transit map.

4. London Underground and the Tube Map

London has the world's oldest underground railway system with services operating since 1863. The lines were originally printed over existing street maps, but as the system grew in complexity, many maps became increasingly illegible. Many experiments were performed in the early 1900s, which mainly focused on Central London and gradually teased out the geographical features (Ovenden 2007). The first full-system diagrammatic map appeared in 1929, but it was Harry Beck's sketch in 1931 that set the standard and become the permanent system of the map, often called the tube map, a masterpiece of the map design.

Inspired by the sewage system map, Beck made the map conform to a set of rules: multiple colors, an artificially enlarged center, and an octagonal grid. Lines ran only vertically, horizontally, or on 45 degree diagonals. For example, he pulled the wobbly Central Line into a simple horizontal line, smoothed the curving District branch to Wimbledon into a single vertical column, and neatened the meandering Bakerloo, Metropolitan, and Hampstead lines into fixed 45-degree diagonals. He used smart rudimentary ticks for stations and placed them according to their spatial relationship rather than geographic scale. All topographic detail was excluded, but London's pride as a great city on either side of the Thames River was preserved by including the river on the map (Ovenden 2007).

Since its official acceptance in 1933, Beck's map has gradually become the most widely recognized symbol of London along with Tower Bridge and Big Ben (Halliday, 2001). It appeared on the city logo when London vied to host the 2012 Olympic Games. In 2006, the design was second in a televised search for the most well-known British design icon [3]. It is extremely popular to both residents and visitors. It is featured all over the city on tourist trinkets, such as T-shirts, shoes, wallets, pens, mugs, umbrellas, lighters, and postcards. Each year, more than fifteen million pocket versions are printed, and an estimated 95 percent of Londoners are said to have a copy at home (Vertesi, 2008).

The London Underground presents an ideal case for this research for three reasons. First, geographically, the urban space in London presents few organizing principles. Despite the city's rebuilding after the Great Fire in 1666, it largely remains a tangled medieval street network. It is hard to navigate even with the assistance of a map. There are few critical landmarks that can be used to help form a cognitive map of the city. Second, the tube map excludes all topographic features aside from the Thames River, which is not very helpful either for spatial orientation because it is difficult to identify how the River flows even when one is walking along it (Vertesi, 2008). Third, the transit agency has been careful to preserve the identity of the tube map. The map has been stable since its adoption in the 1930s. For example, despite the addition of 110 stations and six lines, the 2007 tube map is remarkably similar to the original 1933 map. The map is always presented alone, and alternative views of the network are strictly prohibited by the London Underground (Vertesi, 2008).

Therefore, to many residents and visitors, the map represents the actual Underground network and even London itself. There are few other cartographic images more ingrained into the psyche of a population (Ovenden, 2007). In an interesting experiment conducted by Vertesi (2008), Londoners often draw the map of London based on the tube map: London is represented as an x/y axis of the Northern and Central lines or a collection of distinct localities (Underground stations).

5. Modeling the Map Effect on Path Choices

To test the transit map effect on passengers' path choices, a reference is defined as the reality. If a transit map presents a distorted reality, then the key research question is what passengers trust more: the schematic map or their actual experience in reality.

In this paper, the map effect is operationalized into two aspects: map distance and transfer connection. The former is the distance of a path measured from a transit map. A passenger is often able to infer this distance by reading the transit map and taking into account the angles and turns of line segments, or connections. Therefore, the map distance is not just a measure of distance; it also accounts for the general layout of the transit system on the transit map. The latter refers to how a transfer station is coded on a transit map. Two types of codifications are compared: the dot connection with two overlapped stations and the link connection between two separate transfer stations. A transfer may look shorter or longer on a transit map than the reality.

Related to these two aspects, there are two research questions:

Q1: Does the map distance affect passengers' path choices? If so, how does the map distance interact with the actual distance as represented by the actual travel time?

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[3] http://www.icons.org.uk/theicons/collection/the-tube-map

Q2: Does the codification of transfer stations affect the perceived transfer inconvenience at the station? If so, how and to what extent?

To answer the first question, map distance was included in path choice models with the significance level tested, and its influence compared with that of the actual travel time. The variation of the map-actual relationship across different passenger groups was examined to understand the interaction between the transit map and travel experience. For example, the relationship could potentially be different between passengers who were familiar with the system and passengers who were first-time users (Lotan, 1997).

To answer the second question, the effect of codification on the perceived transfer inconvenience at a station was measured. Because transfer is unique to individual transfer stations, a dummy variable for the codification type (e.g. dot or link) could be "contaminated" by station-specific attributes. Therefore, the codification effect on the transfer inconvenience was captured by comparing models with and without the map distance. A convenient transfer station with a short-distance transfer walk may look "bad" on a map when the transfer connection is represented by a long link on a transit map. Because the perceived map distance is partially affected by the transfer link, including the map distance in models could partly capture the codification effect on the perceived transfer inconvenience.

5.1 Data and Variables

The main dataset is the Rolling Origin and Destination Survey (RODS), conducted by Transport for London (TfL) or its predecessor organization London Transport from 1998 to 2005. RODS records travel paths including the access, transfer, and egress stations for more than 250,000 trips in the Underground network.

There are 691 station-to-station links (two directions) for more than 300 stations in the Underground network. The map distance of each link was measured manually in Adobe Photoshop, so the unit has no real meaning. Travel times were obtained from RailPlan, a network model developed by TfL for public transport users for the AM peak period in London (RailPlan Modeling User Guide 2006). These include in-vehicle travel time, station entry/exit time (walking time between the station entrance and a platform), initial waiting time, and transfer walking and waiting times.

Another interesting variable is the number of stations along a path. It might act as either a map or a "reality" variable because a passenger may count the number of stations from a transit map in addition to mentally calculating the path distance. The variable is also a good proxy for the actual travel time. Including it in models makes a fair comparison between the map distance and in-vehicle time. Table 1 lists the descriptive statistics for all variables.

5.2 Path Choice Models

The most challenging task of modeling path choice is identifying the alternative paths considered by a passenger. Unfortunately, most travel surveys like RODS only reveal the final decision (a chosen path), not the available options (alternative paths). Analysts normally rely on commonly accepted rules to infer these alternative paths (Bovy and

Stern 1990). In this research, the labeling approach developed by Ben-Akiva (1984) was used to generate the path choice set.

Not all RODS origin-destination (OD) pairs and paths can be used for path choice modeling. ODs with too few trips were excluded as well as paths with more than two transfers and a smaller share (≤ 10percent) of trips compared with other paths between the same OD because they did not reflect a typical decision. Finally, 9,284 RODS OD pairs, corresponding to 13,925 RODS paths, were selected. Eighty-five labels were then applied to these OD pairs on two types of Underground networks: the default RailPlan network and the map-based network. In the latter case, the network-link attribute was the map distance instead of the actual travel time. In the process, 77 percent of the 13,295 revealed RODS paths, representing more than 90 percent trips, were generated on the default network (75 percent on the map-based network). This result was comparable to the findings in prior studies (Ramming, 2002; Fiorenzo-Catalano, 2005; Bekhor et al., 2006).

OD pairs were further filtered based on the result; those with only a single path option and those with no RODS paths generated could not be used for path choice modeling and were excluded. The final path choice set included 2,240 RODS ODs, corresponding to 2,690 RODS paths and 18,894 RODS trips. For these OD pairs, 7,841 path options were generated. In other words, on average, one RODS OD had 3.5 generated paths. Generated paths tended to have larger averages and standard deviations than those revealed RODS paths, which we expected (Table 1).

A multinomial logit model was adopted. The path overlap issue was partially controlled by including dummy variables for 17 major transfer stations in Central London because most overlapped segments started or ended at one of these stations. The choice set size varied from OD to OD, ranging from two to six. Two models were developed with (Base Model) and without (Map Model) the map attributes.

Since the choice set was generated based on a reasonable “guess,” the validity of the modeling result had to be tested before making interpretations. The dataset was split into two parts, each with half the observations from the original dataset. The split was based on odd and even numbers of the access station codes, so the process was random. Next, half of the dataset was used to estimate parameters using the Map Model specification. Then, the parameters were used to predict the path choice in the other half of the dataset. The average probability of a correct prediction was 80 percent, suggesting that the choice set generation procedure and the model specification worked well. The modeling results are summarized in Table 2.

6. Results and Analysis

Most variables in both models were significant at the five percent level with expected signs. In the Base Model, the more a path had in terms of entry, exit, in-vehicle, initial waiting time, transfer walking or waiting time, the less likely that path was chosen by a passenger. In-vehicle time was perceived as more onerous than the initial waiting time (-0.55 vs., -0.36) probably due to the high frequency of service. Transfer walking was more onerous than entry and exit walking (-0.32 vs., -0.29) while transfer waiting was viewed as more convenient than initial waiting (-0.2 vs., -0.36). This probably reflects the different weights of long- and short-term decisions when waiting in general is not a concern for the high-frequency service.

The 17 transfer station dummy variables captured the perceived transfer inconvenience by each station in addition to the transfer walking and waiting times. Such inconvenience is determined by physical transfer environments, such as escalator availability and ease of wayfinding, and possibly the codification of transfer stations on the tube map. All other transfer stations acted as a base for comparison, and their inconvenience was captured by the variable: number of transfers. A positive coefficient of the dummy variable indicated a better perceived transfer environment (in addition to transfer walking and waiting) than the base. The Base Model revealed a large variation of perceived transfer inconvenience across the 17 stations. The worst transfer stations were generally the large, complex, National Rail terminal stations, including Waterloo, Paddington, and Euston. The best transfer stations were the simple, heavily-used stations, such as Earl's Court, Bond St., Leicester Sq., Oxford Circus, and Victoria.

When the map attributes were included in the Map Model, the explanatory power of the model increased significantly from 0.579 to 0.604. The changes in variable estimations answered the two research questions.

6.1 Map Distance More Influential than Actual Travel Time.

The Map Model confirmed that the tube map indeed has an impact on passengers' path choices. The map distance variable was statistically significant at the one percent level with an expected sign. The longer a path appeared to be on the tube map, the less likely that path was chosen with all other factors being equal. More interestingly, the coefficient of in-vehicle time changed dramatically from -0.554 to -0.169, a 70 percent reduction of influence, while other time variables were largely unaffected. It suggests that much of the travel time effect in the Base Model could be due to the tube map in terms of map distance and stations.

To compare the relative influences between the map distance and the actual travel time, the average elasticity was calculated for all 18,894 trips (Table 3). The map distance had an elasticity of -0.0416, meaning that a 10-percent increase of path length on the tube map would reduce the chance of that path being chosen by 0.416 percent. The elasticity for the actual travel time was much smaller (absolute value) at -0.0194. The ratio between the two was about 2.14, i.e., the tube map was about two times more influential than the actual travel time on a passenger's path choice on the Underground. To test the interaction between the tube map and actual experience, the model was estimated again for two distinct groups: frequent users who rode the Underground at least five days per week and first-time users. The rationale is that when a passenger becomes more familiar with the system, she or he would be more likely to rely on her or his own travel experience instead of using external information, such as a transit map, to make decisions. The modeling results confirm this assumption. For frequent users, the map effect was reduced as indicated by the smaller elasticity of the map distance (-0.0387, a 7 percent decrease), and the reliance on actual travel experience increased, indicated by a higher elasticity of travel time (– 0.0229, 15 percent increase). However, the map distance was still more influential than the actual travel time, as indicated by a decreased yet still greater than one map-travel time ratio (1.69). For first-time users, both map and experience effects remained almost unchanged.

The tube map was even more influential for old (60 year or older) and young (16 to 25 years old) users with a higher map-travel time ratio = 2.8. However, that change was primarily caused by the reduced influence of actual travel time while the map effect remained unchanged. The elderly might be sensitive to the ease, rather than the speed, of travel. Both old and young users might have fewer time constraints compared with middle-aged users, who are more likely to be commuters.

6.2 Codification of Connection Affecting Perceived Transfer Convenience.

The coefficients of several transfer station dummy variables changed significantly after the map attributes were included, suggesting the potential effect of codification on the perceived transfer inconvenience. Such inconvenience was measured as the ratio of coefficients between a transfer station dummy and entry/exit time, the time variable that remained the most stable in both the Base and Map Models. The ratio is the unique "penalty" associated with the transfer station in equivalence of entry/exit walking time.

The tube map makes two transfer stations, Baker St. and Embankment, look more inconvenient than in reality. The coefficient of the Baker St. station increased from -0.512 to -0.298 (42 percent) with the latter being insignificant at the 5 percent level. In other words, the link for the Baker St. station on the tube map increased the perceived transfer inconvenience from 1.1 (-0.298/-0.281) to 1.8 (-0.512/-0.288) minutes of entry/exit walking. A similar result occurred at the Bank/Monument station. The perceived transfer inconvenience increased from 1.5 to 2.2 (33 percent) minutes of entry/exit walking.

Including the map attributes also reduced the perceived transfer inconvenience for some transfer stations, especially Victoria and Oxford Circus. In other words, they appeared to look like more convenient locations to transfer than they are in reality. Transfer at each of these two stations was coded as a simple dot even though the actual transfer environment was relatively challenging. For example, both stations are the busiest in the Underground and operate constantly at or over capacity. Oxford Circus has the largest transfer volume, more than 110,000 per weekday, while at Victoria closing of ticketing gates to reduce platform overcrowding has become a daily practice [4]. The easy connection coded for the two stations on the tube map, in turn, might contribute to this problem.

The modeling result also enabled us to quantify the effect of the codification of a transfer connection. For example, the extra or precluded transfers can be calculated for these stations using the elasticity of entry/exit walking time (= -0.02). Results show that the link codification for the Baker St. and Bank/Monument stations might prevent 216 and 147 transfers, respectively, on a typical weekday. The dot codification for the Victoria and Oxford Circus stations might attract 960 and 516 more transferring passengers on a typical weekday (see Table 4). Codification of connections on the tube map could likely affect the daily operation of the Underground.

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[4] Comment by Mike Strzelecki, Director of Safety in London Underground, made at a meeting organized by the London Underground Railway Society on June 9 2009. http://www.lurs.org.uk/

7. Discussion and Conclusion

This paper investigates the effect of schematic transit maps on travel decisions in public transit systems. The relationship might have significant implications for public transit operation and planning, but so far, it has been largely overlooked by both academics and practitioners. The paper first defines four types of information conferred from a transit map: distortion, restoration, codification, and cognition, and then discusses their potential influence on travel location, mode, and path choices.

The case study on the London Underground confirms that a schematic transit map indeed affects passengers' path choices. Moreover, the map effect is almost two times more influential than the actual travel time. In other words, Underground passengers trust the tube map (two times) more than their own travel experience with the system. The map effect decreases when passengers become more familiar with the system but is still greater than the effect of the actual experience, even for passengers who use the Underground five day or more per week. .

The paper also shows that the codification of transfer connection is also important. Different codification can make a transfer look more or less convenient on a transit map than the reality, which will either decrease or increase the perceived transfer inconvenience for the corresponding stations. This paper identifies both situations in the Underground case study and quantifies this codification effect, in terms of the number of attracted or precluded transfers, for four major transfer stations: Baker St., Bank/Monument, Victoria, and Oxford Circus.

Of course, these results are only based on the London Underground, a unique case in many aspects. Few transit maps enjoy such public popularity as the tube map in London. Many transit maps include prominent geographical features, which dilute the map effect. Many systems have different versions of a transit map in history or currently, which precludes a lasting and stable map effect. Many metropolitan regions possess an easier-to-comprehend urban form than London, which could weaken the role of a transit map in the formation of a cognitive map. The subway map effect in New York City is probably different from that in London. Therefore, readers should be cautious about making generalizations.

If a transit map has an impact on travel decisions, what are the implications for transit operation and planning? First, if passengers trust a schematic map more than their own experience, all planning efforts aimed at changing travel behavior need to consider the map effect; otherwise, their effectiveness might be weakened. For example, this map effect might partially explain why Advanced Traveler Information Systems (ATIS) often yields modest improvements in terms of travel time savings in public transit (Hickman and Wilson, 1995; Avineri and Prashker, 2006; Ben-Elia et al., 2008). Secondly, a transit map might cause certain operation problems. For example, it might unintentionally shift more passengers to a congested segment in the network and thus form a bottleneck. The overcrowding at the Victoria and Oxford stations and the link between the King's Cross and Old Street stations, which is relatively much shorter on the tube map than in reality, are possible examples.

Accordingly, a transit map could potentially become a planning tool to solve operation problems and improve system efficiency. For example, link lengths could be revised, and transfer stations could be re-coded on a transit map to change passenger behavior and mitigate platform and train crowding. Annotations of waiting time or crowding for selected stations on the map might also be important (Hochmair, 2009). Clearly, this approach has its own limits: we could not redraw a transit map how and when we wanted.

In terms of future trends, ATIS and alternative travel information channels, such as the iPhone and internet, might change the role of a transit map in mixed ways. On the one hand, they may weaken the transit map effect. For example, iPhone or internet-based trip planners may recommend specific travel paths based on their actual attributes. On the other hand, they may strength the map influence as well. For example, a transit map might become more accessible to passengers through, for instance, the iPhone or internet. Travel information, such as crowding and delays, delivered in a map format could be more effective than other media (Htao et al., 1999). Conventional media like the transit map will likely still be critical and indispensible for trip planning despite the prevalence of real time information (Cluet et al., 2003).

In summary, transit maps can have a profound impact on passengers' travel decisions and system performance. Both individual passengers and transit agencies should "mind the map" in order to make their best planning decisions.

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Path Attributes (minutes)		Average	Max.	Min.	Standard Deviation
In-vehicle	RODS Paths	17.9	55.5	1.5	8.3
	Generated Paths	21.1	88.6	1.0	10.5
Entry within Station	RODS Paths	1.8	6.6	0.2	1.0
	Generated Paths	2.1	7.1	0.1	1.3
Exit within Station	RODS Paths	2.6	7.1	1.0	0.9
	Generated Paths	2.8	8.6	1.0	1.6
Initial Waiting	RODS Paths	2.2	16.6	1.0	1.6
	Generated Paths	2.6	30.2	1.0	1.9
Map Distance *	RODS Paths	19.3	54.8	1.9	8.3
	Generated Paths	24.3	105.6	1.1	12.0
# of Stations	RODS Paths	9.7	28.0	1.0	4.1
	Generated Paths	11.7	43.0	1.0	5.6
# of Transfer	RODS Paths	0.95	2	0	0.33
	Generated Paths	0.97	3	0	0.36
Transfer Waiting Time **	RODS Paths	1.7	30.2	0	1.8
	Generated Paths	2.1	30.2	0	2.1
Transfer Walking Time **	RODS Paths	1.6	10.1	0	1.2
	Generated Paths	2.2	13.7	0	2.2

Note: * Photoshop map unit; N = 2,690 for RODS paths, and 7,841 for generated path
** from N = 1,044 transfer movement directions for both RODS and generated paths

Table 1 Descriptive Statistics of Path Attributes

Variables \ Models	Base Model		Map Model	
	Coefficients	**t**	**Coefficients**	**t**
Control Path Variables				
Entry/exit walking	-0.288	-9.0	-0.281	-7.9
Initial waiting	-0.362	-7.4	-0.299	-6.4
# of interchanges	-2.270	-11.6	-2.690	-12.1
Interchange walking	-0.322	-8.9	-0.350	-9.6
Interchange waiting	-0.197	-4.6	-0.193	-6.4
Control Station Variables				
Baker St.	-0.512	-2.8	-0.298	-1.6
Bank/Monument	-0.638	-3.0	-0.430	-2.1
Bond St.	1.198	4.4	1.110	3.9
Earl's Court	1.417	3.9	1.671	4.7
Embankment	-0.301	-0.9	0.469	1.3
Euston	-0.462	-2.0	-0.618	-2.3
Green Park	0.763	4.0	0.766	3.7
Holborn	0.620	2.8	0.448	2.1
Leicester Sq.	-0.120	-0.5	0.107	0.4
London Bridge	0.096	0.2	-0.073	-0.2
Oxford Circus	0.592	3.3	0.960	5.7
Paddington	-1.896	-4.7	-2.178	-4.8
Piccadilly Circus	-0.516	-1.7	-0.275	-1.0
Victoria	-0.060	-0.3	0.683	3.1
Warren St.	-1.523	-4.3	-1.211	-3.0
Waterloo	-0.501	-2.1	-0.560	-2.2
Westminster	0.249	0.9	0.452	1.6
Actual Travel Experience				
Actual in-vehicle time	-0.554	-21.1	-0.169	-3.8
Map Attributes				
Map distance			-1.129	-8.8
# of stations			-0.259	-5.4
Model Attributes	N=18894 Init log-likelihood: -25786.6 Final log-likelihood: -7060.92 Likelihood ratio test: 19502.6 Adjusted rho-square: 0.579		N=18894 Init log-likelihood: -9402.05 Final log-likelihood: -6834.68 Likelihood ratio test: 19955.1 Adjusted rho-square: 0.604	

Table 2 Results of Base and Map Models

Passenger Groups		**Elasticity (on path choice)**		
Name	# of obs.	Actual Travel time	Map Distance	Ratio (Map : Time)
All passengers	18,894	-0.0194	-0.0416	2.14
First-time users	1,576	-0.0200	-0.0419	2.10
Frequent users (5+ days/week)	9,811	-0.0229	-0.0338	1.69
Old users (60 or older)	1,339	-0.0149	-0.0425	2.84
Young users (16-25 years old)	2,808	-0.0148	-0.0412	2.78

Table 3 Comparison between Map Distance and Travel Time

Transfer Stations	Coefficients		Map Effect = (entry/exit walking minutes)	Current Weekday Transfers	Codification Effect on Transfer Volume (per weekday)
	With Map Effect	Without Map Effect			
Baker St.	-0.512(-2.8)	-0.298(-1.6)	-0.72 minutes	84,439	-216
Bank/Monument	-0.638(-3.0)	-0.430(-2.1)	-0.69 minutes	66,755	-147
Oxford Circus	0.592(3.3)	0.960(5.7)	1.36 minutes	109,349	+960
Victoria	-0.060(-0.3)	0.683(3.1)	2.43 minutes	52,006	+515

Table 4 Effect of Connection Codification on Transfers at Four Stations

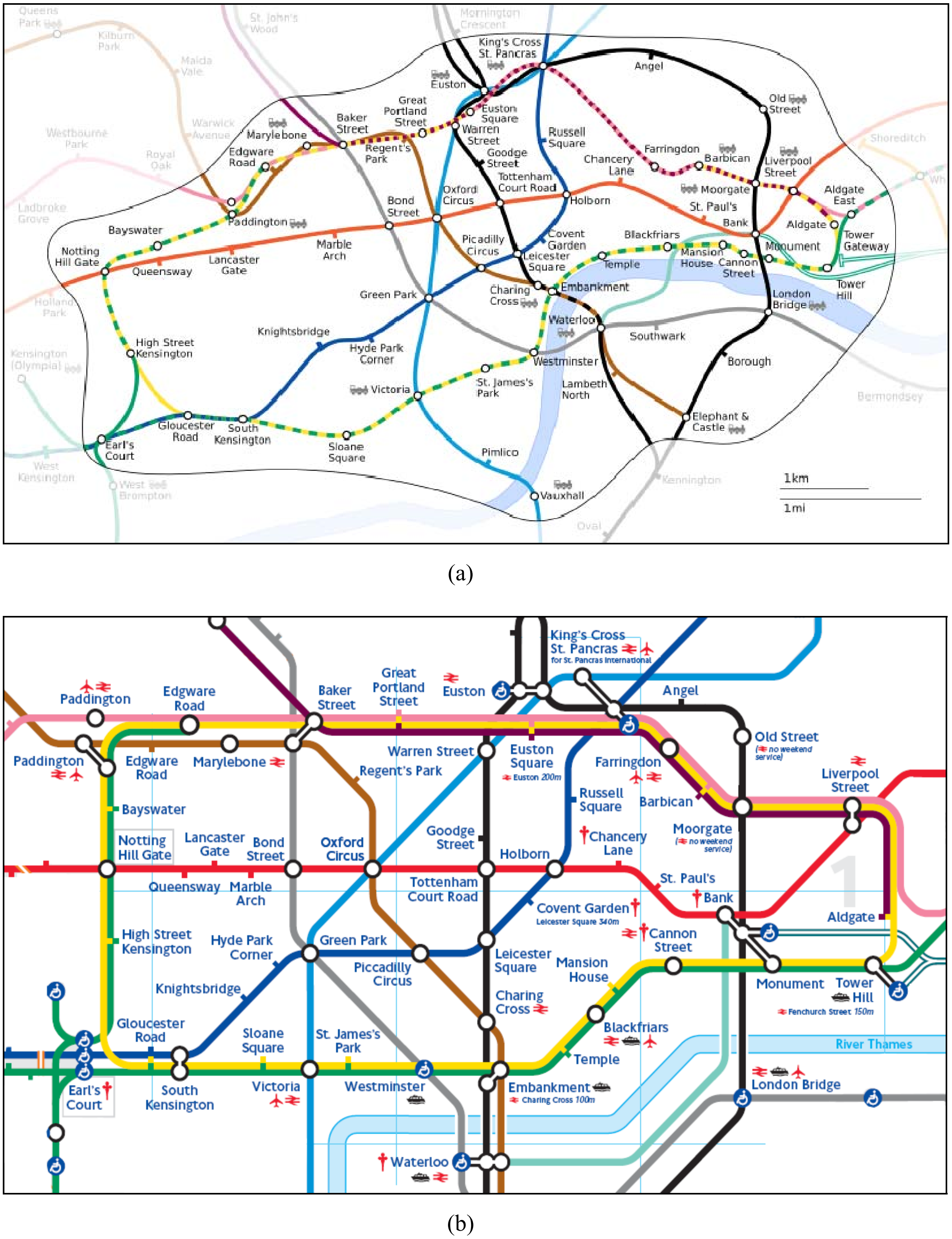

Figure 1 London Underground in Central London
(a) Actual Map (b) Tube Map