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REFEREED PAPER

The Influence of Map Design on Route Choice from Public Transportation Maps in Urban Areas

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Based on a user study in the Internet, this research analyses how map design and annotated network information in public transportation maps affect utilized proxy criteria when planning the fastest route in an intra-urban transportation network. Further, it is examined whether annotated network information on schematic maps affects the map reader in successfully finding the fastest route within the trip planning process. For this second task, a schematic map and maps with annotated headways, departure times and current positions of transit vehicles are compared.

Keywords: public transportation maps, map design, route choice, proxy variables, fastest route, discrete choice model

INTRODUCTION AND MOTIVATION

In a conceptual model that describes the different tasks in human navigation, Timpf *et al.* (1992) distinguish between planning level, instructional level and driver level. The research in this paper focuses on the planning level, where an individual traveller is assumed to search for the fastest connection in an intra-urban public transportation network with the help of a transit map. Usability studies on public transit maps for trip planning are sparsely reported in the literature, although this is of practical interest for various situations. Browser based public transit route planners[1], which can also be accessed from mobile devices that support GPRS or UMTS technology (Gartner, 2007), use exact time tables. However, these applications are not always accessible for travellers during their trip. Instead, travellers often rely on stationary maps posted at public transit stations to plan their route. Travel time between two stations in a transit network consists of several components, including access time (the waiting time at a platform for the next departure), transfer walking time between platforms, and travelling time (the time the vehicle takes to move between stations). Some of this time information cannot be visualized on a map for all possible connections between trip origin and destination since it varies with the route under consideration. For example, access times at transfers depend on the time of arrival at a transfer station, i.e. the route chosen up to that transfer point. Other information may be too extensive to be visualized on a map. For example, the number of transfer options at major transportation hubs is large, so are the corresponding transfer walking times. Since time relevant information is omitted in transit maps, the map user has to rely on proxy variables, such as number of transfers, to plan the fastest route. The term proxy variable in this context is used as a partial and fallible indicator of attainment of the objective 'find the fastest route'. The research in this paper assesses the effects of map annotations and geometry distortion on the map reader's route planning process.

The first task is to examine how a variation in map information affects route choice. More specifically, a variation in the type of network information visualized on the map may lead to a change in proxy criteria used by the map user for trip planning. A variation in proxy criteria would indicate that the map user comprehends the additional map information and uses it for the decision making process.

The second task is to assess to which extent the different types of map annotations support the map reader in successfully planning the fastest route. Robinson *et al.* (1995) describe map effectiveness as the quality of interrelation between map making and map use within map communication. There are a variety of different possible maps containing the same information but using a different cartographic design, each of which will reveal communication advantages as well as limitations. In this research, we use map effectiveness in the context of route planning, more specifically, as a measure of how well the map information supports the map reader in planning the fastest route between trip origin and destination on a public transportation map. In doing so, we focus on the effect of map information rather than on the role of cartographic representation *per se*. The maps used in the study vary in selected aspects of the information content, but use the same cartographic visualisation otherwise. Solely the

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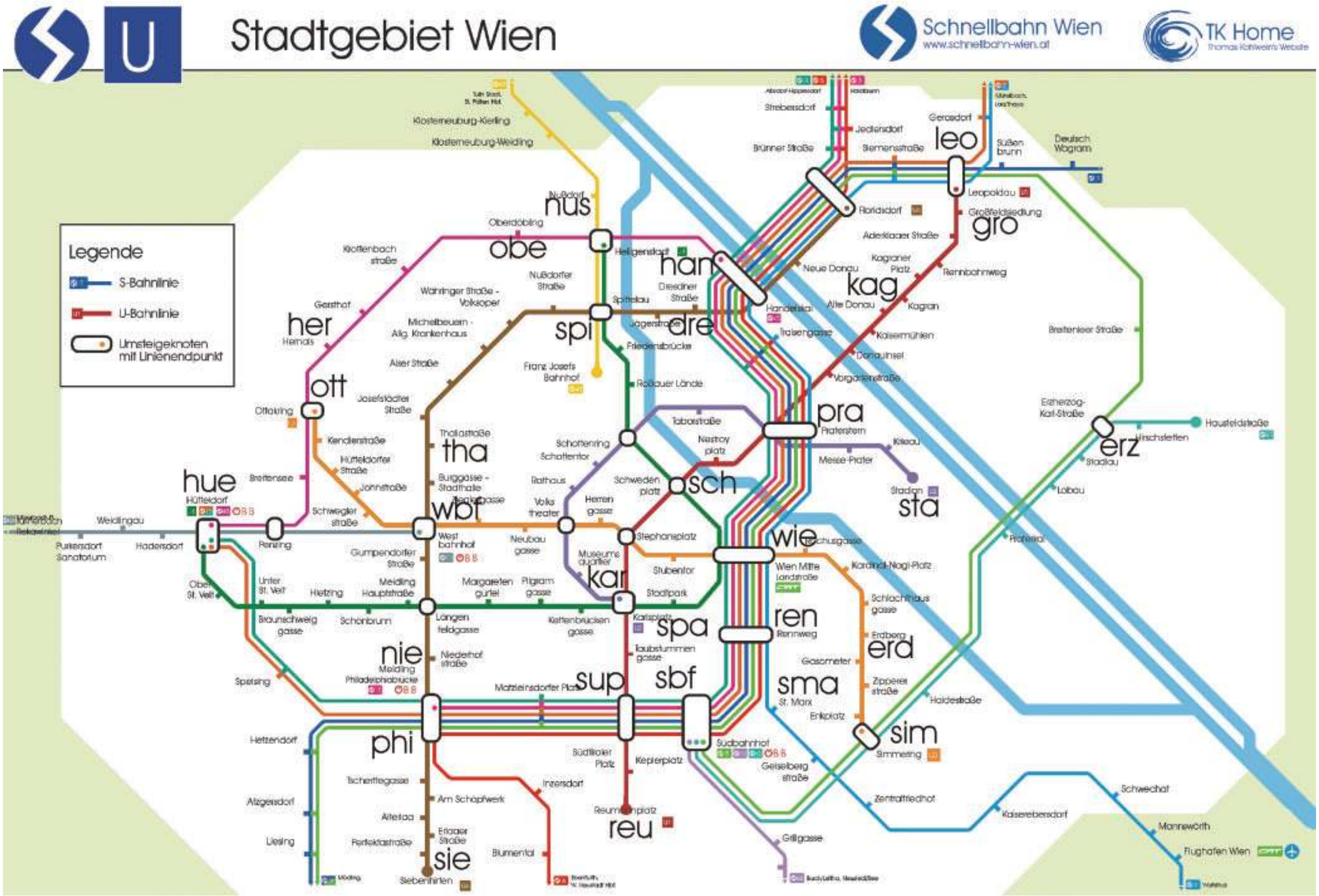

Figure 1. Schematic transit map for Vienna with metro lines ('U-Bahn') and rapid train lines ('S-Bahn') (source: http://www.schnellbahn-wien.at/netz, modified)

reference map varies from the other maps in the station symbols used.

The research in this paper is based on empirical data collected from an Internet study. Participants were asked to identify the assumed fastest routes between given trip origin and destination stations on five types of transit maps that show the layout of the metro and rapid train network in Vienna, Austria. Figure 1 visualizes the layout in a schematic map, and Figure 2 is a reference map. The three-letter labels in Figure 1 indicate the locations of the 30 transit stations that are used as trip origins or destinations (or both). These labels were, however, not included in the maps shown to the participants. The transit network includes five metro and 14 rapid train lines serving 122 stations, and covers about 165 route kilometres. The restriction to metropolitan scale is because for local, intraurban journeys, many passengers will just turn up at transit stops and consult provided travel information, such as maps or time tables. As opposed to this, coach and train travel is relatively more often planned in advance (Farag, 2008), and maps at stations would not be used so often.

The next section provides an overview of the interrelation between maps and trip planning, and reviews common criteria used for trip planning. This is followed by the formulation of research questions, an introduction to the modelling framework of route choices, and the data collection procedure. Another section estimates route choice models for selected map types, and assesses the map effectiveness for the different map annotations. The paper concludes with a summary and presents plans for future work.

PREVIOUS WORK

Maps and trip planning

Route choice problems involve a set of route alternatives from which a choice must be made under consideration of several evaluation criteria. Verbal description from a route planning application provides turn by turn instructions and therefore contains all the decisions to be taken in a pre-compiled form. As opposed to this, maps must be interpreted and analysed in more depth to identify decisions, and finally select a route (Freksa, 1999). In that sense, a map supports the wayfinder in a lesser extent than a precompiled description.

With general reference maps, the objective is to show the locations of a variety of different features. They can be seen as structures containing points, lines and regions, and as providing an aerial view, where meaningful entities and spatial relationships between entities are partially replaced

Figure 2. Reference map for Vienna metro lines and rapid train lines

by symbols (Berendt *et al.*, 1998). Map scale has a major impact on the degree of generalisation in a reference map and its accuracy. Greater attention to accuracy in terms of positional relationships among mapped features is paid in large scale reference maps, such as topographic maps, whereas small scale maps must be greatly reduced and generalized, and thus cannot attain the detail and positional accuracy of large scale maps (Robinson *et al.*, 1995).

Schematic maps can be obtained by relaxing spatial and other constraints from more detailed maps (Barkowsky and Freksa, 1997), where topological and certain spatial relations are still preserved. However, certain relations in the map will be distorted in favour of a greater transparency of the aspects relevant for the task (Freksa, 1999). In public transportation systems, schematic maps lead the user's attention to decision points and routes can be more easily derived than from more general maps.

Whereas schematic maps focus on decision points in a transportation network, strip format maps focus a map user's attention on an individual route which is presented as a sequence of features and decision points along the route (MacEachren and Johnson, 1987). Its linear form is analogous to a verbal process description, i.e. step by step instructions, where the limitation of this aid to navigation is its inflexibility. Golledge and Stimson (1987) refer to the knowledge of the sequence of steps needed to get from one place to another as procedural knowledge. Reported difficulties of travellers with maps suggest that the transformation from configurational to procedural representation is sometimes difficult. This implies that alternative navigation aids that provide procedural rather than configurational information may have an advantage over traditional maps for some travel needs, particularly for following a route once it has been selected (McGranaghan *et al.*, 1987). For intraurban transit by bus or subway, strip format maps have not found much attention, and the schematic map is the dominant map type (MacEachren, 2004).

Most schematic transportation maps omit explicit time or distance information. In response to this, Pontikakis and Twaroch (2006) propose to supplement schematic tourist maps with time weights and distances along a route. Such map annotations increase a map reader's knowledge for planning a satisfactory route which, however, requires the map reader to understand this information as part of a successful map communication process.

There exist only few studies about route choice behaviour on maps, most of which refer to pedestrian or car transportation mode. Empirical studies on street maps show that applied route criteria on maps change as the environment visualized on the map changes. For example, a desktop study by Golledge (1995) indicated that the fewest turn criterion was applied by 67% of subjects in an artificial grid environment, and only by 25% in a curvilinear environment. The study also indicated that path selection criteria on maps changed when the perspective changed. In the grid environment, choice of the fewest turn strategy was higher when the path to be travelled headed from south to north (65%) when compared to a heading from north to south (7%). Similarly, differences were found for the shortest path criterion. The reason for asymmetries in route selection from maps has also been revealed in other empirical research. In a map study and a real-world navigation study, participants could choose between routes, each of which had the same number of turns (Christenfeld, 1995). Routes only differed in when along a route a turn could be made. Results showed that people preferred to wait and travel straight ahead for the greatest possible distance, which was attributed to the use of a general heuristic to minimize mental effort. Map experiments in Bailenson *et al.* (1998, 2000) reveal that subjects generally prefer routes which are initially long and straight, even if these routes are not the optimal routes in terms of Euclidean distance. This road climbing effect was revealed both in artificial map environments and a schematic campus map.

An experiment with a virtual desktop environment examined how length and direction of initial route segments affect route choice (Hochmair and Karlsson, 2005). Participants could only see a distal destination and the initial segments of two outgoing streets at an intersection. All intermediate street segments were blocked from the participants' view by buildings. The observed decision behaviour could best be described as choosing the minimum triangle path. Such path minimizes the total length of the (perceived) initial street segment and the fictive segment running from the endpoint of the initial segment to the distal target. Thus, the longest initial leg was generally only followed if it was more directed towards the destination than the shorter leg. This behaviour supports a hypothesis by Hillier (1997) that people tend to follow the longest line of sight that approximates their heading. With both initial segments of equal length, participants tended to choose the street that is most 'in-line' with the target direction, which is referred to as least-angle strategy (Hochmair and Frank, 2002), and in accordance with the minimum triangle path heuristics. We include this least-angle criterion as independent variable in the route choice model from maps as a measure of route directness. Since the initial segment in the transit network may be very short when compared to the total route length, this criterion is slightly modified so that the angle is not measured for the initial segment, but as the angle between the direction to the point at one-third of a route and the direction to the destination. In addition to this, we also include a second measure of route directness which will be called cumulative normal distance (CND). Both the least-angle and CND criterion are based on angles and distances of available route alternatives. Therefore, the choice outcome, when applying either of these two criteria in a choice situation on maps, may vary if the route geometries are visualized differently because of map generalisation or projection.

Route choice in public transit networks

The number of studies that analyse route choice behaviour in intraurban public transit systems is relatively small. Pursula and Weurlander (1999) conducted a combined revealed preference and stated preference survey in the Finland Metropolitan Area, Helsinki, to reveal the importance of different level-of-service factors in public transportation. It showed that one transfer equals about 10 min of door-to-door travel time, and that passengers are willing to travel 15 min longer to get a seat for the trip. A study by Bovy and Hoogendoorn-Lanser (2005) analysed the importance of various aspects of travel time, railway station types, train service types and parking costs on door-to-door route choice in an inter-urban multi-modal transportation network. Using a variation of the generalized extreme value model, the authors found that the travellers first decide which railway station type to use (intercity versus non-intercity), which is followed by choosing the mode type to access the station.

Choosing the fastest route is one of the most prominent route selection criteria in transit networks (Wu and Hartley, 2004). In evaluating available route alternatives and planning for the most preferred route, travel time is, however, sometimes traded off with other criteria that increase travel comfort. These criteria include walking distance at transfers, train service type, travel cost (Chiu *et al.*, 2005), stairs (Daamen *et al.*, 2005), intermediate stops (Bovy and Hoogendoorn-Lanser, 2005), route complexity (Heye and Timpf, 2003) or seating availability (Pursula and Weurlander, 1999). Minimizing transfers is another prominent criterion in route choice and may generally be preferred over fastest route for specific traveller groups (e.g. elderly people) or trip purposes (e.g. recreational trips).

Map users can use some of the previously listed network variables as proxy criteria for planning the fastest route. For example, the route with the smallest number of transfers or the smallest deviation from the direction to the trip destination will often provide a satisfactory, if not optimal route. Travellers familiar with the environment may apply further proxy criteria, such as headway information, where the headway is the time between two vehicles passing the same point travelling in the same direction on a given route. The traveller may deviate from the planned route if he or she acquires additional knowledge about the network status while travelling. For example, the traveller may realize that a vehicle from another transit line is currently stopping at a transfer station, and thus decide to transfer to the other line at that station, which may not have been the initial plan.

RESEARCH QUESTIONS AND HYPOTHESES

Since travel time is a prominent criterion in trip planning (although sometimes not the only one), we formulate research questions related to map based planning of the fastest route. With respect to the two tasks presented at the beginning of this paper, this research aims at answering the following questions:

1. Do changes in map information and network geometry influence the use of proxy criteria for planning the fastest route?
2. Does information annotated to schematic maps improve the effectiveness of the schematic map?

Figure 3. Five map types used in the study: (a) Schematic map; (b) Schematic map showing current vehicle positions and directions; (c) Schematic map showing headways; (d) Schematic map showing departure times; (e) Reference map

Five map types are used in the empirical study. Four out of these map types are based on a schematic network map, where the annotated information content varies. The fifth map is a reference map, which, except for showing an approximately correct spatial layout of the network, provides the same information as the schematic map. Figure 3 shows examples of the five map types. All maps but the one visualizing vehicle positions are used to answer question 1, whereas the schematic based maps allow determining the differences in information content and are therefore used with regard to research question 2. The reason for excluding the vehicle map from question 1 is that this information is spatially complex and cannot be easily translated into route characteristics. The annotations for the schematic maps (Figure 3b–d) are as follows:

- current positions and driving directions of metro or train vehicles. If a vehicle is waiting at an end station for departure, the minutes until departure are indicated (Figure 3b);
- headways annotated to each route (Figure 3c). At 10:30 a.m. weekdays, service frequencies range between 4 and 5 min for metro lines, and between 15 and 60 min for rapid trains;
- departure times for next departing vehicle in all directions at the station of trip origin (Figure 3d).

Since the chosen cartographic representation of the annotated information is only one out of many possible representations, potential improvements in terms of map communication and map effectiveness might be possible and found through further testing in future studies.

The following related hypotheses are formulated:

- Hypothesis 1: the map type affects proxy criteria utilized for planning the fastest route;

- Hypothesis 2-1: annotated vehicle positions increase the map effectiveness;
- Hypothesis 2-2: annotated headway information increases the map effectiveness;
- Hypothesis 2-3: annotated departure times increase the map effectiveness.

MODELLING APPROACH

This section provides the mathematical formulation of the route choice model that is estimated and therefore used to identify significant proxy variables for the fastest route choice on maps. The observed data consists of fastest routes indicated on maps within the Internet study. Most route choice models in transportation research follow a decision-theoretical approach and are variants of discrete choice utility models (Ben-Akiva and Lerman, 1985). In these models, the decision maker can choose from a finite set of alternatives, and the utility of alternative i for person n consists of a systematic component V_{in} and random part ε_{in}. A logit model is derived from the assumption that the random parts of the utility functions are independent and identically Gumbel distributed. Multinomial logit models are commonly used to derive choice probabilities in choice situations with more than two alternatives. The probability $P_n(r)$ of an individual n selecting a route r within a choice set R is given by

$$P_n(r) = \frac{e^{\mu V_r}}{\sum_{r \in R_n} e^{\mu V_r}} \qquad V_r = f(C_r, A_r, H_n) \tag{1}$$

where R_n is the route choice set of individual n, V_r is the systematic component of the utility for route r for person n, μ is the scale parameter, C_r is the alternative specific constant for route r, A_r is the attribute set of route r and H_n is the attribute set of person n.

The choice set is the set of options or alternatives that are considered by an individual to perform a choice. The systematic component is a function of the attributes of the alternative itself and of the decision maker. This paper focuses on route attributes and leaves aside characteristics of the decision maker.

Owing to the Independence from irrelevant alternatives property of multinomial logit models, the overlap of routes for a given start–destination pair needs to be taken into account. Otherwise, too many passengers would be assigned to routes with a large overlap when predicting route choice. We use a path-size logit model which includes a route overlap factor in the utility function. Ramming (2002) introduces a path size variable (PS) where the physical overlap is expressed in length. We use a model formulation in (Daamen *et al.*, 2005) and calculate PS as follows

$$PS_r = \ln\left(\sum_{a \in r} \frac{l_a}{L_r} \frac{1}{N_a}\right) \tag{2}$$

where PS_r denotes the overlap factor for route r, a is the index of a link connecting two adjacent transit stations, l_a is the length of link a that is a part of route r and L_r is the length of route r. N_a is the number of alternatives in the choice set which contain link a.

Each route can be characterized through a set of attributes. The list below shows proxy criteria that map readers may apply when trying to plan the fastest route from a transit map. The criteria are motivated from related research on route choice (Stern, 1980; Pursula and Weurlander, 1999; Bailenson *et al.*, 2000; Hochmair and Frank, 2002; Bovy and Hoogendoorn-Lanser, 2005):

- number of transfers;
- travel distance;
- the longest waiting time for the next vehicle (M);
- cumulative normal distance (CND);
- number of stops along route;
- number of transfer options at transfers. Passengers may perceive routes that require transfers at central hubs as longer because of the time it takes to find the correct platform and because of longer transfer walking times;
- deviation angle between direction to destination and direction to point located at end of first third of the route;
- waiting time for next departure at trip origin.

Route directness has been found to play an important role for route selection in real world activity patterns (Golledge, 1997) or virtual environments (Dalton, 2001; Hochmair and Karlsson, 2005). Therefore, we assume that it also plays a role for route selection from maps. Besides the angular measure that was introduced before, route directness, which is also known as sinuosity, is traditionally computed as ratio of route distance to straight-line distance for two selected points (Dill, 2004). One alternative measure is the area enclosed between the route and the direct line from trip start to destination. As a second alternative, we introduce the CND, where for a given route r, normal distances to the direct line between start and destination are measured from all path segments j at a constant sampling interval d, and added up (equation (3))

$$CND_r = \sum_{j=1}^{J} \frac{l_j}{d} \frac{n_{s(j)} + n_{e(j)}}{2} \tag{3}$$

where J is the number of links of route r, d is the arbitrary sample distance along segments (we use d=1 m), l_j is the length of link j, $n_{s(j)}$ is the normal distance at start node of link j and $n_{e(j)}$ is the normal distance at end node of link j.

Figure 4a illustrates the parameters of equation (3) for a route between station A and D that consists of three segments. Along with Figure 4b, we show that sinuosity and the enclosed area measure can lead to counterintuitive directness rankings of routes, as opposed to CND.

Let in Figure 4b A be the trip origin, and let C be the trip destination, with a straight-line distance (AC) of a. Computation results for route directness of three route alternatives, i.e. ABC (dashed line), ABDC (continuous line) and AEFGC (point-dashed line), are presented in Table 1.

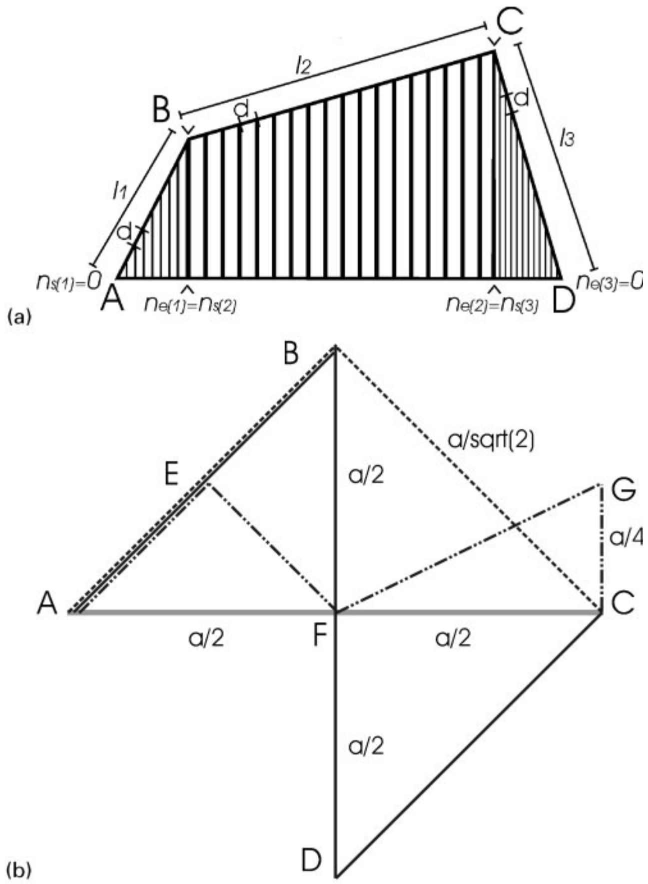

Figure 4. Measuring the cumulative normal distance (CND) (a), and sample network for demonstrating various measures of route directness between A and C (b)

Minimum sinuosity ranks ABC first, followed by AEFGC and ABDC. The ranking order of the first two routes seems somewhat counterintuitive, since AEFGC diverts less from the straight line than ABC. With the area measure, ABC and ABDC are tied at the second rank. This tie is counterintuitive, as with ABDC the traveller also needs to traverse line BD, which is not the case with option ABC. Finally, minimum CND yields an intuitive ranking. It is therefore used as variable in the model estimation.

EMPIRICAL STUDY

The purpose of this browser based study is to estimate a route choice model on public transportation maps and to determine the effectiveness of transit maps that vary in map annotations.

Participants

About half of the 35 participants were volunteers recruited via the Internet, and the other half were undergraduate students who received partial course credit. Participants were asked to rate their familiarity with the Vienna public transit network on a scale from 1 (completely unfamiliar) to 5 (very familiar). Twenty-three participants stated to be completely unfamiliar, two stated to be hardly familiar, two stated to be somewhat familiar, four stated to be pretty familiar and four stated to be very familiar. Subjects in the first three categories ($N=27$) will be referred to as the ‘unfamiliar’ group, and subjects of the last two categories will be referred to as the ‘familiar’ group ($N=8$). The splitting into these two groups is somewhat arbitrary. On the one side, one may argue that already a onetime experience of an environment can change how information about this environment is processed (Heft, 1979). On the other side, after a one time visit, one will remember at most the headways or transfer times for the few transit lines used during one’s visit. Owing to the larger sample size available, the route choice analysis of this paper will primarily focus on the unfamiliar group. All analysis described later was also run for a ‘reduced’ unfamiliar group where the four members of the second and third categories, i.e. hardly and somewhat familiar subjects, were excluded. But this did not change the results noticeably.

Material

Five public transportation maps (Figure 3) covering the metro and rapid train network within and around Vienna were prepared for visualisation within a Web based Internet study. On top of these maps, participants were to indicate the presumed fastest route between highlighted trip origin and destination stations. Twenty-six origin–destination pairs based on 30 transit stations were identified in the network for testing. These 30 stations are marked with three-letter labels in Figure 1.

Procedure

At the beginning of the study, eight out of the 26 choice situations were randomly chosen for each participant. These eight situations were shown to the participant on all five map types. Thus, each participant was to provide a total of $5\times8=40$ route choices during the study. The sequence of map types, on which the eight assigned choice situations were shown, was also randomized, except for the schematic map, which was shown first since it was the map with the least information.

For each map type, an introductory page was provided with short instructions on how to indicate the selected

Table 1. Comparison of three proxy parameters for route directness

Path	Sinuosity []		Enclosed area [a^2]	CND [a]	
	Exact	Rounded	Exact	Exact	Rounded
ABC	$(2)^{1/2}$	1.41	1/4	$1/(8)^{1/2}$	0.35
ABDC	$1+(2)^{1/2}$	2.41	1/4	$1/(8)^{1/2}+1/4$	0.60
AEFGC	$1/(2)^{1/2}+(5)^{1/2}/4+1/4$	1.52	1/8	$1/8\times[1/(2)^{1/2}+(5)^{1/2}/4+1/4]$	0.19

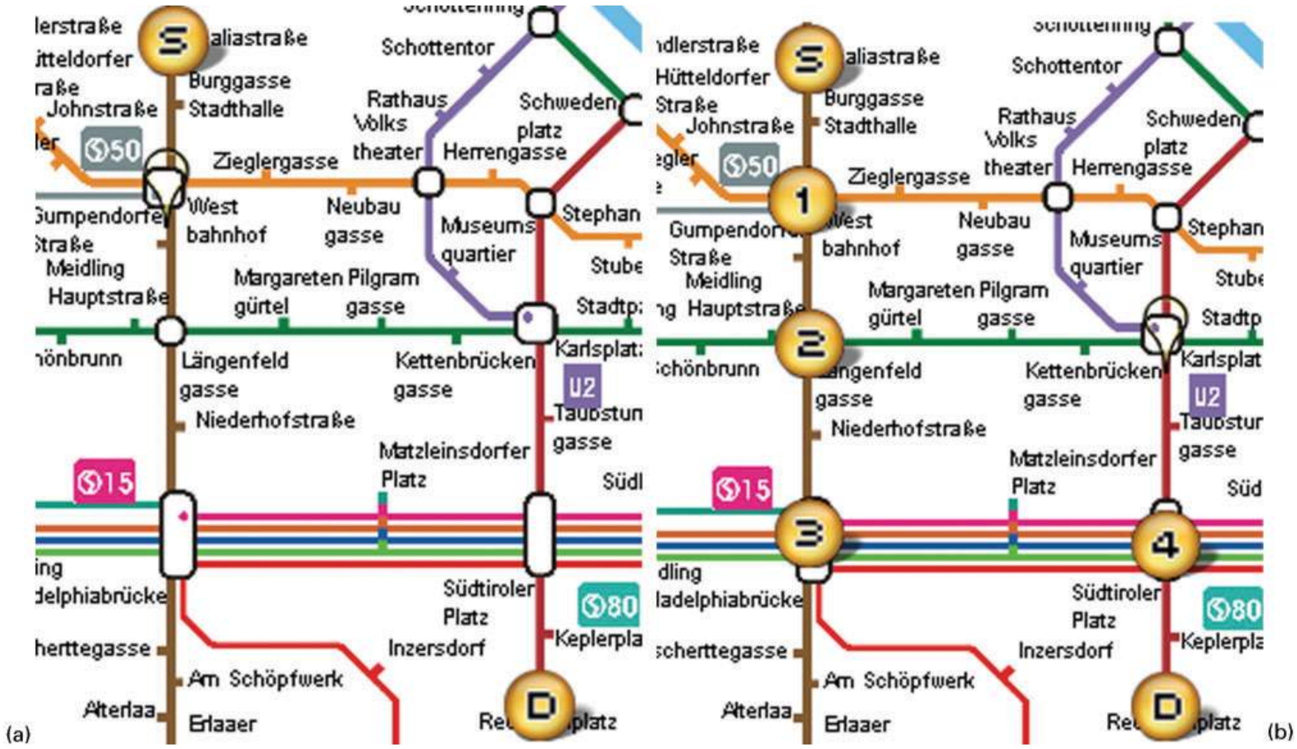

Figure 5. Start and destination highlighted (a), with user-chosen waypoints highlighted (b)

route, followed by the eight randomly selected choice situations which were presented one after another to the participant. Trip start and destination stations were highlighted through ‘S’ and ‘D’ symbols, as shown for the schematic map in Figure 5a. Participants were asked to indicate through mouse clicks on transfer stations, which route they believed to be the fastest one. Selected transfer stations were then marked as numbers in the browser window (Figure 5b) and logged on the Web server. Then the sequence of eight choice situations was re-shuffled, and the same task repeated for the four remaining map designs. Some chosen routes indicated by participants were incomplete and removed from the analysis. All participants of the familiar group together provided for each map type a total of 187 valid route choices from a total of 897 choice alternatives.

RESULTS

Model estimation for route choice behaviour on maps

Separate model estimations were made for the schematic map, the headway map, the departure time map and the reference map. The utility functions to be estimated consist of route characteristics and an overlap factor

$$U_r = \alpha PS_r + \beta T_r + \delta N_r + \psi D_r + \gamma M_r + \eta S_r + \kappa R_r + \lambda A_r + \mu W_r + \varepsilon_r \qquad (4)$$

where U_r is the utility of route r, PS_r is the overlap factor of route r, T_r is the number of transfers along route r, N_r is the cumulative normal distance of route r (in metres), D_r is the mapped distance of route r (in metres), M_r is the maximum average waiting time of any link on route r (in minutes), S_r is the number of stops along route r, R_r is the total number of transfer options at transfers taken along route r, A_r is the deviation angle of end point of first third of route from destination direction (in degrees), W_r is the waiting time for next departure at trip origin (min), ε_r is the disturbances for route r, and α, β, δ, ψ, γ, η, κ, λ and μ are the parameters to be estimated.

The nine variables were used to estimate unrestricted multinomial logit choice models (Table 2). The null log-likelihood L^0 is the same in all estimated models. It describes the value of the log-likelihood function when all parameters are zero, i.e. when the alternatives are assumed to have equal probability to be chosen.

$$L^0 = \sum_{j=1}^{N} \ln \frac{1}{|R_j|} \qquad (5)$$

where $|R_j|$ is the number of choice alternatives available to the individual decision maker in decision situation j, and N is the total number of decision situations. The final log-likelihood L^* is the log-likelihood of the sample for the estimated model. The rho-square value is an informal goodness-of-fit index that measures the fraction of an initial log-likelihood value explained by the model.

$$\rho^2 = 1 - \frac{L^*}{L^0} \qquad (6)$$

Another measure of goodness of fit is known as ‘% right’. It describes the percentage of correct predictions, i.e. the percentage of choice situations where the highest predicted probability corresponds to the chosen alternative. When routes are chosen randomly, the fraction of correct predictions equals

$$p=\sum_{j=1}^{N}\frac{1}{|R_j|}/N \qquad (7)$$

which in the observed choice situations amounts to 44.4/187=23.8%. Following routes were included in choice sets of origin–destination pairs:

- the shortest route;
- the route with the fewest transfers;
- the route with the fewest stops;
- the route chosen by any participant.

The likelihood ratio test statistic

$$-2(L^0-L^*) \qquad (8)$$

is used to test the null hypothesis that all the parameters are zero. It is asymptotically distributed as χ^2 with K degrees of freedom, where in this study design K equals the number of coefficients to be estimated.

Expected waiting times (WT) for the next vehicle at a station depend on the number of lines that are serving this network segment, and on their headways. With only one line operating at a headway h, WT equals $h/2$ (ReVelle and McGarity, 1997). With more than one line operating on a segment, WT decreases. We assume that map users intuitively estimate the combined WT based on the assumed or given headways of these segments. For the input in the route choice model, the WT values of multi-served route segments were computed in a simulation tool that randomizes offsets in departure times (Δd) between vehicles of different lines serving the segment of interest, and that averages the computed waiting times from all randomized offsets. For illustration purposes, Figure 6 visualizes some headway combinations and their average WT when one, two or three different lines are serving a route segment simultaneously. For the illustrated examples, the simulation randomizes Δd, $\Delta d2$ and $\Delta d3$ between 0 and 59 min, and $\Delta d1$ between 0 and 29 min. In the utility function (equation (4)), M denotes the maximum WT value along a given route.

Estimation results in Table 2 reveal good model accuracies of 38% or more (see % right) when compared to the random rate of 23.8%. The likelihood ratio test rejects for all four models the null hypothesis that all parameters are zero. Variables that are estimated significantly at the 5% significance level in the unrestricted models are printed in boldface. The signs for all significant coefficients are as expected, i.e. negative.

To analyse whether variables other than the ones estimated significant in Table 2 contribute to route utility, we first define a reference model for each map type with the significantly estimated variables. This is followed by a model extension with remaining variables. A chi-square test determines whether an extended model (*) gives better estimation results than a reference model (R), taking into

Table 2. Estimation results for unrestricted multinomial logit choice models

Variable name		Schematic map	Reference map	Headway map	Departure time map
Overlap factor PS	α	-7.92×10^{-2}	−0.416	0.280	0.481
	t-statistic	−0.2	−0.9	0.8	1.4
Transfers	β	**−0.856****	-7.49×10^{-2}	−0.366	**−0.499****
	t-statistic	**−4.1**	−0.5	−1.9	**−2.6**
Cumulative Normal distance	δ	-2.26×10^{-5}	-1.95×10^{-5}	-2.52×10^{-5}	-1.82×10^{-5}
	t-statistic	−1.1	−1.7	−1.2	−1.0
Distance	ψ	$\mathbf{-2.21\times10^{-4}}$*	$\mathbf{-1.71\times10^{-4}}$*	$\mathbf{-2.03\times10^{-4}}$*	-1.61×10^{-4}
	t-statistic	**−2.3**	**−2.3**	**−2.1**	−1.9
Max. waiting time	γ	-1.79×10^{-2}	1.07×10^{-2}	-4.26×10^{-2}	-3.72×10^{-2}
	t-statistic	−1.0	0.5	−1.6	−1.6
Stops	η	-3.96×10^{-2}	**−0.130****	2.73×10^{-2}	-4.82×10^{-2}
	t-statistic	−0.8	**−3.7**	0.8	−1.5
Transfer options	κ	-4.62×10^{-3}	-7.49×10^{-2}	$\mathbf{-4.87\times10^{-2}}$**	-2.37×10^{-2}
	t-statistic	−0.3	−0.5	**−2.7**	−1.4
Deviation angle	λ	-6.86×10^{-3}	-3.28×10^{-3}	$\mathbf{-1.58\times10^{-2}}$*	-3.06×10^{-4}
	t-statistic	−1.0	−0.5	**−2.2**	0.0
Waiting time	μ	-6.18×10^{-2}		-4.76×10^{-2}	-3.22×10^{-2}
	t-statistic	−0.4		−1.9	−1.8
No. of parameters to be estimated		9	9	9	9
No. of observations		187	187	187	187
Likelihood ratio test		82.0	83.8	69.8	49.4
$\chi^2_{(9,0.05)}$		16.92	16.92	16.92	16.92
Final log-likelihood L^*		−240.3	−239.5	−244.3	−256.7
Null log-likelihood L^0		−281.4	−281.4	−281.4	−281.4
ρ^2		0.146	0.145	0.132	0.088
Right (absolute)		91	97	87	72
% right		48.7	51.9	46.5	38.5

*Significantly different from zero at the 0.05 level.
**Significantly different from zero at the 0.01 level.

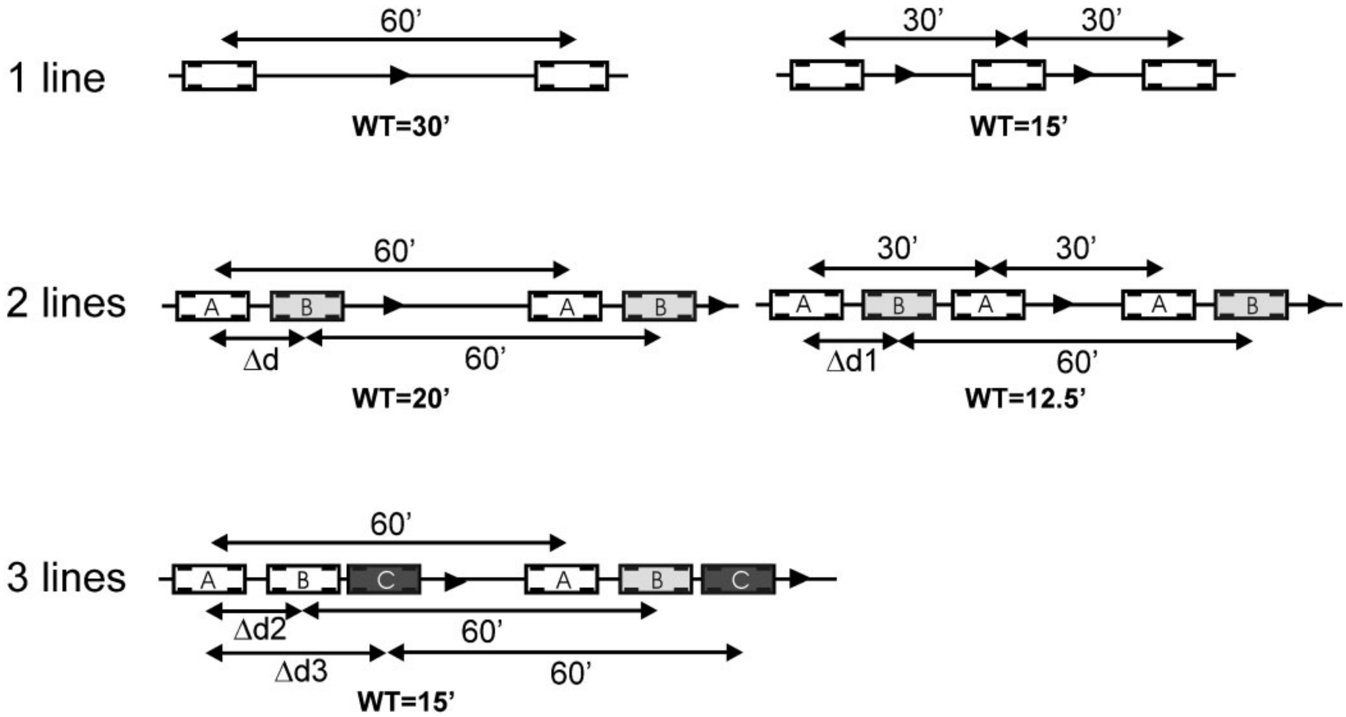

Figure 6. Expected waiting times at multi-served segments. Capital letters denote names of transit lines

account that the extended model contains more parameters. The chi-square test statistic

$$-2(L^{\mathrm{R}} - L^{*}) \quad (9)$$

is compared to a critical test value $\chi^2_{(\mathrm{df},\alpha)}$, where df stands for the degree of freedom, which equals to the difference in the number of model parameters to be estimated. Table 3 shows the reference models and extended models.

For the schematic map, one additional parameter could be estimated significantly. The extended model indicates that users of the schematic map tend to minimize number of transfers, CND and travel distance. The global scale used in the schematic map, which affects the meaning of the coefficients related to travel distance, was determined through manually overlaying the schematic map on top of the reference map in a geographic information system. For the reference map, no extended model could be identified, and map users tend to minimize stops and travel distance to determine the fastest route. As opposed to the schematic map, the number of transfers does not play a significant role in route selection with that map type.

For the headway map, a model extension was identified with two additional variables that estimates maximum waiting time significantly and waiting time at trip origin not significantly ($p<0.10$). In spite of the latter, the model is significantly better than the two other models for that map. It is the only model for any map type where route choice is significantly affected by headways, or more specifically, the maximum expected waiting time associated with headways. This is because none of the other map types provides annotated headway information. This result indicates that the annotated information on headway maps is successfully communicated to map users. Further, the results for this map type suggest that even with annotated headway information, the map user can, at least partially, identify trips with a short waiting time at the trip origin. On headway maps, estimation of lines with early departure can only be retrieved on transit stations where lines of different headways are operating. The line with a smaller headway has a higher chance for a shorter waiting time for the next departure than lines with a larger headway.

For the departure time map, a model extension could be found which is significantly better than the other two models for that map, although the newly added variable (waiting time for next departure) is only significant at the 10% level. The reason for the coefficient not being significant at the 5% level may be found in the visual representation of this annotated information. In the presented map design, all departure times for a station were listed in one composite text field next to the station (Figure 7a). In the text field, the direction of a line is described through the label of the end station in that direction. Especially unfamiliar users may have some problems in finding these station labels on the map and to identify which direction the departure times referred to. A possible design improvement is to break the composite text field into individual rows and place the information next to the corresponding direction (Figure 7b).

The results of the multinomial path-size logit models (Table 3) indicate that choice behaviour and used proxy criteria vary significantly between the four analysed map types, which confirms Hypothesis 1. The following route utility functions can be formulated for the four map types

$$U_r(schematic) =$$
$$-0.854\,T_r - 3.44x10^{-5}\,N_r - 2.33x10^{-4}\,D_r + \varepsilon_r \quad (10)$$

Table 3. Estimation results for reference and extended multinomial logit choice models

		Schematic map		Reference map	Headway map			Departure time map		
Variable name		Reference	+CND	Reference	Reference	+Waiting time	+Max. waiting time	Reference	+Distance	+Waiting time
Overlap factor	α									
PS	t-statistic									
Transfers	β	−0.751**	−0.854**					−0.381**	−0.536**	−0.606**
	t-statistic	−5.2	−5.5					−3.2	−4.0	−4.3
Cumulative	δ		-3.44×10^{-5}*							
Normal distance	t-statistic		−2.1							
Distance	ψ	-3.81×10^{-4}**	-2.33×10^{-4}**	-2.57×10^{-4}**	-1.84×10^{-4}**	-2.14×10^{-4}**	-2.38×10^{-5}**		-2.30×10^{-4}**	-2.59×10^{-4}**
	t-statistic	−6.9	−2.7	−4.7	−3.2	−3.5	−3.8		−4.7	−4.9
Max. waiting	γ						-4.45×10^{-2}*			
time	t-statistic						−2.0			
Stops	η			−0.125**						
	t-statistic			−4.8						
Transfer options	κ				-6.30×10^{-2}**	-6.89×10^{-2}**	-6.54×10^{-2}**			
	t-statistic				−4.6	−4.8	−4.5			
Deviation angle	λ				-1.85×10^{-2}**	-2.04×10^{-2}**	-1.94×10^{-2}**			
	t-statistic				−3.3	−3.6	−3.4			
Waiting time	μ					-4.63×10^{-2}*	$-4.20\times10^{-2+}$			$-2.64\times10^{-2+}$
	t-statistic					−2.1	−1.7			−1.8
Parameters to		2	3	2	3	4	5	1	2	3
be estimated										
No. of observations		187	187	187	187	187	187	187	187	187
df			1			1	2		1	2
Final log-likelihood		−244.0	−241.9	−243.1	−253.0	−249.6	−247.5	−276.1	−263.3	−261.3
L^*										
Null log-likelihood		−281.4	−281.4	−281.4	−281.4	−281.4	−281.4	−281.4	−281.4	−281.4
L^0										
ρ^2		0.133	0.140	0.136	0.101	0.113	0.120	0.019	0.064	0.071
Right (absolute)		84	99	90	80	80	81	51	68	72
% right		44.9	52.9	48.1	42.8	42.8	43.3	27.3	36.4	38.5
$\chi^2_{(df,0.05)}$			3.84			3.84	5.99		3.84	5.99
$-2(L^R-L^*)$			4.2			17.2	21.4		25.6	29.6
$-2(L^R-L^*)>\chi^2_{(df,0.05)}$			True			True	True		True	True

*Significantly different from zero at the 0.05 level.
**Significantly different from zero at the 0.01 level.
+Significantly different from zero at the 0.10 level.

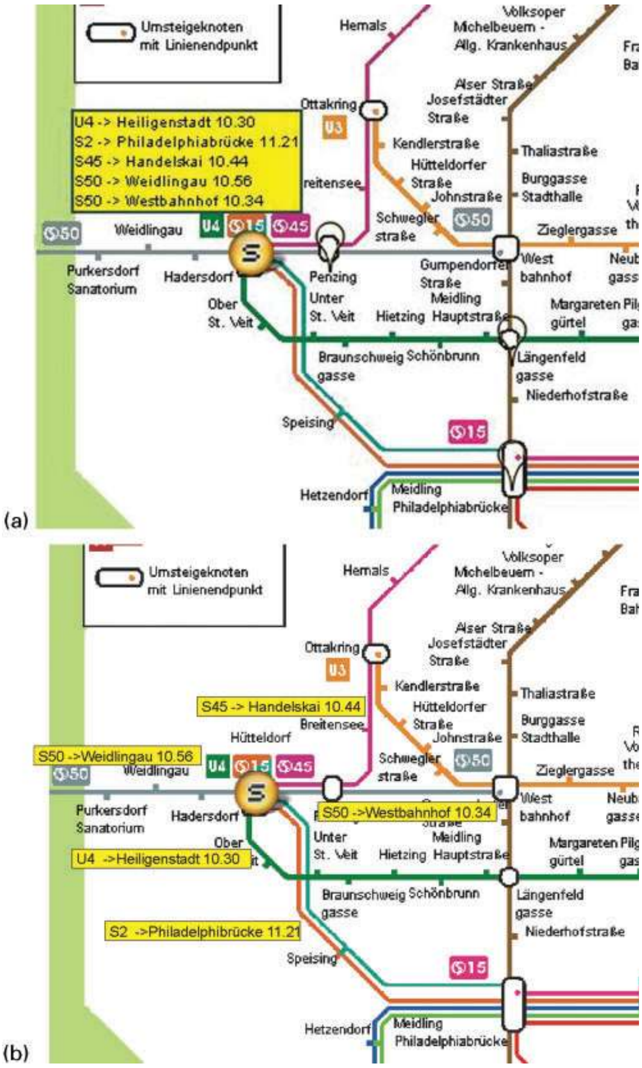

Figure 7. Composite (a) and separated (b) annotation of departure times

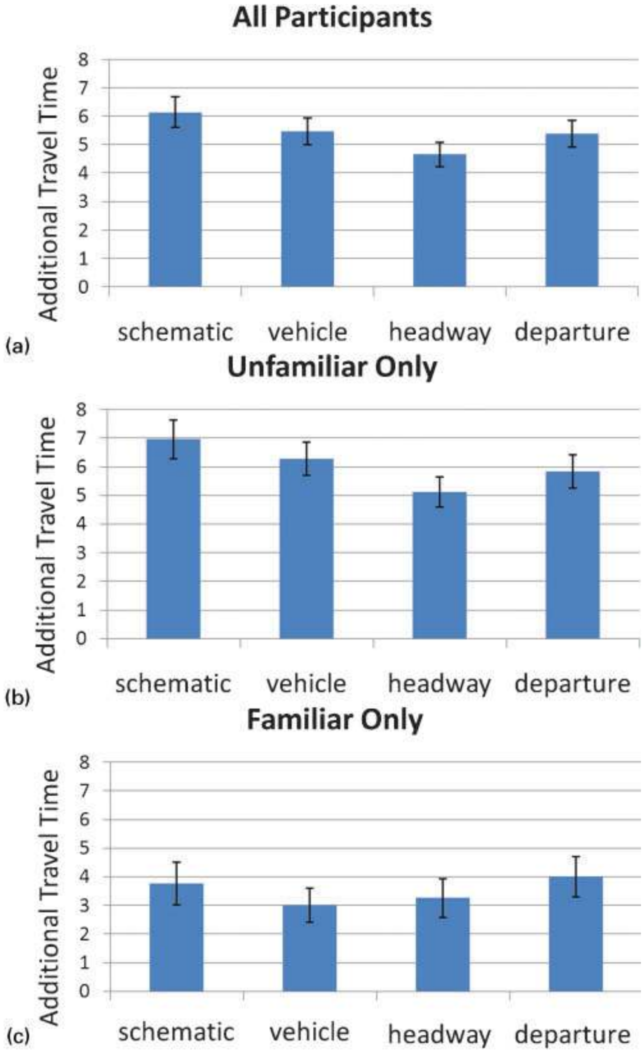

Figure 8. Map effectiveness of different map types: (a) all participants; (b) unfamiliar only; (c) familiar only. Error bars indicate ± standard deviation of the mean

$$U_r(reference) = -2.57x10^{-4} D_r - 0.125 S_r + \varepsilon_r \quad (11)$$

$$U_r(headway) = -2.14x10^{-4} D_r - 6.89x10^{-2} R_r - 2.04x10^{-2} A_r - 4.63x10^{-2} W_r + \varepsilon_r \quad (12)$$

$$U_r(\text{departure}) = -0{\cdot}536\, T_r - 2{\cdot}30 \times 10^{-4} D_r + \varepsilon_r \quad (13)$$

Map effectiveness

Based on observed route choices, map effectiveness can be computed for the four map types. A higher map effectiveness means a smaller additional travel time for user selected routes when compared to the actually fastest route (Figure 8).

According to Hypotheses 2-1, 2-2 and 2-3, three paired samples *t*-tests were conducted to determine the level of significance for observed differences in effectiveness between the schematic map and three schematic maps with annotated time related network information (Table 4). Tests were performed for all participants as well as for the unfamiliar group. There was a significant difference between the scores of the schematic map ($M=6.2$, $SD=8.64$) and the headway map ($M=4.7$, $SD=6.72$); $t(247)=2.85$, $p=0.005$, for all participants, and a significant difference between the scores of the schematic map ($M=7.0$, $SD=6.28$) and the headway map ($M=5.1$, $SD=7.06$); $t(186)=2.75$, $p=0.007$, for unfamiliar participants. These results suggest that the additional information on headway maps allows planning faster routes when compared to a schematic map without map annotations, which confirms Hypothesis 2-2. There was no significant difference in scores between schematic and vehicle maps, and between schematic and departure time maps, which leads to reject Hypotheses 2-1 and 2-3.

Table 4. Differences in additional travel time between schematic map and annotated maps

	Map 1	M	SD	Map 2	M	SD	*t*	*p*
All participants	Schematic	6.2	8.64	Vehicle	5.5	7.54	1.34	0.181
N=248	Schematic	6.2	8.64	Headway	4.7	6.72	**2.85**	**0.005**
	Schematic	6.2	8.64	Departure	5.4	7.37	1.48	0.140
Unfamiliar only	Schematic	7.0	6.28	Vehicle	6.3	8.10	1.05	0.295
N=187	Schematic	7.0	6.28	Headway	5.1	7.06	**2.75**	**0.007**
	Schematic	7.0	6.28	Departure	5.8	7.83	1.65	0.101

Many trips involve several transit lines and transfers in-between. With the headway map, headway information is provided for all lines of a network. As opposed to this, departure times in the departure time map are only annotated to lines departing from the trip origin, which covers a smaller portion of the network. This is a possible explanation of why headway maps have a higher effectiveness than schematic maps, but why this is not the case for the departure time map. Besides this difference in content, ineffective cartographic design in the departure time map (Figure 7a) may be another explanation for this observation. Since headway and departure time annotations refer to different network segments and provide different kinds of information, we expect that a combination of annotated headways and departure times can provide a better map effectiveness than each of these annotation types alone.

The position of vehicles along a transit line in the vehicle map can be used to estimate relative headways and waiting times until the next departure. Thus, the information provided in this map type combines information from the headway and the departure time map. However, the cognitive load for the user to decode this information is higher than for other map types since the information needs to be derived from numerous scattered arrow symbols. Thus it can be suspected that for this map, the cartographic representation is partially accountable for not providing significant improvement of effectiveness over the schematic map.

Visual inspection of Figure 8b and c indicates shorter additional travel times for the familiar group of participants compared to the unfamiliar group. Considering responses of all 35 participants, a small negative correlation of additional travel time and subject familiarity was significant [$r(1238)=-0.154$, $p<0.001$]. This indicates that map users who are more familiar with the environment are able to plan faster routes.

CONCLUSIONS

The first contribution of this paper was the estimation of a path-size logit model for fastest route choice on four types of public transportation maps that vary in map information and network geometry. Map distance was estimated significantly in all four extended models, whereas other coefficients varied between map types. The headway-related time measure (maximum waiting time), was found significant in connection with headway maps, which indicates that this additional information is received and utilized by the map user within the map communication process. Further, departure time is estimated significantly with the headway map, and marginally significant ($p<0.10$) for the departure time map, which also supports these findings. This study also revealed that deviation angle and Cumulative Normal Distance are significant variables in route choice from the schematic map and the headway map, respectively. This effect of route directness extends criteria that have so far been identified for route choice from maps (Christenfeld, 1995; Golledge, 1995; Bailenson *et al.*, 2000).

The second contribution of this paper was to assess the effect of time related map annotations on planning the fastest route in an intra-urban transit network. It was found that headway information increases map effectiveness for unfamiliar users when compared to traditional schematic maps, whereas no increase in effectiveness was found for annotated vehicle positions and departure times. Annotated maps could be installed at transit stations and upgrade stationary maps. Map annotations, e.g. current headways retrieved from the time table, could be displayed dynamically on top of the visualized network geometry.

The statistical analysis was conducted for map users that are unfamiliar with the environment, most of whom have never travelled in the network before. For future work, the effect of map annotations for familiar users needs to be examined as well. The analysed network contains only fast connections, such as metro lines and rapid trains, which can be relatively easy visualized on a schematic map. If including busses and tram lines, the network of lines gets denser, and it is more common to use a reference map combined with a visualisation of the street network instead. This allows for planning a door-to-door trip including foot paths. For future work, it needs to be examined whether headway annotations are also useful in increasing map effectiveness on such reference maps. Another aspect of future work is to analyse whether electronic route planning applications, such as browser based tools on mobile devices, or customized applications on public information kiosks at the station for travellers, are preferred over stationary public transit maps posted at transit stations. We expect a trade-off between information access time with routing accuracy: a transit network map posted at a station can be accessed immediately, but it does not provide customized routing information to the user. As opposed to this, a trip planning application takes some time to be loaded, but provides precise routing instructions. A related challenge is to advance with the combination of mobile devices alongside large, public, stationary maps for route planning purposes (Reilly *et al.*, 2008).

BIOGRAPHICAL NOTES

Hartwig Hochmair is Assistant Professor of Geomatics at the University of Florida (USA). His research areas include investigation of human wayfinding strategies in the real world and the WWW, interface design of route planning tools, and network analysis with a focus on bicycle and public transportation mode.

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NOTES

[1] For example: http://maps.google.com/transit

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