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Map-induced journey-planning biases for a simple network: A Docklands Light Railway study

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ABSTRACT

A usability study was conducted to identify the most effective prototype Docklands Light Railway map for installation on trains. This comprised a series of tasks that required station finding and also planning of routes between pairs of stations, with response time and accuracy as measures of performance. In addition, subjective ratings of map design were collected via questionnaire-based evaluations, and also ranked preferences between designs. A clear best-option was easily identifiable as a result of this research. The existing design was associated with the most journey planning errors, and two of the prototypes were associated with inefficient journey choices. The latter finding suggested that respondents were using unsophisticated planning strategies that were put at a disadvantage by certain route depictions. This has wider implications for suggestions that schematic maps should maintain topographical relationships in order to facilitate appropriate journey choices, with the danger that the inevitable increased complexity of line trajectories for such designs would simultaneously reduce the ability of passengers to identify the most appropriate routes.

1. Introduction

Urban transit networks, including rail-based ones, are steadily increasing in complexity worldwide, owing both to lines and extensions being added within existing networks (particularly in Asia), and also to the increasing tendency to integrate different transport modalities within cities, made possible by common fare arrangements. Ovenden (2003, 2009, 2015) provides an excellent time-lapsed overview of this phenomenon worldwide. With this increasing complexity, the user has to cope with ever more options when journey planning – a task that requires identifying appropriate departure and arrival points, and determining the most efficient route for travel from one to the other. The challenge for designers – the creation of legible, effective network maps – likewise increases year-by-year. Indeed, a recent mathematical analysis (Gallotti et al., 2015) suggests that there is a cognitive limit to the understandability of complex transport networks, and that a number of these worldwide have already exceeded this threshold. Despite the proliferation of journey-planning software, the network map remains an important source of information. Indeed, many applications for hand-held devices are merely network maps with extra functionality added, such as options to add additional layers of information to a base design.

In response to this complexity, many network maps are *schematized*, which involves simplification via at least some of the following techniques.

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(1) *Omission of surface details other than the most important landmarks.* The intended use of such a design is therefore to plan routes between pairs of *already-known* origin and destination stations, rather than the selection of target stations.
(2) *Simplification of line trajectories*. At the very least, complex twists and turns may be smoothed, but often the network is depicted using straight lines; typically horizontal, vertical, and 45° diagonals linked by tightly radiused corners. The technical name for this is *octolinearity*, as used for over eighty years on the London Underground diagram.
(3) *Global and/or local scale distortion*. For many networks, at least some expansion of the centre and compression of the suburbs is required in order to produce a compact design that is legible. However, in order to accommodate station labels and simplify line trajectories, local distortions may also be applied, with the consequence of altering relative station positions, line directions, and distances between stations, both within and between lines.

Roberts (2012) discusses a number of issues surrounding topographical distortion on schematic maps. Individuals vary massively in their tolerance of this (see also Forrest, 2014; Roberts, 2014b), and network maps differ considerably in this regard. For example, at the time of writing, Berlin, Boston, and London have far higher levels than Chicago and Paris. In London and Berlin, distortion is necessitated by extensive networks with widely spaced stations in the suburbs, and dense central areas with closely-spaced stations. In Boston, distortion has been driven by the numerous closely-spaced stations on the 'Green Line'. For Chicago, the network structure closely follows the city's grid street layout, and stations are named by intersecting streets – resulting in numerous duplicated station names. Topographical distortion would run the risk of confusing users and conflicting with their mental models of the city. For Paris, there is a very compact dense network; the correct relative positioning of stations is likely to be more important for users when these are nearby than when these are distant.

In general, for any network schematic, if high topographical fidelity is specified for one particular location in order to assist users, then accuracy is required for all locations, because it is logically impossible for a naive user to know, *a-priori*, which parts of a map have been configured to provide journey planning hints, and which have been distorted, for example, in order to accommodate long station names. However, for many networks, a requirement to minimize topographical distortion is in conflict with the necessity to provide a compact legible design with simple line trajectories – the main goal of creating a schematized map to begin with. Roberts (e.g. 2012, 2014a, 2014b; Roberts et al. 2013) has argued that merely creating an octolinear schematic depiction of a network is not sufficient by itself to ensure enhanced usability. It is also necessary to simplify line trajectories so that the major system elements, their relatedness, and the underlying network structure can be readily identified. Roberts et al. (2013) argue that in the case of Paris, the network properties – dense interconnected lines with complex trajectories – coupled with the requirement for correct relative positioning of stations, means that the current schematized map fails this prime requirement of presenting the user with a simplified depiction of the network. The twisting meandering lines have merely been converted to short straight line segments and numerous zig-zags, so that the complexity of line trajectories has been reshaped rather then reduced.

The psychological concept of *cognitive load* is of prime importance (e.g., Carpenter et al., 1990). The more information that must be processed in order to perform a task, the greater the cognitive load and therefore the greater its difficulty. This can easily be demonstrated, for example, with items used to test intelligence, where the elements of the hardest items are not only greater in quantity, but also have low *structural salience*: their visual complexity makes their identification difficult (Meo et al., 2007; Roberts et al., 2000). An appropriately designed schematic map should have simple line trajectories giving it high structural salience, facilitating both journey planning and learning, so that a virtuous circle is setup, with performance getting better as more is learnt. For such a design, we would expect fast journey planning, few errors, better remembered plans, and more easily reconstructed plans in the event of a failure to remember. In comparison, a poorly designed schematic will not have these benefits, and may even have little to offer compared with a topographical map, other than the simplification entailed in removing street details and most other landmarks.

It has been argued earlier that the criteria for effective schematization – simplifying line trajectories while attempting to maintain topographical accuracy – are potentially in conflict. It is therefore important to consider how topographical information might assist users in journey planning and, conversely, how distortion might hinder their efforts. If a compact schematic map has most surface detail omitted, then its utility for identifying target stations is limited. However, in the event of service disruption, a map that preserves relative station positions and distances will enable users to identify nearby alternatives. Hence the need for topographical accuracy is greater in areas of high station density. Even so, the variable scale of many schematic maps may mislead users, and Mijksenaar and Vroman (1983) proposed a hybrid map of the London Underground, with curvilinear lines at a topographically accurate centre to show accurate station placement in the region of the map where this information is likely to be of most use, and octolinear schematized suburbs, for simplicity, where topographical accuracy and scale is less important.

Guo (2011) discusses two further ways in which topographical distortion can influence journey planning. These are particularly important because the entire basis of the schematic map – facilitation of the planning of efficient journeys – may be undermined. Firstly, by exaggerating distances between stations, it is possible that users may be induced into taking inappropriate journeys in which there is little time benefit, even compared with walking. Secondly, by altering relative lengths and implied directness of competing options, inappropriate roundabout routes may be made to appear viable.

The basis of Guo's (2011) work is an in-depth analysis of actual London Underground journeys. The major finding in this study was that map-depicted journey distance is a better predictor of journey choice than actual journey distance, even for experienced users (see also Hochmair, 2009; Raveau et al., 2011), and that map-implied interchange quality is also influential. The official London Underground schematic does distort topography, but it is difficult to devise global measures of this