A Vision for Pervasive Information Visualisation to Support Passenger Navigation in Public Metro Networks

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***Abstract*—This paper presents a vision of how pervasive information visualization can be used to support passenger navigation in public metro systems. The system we propose combines mobile devices with large display interfaces in order to make the process of metro system navigation more convenient by allowing a passenger to plan their route in the station using a large-display interface and follow the route using notifications on a smartwatch or similar wearable device. This system will remove the need for passengers to search in-station maps for their destination, rely on their view of in-carriage route maps, or work a metro navigation app on their smartphone on crowded carriages. This aims to make the process of metro travel less of a hassle for most travelers, and especially travelers who are not familiar with the metro network. Our system acts also acts as an early stage case-study for testing the concept of pervasive information visualization.**

Keywords—Information Visualization, Pervasive Computing

I. INTRODUCTION

Metro systems, also known as rapid transit or mass rapid transport systems, are high-capacity public transport systems typically found in urban areas. These can have underground-trains, overground-trains, trams or busses running between stations on different interconnected lines. Metro systems typically handle a large volume of passengers, and can have large numbers of stations and lines with, for example, the London Underground having 315 stations and 12 lines and the New York subway having 472 stations and 27 lines. This can make navigation challenging for travelers who are unfamiliar with the network, especially at busy times when stations and carriages are crowded.

The need to accommodate growing numbers of passengers and aid navigation around expanding metro systems around the world [1] has called for the introduction of some inventive aids to navigation over the years. For example, the classic octilinear schematic representation [2] originally developed for the London Underground map by Harry Beck in 1931 and used for most metro maps today (see figure 1) is often cited as classic example of information visualization design. These maps are typically displayed in a predominate position in the station and can be used for a passenger to plan their route. These are used in conjunction with maps on-board the train or bus that show stations and transfers along a single transit line (see figure 2).

More recently transport authorities and various commercial originations have developed mobile applications to help passengers navigate metro systems. These tend to use either a version of the standard octilinear schematic map or a specialized route map (showing the number of stops on each line and the transfers) to help passengers plan their route and navigate the route while they are in transit.

An initial evaluation of usability of metro navigation aids led us to the conclusion that while the existing provision is useful and ultimately helps passengers reach their destination, there are however certain issues for the passenger that can be exacerbated when they are not familiar with the network or the network is crowded. The first issue our study identified was that when using the schematic map the passenger needs to take the time to locate the destination station and find the best route from the current station to the destination. This becomes progressively more difficult for larger networks with more lines and stations. For larger systems where the passenger is unfamiliar with the network this can take a considerable amount of time. After this the passenger needs to remember the different lines and the names of the transfer stations on their route before boarding the train where they can then use the maps on-board the train to help them know how many stations there are until they need to transfer or arrive at their destination. Remembering this information can be easy if the route is simple, but if there are multiple transfers and the station names are in an unfamiliar language it may be difficult for the passenger, and ultimately make their journey less comfortable.

If a traveler uses a mobile application to help them navigate the metro system, they do not need to rely so much on memorizing the route, but they need to be able to look at their phone in order to navigate. While this may not seem like such a hardship for passengers as the majority of metro passengers already use their mobile devices for entertainment or social media, it can be disruptive for a number of reasons. Passengers with shopping or small children could find it difficult to find a free hand for their phone on a crowded carriage or moving bus. Using a smartphone can also make us less aware of our surroundings and more likely to lose loose items or have them taken from us. Actively using mobile devices can also make us less aware of other people and act antisocially to ignore our friends or any fellow passengers who need to interact with us for some reason. We might also prefer to use our phones for some other activity like watching a movie, playing a video-game or even making or receiving a phone call.

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Fig.1. An example of the classic octilinear schematic representation used in most metro maps today and originally developed for the London Underground map by Harry Beck in 1931.

This paper proposes a new approach to supporting navigation in public metro systems using interconnected visualization applications running on different devices. This aims to combine the benefits of an interactive large display for planning a journey and wearable devices such as smartwatches for navigation within the metro network.

II. Related Work

Pervasive computing, also known as ubiquitous computing, is the idea of computers appearing anytime and anywhere to support the user [3]. Pervasive information visualization [4-7] is the idea of information visualization supporting the user in a similar fashion. This implies a multi device environment with multiple devices interconnected to meet the needs of the user.

In the area of information visualization there is a great deal of research into the area of metro map drawing [2, 8], and particular algorithms for the automatic layout of maps [9-12], but very little research into interactive maps (where work tends to focus on a standard desktop interface with different distortion techniques to aid navigation for a standard layout map [13, 14]) or how visualization can improve the user experience (where work focuses of support for the people with disabilities [15, 16] or technical issues such as geolocation underground [17, 18]).

Rather more work has been done in the related areas of mobile-information visualization [19-22] and multi device visualization and collaborative visualization where devices are connected to help users work together [4, 23, 24]. These areas become more promising for productive research as devices become more interconnected [25, 26], high-performance mobile devices become more widely used [27], ... technology becomes cheaper.

...e co-located and mobile interfaces have ...r information visualization [4] but research ...nited [28]. There are a number of possible ... These include device limitations such as ... input peripherals [29], social factors [30, ...ficulty of adapting existing software and ...delines to a multi-device context [31]. ...of control and display space together over ... is an important consideration that has not ...by current research [32, 33]. On the other ...seen that information visualization [34] ... great promise for overcoming device limitations [25, 35, 36] and, in other studies, managing collaborative working with multiple users [24, 29, 37, 38]. HCI research has also demonstrated techniques for multi-user control on table-top displays [39] and single-user control of applications on multiple devices [40, 41]. Hence there is great promise and potential for the development of pervasive information visualization applications in the future if usability issues can be resolved. This paper describes an early stage case study of a prototype application designed to explore the issues, to consider some technical issues and gauge user attitudes toward this type of system.

In work directly related to this study we have developed a large display educational game for schoolchildren [42], an interface that allows groups of tourists to link mobile devices to a large display in order to collaborate to book a hotel in Shanghai (in order to investigation different ways to coordinate selections on a large-display) [7] and an interface that allows users to multiple users to select locations on a world map (in order to investigate different ways to manage the display space) [6]. Key findings from these studies, that carry over directly over into the study described in this paper, are that user collaborate more easily and communicate more when using a large display [42], and that overall users adapt well to a multi device environment and see great potential for applications that run this way [6, 7]. These studies also indicated that users tended to over-rely on mobile devices when they duplicate too much of the information on the large display.

The aim of the study described in this paper is to explore a case study that tests the idea of pervasive information visualization for the complete set of tasks associated with a common activity. Metro system navigation is chosen as a common activity that many users can relate to.

III. System Design

The design of our system is shown in figure 3. Initially

Fig. 2. An example of a line map used in metro sytem carriages to aid navigation for passengers while on-board trains.

when the passenger enters the station they will be faced with a large display where they can interact to plan their journey. After the passenger decides where they want to go they can scan a QR code to transfer the journey details onto their smartphone. The route of the journey can then be show on the smartphone with relevant alerts, telling the passenger when to transfer or when they have reached their destination, sent to the passenger's smartwatch or another wearable device with a screen.

A. Large display map

Our large display map is designed to be an interactive version of the traditional schematic octilinear map to be place in an accessible point in the station to be used for travelers to plan their route. The design accommodates multiple travelers using the map at the same time by allowing them to interact by speaking or typing the name of a destination station to be overlaid onto the map with the relevant metro lines and transfer stations.

The layout of the map is designed to make it easy for users to read different routes which are overlaid onto the map by simplifying the path between transfer stations and

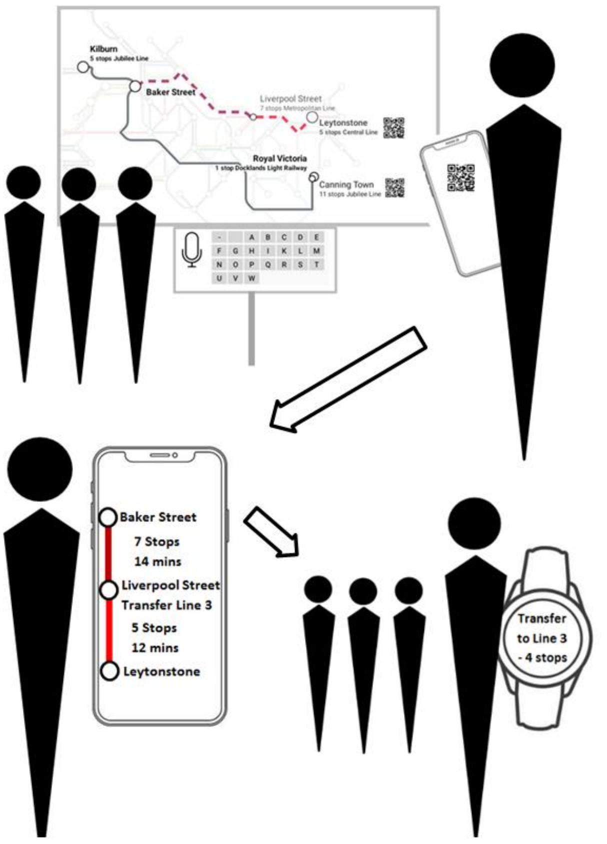


Fig. 3. Our design for a pervasive information visualisation syster for public metro system navigation. Multile passengers can plan their route using a large display interface positioned in a prodominent position in the station. Users speak or type the destination station nave to highlight the route to that station on the map with a QR code. Scanning the QR code passes the route detatils to the passengers smartphone which then relays important information to the passencer as they travel the route.

providing adequate space between transfer stations. This layout operates with similar constraints to a traditional metro map layout algorithm [2] without the requirement to have adequate space for station labels which are only drawn when they are explicitly needed. The algorithm for the layout is as follows.

1) Stations are assigned to a hierarchy with the most connected station at the top and less connected stations at different ranks below.
2) The root station is placed at the origin, with its children in the hierarchy placed around it displaced by two units on one axes or one unit on both axes. These stations are displaced according to angle closest to their actual geographical location in relation to the root station.
3) Next the children of each station in the hierarchy are placed in a similar manner. If there is not enough space for any station in the hierarchy to place all of its children, then the parent of that station is told to re-place its children with a different layout that prevents stations being placed at certain angles.
4) In the next stage, we try and move each station up, down, left or right into an empty position or to swap with another station in order to minimise the total number of crossing lines and the total distance of lines between stations. If the total number of crossing lines in the network is not reduced, or the total drawn line distance does not get smaller, the station is moved back to it's original position.
5) Finally, we draw the lines between stations using only lines at 45 or 90 degrees to reduce the visual complexity of the map and make it easier to read.

Figure 4 shows the layout applied to some different metro networks of different sizes. This will be the default state of the map with a few of the most popular destination stations highlighted. This will allow most map users to find the route to their destination and transfer it to their smartphone without any interaction.

To find the route to stations that are not already highlighted on the map, a user needs to interact with the map. Once a traveler interacts with the large display map, by speaking or typing the name of a station, the best route is highlighted using animated dashes which gradually merge to form a solid line. This means that even if the display is already in use, a new person approaching the display can highlight and identify the best route to their target station. So, the display can be used by many people at the same time. The manner by which the interface highlights different routes when users select different destination stations is illustrated in figure 5

B. Smartphone and smartwatch displays

After a traveler enters the name of their station to view the best route to their destination they will be able to scan a QR code next to the station name. This encodes the route and allows it to stored on the user's smartphone which can,

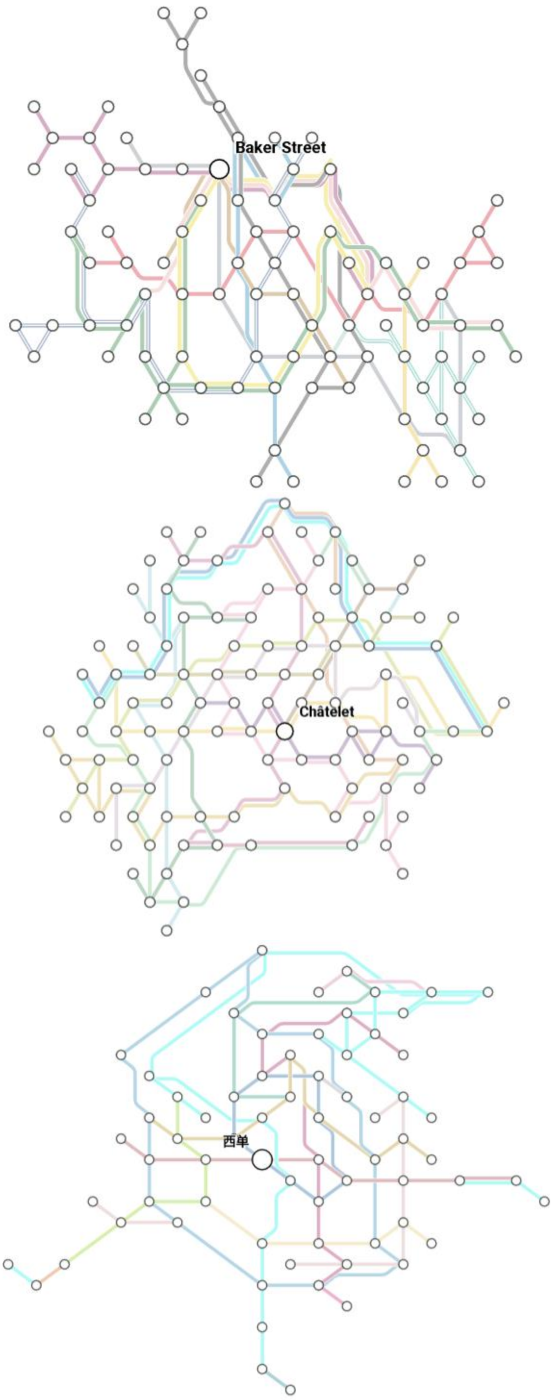


Fig. 4. Metro maps for London, Paris, and Beijing using our layout algorithm for the large display.

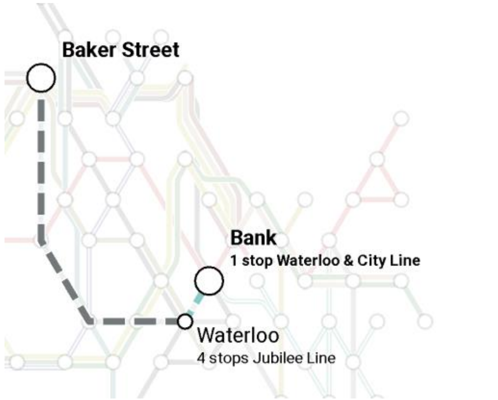
in turn, relay critical notifications to the user's smartwatch or another wearable device.

Figure 6 shows the design for the interfaces of our smartphone and smartwatch applications. The smartphone interface shows only the critical information about the selected journey, while the smartwatch shows information about the next step of the journey and vibrates when the passenger needs to leave the train. Using a smartwatch, or a similar wearable device, would mean that the passenger does not have to rely on handling their phone inside the train carriage which may be busy or unstable.

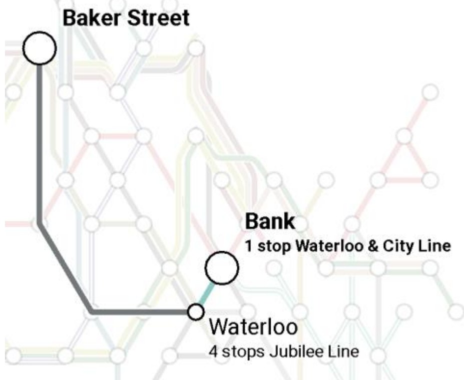
C. Device configurations

As there are multiple components in our design for our application, it is important to consider that not all of these components will be used by all users at all times. Indeed, this is likely the case as not all users will have the same equipment, the same knowledge of the subway system, or the same familiarity with technology. This led us to identify and characterize the following different types of usage.

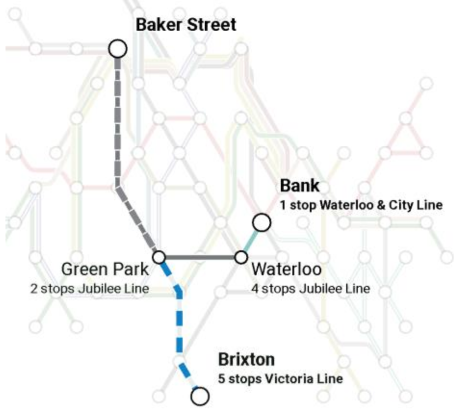
Firstly a passenger without any device could just use the public large display to plan their route, and then rely on the line maps in the carriages for navigation. A passenger without a smartwatch could also use their phone for



a) When the first user selects a destination station (Bank) the route is highlightd with animated dashing lines.



b) The lines gradually merge to form a solid line.



c) A new user selects a destination station (Brixton), and the new route is highlighted with animated dashes to draw the new users attention.

Fig. 5. Two users interacting with the large display map to find the best route to their destination.

Fig. 6. Smartphone and smartwatch interfaces.

notifications, or a passenger could plan their route using the mobile device and choose not to use the large display. It is also likely that many metro users would use choose to use an alternative form of metro navigation, such as a printed map, or not need any form of navigation.

IV. Early Evaluation

For an initial evaluation of our design we implemented the large display part of the application and prepared paper prototypes of the smartphone and smartwatch applications. The aim of this evaluation was to test the large display interface gauge the attitude of potential users of this sort of application.

For the evaluation we involved a small group of eighteen university students and five university staff who were allowed to use the large screen interface then walked through a scenario using paper prototypes where they imagined using the system to complete a journey. After this, we held a focus group meeting to take feedback on the interface, try and identify potential issues, and gauge the users' general attitude toward the interface.

The results of the focus group meeting where generally positive with users considering that this sort of application could work well and improve their travel experience. Initially there was some resistance to the idea of a pervasive information visualization system for subway navigation as the subjects could already use their mobile phones to navigate the local metro system, but when the subjects were asked to imagine the scenario of being a visitor to a foreign network or having to travel to an unfamiliar station at rush hour, they were able to envisage the benefits of our design. Overall they considered that this design would be more convenient and that it would take some of the stress out of travelling making them feel more comfortable using the network. They were, however, unsure of whether a system like this would increase their usage of the metro system as most of their travel was through necessity rather than choice.

The subjects also had some more specific comments about the system design. They were already familiar with scanning QR codes while using electronic payment mobile applications and could understand that these might also work well to transfer travel data to their mobile phone. They also suggested that the QR codes could also be used on printed maps or travel brochures to help tourists navigate to these locations. A limitation of the system was identified as the reliance on the smartwatch interface as many of the subjects did not use a smartwatch (or even a normal watch) preferring to use their phone. A recommendation here was to have notifications on the user's smartphone or another wearable device that may become popular in the future.

A limitation of our evaluation is that the participants where predominantly computer science students and tended to be younger and more tech-savvy than metro users on average. While this certainly wouldn't give a fair reflection of the attitudes of metro passengers in the present day, it allowed us to identify a range of issues with our application and gauge how attitudes to this type of system may be in the future as the general population becomes more familiar with technology and more ready to use technological devices.

V. Conclusion

This paper presents a vision for how pervasive information visualization can be used for public metro system navigation and evaluates an early prototype design. This allowed us to identify some issues with our system and gauge the general reaction to such a system from a subset of users who were generally positive about the potential for such a system. Overall our subjects considered that the design would allow for travel to be more convenient and that it would take some of the stress out of using the metro network at busy times. This has encouraged us to continue the development of the system which we plan to build to a state where it can be more completely tested and evaluated with a larger group of users.

We also feel that this research uses a suitable, relatable, case study that allows us to investigate the general issues of pervasive information visualization and the results could be related to other potential applications where large displays could be used with mobile devices. Examples of such applications might be an electronic notice board where different users post notices that can also be moved to and from their mobile devices, or electronic planning or brainstorming where tasks or ideas can be gathered on a large display or carried away by different users. These are possible directions for future research.

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