Issue 23(1), 2023, pp. 63-84
https://doi.org/10.18757/ejtir.2023.23.1.6261

TU Delft OPEN

EJTIR

ISSN: 1567-7141
http://ejtir.tudelft.nl/

Mind the gap: navigating the space between digital and physical wayfinding in public transit

Anthony Ferri[1]
Chair for Urban Structure and Transport Planning, Technical University of Munich, Germany.

Monika Popp[2]
Department of Geography, Ludwig-Maximilians-Universität, Munich, Germany.

Wayfinding in public transit environments is especially complex, combining both spatial and temporal tasks for users to reach their destination. However, a gap exists between users' needs and existing infrastructure design. With the introduction of Information and Communications Technologies (ICT) to the broader public, the wayfinding process has shifted from more traditional methods to more digital approaches, leaving individuals with the task of navigating the space between both physical and digital milieus. The exploratory study presented in this paper provides insights into physical and digital navigational practices in public transit wayfinding systems. The method employed was that of a Destination-Task Investigation, a qualitative mobile interviewing method used to capture participants' feelings, thoughts, and experiences. The study focuses on three transit spaces within the network: (a) aboveground transfer stations, (b) belowground transfer stations, and (c) on transit, and reveals that participants often relied on their smartphones instead the physical wayfinding infrastructure. Moreover, participants were found to use their smartphones in three navigational approaches: (1) Directional Confirmation, (2) Current Positioning, and (3) Future Planning. Results show that participants preferred the Directional Confirmation approach in both aboveground and belowground transfer stations and used their smartphones for navigational purposes most often while on transit. The study also helps illuminate that the presence of a robust wayfinding system within a public transit system increases user trust in the overall system. This study contributes to better understanding user behavioural patterns which has significant relevance for researchers as well as practitioners.

Keywords: *design for behaviour change, information and communication technology, public transport, smartphone, wayfinding.*

Publishing history

Submitted: 19 January 2022
Accepted: 20 February 2023
Published: 27 March 2023

Cite as

Ferri, A., & Popp, M. (2023). Mind the gap: navigating the space between digital and physical wayfinding in public transit. European Journal of Transport and Infrastructure Research, 23(1), 63-84.

[1] A: Chair of Urban Structure and Transport Planning, Department of Mobility Systems Engineering, Technical University of Munich, Arcisstraße 21, 80808 Munich, Germany E: anthony.ferri@tum.de
[2] A: Department of Geography, Lugwig-Maximilians-Universität, Luisenstraße 37, 80333, Munich, Germany. E: monika.popp@lum.de

1. Introduction

While transferring between the train and the bus in Munich's public transit system, a participant from our study turned a corner and found themselves having to make a crucial decision: do they turn left or right to make their connection? The user was aware there was only a few minutes before their bus's departure – a stressful predicament. What made this decision so difficult for the participant was that they were unable to find any physical navigational information to guide them through their transfer. As a result, they used their smartphone for navigational assistance, only for it to suggest a completely new route, which in turn, caused further delay. In the end, the conflicting navigational information caused the participant to miss their connection, leaving them confused and frustrated. This experience is likely familiar to those who use public transit. But how can public transit wayfinding networks be improved in order to reduce user confusion and frustration?

This paper discusses the importance of digital navigational tools in public transit settings. Findings used for the paper are from a Destination-Task Investigation study we conducted in 2019. The study consisted of twelve participants who travelled between a start and an end point, with a mandatory mid-point interchange stop, in Munich's public transit system. Participants were permitted to use any form of navigational aid to help them reach the designated destination point. It was shown that smartphones were a popular navigational aid choice amongst most participants.

1.1 Wayfinding within public transit

The act of wayfinding itself is a multi-tasked activity involving multiple senses to read the external environment in order to reach a destination (Allen, 1999; Arthur & Passini, 1992; Lynch, 1960; McDonald & Pellegrino, 1993; O'Neill, 1992).

A public transit wayfinding network is a physical and localized system made of signage, lighting, colours, maps, and other design features that aid users in navigating the transit space. Wayfinding systems within public transit provides a network of spatio-temporal guidance for passengers (Fendley, 2016; Rodrigues, et al., 2018, Scollon & Scollon, 2003, and van der Hoeven & van Nes, 2014). While traveling through public transit, individuals rely heavily on reading their surroundings to contextualize their current positioning in order to reach their destination (Lynch, 1960; Mollerup, 2013; Timpf, 2002).

Each public transit wayfinding system has a distinct look and feel, and users are required to intuitively understand the transit culture of the system the moment they step foot into the network – regardless of experience (Mollerup, 2013). The network is localized and functions as a stand-alone directional system and are sometimes overlooked, not updated, or simply neglected, leading to user confusion, frustration and, eventually, retention issues (Fendley, 2016; Fu, et al., 2018). Additionally, improving wayfinding networks proves to be challenging, as not all public transit systems are controlled by one regional authority often creating fragmented and inconsistent navigational information for users. Leaving it up to the transit user to decipher the minutiae of directional information within the public transit space. Moreover, can lead to the use of external navigational options, such as smartphones, to get route clarification external of the user's physical surroundings (Line, et al., 2011; Ferri, et al, 2021). By retrieving externalized route information increases perceived navigational complexity, through contradictory directional information provided by the smartphone (Ferri and Popp, 2022).

The continuous inside-outside and aboveground-belowground dichotomy of transit spaces, especially that of larger transit network, adds to the intricacies of user experience as the transit space intersects both internal and external stimuli. Creating a very complex navigational environment. The availability and legibility of a wayfinding network also has a direct impact on user behaviour, mood, and overall experience (Carpman & Grant, 2002; Diab & El-Geneidy, 2015, Diab, Badami, & El-Geneidy 2015; Ferri and Popp, 2022 Haake, et al., 1984; Natapov, et al., 2015). Throughout a transit journey, a user's overall confidence in using public transit can fluctuate depending on the level of perceived complexity which leads users to predominately navigate based

on familiarity and comfort (Afrooz, et al., 2018; Arthur & Passini, 1992; Allen 1999; Marchette, et al., 2011; Montello, 2007; Li & Klippel, 2016, Tzeng and Huang, 2009). Furthermore, all users come with their own set of behaviours and perspectives and are expected to understand the norms of the transit system, while also navigating alongside other users with their own goal destinations, and varying experience levels with public transit (Lee, et al, 2014; Scollon & Scollon 2003; Timpf, 2002). Consequently, the effectiveness of a public transit wayfinding system lies in the interaction of structural design principles and the users' basic understandings of the system itself.

1.2 The complexity of public transit spaces

With high passenger volumes and multifaceted transiting areas, public transit spaces remain some of the most complex navigational environments, as spatial and navigational cues are found to be confusing, misleading, and equally intimidating for many individuals (Chang, 2013; Haake, et al, 1984; Natapov, et al, 2015; Peponis, et al, 1998; Stankiewicz & Kalia, 2007). Several studies have shown that individuals prefer to be physically distant with one another in public transit (Clayton, et al, 2016; Evens & Werner, 2007; Hall, 1966), and when feeling crowded, begin to feel a loss of control and attention and increases in stress (Schmidt & Keating, 1979). As a result, transit spaces are seen as overly complicated, unclean, and void of navigational information, which adds to user retention challenges and perpetuate negative attitudes toward the local public transit system as a whole (Cox, et al, 2006; Diab & El-Geneidy, 2015, Diab, Badami, & El-Geneidy 2015; Evans & Werner, 2007; van Lierop, et al., 2018; van Lierop, et al., 2021, Vuchic, 2005). Subsequently, the need for well-designed wayfinding networks within these systems becomes essential to functioning public transit environments (Egger, 2016).

1.3 The seamless experience

While the idea of the "seamless experience" or "seamless journey" (Fendley, 2016; Wrede, 2016) for users in transit space is often discussed by architects, urban planners, and designers (many of whom have long contributed to inclusive community development and the bettering of public spaces), the concept is not always found in the final product. This is made evident as wayfinding practices in public transit have begun to shift from a reliance on internal methods, produced by a transit authority (through static on-site wayfinding devices), to an externalized and fragmentary path selection activity by users (through dynamic navigational apps via the smartphone).

This is partly to do with the fact that wayfinding is a multi-tasked activity involving multiple senses, and individuals often break tasks down into more manageable segments which aid in creating a cognitive map and route planning (Chen, et al, 2009; Lynch, 1960; Timpf, 2002); in which using the smartphone can enhance and synthesize these tasks (Ferri, et al., 2021). Understanding how individuals behave during wayfinding tasks has been at the centre of wayfinding research for decades (Allen, 1999; Arthur & Passini, 1992; Golledge, 1999; Lynch 1960; Montello 2001, 2005). Researchers have become increasingly interested in understanding users' navigational behaviours in public transit environments (Bohte, et al, 2009; Ferri & Popp, 2022; Gountas & Gountas, 2007; Lai & Chen, 2011; St. Louis, 2014; Olsson, et al, 2014; Urry, 2007; van Lierop, 2021). Due to rapid innovations and a widespread adoption of information and communication technologies (ICT) over the last decade, more attention has been given to wayfinding and the use of ICT, specifically smartphone activities, by users within public transit systems (Alosaimi, et al, 2016; Bian, et al, 2021; Ferri, et al., 2021; Line, et al, 2011; Narimoto, et al, 2018; Shaheen, et al, 2016). The smartphone connects users with public transit systems through a digital platform that provides accessible and up-to-date information, giving users more control in their wayfinding experiences. This has led to both formal and informal integration of the smartphone into public transit spaces.

1.4 Smartphones in transit space

Increasingly, the concept of having access to information in a matter of seconds has become standardized in day-to-day activities, making the smartphone the benchmark for how we obtain information. This has clear implications to how we navigate and understand public transit spaces

(Bian, et al, 2021). Smartphone technologies are ubiquitous across all aspects of everyday life. Due to the smartphone's high functionality, people have begun to replace the physicality of everyday activities (such as navigating public transit) with digitalization of these activities (such as buying tickets, looking at transit schedules, and using positioning maps) within the context of smart mobility (Cisterna, et al, 2021; Guidon, et al, 2020). Over the last decade, countries such as Germany, have seen an upward trend in smartphone ownership with levels topping over 60% of the population (VuMa, 2021). Line, et al. (2011), discuss the significance of mobile and smartphone technologies and how they have infiltrated everyday life, including the way we navigate and understand wayfinding. They argue how smartphone technologies have come to the aid of users in transit spaces and indicate a switch in user navigational behaviour. However, the limitations of smartphone-led-navigation are evident in terms of aiding the user in spatial learning as users do not take the time to learn about their environments but rely heavily on the information provided by their smartphone (Münzer et al, 2006; Münzer, et al, 2012).

Third party apps such as Google and Apple can provide a user with navigational information, but creates visual and physical conflicts for the user, as branding, visual identity, guidance, and information varies from that of the physical and existing wayfinding devices while oversaturating navigational information (e.g. conflicting schedules on the platform versus what is showing on the smartphone). This leads potential negative outcomes, such as a higher risk in missing a transit connection. Moreover, smartphone reliance has come at a cost to wayfinding design, as public transit spaces are slow to keep-up with a rapidly evolving transit culture and current ICT technologies (Ferri, et al, 2021; Line, et al, 2011; Narimoto, et al, 2018; Urry, 2007).

1.5 Digital and Physical: Conflicting Complimentary Practices?

Looking at navigational practices of transit users can help categorize and understand how space is being perceived and how design can be adjusted. Distracting environments or environments that may be perceived as chaotic by a user, increases a user's need to find clarity (Bell & Sundstrom, 1997; Bell, et al., 2001; Chang, 2013; Haake, et al., 1984; Mollerup, 2013; Wisner, et al., 1991). In the context of communication and semiotics, public transit environments that lack legible wayfinding cues for passengers increase users' need to incorporate alternative wayfinding methods. Smartphones provide an alternative, yet familiar, wayfinding method for individuals who are unable to read their physical surroundings. The growing use of ICT and subsequent transformative behavioural change in public transit has not yet been addressed under the larger umbrella of mobilities research, and within the branch of wayfinding design. There remains a gap in the literature in terms of understanding how ICT affects the design functionality of existing transit wayfinding networks, and the interplay between two navigational practices (physical and digital) in terms of user interaction. The popularity of using one's smartphone in a public transit space sheds light on the importance of user focussed design, and thus provides opportunity to observe the functionality of navigation practices within the system.

1.6 Overview of this Study

This exploratory study examines two navigational practices found within public transit systems; that of the physical transit network and implied design functionality, and that of the digital - the smartphone and subsequent navigational apps as applied by a transit user. Examining the overlap of the two practices provides insight in terms of wayfinding design solutions as the use of a smartphone can help to indicate a potential weakness in the wayfinding design through a network evaluation. The navigational practices were examined side-by-side through a multi-participant Destination-Task Investigation (DTI) - a qualitative empirical study involving 12 participants navigating from an origin to a destination within the Munich public transit system with a focus on transferring between modes via transit interchanges (where one might need wayfinding devices the most). The objective of the study was to determine if design gaps exist in the public transit wayfinding network, and to therefore identify where the gaps are occurring and how individuals behave to overcome these gaps.

The study focuses on three major transit spaces within the network: (a) aboveground transfer stations, (b) belowground transfer stations, and (c) on transit. Additionally, this paper focuses on three navigational approaches DTI participants displayed (or more simply, how a participant used their smartphone compared to that of the physical environment): (1) Directional Confirmation ("Where am I going?") - confirming the route that one is currently on, (2) Current Positioning ("Where am I?") - confirming where one is located within the overall transit network, and (3) Future Planning ("How will I be getting there? / What's my next step?") - confirming the upcoming steps one must take to reach their destination. The exploratory study presented in this paper provides further insights into the understudied nexus of physical and digital navigational practices in public transit systems. A particular emphasis is put on the role of the smartphone in the wayfinding process, and the importance individuals placed on ICT in public transit spaces. This is done through observing users' wayfinding experiences and providing network evaluation. Using qualitative analysis, including field observations, think-aloud protocol, and semi-structured interviews, the study aims to assess the gap in literature comparing two navigational practices (physical and digital) in public transit wayfinding. This also contributes to better understanding user patterns and how to improve wayfinding design in these spaces, which has significant relevance for practitioners as well.

2. Method

The method employed for this study was that of a Destination Task Investigation (DTI); a qualitative mobile interviewing method that captured participant's feelings, thoughts, and experiences in detail as they navigated through Munich's public transit network. Mobile interviewing techniques have become more popular within the mobilities research field as they are flexible in structure and allow for an in-situ description of the participants' experiences (Büscher and Urry 2009; Levy 2001; Kazig & Popp 2012; Sheller and Urry 2006). All participants began their DTI at Munich's East station (P1) and then made their way westward with a mid-point stop in the city centre at Karlsplatz/Stachus (P2) and finished their journeys at Schloss Nymphenburg (P3) [Figure 1].

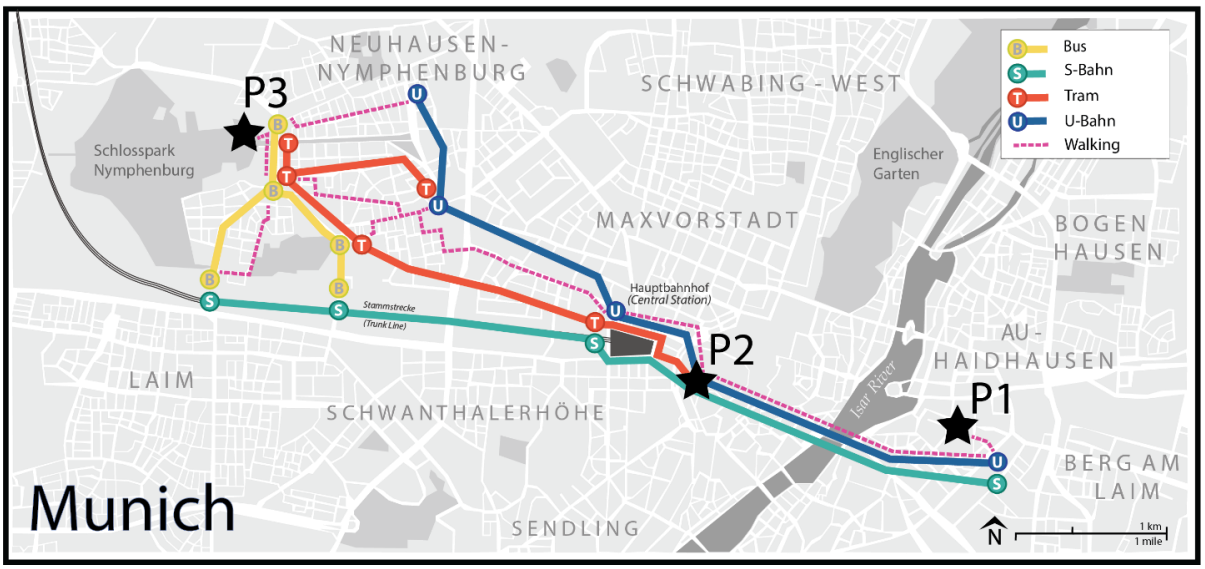


Figure 1. The route options of the Destination Task Investigations in Munich showing origin (P1), mid-point (P2), and destination (P3).

2.1 Destination-Task Investigation (DTI)

The DTI itself consists of two parts, (1) a Destination-Task Activity and (2) a follow-up interview based on a cognitive map.

1. Destination-Task Activity

A short, semi-structured introductory interview was included at the beginning of the activity in order to understand how well users knew the Munich public transit system. Afterwards, participants were asked to reach a specified destination and be observed by the researcher. Participants were equipped with both audio and visual recorders and shadowed by the researcher. While navigating to the destination, participants were encouraged to use a think-aloud process to explain their thoughts, decisions, actions and feelings. Participants were allowed to use all forms of public transit, including Bus, Tram, S-Bahn (German word for a suburban rail network), and U-Bahn (German word for an underground rail network – known as a Metro, Underground, Subway, or Tube in English), and instructed that they could use any form of aid they deemed necessary (e.g. smartphone, talking to people, looking at maps, etc.). The participants were made aware that they were in charge of all navigational decisions and that the researcher would be observing them. The objective of the researcher's role was to encourage comments and discussion from the participant during their journey and would do so by interjecting with questions when they needed a clearer understanding of the participant's decisions. In general, the researcher encouraged conversation surrounding the participant's journey, but maintained no influence over a participant's decisions (noting that the presence of the researcher alone already adds a layer of influence).

2. Follow-Up Interview based on a cognitive map

After completing the Destination-Task Activity participants sat down with the researcher and were asked to recall as much detail from their journey as possible through discussion, as well as drawing their experience, to allow for an exploration of emotions (Reason, 2010). Participants were encouraged to draw their journeys in the form of a cognitive map and reflect upon their actions in as much detail as they could remember. Users were then asked to mark their maps in three colours (green, yellow, and red) to indicate on their maps corresponding positive, neutral, and negative experiences they had during their journey.

2.2 Participants

The study consisted of twelve participants between the age of 25 and 45 from various nationalities, all of whom had been living in Munich for at least a year by the time of the start of the study [Figure 2]. Participants were found through a call for volunteers and subsequent snowballing of individuals. Participants' background, age, and transit usage was considered during the selection process to allow for a broad scope in transit and navigational behaviour. However, the process led to a bias in participant selection as all participants were highly educated able-bodied individuals. This still provided comparability by focusing on early-to-middle aged individuals with experience riding Munich's transit system. All participants had unimpaired vision, except one participant (Trevor), who mentioned he had a red-green deficiency. As the native language for the interviewer was English speaking, all participants had either an intermediate, advanced, or native level of speaking English. The DTIs were conducted between June 2019 and January 2020. The destination task itself took between 40 to 120 minutes depending on the participant, and the follow-up interviews took 15 to 30 minutes per participant.

Name	Gender Identity	Nationality of Participant	Public Transit Frequency	Frequented Modes	Preferred Mode	Preferred Navigational Tool
Lita	Female	Denmark	Daily	B S U	S	S X
Samuel	Male	Germany	Daily	T S	S	S
Marek	Male	Slovakia	Monthly	B T	U	S X
Tobias	Male	Spain	Daily	B S U	U	M S
Amy	Female	U.K.	Daily	B T S U	T	I S
William	Male	Canada	Daily	B U	T	S
Trevor	Male	Germany	Monthly	S U	U	M S X
Felix	Male	U.K.	Daily	B T S U	S	S
Mina	Female	Germany	Weekly	B U	T	S
Serena	Female	Greece	Daily	B U	U	I L M S X
Raye	Female	Germany	Seasonally	U	T	I L M
Simon	Male	Taiwan	Daily	B U	⊘	S

B Bus T Tram S S-Bahn U U-Bahn ⊘ Not Applicable

I = Intuition/Feeling
L = Landmarks
M = Maps
S = Smartphone
X = Signs/Arrows

Figure 2. A list of DTI participants, including their nationality and their transit frequency/preferences – Participants were asked at the start of the DTI about their preferences – these preferences were then grouped into the five categories presented.

While all participants had been living in Munich for at least a year before the start of this study, their level of familiarity with the chosen DTI route varied. Of the twelve participants, two were very familiar with the entire route, while the other ten were only familiar with sections of the route.

2.3 Data Analysis

The audio from the DTI was used as the primary data source, where the video footage allowed the researchers to capture instances of navigational decision making that were purely visual and otherwise missed through audio recordings. The researcher also took observational notes, which allowed for further conclusions on the wayfinding process. Interpretation of the results were based on the transcripts of the interviews, the video and audio recordings, the researcher's observational notes, and the participants' cognitive maps. This information was then transcribed in MAXQDA and then consolidated and visualized into participant graphs, otherwise called Customer Journey Map (CJM).

The CJM was created in order to overlay participant data in a concise and clear format. A CJM is a visual story-telling tool that takes complex situations and simplifies them into a graphical presentation – for easier communication of data (Bucolo & Matthews, 2011; Kolko, 2015; van Lierop, et el., 2019; Zemke & Bell, 1989). For this study, a modified version of the CJM was created which included important data such as location, time, transit mode, participant thoughts and quotes, participant emotion, and participant smartphone use were key to understanding the participants' behaviours and actions during the DTI [Figure 3]. By creating a modified CJM for each participant allowed the researcher to compare where participants used smartphones during their journeys, what was happening when they used their smartphones, what was said when they decided to use their smartphones, and how they were feeling when they used their smartphones. The modified CJM provided a full overview of a participant's journey and the multiple facets of the wayfinding experience, including the emotional highs and lows of navigation, as well as the sensorial experiences of participants in public transit.

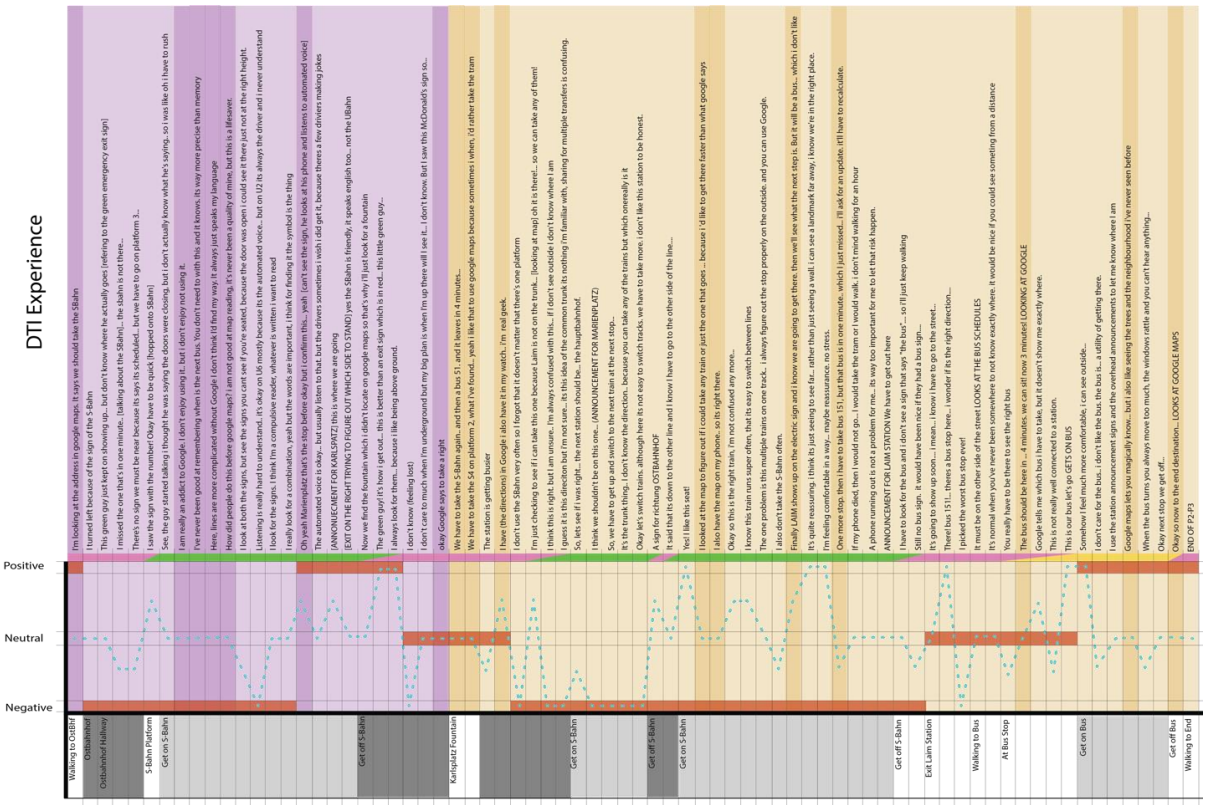


Figure 3. An extract of the modified Customer Journey Map for a participant showing both parts one P1-P2 (purple) and two P2-P3 (orange) of the DTI.

How to read the CJM: Columns in the modified CJM which show darker purple and darker orange indicate where participants used their smartphone, with quotes listed along the timeline. Pink, blue, green, red, or yellow indicate the mode type participant was using. The orange bars and blue dotted line indicates the positive-negative scale participants experienced. The grey section indicates whether a participant was aboveground, belowground, or on transit. Additional quotes and situational context are listed at the bottom.

2.4 Three Transit Spaces

Finding one's way through the multitude of modes, nodes, scenes, and networks within public transit often requires an understanding of several different (and sometimes conflicting) wayfinding and transit systems. Participants of the DTI had the choice of using Bus, Tram, S-Bahn, and U-Bahn throughout their journeys. Based on data analysis of participant experiences, we categorized three types of spaces within the transit network: (a) Aboveground Transfer Station, (b) Belowground Transfer Station, and (c) transit mode spaces – which for this study we will call "*On Transit*".

(a) Aboveground Transfer Station

An aboveground transfer station is a public transit platform located at or above ground level [Figure 3 and Figure 4]. Passengers can access these platforms in a variety of ways. Passengers typically walk onto them from the street level, walk to these platforms from a designated staircase, or access them from a particular mode. Aboveground transfer stations can be multi-platform structures, where passengers can easily transfer from one mode to another (e.g. from Tram to Bus). In Munich, these types of platforms primarily serve Bus, Tram, and S-Bahn routes.

(b) Belowground Transfer Station

A belowground transfer station is a self-contained public transit platform located underground [Figure 4 and Figure 5]. Passengers can only access these locations through limited designated

access points – or via the arrival of the mode they are currently taking (e.g. exiting a train at a designated station underground). In Munich, the belowground platforms are used only by S-Bahn and U-Bahn modes.

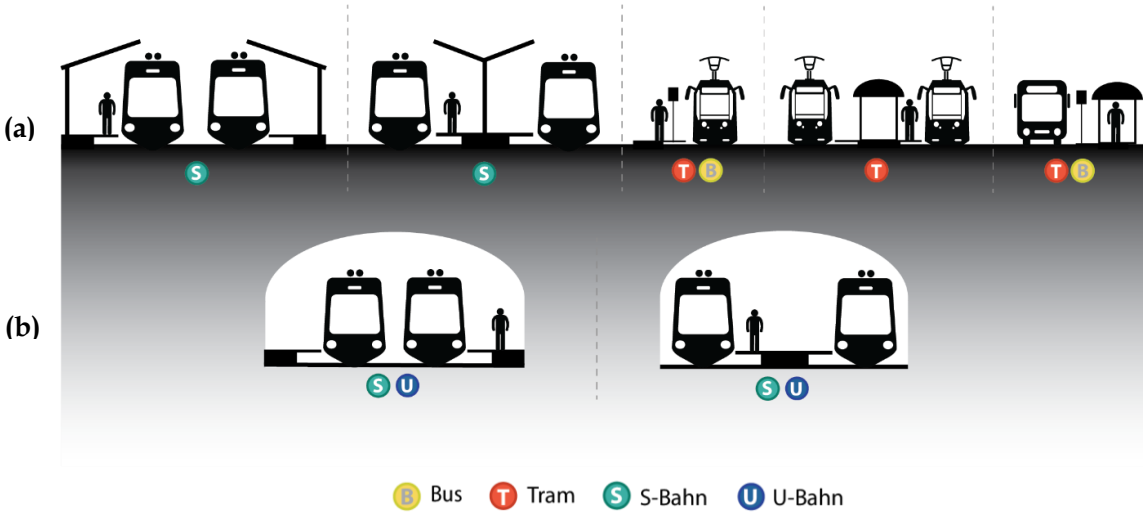


Figure 4. Station forms for aboveground and belowground transfer stations in Munich.

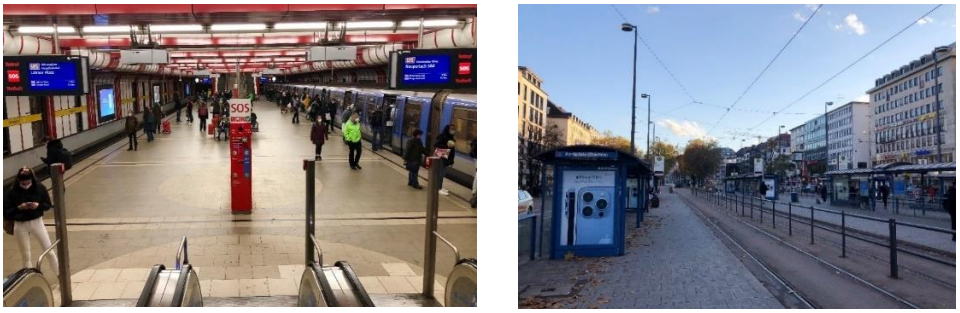


Figure 5. Left: Belowground transfer station at Munich's Ostbahnhof U-Bahn. Right: Aboveground transfer at Karlsplatz tram station in Munich.

(c) On Transit

On transit signifies when a participant is physically on a public transit mode type (Bus, Tram, S-Bahn, and U-Bahn). [Figure 6]. This includes both a moving and stopped vehicle.

Figure 6. Top Left: Inside a Munich Bus. Top Right: Inside a Munich Tram. Bottom Left: Inside a Munich S-Bahn. Bottom Right: Inside a Munich U-Bahn.

2.5 Using the Smartphone

Participants were not required to use their smartphones during the DTI and were allowed to navigate freely (or how they normally would navigate through a transit space). Eleven out of twelve DTI participants decided to use their smartphone at least once during the DTI experience. The number of times a participants used their smartphone depended on personal factors (such as familiarity and comfort), as well as physical design factors (such as a perceived lack of visible navigational information). Smartphone usage for navigational purposes is categorized into three navigational approaches based on our analysis of the usage patterns by participants during the DTI:

1. Directional Confirmation: An individual found themself in a situation where they were unable to recall their direction and used their phone to confirm a navigational action and/or orient themselves through the transit space as they moved towards their destination (Münzer et al, 2006; Münzer, et al, 2012; Narimoto, et al, 2018). E.g. using the smartphone's compass, map, or directional instructions to orient oneself dynamically through the system.
2. Current Positioning: An individual used their smartphone to place themselves within the transit network or urban environment (Ferri, et al, 2021; Line, et al, 2011). E.g. using a city or transit map to situate one's exact static location within the physical space.
3. Future Planning: An individual uses a schedule or map to determine the next step(s) in their journey required to reach their destination (Line, et al, 2011; Shaheen, et al, 2016). E.g. using a network map or schedule to "look-ahead" in time for potential navigational obstacles, alternative routes, and mode choices.

3. Results and Discussion

Participants in the study were permitted to navigate in the DTI using whichever navigational tool they felt they required. When participants used their smartphones, it helped the researchers determine that physical wayfinding guidance was perceived as missing. This study assessed how and where participants used their smartphones within the transit space to help understand better design solutions to improve the space.

3.1 (a) Aboveground Transfer Stations

The design of aboveground stations includes a range of architectural and infrastructural forms depending on the mode featured in the station. Unique characteristics of these stations help users easily identify their locations. For example, Tram, S- and U-Bahn platforms are located next to rails, and rails provide a visual cue for users that transit and a subsequent transit station is nearby. Aboveground transfer stations also include smaller; less identifiable features, an example being a bus-stop. In Munich, bus-stops often consist of a sign and/or a shelter, and do not provide the same level of visual identifiers for transit users. This can be said for many bus-stops in many cities which cause some individuals to struggle to find the bus-stop location (Diab & El-Geneidy, 2015, Diab, Badami, & El-Geneidy 2015; Vuchic, 2005). In Munich, all aboveground transfer stations on the DTI route were located outdoors, and therefore competed with surrounding visual distractions as well as exposed to environmental elements. Because of this, wayfinding devices competed in capturing participant attention with other non-transit related elements. Depending on the station size, individuals can easily be distracted from navigating their surrounding environment in search of an aboveground transfer station.

Overall, during the DTI there was a moderate use of smartphone devices by participants at aboveground transfer stations. There were eight aboveground transfer station locations along the routes in the DTI [Figure 7]. All participants were faced with interacting with these transit spaces throughout their journey. Participants were found to use their smartphones frequently when located at an aboveground transfer station. When comparing the two navigational practices, digital navigational usage was preferred over existing physical design in terms of station legibility and route scheduling. All three smartphone usage types were used, however certain aboveground transfer stations (e.g. S-Bahn to Tram, S-Bahn to Bus, and Tram to Bus) warranted more smartphone use than others [Table 1].

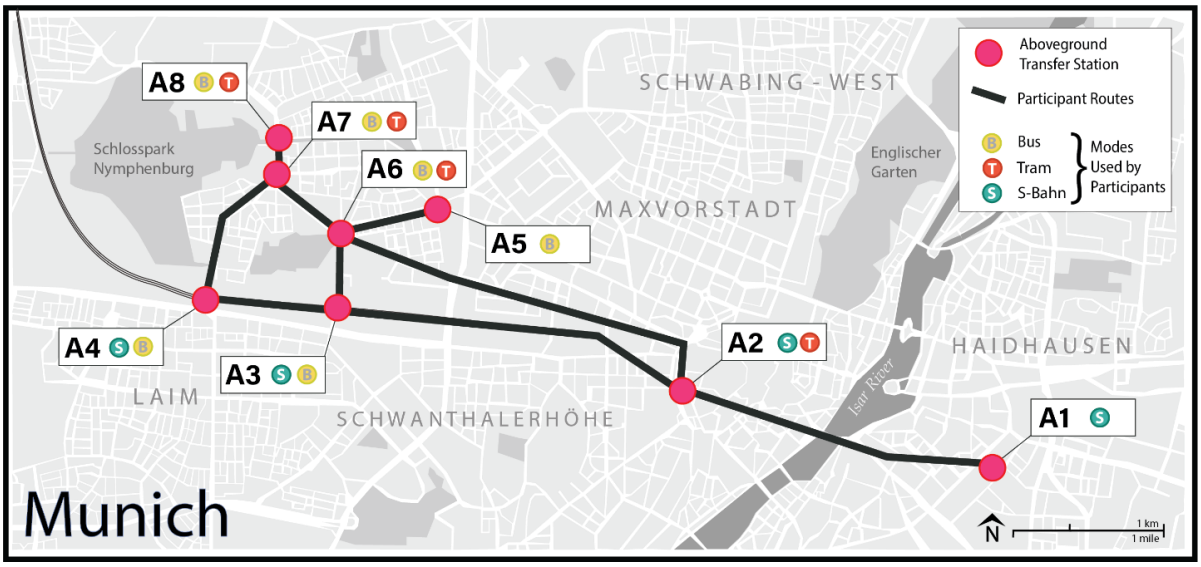
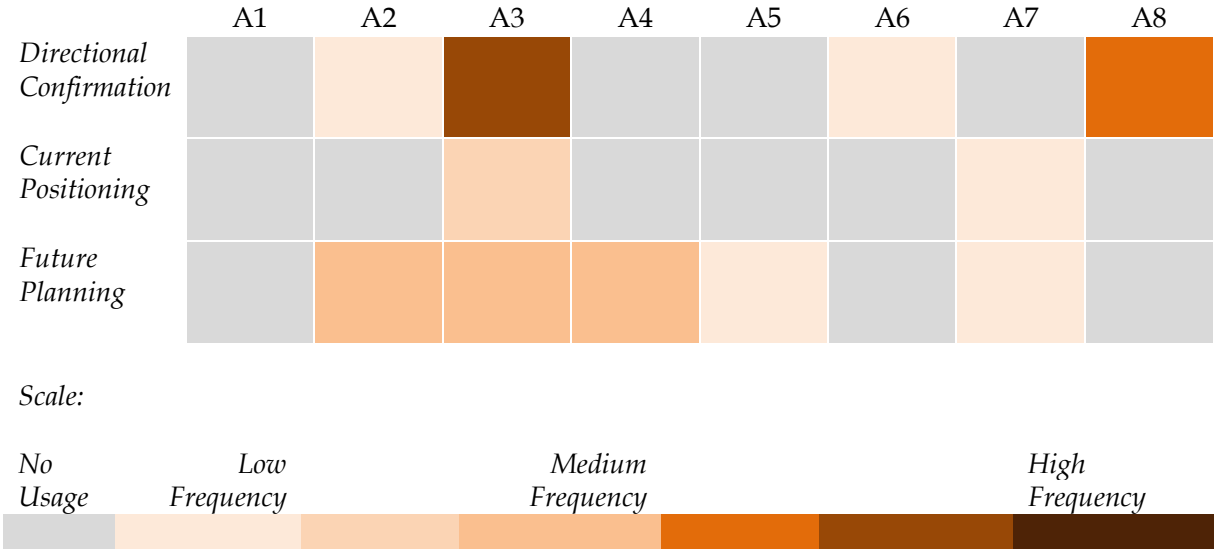


Figure 7. DTI route showing participant-used Aboveground Transfer Stations highlighted in pink.

The frequency of smartphone use was dependant on the availability of wayfinding devices located in and around the station, and on the design of the aboveground transfer station. Certain station locations required more smartphone usage than others.

Table 1. Breakdown of participant smartphone usage in DTI Aboveground Transfer Stations.



Directional Confirmation:
Directional Confirmation (DC) was performed by participants at A2, A3, A6, and A8 in the DTI. The overarching theme in DC was that in locations with less directional signage, participants felt the smartphone provided more reliable directional information than the physical environment.

In the cases of A2, A6, and A8, all of which involved a mode-to-tram transfer, participants were more inclined to use their smartphones for DC. Determining the correct position on the platform was an issue mentioned specifically by participants due to the platform design. While transferring between bus and tram at A6, DTI participant Serena mentioned that she wanted to confirm her destination: "I want to make sure that I'm not going to the wrong station". In order to get between the bus-stop and the tram platform, there were no directional indicators. This not only made it difficult for Serena to navigate to the platform, but also for her to know which side of the tracks she should be on. A lack of directional information between modes creates a sense of confusion among users (Chang, 2013; Diab, Badami, & El-Geneidy 2015; Li & Klippel, 2016). Because the smartphone provides map and compass-like features, participants were able to better orient themselves in their surroundings. The smartphone's map feature became popular amongst participants while at aboveground transfer stations. Map features on smartphones give individuals access to customizable routes, which in turn reduces reliance on physical devices. Physical maps are typically provided on platforms for navigational aid; however, they are not portable and not as accessible as the map provided by a smartphone.

Participants mentioned the difficulty of navigating between modes in stating that their smartphone can help with the entire route, but it isn't able to give enough details to know which exact stand or location on the platform to wait at for trams and buses. Details at this level are left to the physical surroundings and are not yet prominent on smartphone apps. Participants became more vocal about these concerns when there were multiple shelters at one stop, or several different vehicles leaving from one location. Participants noted the confusing nature of the design, as shelters and platform locations were not clearly marked, which added to the stress of using public transit. Clear delineations of mode-space increases user understanding of the transit system (Natapov, et al, 2015; Peponis, et al, 1998). In this case, both the physical and digital design were not precise enough for comfortable navigation.

In terms of A3, S-Bahn-to-bus transfer, there was a particularly high frequency of DC. Construction and temporary relocation of bus-stops in this location led to participants using their smartphones as a directional aid as physical signage was not present enough for clear navigation. The transfer between S-Bahn and bus was not clearly indicated once participants exited the S-Bahn. Participants felt that the lack of signage of how to get from the S-Bahn platform to the bus stop hindered their abilities to navigate the space and made them feel like they had to guess which direction to travel. In addition, once participants found the bus stop, they were uncertain which side of the road they should be on due to the lack of navigational signage leading them to this point. These shortcomings in physical design increased participant reliance on the smartphone.

Current Positioning:
It was less common for participants to use Current Positioning (CP) at aboveground transfer stations. As participants moved through the transit network, the whereabouts of an aboveground transfer station was generally understood in terms of where in the city they were located – as a participant could simply look around them to get a general sense of where they were in the city via landmark identification. In cases like A3 and A7, there were construction sites and temporary stop re-locations. The fact the station was temporary, relocated, or under-construction, added to the sense of "where am I?" from participants, prompting them to use their smartphone to use CP.

At A7, there was construction upon exiting the tram, and therefore a relocation in the exiting location, resulting in participants feeling confused at the station. The presence of construction material and path rerouting created a sense of doubt that they were at the correct location. Although construction is not a permanent feature at these locations, the presence of construction work and temporary relocation of stops is common in public transit and requires updated user navigational information.

Future Planning:
In several situations, participants often had spare time while waiting for their mode to arrive, particularly at A2, A3, and A4. At these locations, participants did not feel that scheduling information was adequately provided. Because of this, participants then found it difficult to make accurate route planning decisions and therefore relied on their smartphones to give this detail. Serena, while waiting for the bus at A3 stated, "Google says two minutes until the bus, but the electronic sign says 11 minutes.". A comparison of the two navigational practices revealed a clear mismatch of information given to individuals. These discrepancies in scheduling led Serena to boarding the wrong bus, which later caused delays in reaching the destination. Participants did not feel as though there was enough temporal information on the platform to help them confirm their directional decisions, and therefore turned to their smartphones for more detailed information to plan their overall routes.

When a mismatch in scheduling information from the physical to the digital occurred, participants were more likely to experience delays and trouble navigating the transit system, leading to higher stress and negative emotions. Because of the conflicting scheduling information, users may feel they cannot trust the information being provided to them within the transit system (Diab & El-Geneidy, 2015; Vuchic, 2005). A lack of trust in the physical surroundings increases a user's reliance on their smartphone and this feeling leads to individuals preferring to rely on their smartphones, this, in turn, causes a lack of trust in the public transit system as a whole and user retention issues later-on.

3.2 (b) Belowground Transfer Stations
In Munich, belowground transfer stations are only rail transit (S-Bahn and U-Bahn). During the DTI, participants encountered two belowground transfer stations, B1 and B2 [Figure 8]. Participants relied mostly on DC in belowground transfer stations [Table 2]. The confusion brought on by station design, crowds, or excessive signage increased participant uncertainty in these areas,

and resulted in a greater desire to use their smartphones. It is found that individuals that use crowded transit locations with poor design and wayfinding networks increases their stress and anxiety (Lai & Chen, 2011; Line, et al, 2011; Narimoto, et al, 2018). In order to improve this in terms of design, signage clarity, and a physical-digital alignment is required. Some participants mentioned they did not like being underground and felt that the way the stations were designed on the S-Bahn line made it difficult to read and know what station they were in - especially when the audio cues were inaudible or unclear. This made them feel uncertain about their route choices. Participants that chose to use their smartphones in these belowground stations found the spaces non-conducive to smartphone use as mobile signal and data availability is limited or out of range due to the location of the space.

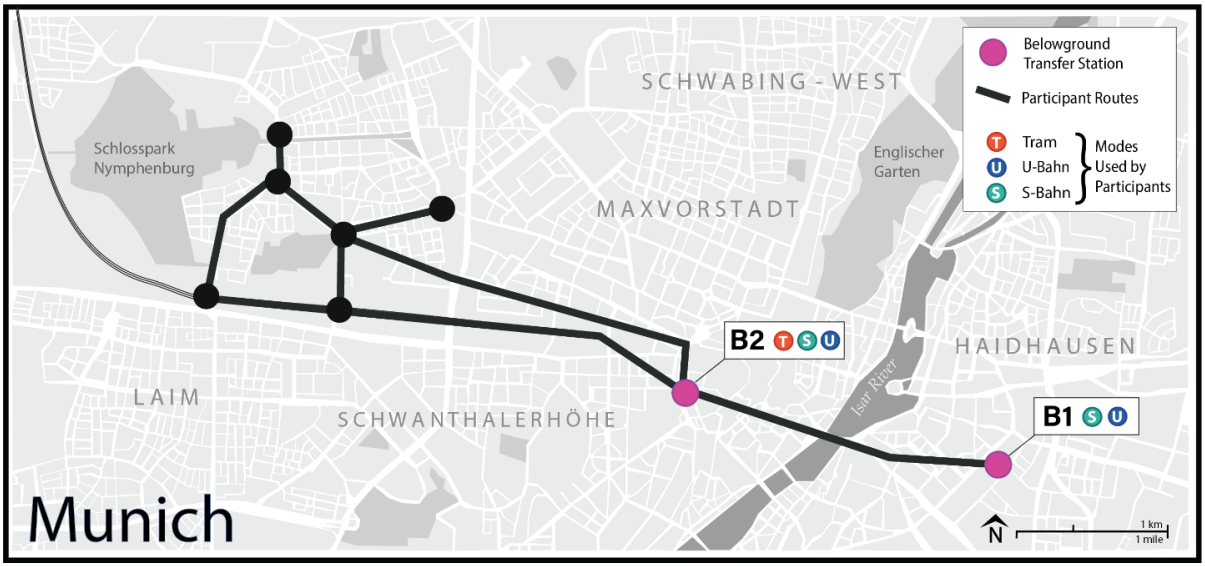


Figure 8. DTI route showing participant-used belowground transfer stations (in purple).

The frequency of instances participants used their smartphones in belowground transfer stations:

Table 2. Breakdown of participant smartphone usage in DTI Belowground Transfer Stations.

	B1	**B2**
Directional Confirmation		
Current Positioning		
Future Planning		

Scale:

No Usage	*Low Frequency*	*Medium Frequency*	*High Frequency*

Directional Confirmation:
B1 and B2 both provide S-Bahn and U-Bahn services. There was a high frequency of DC in belowground transfer stations during the DTI. As belowground transfer stations are contained spaces, the signage is often the only form of wayfinding aid users have when navigating through them. Visual distraction takes place within the transfer station itself with commercial business

and/or overcrowding within the corridors of stations. The stations themselves were made up of several corridors, which participants found difficult to navigate. However, after arriving at the platform, visual distraction and directional choice was limited. Use of smartphone as a navigational aid was significantly reduced once participants reached the platform. In the case of the U-Bahn, each side of the platform is designated for a specific direction of travel, users are informed as to which side of the platform they are to use by overhead screens and audio messaging when their trains are arriving and departing. The concept of reading the platform signage, expected behaviour on a platform, and the protocol required to enter the train platform is afforded through social practice (Scollon & Scollon, 2003). The process of entering and exiting an S- and U-Bahn is a learned experience, and the practice is generally the same around the world. The act of getting on and off an S and U-Bahn is an internationally understood process, and therefore the act becomes automatic for the user – which creates a sense of familiarity for the user.

In some cases, DC was used at the station platform. Mina, a participant in the DTI, found herself checking her smartphone on the U-Bahn platform as she wanted to double check she was heading in the right direction. Mina explained: "I need to check if Laimer Platz *(the name of the train direction)* is the right way. Sometimes I get scared with the U-Bahn and taking the wrong direction". As the end station is provided on the platform signage of the incoming train, she was able to clarify with the use of her smartphone that she was standing at the correct side of the platform by comparing information on the smartphone with the current information displayed on the platform. For Mina, the platform signage wasn't enough detail in order for her to trust that the arriving U-Bahn was heading in the direction she needed. The smartphone provided an option to double check the route details (e.g. the name of the end station, the intermediate stops on the route, and a schedule time) so she could confidently confirm her navigational decision. Having the end station named on the train is a standard practice in Munich, however for those who are less familiar with train routes, the use of the smartphone can provide further navigational information (Ferri, et al., 2021).

At B2, Serena was looking for the correct side of the S-Bahn platform and was unable to find the proper signage to lead her there. "I have to check my phone, again!", she explained. Serena felt that the available signage was unclear and the transit space un-readable. The smartphone provided her with station names and route details otherwise not provided to her on the platform. The platforms provide a limited amount of navigational information for users. Ultimately, the practicality of this information is dependent on the familiarity the user has of the route (Chang, 2013; Li & Klippel, 2016). Otherwise, a user requires further detail in order to make a decision.

Current Positioning:
There was a low frequency of use of CP in belowground transfer stations. This is not unexpected, as once participants step inside the transit system and head belowground, they become aware they are within the confines of the station's walls. There is little opportunity for the participant to wander outside the transit space. The general sense of "where am I?" is reduced by the fact they know exactly "where" they are within the system's network. For example, if an individual enters "Karlsplatz Station" they recognize they are at Karlsplatz Station within the wider transit system. Therefore, the use of CP with a smartphone becomes less desirable method of navigation as the information provided by the smartphone does not increase user awareness or knowledge.

Future Planning:
There was a moderate frequency of participants using their smartphones for Future Planning (FP) in belowground transfer stations, especially at B2. Mina, while on the S-Bahn platform, continuously checked her phone while waiting for the S-Bahn. Mina found the platform readable, however required her smartphone in order to help her plan out her next steps, as she felt the information provided on the platform was limited in terms of train schedules. Google had mentioned a specific train to take, so she decided to follow the advice from Google, and waited as several trains heading in the same direction passed by. The train suggested by Google ended up

being late. Because of this, the connecting bus she needed at the next stop was missed. Individuals require a certain amount of information in order to feel confident enough in making a "next step" in their transit journeys (Natapov, et al, 2015; Stankiewicz & Kalia, 2007). Had Mina decided not to use the information provided by her phone and taken one of the earlier trains, she would have made her bus connection. In this case, there was a disconnect between the information being provided to her on the platform and the digital information given to her through Google. The digital information provided by Google was not up to date with delays and schedule changes, and therefore led to a navigational error. This is a prime example of when the two navigational practices do not line up adding to excess complexities experienced by the user.

3.3 (c) On Transit

When it comes to navigating and wayfinding while on a moving vehicle, clarity and information availability are important. Wayfinding in *On Transit* situations was found to be more complex than both aboveground and belowground Transfer Station situations, as this involved a moving environment and greater temporal pressure for participants [Figure 9]. Studies have shown that complex environments increase the likelihood of increased user pressure and stress due to environmental and temporal challenges (Chang, 2013; Cox, et al, 2006) [Table 3].

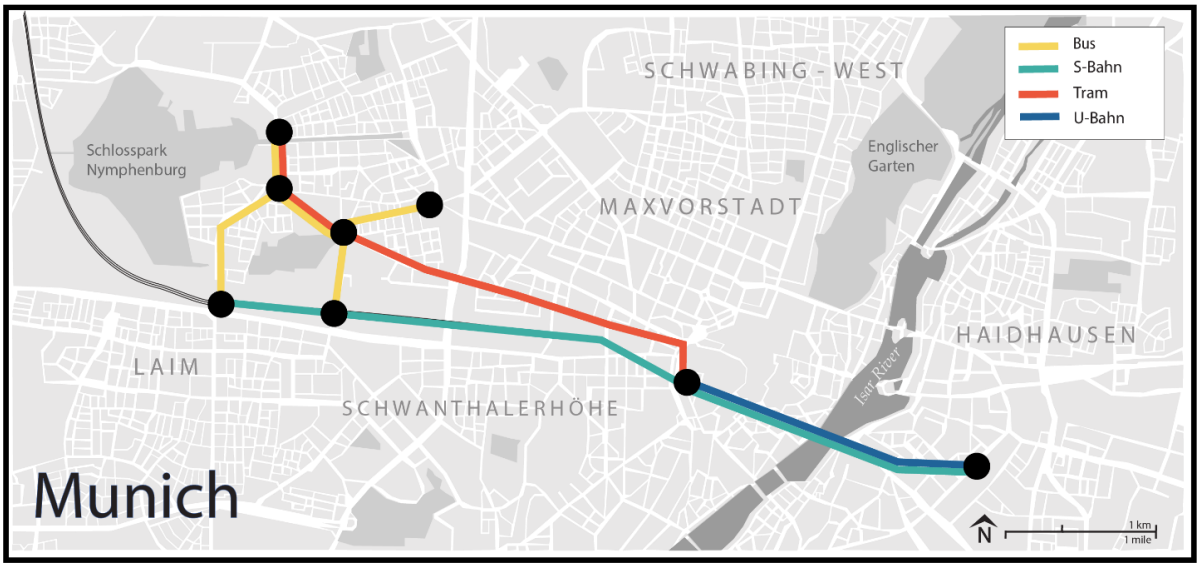


Figure 9. DTI route showing participant On Transit mode routes.

Table 3. Breakdown of participant smartphone usage in DTI On Transit.

	Bus	Tram	S-Bahn	U-Bahn
Directional Confirmation				
Current Positioning				
Future Planning				

Scale:
No Usage — *Low Frequency* — *Medium Frequency* — *High Frequency*

Participant perception of time and space shifted immediately as they entered and sat on transit. Participants became more aware of the environmental changes, such as vehicle movement and scheduling updates (such as the electronic schedules in public transit vehicles). Participants' frequency in smartphone usage increased during their time on transit for several reasons. The ease at which one feels on transit is highly dependent on the vehicle set-up and design, and the individual's comfort level while using said mode (Brakewood, et al, 2014; Evans & Werner, 2007; St-Louis, et al, 2014). In most cases in Munich, rail-based transit such as, trams, S- and U-Bahns provide multiple digital screens and audio cues for users to understand their location within the network. The structure and design of the vehicles are standardized in that they provide a long, level aisle with seating to both the left and the right sides. Users are familiar with the set-up as they would have seen this, or similar designs had they taken public transit before.

The set-up and design of buses in Munich can differ depending on which bus one happens to take. Like rail-vehicles, buses provide an aisle with seating on the left and the right, but can also contain empty sections reserved for wheelchairs and prams, level differences between seating sections (typically with a small set of stairs), different levels of seating, accordion-middle section which bends as the bus turns, and in Munich, vehicle extensions called bus trailers, which have a separate compartment connected to the back of a bus that provides more seating. Often on buses, the availability of navigational information is unreliable. In several cases, participants noted that digital screens were broken, and that audio cues were off. This coupled with the nature of bus transit (the fact buses are at the will of traffic and construction constraints often leads to shifts and changes in schedules and stop locations, and not all stops are used) creates a sense of uncertainty for the users (Diab & El-Geneidy, 2015, Diab, Badami, & El-Geneidy 2015). The lack of positioning updates, coupled with the nature of the bus requiring users to let the driver know when they want to stop, added to the increase in participants using their smartphones for current positioning.

Participants mentioned that they disliked the bus due to the randomness and unreliable feeling they get from the mode. In addition, the bus system does not function the same way as a railed system in terms of a set route path denoted by rails where the vehicle stops at every stop, and the stops aren't selected by or dependent on the riders. In many cases stops are not signed clearly or the audio announcements are unclear. This in turn, exacerbated participants' perceived sense of uncertainty. It is this level of uncertainty while on the bus that led participants to rely on their smartphones for navigational information. The unreliability of inconsistent navigational information in public transit leaves many users with few options but to figure out their route and location with their smartphone (Egger, 2016). All these factors play into an individual's desire to use the smartphone to help give themselves a sense of consistency and familiarity in an unknown situation.

S-Bahn was perceived as the more reliable mode by participants during the intro-interview of the DTI, however smartphone usage was significantly higher compared to any other mode choice. This could be due to the S-Bahn travels both above and belowground. Additionally, S-Bahns all use the same tracks in the centre of Munich (the Stammstrecke), resulting in multiple lines running from the same stations. Added choice increases complexity for the user as there is an increase in mode availability (Allen 1999; Montello, 2007; Li & Klippel, 2016). When participants entered the S-Bahn, the amount of physical navigational guidance was reduced (depending on the age of the train itself), with older trains having less visual and audible guidance, requiring participants to use their smartphones for all three navigational approaches.

In several cases, participants' smartphone usage was directly linked to the participant's aversion for riding a certain mode choice. For example, William, a DTI participant stated: "I don't care for the bus. I don't like the bus. The bus is a utility of getting there". Participants often exhibited strong feelings towards certain mode choices and routes, which underscores findings from studies that state users tend to lean towards taking familiar mode choices (Chang, 2013; Ferri and Popp, 2022; Olsson, et al, 2013). Typically, the participants avoided modes and routes they were less

comfortable with unless otherwise required. The more uncertain a participant was with a mode or route increased the chance they used their smartphone for directional advice.

3.4 Phone-induced Navigation Anxiety

Access to smartphones in public transit spaces has led to an increase in user comfort and sense of security in terms of using these transit spaces (Brakewood, et al, 2014). However, this also results in an increase in individual smartphone-related anxieties. Several participants mentioned the fear of not having access to their smartphone to confirm navigational decisions, and how that fear influenced their navigational decision- making throughout the DTI. When an individual is put in an unfamiliar environment their stress levels increase, when an individual relies on their smartphone for navigational aid and it is not available to them, this increases their already heightened stress levels (Afrooz, et al., 2018; Ferri and Popp, 2022; Montello, 2007; Li & Klippel, 2016,). Participants referred to having a low battery on their phone as a hurdle in their navigational process, as it made them feel like they had to memorize more than they normally would during their journey, and rush to get to the destination. When asked about why they felt this way, participants used terms such as "addicted" and "reliant" when it came to smartphone usage. Upon further questioning, participants revealed that they felt that the information provided to them in the wayfinding system wouldn't be enough to get them through to their exact destination, and therefore felt the smartphone was more accurate and reliable for navigation.

Many public transit wayfinding systems have not adjusted to the ubiquity and popularity of smartphones, nor have these systems fully integrated them into transit design. Participants who felt stressed about their smartphones were also the ones to refer to their smartphones throughout the DTI the most. Physical smartphone infrastructure in transit systems (e.g. accessible wifi, charging stations, etc.) can aid in assisting users and provide a holistic system that adjusts to its user's needs. By including smartphone-friendly infrastructure into public transit, can help to increase user accessibility, which in turn, can aid in overall user retention.

4. Conclusion

Wayfinding is intended to enhance a user's experience throughout their journey (Fendley, 2016; Egger, 2016; Mollerup, 2013; Wrede, 2016). However, there are several instances in public transit where wayfinding design does not fulfil its intended purposes. Understanding the role of the smartphone in individuals' transit journeys is critical for future wayfinding design. This study has helped shed light on the increasing importance of digital practices in public transit navigation. The goal of this exploratory study was to illuminate the importance users put on their smartphones during wayfinding in public transit by examining two navigational practices found in public transit systems – digital and physical. Observing moments of smartphone use in navigation allows researchers to find design gaps in wayfinding networks.

The study revealed that in both above- and belowground transfer stations, *Directional Confirmation* was the most widely used navigational approach by participants. Meaning that participants relied more on their smartphones during orientation within stations. Participants felt that in several sections of the public transit network, physical directional information was lacking in order to lead them to their next step in their DTI journey. The more participants used their smartphones for Directional Confirmation, the more they began to trust their smartphone over the physical space.

In terms of *On Transit* navigation, participants were more likely to rely on their smartphone for all navigational approaches, rather than using the static navigational information provided to them. Modes such as the bus and the S-Bahn were perceived by participants as lacking in wayfinding guidance as they felt they required their smartphones when on these modes.

The approach of the study showed us that observing participants' smartphone usage while performing wayfinding tasks can help reveal deficiencies within a public transit environment. A

user's perception and reaction to their surroundings is more telling than the intention behind a designed space. If a user does not feel that they are receiving enough information for them to continue their journey, they respond by actively seeking for guidance outside of their surroundings. The smartphone provides a solution for these perceived gaps. By observing participants struggling to read their physical environment and rely on their smartphones while performing wayfinding tasks during the DTI reenforces the idea that a robust wayfinding system within a public transit system increases trust and perceived functionality of the overall system.

Although more traditional methods of wayfinding design (including signage and audio announcements) are effective in relaying transit navigational information, they are not always reliable in relaying their messaging. With the increase in smartphone ownership worldwide, embracing of smartphone capabilities into overall wayfinding design can help to alleviate many of the wayfinding design issues described by participants in this study and prepare for a newer generation of navigation.

The DTI provides a robust method to gather empirical information from individuals. Limitations in the method include the fact our participants were all early to middle aged and educated individuals familiar with the Munich transit system. Future research using the DTI method should include a larger number of participants and a wider range of generational and social groups, providing for greater validity to final data. Future studies looking at smaller public transit networks, or specific sections of a transit network (e.g. just the bus network) could help to reveal larger discrepancies in public transit wayfinding design and user reliance on smartphone navigation, helping to reveal design solutions that combine both digital and physical practices.

Acknowledgements

This article was developed with the support of the mobil.LAB Doctoral Research Group: 'Shaping Mobility Cultures' joint PhD program by Technical University Munich (TUM) and Nürtingen-Geislingen University (HfWU), funded by Hans Böckler Foundation, Germany (PK 032).

Conflicts of Interest

The authors declare no conflict of interest.

References

Afrooz, Aida, David White, and Bruno Parolin (2018) Effects of Active and Passive Exploration of the Built Environment on Memory During Wayfinding. *Applied Geography* 101: 68–74

Allen, G. (1999): Spatial Abilities, Cognitive Maps, and Wayfinding. Pages 46–80 in *Wayfinding behavior: cognitive mapping and other spatial processes* edited by R. G. Golledge. Baltimore, Maryland: John Hopkins University Press.

Alosaimi, F.D., H. Alyahya, H. Alshahwan, N. Al Mahyijari, S.A. Shaik (2016): Smartphone addiction among university students in Riyadh, Saudi Arabia. *Saudi Medical Journal*, 37, pp. 675-683.

Arthur, P. and Passini, R. (1992) *Wayfinding. People, Signs, and Architecture.* New York: McGraw-Hill.

Bian, Jiahe, Wei Li, Sinan Zhong, Chanam Lee, Margaret Foster, & Xieyue Ye (2021) The end-user benefits of smartphone transit apps: A systematic literature review. *Transport Reviews.* July, 9

Bohte W, Maat K, van Wee B (2009) Measuring attitudes in research on residential self-selection and travel behaviour: a review of theories and empirical research. *Transport Review* 29(3):325–357

Brakewood, C., Barbeau, S., & Watkins, K. (2014). An experiment evaluating the impacts of real-time transit information on bus riders in Tampa, Florida. *Transportation Research Part A: Policy and Practice*, 69, 409–422.

Bucolo, S., and J. H. Matthews. (2011) A Conceptual Model to Link Deep Customer Insights to Both Growth Opportunities and Organizational Strategy in SME's as Part of a Design Led Transformation Journey. Presented at *Design Management Toward a New Era of Innovation*, Hong Kong Convention and Exhibition Center.

Chang, Hsuan Hsuan. (2013) Wayfinding Strategies and Tourist Anxiety in Unfamiliar Destinations. *Tourism Geographies* 15 (3): 529–550.

Chen C.-H., Chang W.-C., Chang W.-T. (2009). Gender differences in relation to wayfinding strategies, navigational support design, and wayfinding task difficulty. *J. Environmental Psychology.* 29 220–226.

Cisterna, C., Giorgione, G., & Viti, F. (2021). Explorative analysis of potential MaaS customers: an agent-based scenario. *Procedia Computer Science,* 184, 629–634.

Cox, T., Houdmont, J. & Griffiths, A. (2006). Rail passenger crowding, stress, health and safety in Britain, *Transportation Research: Part A*, 40, 244-258.

Diab, E. I., & El-Geneidy, A. M. (2015). The Farside Story: Measuring the Benefits of Bus Stop Location on Transit Performance. *Transportation Research Record,* 2538(1), 1–10.

Diab, Ehab I., Madhav G. Badami & Ahmed M. El-Geneidy (2015) Bus Transit Service Reliability and Improvement Strategies: Integrating the Perspectives of Passengers and Transit Agencies in North America, *Transport Reviews: A Transnational Transdisciplinary Journal*, 35:3, 292-328

Egger, Veronika (2016) The virtual railway station: Wayfinding experiences in a virtual environment and their application to reality. *Information Design Journal* 22(2), 116–126

Evans, G. and Wener,R. (2007) Crowding and personal space invasion on the train: Please don't make me sit in the middle, *Journal of Environmental Psychology*, Volume 27, Issue 1, Pages 90-94

Fendley, Tim (2016): What next for legible cities: An assessment of the potential future for urban wayfinding. *Information Design Journal* 22(2), 165–171

Ferri, A. and Popp, M. (2022) 'Wayfeeling': Navigating through emotional and sensorial responses in public transit. *Wellbeing, Space and Society*, Volume 3

Ferri, A., Popp, M., & Wulfhorst, G., (2021) Digital Directions: Smartphone Usage While Performing Wayfinding Tasks in Munich's Public Transit System. *Interdisciplinary Journal of Signage and Wayfinding*. 5 (2), 7-21.

Gountas J, Gountas S (2007) Personality orientations, emotional states, customer satisfaction, and intention to repurchase. *Journal of Business Research* 60(1):72–75.

Guarino, N., Oberle, D., & Staab, S. (2009). What is an ontology?.In *Handbook on ontologies* (pp. 1-17). Springer, Berlin, Heidelberg.

Guidon, S., Wicki, M., Bernauer, T., & Axhausen, K. (2020). Transportation service bundling – For whose benefit? Consumer valuation of pure bundling in the passenger transportation market. *Transportation Research Part A: Policy and Practice*, 131, 91–106.

Haake, Robert, Robin Smith, and Herbert Pick, Jr. 1984. Wayfinding in Unfamiliar Environments. *Infant Behavior and Development* 7: 153.

Hall, E. *The Hidden Dimension.* Doubleday, Garden City, N.Y., 1966.

Jepsen, T. C. (2009). Just what is an ontology, anyway? *IT Professional Magazine,* 11(5), 22.

Kazig, R. & M. Popp (2011) Unterwegs in fremden Umgebungen. Ein praxeologischer Zugang zum Wayfinding von Fußgängern, *Raumforschung und Raumordnung*, 69 (1), 3-15.

Lai W & Chen C (2011) Behavioral intentions of public transit passengers—the roles of service quality, perceived value, satisfaction and involvement. *Transport Policy* 18(2):318–325

Li, R. and Klippel, A. (2016) Wayfinding Behaviors in Complex Buildings: The Impact of Environmental Legibility and Familiarity. *Environment and Behavior* 2016, Vol. 48(3) 482–510

Line, T., Jain, J., & Lyons, G. (2011). The role of ICTs in everyday mobile lives. *Journal of Transport Geography*, 19(6), 1490-1499.

Lee, Seunghae, Sibel Seda Dazkir, Hae Sun Paik, and Aykut Coskun (2014) Comprehensibility of Universal Healthcare Symbols for Wayfinding in Healthcare Facilities. *Applied Ergonomics* 45: 878–885.

Levy, E. (2001) Saisir l'acessibilite. Les trajets-voyageurs a la gare du Nord. In: Grosjean, M.; Thibaud, J.-P. (Hrsg.): *L'espace urbain en methodes.* Marseille, 47-62.

Lynch, K. (1960): *The Image of the City.* Cambridge, Massachusetts: M.I.T. Press.

Mollerup, P. (2013). *Wayshowing > Wayfinding: Basic & Interactive.* BIS.

Montello, Daniel R. (2001) Spatial Cognition. In International Encyclopedia of the Social & Behavioral Sciences, edited by Neil J. Smelser and Paul B. Baltes, 14771–14775. Oxford: Pergamon Press.

Montello, Daniel R. (2005) Navigation. In *The Cambridge Handbook of Visuospatial Thinking*, edited by Priti Shah and Akira Miyake. New York: Cambridge University Press.

Montello, D. R. (2007). The contribution of space syntax to a comprehensive theory of environmental psychology. Paper presented at the 6th *International Space Syntax Symposium,* Istanbul, Turkey.

Münzer, S., Zimmer, H. D., & Baus, J. (2012). Navigation assistance: A trade-off between wayfinding support and configural learning support. *Journal of Experimental Psychology: Applied*,18 (1), 18–37.

Münzer, S., Zimmer, H. D., Schwalm, M., Baus, J., & Aslan, I. (2006). Computer-assisted navigation assistance and the acquisition of route and survey knowledge. *Journal of Environmental Psychology,* 26 (4), 300–308.

Narimoto, R., S. Kajita, H. Yamaguchi and T. Higashino, (2018) "Wayfinding Behavior Detection by Smartphone," *IEEE 32nd International Conference on Advanced Information Networking and Applications (AINA)*, 2018, pp. 488-495.

Natapov, Asya, Saskia Kuliga, Ruth Conroy Dalton, and Christoph Hölscher (2015) Building Circulation Typology and Space Syntax Predictive Measures. Proceedings of the *10th International Space Syntax Symposium,* Space Syntax Laboratory, The Bartlett School of Architecture, University College London, 13–17

Olsson, L., et al. (2013). Happiness and satisfaction with work commute. *Social Indicators Research* 111(1): 255–263

O'Neill, M. J. (1992). Effects of familiarity and plan complexity on wayfinding in simulated buildings. *Journal of Environmental Psychology*, 12, 319-327.

Peponis, John, Jean Wineman, Sonit Bafna, Mahbub Rashid, and S. H. Kim. 1998. On the Generation of Linear Representations of Spatial Configuration. *Environment and Planning B: Urban Analytics and City Science* 25 (4): 559–576

Reason, Matthew (2010). Watching Dance, Drawing the Experience and Visual Knowledge. *Forum for Modern Language Studies Vol*. 46, No. 4

Schmidt, D. E., and J. P. Keating. (1979) Human Crowding and Personal Control: An Integration of the Research. *Psychological Bulletin*, Vol. 86, No. 4, 1979, pp. 680–701.

Scollon, Ron, & Suzie Wong Scollon (2003): *Discourses in Place. Languages in the Material World.,* London. Routledge

Shaheen, S., Cohen, A., Zohdy, I., & Beaudry, K. (2016). Smartphone applications to influence travel choices. *Practices and policies*, No. FHWA-HOP-16-023.

Sheller M, Urry J. (2006) The New Mobilities Paradigm. *Environment and Planning A: Economy and Space;* 38(2):207-226.

Stankiewicz, Brian, and Amy Kalia. (2007) Acquisition of Structural Versus Object Landmark Knowledge. *Journal of Experimental Psychology: Human Perception and Performance* 33 (2): 378–390.

St-Louis E, et al. (2014) "the happy commuter: a comparison of commuter satisfaction across modes. *Transportation research part F: traffic psychology and behaviour* 26, part a (0): 160-170

Timpf, Sabine (2002). Ontologies of Wayfinding: a Traveler's Perspective. *Networks and Spatial Economics,* 2: (2002) 9–33

Tzeng, Szu-Yu & Jui-Sung Huang (2009) Spatial Forms and Signage in Wayfinding Decision Points for Hospital Outpatient Services, *Journal of Asian Architecture and Building Engineering*, 8:2, 453-460,DOI: 10.3130/jaabe.8.453

van Lierop D, Badami MG, el-Geneidy AM (2018) What influences satisfaction and loyalty in public transport? A critical review of the literature. *Transport Review* 38(1):52–72

van Lierop, Dea & Bahamonde-Birke, Francisco. (2021). Commuting to the future: Assessing the relationship between individuals' usage of information and communications technology, personal attitudes, characteristics and mode choice. *Networks and Spatial Economics.*

van Lierop,Dea, Jasmine Eftekhari, Aislin O'Hara , and Yuval Grinspun (2019) Humanizing Transit Data: Connecting Customer Experience Statistics to Individuals' Unique Transit Stories. *Transportation Research Record* 2019, Vol. 2673(1) 388–402

Urry, J. (2007). *Mobilities.* United Kingdom: Wiley.

Vuchic, V. (2005). *Urban transit: Operations, planning and economics.* New York, NY: John Wiley & Sons

VuMa, Bitkom Research, and comScore MobiLens (2019) Number of smartphone users in Germany from January 2009 to 2021 (in millions). In Statista – *The Statistics Portal.* Retrieved September 1, 2022, from https://www.statista.com/statistics/461801/number-of-smartphone-users-in-germany/

Wrede, Oliver (2016): Continuity in travel information. *Information Design Journal* 22(2), 172–178