Pervasive Displays for Public Transport – An Overview of Ubiquitous Interactive Passenger Services

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ABSTRACT
Useful and easy-to-use digital passenger services are one component for increasing the overall attractiveness of public transportation. In this paper, we provide an overview and a critical review of the current state of interactive passenger services through a case study involving mobile apps as well as situated public screens at two major stations. By relating the identified key features to prior research in the field, we identify trends and opportunities for impactful future research. We found that intermodal routing and ticketing in today's mobile apps are sophisticated, yet socializing features and interactive applications on public screens lag behind research in this field. Promising future research opportunities include improving personalization and investigating trust in public transportation and its digital services.

Author Keywords
Public transport; passenger services; mobile apps; public screens; personalization; trust; ticketing

CCS Concepts
•**Human-centered computing → Human computer interaction (HCI); Ubiquitous and mobile computing;**

INTRODUCTION
Public transportation plays an important role within global efforts towards more sustainable, green, and livable cities. Besides obvious quality criteria, such as an adequate level of service, reliability, safety, and cleanliness, digital passenger services are an important component for increasing the attractiveness of a city's public transport system. Advances in mobile and pervasive computing technologies, particularly personal smart devices and ubiquitous public screens, provide countless opportunities for respective passenger services (cf. [6, 10]). Over about two decades, the field has developed from preliminary context-aware guide prototypes in the early days of ubiquitous computing (UbiComp) to fully-fledged publicly available travel apps. More recently, digital passenger services re-aroused interest among the human-computer interaction (HCI) and UbiComp communities, as demonstrated by recent academic workshops [16, 35].

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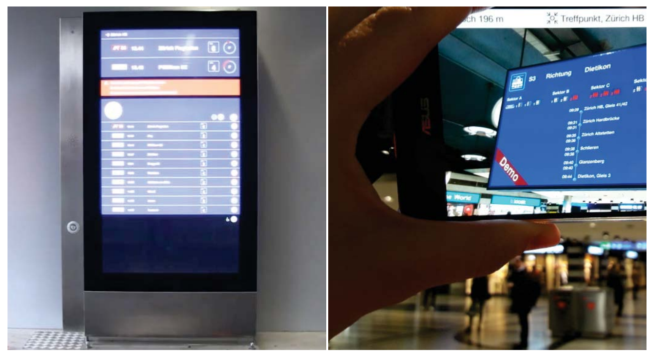


(a) (b)

Figure 1. Novel interactive presentation forms for real-time information at the station: a large interactive touchscreen (a) and a mobile augmented reality app (b).

In this paper, we present a review of ubiquitous interactive passenger services, i.e. digital services which are used on-the-go and in-situ. Using two major train stations in Switzerland as a case study, we surveyed real-world applications on pervasive displays (mobile and public screens, cf. Figure 1). Rather than providing a comprehensive market analysis, our objective was to contrast the current state of digital passenger services with prior research work. The contributions of this paper are, (1) a compact structured overview of existing research on interactive passenger services, (2) the findings from an exemplary case study to illustrate the current state of ubiquitous interactive passenger services, and (3) a critical reflection on the developments of the field leading to the identification of trends and opportunities for impactful future research. The contributions offer value for both practitioners and researchers. Practitioners are provided with a compact overview of relevant research and might find inspiration through the real-world applications surveyed in the case study. For researchers, the paper provides an entry point into the hitherto clustered field of ubiquitous passenger services and outlines avenues for future research in this field.

RESEARCH ON INTERACTIVE PASSENGER SERVICES

In this section, we summarize relevant prior research on interactive passenger services. We classify the existing body of research into work on (1) passenger-centered service design, which offers methodologies for addressing the needs of passengers, and (2) novel ubiquitous passenger services published in the fields of HCI and UbiComp.

Passenger-Centered Service Design

Prior research proposed different approaches to create digital services with added value for passengers.

Identifying Passengers' Information Needs

Caulfield and O'Mahony [7] conducted a web-based survey to collect data on passenger preferences and describe the methods of information delivery a passenger requires at each stage of the trip. The authors defined the stages *pre-trip to destination*, *at-stop*, *onboard*, and *pre-trip to origin* (the return journey). A key finding was the importance of real-time information: The lack of certainty as to when the passengers' service would arrive was indicated as a crucial factor that causes frustration when using public transport. Furthermore, passengers on intermodal journeys (i.e. trips containing different transportation modes) were more likely to use public transport information in general. Grotenhuis et al. [22] further found that passengers are most concerned about the timely arrival at interchanges. Based on interviews with bus drivers and service clerks, Beul-Leusmann et al. [4] found that passengers appreciate self-service applications for informational, and particularly, for confirmatory reasons.

Hörold et al. [21] introduced a framework for identifying information needs of public transport users based on a journey workflow analysis and a hierarchical task analysis. They conclude that during the design of a passenger information system three fundamental criteria need to be considered: (1) addressees of information (individual/collective), (2) right location for system (stop, in-vehicle, mobile device), and (3) purpose of information (dynamic/static).

Design Support for Public Transport Services

To support designers working for public transport services, HCI researchers started to create dedicated tools to support the passenger-centric design of passenger services. For example, the "Bus Travel Experience Model" [19] was derived from a qualitative field study with ten regular bus passengers and describes the central experience elements (user, context, and the system) for intra-city bus journeys. The subsequently presented "Travel Experience Toolkit" [18] entails bus passenger personas, bus-specific context cards, and passenger journey maps describing relevant actions of a passenger.

Passenger Involvement

Multiple studies suggest involving passengers in the design of novel services and to exploit their collective knowledge. Filippi et al. [13], for example, recommend applying user-driven innovation strategies in transport services and outline a strategy in three steps to empower users and improve public transport services. A "passenger involvement framework" was proposed by Nunes et al. [27] to draw on the collective intelligence of public transport passengers through crowd-sourcing. Using mobile phones, passengers are enabled to provide spatio-temporal information. A field study evaluation indicated positive uptake by commuters.

Novel Ubiquitous Passenger Services

Researchers in the fields of HCI and UbiComp have been proposing and studying various innovative passenger services to be used on-the-go and in-situ.

Navigation and Routing

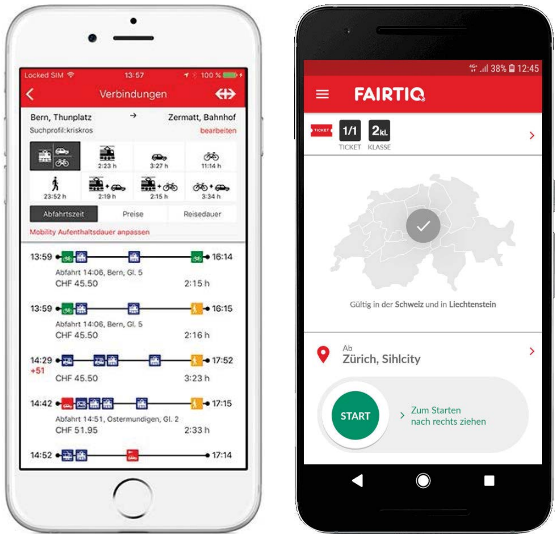
Several researchers introduced potential improvements for traditional navigation in public transport. Examples include the *Urban Bus Navigator* [14], which provides contextual "micro-nagivation" beyond typical A-to-B routing tasks. The system was aimed particularly at disadvantaged users by providing information about the currently used bus and upcoming stops, and when to leave the bus. Similarly, Samsel et al. [32] proposed "cascading information" for public transport apps, i.e. turn-by-turn-like instructions for intermodal public transport. In their app prototype, passengers were only presented with information necessary at that point in time to reach their next intermediate target and thus continuously progress through their trip. The use of contextual information was also investigated by Ferris et al. [12], who were among the first studying the benefits of real-time information for public transport passengers. Their set of transit tools called *OneBusAway* provided real-time arrival information for bus passengers (e.g., through a web interface, interactive voice, etc.). A survey among its users showed positive outcomes with passengers reporting an increased overall satisfaction with the public transport system and decreased waiting times. The *UbiBus* project [36] investigated technical foundations for providing real-time arrival information. Zimmerman et al. [38] studied the contribution of GPS traces by passengers to derive real-time arrival estimates for others. A field trial of their crowd-sourcing approach showed high participation rates for explicitly sharing location traces. Similarly, Chahine and Tomitsch [8] proposed and evaluated a mobile app to crowd-source data on bus arrival times and their level of crowdedness, also observing high participation rates with participants citing reciprocity and the feeling of contributing to a community as motivating factors.

Mobile Ticketing

Mobile ticketing (in this context) refers to purchasing and showing a validatable ticket for public transport on a mobile device. In early work, Mallat et al. [24] investigated adoption of SMS-based mobile ticketing in public transportation. More recent studies focused on alternative ticketing approaches, including a study carried out by Stopka et al. [33] on an NFC-based open ecosystem to offer secure identification for mobile ticketing services in the domain of public transportation. A key finding were practical issues regarding the interoperability of current mobile devices.

Social Networking for Passengers

Another strand of research explored ways to exploit or foster social aspects of public transport. For example, the platform *tripzoom* [5] combines a mobile app (which collects personal



(a) (b)

Figure 2. Exemplary features of modern mobile apps for public transport: intermodal pearl-chains and transport mode filters (a) and "check-in ticketing" through a slider (b).

mobility data), social networking, and incentives to motivate users towards more sustainable mobility behaviors. The platform pursued a social competition approach, visualizing and comparing elements, such as financial savings and carbon emission savings, within a dedicated online community. More recently, Müller et al. [25] presented *Honeypot*, a "'socializing app", which aimed at helping commuters to find other passengers to chat with, with the aim to enhance their wellbeing. The app was informed by contextual inquiries, finding that that most commuters seemed to be interested in talking to other people. A field trial of the app found participants reporting positive effects of the app.

Situated Information on Interactive Public Screens

Besides passenger services for mobile devices, HCI studies have also investigated the use of interactive public screens in public transport environments. For example, Hörold et al. [20] investigated challenges of interactive screens in public transport as a means to extend the functionality of traditional static timetables. The study identified a number of criteria, including their visibility, correct positioning (e.g., to ensure accessibility for wheelchair users), content (timetables, network plans, other maps as main information elements), and functionality. These findings were confirmed in a later study by Parker and Tomitsch [30], which evaluated four interactive screens, including a bus timetable prototype. The study further concluded that public screens should not purely replicate content available on smartphones, but instead "provide supplementary information that cannot easily or quickly be accessed via a smartphone".

Several studies investigated the interplay of mobile devices and public screens for useful and/or joyful urban transportation services (cf. [15]). Early approaches include *Cityware* [23], which presented information about frequently encountered co-passengers (based on Bluetooth and link to a Facebook profile), and *VirtualFish* [37], which visualized passers-by anonymously within a virtual aquarium. More recently, Tokunaga et al. [34] proposed the combination of large touchscreens and mobile devices for collaborative journey planning.

Coenen et al. [9] studied the combination of touch and mid-air gestures, and floor mat interaction with a large display in a public transport context. Their prototype featured geographically-located tweets about train travel and information on departing trains. Findings from a field study showed that passers-by tended to assume that a public display only supports a single interaction modality, which the authors describe as "affordance blindness".

METHOD

To contrast the prior research work outlined in the previous section against the current state of digital passenger services, we conducted a case study in Switzerland, which is known for its economic wealth and sophisticated public transport system. As our study focus was on pervasive displays, we did not consider other types of novel technologies in the public transport domain such as autonomous robots. Within the area of pervasive displays, we specifically considered two types of interactive passenger services:

Mobile Passenger Services. We surveyed mobile applications in Google's Play Store for Android and Apple's App Store. We used regional filters and keywords such as "public transport" and "bus app" (and their local translations) to search for available apps, which included apps from official transport providers as well as apps from independent mobility providers and start-ups. We only included apps with at least a few thousand installations. We excluded global solutions, such as *Google Maps*, as we were specifically interested in regionally restricted apps, allowing us to better compare their features to the locally-specific situated services. We further excluded mobile travel guides and related apps aimed at tourists.

Situated Passenger Services. Additionally, we surveyed appearances of situated pervasive displays at two major train stations in Switzerland, Zurich and St.Gallen. The stations were selected since they serve as major regional transport hubs for trams, buses, and trains. In preparation, we searched for information and press releases regarding newly deployed technologies at these stations. We subsequently completed site inspections, during which a researcher surveyed, tried out (as far as possible) and logged respective situated applications. Non-interactive public screens used, for example, for wayfinding or timetable information, were excluded from the survey, as we were specifically interested in comparing interactive features across situated and mobile services.

MOBILE PASSENGER SERVICES

Our survey identified a total of 13 well-established and upcoming mobile apps for public transport in Switzerland. The two apps with the highest number of installations, *SBB Mobile* and *Postauto*, were the ones provided by the two national transport agencies for trains and buses. The remaining 11 apps represented innovative solutions offered by smaller transportation companies as well as startups. Examples include *Wemlin*, *abilio*, *FAIRTIQ*, *moovit*, and *Lezzgo*. In this section, we present the core features of these mobile apps. The purpose of our survey was to identify and capture these features, rather than recording a distribution of features and their availability across apps. Thus, this section is grouped by common types of features and highlights some of the apps to illustrate the manifestation of core features.

Intermodal Route Planning

Route planning was one of the core features across all apps. While early mobile route planners only considered one transport mode (typically train or bus), recent apps feature intermodal routes combining multiple transportation modes. It is noteworthy, that not only apps from startups but also official apps from national transport companies support intermodal routing. Figure 2a depicts a typical route selection screen with the "pearl-chain view" in the *SBB Mobile* app, featuring routes involving tram, bus, bike, car, and walking.

For selecting the preferred route, users are provided with various attributes to compare calculated routes. Besides the obvious departure and arrival times, the apps offer information on the trip, such as duration, distance, number of interchange points, the price of the trip, and the elevation difference. As a further selection criterion, some apps indicate the availability of nearby car and bike sharing services or parking slots. Filters enable the (de)selection of (un)wanted or (un)available transport modes (e.g., if the user does not own a private car). Some apps also offered advanced filtering, letting users specify, for example, whether they have any physical disabilities or carry luggage. In most apps, users were able to sort results to quickly find the fastest or cheapest one.

To avoid typing destinations repeatedly, all apps provided personalization features. Users are able to save routes as favorites or select from suggestions of commonly used routes. In many cases, users may store favorite destinations, such as home or work, allowing for quick access, e.g., in the form of a "Take me home" button. Some apps offered the ability to retrieve upcoming destinations from the user's mobile calendar.

Advanced Ticketing

Most apps offered the ability to purchase a mobile ticket, represented in the form of a QR code which can be scanned by ticket inspectors equipped with corresponding validation apps. To support intermodal routing, several apps integrated multiple ticket providers to cover the available traffic modalities and offer combined tickets. One app even allowed car drivers to purchase parking tickets for interchange points (by submitting the private car's license plate number). For routes that did not have direct integration of external ticket providers, the apps provided users with a link to the respective apps, e.g. to book a taxi.

A novel ticketing feature offered by several of the investigated apps, was a "check in/out" mode. Instead of having to purchase a ticket in advance for the entire trip, this mode allows users to indicate when they start their trip ("check in", e.g., using a slider such as in *abilio* and *FAIRTIQ* depicted in Figure 2b). By tracking the route (until the users finish their trip and "check out"), the service providers then automatically select the most appropriate ticket and charge their users in regular intervals (e.g., monthly). Reminders in the mobile app support users, who forget to "check out", when having reached their destination. A further development of the "check in/out" mode is the "walk-in" option (e.g., temporarily supported by *abilio*). Based on Bluetooth beacons, the mobile app detects entering and leaving a public transport vehicle. Thus, dispensing a ticket and charging, respectively, happens automatically in the background without requiring manual input from the passenger.

Real-time Information

Providing passengers with up-to-date information on the current traffic situation proved to be another core feature of today's public transport apps. For example, this included informing the user during route selection about expected delays and late arrivals (e.g., depicted by the red minutes label in Figure 2a). Extending such simple delay labels, *PostBus*, for example, featured an "alarm" button to obtain push notifications regarding interruptions or delays on the planned public transport route. The *SmartShuttle* app, used within a pilot study with autonomous buses, not only offered real-time schedule data but also depicted the current position of the bus on an interactive map. Another app allowed users to share news on a real-time dashboard, allowing for crowd-sourcing of traffic-related information and incidents.

Additional Mobile Services

The investigated mobile apps featured a few specialized add-on features for passengers pre and post trip. For example, this included a countdown to notify users to start their journey in order to reach the selected connections in time as well as suggestions for short trips at the destination (including making reservations for nearby restaurants or museums). One noteworthy post-trip feature was the opportunity to ask for items lost during the journey right within the app.

SITUATED PASSENGER SERVICES

Through our on-site surveys, we identified several innovative applications of interactive public screens across the two stations.

Interactive Travel Information

While the majority of public screens currently deployed at stations and stops are non-interactive displays, we found a few touch-enabled large screens, which offered interactive digital maps of the surroundings, information about the station, and real-time schedules and timetables. For example, Figure 1a shows an "interactive departure monitor", which enables browsing timetables and general information, while also displaying a countdown for the next train connections. To support accessibility for passengers with physical disabilities, the screen features a button to read aloud connections for the visually-impaired and a button to move the entire digital content towards the bottom of the screen for passengers in wheelchairs.

A mobile extension of the non-interactive digital destination boards at platforms was recently tested in pilot studies at Swiss stations. Using augmented reality (Figure 1b), a mobile application provides contextual information completing the

(a) (b)

Figure 3. Examples of pervasive displays from our survey of situated passenger services in public transport environments: "social media screens" (a) and small-area projections for advertisement (b).

destination board. Examples include listing intermediate stops of a connection and visualizing a utilization rate per carriage to allow passengers without a seat reservation in finding a seat.

Social Media Screens

We found social media screens (Figure 3a) installed in the travel center at Zurich main station, offering passers-by and customers entertainment while waiting for a service or to be served. Akin to popular "Twitter walls" used at conferences, these large screens dynamically visualized photos from *Instagram* tagged with a predefined hashtag. The screens enable customers to share their travel impressions while trying to reduce the perceived waiting time in the travel center.

Advanced Advertising

Several underground stops are already equipped with projectors and corresponding large screens displaying advertising while there is no train at the platform. In our survey, we found experimental smaller projectors at stations and stops, for example, to casts content on elevator doors at Zurich main station (Figure 3b). These types of displays, did not include interactive features, however, we included them in our survey as examples of innovative applications for non-interactive content delivery.

DISCUSSION

In our discussion, we reflect on the introduced passenger services and derive general trends and corresponding research opportunities for researchers in HCI and UbiComp. Those insights need to be read, however, while keeping in mind that our survey of transport services used in practice was limited to public transport apps available specifically in Switzerland and public screens found at two Swiss train stations.

Reflection on Studied Services

We now refer back to our categories used to structure novel pervasive passenger services proposed in research. In order to discuss potential trends and open research aspects, we relate the identified features and services from the field to those in research.

Navigation and Routing

As we have seen in the investigated apps, intermodal navigation and routing has become a de-facto standard feature in mobile transport apps. While respective needs of passengers in intermodal travel chains and implications on passenger information systems have been, for example, studied by Digmayer et al. [11] previously, modern apps for public transport provide a high standard in planning and filtering intermodal connections to a destination. Yet, we consider the efficient presentation of intermodal routes and corresponding manifold information on mobile devices an ongoing challenge. As modern "mobility as a service" offers contain more and more modalities with special attributes (in case of shared bikes, for example, their actual availability at the intermediate stop or the precise location of the bicycle station), passengers will be confronted with an increasing amount of relevant information. Appropriate approaches to address this might involve novel visualizations beyond the traditional "pearl-chain-view" or moving from pre-trip planning to "on-trip guiding", where smart routing algorithms take over responsibility that a passenger reaches his destination (while meeting his diverse requirements and preferences) and rather presents short contextual instructions than forcing him to select from a list of connection opportunities. Initial prototypes testing such features have been proposed by researchers (cf. [14, 32]), yet, have not found their way into any of the apps included in our survey.

Mobile Ticketing

We found mobile ticketing to be another common feature in modern public transport apps. The apps covered in our study supported various payment methods and used visual codes to represent a valid ticket during the journey. In contrast to NFC-based mobile tickets, the visual codes are suitable across platforms and are supported by both Android devices and iPhones. As an alternative to purchasing tickets before the trip, two of the apps provided ad-hoc "check-in" ticketing; in the case of *abilio* even including a "walk-in" feature, which automatically detects and bills a passenger's travelled routes. Empirically validated knowledge regarding the user experience of these innovative solutions is scarce. It might be worth investigating, to what extent users are willing to move from traditional mobile tickets to automated invoices based on location traces and what the relevant impact factors are.

Social Networking for Passengers

While different "socializing" features in public transport, i.e. enabling communication between commuters, have been studied in prior research, we did not observe any related functionality in the investigated applications (the "social media screens" we found at one of the stations used an established social network, yet served marketing and entertainment purposes rather than encouraging direct communication between passengers). Current app providers either do not consider such applications to be required or useful, or lack a solid business case, which is further complicated through the need for moderation of content to avoid trolling and malicious intentions. Previous research does not agree on the actual need or wish of passengers for such social features (e.g., the socializing app *Honeypot* [25] is reported to be well-perceived in comparison to statements, such as "Commuting is my private quality" or "I don't want to be social" [17]). It seems, in-depth and critical investigations are required to dig deeper regarding the social requirements of passengers and how pervasive displays could support those (either on a mobile device, screens in a station, or in-vehicle screens). Studying the impact of cultural characteristics might be further interesting in this context.

Situated Information on Interactive Public Screens

The public screens, which we observed, mainly provided real-time schedules as well as maps and navigation support. Yet, experimental installations (currently in a pilot phase) featured a large touchscreen with browsable schedules as well as read-aloud functionality and interaction support for wheelchair users, implementing recommendations from the literature (cf. [20]). Despite these rare advanced features, it became obvious that applications on public screens are relevant due to their situatedness (e.g., people look up the platform number for their connection train while passing by), yet also in some instances duplicate functionality which is present in mobile applications, which is against recommendations from the literature (cf. [30]). Whether and how public screens can provide benefits beyond showing typical travel information remains an open question for further investigation.

We also found initial appearances of applications on public screens, which support interaction through mobile devices. On the social media screens, passersby were able to share their travel experiences by posting a photo and watching it appear on these screens. In another instance, passers-by could retrieve additional information about their train services through a mobile augmented reality app. The combination of smart mobile devices and public screens has been extensively investigated in research (cf. [26]) with various ideas to simplify spontaneous interaction (e.g., browser-based approaches [1] and assistance techniques [2]), but we did not find yet any advanced real-world applications in the domain of public transport beyond these experimental applications in our case study. User-accepted applications leveraging the combined potential of smartphones and public screens seem scarce and still worth exploring in the field.

General Research Opportunities

Based upon the analysis of the passenger services from our case study and respective trends from the literature, we identified several general, application-independent research opportunities in the field, which we outline below.

Improved Personalization

The investigated ubiquitous passenger services feature personalization to a limited extent. Typical examples are the manual specification of home or work addresses or the presentation of commonly used locations to select a destination from. We argue, that modern services might provide better support through improved personalization. Services might increasingly learn from prior journeys and selected preferences and consider more contextual parameters. For example, in case of bad weather, routes involving longer paths by foot or by bike might be rated lower or, dependent on the user's prior behavior, not suggested at all. Similarly, the benefits of traffic information on public screens can be increased by providing personalized views, making public screens more relevant to users [31]. As demonstrated by the app providing a mobile augmented reality view of a non-interactive timetable display, mobile devices can offer personalized views, implementing experimental findings from the literature (cf. [3, 28, 29]).

Trust in Public Transport (Services)

Real-time information on delays or incidents on a route was a common feature in the studied public transport mobile apps. Passengers must be able to rely on the correctness of this information in order to reach their destination in time. More recent features such as "implicit" ticketing (by detecting a passenger entering and leaving a public transport vehicle) are even more crucial since they relate directly to costs and rely on trust by the passengers. To that end, the *Smart Shuttle* app with its real-time monitor for available autonomous buses likely not only provides information but also helps to foster trust in these unfamiliar vehicles. We consider trust in recent and upcoming passenger services a critical research topic in order to continuously support and foster acceptance and usage of public transport means, in particular as we move towards more autonomous futures. Future research should study influencing factors of trust in public transport (information), investigate algorithms to consolidate and assess information from different sources (cf. aforementioned crowdsourcing approaches) to provide correct information, and explore how design can foster trust in passenger services.

Rethinking Public Transport Services

Several identified features and trends indicate shifts in the traditionally used phases *pre-trip to destination*, *on-board*, etc. While the phases themselves are still valid, ubiquitous technologies allow for novel service approaches. For example, ticketing is no longer limited to being an activity done before starting a trip. As demonstrated by the "check-in" feature, ticketing can be an on-board or even post-trip activity. Similarly, proposed forms of navigation do not rely on pre-trip planning but allow for on-trip guidance. Future services might soften up these previously strict traditional phase/service assignments even further. To identify and assess such service opportunities, tailored ideation and design tools can be helpful. Preliminary tools to achieve this have been presented recently (cf. [18, 19]), offering a foundation for future research on this topic.

CONCLUSIONS

In this paper, we provided a critical reflection of the current state of ubiquitous interactive passenger services for public transport in literature and in the field in order to identify trends and opportunities for future impactful research. We found that intermodal routing and ticketing functionalities of today's applications are sophisticated, yet socializing features and interactive applications on public screens lag behind research proposals from the literature.

While acknowledging that our findings are limited by the focus of our our case study on a Swiss public transport context, we presented trends and opportunities for practical applications and research in this field. Based on our study, we were further able to point towards open areas for research on ubiquitous interactive passenger services, such as improving personalization, fostering trust, and advancing customized design tools.

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