How to get in Touch with the Passenger: Context-Aware Choices of Output Modality in Smart Public Transport

Christine Keller, Thomas Schlegel
Karlsruhe University of Applied Sciences
Karlsruhe, Germany
christine.keller@hs-karlsruhe.de
thomas.schlegel@hs-karlsruhe.de

ABSTRACT

Public transport plays an essential role in sustainable urban mobility. The increasing availability of public transport data and the dissemination of interactive devices in the public and in public transport specifically provide a basis for smart mobility systems. Urban mobility is characterized by rapid context changes and a very personalized and situational information need of users. Smart mobility systems therefore support users in their mobility in intelligent ways and bring together ubiquitous and mobile computing, the Internet of Things as well as context-awareness. In this paper, we focus on the delivery of mobility information in public transport and present a model and an adaptation scheme for context-aware choices of output modality and device. Our approach enables a smart mobility system to choose output modality and device based on the user's situation and their preferences as part of a context-aware application design. The model and adaptation process are part of our ongoing work in the field of context-aware smart mobility applications.

CCS CONCEPTS

• **Human-centered computing → Ubiquitous computing**; **Ubiquitous and mobile computing systems and tools**; *Interaction design theory, concepts and paradigms.*

ACM ISBN 978-1-4503-6869-8/19/09…$15.00
https://doi.org/10.1145/3341162.3349321

KEYWORDS

Smart Mobility, Adaptation, Context-Awareness, Modality Choices

ACM Reference Format:
Christine Keller, Thomas Schlegel. 2019. How to get in Touch with the Passenger: Context-Aware Choices of Output Modality in Smart Public Transport. In *Adjunct Proceedings of the 2019 ACM International Joint Conference on Pervasive and Ubiquitous Computing and the 2019 International Symposium on Wearable Computers (UbiComp/ISWC '19 Adjunct), September 9–13, 2019, London, United Kingdom.* ACM, New York, NY, USA, 9 pages. https://doi.org/10.1145/3341162.3349321

1 INTRODUCTION AND MOTIVATION

The increasing application of computing changed public transport and the usage of public transport significantly. More public transport data is available, from sensor data of vehicles to realtime information on traffic situations, disruptions or delays. Several approaches towards the intelligent usage of this data have been developed, both to the benefit of public transport planning and passenger information [4, 12, 18]. Approaches from the Internet of Things domain are transferred to the public transport domain, to utilize rich sensor data [5].

From the passenger's point of view, the rise of smartphones has created a personal and ubiquitous access to public transport information. Smartphone applications can be used to access realtime information or timetables and to purchase tickets anytime and anywhere. Digital information systems enhance the possibilities of passenger information as public displays permeate urban space [1, 8, 11, 16].

For public transport agencies, punctuality and efficiency are core quality metrics of public transport, but the passenger's mobility experience is becoming increasingly important. Ubiquitous technologies enable the development of passenger-centric public transport services, focusing on mobility experience [2, 3]. The amount of available data, reaching from schedules to information on delays or vehicle occupancy to the user's agenda for the day, enables context-aware passenger information systems to support passengers individually during their trip [15, 19]. There are several possibilities to design such systems, ranging from context-aware trip planning that takes the user's preferences, appointments and interests into account, to support during interchanges, for example while navigating to the correct platform. Core to most of these possible applications is to provide the passenger with the necessary information for each step of their trip. In this paper, we focus on *how* to deliver this information to a passenger.

Depending on the passenger's activity, their location and the time constraints for the information that an application needs to deliver, different modalities or devices may be appropriate. If a passenger is using their smartphone, a simple textual notification might be sufficient, whereas in a situation when they are looking out of the window and the smartphone is in their bag, such a notification goes unnoticed. However, designers and developers can hardly conceive and consider all possible situations comprehensively at design time to carefully design these decisions. A much more flexible solution is needed that enables a system to adapt output modalities and choose devices at runtime.

The goal of our work is to enable context-aware passenger information systems to choose how to get in touch with the passenger depending on the situation and given information. At the same time, we don't want to introduce yet another complex component into an already complex system. This is why we chose to model the output modality and device choice as a context-aware adaptation decision that may be implemented the same way as other context-aware adaptations. Therefore, we analyzed general public transport context and extracted basic contexts that are relevant for output modality and device choices. We modeled output modality and devices as context as well. On top of that, we modeled general adaptation rules for these system decisions. A context-aware passenger information system can then manage output modality and device choices similar to any other context-aware adaptation.

This paper is organized as follows. In the following section, we will describe the project, in which our research is applied, in more detail. In section 3, we examine some related work on smart or context-aware public transport systems and on approaches for interactive device or modality choices. In section 4 we describe our model and adaptation approach and close with a discussion and outlook in section 5.

2 A SMART PUBLIC TRANSPORT PROJECT

In our research project, we specifically research how to optimize passenger information in public transport. We investigate how to use interactive public displays at public transport stops and in public transport vehicles, in conjunction with smartphones and possibly other personal devices. Our goal is to improve passenger information in all situations along the travel chain. We study the application of semi-transparent interactive displays that can replace a window in a public transport vehicle, for passenger information. These displays, called SmartWindows, are multi-touch enabled. In this project, one such display will be installed in a public transport vehicle and evaluated in an extensive field test in the local public transport network. Furthermore, a smartphone application that is able to connect with SmartWindows or public displays at stops is developed and deployed in our field test. We are also developing a smart information platform that integrates several data sources and provides information suitable to the passenger's specific situation. It considers their travel plans, tickets, the current weather, traffic situation and several other context factors. Figure 1 shows how the platform gathers and manages context information. The smart data platform integrates several context sources, such as public displays at stops, SmartWindows in vehicles and the smartphone application via JSON interfaces. Web services are also used as context sources, for example weather forecasts. This data is fed into an triple store, using a mapping component and SPAQRL[1]. In order to use this context information for adaptations, we apply SPARQL queries.

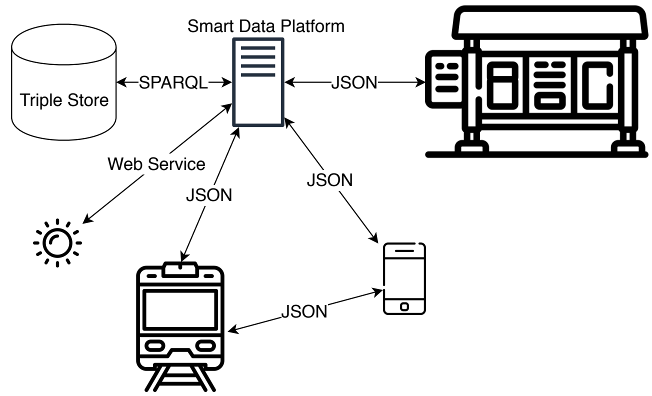

Figure 1: The SmartMMI smart information platform and the SmartWindows, public displays, the app and web services as context sources.

Interactive public displays at stops and in vehicles, complemented by smartphones already result in a variety of possibilities for information distribution to the user, which is why we developed adaptation rules that decide *how* to inform the user based on their situation. Our goal was to apply these rules just as we apply other adaptation rules, by querying context using multiple SPARQL queries.

[1] https://www.w3.org/TR/rdf-sparql-query/

3 RELATED WORK

There are many examples for context-aware mobility applications. Most of them are mainly location-aware and do not integrate additional context factors. Applications that utilize more than one interactive device are rare as well. We will describe some approaches in the following, to give an impression of the variety of context-aware application in mobility.

Lemme et al. describe context-aware adaptations on public displays in public transport [13]. In their approach, the content on the display was adapted to the personal information of a user that connected their smartphone to the display.

Hoerold et al. describe basic guidelines for the usage of public disaplays in public transport [11]. They describe several categories for information that can be displayed on public displays - from static to interactive and individual information. The authors also consider approaches for ensuring visibility, selecting content, positioning and functionality. They do not propose a specific application and do not consider context-awareness as a design aspect, but look at necessary design choices from a public transport perspective.

Chow et al. developed an adaptive mobile application for planning trips in Hong Kong public transport [4]. The system considers the location of the user via their mobile phone's GPS sensor as well as their walking speed, measured by a wearable device. The application supports planning as well as re-planning of trips due to real-time information, for example in case of missed buses. The wearable device is used for haptic output, to remind users to increase their walking speed, in order to catch a bus.

Handte et al. present an application called Urban Bus navigator (UBN) that is designed and implemented as a Internet of Things application and supports passengers on bus journeys [10]. Their smartphone application supports ad hoc trip planning from the user's current location and supports passengers at every step during their bus journey. It indicates the right bus to board as well as supports re-scheduling in case of a missed bus and navigation while walking towards bus stations.

Most approaches that enable the adaptation of output options are relatively extensive architecture frameworks and they are not considering adaptive interaction from a context-awareness point of view. We describe three of those approaches in the following.

Hallensteinsen et al. developed the MUSIC framework, a model-driven framework that provides tools, an adaptation middleware and modeling approaches to develop adaptive applications [9]. One of their motivating scenarios and implemented prototypes realized an adaptive public transport application that allowed context-aware choices of interactive devices for both input and output. This is, however a very extensive approach that, while it supports the same goal we focus on, requires extensive modeling and the usage of MUSIC middleware components. Its usage affects the whole system design.

Tang, Lo et al. proposed the I*Chameleon framework, which is an extensible, Web Service-based framework that aims at the integration of different interaction devices [17], [14]. Their goal is to provide a developer framework that abstracts from hardware and raw data processing. The I*Chameleon framework is supposed to provide loose coupling of interaction devices and support the interpretation of raw data from interaction devices and the recognition of input events as well as the combination of input events for multimodal interaction. Their architectural approach relies on Web Services for flexibility. Tang et al. do also describe a graphical editor that allows customization of applications via drag and drop, which is a useful addition to their approach, since it increases its accessibility [17]. However, while this approach provides an abstraction layer from specific interaction technologies and hardware, it lacks runtime flexibility. The authors do not address the context-aware adaptation of interaction, specifically.

DiMauro et al. also propose a framework for multimodal interaction in Intelligent Environments [7]. They developed a highly flexible distributed approach, where a set of independent nodes provides some services, specifically including input or output. A node automatically connects to other nodes when it cannot process a request and forwards that request [6]. They include modules that are able to process multimodal input and output and they focus on dialogues and supporting gestures. They do not describe, however, how the nodes *decide* which node processes output - it seems that output is mainly generated when input was given before and the node handling the input also processes the output and only forwards it, when it does not have the necessary capabilities. Adaptivity with regard to interaction is only given when a user chooses to use a node to interact with, not system-wise.

4 MODELING AND ADAPTATION APPROACH

Our approach is based on context modeling. We modeled the contexts of devices and users in a way that allows their matching for output choices. Location information about users and devices is an essential part of smart mobility services. In our model, we attach location information to users and devices through a location context. A second aspect is the context involving output modalities. Users have perceptive abilities that match some modalities and may have preferences, as well. Finally, the situation and the surroundings of the user affect the possibilities and the effectiveness of device and modality choices. For devices, their technical

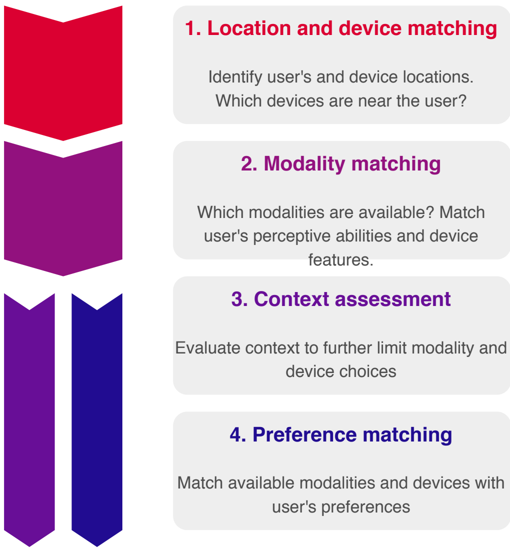

Figure 2: The steps of the adaptation process that matches available devices and modalities with the given context.

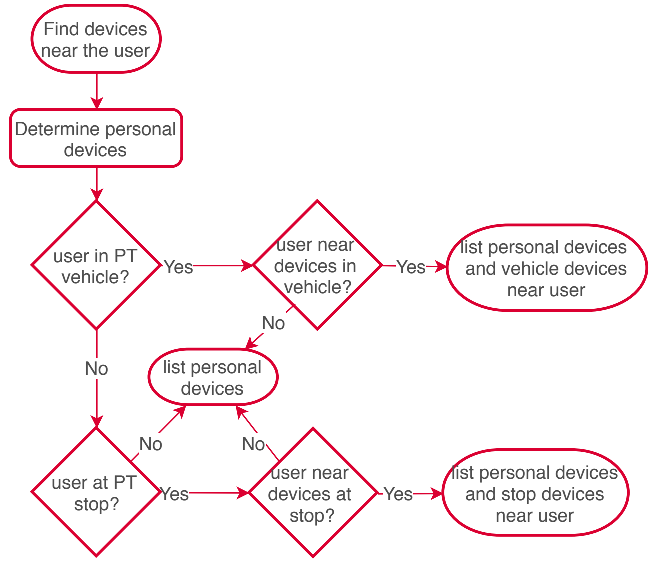

Figure 3: The decision steps to determine which devices may be used.

properties can also affect the effectiveness and appropriateness of their utilization in a given situation. The application of context factors from these context categories is described in the following subsections in greater detail.

We developed a structured adaptation process that takes available devices, the described contexts and matches them. The result is a device and modality choice for the given situation. The process is illustrated in figure 2. The first step is a location matching, where the system decides, which devices are near the user and therefore are available. In the second step, the modalities the devices provide are matched with the perceptive abilities of the user. These abilities may be permanent or temporary, for example, if a person listens to music with headphones and does not respond to other acoustic input. The third and fourth step might be performed in either order. A context assessment evaluates the user's and the environment's context. The preference matching results in the most preferred device and modality for the user. Of course, these filtering steps are only possible if there are enough devices and modalities left to choose from. The process ends whenever a single modality and device combination is left. In case only one option is avaliable there is, of course, no choice to make. The single steps are described in more detail in the following.

Location and device matching

Which devices are to be considered can not solely be determined via matching of GPS coordinates, because it depends on some context factors. The relative position of user and devices is also important. Figure 3 shows a simple workflow for identifying devices that might be used to inform the user. At first, personal devices should be identified. As far as possible, this step should also include the determination which of their personal devices the user carries with them, for example if they wear their smartwatch. Another important context factor is, if the user is currently in a public transport vehicle and which vehicle they have boarded. The determination of public transport as mode of transport is, for example, provided by the Google awareness API[2]. However, for some of the following steps it is not only necessary to know that a user is using public transport, but also to identify the vehicle they are currently in. This identification should allow to resolve the vehicle's line and route and therefore, for example, its next stops or possible delays. In our project, there are several ways to do this. The smartphone application is using the vehicle's wifi. Determining the connected wifi router can result in a mapping to a specific vehicle. The user's itinerary, if known, can help to disambiguate vehicles, if several vehicles are in the vicinity and the smartphone might be connected to the wrong wifi network, for example at big stations.

If the user is currently in a vehicle, the system must check if there are any output devices available in this vehicle. If there are, it must be decided which of them are near the user. In public transport, various types of vehicles with different equipment are in use, especially considering digital output devices, so that this option is not always available. The SmartWindow allows the user to explicitly connect their

[2]https://developers.google.com/awareness/

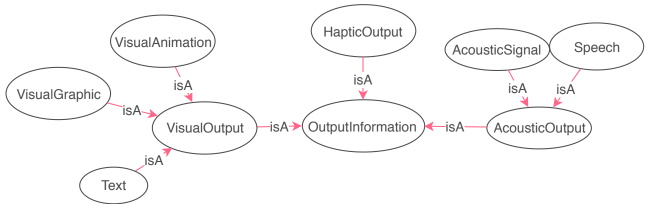

Figure 4: The modality model for output information.

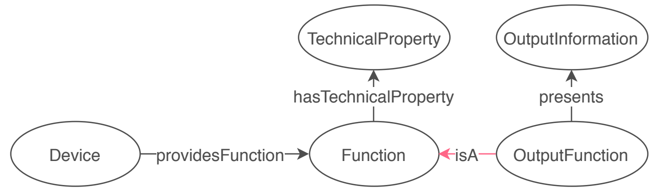

Figure 5: The device model

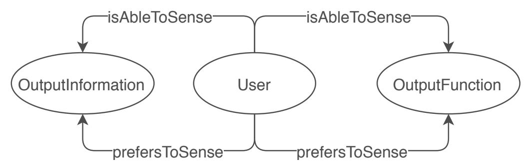

Figure 6: The ability and preference model.

personal device, which then identifies not only the vehicle but their specific position in this vehicle, next to the window. For future work, for example considering long distance trains, indoor positioning and seat reservation matching is also applicable in this step. If the user is near output devices in a vehicle, these are considered in addition to their personal devices, if not, only the personal devices are taken into account. If the user is not on board of a vehicle, the system checks if the user is at a public transport stop, which can be determined using GPS coordinates. At a stop, devices may be available and therefore it must be determined if the user is near any of these. Nearby devices then are added to the list of personal devices as possible output options. If the user is currently not at any stops or in public tranport vehicles, personal devices are considered as only options. If other means of transportation and output devices should be considered, this scheme can be extended. If, for example, individual transport is incluced, the devices available in cars can be complemented. A mechanism for the determination if and in which car a user is currently driving is required, respectively.

Modality Modeling and Matching: Abilities and Preferences

The model for output modalities considers visual, haptic and acoustic output and further specifies varieties of visual and acoustic output, as shown in figure 4. It is used to characterize devices and their output functions as well as the user's abilities and preferences for perceiving information.

The device model contains a class `Function` and its subclass `OutputFunction`, that may be associated with a device via the `providesFunction` property, as shown in figure 5. Such functions may be further specified by technical properties associated to them. As one of our goals is to keep our modality adaptation scheme interoperable with ontology-based context-aware systems, we modeled modality preferences and abilities by two properties that may be added to any user model, as shown in figure 6.

These abilities and preferences may affect either an output modality as a whole, for example for a deaf person who is unable to sense acoustic information, but they also may affect only certain output functions of specific devices. An example for the latter case is a user who uses their headphones and is unable to perceive acoustic output from other sources. This distinction lead to the decision to allow the ability and preferences model to imply general `OutputInformation` as well as, more specifically `OutputFunction`, provided by a `Device`.

As described above, abilities are given more weight than preferences in the decision making process for an output modality, which is why we modeled these concepts separately. Abilities may be permanent or temporary and can be added or removed by the context managing component. Figure 7 shows the process to filter the list of devices that are near the user. In the overall adaptation process shown in figure 2, the context assessment step and the preference matching step are shown as parallel steps. The actual order of these steps is relevant if the process stops before all matching steps are completed. If at any time only one device is left, this device is used and if it was the result of preference matching before context assessment, context factors were not considered. If the order was reversed, the result might have been different. We are still evaluating which results might be rated better by users.

In figure 7 preference matching takes place after ability matching and before context assessment. If at some point a matching step yields no devices as a result, we chose a backtracking approach. If this is the case for ability matching, the process should loosen the location filter and consider devices that are further away. If preference matching results in zero devices, the list of devices that was matched against the user's preferences can be used for context assessment and the preference matching can be omitted.

Context assessment

The context assessment step can be used to check many different context factors that might influence usability. It is,

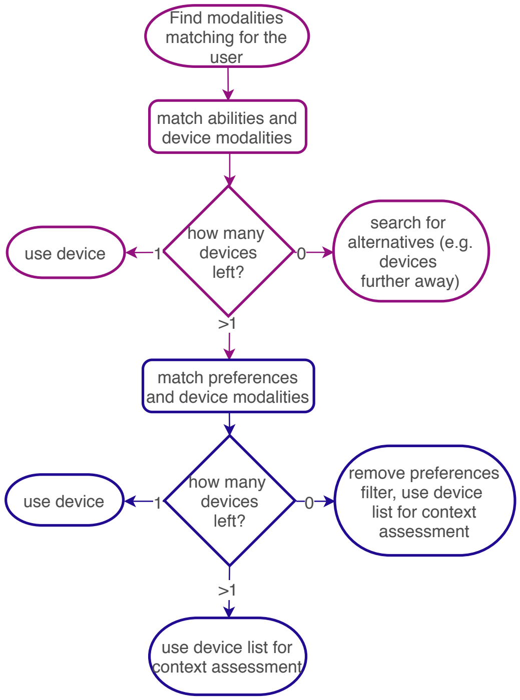

Figure 7: Matching device modalities, user abilities and user preferences.

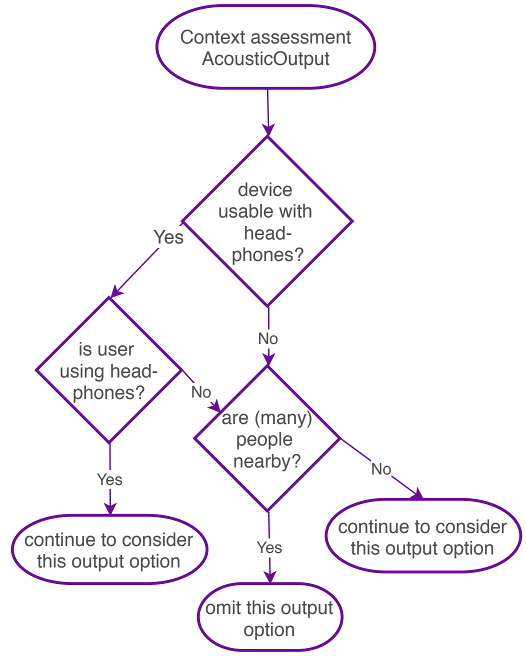

Figure 8: Assessing the selection of a device and its acoustic output option, based on privacy considerations.

however, very probable that too many filtering steps result in zero devices and therefore the used context factors should be picked with care. We will discuss some examples that we considered in our system's design. The context assessment differs for specific devices and modalities, so we modeled it as a set of more specific adaptation rules, in contrast to the more general matching processes described before.

Figure 8 shows an example for context assessment applying privacy considerations. Acoustic output may be overheard and therefore is privacy sensitive. If the device is usable with headphones and the user has them in use, privacy is no issue. Using the Google awareness API, for example, a smartphone application can determine if the user's headphones are plugged in, which can be used to decide this step. If headphones are not an option, the application of acoustic output can be decided based on how many people are in the vicinity of the user. Since the user is moving in public space, this is not easy to determine. However, an approximation we use is to use the determination of the user's location. If the user is in a vehicle at the moment, it is very probable that other users are nearby and therefore acoustic output should not be considered further. In our adaptation scheme, we also omit acoustic output, if the user is currently at a public transport stop, but we continue to consider it, if they are somewhere else. This assessment can be further refined, of course.

Another example for a context assessment applying privacy criteria is shown in figure 9. The context assessment differs for personal and public devices. Privacy considerations are to be taken seriously for public displays, of course. We therefore consider the urgency of the message as a relevant context factor. Messages of high urgency in public transport are, for example, reminders to alight the vehicle just before it is about to stop or notifications of platform changes of a vehicle just before it's departure. If the message is urgent, it is still necessary to consider how many people are in the vicinity. This decision can be made as described above. If it can be determined, if there are no or not many people in the vicinity, the public device can be considered as output option. If there are many people nearby and other options are available, visual output on a public device should not be considered. Due to several reasons, alternatives might not be available.

Message Modification: An additional step that might enable the system to deliver its message anyway is the modification of the message. For this step, we are currently considering to remove personal aspects from a message and to deliver the non-personal part of the message on the public device. It might be an option to additionally relay the personal part of the message to a personal device of the passenger and therefore split the notification into two steps: first catch the user's attention and second, provide additional information using a more private communication channel. When the departure

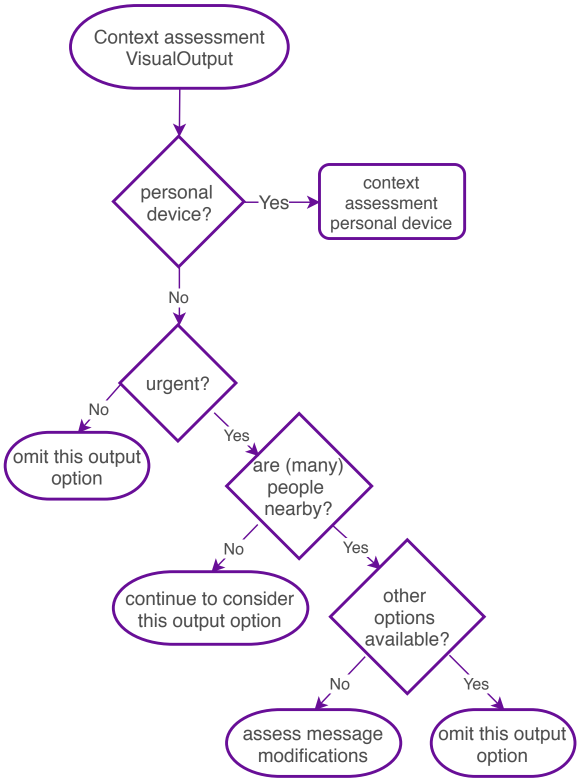

Figure 9: Assessing the selection of a device and its visual output option, based on privacy considerations.

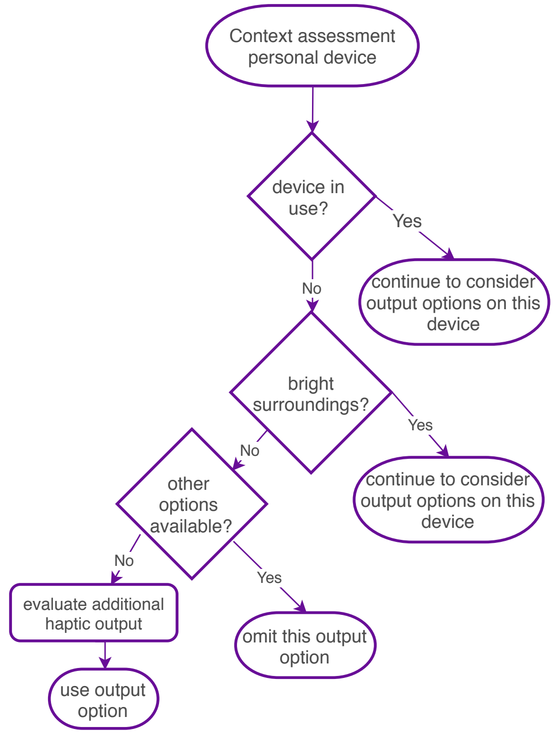

Figure 10: Assessing personal device context.

platform of a vehicle is changed in the minutes before its departure, and the user is still on the wrong platform, the platform change might be shown or highlighted on a public display at this platform, to catch the passenger's attention. From the prompt that a platform change has occurred, other passengers can not conclude that exactly this person is receiving this notification and therefore this solution preserves the passenger's privacy. If the passenger notices this information on the public screen, they might check their personal device or even just their ticket to verify that it is their vehicle that is affected of the platform change.

Figure 10 shows the context assessment for personal devices. This example shows the usage of context factors that are not privacy-related. The decision to use output options of a personal device depends on an evaluation if the user is likely to notice a message. If the device is currently in use, then it is very probable that the passenger would notice. This decision can be based on a check of the display status of the device. If the display is not on and the user is not currently using it, the system checks if the surroundings are currently bright, using the device's ambient light sensors. If they are not, we conclude that the device might currently be stowed away in a pocket or bag and the passenger won't notice any messages. If other output options are available at this point, this output option is omitted, but if there are not, the system evaluates if additional haptic output can be used and then uses the output on this personal device anyway. Depending on the situation and the user's preferences, this step could be complemented by an evaluation to use an additional acoustic signal as well.

If, after the context-assessment of all device and modality options, more than one option is left, the system needs to make a decision. It is possible to introduce further context factors to shape such decisions, but we anticipate that it is not necessary very often. We therefore implemented a random decision.

5 DISCUSSION AND OUTLOOK

We currently are implementing the adaptations of output modality in the same way as any context-based adaptations in our smart public transport system, without having to use an extensive framework just for handling output adaptations. This mainly works because we modeled output functionality and output modalities in an ontology that is interoperable with context ontologies and structured the decisions of which device and modality to use the same as other adaptation decisions in our context-aware public transport system. In feasibility studies we were able to successfully test our

SPAQRL-based adaptation approach. For this tests, we implemented a random triple generator that randomly generates context data for users. Based on that data, the SPARQL queries for the described adaptations were tested and refined. Currently, our adaptation scheme is implemented for lab and field tests, which will involve user tests for usability evaluation to finetune the adaptation decisions.

In future work, we are discussing to refine some of the matching steps to include basic usability assessments in the decision if a device is *nearby*. We plan on experimenting with proximity functions that differ for device categories. If the passenger notices output on a public display is not simply decided by how far away this display is. It depends, for example, on the display size and the passenger's line of sight. We plan to evaluate if considering these factors could further improve usability.

We also want to further investigate the modification or supplement of output based on context assessments. Deped-ing on the situation it may be appropriate to first get the user's attention and then relay the full message on another device. Just before a user should alight a vehicle, the highlighting of the next stop at the SmartWindow next to them might catch their eye and a personal notification to alight at this next stop on their smartphone can reassure them that they get out at the right time. This version is respecting the passenger's privacy while at the same time prevents them from missing their stop. Such solutions can help overcome passenger's insecurity while using public transport and increase popularity of a sustainable mobility choice [15].

In this paper, we presented our approach towards pervasive and smart public transport, by enabling a context-aware public transport system to choose output modality and device for passenger information based on context information and the overall user's situation. We modeled our approach to be interoperable and compatible with ontology-based context adaptations. It is also easily extendable. We integrate our approach into a context-aware passenger information system and our goal is to use the pervasive nature of public transport and of digital devices that are used in mobility to improve passenger information and therefore improve the passenger's mobility experience.

ACKNOWLEDGMENTS

This work was conducted within the scope of the research project "SmartMMI - model- and context-based mobility information on smart public displays and mobile devices in public transport" and was funded by the German Federal Ministry of Transport and Digital Infrastructure as part of the mFund initiative (Funding ID: 19F2042A). We would like to thank Waldemar Titov and Tom Lutze for their contribution to this work. Some figures include icons made by Freepik (https://www.freepik.com/home) from http://www.flaticon.com.

REFERENCES

[1] Florian Alt, Nemanja Memarovic, Ivan Elhart, Dominik Bial, Albrecht Schmidt, Marc Langheinrich, Gunnar Harboe, Elaine Huang, and Marcello Scipioni. 2011. Designing Shared Public Display Networks – Implications from Today's Paper-Based Notice Areas. In *Pervasive Computing*, Kent Lyons, Jeffrey Hightower, and Elaine Huang (Eds.). Lecture Notes in Computer Science, Vol. 6696. Springer Berlin / Heidelberg, 258–275. http://dx.doi.org/10.1007/978-3-642-21726-5_17

[2] Tiago Camacho, Marcus Foth, Andry Rakotonirainy, Markus Rittenbruch, and Jonathan Bunker. 2016. The role of passenger-centric innovation in the future of public transport. *Public Transport* 8, 3 (01 Dec 2016), 453–475. https://doi.org/10.1007/s12469-016-0148-5

[3] T. D. Camacho, M. Foth, and A. Rakotonirainy. 2013. Pervasive Technology and Public Transport: Opportunities Beyond Telematics. *IEEE Pervasive Computing* 12, 1 (Jan 2013), 18–25. https://doi.org/10.1109/MPRV.2012.61

[4] V. T. F. Chow, K. W. Sung, H. M. Meng, K. H. Wong, G. K. Leung, Y. Kuo, and K. K. F. Tsoi. 2016. Utilizing Real-Time Travel Information, Mobile Applications and Wearable Devices for Smart Public Transportation. In *2016 7th International Conference on Cloud Computing and Big Data (CCBD)*. 138–144. https://doi.org/10.1109/CCBD.2016.036

[5] Paul Davidsson, Banafsheh Hajinasab, Johan Holmgren, Åse Jevinger, and Jan A. Persson. 2016. The Fourth Wave of Digitalization and Public Transport: Opportunities and Challenges. *Sustainability* 8, 12 (2016). https://doi.org/10.3390/su8121248

[6] Dario Di Mauro, Juan C. Augusto, Antonio Origlia, and Francesco Cutugno. 2017. A Framework for Distributed Interaction in Intelligent Environments. In *Ambient Intelligence*, Andreas Braun, Reiner Wichert, and Antonio Maña (Eds.). Springer International Publishing, Cham, 136–151.

[7] Dario Di Mauro and Francesco Cutugno. 2016. A Framework for Interaction Design in Intelligent Environments. In *Intelligent Environments (IE), 2016 12th International Conference on.*

[8] Marcus Foth and Ronald Schroeter. 2010. Enhancing the Experience of Public Transport Users with Urban Screens and Mobile Applications. In *Proceedings of the 14th International Academic MindTrek Conference: Envisioning Future Media Environments (MindTrek '10)*. ACM, New York, NY, USA, 33–40. https://doi.org/10.1145/1930488.1930496

[9] S. Hallsteinsen, K. Geihs, N. Paspallis, F. Eliassen, G. Horn, J. Lorenzo, A. Mamelli, and G.A. Papadopoulos. 2012. A development framework and methodology for self-adapting applications in ubiquitous computing environments. *Journal of Systems and Software* 85, 12 (2012), 2840–2859. https://doi.org/10.1016/j.jss.2012.07.052 Self-Adaptive Systems.

[10] M. Handte, S. Foell, S. Wagner, G. Kortuem, and P. J. Marrón. 2016. An Internet-of-Things Enabled Connected Navigation System for Urban Bus Riders. *IEEE Internet of Things Journal* 3, 5 (Oct 2016), 735–744. https://doi.org/10.1109/JIOT.2016.2554146

[11] Stephan Hörold, Cindy Mayas, and Heidi Krömker. 2015. Interactive Displays in Public Transport – Challenges and Expectations. *Procedia Manufacturing* 3 (2015), 2808–2815. https://doi.org/10.1016/j.promfg.2015.07.932 6th International Conference on Applied Human Factors and Ergonomics (AHFE 2015) and the Affiliated Conferences, AHFE 2015.

[12] Christine Keller, Sören Brunk, and Thomas Schlegel. 2014. Introducing the Public Transport Domain to the Web of Data. In *Web Information Systems Engineering – WISE 2014*, Boualem Benatallah, Azer Bestavros, Yannis Manolopoulos, Athena Vakali, and Yanchun Zhang (Eds.). Springer International Publishing, Cham, 521–530.

[13] Diana Lemme, Romina Kühn, Alexandra Funke, and Thomas Schlegel. 2014. A Feasibility Study of Context-adaptive Visualizations in Public Transport Information Systems. In *Proceedings of the 13th International Conference on Mobile and Ubiquitous Multimedia (MUM '14)*. ACM, New York, NY, USA, 262–263. https://doi.org/10.1145/2677972.2678013

[14] K.W.K. Lo, W.W. Tang, H.V. Leong, A. Chan, S. Chan, and G. Ngai. 2012. i*Chameleon: A unified web service framework for integrating multimodal interaction devices. In *Pervasive Computing and Communications Workshops (PERCOM Workshops), 2012 IEEE International Conference on*. 106–111.

[15] L. Oliveira, C. Bradley, S. Birrell, A. Davies, N. Tinworth, and R. Cain. 2017. Understanding passengers' experiences of train journeys to inform the design of technological innovations. In *Re: Research - the 2017 International Association of Societies of Design Research (IASDR) Conference*. Cincinnati, Ohio, USA, 838–853.

[16] Hasibullah Sahibzada, Eva Hornecker, Florian Echtler, and Patrick Tobias Fischer. 2017. Designing Interactive Advertisements for Public Displays. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems (CHI '17)*. ACM, New York, NY, USA, 1518–1529. https://doi.org/10.1145/3025453.3025531

[17] Wai Wa Tang, Kenneth W.K. Lo, Alvin T.S. Chan, Stephen Chan, Hong Va Leong, and Grace Ngai. 2011. I*Chameleon: A Scalable and Extensible Framework for Multimodal Interaction. In *CHI '11 Extended Abstracts on Human Factors in Computing Systems (CHI EA '11)*. ACM, New York, NY, USA, 305–310.

[18] Jameson L. Toole, Serdar Colak, Bradley Sturt, Lauren P. Alexander, Alexandre Evsukoff, and Marta C. González. 2015. The path most traveled: Travel demand estimation using big data resources. *Transportation Research Part C: Emerging Technologies* 58 (2015), 162–177. https://doi.org/10.1016/j.trc.2015.04.022 Big Data in Transportation and Traffic Engineering.

[19] Tobias Wienken, Cindy Mayas, Stephan Hörold, and Heidi Krömker. 2014. Model of Mobility Oriented Agenda Planning. In *Human-Computer Interaction. Applications and Services*, Masaaki Kurosu (Ed.). Springer International Publishing, Cham, 537–544.