An Evaluation Approach for a Smart Public Display in Public Transport

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ABSTRACT

In this paper, we present our iterative evaluation approach for a smart public display prototype in public transport. In our research project, we developed a working prototype of a smart and mobile public display. We iteratively evaluated several facets of our prototypes, following a user centered design approach. In this paper, we describe challenges and experiences during the development and evaluation of this smart and mobile public display, as well as the results of our studies so far and we discuss our evaluation steps as best practice examples.

KEYWORDS

mobile public displays; eye tracking; evaluation methods

1 Introduction

Public displays are common in commercial or in research places like shopping centers or university buildings [1, 2]. Large interactive displays are also widely used in other public places like airports, train stations or touristic places, informing individuals about the schedule of the next flight or about points of interest [3, 4]. In the context of public transport, most public displays are used as a source of information about upcoming trains and connections. However, most interactive public displays, are used in a stationary context. They are built in existing or new infrastructure and, obviously, do not change places. In public transport vehicles, public displays become mobile, which affects the information they present. While moving, their context constantly changes.

Most public displays in vehicles therefore show contextually adapted information, referring to the next stop, for example. However, the displays used in public transport vehicles are not interactive at present. Considering the varying information need of passengers, whom most have different destinations, tickets and different familiarity with the public transport network, interactive mobile displays can help passengers get the information they need during their trip.

Therefore, in our research project SmartMMI we focus on improving passenger information along their travel chain. In this project, we research model and context based mobility information on smart public displays and mobile devices in public transport. We want to improve the information provision for passengers in every situation. Depending on the situation, but also depending on the passenger, the need for information changes. This can happen in the event of a disruption, plan changes, the discovery of tourist destinations or of services available along the route. Our goal is to inform passengers appropriately in their individual situation. To this purpose, we combine a variety of data sources to form a smart public transport data platform that integrates real time public transport information, information in points of interests, but also information on bike or car sharing services along the route. The integrated data is then adapted to context, and presented either on semi-transparent public displays in public transport vehicles or on passenger's smartphones. These semi-transparent, multi-touch-enabled public displays are built-in as windows in public transport vehicles. They are called "SmartWindows".

For the design of our SmartWindow prototype, we chose to follow the user centered design process. We therefore continually involve public transport passengers in our evaluation and in the

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further development process. Since public transport is widely used by passengers of very different backgrounds, we developed public transport personas to sort passengers in different user groups.
In our evaluations, we considered these user groups, whenever possible, in order to take their different requirements into account. We iteratively developed several prototypes and assessed various aspects of these prototypes in different evaluations. In this paper, we describe and analyze the used methods and their results. We focus on the usability evaluations we performed to determine the information structure and interaction design of our public display and will therefore not refer to some studies we performed in order to develop and evaluate the context-awareness features for the SmartWindow. We will also omit our design process for the mobile application that is developed concurrently.
Our paper is structured as follows. In the next section, we will look at approaches towards passenger information in public transport and at public displays and their evaluation, respectively. We will then, briefly, describe the scope and intended configuration of our SmartWindow. Following this section, we will describe our development process of a SmartWindow for public transport and discuss each of our evaluation steps, as well as their results. In the last section of this paper, we will discuss the challenges and findings of our development and evaluation process and will give an outlook on our future work, pointing out evaluation steps we are planning in the upcoming months.

2 Related Work

Interactive digital displays are becoming a ubiquitous part of urban environments [5]. The use of interactive public displays varies greatly across different situations, yet the effectiveness of all public displays relies on the assumption that they will be noticed and used [6]. However, since public displays are used very contextually in various public spaces, lab studies can often not paint the whole picture and determining the real effectiveness of an interactive public display is hard [5]. A user-centered design of public displays can ensure to keep the user's requirements in the specific application area in focus during the development process. In public transport, the user's requirements are hard to grasp, since the user group is as wide as it can get – almost anybody uses public transport at some time.
To understand the basic requirements of passengers in public transport, it helps to design personas [7]. Personas represent archetypical users and can facilitate the understanding of the user's behavior, needs, motivations and limitations. Hörold et al. describe personas and their interaction preferences in german public transport [7]. The personas we developed in our research project were based on this work.
For the UK, Oliveira et al. described the development of personas in a collaborative research project of academic institutions and industry partners in the UK [8, 9]. Based on their personas, they found that newly designed technology can improve passenger's experiences in public transport and argue for a solid understanding of the users and their needs when conceiving innovations in public transport. Oliveira et al. collected data by face-to-face semi-structured interviews and additionally used questionnaires. Questionnaires are a suitable method to have a closer look on which information passengers need in which situations. We also included a questionnaire in our design process.
Interactive public displays introduce new possibilities for transportation companies, like using less paper-based information at different stages of the journey. Hörold et al. suggest an user-centered design process and four different evaluation methods to identify where and how to apply public displays in public transport: expert workshops, comparative usability evaluations, two lab-based usability evaluations and an expert evaluation [4]. These multiple evaluation methods combine the knowledge of experts and the expectations of passengers as well as knowledge from transport companies. In our user centered design process, we also used several different evaluation methods. Public transport experts were involved in the development of our personas and requirements and regular passengers in lab-based evaluations. We also had the chance to evaluate our design with some media communications experts. We argue to extend the range of evaluation methods by studies that involve public transport context, such as real public transport data up to field studies in real public transport settings, which is planned for our prototype at the beginning of next year. Ardito et al. also argue for field tests and report a certain tendency for more field tests in their survey on interaction with large displays [10].

3 A smart, mobile, context-aware and semi-transparent public display for public transport vehicles

The project in which we conduct our research is funded by the German Federal Ministry of Transport and Digital Infrastructure. The local public transport provider is a partner in our project, as well as industry partners that have expertise in passenger information systems, both in journey planning systems and in display technologies. Our joint research goal is to improve passenger information using innovative technologies, such as a smart and context-aware data platform and the SmartWindow.
The SmartWindow is a semi-transparent display that will be installed in a public transport vehicle in place of a window in the course of our project. It is multi-touch-enabled and can adapt its transparency as well as brightness. In our research project we mainly research the configuration of a SmartWindow besides two rows of two seats facing each other. The passengers will therefore interact with the SmartWindow while seated. The whole SmartMMI system combines a smart public transport data platform, a mobile application and a SmartWindow and enables context-aware passenger information. Beyond the design of the interactive SmartWindow, we also research the interplay of mobile application and SmartWindow for situational passenger information.

4 Overview of evaluation methods for a smart public display

Figure 1 shows an overview of the development and evaluation process we went through up until today. In phase I, we performed an online survey to determine the usefulness of different types of information that can be displayed on a SmartWindow. In this phase, we also analyzed the interactive areas on our special a smart public display, in order to determine applicable interaction patterns. Based on the results of the evaluations in phase I, a first prototype was designed. This mockup was evaluated in a user study in phase II, applying the thinking aloud method. The results of this study were incorporated in a second interactive prototype. This prototype was evaluated in an eye tracking study with experts in phase III. Subsequently, we used the results of this evaluation phase to develop a third prototype, which is a high fidelity prototype that utilizes the interfaces of our smart public transport data platform. In phase IV, we will further evaluate this prototype in a lab study that utilizes a mockup of a public transport vehicle.

In our final phase V, we will deploy the final prototype on a SmartWindow in a public transport vehicle of the local public transport provider and the SmartWindow will be available in general public transport outside our lab. We will perform further user studies and surveys in this phase, resulting in recommendations on the design of mobile smart public displays for public transport. In the consecutive evaluations of our SmartWindow, we went from low fidelity prototypes to high fidelity prototypes and we gradually increased public transport context of our prototype and study settings, in order to allow study participants to experience a situation as similar to traveling with public transport, as possible. We will elaborate on these steps, the evaluation settings and our results in the next subsections.

5 Phase I: Online Survey

As a first step towards a SmartWindow prototype, we focused on the information need of different user groups, based on the personas developed before. We designed an online questionnaire to investigate the following questions.

- Which information is important to passengers during a train journey?
- Which information should be displayed on the SmartWindow, specifically?

The online study was designed to give participants as much freedom of answering as possible. Therefore, the questionnaire included many free questions without given answering options. With this approach, we hoped, that users bring up new ideas for information that could be displayed on the SmartWindow. We asked what information the participants would like to receive while riding the train, before changing and alighting the vehicle. About 250 participants of different age groups, different experiences with public transport and affinity towards new technologies participated in the survey. The results give a good insight into the varying needs of different passengers.

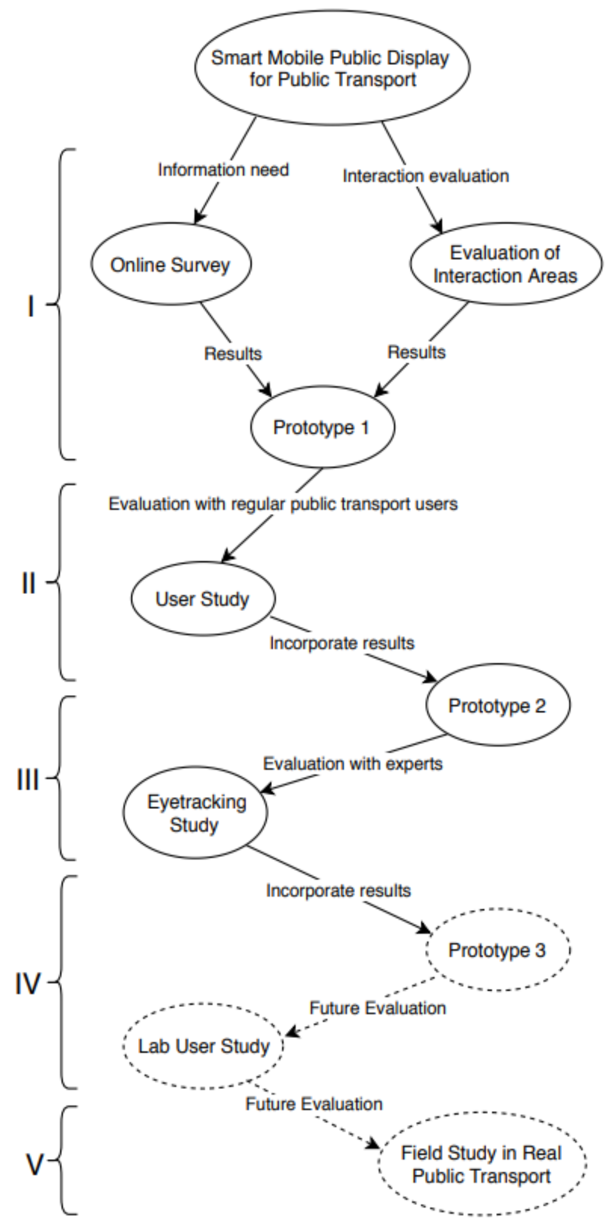

Figure 1: Procedure of evaluation methods on a smart public window

5.1 While riding the train:

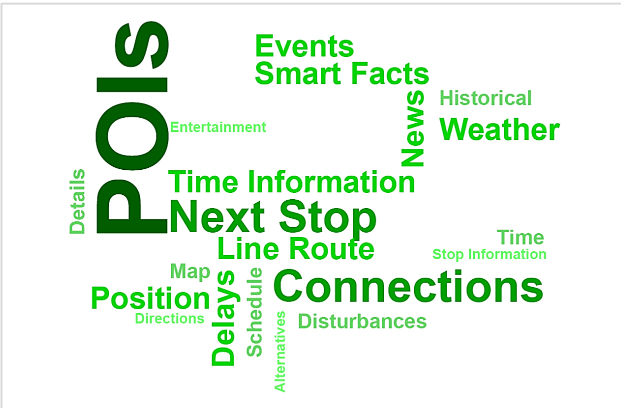

Figure 2: Information demand while riding the train

The results of the online survey indicate the majority of the study participants (55%) would like to receive additional information about points of interest on the SmartWindow while riding the train. About 50% of study participants want to see traffic related information like next stops, interchanges and information on connecting vehicles. Information about the position of the vehicle, the route map as well as additional information about the infrastructure existing at next stop points was mentioned by 5,7% of the participants. Furthermore, participants asked for additional information like weather, time and information about disruptions or delays in the public transport system, as shown in Figure 2, where size and color of the terms represent the frequency, this kind of information was mentioned in the survey.

5.2 Before changing and alighting the train:

Figure 3: Information demand before changing and alighting the train

Asked about information they would like to see before alighting a vehicle, 75% of participants indicated that they would like to be informed about their next connections, about delays, next stops and changing information like transition times and directions. About 10% of respondents additionally would like to see information about points of interest at the alighting station, like historical or shopping information. The suggestions of the study participants are shown in Figure 3.

Figure 4: First mockup containing the requested information

Based on the results of this online survey, first mockups, structuring and displaying most of the requested information were designed, as shown in Figure 4. In this state, interaction with the displayed information was limited to only one individual interacting simultaneously. However, we knew that in our final prototype that will be installed in a real public transport vehicle, the SmartWindow will be next to two rows of two passenger seats facing each other. Therefore, we knew that the prototype will be operated by users while seated and by possibly two users facing each other, at the same time. Hence, in a second evaluation during our first evaluation phase, we analyzed the interaction areas sitting passengers can operate on the SmartWindow.

6 Phase I: Evaluation of Interaction Areas

We developed a study setup to study user interaction areas, as displayed in Figure 5. The goal of the study was to find out:

- Which areas are comfortable for the user to reach?
- Which areas are usable for interaction with the display?

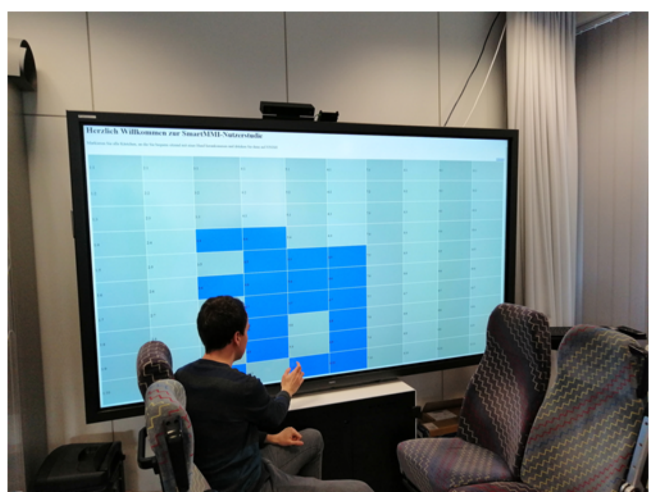

Figure 5: Study prototype with interaction fields

We created a clickable HTML webpage that consisted of 10x10 single, clickable fields with the size of 20x10 cm. The size of the cluster was chosen due to the size of the used multi-touch display, which has a screen diagonal of 98 inch. The display has an integrated infrared multi touch frame.

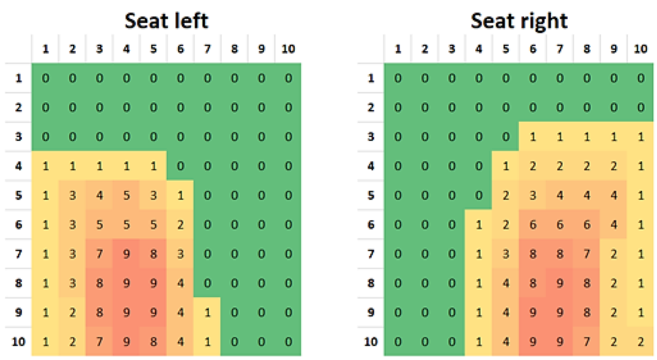

Figure 6: Heat map of interaction without knowledge about the SmartWindow

In front of the display, we installed original tram seats we received from the local public transport network, our partner in the project. The seats were installed on top of a wooden plank, with the exact same distance between them as they have when installed in a tram. The study participants could choose if they wanted to be seated right or left and then were given the task to choose and touch the fields on the display that are comfortable and reachable for them in their seat position. After that, they were seated on the opposite seat and given the same task again. The selected fields were recorded for each participant and their interaction with the display was observed and recorded in written notes. To compare the user's interaction given their prior knowledge about the SmartWindow setting, two separate study iterations were conducted. Among all participants, we asked for the body size which was between 159 cm and 186 cm. All participants were right handed. Their age was between 20 and 34 years. In the first iteration, part A, the participants (N=18) had no prior knowledge of the SmartWindow and its purpose. Our mockup designs and interaction possibilities were unfamiliar to them. In the second iteration, part B, the participants (N=13) were shown sketches of the design and were allowed to interact with a first prototype to gain basic knowledge about the SmartWindow. After this introduction, they were given the same tasks as the participants of the first iteration of the study.

6.1 Analysis and Results

The heat maps in Figure 6, Figure 7 and Figure 8 show how often participants chose the respective field. The scale of the heat maps ranges from green (no participant) to red (all participants).

Part A: Analysis without knowledge of the SmartWindow

The results for both seat positions are shown in Figure 6. Compared to the seat position, there are similar areas identifiable that were chosen as comfortable by participants.

Notable is that the participants seated on the right chose higher interaction fields than when seated on the left. We suspect that this is because most of our participants were right handed and could reach higher when seated on the right. It is remarkable, that the participants touched areas behind their back.

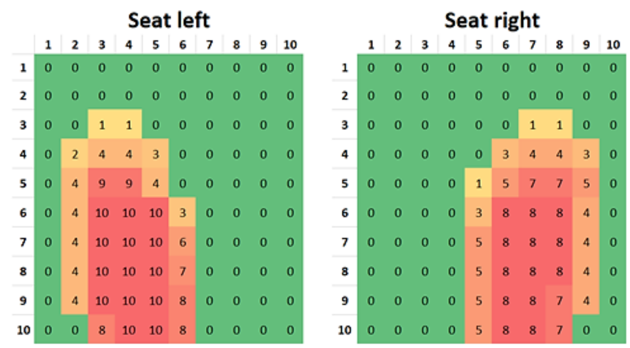

Figure 7: Heat map of interaction with knowledge of the SmartWindow

Part B: Analysis with knowledge of the SmartWindow

When participants were familiar with the SmartWindow and our SmartWindow mockup, the results were quite different. The results for both seat positions are illustrated in Figure 7.

Compared to the analysis seen in Figure 6, the participants chose fields closer to their seat position and preferred field positions in the center that are in front of them when they sit next to the display. They did not reach as high as the participants of the first iteration of the study and did not reach behind themselves.

Analysis in total – Part A and B

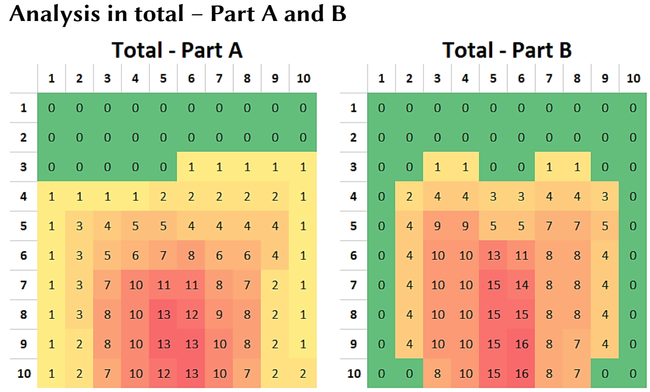

Figure 8: Heat map of interaction areas in total

Figure 8 shows interaction areas of both study iterations in total. In part A, most of the interaction fields were touched by at least one participant. The majority of the selected fields are in the middle or in the lower area. In part B, the center of comfortable interaction areas ranges from the middle below (around 10:6) to the center (around 7:6). Compared to the results of the first

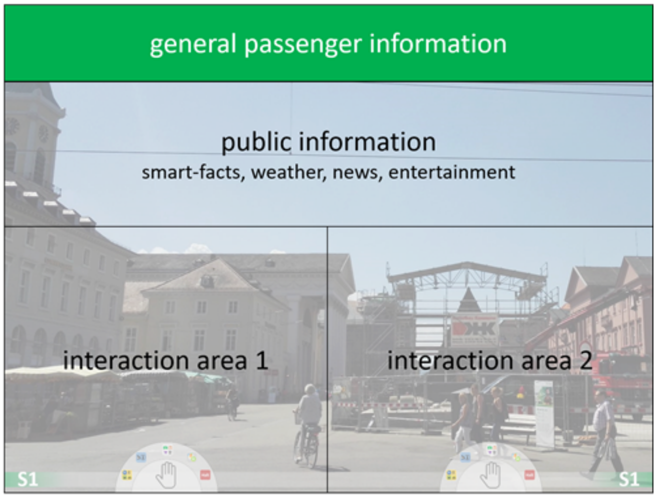

Figure 9: Arrangements for interaction and information areas on the SmartWindow

iteration of the study this indicates that the reachable and comfortable areas are in the middle and lower area of the SmartWindow. We also assume that knowledge of the public transport context and the intended usage of the SmartWindow did influence the interaction choices of the participants. For example, knowing that they would travel in a tram while interacting, participants did not stand up, to reach interaction fields higher up and they did not touch fields behind their back.

We assume that the results of part B are more realistic and give a good indication of areas on the SmartWindow that can comfortably be interacted with. In part A of the study, we assume, we observed the Novelty Effect, since the participants knew nothing about the SmartWindow. As a result, the participants moved more as they touched fields. Seeing the results of part B, we concluded, that passengers in a public transport vehicle probably prefer to interact next to their seat position, oriented towards the center of the SmartWindow and we could measure the size of the comfortable interaction areas. These results indicate possible positions for user interface elements.

As a result, we developed the arrangement for information areas on the SmartWindow as shown in Figure 9. At the top and therefore visible for standing passengers, general passenger information can be displayed. In our following prototypes, this is the area where upcoming stops and the next departures are located. Beneath this area, we placed an area that can contain public information like weather, news and entertainment. Located at the bottom of the SmartWindow there are two interactive areas. Those interaction areas can be operated individually by the passengers sitting next to the SmartWindow either on the left or on the right.

7 Phase II: User Study

Based on this information arrangement, an interactive, clickable prototype was developed, as shown in Figure 10. This prototype was designed containing the information identified with the online questionnaire. It was designed to be displayed on our multi-touch display next to the tram seats. In order to add further public transport context that enabled the participants to picture themselves in a public transport vehicle, the background of the prototype shows a photograph taken from an actual tram in the local public transport. It resembles the view from a tram, seen through a semi-transparent SmartWindow.

The clickable prototype was evaluated in multiple small user studies. One of these studies utilized the thinking aloud method, where participants were asked to perform some tasks using the prototype and to express their thoughts while doing so. A study coordinator recorded the statements of the participants and at

Figure 10: Clickable prototype used for user studies

some point asked questions to pick up additional information about the behavior and reactions of the participants. This study was focused on:

- The usability of user interface elements
- The usability of information display and information access
- The user experience of users while interacting with the SmartWindow

The 13 study participants were asked to complete given tasks using the prototype. Figure 12 shows a participant during the study.

After the completion of the tasks, participants were asked to complete a questionnaire assessing the usability of different interactive components of the prototype.

Participants rated the likelihood of using given interactive elements and interaction modalities on the SmartWindow. On the questionnaire, we included interaction modalities that were not part of the prototype. The majority of study participants marked methods like voice input and gesture control as awkward and unintuitive. Interaction with the SmartWindow using a personal device like a smartphone was indicated as too futuristic and not suitable. Multi-touch interaction however, was rated as intuitive and Participants rated the likelihood of using given interactive elements and interaction modalities on the SmartWindow.

Hygiene was mentioned as a negative issue of touch interaction with a public display.
After this evaluation phase, we developed a second, high fidelity prototype based on HTML and JavaScript that implemented interfaces to our smart public transport data platform. In the design of this high fidelity prototype, we applied the results of all prior evaluation phases. This prototype is further evaluated using additional evaluation methods.

Figure 12: Study participant completing given tasks during the study

Prototype 2

This prototype is also run on our 98-inch multi-touch display and we continued to use the tram seats in front of it, to create the resemblance of a tram compartment. Additionally, we created a video of a tram ride on one specific line in our local public transport network. This video is shown in the background of the prototype and creates the illusion of sitting next to a window of a moving tram. Since most of our study participants are familiar with local public transport, we also synchronized the display of next stops and departures at these stops with the stops of the tram ride shown in the video. The display of next stops changes at the exact moment, when the tram leaves a stop. Furthermore, the size of the prototype was adapted to the exact size of vehicle windows in local trams. The prototype is displayed in Figure 11.

8 Phase III: Eye tracking Study

Following the development of the second prototype, we designed and performed a user study that combined the thinking aloud method and eye tracking, utilizing eye tracking glasses. Those glasses are naturally portable and make it possible to study focus, areas of interest in great detail, and in context, in contrast to stationary eye tracking devices. Participants could comfortably wear the eye tracking glasses while sitting on the tram seats, looking at the prototype. Data on the eye movement of participants provides information about how long a participant looked at a symbol or interactive element and helps to identify which of the user interface elements are of particular interest. For our study, we used the eye tracking model Tobii Glasses 2.0. The eye tracking glasses were calibrated using the Tobii Pro Glasses Controller (Version 1.83.11324-RC1).

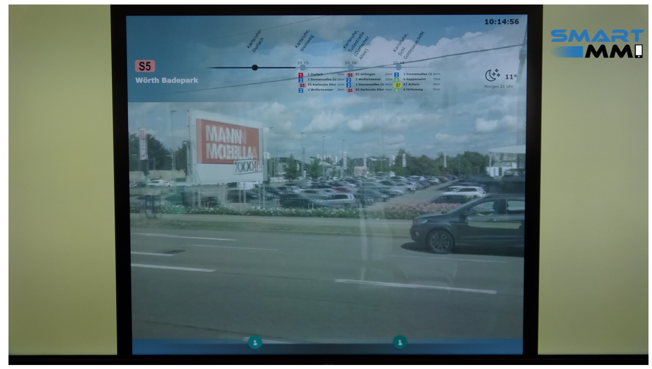

Figure 11: Prototype 2 with a video from real traffic in the background

8.1 Experiment Design and Research Questions

To investigate interaction and behavior of users and to evaluate the acceptance of a smart and mobile public display, we gave participants different tasks to fulfil, using our SmartWindow prototype.
We had multiple research questions for this study:

- Does the size of the icons and interactive elements fit and are they well placed, considering the user’s field of vision?
- Are the icons and interactive elements understandable for the user?
- Do users overlook elements?
- Which hand did participants use for interaction and was the interaction perceived as comfortable by users?
- How do participants perceive different variants of disruption notifications?

8.2 Experimental Procedure

The eye tracking study was realized with six participants, who are qualified media communication experts of the International University Karlshochschule. Five female and one male expert participated in our study. First, they were divided in groups of two and the eye tracking-glasses were calibrated.
Then the group of two participants was asked to seat themselves in front of the SmartWindow Prototype and to describe what they saw on the SmartWindow, as shown in Figure 13. After that, the participants were asked to perform several tasks and to comment on their thoughts while doing so. While interacting with the

Figure 13: Participants describing the SmartWindow

SmartWindow, a disruption notification showed up on the SmartWindow. We implemented two variants of disruption notifications and each was shown alternating with the other. The study coordinator noted how long it took the participants to notice this information.

8.3 Analysis of the eye tracking data

Using the software Tobii Pro Lab (Version: 1.102.16417), we analyzed the eye tracking data from the study. We visualized the data using heat maps, as shown in Figure 14 and Figure 15. These two heat maps show how long a participant looked at a point on the SmartWindow.

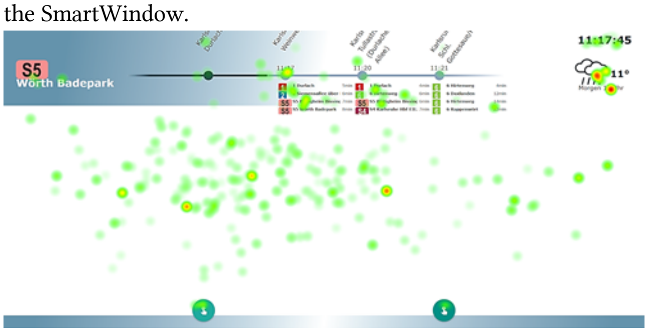

Figure 14: Heat map of participant, who chose the left seat

Points of particular interest, on which participants focused a relatively long time, are displayed in red. We compiled heat maps for each participant and the results must be analyzed separately, depending on the seat position and therefore the viewpoint the participant chose. Figure 14 shows a heat map of a participant in the left seat and Figure 15 the heat map of a participant on the right side. It is notable that the participant who sat on the right did not notice the time or the menu icon displaying a touching finger, on the right side. Compared to the participant on the left, the participants on the right focused less on the weather icon. Based on our notes, we could reproduce that they only saw the weather info after the participant on the left commented on it. Figure 17 shows the Areas of Interest (AoI) of the SmartWindow. These Areas of Interest allow a statistical analysis of stimulus data. Figure 17 also shows the analysis results for each AoI: how long the participants looked at it and how often. The results confirm the analysis of the heat map. For example, only two participants looked at the menu icon on the right. They looked at it for an average of 0,41ms and with only one view. Most participants gave feedback that they did not understand the menu / touch icon as an interaction possibility. Conclusively, they had problems interacting with the SmartWindow. Their first thought was to touch the middle of the video or the list of next stops at the top. After some time they found out that, the touch icons are interactive. Based on these results, we decided to revise the menu icon and menu form for our future prototype. We also used the results and feedback on the other icons, interactive elements and the disruption notifications to further adapt our prototype.

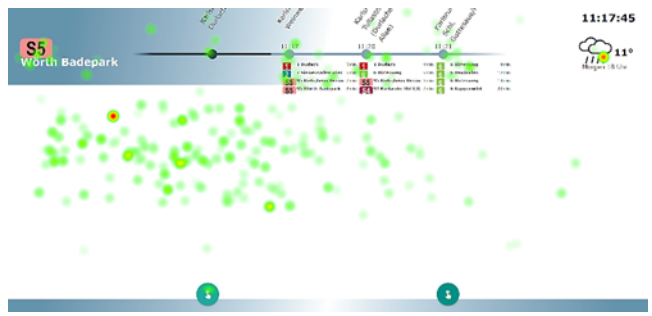

Figure 15: Heat map of participant, who chose the right seat

Prototype 3

We further refined our prototype and incorporated the results of the eye tracking study.

This is still work in progress. In order to increase the realistic setting for user studies with our prototype, we now have a demonstrator passenger cabin, as shown in **Figure** 16**Error! Reference source not found.**. This demonstrator is a replica of a railway compartment of local trams. Since at the moment, an actual semi-transparent display is hard to come by and our efforts are focused on installing such a real semi-transparent display in a local public transport vehicle, we had to choose an alternative option for the demonstrator. It is equipped with a semitransparent plastic pane, which can be replaced or removed. The pane itself can be used in combination with a mountable multi-touch frame and a projection via short-throw projector. We are planning to also use it with several multi-touch displays that can be mounted in front of the “window”.

In this third prototype, combined with the passenger cabin, the previously developed components come together and can be evaluated in an even more realistic setting.

Figure 16: Passenger cabin used for further user studies

9 Conclusion and Discussion

In this paper, we described the user-centered, iterative development of a high-fidelity prototype for a semi-transparent, interactive mobile public display in public transport vehicles. The goal of such SmartWindows is to improve passenger information during a trip in a public transport vehicle.

Our development process was divided in several evaluation phases and the result of each study in each phase resulted in an improved prototype.

During the studies or in the analysis of study results, we were able to identify several challenges for the usage of a SmartWindow.

The online questionnaire in phase I allowed us to identify, rate and structure information that might be shown or accessible via SmartWindows. The evaluation of interaction areas on the other hand guided the structuring of information areas on the display and supported the development of interactive elements. A first explorative user study shaped the development or our high fidelity prototype, which we were able to evaluate using eye tracking glasses. Based on the combined results of all studies, this high fidelity prototype will be refined further and deployed in phase V during the field test starting in the beginning of next year. Our design was refined repeatedly based on the results of our studies and some results would not have been possible with only one user study to evaluate the whole design. The outcome of the interaction area study showed, for example where the menu icons should be placed, in order to be reachable from the tram seats. However, the eye tracking study revealed that the touch icons indicating the menus are not in the field of vision for everyone. This result lead us to rethink the design. All of the studies we performed have their drawbacks. The assignment of two persons in the eye tracking study resulted in some unintended effects, like one person pointing something out, the other would not have noticed and therefore influencing the opinion and exploration process of the second participant. However, it also had some benefits, because the participants discussed the prototype, which increased the spoken feedback.

We continually increased the incorporation of context into our prototypes and study settings, in order to achieve a realistic scenario and therefore more realistic responses by participants. From background pictures and videos, to real tram seats we moved to a whole tram mockup. In next steps, we will further evaluate several interaction and information elements of the SmartWindow prototype using our passenger cabin. The goal is to fully refine the prototype and to apply it in field test in the beginning of 2020. A SmartWindow will be installed in a public transport vehicle, which will be in operation in our local public

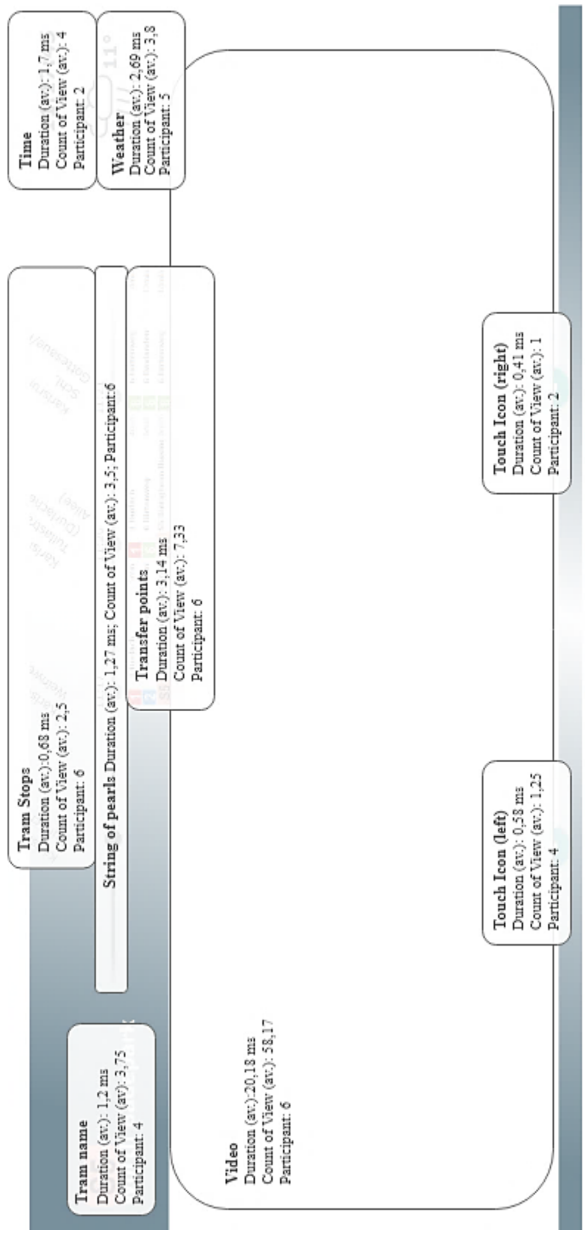

Figure 17: Areas of Interest of the SmartWindow

transport and therefore accessible for the public. In the upcoming evaluation phase V, we plan an extensive usability evaluation of the SmartWindow prototype, including passenger observations, more guided user studies. We are also planning to utilize the eye tracking glasses again.

From our point of view, it is important to consider different types of studies while evaluating a public display. They help to understand different facets of what the users need and how different types of persons behave. Our design has benefited greatly from each evaluation during our development process. We also consider it vital to incorporate context into public display prototypes and evaluations, in order to help participants to envision themselves in a “real” situation rather than a lab. Since field studies are expensive and complex, we showed how we gradually extended the usage of public transport context in our prototypes and studies by simulating more realistic environments in every iteration.

Our iterative development process with multiple evaluations helped to optimize our prototype to meet the demands of public transport users and will be evaluated in our field study in 2020. We are planning to summarize and publish our experiences after the field study and hope that we will be able to publish some lessons learned from designing and evaluating a smart mobile interactive public display for public transport. Additionally, we are researching the interplay of a smartphone application and the SmartWindow in passenger information and are hoping for some interesting results in this area, as well.

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