PasVis: Enhancing Public Transport Maps with Interactive Passenger Data Visualizations

Category: Research

Figure 1: Travelling in a foreign city can be a challenging task. The task performance for finding the best route while inspecting a public transport map depends on the design of the map. But planning alternative routes based on passenger numbers is typically not doable with standard maps. Enhanced maps with extra views, perspectives, and interaction techniques are a way to support travelers at route finding tasks.

Abstract

Public transport maps are typically designed in a way supporting route finding tasks for passengers while they also provide an overview about stations, metro lines, and city-specific attractions. Most of those maps are designed as a static representation, maybe placed in a metro station or printed in a travel guide. In this paper we describe a dynamic, interactive public transport map visualization enhanced by additional views for the dynamic passenger data on different levels of temporal granularity. Moreover, we also allow extra statistical information in form of density plots, calendar-based visualizations, and line graphs. All this information is linked to the contextual metro map to give a viewer insights into the relations between time points and typical routes taken by the passengers. This might be important for a traveler to plan a route, for example, taking a less crowded train at a certain time point during a day or finding alternative routes, maybe with the negative consequence of travelling much longer while also changing trains several times. We illustrate the usefulness of our interactive visualization by applying it to the railway system of Hamburg in Germany while also taking into account the extra passenger data. As another indication for the usefulness of the interactively enhanced metro maps we conducted a user experiment with 20 participants.

Index Terms: Human-centered computing—Visualization—Visualization techniques—; Human-centered computing—Visualization—Visualization design and evaluation methods

1 Introduction

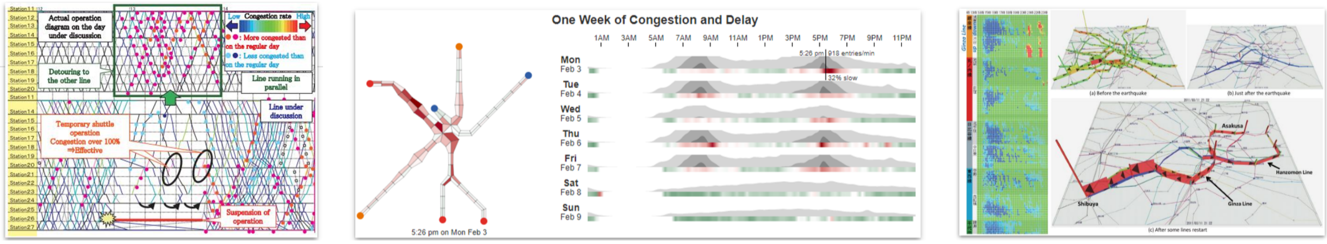
Travelling in a foreign city typically requires inspecting a public transport map [19] placed at a metro station's wall, in a travel guide, on carriage walls, on the web, or on a smart phone. The major goal of those maps is showing the most important information like the metro stations, lines, or interchange points [6], and in some cases additional features like famous sights, rivers, or airport locations [26].

The 'old-fashioned' maps try to focus on an uncluttered and aesthetically looking appearance by distorting the stations in a way that the exact geographic position is not given anymore, but the topology is still preserved to a high degree. This layout strategy allows to reclaim space that would be wasted if the exact geographic positions of the stations were used. Moreover, many aesthetic drawing criteria are followed [16] to generate readable, understandable, and intuitive maps. The design of public transport maps is still an ongoing story since the transport systems grow larger and larger in complexity and also provide more and more ways to travel in a city in an interconnected way.

Unfortunately, although they are mostly well designed, they do not allow interactions nor do they show extra dynamic information about the passengers like number of people in a certain train at a certain time point [6]. Actually, it may be important to see how many people enter or leave a train at a certain metro station to better plan a journey for example. Getting extra views for this kind of data integrated in and aligned with the public transport map as well as side-by-side interactive and linked perspectives can help to find the best travelling route for a passenger at a certain point in time, for example avoiding crowded trains or busy interchange points.

In this paper we illustrate an approach to enhance public transport maps with time-varying passenger data on different temporal granularities. The extra data is attachable to all stations and metro lines. This extension was not possible for public transport maps designed before the invention of the computer [20], although they have been designed for supporting travelers at route finding tasks for the state-of-the-art at these times [5]. But, negatively, they typically could not provide integrated or additional side-by-side and linked views on dynamic data like passenger numbers, how many enter or leave the trains at certain metro stations on different levels of temporal granularity, or even interactions with such data in order to find the best travelling route for the passengers.

We illustrate the usefulness of our interactive and web-based enhanced public transport maps by showing travelling scenarios in the city of Hamburg in Germany (see Figure 1). A user experiment with 20 participants has been conducted to investigate if non-experts in visualization are able to understand the original maps as well as the visually enhanced maps. Moreover, as a major result we found out that the interactive and visually enhanced maps are useful to plan routes in a city by taking into account extra passenger information. The enhanced maps also do not lead to longer completion times compared to the original maps, although we expected this effect due to the increased amount of visual clutter. Finally, we discuss data, visual, perceptual, and algorithmic scalability issues as well as limitations of our tool and we provide a look into future directions.



(a) (b) (c)

Figure 2: Map enhancements in previous work: (a) Passenger flow by Kunimatsu and Hirai [13] or [17], (b) an interactive exploration of Boston's subway system [2], and (c) another passenger flow in a metro by Itoh et al. [11].

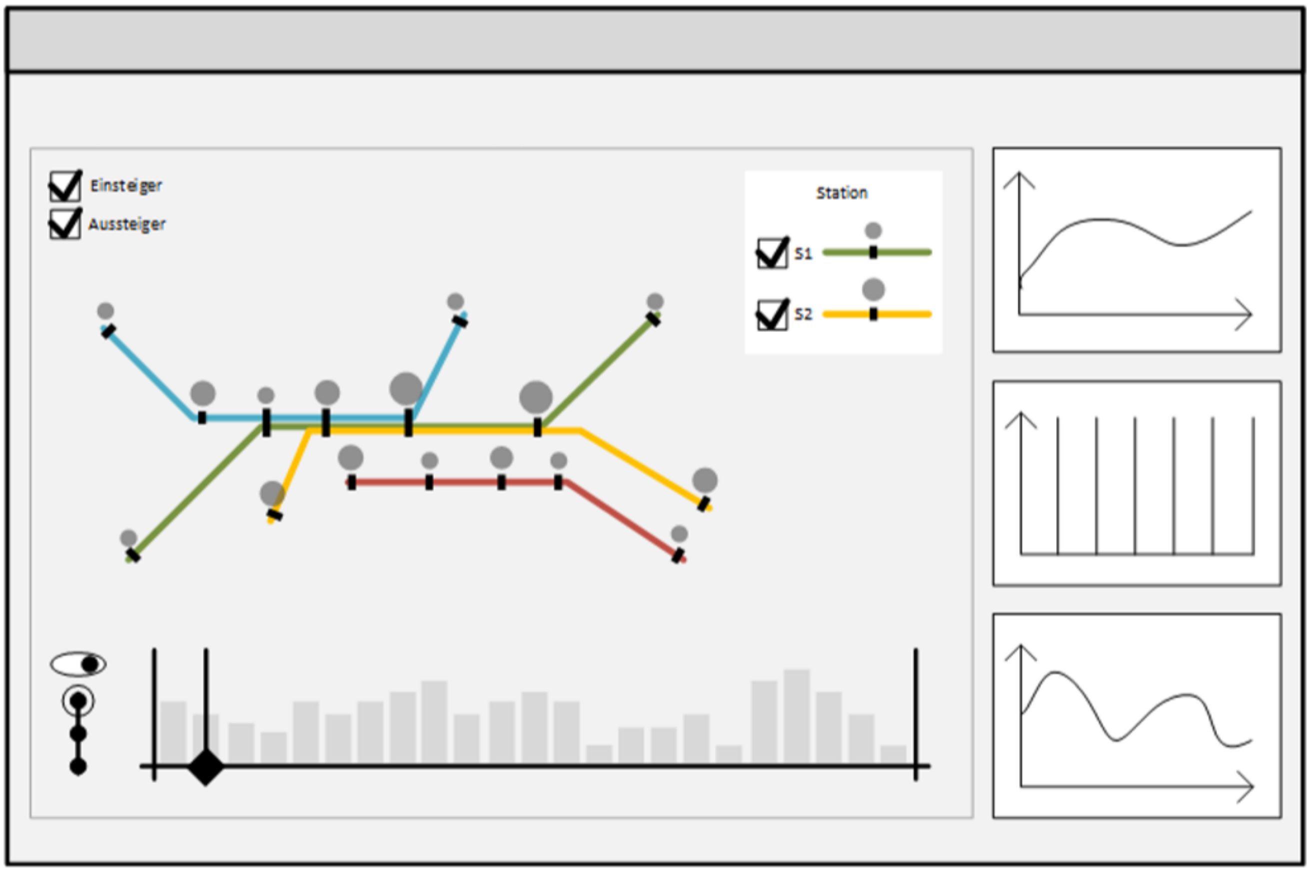


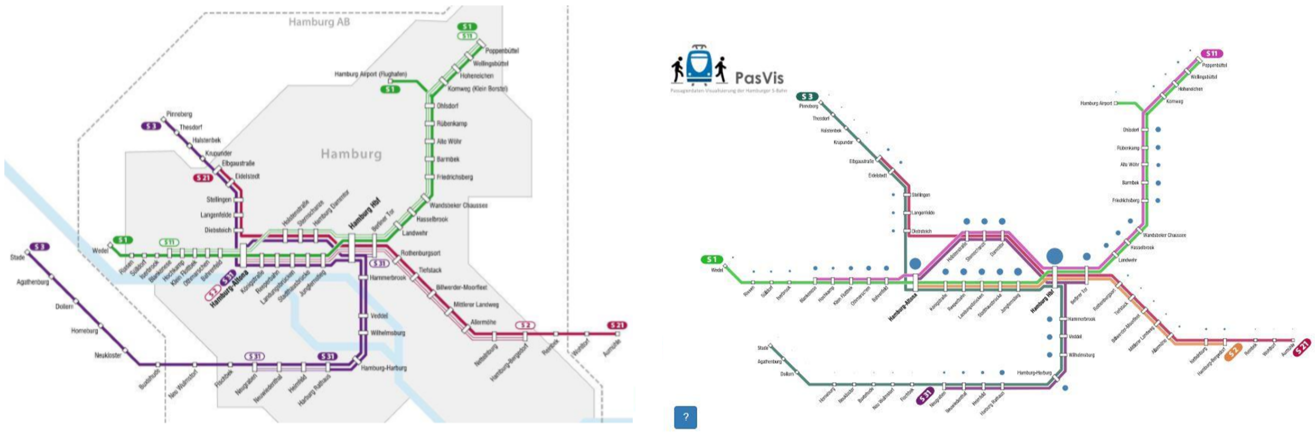
Figure 3: A public transport map is in the center of the view while additional passenger information is added to the stations as well as simple histograms and time-series plots provide additional information. Interactions can be applied to inspect the metro map from a user-defined perspective.

2 Related Work

Metro maps have been designed a long time ago and have become successful designs since the work by Henry Charles Beck [8] or even earlier by Dow [7]. Actually starting in London with the famous Underground tube map, more and more cities around the globe have been in focus of public transport and hence, providing maps to support the travelers. This is also due to the fact that the world gets more and more connected and many more people travel in foreign cities.

However, the usefulness of those maps depends on several factors and still some improvements are made. Consequently, there are various studies on map designs, typically looking into geographic maps [12]. Netzel et al. [18], for example, investigated which additional hints support a viewer to find labels. Moreover, Netzel et al. [19] also investigated where people pay visual attention when answering route finding tasks in public transport maps and Burch explored the visual attention distribution in public transport maps [4].

A major result shows that people tend to subdivide the task into subtasks [3], follow the geodesic path tendency [10], combine all subsolutions, and crosscheck the final solution. However, in these eye tracking studies the authors do not investigate additional time-varying passenger data to enhance those maps and to provide extra information for finding the best route from a start station to a destination station. For example, the passenger data might play a crucial role when choosing a route, to avoid crowded trains at a certain point in time.



(a) (b)

Figure 4: An original public transport map [1] (a) is enhanced by integrated visual features (b). Those features can come in many forms, for example differently large circles attached to the stations to indicate the number of passengers entering or leaving a train at a certain point in time.

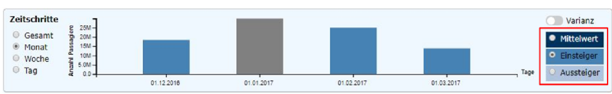


Figure 5: A simple visualization indicating the number of people entering or leaving a train in a certain time interval.

Zeng et al. [28] integrate mobility-related aspects like riding time, transfer time, waiting time, and round-the-clock patterns. Although this is an extension to standard static public transport maps, their work focuses more on the exploration and analysis of passenger mobility by analytical tasks. In our work we focus more on the enhancement of the map in an intuitive and easy way, designed for the non-experts in data analysis and visualization.

Figure 2 visually depicts some illustrative examples of previous and related work [2, 11, 13, 17] trying to enhance maps by additional perspectives on extra data sources, for example passenger flows with an additional view on the map. However, those visualizations do not provide extra views on different levels of temporal granularity and might be difficult to be used by the human user which is due to the fact that the provided views are sometimes suffering from visual clutter [22] or combine the views in a way that it might not be trivial anymore to understand them quickly.

3 Visualization Techniques and Interactions

The basic visualization is a standard static public transport map that is enhanced by additional views on dynamic passenger data and interaction features. Moreover, extra perspectives on the passenger data are given as simple diagrams, interactively linked to the public transport maps, to preserve the usability aspect of the enhanced maps for the non-experts in visualization, i.e. the everyday traveler (see Figure 3 for an illustration of how the enhanced map might look like).

3.1 Maps and Passenger Data

The passenger data was accessed from the web page *data.deutschebahn.com* and we exported it in a CSV data format. In this research and for illustrative purposes we focus on the time period from December 2016 to March 2017 that resulted in more than 600,000 data samples. However, there is no limitation to the time period from which the data is extracted from the online system.

The acquired data has a tabular form consisting of several relevant attributes like train number, start station, number of passengers entering the train, number of passengers leaving the train, arrival time, departure time, destination station, and train line. Before working with the data we had to get rid of missing data entries and wrong stopping points. The acquired data is sufficient and contains the relevant variables to enhance a public transport map in the desired way.

3.2 Design Decisions

We base our visualization tool on a list of design decisions that are also visible in the layout of the graphical user interface (see Figure 3). Moreover, we integrated visual features in public transport maps (see Figure 4).

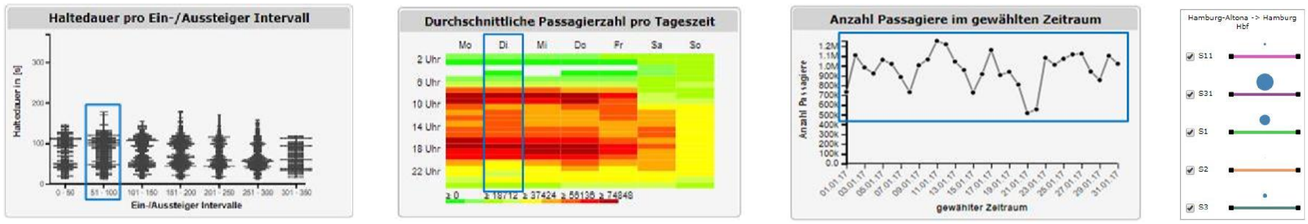
- **Focus on dynamic passenger data:** We focus on providing extra views on the time-varying passenger data. This means that travelers looking at the interactive maps should be able to easily understand this information attached to the metro map stations and also given as visual means for filtering the data.

- **Provide several linked views:** All the extra views should be interactively linked with the public transport map. This means that a change in any of the views has an impact on the change in all of the other views, helping to understand the direct correspondences between the views.

- **Enhance public transport maps:** Looking at standard public transport maps is already helpful to find the metro lines and interchange points to come from a starting station to a destination station. But, extra information on passenger numbers (crowded or empty) trains is typically not available.

- **Use easy-to-understand diagrams:** Since the interactive visualization tool is designed for non-experts in visualization we focus on easy-to-learn and easy-to-use diagrams. Otherwise travelers might get confused and consequently, will not use them for travelling in a city.

- **Support interaction techniques:** Public transport maps placed as a poster to a station's wall are typically static depictions of the transport system. In our design we focus on supporting travelers to interact with all the views in order to find a suitable parameter setting for their tasks at hand.



(a) (b) (c) (d)

Figure 6: Several views are added to the original public transport map to provide more information than the standard metro maps: (a) Density plots. (b) Calendar-based matrix visualization, (c) line graphs, and (d) metro line bubbles.

Select (a) Explore (b) Reconfigure (c) Abstract/Elaborate (d)

Figure 7: Different ways to interact with the visually enhanced public transport maps: (a) Select. (b) Explore. (c) Reconfigure. (d) Abstract/Elaborate.

- **Show different temporal granularities:** We also support filtering of the time-dependent data, in particular, we allow different perspectives on the passenger data, for example, by changing the temporal granularity of the data (temporal aggregation).

With the interactive visualization we focus on answering a list of user-defined tasks like:

- **Train stops:** Does a train stop longer at a certain station if more people enter the train?
- **Time points:** At what time points of the day is the number of passengers the largest and at which stations?
- **Stations:** Are their superfluous stations at which not many passengers enter or leave a train?
- **Outliers:** Are there temporal outliers in the sense that at certain time periods really many or only a few passengers travel?

3.3 Data-to-Visualization Mapping

In this section we describe how the public transport map and the additional data is visually encoded, i.e. to which visual variables it is mapped. To show all of this information we provide several views [21] with the public transport as the largest view.

3.3.1 Metro Map View with Bubbles

We use color coded bubbles to indicate the number of passengers entering or leaving a train at a certain station. The sizes of the bubbles proportionally encode the number of people while the bubbles are always aligned with the stations. Although this produces extra visual features in the map it also has the benefit to give the passengers insights about which stations are rather crowded with people and at what times during a day (see Figure 4 (a) and (b) for the enhanced map with bubbles).

3.3.2 Time Histograms

The histograms provide an information about the number of people using public transport on different levels of temporal granularity. We support perspectives on days, weeks, and months as well as an overview about the total number of people using the train. This information can be split into passengers entering a train or leaving it as well as the average value can be displayed together with the variance (see Figure 5 for an illustration of such a time histogram).

3.3.3 Density Plots

For each station we can have a look at a density plot about the number of people entering or leaving a train as well as the length of a stop of a train. The number of people is hereby given as intervals of size 50 and the stopping times in seconds (see Figure 6 (a) for an illustrative example and the visual patterns that are created).

3.3.4 Calendar-Based Matrix Visualizations

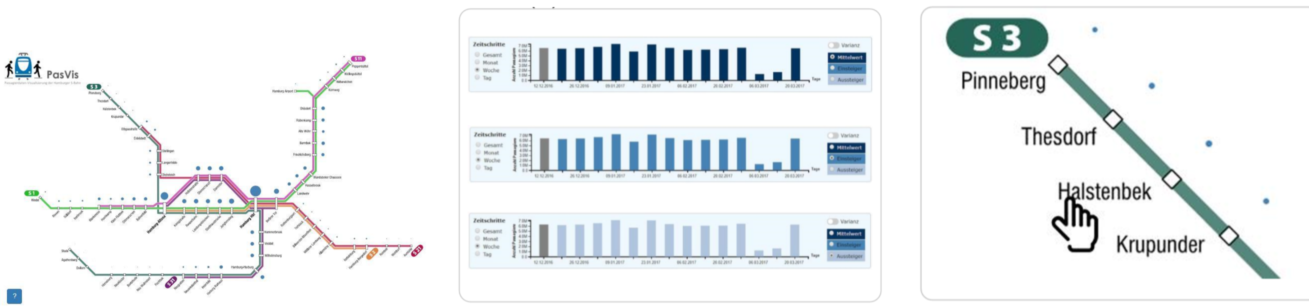
In the calendar-based visualization [23] we can observe the number of passengers at a certain time of day and at a certain weekday. The color coding is used to indicate the number of people travelling while a red color reflects the highest number of passengers (see Figure 6 (b) for an illustrative calendar-based visualization of the number of passengers).

3.3.5 Line Graphs

Some non-experts in visualization also prefer a line graph indicating the number of passengers in a certain time period. The time-dependent patterns of the lines easily reflect the travelling behavior. Such a line plot can be computed for every station and also for entering and leaving passengers as well as for different temporal granularities. The vertical axis describes the number in one hundred thousands (see Figure 6 (c) for an illustrative example of a line graph for a specific user-selected station).

3.3.6 Metro Line Bubbles

In some cases it might also be of interest to explore how many people are actually travelling in a train on a certain metro line segment (between two stations) and also at a certain time point during a day.



Encode (a) | Filter (b) | Connect (c)

Figure 8: Some other ways to interact with the public transport maps: (a) Encode. (b) Filter. (c) Connect.

This information can also be shown for different time scales as well as accumulated over all time points indicating the metro line segment on which most people travel over the entire year for example (see Figure 6 (d) for an illustrative example of the metro line bubbles).

It may be noted that with these simple visualizations and diagrams, the non-expert in visualization can easily navigate and interact in the data. However, the metro map can also be used as a standard map without any extras, for example, for passengers who are actually just trying to find a route and not one focusing on extra passenger data.

3.4 Interaction Techniques

To provide and implement a list of useful interaction techniques we follow the taxonomy by Yi et al. [27]. The users of the interactive and visually enhanced maps should be able to see the map in its original form but also with visual enhancements. If the latter is the case they should be able to modify several parameters, for example, the temporal granularity of the passenger data, flipping between people leaving or entering the train, filtering for time and number of people, as well as changes in color codings to mention a few. Since the scope of this work is on providing a visualization for the non-expert in visualization we also focus on developing easy-to-use and intuitive interaction techniques.

- Select: All visual elements in the metro map can be selected, for example, for getting a details-on-demand information. Figure 7 (a) shows the selection of a bubble to get some insights in the actual number of participants in a textual form.

- Explore: Selecting a certain time point or period as well as additional parameters we can observe the impact of the parameter selections on the attached data to the metro map, i.e. the number of passengers. By this feature we are able to further explore the map with extra data perspectives. Figure 7 (b) shows the selection of parameters in the time histograms and the impact on the passenger data visualization.

- Reconfigure: The extra views can be adapted, for example to show the difference between people entering the train and leaving it, resulting in positive as well as negative numbers indicated in the timeline histogram. By this reconfiguration, we can get extra insights that have not been possible with the standard view. This is represented in Figure 7 (c).

- Abstract/Elaborate: Inspecting the data on different levels of temporal granularity can be important to understand seasonal trends, for example daily or weekly travelling behavior. Passengers might be able to decide about a journey not on a specific day but in a specific time period in the year (see Figure 7 (d)).

- Encode: The user can decide which views to show and also which visual features as well as the color codings of the extra data visualizations. Figure 8 (a) shows a scenario in which the user is able to see the public transport map attached with the bubble view on the passenger data only.

- Filter: Selecting a certain time period for example can be done in the timeline histogram. This is typically used to filter the data based on a previously given insight about the time-dependent data, here the number of passengers. Figure 8 (b) shows such an example where the first bar is selected and the selection is indicated in gray color.

- Connect: There are several ways to connect the extra views on the passenger data with the given public transport map. First of all, it might happen visually by looking at a certain alignment (for example the bubbles aligned with the stations), or the user might interact with a visual element and then the extra information is highlighted. In Figure 8 (c) we can see a hovering over a station name to initiate a connection with the attached information.

4 Application: Public Transport in Hamburg

The Hamburg railway system consists of 68 stations and 6 metro lines. Although it is not the most complex public transport system in the world, it already has some kind of complexity making it hard to understand, in particular, if time-varying passenger data has to be explored in combination to the map. In this section we will have a look into typical tasks that might be solved by travelers when using this map.

We will focus on a scenario where a family with three children plans a travel in Hamburg. This would mean that the trains should not be too crowded in order to safely travel with the family in a relaxed way. Since the family is free in choosing the dates between December 2016 and March 2017 for travel they first have a look at the overview representation to figure out at what time periods there are not that many passengers.

For this reason they look at the timeline histograms (see Figure 9, bottom) for the number of passengers travelling in a certain month. It turns out that December 2016 is a good month to make such a journey since the other months during the available dates indicate much more passengers. The only better month would be March 2017, but in this month the family has other obligations and cannot travel.

Looking at the calendar-based visualization (Figure 9, right side in the center), it can be observed that in the selected month (December 2016), the weekends (Saturday and Sunday) seem to be good dates since the number of passengers seems to be much less than over the week days which can be seen by the less red visual patterns in the

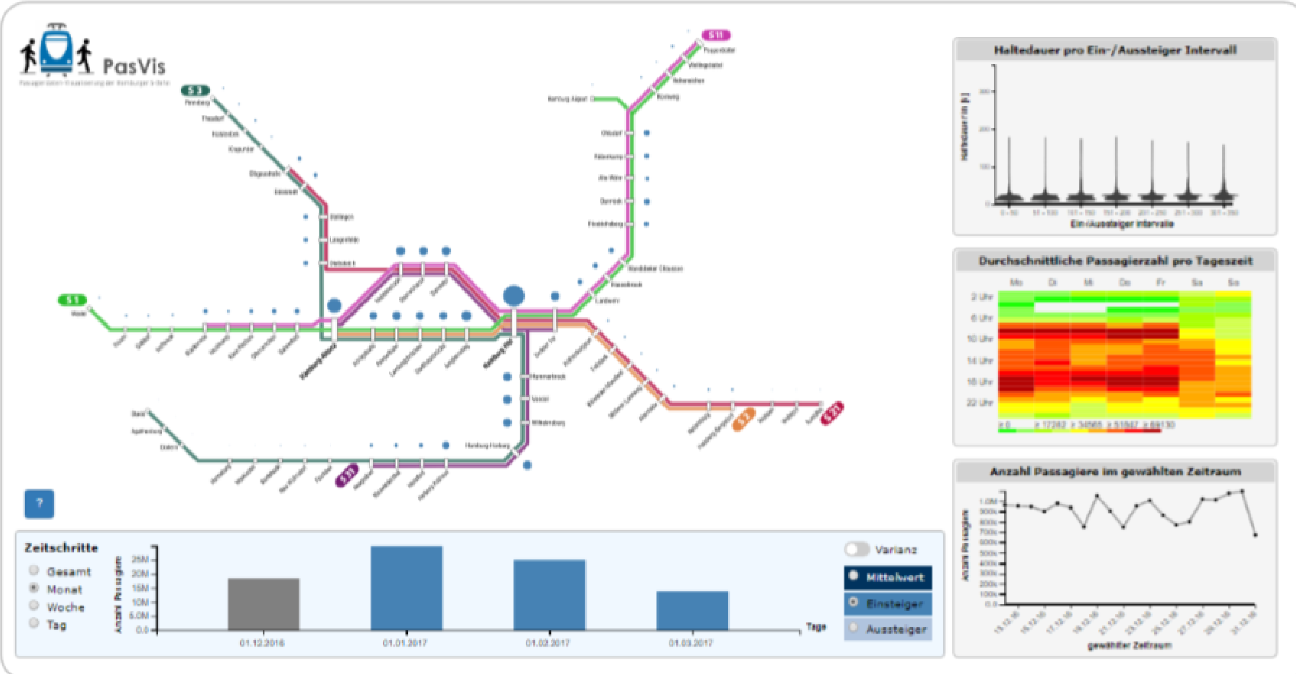


Figure 9: The metro map of Hamburg with attached passenger data as well as extra views on the time-dependent number of passengers

calendar-based visualization. This gives the family the impression to plan their journey on a weekend in December. There are many more insights about the Hamburg public transport system once we start interacting with the visually enhanced metro maps, too many to explain all in this application scenario. For example, we might change the parameters to see the differences between people entering or leaving the trains or we might look at average values or variances in the values.

Once arrived in Hamburg, it is up to the family when to travel during the day, but they decided to travel early in the morning due to the fact that they have kids and their travel times cannot be freely chosen. Looking at Figure 9 indicates that travelling in the morning is much better compared to the afternoon. This can again be seen in the calendar-based visualization.

Looking for special attractions or doing sightseeing over the weekend is better on Sundays since on Saturdays the public transport is much more crowded than on Sundays. Hence, the family decides to do most of their sightseeing tours on Sunday (see Figure 9).

Looking for special routes in the city is also a challenging task, in particular if the chosen routes and trains should not be too crowded. This should typically be avoided for interchange stations. Looking at the maps for the selected time period (Figure 10) the metro station ”Hamburg Hbf” and ”Hamburg Altona” should be avoided because the station-aligned bubbles indicate many passengers, even for Saturday and Sunday.

Figure 10 shows a calendar-based visualization for the Monday after the weekend. It seems that it is not a good idea to travel home in the morning since on Mondays there is typically rush hour in the morning, hence the family decides to travel home after lunch.

5 User Evaluation

We invited 20 participants to investigate if the enhanced public transport maps have any benefits compared to the original public transport maps without visual enhancements. To reach this goal we first come up with a list of hypotheses and then as a second step we ask specific tasks to test those hypotheses and research questions.

The independent variables in our user study are ’map without visual enhancement’ and ’map with visual enhancement’. The dependent variables are accuracies and completion times whereas the accuracies mean that the task could be solved in a meaningful way in a reasonable time.

5.1 Hypotheses and Research Questions

Actually, we have designed and implemented the visually enhanced metro maps to provide benefits for the travelers, i.e. people trying to find an optimal way between two stations based on their personal preferences. Hence, our hypotheses are in favour of the enhanced maps and typically involve route finding tasks as well as judging time periods:

- **Research Question 1 (Comparison to original maps):** The map enhancements have NOT a bad impact on route finding tasks. This might be the case since every visual element in a map can be the cause of additional visual clutter and hence, difficulties to read and understand the visual representations.
- **Research Question 2 (Identification of time periods):** The map enhancements help to identify time periods (months, weeks, days) with a low number of passengers and hence, this information would improve the travelling between certain stations represented in the public transport map.
- **Research Question 3 (Identification of routes):** The map enhancements help to plan routes with a low number of passengers, for example avoiding crowded interchange points which could be beneficial to have faster travel times or to travel in a more relaxed way.

5.2 Study Design

For answering the first research question (RQ1) we conducted a between-subjects study design, i.e. we showed 10 participants the original metro map and the other ten people were shown the visually

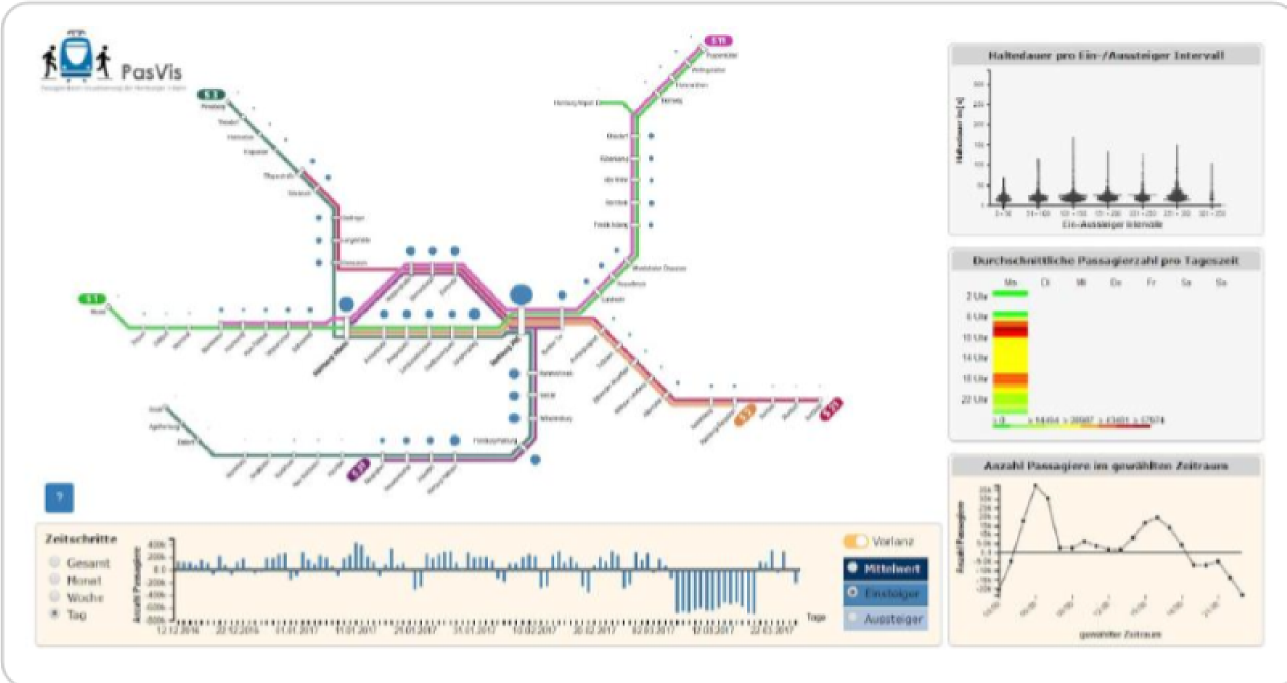


Figure 10: Changing the temporal granularity as well as modifying several parameters gives additional insights into the passenger numbers. The views are linked and changing one aspect has the impact of also adapting other views simultaneously.

enhanced map. Since the other two research questions (RQ2 and RQ3) are based on the enhanced maps we showed all of them to the 20 study participants.

Before conducting the study we asked the study participants to fill out a questionnaire about typical personal details. In this form we also asked them to mention in which cities they have travelled to avoid possible prior knowledge when using the metro map. Finally, we provided a textual description of the user study, the stimuli, and the procedure of the experiment.

We kept the metro map the same but varied the start and destination stations for which the participants had to find a route. This serves as an independent variable in the study to judge if the visual enhancements might have a negative impact on the completion times or the correctness of the found routes. Each participant was shown 10 different start and destination stations, one after the other, and clearly highlighted to avoid searching tasks (similarly to the study by Netzel et al. [19]).

For answering research questions 2 and 3 we let the 20 participants interact with the given map and either asked them to identify good time periods to travel (with a low number of passengers) for a given route or we asked them to identify a route for which they find a low number of passengers. For answering research question 2 we asked 10 trials for each participant, for answering research question 3 we gave the participants a time interval and just asked for identifying routes with a low number of passengers. The difference between research questions 2 and 3 is that in the first case we fix the route and ask for a time period while in the second case we fix the time period and ask for a suitable route with a low number of passengers.

5.3 Stimuli and Tasks

For the stimuli we used our manually generated interactive metro maps (see Figure 4 (b) for an example) and highlighted start and destination stations in a way that they can be found preattentively [9, 25], i.e. without ending up in a long-durating search task.

The 2 tasks to answer were either based on finding routes and telling the station names that lie on the found route in the travelling order or based on identifying a time period with a low number of passengers.

5.4 Pilot Study and Setup

We also conducted a pilot experiment with 2 participants who were excluded from the 'real' user study. Those 2 participants had to answer the 2 tasks for the 3 scenarios helping us to find answers to the given research questions.

In the pilot experiment we asked for 20 trials of each task, but as a result we decided to reduce the number of trials to 10 for answering research questions 1 and 2 and only 1 for answering research question 3.

The study was conducted in an office that was isolated from outside distractions, artificially illuminated, and only a few number of objects were placed in the room to avoid paying attention to other things than to the stimuli. The computer monitor had a resolution of 1920×1200 pixels while the participants sat on a chair with their eyes at the same height as the monitor and at an approximate distance of 50 to 80 centimeters from the monitor. We did not accurately measure those parameters but let the study participants feel comfortable.

5.5 Participants

We conducted a between-subjects study design for the first research question by splitting the 20 participants into two groups of ten each. Research questions 2 and 3 were investigated by a within-subjects study design in which each participant got 10 trials for the first part and just one trial for the second part.

All the 20 participants came from Western countries with a left-to-right reading behavior. The average age of the participants was 22.3 years while the youngest participant was 16 and the oldest one was

51. The participants were non-experts in information visualization that we checked by showing them figures from traditional diagrams in information visualization like treemaps, node-link diagrams, or parallel coordinates plots. They had to name those diagram types and as a second stage they had to explain the visualizations in a few words in a written form. Nobody of our non-experts in visualization was really able to name or explain those diagrams. However, they mentioned that they have seen metro maps before, but nobody ever travelled in Hamburg which was checked by requesting the prior knowledge of the participants.

All of our participants had normal or corrected-to-normal color vision which was confirmed by an Ishihara test or Snellen chart. 6 participants wore glasses and 2 contact lenses. For taking part in the user study we offered them some cookies. The individual experiments lasted for 23 to 35 minutes while the two experiments in the pilot study took much longer, 60 and 67 minutes which made us rethink the study design and reduce the number of trials.

5.6 Study Procedure

We invited the participants to an office isolated from outside noise and tried to reduce the number of distracting objects. The participants first received a questionnaire that was just used to ask personal information like gender, age, prior knowledge in visualization and the like.

Then they were shown public transport maps as they could be found in the interactive visualization tool. A 3-page-tutorial explained how to read and interpret the maps and which symbols and visual variables were used. After the participants confirmed they have understood the maps and the extra visuals in the maps we asked them 3 test questions related to the tasks and stimuli they will see in the 'real' user experiment. Then the participants got some extra time to interact with the metro map tool and to test the scenarios given in the tutorial.

All of the shown stimuli and tasks in the test experiment will not be used in the 'real' experiment to avoid learning effects. In the real experiments an operator was present in the room to take the time and write down remarks about the participants.

The real user study consisted of three separate parts, each testing one of the research questions while for the first part the participants were split into two groups. This splitting was done randomly and not on any preferences based on the personal details. In the parts with the ten trials we permuted the trials to avoid learning and fatigue effects. Between each part there was a short break of a few minutes while the duration was decided by the participant. There was also a give-up possibility but nobody made use of it. We did not limit the time for the single experiments but nobody was really an outlier in terms of taking too much time compared to the others. When the participants were ready with one experiment, i.e. when they were sure they found a good solution, they should clearly state that in a way that the operator was well informed and could write down some remarks.

After the user study each participant could give some final remarks that were recorded by the operator.

5.7 Results

In this section we present the outcome of the user study focusing on the formerly asked research questions concerning comparisons between the original and visually enhanced maps, the identification of time periods when the route is given, and the identification of routes when the time period is given.

5.7.1 Original vs. Visually Enhanced

Research question 1 was asking about the impact that the visually enhanced maps have compared to the original maps. To get any kind of valuable claim for this we measured the completion times for each of the 10 participants and for each of the trials. In each trial, a different route was shown while the same routes were shown for both, the original maps and the visually enhanced maps but in a permuted order to avoid learning or fatigue effects.

Participant group A that completed the task for the original maps took 387.7 seconds in average to answer all 10 trials. All of the found routes were correct which was checked by us after the experiments. Participant group B that completed the same task for the visually enhanced maps took 398.4 seconds in average to answer all 10 trials. Also those routes were correct solutions.

Given the very similar average numbers of the completion times for the original maps and the visually enhanced maps shows us that the extra visual features have no large impact on the readability of the maps.

5.7.2 Identification of Time Periods

Research question 2 was asking about identifying a time period with a low number of passengers when a certain route was given. For finding a solution to this question the participants had to interact with the visually enhanced public transport maps which took much more time than just finding a route like the task for answering research question 1.

For this task we had all the 20 participants because this was not a comparison task, i.e., there were no learning effects between two scenarios. However, the routes for the 10 trials were permuted.

In total it took 917.8 seconds for the 10 trials in average, i.e. more than 1-and-a-half minutes in average to come up with a good time period for travelling on a given route in a public transport map. It seems that the interaction task takes much longer than the map reading task in a static map as in research question 1. However, such a task might also be solved at home before planning a journey to a city due to the fact that the travel times should be fixed prior to the departure in the city.

5.7.3 Identification of Routes

Research question 3 was asking about finding a good route with respect to a low number of passengers. To find an answer to this we selected a time period and requested a route from the shown map.

This experiment was only done once to reduce the total amount of time the entire user study takes. As a final result the participants could solve this task in 25.4 seconds in average. It is surprising that they were much faster than in research question 1 when just finding a route between a given start and a destination station. For research question 3 they had to check the entire map to locate a good route.

However, although the user study could be extended a lot by involving more parameter variations (independent variables) we are already confident with the results since they show that the interactively enhanced maps can be understood and used by non-experts in information visualization.

5.7.4 Participant Feedback

In general, the participants liked the user study but some of them gave useful remarks on how to improve the study, the maps, or even test the tool on other devices.

For example, one participant asked for the same study on a touch device because she thinks that it is unrealistic to use mouse interaction in a metro station. But for planning a journey at home such an interactive metro map setup with mouse interaction on a computer monitor might be good enough.

Some participants felt that they should have had more training before working with the interactions. They had the impression that there were too many details already and they did not use all the provided extras in the map to find the solution to a given task. However, this is not a big issue since we only checked a few scenarios but many more we could think of, consequently many more features must be used.

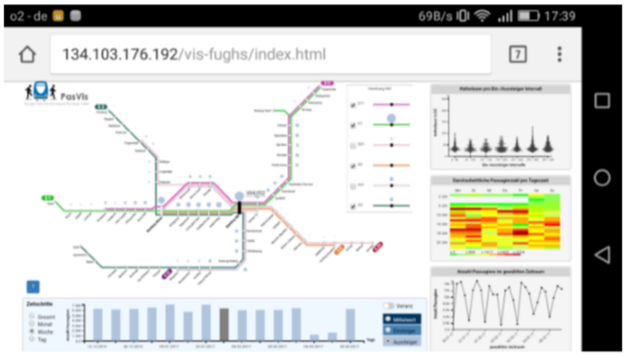


Figure 11: The visually enhanced maps also run on a smart phone although we have not evaluated them in a user experiment. However, the touch interaction might be problematic for selecting tiny visual objects, this is much better on a larger monitor, maybe placed on a metro station's wall.

6 Limitations and Scalability

Although we designed an interactive enhanced public transport map that has been shown to be useful and understandable with several benefits compared to the original not enhanced public transport map we are aware of the fact that it still suffers from lots of limitations, most of them concerning scalability issues like data, algorithmic, visual, perceptual, or users and interactions.

6.1 Data and Algorithmic Scalability

The first problem might come from the data itself. The German train service regularly uses counting trailers to estimate the number of passengers between line segments, i.e. between two stations. Also the number of entering and leaving passengers are counted. However, this data is not totally reliable because the counting trailers are not used for every trip at every time. Hence, there is also some kind of uncertainty in the data which is not taken into account in our current visualization.

Also algorithmic issues might occur when transforming the data into different perspectives given by the fact that users can request the data interactively based on their personal preferences. Also aggregating the data, for example temporally, costs some algorithmic effort, although much of this information can be preprocessed and stored until it is requested.

6.2 Visual Scalability

The user is not able to adapt the design of the metro map, for example the layout of the lines and the stations. This can be problematic if extra visual variables must be added to enhance the metro map. In some cases it would be good to adapt the map layout on the users' preferences, but that would make the implementation of the tool much more complicated.

Another problem concerning visual scalability is the fact that a map might be complex consisting of several hundred stations, possibly with labels. In such a scenario it is pretty difficult to add extra visual information in a way to keep the map readable and to provide more information on the passenger behavior at the same time.

6.3 Perceptual Scalability

From a perceptual point of view it might become difficult to select very small elements, for example the bubbles aligned with the stations in the enhanced metro maps. Clicking on pixel-sized objects is pretty difficult, meaning we need another selection mechanism for that. This effect becomes much more challenging if we have to deal with smart phones and the selection interaction is done by touch where small or tiny visual objects are hidden by the finger for example.

Moreover, the color coding is always problematic if we have to deal with visual variables [24, 25] like they occur in the metro maps. The lines, stations, interchange points, visual enhancements all might have different color leading to misinterpretations for the users. Changing the color coding of metro lines is a bad design choice since normally they follow a mental map preservation concept, i.e. once the colors of the lines are learned they should stay the same all the time.

6.4 User and Interaction Scalability

The scenario of reading and exploring a public transport map is definitely limited to a certain number of people. For example, standing in front of a large touch monitor or even a smaller display, several people at the same time can already hide important information and on the other hand it is pretty difficult to interact 'collaboratively' when planning a journey in a city by using the same metro map. However, using different smart phones (see Figure 11) might be a good solution to the negative effect that the final result has to be found by merging the opinions of several people together. In this way we might speak here of user or interaction scalability.

Another challenging problem is definitely the level of expertise of the travelers. Although the maps are typically designed for non-experts in visualization, also those non-experts might have a different understanding or strength of interpretability of the visual variables encoded in the maps as well as the interactions to be applied to modify the views and the parameters.

6.5 Adaptability to Other Scenarios

It is pretty difficult to make all public transport maps in the world interactively enhanced by additional visual features. Our maps are manually designed and it took a lot of effort to produce the maps first and then attach the extra data to it. Moreover, it is not guaranteed that all public transport systems provide such extra data.

Typically, the maps are only focusing on the metro lines in their simplest form. But it would be beneficial if also other transport options could be added, for example, bus lines. This might again have the negative effect that the maps get visually cluttered.

Also the maintainability of the tool is problematic since public transport systems are not static but they are dynamically changing from time to time. This demands for extending the displayed maps and services in an up-to-date manner.

7 Conclusion and Future Work

In this paper we described a public transport visualization with interactive visual enhancements for taking into account the passenger numbers. This information can be aligned with the stations as well as with the metro lines, moreover additional timeline-based histogram views or calendar-based diagrams can be requested to get an overview about the dynamic passenger behavior on different levels of temporal granularity. We discussed interactions and illustrated the usefulness of the visualization in an application scenario for the public transport map of Hamburg in Germany. Finally, we discussed limitations and scalability issues and described the design and results of a user evaluation. For future work we plan to add more interaction techniques as well as an automatic solution to requested routes with user-defined criteria like passenger numbers, travel times, or sights to be visited. Also an eye tracking experiment [14, 15] with travelers under real conditions might be a good idea to investigate if the interactive metro maps are really useful enhancements compared to the original static maps.

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