Passenger-oriented visualization of urban mobility data

Ana Rita Torres

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Abstract

Currently, the majority of public transportation companies have applications and visualizations with information about the services they provide. These tools are mainly used by passengers, even though these were not developed with a passenger-oriented approach. This culminates in an uncertainty of what is the passenger perspective when interacting with the information provided or if it is even this type of information that the passenger needs. Besides, the techniques, metaphors and layouts used may not be the most adequate when it concerns the understanding of the information by the passenger.

Therefore, this thesis aims to explore the problem of passenger-oriented visualization of urban mobility data, to improve the passengers experience in their daily commuting experience. For that effect, there are three main phases in development: data gathering, prototyping and evaluation. Initially, a questionnaire concerning background information of usage of public transportation services, which information would the users find relevant and visualizations prototypes was created. After the data is collected, it will be analyzed in order to extract concrete feedback. This feedback will be essential to know how and what to evolve the prototype. The interactive prototype to be developed will be designed considering user-centered design methodologies and results collected previously. The goal of this prototype is to inspire further development and a realistic implementation of it, either for bus, train or metro services.

The participants were asked about the several visualization prototypes presented to them. The feedback tended to be positive and the participants had the opportunity to comment on them in the way they found more opportune. The series of questionnaires lead to an interesting conclusion, users feel that time is a significant indicator when concerning the use of public transportation.

What brings novelty to the project is the focus on the passenger, which is expected to bring awareness to other researchers in transportation and information visualization. As a practical contribution, new tools can facilitate the way passenger-oriented visualization of data is perceived and studied, benefiting the user.
Resumo

Atualmente, a maioria das empresas de transportes públicos têm aplicações e visualizações com informação relativa aos serviços que providenciam. Estas ferramentas são principalmente usadas por passageiros, apesar de estas não terem sido desenvolvidas com uma abordagem orientada a passageiros. Isto culmina numa incerteza em qual é a perspectiva do passageiro quando interage com a informação fornecida e se o tipo de informação fornecido é relevante para o passageiro. Além disso, as técnicas, as metáforas e os layouts usados podem não ser os mais adequados para o passageiro perceber a informação.

Assim sendo, esta dissertação tem o objetivo de explorar o problema da visualização de dados urbanos orientados ao passageiro, de forma a melhor a experiência quotidiana de deslocamento dos passageiros. Para esse efeito, existem três fases principais de desenvolvimento: recolha de dados, prototipagem e avaliação. Inicialmente, um questionário sobre a experiência de utilização de serviços de transporte público, informação cujos utilizadores achariam relevantes e protótipos de visualizações foi criado. Após recolher os dados, estes serão analisados de forma a extrair feedback concreto. Este feedback será essencial para saber o que prototipar e como fazê-l-o. O protótipo interativo a ser desenvolvido será desenhado tendo em consideração design centrado no utilizador e a informação obtida anteriormente. O objetivo deste protótipo é inspirar desenvolvimento futuro e uma implementação realista do sistema prototipado, sendo para serviços de autocarro, comboio ou metro.

Os participantes foram questionados sobre os vários protótipos de visualização apresentados. O feedback tendeu a ser positivo e os participantes tiveram a oportunidade de comentar sobre estes quando acharam mais oportuno. A série de questionários leva a uma conclusão interessante, os utilizadores sentem que o tempo é um indicador significativo quando se trata do uso de transporte público.

Este projeto é inovador pelo facto de se focar no passageiro, na esperança de consciencializar outros investigadores na área dos transportes públicos e visualização de informação. Como contribuição prática, novas ferramentas podem facilitar a forma como a visualização de informação orientada a passageiros é percecionada e estudada, em prol do utilizador.
I would like to sincerely thank my supervisors Teresa Galvão and Thiago Sobral for all the guidance provided during the dissertation process.

I would also like to thank my friends for the support, piano breaks, listening to my endless ranting and just going for coffees or drinks whenever: Rafaela, Diana, Jonas, Rui, Cepa, Miguel, João, Bruno, Gonçalo and Nuno.

And last, but not least I would like to thank my family for all the patience, financing and love.

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“Never bend your head. Always hold it high. Look the world straight in the eye.”

Hellen Keller
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<table>
<thead>
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<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>2D</td>
<td>Two Dimensional</td>
</tr>
<tr>
<td>3D</td>
<td>Three Dimensional</td>
</tr>
<tr>
<td>FEUP</td>
<td>Faculdade de Engenharia da Universidade do Porto</td>
</tr>
<tr>
<td>GPS</td>
<td>Global Positioning System</td>
</tr>
<tr>
<td>HART</td>
<td>Hillsborough Area Regional Transit</td>
</tr>
<tr>
<td>ID</td>
<td>Identifier</td>
</tr>
<tr>
<td>iOS</td>
<td>iPhone Operating System</td>
</tr>
<tr>
<td>IPI</td>
<td>Indicator Performance Index</td>
</tr>
<tr>
<td>MPI</td>
<td>Measure Performance Index</td>
</tr>
<tr>
<td>NFC</td>
<td>Near Field Communication</td>
</tr>
<tr>
<td>POPIX</td>
<td>Passenger-Oriented Performance Index</td>
</tr>
<tr>
<td>RVTD</td>
<td>Rogue Valley Transportation District</td>
</tr>
<tr>
<td>SDMTS</td>
<td>San Diego Metropolitan Transit System</td>
</tr>
<tr>
<td>TIP</td>
<td>Transportes Intermodais do Porto</td>
</tr>
<tr>
<td>USA</td>
<td>United States of America</td>
</tr>
<tr>
<td>VBB</td>
<td>The Verkehrsverbund Berlin-Brandenburg</td>
</tr>
</tbody>
</table>
Chapter 1

Introduction

At first sight, it may seem that the information public transportation systems provide to the passenger is more than enough to aid the passengers in their daily commuting activities. However, there is a considerable gap of information transmission between these two entities, mainly, because the passenger has limited access to all the information available, most of it is kept for the benefit of the companies. Public transportation companies share flawed details regarding lines, timetables and their alterations during holidays and festivities. These companies usually do not share information concerning vehicle suppression or delay.

Therefore, this dissertation concerns the visualization of information to aid the passenger in their daily commuting experience making it easier, better and more personal. For this effect, methodologies based in principles of human-computer interaction and user-centered design will be followed to create information visualizations oriented to the passengers.

1.1 Context

There is a necessity of public transportation companies to improve communication with the passengers, which will eventually lead to a more effective system. Although research shows there is a lot of investigation regarding the subject of public transportation system and the visualization of substantial information from the stakeholders perspective, there are few studies that are focused on the passenger. This gap presents an opportunity for research and development. For that effect several areas of study are taken into account, such as public transportation, human-computer interaction, user centered design and information visualization.

1.2 Motivation and Goals

The development of the project described has one main beneficiary: the passenger. Therefore, the principal motivation of this project is to come to a better understanding of what are the current
Introduction

user needs concerning daily commuting. And, based on this, to generate a prototype of a system that the user can rely and trust for everyday trips. This dissertation also intends to analyze how methods based in human-computer interaction and user-centered design can be applied towards the development of a passenger-oriented visualizations.

The main goal will be to analyze if the to be developed visualization system of transportation information will lead to a better customer service. In order to analyze this, it will be important to consider the passenger’s awareness of the services provided and how they can be more helpful.

1.3 Dissertation Structure

This initial chapter serves the purpose of presenting the theme of the dissertation and exploring concepts that will be important for the overall understanding of the project. It also provides insight on the general goals to achieve with the development of the project. The following chapters will delve into more specific subjects:

Chapter 2 - State of Art
This chapter will expose previous research done on the subjects, as well as the supporting technologies to serve similar objectives.

Chapter 3 - A Passenger-Oriented Approach for Visualizing Urban Mobility Data
This chapter will present the methodology that will be used to implement the solution, hand in hand with the process of development.

Chapter 4 - Results and Discussion
This chapter will focus on the experiments conducted during the dissertation, also concerning the results and discussion of those.

Chapter 5 - Conclusions and Future Work
This last chapter will involve conclusions relative to what has been done, expected results and the planning of the work to come.
Chapter 2

State of Art

This chapter describes the current state of research about user-centered design, information visualization and passenger related subjects. It also explores some existing technologies which provide visual tools to help the passengers during their commuting experience.

2.1 User-Centered Design

User-centered design is focused on the users’ necessities and interests and has an important role in producing functional and coherent products [1]. It can also be defined as a methodology to assure the product is meeting the needs of the user followed by developers and designers [2]. The User-centered design process can be divided into four parts: understanding the context of use, specifying user requirements, designing solutions and evaluating against requirements.

![User-centered design process](adapted from [3])

In the following subsections, each of the phases of the user-centered design process (presented in Figure 2.1) will be explored in more depth.

2.1.1 Understanding the Context of Use

While trying to solve a design problem one of the main issues and recurrent errors is to begin with a "physical" design, instead of defining strong goals. Consequently, a major importance is attributed to defining usability objectives and user needs. The design of process should start by
conceptualizing what to create and express how to create it, in other words, defining the problem space \[4\].

Afterwards, the conceptual model or design model should be defined since it concerns the concepts and ideas to be transmitted and applied. This model can be based on activities such as instructing, conversing, direct manipulation and exploring. Another model, just as relevant, is the mental model which is commonly related to the user’s perspective of how things should work, also called the user’s model. Finally, the system image should be a combination of both, in order to create a clear and useful system \[1\].

![Diagram](image.png)

Figure 2.2: Norman’s design model (adapted from \[1\])

Essentially, to obtain a first solid idea of what the final product will be both the user and the designer need to be involved and come to a conclusion together.

### 2.1.2 Specifying User Requirements

A requirement must be explicit, simple and unequivocal while portraying what the product should do and how it should work. Requirements can be divided into two types: functional and usability. The first type concerns system behaviour describing, which functionalities the product should have. The second type focuses on constraints of the system and how it should work. To consolidate these concepts, imagine a word processor. A functional requirement would be to be able to format text, while an usability requirement would be it should be available for a diverse set of operating systems \[4\].

In order to gather essential requirements, a data collection process should be executed. This data gathering can be achieved through a series of methods, presented in the Figure 2.3. This
State of Art

image exposes what the techniques are suitable for and what type of that is gathered while using them, as well as describing the advantages and disadvantages concerning their use.

<table>
<thead>
<tr>
<th>Technique</th>
<th>Good for</th>
<th>Kind of data</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Questionnaires</td>
<td>Answering specific questions</td>
<td>Quantitative and qualitative data</td>
<td>Can reach many people with low resource</td>
<td>The design is crucial. Response rate may be low. Responses may not be what you want</td>
</tr>
<tr>
<td>Interviews</td>
<td>Exploring issues</td>
<td>Some quantitative but mostly qualitative data</td>
<td>Interviewer can guide interviewee if necessary. Encourages contact between developers and users</td>
<td>Time consuming. Artificial environment may intimidate interviewee</td>
</tr>
<tr>
<td>Focus groups and workshops</td>
<td>Collecting multiple viewpoints</td>
<td>Some quantitative but mostly qualitative data</td>
<td>Highlights areas of consensus and conflict. Encourages contact between developers and users</td>
<td>Possibility of dominant characters</td>
</tr>
<tr>
<td>Naturalistic observation</td>
<td>Understanding context of user activity</td>
<td>Qualitative</td>
<td>Observing actual work gives insights that other techniques can’t give</td>
<td>Very time consuming. Huge amounts of data</td>
</tr>
<tr>
<td>Studying documentation</td>
<td>Learning about procedures, regulations and standards</td>
<td>Quantitative</td>
<td>No time commitment from users required</td>
<td>Day-to-day working will differ from documented procedures</td>
</tr>
</tbody>
</table>

Figure 2.3: Data gathering techniques (adapted from [4])

2.1.3 Designing Solutions

A design solution can take quite sometime until it reaches its final stage. In order to reach that final stage several prototypes must be evaluated and redesigned as new information and inputs are gathered.

A prototype can be low-fidelity or high-fidelity, meaning that it can be anything from a modeled piece of metal to an extremely complex mockup designed through a specialized software. The objective of prototyping is to generate discussion and test ideas, it can also be very helpful to identify which alternatives work better. A low-fidelity prototype is usually developed in an initial phase, since it is easier to change and do not present the level of detail expected in the final product. It can be in the form of storyboarding or sketching. On the other hand, a high-fidelity prototype
State of Art

has elements that are expected to be in the final product and represents a prototype much similar to the final product. These frequently are designed with software tools such as Macromedia Director and Smalltalk [4]. The following table presents a simple but detailed comparison of advantages and disadvantages of each type:

<table>
<thead>
<tr>
<th>Type</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low-fidelity prototype</td>
<td>Lower development cost</td>
<td>Limited error checking</td>
</tr>
<tr>
<td></td>
<td>Evaluate multiple design concepts</td>
<td>Poor detailed specification to code to</td>
</tr>
<tr>
<td></td>
<td>Useful communication device</td>
<td>Facilitator-driven</td>
</tr>
<tr>
<td></td>
<td>Address screen layout issues</td>
<td>Limited utility after requirements established</td>
</tr>
<tr>
<td></td>
<td>Useful for identifying market requirements</td>
<td>Limited usefulness for usability tests</td>
</tr>
<tr>
<td></td>
<td>Proof-of-concept</td>
<td>Navigational and flow limitations</td>
</tr>
<tr>
<td>High-fidelity prototype</td>
<td>Complete functionality</td>
<td>More expensive to develop</td>
</tr>
<tr>
<td></td>
<td>Fully interactive</td>
<td>Time-consuming to create</td>
</tr>
<tr>
<td></td>
<td>User-driven</td>
<td>Inefficient for proof-of-concept designs</td>
</tr>
<tr>
<td></td>
<td>Clearly defines navigational scheme</td>
<td>Not effective for requirements gathering</td>
</tr>
<tr>
<td></td>
<td>Use for exploration and test</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Look and feel of final product</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Serves as a living specification</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Marketing and sales tool</td>
<td></td>
</tr>
</tbody>
</table>

2.1.4 Evaluating against Requirements

To evaluate a system correctly one needs to know what, why and when to evaluate. The "what" should meet user’s common uses of the product. If the product is a website it could range from something as simple as logging in to changing a password. The "why" is crucial to know if the users can interact with the product and like it. Finally, the "when" depends if the product is new or is an upgrade of an already existing system. In the first scenario, it is recommend that as soon as mockups are created, users should be involved. In the second scenario, a comparison is between the previous product and the new one, but the room for change is much smaller. As a result of this type of situations two evaluation methods appear: formative evaluation and summative evaluation. A formative evaluation occurs during the design process to verify that the user’s needs are being met. A summative evaluation happens after the product is finished to assure stakeholders that the product successful [4]. The Figure 2.4 displays the correct way to use the evaluation paradigms and what can be retrieved from using this methods.
Besides these evaluation paradigms, there is the coaching method which is quite different from most methods, since it focuses in steering the user in the right direction during the evaluation process. Therefore, the user can ask questions at any time about the system at use and the evaluator will clarify any doubts to his best abilities. By doing so, this method allows to test products with novices which may not be familiar with the concept but with help can give valuable feedback [5].
2.2 Information Visualization

This section gives an overview relative to visualization concepts and paradigms, as well as reinforcing the importance of visualization. It also provides an in-depth look into some methods of visualization of public transportation data.

2.2.1 Visualization Analysis and Design

The visualization of a system intends to aid people in everyday tasks by representing data in an effective way. In order to understand if the data is being transmitted correctly, there is a need to analyze the visual system.

![Figure 2.5: Analysis framework](image)

This analysis (presented in Figure 2.5) is done by answering the following questions:

- **what** data does the user see?
- **why** the user wants to use a visualization tool?
- **how** the visual encoding and interaction are built regarding design decisions?

The following subsections will explore in further detail the questions to better understand the analysis framework.

2.2.1.1 What

In order to answer the first question, one needs to think about what can be visualized and the answer is data, datasets, and attributes.

The Figure in 2.6 shows five primitive data types. An item is a discrete entity, e.g., node in a network. An attribute is a particular characteristic possible to log, measure, or observe. A link is a relation between items, e.g., in a network. A grid establishes the approach for sampling continuous data geometrically and topologically between its cells. A position is spatial data, giving the location in 2D and 3D [6].
A dataset is any collection of information that is the target of analysis. The Figure 2.7 presents the several dataset types. A table is composed by rows and columns, it can be either flat or multidimensional. A network specifies a relation among multiple items. A field is a set of grid positions. A geometry dataset clarifies the position of items with unambiguous spatial positions [6].

2.2.1.2 Why

In order to answer the second question, one needs to know why people are using visualization concerning actions and targets. Actions can be divided in three levels to characterize user goals: analyze (high-level choices), search (medium-level choices) and query (low-level choices).

The analyze action presents two objectives, the user may want to consume information or may want to produce information (presented in Figure 2.8). The consumption can happen while unveiling unknown information (discover), during a concise communication of the information (present) and finally, in casual encounters with the information (enjoy). The production focuses on adding graphical or textual notes to preexisting content (annotate), saving and capturing visual elements (record) and to create new data from preexisting data (derive) [6].
The search action presents four search options: lookup, browse, locate and explore (presented in Figure 2.9). These methods of search depend on the knowledge of location (knowing where to look for) and target (knowing what to look for).

<table>
<thead>
<tr>
<th>Target known</th>
<th>Target unknown</th>
</tr>
</thead>
</table>
| Location known | Lookup
| Location unknown | Explore

The query action follows the search and implies that a target for search was found. The target found can fit into three types of tasks: identify, compare and summarize. A single target is the scope relative to identify, if the known targets are searched by lookup or locate the characteristics of the target are returned. If the target is returned by means of browsing and exploring, references are returned. The scope of compare concerns multiple targets, making it complex than the identify tasks. The summarize task covers all possible targets and intends to give a comprehensive view of everything, similarly to an overview [6].
Targets represent information that is relevant in some way for the user. There are three high-level targets: trends which are characterization of patterns in data, outliers which represent data that does not fit the patterns and features which represent any structure of interest (presented in Figure 2.11).

Target attributes are visually encoded properties which encompass one or multiple attributes (presented in Figure 2.12). The one attribute scope covers individual values such as the minimum or maximum of a range and the distribution of a single attribute. When it comes to multiple targets, these can be related by dependency, correlation or similarity [6].

In order to answer the third and final question, one needs to know how to design visual idioms. These can be separated in four parts: encoding, manipulating, faceting and reducing. To encode
data (presented in Figure 2.13) there are several options on how to arrange data by expressing values; separating, ordering and aligning regions; using given spatial data. There is also the possibility to encode non-spatial data by means of mapping with the aid of color, size, angle, shape and motion [6].

Figure 2.13: Encoding [6]

Figure 2.14: Manipulating, faceting and reducing [6]

The manipulation aspect is able to change any view aspect, select any element within the view and change the view point by navigating. The faceting data aspect enables to juxtapose and
coordinate multiple views, partition data between views and superimpose layers on top of each other. The reducing aspect aims to reduce the amount of data visualized, for that effect methods of filtering, elements aggregation and embed focus information compiled within a single view [6]. These idiom visualization aspects are represented in Figure 2.14.

2.2.2 Methods of Visualization of Urban Mobility Data

This subsection will explore some methods of visualization created to disclosure and offer information to the passengers.

2.2.2.1 Visualization of Spatial-Temporal Data

In general, visualizing spatio-temporal information permits humans to discern objects, locations, times and the relationships between them. The goal of Nguyen et al. [7] was to build temporal maps to illustrate the movement of objects, particularly for the challenge of finding bus paths.

In this specific context, there are a few concepts that need to be exposed to obtain a full understanding of the visualization:

- **Bus**: moving object in which the movement is described by their routes and trips

- **Bus route**: space trajectory on the location plane(xy)

- **Bus trips**: trajectories in temporal maps, showing in a 3D environment variables such as: positions of departure stations and arrival stations, as well as, stops with times of departures and arrivals(present in Figure 2.15)

This junction of concepts allows passengers to select bus trips more adequate for their trips. This is possible because information about departure time, arrival time and each bus stop is discriminated.
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Figure 2.15: Bus route and bus trip in space and time [7]

In order to simplify the representation some assumptions are made, such as all trip times of every bus trip is identical and their average velocity on the same route is similar.

The concept developed permits several types of trips supported with visual aid of a spatial-temporal map. The simplest trip (type 1 - presented in Figure 2.16) contemplates a single bus trip without connections, by following four simple steps:

1. **Marking the arrival location**
The passenger marks the arrival location on the location plane(xy) either by using coordinates or an estimation of the location.

2. **Marking the departure location**
The passenger marks the departure location on the location plane(xy) either by using coordinates or an estimation of the location.

3. **Selecting the arrival bus stop**
Firstly, the passenger selects the arrival location and stops near that location are displayed giving the passenger the possibility to select a stop of arrival. That shift allows the display of bus routes which visit the stop of arrival selected. Afterwards, a display of one or more routes close to the departure location is shown and the passenger can choose the stop of arrival.

4. **Selecting the departure stop and the bus travel**
The passenger selects the arrival bus stop triggering the display of bus routes which visit that stop. The passenger can then select the departure stop which shows the normalized trip of the route, by moving the normalized trip through the time axis(t) to reveal the most
suitable bus trip. Finally, the passenger can mark the bus travel that connects the departure and arrival locations.

A slightly more complex one (type 2 - presented in Figure 2.17) contemplates a two bus trip journey with a connection in a bus stop. While Type 1 bus trips concern the existence of one or more routes which reach the departure location, Type 2 concerns the situation where no routes meet the departure location and a repetition of the process from step 3 on failed. In this particular case, the passenger estimates an arrival bus stop and follows the steps there on after:

5. Selecting the arrival bus route
The passenger selects the arrival bus route and the display of every route which visits the stop is shown. After, the passenger marks the arrival route by estimation.

6. Selecting the departure bus stop
The passenger selects the departure location and is shown the every bus stop nearby to it. Then, the estimated departure stop is marked.

7. Selecting the departure bus route
The passenger starts by selecting the departure stop and all of the bus routes that include the departure stop are displayed on the xy axis. As a consequence, one or more routes which intersect the arrival route in a common stop are displayed and the passenger chooses one as the departure route.

8. Selecting the arrival bus trip
By selecting the arrival bus trip, the passenger is shown the normalized bus trip. By moving it along the time axis(t), the passenger can mark the arrival trip which respects the expected arrival time.
9. Selecting the departure bus trip
This step follows the same process as the previous one but regarding the departure bus trip.

10. Building the bus travel
The bus travel is built by combining the arrival bus trip with the departure bus trip.

![Figure 2.17: Type 2 of bus trips in a spatial-temporal map [7]](image)

If it is not possible to select the departure bus route, even by repeating the processes either from step 6 or step 3 on, a more complex trip (type 3) is performed contemplating three bus trips with two connection points.

11. Selecting the near-departure bus stop
The passenger selects a different bus stop on the departure route, fairly near to the departure location.

12. Selecting the near-departure bus route
The passenger selects the near-departure bus stop and sees the display of all the bus routes which visit that stop. If one or more options are displayed where the arrival route is intersected at a common stop a route for the near-departure bus is marked. If this is not viable the previous step is repeated.

13. Selecting the arrival bus trip and the near-departure bus trip
In order to display the arrival normalized bus trip, the passenger selects the arrival route and moves the normalized bus trip along the time axis(t) to encounter the more suitable trip. When found the arrival bus trip is marked. The same process is mimicked regarding the near-departure bus route.

14. Selecting the departure bus trip
The passenger shifts the normalized trip of the departure bus route to find intersections.
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between the departure bus trip and the near-departure bus trip and marks the trip concerning the departure bus trip.

15. Building the bus travel
To build the bus travel, the departure, near-departure and arrival trips are connected.

These trip options are always dependent of the passenger’s necessities and the capacity of the network involved [7].

2.2.2.2 Multicriteria Optimization applied to Map Layouts
This multicriteria optimization method aims to automatically generate metro maps with the goal of finding routes which are more efficient than the ones in published maps and undistorted maps. In order to reach this, a weighted sum of metrics is calculated to find a fitness value for the layout of a map. These metrics consist on the effective placement of stations, good line layout and unambiguous map labeling. Then a hill climbing optimization is performed to reduce the fitness value and achieve improved map layouts. Three clustering methods are also applied to the map to avoid local minima:

- Clustering over length edges
- Clustering non straight lines
- Partitioning

An empirical study using the aforementioned methods was conducted to evaluate the following statements:

1. A map of a metro system drawn with our automated software is better for finding an optimal route than a undistorted map of the system.

2. A map of a metro system drawn with our automated software is better for finding an optimal route than the official published map of the system

3. A map of a metro system drawn with our automated software is preferred over an undistorted map of the system

4. A map of a metro system drawn with our automated software is preferred over the officially published map of the system

The figures presented in 2.20 and 2.21 are the improvements of the map layouts presented in figures 2.18 and 2.19.
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Figure 2.18: Original map - Mexico [8]

Figure 2.19: Original map - Sydney [8]
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Figure 2.20: Generated map - Mexico [8]

Figure 2.21: Generated map - Sydney [8]
According to Walker et al. [8], the empirical experiment conducted showed that, the layouts generated can achieve better results for route planning than officially published maps and undistorted layout maps. However, it is improbable that the maps generated will lead to better results than the finest hand drawn maps.

2.2.2.3 Visualization of Real-Time Information for Journey Planning

The goal of Krause et al. [9] is to use visualization in real-time to prevent time waste when commuting to the next connection or even another station. By examining distance, travel and comparing them using distinct routes and journeys. The tool of choice to visually support it, is BusVis. This tool shows the results dynamically using a node-link scheme, a node illustrates stations, edges illustrate connections between the nodes and the size of the node illustrates the number of lines. The colored lines represent bus lines, while black lines represent walking paths.

The routes are displayed in two layouts: radial and stress-majorization. The radial layout (presented in Figure 2.22 (b)) positions stations concentrically around the starting point (red node) and the distance from that point a station represents precisely the quickest time to arrive to that station. The stress-majorization (presented in Figure 2.22 (c)) layout shows the distance of the starting point (red node) to every station around and the length of the edge is proportional to the time it takes to arrive there [9].

![Konstanz bus transportation system](image)

Figure 2.22: Konstanz bus transportation system (a) Geographical layout (b) Radial Layout (c) Stress-majorization layout [9]

This layouts are interesting, in the sense that as in any other system to calculate routes, the user inserts a starting point and a destination point, however, here possible options are showed and allow an easy visual comparison.

2.3 Related Work

This section presents passenger-oriented studies concerning their behaviours and expectations, as well as how they general experience the public transportation system and the concerns it arises in them.
2.3.1 Passenger Behaviour

A passenger behaviour concerning a service is always dependent on three factors: satisfaction, perception and expectation. If the perception (P) a passenger has of a certain service is relatively better than the expectation formulated (E), the passenger will be satisfied (S). Meaning that the bigger the difference between the perception and the expectation, the greater the chance of a satisfied passenger. Therefore, if the service providers can manage either the expectations or perceptions of the passengers the outcome can be favourable for both parts.

\[ S = P - E \]  

For example, in the specific case of waiting times, which is a relevant factor when talking about public transportation, there are several aspects to take into account. When a passenger is informed that there has been a delay but no other information is given, it evokes feelings of uncertainty and anxiety that lead to a passenger dissatisfaction. In a case where the passenger is warned about how much time until its vehicle arrives, initial feelings of discontent may arise, however in the long run the passenger usually calms down and accepts the situation. In spite of the passenger accepting the delay, there is always the perception on how much time has passed, which is generally superior than the actual time. Information in real-time helps to diminish this sense of boredom or even uselessness a passenger feels when waiting a long time [10].

2.3.2 Passenger Expectations

The passenger expectations are intrinsically related to their personal experience and everyday needs. For this reason it is quite difficult to define passenger expectations in a broad way. However, researchers overlooked self-interested demands and came to a small set of general demands that every passenger can relate to.

When using public transportation systems, the passenger wants a vehicle that takes them where they want to go, meaning that the service needs to be available from a departure point desirable for the user, as well as to drive them to the destination point. Then, the service should be provided at a favourable schedule, that is, it takes the passenger when they want to go. Additionally, the journey should be productive, the passenger should be able to make the most out of it by resting, working or leasing. The service has to ensure the passenger that it is a good use of their time, whether waiting or during the ride. It is also very important that the passenger believes the service is putting their money into good use, essentially that there could not be a better and cheaper service that would serve the same purpose. Likewise the passenger should feel respected, secure, comfortable and appreciated. The reliability of the system is imperative to earn a passenger’s trust and fidelity. The passenger has to be able to rely on the service knowing that it will perform as it is supposed to. Finally, the passenger wants the freedom to be spontaneous and impulsive being able to change plans easily without having to worry about transportation restrictions [11].
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The metrics that sum up the main demands of public transportation users are:

- It takes me where I want to go
- It takes me when I want to go
- It is a good use of my time
- It is a good use of my money
- It respects me
- I can trust it
- It gives me freedom

In spite of being difficult to attain these are not impossible and can make a huge difference in the passengers everyday life.

2.3.3 Passenger-Oriented Studies

2.3.3.1 Real-time versus Perceived time

In order to expose the importance of passengers being able to access waiting times in real-time anywhere, a study was developed while testing the impact of the OneBusAway application (presented in 2.4.1.3) in everyday transportation users. The main goal of Watkins et al. [12] was to understand the difference between the passenger’s perception of waiting time and the real waiting time. For that effect, some riders information was gathered, such as age, gender and distinguishable characteristics such as having a colorful hat, type of jacket or facial hair. For this purpose, passengers where approached in bus stops to answer a set of simple questions, described in Table 2.2. The analysis of the information gathered after the survey was fulfilled lead to a series of statements presented in Table 2.3.

<table>
<thead>
<tr>
<th>No.</th>
<th>Question</th>
<th>Question</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td>As precisely as possible, how long have you been waiting for the bus?</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>On a scale of 1–10, 1 being relaxed and 10 being aggravated, how do you feel about waiting for the bus?</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>As precisely as possible, how long do typically wait for this bus?</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>What they use to find out when the next bus is arriving, what type of device they use to access this information, the bus route, their destination, and how frequently they take this particular bus.</td>
</tr>
</tbody>
</table>
Table 2.3: Statements gathered from the answers to the questionnaire (adapted from [12])

<table>
<thead>
<tr>
<th>No.</th>
<th>Statement</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Passengers’ perception of waiting time is longer than the actual waiting time</td>
</tr>
<tr>
<td>2</td>
<td>The fact of having access to real-time information of timetables reduces the wrong waiting time perception</td>
</tr>
<tr>
<td>3</td>
<td>The access to this kind of information leads to lower stress and anxiety levels</td>
</tr>
</tbody>
</table>

The access to real-time information concerning the arrival of the bus diminishes waiting time, enhancing the awareness of the actual waiting time. It also reduced the stress levels of passengers, as well as increased the sense of security and improved passenger satisfaction. However, this information does not improve the reliability of the service provided by public transportation systems [12].

2.3.3.2 Measures and Indicators of Satisfaction

There are two important concepts for stakeholders that aid the study of passenger-oriented services, passenger view and operator view. A passenger view relates to perceived and expected quality: an operator view to the targeted and delivered quality [13]. The Table 2.4 proposes a set of measures and indicators to evaluate systematically the quality of service. Each measure is composed by a set of indicators e.g. the time measured is composed by the indicators: waiting time, commuting time and reliability.

Table 2.4: Classification of measures and indicators (adapted from [13])

<table>
<thead>
<tr>
<th>Measures</th>
<th>Indicators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>Waiting Time</td>
</tr>
<tr>
<td></td>
<td>Commuting Time</td>
</tr>
<tr>
<td></td>
<td>Reliability</td>
</tr>
<tr>
<td>Cost</td>
<td>Fares</td>
</tr>
<tr>
<td>Accessibility &amp; Transfer</td>
<td>Accessibility to stations</td>
</tr>
<tr>
<td></td>
<td>Transfer Distance</td>
</tr>
<tr>
<td>Comfort</td>
<td>Occupancy rate</td>
</tr>
<tr>
<td></td>
<td>Cleanliness of vehicle</td>
</tr>
<tr>
<td></td>
<td>Temperature inside vehicle</td>
</tr>
<tr>
<td>Safety &amp; Security</td>
<td>Station security</td>
</tr>
<tr>
<td></td>
<td>Station lighting</td>
</tr>
<tr>
<td></td>
<td>Coin sales service</td>
</tr>
<tr>
<td></td>
<td>Station cleanliness</td>
</tr>
<tr>
<td>Service</td>
<td>Information announcements</td>
</tr>
<tr>
<td></td>
<td>Escalators</td>
</tr>
<tr>
<td></td>
<td>Automatic Vending Machines</td>
</tr>
<tr>
<td></td>
<td>Courtesy of station staff in the waiting area</td>
</tr>
<tr>
<td></td>
<td>Signboards and instructions</td>
</tr>
</tbody>
</table>
The metrics present in the Table 2.4 were obtained by exclusively surveying passengers, to get physical results the need of a formal analysis emerged. With that intention a passenger-oriented performance index (POPIX) was elaborated. This index is calculated in three phases. Firstly, the indicator performance index (IPI) is calculated for each one of the indicators and the scores of importance and satisfaction are used as weights (presented in Equation 2.2). Secondly, the measures performance index (MPI) is calculated by averaging the IPI scores (presented in Equation 2.3). Finally, the POPIX is calculated by averaging the MPI scores (presented in Equation 2.4).

\[
IPI_j = \frac{\sum_{i=1}^{m} (I_i \times S_i)}{m}
\]  

(2.2)

where:

- \(IPI_j\): Indicator Performance Index of the \(j^{th}\) indicator
- \(m\): Number of respondents
- \(I_i\): Importance score of the \(i^{th}\) respondent
- \(S_i\): Satisfaction score of the \(i^{th}\) respondent

\[
MPI_k = \frac{\sum_{j=1}^{n} IPI_j}{n}
\]  

(2.3)

where:

- \(MPI_k\): Measure Performance Index of the \(k^{th}\) measure
- \(IPI_j\): Indicator Performance Index of the \(j^{th}\) indicator
- \(n\): Number of IPIs of the \(k^{th}\) measure

\[
POPIX = \frac{\sum_{k=1}^{o} MPI_k}{k}
\]  

(2.4)

where:
POPIX: Passenger-oriented Performance Index

\( MPI_k \): Measure Performance Index of the \( k^{th} \) measure

\( o \): Number of MPIs

The results of Kesten et al. [13] provided through this indicator show that an analysis solely dependent of passengers opinions is subjective and does not demonstrate the real conditions of the service. The passengers tend to share information about what they want, which not always meets what they need. Therefore, to obtain more accurate results the input of experts is also essential to evaluate the performance of public transportation services.

### 2.4 Existing Technologies

This section presents already existing technologies that are related to what is intended to achieve with this dissertation. These technologies range from mobile or web-based applications to visualization maps of public transportation service.

#### 2.4.1 Mobile Applications

This subsection exposes some mobile applications used for everyday public transportation services. Two of them provide arrival and departure time of vehicles while the other is a ticketing application. They are presented here because even if they were not developed with the passenger as the main focus, they provide a service which aids the passengers in their commuting experience.

##### 2.4.1.1 MOVE-ME.AMP

MOVE-ME.AMP [14] is a mobile application that gives access to information about the public transportation service of several operators in the city of Porto (Portugal). Through a variety of functionalities the application allows the user to check the next departures in a certain stop (presented in Figure 2.23 c)), as well as the current waiting time and the destination of those vehicles. The user can also consult the nearest points of interest and by clicking on some of them generate a route. The route calculation feature (presented in Figure 2.23 a)) lets the user choose a point of departure, a point of destination and several passage points and then shows many ways that the route can be done, how long it will take and how much it will cost (presented in Figure 2.23 b)).
2.4.1.2 Anda

Anda [16] is a mobile ticketing application. This application was developed by TIP in collaboration with public transportation operators and FEUP. The target of this application is the users of the Porto (Portugal) Metropolitan Area. The goal of this application is to use the mobile phone as a ticket for bus, train and subway [17] while assuring that the cost of the trips is always optimal. To use it, the user needs to have a mobile phone with NFC, Bluetooth, GPS and internet.
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The user needs to approximate the mobile to the validation device, while the validation screen is shown (presented in Figure 2.24 (a)) and once the application gives the alert of trip started. There is no need to terminate the trip because the application does it automatically. During the trip, the passenger can follow the route (presented in Figure 2.24 (c)). Also, at any time the user has access to past trips and how much they costed (presented in Figure 2.24 (b)). This mobile application is only available for Android [16].

2.4.1.3 OneBusAway

OneBusAway [18] is a mobile application that retrieves real-time arrival information from local transit agencies. This system operates in several cities, such as:

- Rogue Valley, Oregon (RVTD)
- San Diego, California (SDMTS)
- Tampa Bay, Florida (HART)

Besides showing real-time arrival information (presented in Figure 2.25 (a)), the application also shows stops nearby the destination point, so the user has alternative routes (presented in Figure 2.25 (b)) and at which station is the selected vehicle. It has an option to favourite routes, making it easier for the user to access them. And maybe its most interesting feature, the possibility to add reminders for regular trips, such as the path to home from work. These perform as alarm clocks by giving notifications when it is the time to catch the bus (presented in Figure 2.25 (c)). This mobile application is available for both Android and iOS [18].

![Figure 2.25: (a) Real-time arrival information (b) Nearby means of transportation (c) Reminders of the OneBusAway Android application [18]](image_url)
2.4.1.4 AUDIO-GPS

AUDIO-GPS is a prototype of an application that stems from the idea of helping visually impaired people. This application uses sound as a form of guidance in closed spaces where the GPS signal may be weak or undetectable, it benefits from the already installed sound systems in stations. The system propagates sounds which are received in the mobile device and with those allows the device to locate itself. The numbers in Figure 2.26 represent the three different situations in which using the application is helpful. In situation 1, the user is in a closed space where there is no GPS signal which means it is not possible to access location based services. Using sound propagation the device can locate itself. In situation 2, the user may be lost or not know what location services are available and by enabling the localization by sound propagation a whole new set of possibilities are accessible. Finally, in situation 3, if the user knows how to enable the diffusion sound system in a closed space it is possible to transmit audio signals detected by mobile devices, allowing the device to locate itself [19].

Figure 2.26: User guide of AUDIO-GPS (adapted from [19])

2.4.2 Web-based Applications

This subsection examines web-based applications for public transportation services. These kind of platforms have information concerning several means of transportation, lines status updates and timetable updates relative to festive holidays or special services. They compile dense quantities of information making it more accessible for the passengers.
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2.4.2.1 The Verkehrsverbund Berlin-Brandenburg Livemap

VBB livemap [20] is a real-time web map of the states of Berlin and Brandenburg in Germany (presented in Figure 2.27). It shows the live movement of public transportation means such as long-distance transport, regional trains, S-train, underground, tram, bus and ferry. The user can define the map content (presented in Figure 2.28) which best fits his/her needs by selecting the stops and journeys concerning a certain mean of transportation and even select other forms of transportation. These can be bike sharing, car sharing, parking, taxi and park & ride. The mean of transportation icons displayed on the live map are interactive, therefore the user can click on these and a pop up with information regarding the mean of transportation will open. The information in
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the pop up informs the user about which line it is, the timetable and the user can also observe the
route, as well as, follow the journey.

2.4.2.2 Transport for London

Transport for London [21] is a website where the user has access to all the different means of
transportation of the city of London. This web application allows the user to “plan a journey” by
selecting departure and arrival locations, then displaying the respective route (presented in Figure
2.29 (a)). This route shows the fastest way while using public transportation (presented in Figure
2.29 (b)). The user can also access to information about what tube lines are active and their current
state. The website provides maps for all types of vehicles too, e.g. cycle maps, river maps. Lastly,
it has a page where all information about fares is explained [21].

Figure 2.29: (a) Plan a journey (b) Journey results of Transport for London [21]

2.4.3 Visualization of Networks and Maps

This subsection presents visualizations of networks and maps of cities. These visualizations con-
cern the study of the representation of frequency through the use of line color or line weight. Some
of the following examples display the initial design of the network visualization and an improved
design, in order to show the impact the reduction of map complexity has.

2.4.3.1 Perth Network

This Perth (Australia) network representation (presented in Figure 2.30) is a citizen entry involving
the current map available for the city made by Transperth with some alterations. This representa-
tion only includes weekdays and weekends during day time since night time service is significantly
less frequent, sometimes being less than 1/4 of the day time frequency [22]. There is a generic
color code to inform the passengers about the frequency of the lines (not all of the frequencies are
presented in this map) [23]: red (every 1 to 15 minutes), blue (every 16 to 30 minutes) and green
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(every 31 to 60 minutes). These rather simple changes aim to facilitate the reading of the map and be more informative.

Figure 2.30: Perth frequent network [22]

2.4.3.2 Portland Network

The Portland (USA) network was idealized by TriMet, a company that operates public transportation systems in the Portland area. The goal of the previous representation (presented in Figure 2.31) was to clarify the difference of frequency among lines through changes in line weight and
to identify the distinct routes by using different colors. If one examines the network, the only distinguishable factor is the color of the lines, no frequency indicator is detected. This mixture of colors and thickness variation only contributed to visual cluttering. There are three types of lines: strongly defined lines for frequent service, lightly defined lines for standard service and dashed lines for rush-hour service (presented in Figure 2.32). In order to solve this problem a new design (presented in Figure 2.33) was developed. The lines became all blue colored with some shade variations and with that simple alteration the weight of the lines is already more perceptible. The complexity of the map was reduced and is now simpler to interpret [24]. This reduction of complexity can be explained when one considers color guidelines, which are a consequence of the cognitive process of attention. In order to get the users attention, the representation should not use too many colors, instead it should use a few number of colors that can be associated with a consistent coding. This allows a better perception of state change [25].
2.4.3.3 South Auckland Network

The South Auckland (USA) network is a consequence of a regional plan that covers a whole urban region. The first network (presented in Figure 2.34) was developed by private companies that felt the necessity to organize their routes in a way that was advantageous for them. For that reason, these routes are not outstanding when it comes to passenger benefits and have caused a major bus congestion. In order to overcome this problem a new design (presented in Figure 2.35) was
proposed. This design accentuates high-frequency services while reducing the complexity of the map due to a virtual replacement of the express buses by buses connected to the main rail line which is fairly frequent [26].

Figure 2.35: New network in southern Auckland [26]

2.5 Conclusions

Throughout this chapter four subjects were addressed: user-centered design, information visualization, related work and technologies. They helped to analyze which were the gaps in research inherent to the dissertation subject and also clarified which methods were adequate for the development of the project.

A user-centered design is fundamental to understand what are the necessities and interests of users. Firstly, the context of use needs to be defined by combining the user’s expectations with the concepts to be transmitted and applied. Secondly, the user requirements must be specified both functionality and usability wise. Thirdly, a design solution which is based on the two aforementioned steps should be developed so that users can visualize the ideas and concepts discussed. Finally, an evaluation of the design solution is performed. This is a crucial step to know if the design meets the common functionalities users expect and if they can interact with it.

The focal point of visualization of information should concern three factors: what information the user sees, why the user needs that information and how to make that information visually
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appealing and clear. Currently, information visualization methods developed to inform the passengers focus in route calculation and display of maps. In spite of these portraying relevant information, they only cover a portion of what passengers need in their everyday commuting experience.

Passenger studies reveal information in real-time reduces the uselessness passengers feel when waiting for a mean of transportation, since it gives them a sense of control of the situation. That real-time information affects their perception of the waiting time too, approximating it to the real waiting time. They also show expectations of passengers are difficult to pin point, but common ground can be found. In general, passengers believe that a public transportation service should take them where and when they want to go, not be a waste of their time or money, respect them, give them freedom and be a source of trust. Likewise it is possible to infer that analyzing solely the opinion of passengers cannot lead to an objective conclusion on what needs to improve. Passengers tend to share information about what they want rather than what they need, therefore the involvement of experts is still necessary in a passenger-oriented study.

The technologies that currently exist to aid the passengers during their commuting experience focus mainly in real-time information of arrivals and departures, route calculation, ticket purchase and visualization of maps. Even tough these indicators are a necessity, they are far from meeting all of the inherent needs of a public transportation user. Another interesting fact is how little the passengers are involved in the development of these tools, most of them were developed by experts with the goal of gathering information for the public transportation companies instead of focusing on the passenger.
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Chapter 3

A Passenger-Oriented Approach for Visualizing Urban Mobility Data

This dissertation focuses on the development of visual elements which provide clearer information to the passenger, while putting him at the center. Most of the current visualizations with this goal, either failed to involve the users in the process or involved them only to a certain extent. This fault in communication of information between the passenger and the public transportation system led to a gap in this field of study. In order to fulfill this gap, a passenger-oriented approach for visualizing urban mobility data was developed based in a UCD method.

The methodology process followed (presented in Figure 3.1) is composed of three phases, iteratively: data gathering (presented in Section 3.1), prototyping (presented in Section 3.2) and evaluation (presented in Section 3.3). The data gathering phase contemplates the collection of information through research of literature and questionnaires and can be divided in two activities: public transportation usage habits and indicators perceptibility. The prototyping phase concerns the development of visualizations and the implementation of ideas for further testing. The evaluation phase regards presenting the prototypes to the users and analyzing their feedback.

Figure 3.1: User-centered design process
Additionally, this chapter also provides some insight on the technologies used during the dissertation.

3.1 Data Gathering

3.1.1 Public Transportation usage Habits

In-depth research relative to visualization and public transportation led to a series of questions.

1. Which information would improve the experience of a public transportation user?

2. Which factors would convince people to use public transportation?

3. Which visual information is missing that is relevant to the user’s commuting experience?

In order to answer these questions, a questionnaire was performed. The questionnaire presented different sections accordingly to the user’s answers to one simple question "Are you a public transportation user?". In the case of a positive answer, the user encounters questions relative to what is the most frequent mean of public transportation used and what information would be useful in a day to day basis. Otherwise, the user encounters a list of indicators that can influence the experience of using public transportation and is asked to classify them regarding their importance. The next section is common to both types of users, which addresses the visualization of information encouraging the choice of the most appealing and perceptible images for each indicator.

A questionnaire approach was suitable since the goal was to get answers for specific questions and enabled the collection of both quantitative and qualitative data. In addition, it allowed to reach a significant amount of people with relatively low resources.

3.1.2 Indicators Perceptibility

In order to gather information relative to the perception of indicators, an environment with the visualization of indicators was created. For that effect, the users were presented a web-based environment to interact with and afterwards, a questionnaire. This questionnaire displayed some of the visualizations of indicators present in the environment and alternative representations of those. The goal was to inquire the users relatively to what options were more perceptible and if they met the functionalities they were meant to accomplish. The users were able to comment the indicator at all times, if they felt the question did not provide enough feedback by itself. This opportunity allowed the user to express opinions freely, while being not mandatory.

This phase can be separated in two types of data gathering: naturalistic observation and questionnaire. Firstly, naturalistic observation occurred while the user experimented with the web-based environment. This observation allowed to understand how the user interacts with the system and what difficulties may arise. The questionnaire provided qualitative and quantitative data which allowed to collect specific information about each one of the representations.
3.2 Prototyping

The goal of prototyping is to test ideas and identify which ideas are more appropriate to fulfill the functionalities to be met. For that reason two types of prototyping were developed during this dissertation: low-fidelity and high-fidelity prototypes.

3.2.1 Low-fidelity Prototype

The first prototypes which were inserted in the public transportation usage habits questionnaire were rather simple versions of the representation of the indicators. The goal of these prototypes was to quickly sketch the information to be transmitted and test multiple design concepts with low development cost. In spite of having limited error checking, as well as, limited usefulness for usability tests these served the purpose of collecting requirements. These low-fidelity prototypes were designed using moqups. They made use of simplified maps and tables (presented in Figure 3.2) paired with icons, along with color schemes to communicate their goal.

3.2.2 High-fidelity Prototype

These prototypes were a consequence of the feedback obtained from the first prototypes. Instead of simple representations, a high-fidelity prototype was developed using web-based elements. This prototype was completely functional and interactive giving the feel of a final product as to get more concrete information. The environment was created using Vue.js for building the interfaces and Leaflet for interactive maps (presented in Figure 3.3). The indicators used elements such as routes, tables, icons and legends, along with color schemes to express information.
3.3 Evaluation

A formative evaluation was conducted since the overall goal of the prototypes is to verify if the users needs are being met. These evaluations can be separated in two sections: mixed evaluation and usability testing evaluation.

3.3.1 Mixed Evaluation

This evaluation is a mixture of two approaches, "quick and dirty" and usability testing evaluation, which is applied to the public transportation usage habits questionnaire (presented in Appendix A). During this questionnaire, the user was in his natural environment and had no supervision while filling it, thus the evaluator had zero control over the activity. These type of evaluation paradigms are usual in a "quick and dirty" evaluation. On the other hand, the user had to carry out a series of tasks and the data collected was validated by calculating mean averages and creating illusive graphics, following the paradigms of a usability testing evaluation.

3.3.2 Coaching Method Evaluation

This evaluation was solely based on a coaching method approach. The evaluator was present during the interaction with the functional prototype, while the user followed a set of tasks. During that process, the participant can ask any questions to the researcher who will answer in the best way possible. Afterwards, the questionnaire was executed and quantitative data was collected, in order to be statistically analyzed.

3.4 Technologies

In this section, the technologies used during the dissertation will not only be listed, but also accompanied with an explanation on what they were used and why they were chosen for that purpose.
A Passenger-Oriented Approach for Visualizing Urban Mobility Data

will approach continuous integration platforms, questionnaire services, mapping applications and interface creation frameworks.

**3.4.1 Vue.js**

Vue.js\(^1\) is an open-source JavaScript based framework. Its main purpose is building user interfaces and single-page applications. Therefore, a Vue.js project hosts the web application that supports the visualizations developed, creating the environment of interaction for testing effects. This framework was chosen for its incrementally adaptable nature and straightforward integration with other libraries, which was essential to use Leaflet.

**3.4.2 Leaflet**

Leaflet\(^2\) is an open source JavaScript library for building interactive web mapping applications. This library was rather useful since it grants users the possibility of displaying tiled web maps hosted on a public server conveniently. Additionally, it also allows the creation of interactive layers which enabled the drawing of routes, markers and popups.

**3.4.3 Google Forms**

Google Forms\(^3\) was used to conduct the first questionnaire. It provides the collection of data from users through a customized survey. The data collected is then used to populate a spreadsheet, to facilitate the organization of results. This application was chosen for its quick learning curve and the familiarity most users already have with it.

**3.4.4 LimeSurvey**

LimeSurvey\(^4\) is a free and open source online statistical survey web application. It allows users using a web interface to develop and export online surveys, collect answers and generates the respective statistics. This application was used to conduct the second questionnaire, mainly because the questionnaire required a significant amount of images and the application provided several mechanisms of editing and formatting which aided the development of the questionnaire.

**3.4.5 Github**

Github\(^5\) is platform for hosting source code with version control. It allows users to contribute to both private and open source projects from anywhere in the world. This platform was used to host the Vue.js project containing the web-based visualization environment created during the dissertation.

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\(^1\)https://vuejs.org/
\(^2\)https://leafletjs.com/
\(^3\)https://www.google.com/forms/about/
\(^4\)https://www.limesurvey.org/
\(^5\)https://github.com/
3.4.6 Moqups

Moqups\(^6\) is a web application which allows the elaboration of wireframes, mockups, diagrams and prototypes. It also provides the possibility of collaboration between users and go through the several types of models available without the need of changing apps or updating across platforms.

\(^{6}\)https://moqups.com
Chapter 4

Experiment, Results and Discussion

This chapter analyzes thoroughly the experiments conducted and their results. A detailed description of the content of the questionnaires will be discriminated, focusing on the visualizations created. The data collected from these will be explained through the use of graphics. It also shows the evolution of the prototypes, how the participants reacted to what they were exposed to and how that affected the process. For that effect, the chapter will be divided in two parts, each related to an experiment. The first experiment concerns the public transportation usage habits of passengers and the evaluation of four indicators: occupancy rate of vehicles, meteorological conditions, route fare and reliability of timetables. While the second experiment involves a web-based environment where the participant can interact with some of the same indicators presented in the first experiment, but also route search and route exposure.

4.1 Experiment I

Experiment I was conducted in the form of a questionnaire which was sent via e-mail and had 252 participants. This questionnaire was essential to understand the commuting habits of passengers and gather necessities of the passengers during their everyday commuting experience. The questionnaire and its results are available on the Appendix A.1. The majority of the participants belonged to an age group between 18 and 24, even though almost 20% belonged to an age group between 25 and 34. The sample also shows that there were almost the same number of female (47.6%) and male (52.4%) participants.

The first question was "Are you a public transportation user?". The answer to this question defined the course of the questionnaire, as the image presented in figure 4.1 shows 90.5% were public transportation users.
If the participant answered "Yes", the following questions would be presented. Firstly, "Which of the means of transportation do you use more frequently?", the answer options were: bus, metro, train and other. The participant could select several options, accordingly to his experience. The majority of the participants rode the metro and the bus frequently. Secondly, "When planning to travel by public transportation, which indicators would you consider important to be informed about?", the indicators were to classified using an adapted likert scale (presented in Figure 4.2).

The indicators the participant needed to classify from irrelevant to extremely relevant were: price, distance to the stop/station of arrival, distance to the stop/station of departure, frequency of timetables, reliability of timetables, convenience of timetables, security of stop/station, vehicle occupation and real-time information.
Experiment, Results and Discussion

Figure 4.3: Answers to "When planning to travel by public transportation, which indicators would you consider important to be informed about?"

The results show (presented in Figure 4.3) that participants found more relevant indicators concerning price, frequency of timetables and reliability of timetables, followed by convenience of timetables and real-time information. From this information, it is possible to infer that time is a crucial variable when it comes to public transportation services.

If the participant answered "No", another question is presented: "What factors would make you use public transportation?". The participants are asked to classify the following indicators from irrelevant (1) to extremely relevant (5): price, distance to the stop/station of arrival, distance to the stop/station of departure, frequency of timetables, reliability of timetables, convenience of timetables and security of stop/station.

Analyzing the following (presented in Figure 4.4) statistics, non-frequent public transportation users find frequency, reliability and convenience of timetables the most relevant indicators. This reinforces that when it comes to public transportation users consider time a defining factor of decision.
The final part of the questionnaire concerns the visualization of public transportation indicators. The participants were asked to classify the visualizations from 1 to 5, 1 being the lowest score and 5 the highest score. The participants classified indicators related to occupancy rate of vehicles, meteorological conditions, fares and reliability of timetables.

**Visualization 1: Occupancy Rate of Vehicle**

The first indicator is rate of vehicle occupation, the representation of it merges color coding with illustrative figures to transmit information. There are two types of configuration, map and table, both following the same color scheme: red portrays a full vehicle, yellow a bus with half capacity and green a barely occupied vehicle.

The previous images present map configurations. The first image (presented in Figure 4.5 (a)) displays its occupancy rate by the color of the bus icon, while on the second image (presented in Figure 4.5 (b)) it is displayed by the people colored icon inside the circle.
The following images present table configurations. In both images the bus is identified by a code. The first image (presented in Figure 4.6 (a)) displays its occupancy rate by the color of the bus icon, while on the second image (presented in Figure 4.6 (b)) it is displayed by the people colored icon.

<table>
<thead>
<tr>
<th>Autocarro</th>
<th>Ocupação</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bus1</td>
<td>![Bus1 Icon]</td>
</tr>
<tr>
<td>Bus2</td>
<td>![Bus2 Icon]</td>
</tr>
<tr>
<td>Bus3</td>
<td>![Bus3 Icon]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Autocarro</th>
<th>Ocupação</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bus1</td>
<td>![People Icon]</td>
</tr>
<tr>
<td>Bus2</td>
<td>![People Icon]</td>
</tr>
<tr>
<td>Bus3</td>
<td>![People Icon]</td>
</tr>
</tbody>
</table>

Figure 4.6: Table configuration: (a) Bus color coding (b) People color coding

The previous image displays the statistics relative to the vehicle occupation indicator (presented in Figure 4.7), where "Opção 1" is figure 4.5 (a), "Opção 2" is figure 4.5 (b), "Opção 3" is figure 4.6 (a) and "Opção 4" is figure 4.6 (b).

The majority of the participants classified the map configuration with bus color coding the most perceptible option, while the map configuration with people color coding was the second best qualified. Participants preferred the bus icon to the people icon to represent the occupation of vehicles and found a map configuration more appealing than a table configuration, in general.

**Visualization 2: Meteorological Conditions**

The second indicator is meteorological conditions and its goal is to display paths dependent on weather. The participant is informed of which weather is being portrayed by the icons on the top right of the image. The sun icon is yellow when the idea is to represent sunny weather, otherwise it turns black. Following the same method the rain icon is blue when rain is to be expressed, otherwise it turns black. If it is sunnier, the path includes walking segments, on the other hand if it is rainier the path is composed only by segments using public transportation. Both image options represent this intent, the difference being the first one (presented in Figure 4.8 (a))
Experiment, Results and Discussion

displays which part of the path is done by walking or using public transportation through the use of icons. Whereas the second image (presented in Figure 4.8 (b)) displays it using a legend.

Figure 4.8: Icon configuration: (a) Sunny weather (b) Rainy weather

Figure 4.9: Legend configuration: (a) Sunny weather (b) Rainy weather

Figure 4.10: Answers to "Classify the visualizations concerning meteorological conditions:"

Considering the image above shows the classifications of the meteorological conditions indicator (presented in Figure 4.10, "Opção 1" represents the images in figure 4.8, while "Opção 2" represents the images in figure 4.9.
The results relative to this indicator were quite inconclusive, since the participants gave a slightly higher classification to the icon configuration than the legend configuration. The difference between the classification of the visualizations was not significant enough to gather information on which visualization was more perceptible.

**Visualization 3: Route Fare**

The third indicator is route fare and it essentially displays several paths with the same starting and ending point with different prices. Both visualizations created show the routes and pricing, the first one (presented in Figure 4.11 (a)) differentiates the routes with the use of color and the second one (presented in Figure 4.11 (b)) only shows distinct prices.

![Figure 4.11: Route fares (a) color coding (b) Price coding](image)

The figure presented in 4.12 displays the graphics regarding the classification of the route fare indicator. "Opção 1" concerns the figure in 4.11 (a) and "Opção 2" the figure in 4.11 (b).

The visualization of this indicator left no doubts to the participants, most of them preferred the route fares with color coding and were not keen on the visualization with only price information.

**Visualization 4: Reliability of Timetables**

The fourth and last indicator is timetable reliability, its goal is to display arrival time differences relatively to the tabled timetable by the transportation system. The indicator follows the
same base idea of the first indicator having both a table and map configurations. The first configuration is presented in table format and has two variants: emoji and numeric. The emoji representation (presented in Figure 4.13 (a)) is qualitative, since the sad face implies delay and the smiley face implies that the mean of transportation is on time. However, there is no information about how long until the arrival. On the other hand, the numeric representation (presented in Figure 4.13 (b)) is quantitative as it is perceptible how long till the arrival of the mean of transportation. The red numbers exemplify late or early arrivals and the green numbers on time arrival.

![Figure 4.13: Table configuration: (a) Emoji (b) Numeric](image)

The second configuration is map based, it makes use of the bus icons to portray the vehicles and uses symbols to present timetable alterations. The first image (presented in Figure 4.14 (a)) displays emojis while the second one (presented in Figure 4.14 (b)) displays numbers which reflect the same concept as described previously.

![Figure 4.14: Map configuration: (a) Emoji (b) Numeric](image)

![Figure 4.15: Answers to "Classify the visualizations concerning reliability of timetables:"(image)
The image presented before displays the statistics regarding the reliability of timetables indicator, which shows four options. The image in 4.13 (b) is "Opção 1", while the image in 4.13 (a) is "Opção 3". The images in figure 4.14 are respectively, "Opção 2" and "Opção 4".

Generally, the participants elected the numeric configurations as being more perceptible. They also favoured the table configuration in opposition to the map configuration. Therefore, it can be inferred that participants prefer a quantitative information relatively to timetable visualization.

The analysis of the statistical data concerning the visualization of indicators provided useful information relatively to the indicators to be studied in the following experience. As the aforementioned results showed, the participants agreed on which visualization was more perceptible in three of the four indicators. This situation lead to the creation of a new indicator: route exposure. The route exposure indicator arose as a broader version of the meteorological conditions indicator, to be explained in Section 4.2.

4.2 Experiment II

Experiment II was composed by two parts: interaction with the visualizations of indicators in a web-based environment and a questionnaire. This experiment had the participation of 26 people belonging to an age group between 18 and 33, most of them males (81.5%).

4.2.1 Experiment Protocol

This section aims to clarify what the participant’s role is and how he should proceed during the experience without revealing information that would influence its results. As a consequence, a protocol was established with the benefit of allowing the experience to be replicated precisely for each participant. The experimental protocol consists of the following topics:

**Explain the experiment:** A brief description of the dissertation goals and a description of the experiment are given, to ensure that the participant has some context and understands what their contribution is.

**State the conditions of the experiment:** The environment of interaction has visualizations based on real information, in spite of these being slightly altered to serve the purpose of the dissertation. Therefore, the participant needs to be aware that the information is not updated in real-time and is exclusively representative.

**Instruct participant to begin the experiment:** The participant is instructed to access the web page and initiate the interaction by following instructions discriminated there. These instructions will lead the participant through a series of tasks, in order to present the features available.
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Fill the questionnaire: After the participant finishes performing the tasks discriminated, a questionnaire is presented for the participant to fill in. The questionnaire and its results are available on the Appendix A.2.

Thank for the participation: After completing the tasks aforementioned, the researcher thanks the participant for the collaboration.

At any moment, during the experience, the participant may ask any questions and the researcher will gladly answer as long as it does not interfere with the experiment.

4.2.2 Web-based Environment

When the participant accesses the web page, the first page to be displayed simply has the title of the dissertation and a button to initiate the interaction (presented in Figure 4.16).

By clicking the button, the participant is redirected to another page where identification credentials and instructions for tasks to be performed are discriminated. There are two identification credentials, a personal identification number and a test identification code which are both generated randomly (presented in Figure 4.17). The personal ID identifies the participant, while the test ID identifies which visualizations of each type are being displayed. For this reason, only one visualization of each type will be displayed. The number symbolizes the visualization and the letter symbolizes the indicator, using the following correspondence:

O: Vehicle occupancy
T: Timetable reliability
F: Route fares
Experiment, Results and Discussion

E: Route exposure

R: Route search

Figure 4.17: Identification credentials

In order to interact with the environment, the participant is faced with a set of instructions to follow (presented in Figure 4.18). Firstly, the participant had to insert the starting point of the route "Aliados", the ending point "Devesas" and proceed with the search by clicking in the magnifying glass icon. Then click on the stop surrounded by a blue circle, this triggers a menu to open with the indicators available. Finally, by selecting the different icons the participant is able to visualize the information of each indicator.

Figure 4.18: Instructions

**Visualization 1: Route Search**

When the participant completes the first task which the search, he/she comes across the first indicator: route search. As the name implies it allows the user to insert a starting and ending point generating the possible routes. The routes present two types of lines: full and dashed, the dashed ones represent walking path and the full ones represent a path using public transportation. Different routes are represented by different colors and their starting point is identified by a black location marker (presented in Figure 4.19 (a)), while the ending point is identified by a red location marker (presented in Figure 4.19 (b)). Through the routes there are also symbols representing which mean of transportation is assigned to the route: bus (presented in Figure 4.19 (c)), train (presented in Figure 4.19 (d)) or metro (presented in Figure 4.19 (e)).
This indicator has two variations: accessible and non-accessible route search. The following images show the search box with input fields (presented in Figure 4.20 (a)) and the result of a non-accessible search (presented in Figure 4.20 (b)).

In the case of an accessible search, the user is presented with a search box similar to the previous one but with a tick box next to a disabled symbol (presented in Figure 4.21 (a)). By ticking the box the accessible search is activated (presented in Figure 4.21 (b)) and different routes are displayed as a result (presented in Figure 4.21 (c)).
Experiment, Results and Discussion

The second task is clicking on the stop surrounded by the blue circle which triggers a menu with the other indicators: vehicle occupancy (presented in Figure 4.22 (a)), timetable reliability (presented in Figure 4.22 (b)), route fares (presented in Figure 4.22 (c)) and route exposure (presented in Figure 4.22 (d)). At any time, the participant can close the menu by clicking in the "x" at the right top corner.

Figure 4.22: Indicators Menu (a) Vehicle occupancy (b) Timetable reliability (c) Route fares (d) Route exposure
Visualization 2: Vehicle Occupancy

If the participant selects the first icon on the menu the vehicle occupation indicator is displayed. This indicator is an improvement of the one described in experiment I, it displays the same information using a table and a map configuration also. The table configuration displays the type of mean of transportation and an identifier, in the format "mean-id". The occupation rate is expressed by the colors as shown in the legend, green (free), yellow (medium) and red (full).

![Table configuration of rate of vehicle occupation](image)

The map configuration makes use of the public transportation icons shown previously (presented in Figure 4.19), the color coding defined and the identifier referred in the table configuration. The following images display a free bus with the identifier "207" (presented in Figure 4.24 (a)) and three trains: "U1593" which is also free (presented in Figure 4.24 (b)), "U15743" which shows medium capacity (presented in Figure 4.24 (c)) and "U15937" which is quite full (presented in Figure 4.24 (d)).

![Occupation icons](image)

The result of this kind of representation is as follows (presented in Figure 4.25), the routes are still perceptible and the map if fully functional, while the user is able to spot the occupancy rate of nearby means of public transportation.
Experiment, Results and Discussion

Visualization 3: Timetable Reliability

If the participant clicks on the second icon on the menu the timetable reliability indicator is displayed. This is the indicator with more visual variations. All of the visualizations display the foreseen time, as well as, the real-time of arrival. Three representations use a table configuration displaying the vehicle identifier, the foreseen timetable and the real-time timetable in this order with little alteration. The first table displays the real-time by simply showing the actual time of arrival in comparison with the foreseen time (presented in Figure 4.26 (a)). The second table displays the real-time by showing the value of difference between the foreseen time and the actual time (presented in Figure 4.26 (b)). The third table uses a color scheme giving an estimate to the user (presented in Figure 4.26 (c)).

![Figure 4.25: Map configuration of rate of vehicle occupation](image)

![Figure 4.26: Timetable reliability (a) Real-time (b) Time difference (c) Time estimation](image)
Experiment, Results and Discussion

These representations display the station, the foreseen time and the real-time of arrival. The first representation shows that the user is at "Porto-Campanhã" and the last stop of the line is "Vila Nova de Gaia-Devesas", while the station "General Torres" is an intermediate stop in the route (presented in Figure 4.27 (a)). The second representation displays a different situation, the user is at "Porto-Campanhã" and the immediate next stop is "General Torres", while the last stop is the same as before (presented in Figure 4.27 (b)).

Visualisation 4: Route Fare

If the participant selects the third icon on the menu the route fares indicator is displayed, it has two visualizations, both map based. This indicator displays the price of the journey and the duration of the journey. The first representation displays a legend that uses the color of the routes as identifiers, associating the price and duration in the format "price (duration)" with the color of the route (presented in Figure 4.28).

The second representation displays tooltips on top of the route (presented in Figure 4.29).
Experiment, Results and Discussion

These can be closed at any time by clicking the "x" at the top left corner and can be opened by clicking on the line representing the route. The information provided is exactly in the same format as in the previous representation.

![Figure 4.29: Route fares tooltip](image)

**Visualization 5: Route Exposure**

If the participant selects the fourth and final icon on the menu the route exposure indicator is displayed. This indicator arises as an improvement of the meteorological conditions indicator, instead of being dependent on weather the user can choose to be more or less exposed to the current weather, enabling the user’s choice. The choice is performed using a menu (presented in Figure 4.30) that explains what more and less exposure means clarifying any doubts from the user’s side. By using radio buttons, the user can select which option is more suitable.
In the case of selection of the first button (sun, rain, wind), the map displays routes with walking segments which lead to more exposure during the path (presented in Figure 4.31 (b)). If the other button (trees, umbrella, tunnel) is selected routes with less exposure are displayed in the map (presented in Figure 4.31 (a)).

Once the participant finishes the tasks, he is directed to the questionnaire.

4.2.3 Questionnaire

This questionnaire was conducted with the objective of gathering data concerning the type of visualizations the participant interacted with. For this effect, the participant is asked to evaluate
the perceptibility of the indicators while using an adapted likert scale (presented in Figure 4.32). Moreover at each question the participant is able to write additional feedback whenever desired.

![Likert scale](image)

**Figure 4.32: Likert scale**

**Visualization 1: Route Search**

Concerning the visualization of the indicator route search, the participants were asked to classify the non-accessible route search box (presented in Figure 4.20) and the accessible route search box (presented in Figure 4.21). In both cases, when asked if the visualizations were perceptible the majority of the participants strongly agreed with the affirmation, as shown in figure 4.33. Some even commented that what made it perceptible was the fact that a default style for this kind of functionality was used and therefore facilitated the understanding of its purpose.

![Answers concerning: (a) Non-accessible route search (b) Accessible route search](image)

**Figure 4.33: Answers concerning: (a) Non-accessible route search (b) Accessible route search**

Besides the main visualizations the participants were also asked to classify the menu of indicators (presented in Figure 4.22), most of them tended to agree with the representation as the figure in 4.34 displays. However, some comments indicated that the icon for occupation was not
very clear to the participants.

Visualization 2: Vehicle Occupancy

In order to classify the perceptibility of the vehicle occupancy indicator, the participants were shown a table approach (presented in Figure 4.23) and a map approach (presented in Figure 4.25) to the indicator. While most of the participants strongly agreed with table representation of the indicator, the map representation divided the participants between strongly agreeing and tending to agree with the visualization, as presented in figure 4.35. In the table representation of vehicle occupancy, some participants referred that it would be more useful to maybe have a percentage value to identify the occupancy rate, instead of the colors.

Figure 4.35: Vehicle occupation classifications (a) Table (b) Map

Visualization 3: Timetable Reliability

Regarding timetable reliability, instead of classifying each one of the table visualizations these were grouped and ordered, meaning that 4.26 (a) is option 1, 4.26 (b) is option 2 and 4.26 (c) is option 3. The majority chose the timetable reliability representation that display time difference between the foreseen time and the actual time of arrival of the vehicle - option 1 (presented in Figure 4.36). In spite of that, some comments indicated that a combination between the real-time representation and time difference representation would be more helpful. The idea would be to use the color scheme along with time in the format "hour-minutes".

Figure 4.36: Answers concerning default table classifications
Experiment, Results and Discussion

Figure 4.37: Answers to "Which table is more perceptible?"

Figure 4.38: Answers to "Which of the visualizations represents the following order of stations: current station, following station and final station?"

The following classification was, as the previous ones a matter of analyzing the visualizations and assign them a value in the likert scale. These visualizations represented a distinct form of presenting the indicator by also providing information about at which stop/station the vehicle is at a certain time (presented in Figure 4.27). In order to understand the statistics above presented, figure 4.27 (a) is represented by number 1 and figure 4.27 (b) by number 2. Most of the participants chose the dotted line representation, instead of the full line representation (presented in Figure 4.37). The next question, also concerned these representations, the goal was to understand if the participants noticed any difference between them. The question was as follows: "Which of the visualizations represents the following order of stations: current station, following station and final station?". The majority of the participants guessed correctly by choosing the full line visualization (presented in Figure 4.38).

Visualization 4: Route Fare

Once again, the participants were asked to classify the visual indicators using the likert scale. The visualization of route fares with legend (presented in Figure 4.28) was classified as extremely perceptible, since most participants selected the strongly agree field. Nonetheless the classification results of the tooltip visualization (presented in Figure 4.29) suggested participants either strongly agreed with design or tended to agree with it. This information can be observed on the following figure 4.39.
Experiment, Results and Discussion

Visualization 5: Route exposure

Firstly, the participants are asked to classify the menu of exposure on its perceptibility (presented in Figure 4.30), which the majority tended to agree it was perceptible as displayed in figure 4.40. However, there were comments which mentioned the icons could be clearer or to use just the text information because it is clear enough. Afterwards, a question to understand if the participants were able to pinpoint which visualization of the routes represented less and more exposure (presented in Figure 4.31) was placed. In figure 4.41, 1 represents the image in 4.30 (a) and 2 the image in 4.30 (b). The color blue represented more exposure, while red represented less exposure. Most of the participants were able to perform the correct association between the image and the type of exposure.

Figure 4.39: Answers concerning the route fare indicator with (a) Tooltips (b) Legend

Figure 4.40: Answers concerning the perceptibility of the menu of exposure

Figure 4.41: Answers concerning the perceptibility of the route exposure
4.3 Discussion

The objective of this dissertation is to design and develop prototypes regarding urban mobility data information focusing on the passenger needs. For discussion purposes, this section is divided in two parts: user-centered design process and visualization prototypes.

4.3.1 User-centered Design Process

The data gathered during this process was relevant and aided in the development of the prototypes since it was conclusive generally. A questionnaire approach was heavily used, because it reaches a large amount of people with little resources and consumes the least amount of time when compared to other methods. It also has the advantage of working well when in conjunction with other methods. Despite leaving the users with no support, since they have no one to explain the questions it led to great results. Another viable approach could have been focus group. It facilitates the collection of multiple viewpoints while encouraging the contact between users and the researcher. Another benefit is the easy identification of areas of disagreement and consensus.

The design of prototypes was useful in both experiments allowing to test out the viability of ideas, define requirements and direct the designs. The first batch of visualizations were low-fidelity prototypes due to the need of a quick and low cost development with the purpose of evaluating designs and communicating with the users through a proof of concept. In opposition, the second batch of visualizations were high-fidelity, in order to show the users a prototype that had the look and feel of a final product. This prototypes are fully functional for exploratory and testing reasons.

The evaluation process was essential to understand if the designs proposed satisfied the users needs. The first evaluation aimed to be both informal and within a short time frame, for that effect a "quick and dirty" evaluation was performed. This approach turned out to be rather fruitful leading to conclusive results. The users were able to limit the options of design for the visualizations through feedback. If there was more than one researcher or more time a field studies would have been an interesting approach. The observation of users in their natural setting usually increases the understanding about users natural behavior and how the technology impacts them. In this specific case, the fact that this method is recommended for prototypes in initial phases of development with the goal of assessing issues or design opportunities fits just right. The second evaluation followed a coaching method since the users were not familiar with the web-based environment. This method allows the user to ask questions about the system and the researcher can answer to steer the user in the right direction. It also favours the interaction between the user and the researcher allowing the learning curve to be quicker. The predictive method of evaluation was never in consideration because the users are not involved and the focus of this dissertation is the user, specifically the passenger.
Experiment, Results and Discussion

4.3.2 Visualization Prototypes

This section will describe the preferences of users relatively to the design visualization prototypes, as well as, brief suggestions to improvements based on comments or observations.

4.3.2.1 Rate of Vehicle Occupancy

Initially, the users were more inclined towards a color coded map configuration to represent the rate of vehicle occupancy. However, the second experiment revealed an alteration in favor of a color coded table configuration. Even if the users chose this type of visualization as the more perceptible one, there is still room for improvement regarding both visualizations present in experiment II. The table visualization could present quantitative occupancy information through the use of percentage (%) or fractions which could be in the format "occupied seats/total number of seats". Relatively to the map visualization, the positioning of the icons could be improved.

4.3.2.2 Meteorological Conditions/Route Exposure

The results concerning the meteorological conditions indicator were inconclusive, since the difference of classification between the available visualizations presented was rather insignificant which prevented further development. As mentioned before, to surpass this situation a new indicator was created: route exposure, which allows the user to be more or less exposed to the current weather. In spite of most users associating the map visualization and the type of exposure correctly, there were some critics concerning the menu of selection of exposure. Particularly, it was pointed out that the icons used were not clear enough and just written information would improve the menu. To solve this issue, more research what icons users associate with exposure and how to transmit the function of this indicator more clearly.

4.3.2.3 Route Fare

During the first iteration of the UCD process, the users found pleasant a visualization display the fares of the routes recurring to a pop up. Despite that, in the second iteration they were inclined to a visualization which used a legend to display the information of route fares. The first visualization described had the impediment of limiting the visualization of the routes, since it could overlap these. While the second visualization obligated the user to keep looking back and forward to the map and the legend to observe which information matched each route. In order to facilitate the observation of both the routes and the information, the route could display the information when the route was hovered.

4.3.2.4 Reliability of Timetables

The initial feedback concerning the reliability of timetables indicated that users preferred a table visualization to present time. This fact could be a consequence of it being the default representation of this type of information in most applications regarding time and public transportation.
Since the users were inclined towards this type of visualization, the visualizations designed followed a table configuration even if with diverse formats. When considering the improvement of visualizations that displayed information such as mean of transportation identification, foreseen time and actual arrival time the direction was to combine approaches. Even though users were mainly keen on a visualization that showed the actual time of arrival through color coding and how much time the vehicle was late or early, some comments indicated that it would be more perceptible to display the new time of arrival. This implies that the combination of the first two visualizations concerning timetable reliability from experiment II is relevant for further development. Another visualization concerning this indicator was also developed, raising some doubts since it displayed the information in an untypical form. It displayed two types of time lines: current stop, intermediate stop and final stop and current stop, immediate next stop and final stop. The users found quite difficult to differentiate these through the use of dashed and full lines. To clarify the visualization, an information about which is the current position, while the first stop represented is the beginning of the line and the last stop represented is the end of the line would maybe help.

4.3.2.5 Route Search

This indicator, only came about in the experiment II as a necessity since there was the need to draw routes and it did not make sense for them to appear out of the blue. This specific visualization did not raise any disagreement or doubts, the users were familiar with this type of design and were able to understand it.

Since the main goal of the dissertation was to design prototypes of possible visualizations of urban mobility data information real data was used, but it was static data. There is no real-time information being displayed and the only information available is the one displayed in the web-based environment. That fact did not imply the results or the process because the main goal of the dissertation was to evaluate the perceptibility of the visualizations designed and how the users interacted with them, which was ascertained.
Experiment, Results and Discussion
Chapter 5

Conclusions and Future Work

5.1 Conclusions

This dissertation addressed the design and prototype development of urban mobility information tools focused on the passengers of public transportation. The underlying problem here explored was that the tools provided to the passengers are not always idealized with them as the focus. This leads to a mismatch of the information the passenger needs and the information the public transportation companies provide.

The research process for the dissertation made clear there is a research gap where this project fits perfectly. There is relevant information not transmitted to the passengers that can diminish their sense of uncertainty, namely alternative routes when the weather presents extreme conditions. Relatively to visualization, features to personalize systems and to alter the way the user perceives them have been developed. The problem is that they mainly concern personalizing routes, while some other interesting indicators are discarded and seen as less pertinent. That struggle will be analyzed to gather conclusively if it exists because the users would not take advantage of it or of the companies just have not perceived as necessary.

This dissertation followed an adapted user-centered design based in three phases: data gathering, prototyping and evaluation. The data gathering phase used questionnaires and a lighter version of a natural observation approach to collect information. The prototyping phase embraced both low and high-fidelity prototypes to display visualizations of urban mobility data to users. Finally, the evaluation phase took advantage of methods such as questionnaires and coaching to evaluate the results gathered.

The results showed that when asked what indicators the users found more relevant, both frequent and non-frequent users of public transportation felt drawn to the following indicators: reliability of timetables, frequency of timetables, convenience of timetables and real-time information. All four indicators can be summed up in one word - Time. This result explains why most applications regarding public transportation focus on timetables and the need to study the perception of time the passenger waits for public transportation, as described in Chapter 2. In general the visualization prototypes were well received by the users, the feedback was positive and the indicators
Conclusions and Future Work

presented were found useful and perceptible, even tough some alterations are suggested. During the development of this dissertation some limitations arose such as:

- The participants all belonged to the same age group (18 to 33), therefore it is not feasible to assume that the visualizations prototyped would be perceptible for every public transportation user. Users from other age groups could appreciate a different layouts or even a different set of indicators that fitted their needs more accurately.

- The public transportation companies do not provide information for privacy reasons. This may have implicated the interaction with the web-based environment, since the users would have been able to have an experience closer to reality. If they were able to input their usual routes and visualize the occupation of the vehicles they ride, it could have been more impacting.

Ultimately, the process and overall solution were conclusive and lead to some interesting findings, even if there is still room for improvement and future work to develop.

5.2 Future Work

This section presents some improvements and features that emerged during the development of this dissertation but were not part of the plan of implementation.

- **Testing with other age groups**
  This improvement is essential before developing the project any further, the demographic presented in experiment II was limited only with people ranging from 18 to 33 years. For this reason, it is extremely important to figure out if the visualizations are perceptible for different and even more important to know if elder age groups would interested at all in this type of information.

- **Implementing alterations concerning experiment II results**
  This topic also presents an improvement consequent from the results obtained. The suggestions made by the participants revealed there is still a lot of room to improve and some minor changes could solve some major issues, mentioned in the Subsection 4.3.2.

- **Using real data for a dynamic visualization**
  A dynamic implementation would be more appealing for the passengers. The display of timetables in real-time, as well as, the movement of means of transportation while displaying the occupation of those vehicles. Another indicator that would benefit from this would be the route search, since the user could explore his usual paths and interact with them. The use of real information provided by public transportation companies would make the user more comfortable and closer to a real case of utilization, which could lead to a more accurate feedback.
Conclusions and Future Work

- **Adaptation for color blind users**
  The use of colors to display information is a recurrent method used throughout the dissertation. For that reason, it would be an inclusive and interesting subject to explore how to make the visualizations viable for color blind users.
Conclusions and Future Work
References


REFERENCES


REFERENCES


Appendix A

Appendix

A.1 Questionnaire 1

The following section presents the questions and respective answers to the questionnaire created. The goal of this questionnaire is to gather preconceived ideas that public transportation users have, as well as, gather intel on new approaches developed for this project. The questionnaire was developed using the Google Forms platform. Taking into account the target public the questionnaire is presented in Portuguese.

A.1.1 Questionnaire

Visualização de Dados de Mobilidade Urbana Orientada a Passageiros

No âmbito da dissertação do Mestrado Integrado em Engenharia Informática e computação na Faculdade de Engenharia da Universidade do Porto, o inquérito que se segue pretende analisar hábitos utilização de transportes públicos e explorar diferentes modos de visualizar a mesma informação.

Obrigada pela participação!

Obrigatório*

1. Idade *

□ 18-24
□ 25-34
□ 35-44
□ 45-54
□ 55 ou mais
Appendix

2. Sexo *

□ Feminino

□ Masculino

3. É utilizador(a) de transportes públicos? *

□ Sim

□ Não

Utilização não frequente de Tranportes Públicos

4. Quais os fatores que o levariam a usar transportes públicos?

4.1. Preço*

1 2 3 4 5

Não é importante □ □ □ □ □ Extremamente importante

4.2. Distância à paragem/estação ao Destino*

1 2 3 4 5

Não é importante □ □ □ □ □ Extremamente importante

4.3. Distância à paragem/estação ao Ponto de Partida*

1 2 3 4 5

Não é importante □ □ □ □ □ Extremamente importante

4.4. Frequência de Horários*

1 2 3 4 5

Não é importante □ □ □ □ □ Extremamente importante

4.5. Fiabilidade de Horários*

1 2 3 4 5

Não é importante □ □ □ □ □ Extremamente importante

4.6. Conveniência de Horários*

1 2 3 4 5

Não é importante □ □ □ □ □ Extremamente importante
Appendix

4.7. Segurança da estação/paragem*

Não é importante □ □ □ □ □ Extremamente importante □ □ □ □ □

Utilização frequente de Tranportes Públicos

5. Qual dos meios de transporte públicos usa mais frequentemente?*

☐ Autocarro
☐ Metro
☐ Comboio
☐ Outro

6. Quando pretende efetuar uma viagem em transporte público, quais os indicadores acerca dos quais considera importante ser informado?*

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<td>Informação em Tempo-real</td>
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Visualização de Informação

7. Pontue de 1 a 5 as visualizações apresentadas para cada informação.

Ocupação do Veículo

As imagens que se seguem representam a ocupação do veículo relativamente à sua capacidade máxima: vermelho (cheio), amarelo (médio) e verde (com bastantes lugares).
7.1. Pontue as visualizações relativas à ocupação do veículo:

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<td>Opção 4</td>
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Condições Metereológicas

As imagens que se sequem representam trajetos que se adequam ao estado metereológico atual, no caso de estar sol o passageiro pode preferir andar a pé, se isso lhe permitir fazer uma viagem mais curta. No caso de chover, pode preferir demorar mais tempo, mas fazer a viagem abrigado.
7.2. Pontue as visualizações relativas às condições metereológicas:

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Informação sobre Tarifas

As imagens que se seguem usam cor e espessura de linha para representar caminhos com o mesmo ponto de partida e destino, mas com preços diferentes.
7.3. Pontue as visualizações relativas à informação sobre tarifas:

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**Fiabilidade de Horários**

As imagens que se seguem usam emojis e números para representar atrasos e adiantamentos dos serviços assim como quando o horário é cumprido.

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<td></td>
<td>Bus2</td>
<td>16h45   -3</td>
</tr>
<tr>
<td></td>
<td>Bus3</td>
<td>19h30   +0</td>
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<td></td>
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<td>16h45   😊</td>
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<tr>
<td></td>
<td>Bus3</td>
<td>19h30   😊</td>
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7.4. Pontue as visualizações relativas à fiabilidade de horários:
## Appendix

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### A.1.2 Answers

#### A.1.2.1 Introductory Questions

![Figure A.1: Answers to question 1. - "Idade"](image1)

Figure A.1: Answers to question 1. - "Idade"

![Figure A.2: Answers to question 2. - "Sexo"](image2)

Figure A.2: Answers to question 2. - "Sexo"
Appendix

Figure A.3: Answers to question 3. - "É utilizador(a) de transportes públicos?"

A.1.2.2 Factors that would lead users to use public transportation

Figure A.4: Answers to question 4.1. - "Preço"

Figure A.5: Answers to question 4.2. - "Distância à paragem/estação ao Destino"
Appendix

Figure A.6: Answers to question 4.3. - "Distância à paragem/estação ao Ponto de Partida"

Figure A.7: Answers to question 4.4. - "Frequência de Horários"

Figure A.8: Answers to question 4.5. - "Fiabilidade de Horários"
Appendix

Figure A.9: Answers to question 4.6. - "Conveniência de Horários"

Figure A.10: Answers to question 4.7. - "Segurança da estação/paragem"

A.1.2.3 Frequent use of public transportation

Figure A.11: Answers to question 5. - "Qual dos meios de transporte públicos usa mais frequentemente?"
Figure A.12: Answers to question 6. - "Quando pretende efetuar uma viagem em transporte público, quais os indicadores acerca dos quais considera importante ser informado?"
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A.1.2.4 Visualization of Information

Figure A.13: Answers to question 7.1. - "Pontue as visualizações relativas à ocupação do veículo:"

Figure A.14: Answers to question 7.2. - "Pontue as visualizações relativas às condições meteorológicas:"

Figure A.15: Answers to question 7.3. - "Pontue as visualizações relativas à informação sobre tarifas:"
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Figure A.16: Answers to question 7.4. - "Pontue as visualizações relativas à fiabilidade de horários:"

A.2 Questionnaire 2

The following section presents the questions and respective answers to the questionnaire created. The goal of this questionnaire is to gather intel concerning the visualizations in the web-environment developed. The questionnaire was developed using the LimeSruvey platform. Taking into account the target public the questionnaire is presented in Portuguese.

A.2.1 Questionnaire

Visualização de Dados de Mobilidade Urbana Orientada a Passageiros

No âmbito da dissertação do Mestrado Integrado em Engenharia Informática e computação na Faculdade de Engenharia da Universidade do Porto, o inquérito que se segue pretende obter opiniões relativas ao trabalho desenvolvido e ao ambiente de teste criado.

Obrigatório*

Identificação

1. Insira o ID Pessoal atribuído, anteriormente:* 

2. Insira o ID de Teste atribuído, anteriormente:* 

3. Idade:* 

  □ 18-33

  □ 34-49
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☐ 50-64
☐ 65 ou mais

4. Sexo: *
☐ Feminino
☐ Masculino

5. É utilizador regular de transportes públicos?: *
☐ Sim
☐ Não

Indicadores

6. A imagem abaixo representa a pesquisa de rotas sem acessibilidade, acha a imagem adequada para tal efeito? *

☐ Discordo totalmente
☐ Tendo a discordar
☐ Neutro
☐ Tendo a concordar
☐ Concordo totalmente

Por favor, escreva o seu comentário aqui:
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7. A imagem abaixo representa a pesquisa de rotas com acessibilidade, acha a imagem adequada para tal efeito? *

□ Discordo totalmente
□ Tendo a discordar
□ Neutro
□ Tendo a concordar
□ Concordo totalmente

Por favor, escreva o seu comentário aqui:

8. A imagem abaixo representa o menu de opções, acha os símbolos adequados para a representação dos indicadores? *

□ Discordo totalmente
□ Tendo a discordar
9. A imagem abaixo representa a ocupação de veículos em tabela, acha a imagem adequada para tal efeito?*

☐ Discordo totalmente
☐ Tendo a discordar
☐ Neutro
☐ Tendo a concordar
☐ Concordo totalmente

Por favor, escreva o seu comentário aqui:

☐ Discordo totalmente
☐ Tendo a discordar
☐ Neutro
☐ Tendo a concordar
☐ Concordo totalmente

Por favor, escreva o seu comentário aqui:
10. A imagem abaixo representa a ocupação de veículos em mapa, acha a imagem adequada para tal efeito?*

□ Discordo totalmente
□ Tendo a discordar
□ Neutro
□ Tendo a concordar
□ Concordo totalmente

Por favor, escreva o seu comentário aqui:

11. A imagem abaixo representa as tarifas relativas a cada rota, acha a imagem adequada para tal efeito? *
□ Discordo totalmente

□ Tendo a discordar

□ Neutro

□ Tendo a concordar

□ Concordo totalmente

Por favor, escreva o seu comentário aqui:

12. A imagem abaixo representa as tarifas relativas a cada rota, acha a imagem adequada para tal efeito? *
□ Discordo totalmente

□ Tendo a discordar

□ Neutro

□ Tendo a concordar

□ Concordo totalmente

Por favor, escreva o seu comentário aqui:

13. As imagens abaixo representam diferentes tipos de horários em tabelas. Qual das representações acha mais perceptível? Sendo que, da esquerda para a direita, as imagens são 1, 2 e 3. *

95
14. Qual das representações de horários acha mais perceptível? Sendo que, da esquerda para a direita as imagens são 1 e 2. *

<table>
<thead>
<tr>
<th>Transporte</th>
<th>Hora Previa</th>
<th>Hora Real</th>
</tr>
</thead>
<tbody>
<tr>
<td>comboio-U</td>
<td>16h55</td>
<td>17h00</td>
</tr>
<tr>
<td>comboio-U</td>
<td>17h09</td>
<td>17h00</td>
</tr>
<tr>
<td>autocarro-207</td>
<td>17h00</td>
<td>17h11</td>
</tr>
<tr>
<td>autocarro-207</td>
<td>17h11</td>
<td>17h11</td>
</tr>
<tr>
<td>comboio-U</td>
<td>17h14</td>
<td>17h14</td>
</tr>
</tbody>
</table>

Por favor, escreva o seu comentário aqui:

□ 1
□ 2
□ 3
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15. Qual das representações anteriores representa a seguinte ordem de estações: estação atual, estação imediatamente a seguir e estação final? (escolher entre 1 e 2) *

□ 1
□ 2

Por favor, escreva o seu comentário aqui:

16. A imagem abaixo representa o menu de seleção de exposição, acha a imagem adequada para tal efeito?*

Selezione as imagens acima (sol, chuva e vento) para visualizar rotas com mais exposição e as imagens abaixo (árvores, guarda-chuva e túnel) para rotas com menos exposição:

☐ ☐ ☐

☐ ☐ ☐
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□ Discordo totalmente
□ Tendo a discordar
□ Neutro
□ Tendo a concordar
□ Concordo totalmente

Por favor, escreva o seu comentário aqui:

17. As imagens representam menos e mais exposição (não respetivamente). Escreva nas caixas 1 ou 2, de forma a especificar qual representa cada tipo de exposição. Sendo que, da esquerda para a direita as imagens são 1 e 2. *

Mais Exposição

Menos Exposição

Por favor, escreva o seu comentário aqui:
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18. Se tem alguma observação a fazer que acha que não ficou explícita durante o preenchimento do inquérito ou quer acrescentar alguma ideia, pode fazê-lo aqui.

A.2.2 Answers

A.2.2.1 Identification Questions

![Figure A.17: Answers to question 3. - "Idade"](image)

![Figure A.18: Answers to question 4. - "Sexo"](image)
Figure A.19: Answers to question 5. - "É utilizador regular de transportes públicos?"

A.2.2.2 Indicators Questions

Figure A.20: Answers to question 6. - "A imagem abaixo representa a pesquisa de rotas sem acessibilidade, acha a imagem adequada para tal efeito?"
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Figure A.21: Answers to question 7. - "A imagem abaixo representa a pesquisa de rotas com acessibilidade, acha a imagem adequada para tal efeito?"

Figure A.22: Answers to question 8. - "A imagem abaixo representa o menu de opções, acha os símbolos adequados para a representação dos indicadores?"
Appendix

Figure A.23: Answers to question 9. - "A imagem abaixo representa a ocupação de veículos em tabela, acha a imagem adequada para tal efeito?"

Figure A.24: Answers to question 10. - "A imagem abaixo representa a ocupação de veículos em mapa, acha a imagem adequada para tal efeito?"
Figure A.25: Answers to question 11. - "A imagem abaixo representa as tarifas relativas a cada rota, acha a imagem adequada para tal efeito?"

Figure A.26: Answers to question 12. - "A imagem abaixo representa as tarifas relativas a cada rota, acha a imagem adequada para tal efeito?"
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Figure A.27: Answers to question 13. - "As imagens abaixo representam diferentes tipos de horários em tabelas. Qual das representações acha mais perceptível? Sendo que, da esquerda para a direita, as imagens são 1, 2 e 3."

Figure A.28: Answers to question 14. - "Qual das representações de horários acha mais perceptível? Sendo que, da esquerda para a direita as imagens são 1 e 2."
Figure A.29: Answers to question 15. - "Qual das representações anteriores representa a seguinte ordem de estações: estação atual, estação imediatamente a seguir e estação final? (escolher entre 1 e 2)"

Figure A.30: Answers to question 16. - "A imagem abaixo representa o menu de seleção de exposição, acha a imagem adequada para tal efeito?"
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Figure A.31: Answers to question 17. - "As imagens representam menos e mais exposição (não respetivamente). Escreva nas caixas 1 ou 2, de forma a especificar qual representa cada tipo de exposição. Sendo que, da esquerda para a direita as imagens são 1 e 2."

Comments concerning question 6:
1. É intuitivo por ser estar visivelmente explicito para o efeito e é o que é utilizado normalmente em mapas o que faça com que a pessoa não precise de se ambientar a este elemento
2. O ícone do indivíduo fisicamente debilitado com uma cruz vermelha por cima poderia ficar mais explícito ou na idk
3. Drop down com opções seleccionáveis

Comments concerning question 7:
1. Pelas mesmas razões anteriores
2. mais só se fosse em letras maiores para pessoal com problemas de visão
3. Devia ter um check na caixa
4. Acharia mais simples, um botão maior do tipo "toggle"

Comments concerning question 8:
1. Com os últimos três símbolos concordo totalmente mas o primeiro não achei intuitivo que significaria ocupação pois ainda tive de pensar para me lembrar do que seria quando vi esta imagem
2. A utilização de símbolos no geral não me parece a melhor, sendo que prefiro texto. Mas admitindo que é necessário usar símbolos, parece-me que apenas o 2º e 3º são adequados, sendo que o 1º e 4º só percebi o que eram depois de os selecionar.
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3. Todos menos o primeiro.
4. O primeiro ícone não é intuitivo.
5. A primeira imagem da ocupação não é muito perceptível
6. Alguns deles podiam ser mais explícitos
7. O primeiro não é tão intuitivo
8. o da ocupação não é totalmente intuitivo, se calhar um indivíduo sentado ou coisa do género era mais imediato idk
9. o primeiro símbolo não é claro à primeira vista apenas
10. O símbolo da exposição é relativamente ambíguo.
11. Deveriam existir as etiquetas, mesmo que diminutas para cada um dos icons
12. O de ocupação podia ser mais claro, mas o resto está bom
13. O ícone de ocupação e de exposição não são claros

Comments concerning question 9:
1. As cores utilizadas por norma já representam o objetivo, porém acho que deveria existir outro elemento para pessoa daltónicas
2. muito claro, gostei
3. Um valor numérico (% de ocupação, por exemplo) seria útil.
4. Seria bom uma indicação de quão cheio está. Cheio não deveria ser uma medida "estática", na minha opinião. Talvez uma percentagem?
5. Talvez mostrar uma taxa de ocupação em %
6. Cada categoria podia ter um intervalo de números ou percentagens associado. O quão ocupado é meio? 50%? 80%?
7. Não apareceu

Comments concerning question 10:
1. Por momentos na utilização do mapa duvidei se seriam linhas diferentes apenas ou se representam a ocupação do veículo
2. este é superior ao anterior quando há maior nº de coisinhas
3. Identificação/visualização do transporte pouco legível
Appendix

4. Nao e muito intuitiva a localizacao dos simbolos

5. Aqui o valor numerico ja nao acho necessario.

6. As cores sao facilmente percetiveis. Nada a apontar

7. Uma seta a apontar para o sitio com um icone maior para melhor leitura

8. Um pouco complicado compreender a localizacao exata. Os baloes dos preços parecem-me mais diretos, por exemplo

9. Só entendi o que representavam agora

Comments concerning question 11:

1. Acho que pode levar a confundir linhas em certos casos. Poderiam utilizar o nome da linha na tag para evitar isso

2. Fiquei um pouco confuso com isto, não me parece claro os trajetos a fazer

3. Seria bom uma indicação do onde vem este valor a pagar. Acho que ficaria mais claro: 1,20 (bilhete de metro)

4. pode nao ser totalmente imediato associar o preço à rota inteira e só a uma parte dela

5. podia dizer no popup o número do transporte para comparar mais facilmente.

6. Sim, embora não me tivesse apercebido que dava para fazer hover (?)

Comments concerning question 12:

1. Este esquema como cada linha terá uma cor diferente não haverá dúvidas, mas novamente poderá trazer problemas para pessoas daltónicas

2. é ligeiramente melhor ao anterior, mas a sobreposição de trajetos torna confuso

3. podia dizer o número do transporte para comparar mais facilmente.

4. Dá para compreender, mas é preciso estar sempre a consultar a legenda. Para além disso não é claro o porquê de uma das linhas estar a tracejado.

Comments concerning question 13:

1. Escolhi a segunda por ser mais visualmente apelativa pela presença das cores, mas acho que para o utilizador é melhor ter a hora real explicita em vez de ter de estar a somar ou subtrair minutos à hora. Por isso na minha opinião a primeira com cores na hora real seria uma melhor opção para mim
Appendix

2. prefiro ver o nº em atraso do que um valor aprox ou do que ter de fazer contas (sim, sou burro)

3. Gosto de designs clean.

4. "Hora Real" - não é exatamente perceptível que se refere aos atrasos

5. A segunda e a terceira facilitam a visualização. A segunda está mais organizada.

6. apresentação mais simples e consegue conter a mesma informação que as restantes opções.

Comments concerning question 14:

1. Escolheria a segunda se a paragem de general torres significasse uma troca de veículo same?! o 1º não se percebe a mudança do tipo de trajetória

2. não percebo a diferença ao nível do horário

3. Não percebo a diferença nem o que significa.

4. é igual

5. São ambas bastante semelhantes

6. opá nº ao sei a diferença

7. Não me parecem diferentes

Comments concerning question 15:

1. Neste caso a diferença de ligação faz todo o sentido

2. o 1º não se percebe a mudança do tipo de trajetória

3. não percebo

4. Respondo a 2 mas só depois da explicaçãõ na pergunta. Só pela imagem não acho perceptível.

5. Talvez uma diferença de cor entre a estação inicial e a final ficasse bem é igual

6. A da direita dá a entender que se está em General Torres, a da esquerda é ambígua sendo que o traço no lugar dos pontos tanto pode ser interpretado como o próximo caminho a percorrer ou o caminho já feito

7. preferia que a linha continua estivesse em baixo e o círculo com a pinta branca que estivesse na estação de de destino

8. Mais uma vez parecem-me iguais
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Comments concerning question 16:

1. Percebo o objectivo e concordo, mas não acho muito intuitivo pois temos de relacionar árvores com sombra, guarda-chuva com sitios abrigados e tunel com sitios abrigados de vento. Mas os primeiros três concordo plenamente

2. giro

3. Nao percebi que tipo de esposiçao era. Podia ter palavras descritivas em vez de imagens alusivas

4. o texto poderia ser melhor

5. no primeiro impacto não consegui associar as imagens

6. O guarda chuva na menos exposição é contraditória pois o guarda chuva só é necessário se houver chuva

7. Deveriam haver etiquetas para cada simbolo

8. Dá para perceber, até pela descrição, mas não percebo a utilidade dos ícones