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A MOBILE APP BASED ON CROWDSOURCING TO ENHANCE MOBILITY FOR VISUALLY IMPAIRED PEOPLE

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INSTITUTO POLITÉCNICO
DE VIANA DO CASTELO

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Abstract

The number of people with sight disabilities, including blindness, is growing over the years being expected to reach 115 million by 2050. Providing access to urban mobility has an impact on several other sectors of the society such as economic or education level growth, among others. The United Nations, expecting 80 trillion annual passenger traffic by 2030, came up with a Global Mobility report with the aim of bringing equality through sustainable mobility. Visually Impaired People (VIP) face several challenges in their mobility which reflect on how they perform tasks like reaching a desirable destination. Their perception of space, safety, and orientation are leading to the isolation of this group of people, which consequently can lead to lower economics, depression, literacy, among other problems. Having that in mind, this work proposes a mobile application that encompasses a routing algorithm that aims to return the most adequate path, considering several criteria, with the final purpose of promoting a greater level of independence and autonomy to this segment of people. The application relies on the crowdsourcing paradigm and makes use of OpenStreetMaps and OpenTripPlanner. The solution presented, based on the results obtained, reveals itself to be a feasible solution for the addressed problem, easing the VIP mobility and also improving their security feeling while walking on the streets, as they will know in advance the obstacles that the path will have and the places where they can cross the streets safely, which will allow them to have an informed choice between paths.

Resumo

O número de pessoas com deficiência visual, incluindo a cegueira, tem crescido ao longo dos anos e espera-se que chegue a 115 milhões até 2050. O acesso à mobilidade urbana tem impacto em vários outros setores da sociedade, como o crescimento do nível económico ou educacional, entre outros. As Nações Unidas, esperando um aumento do tráfego anual de 80 biliões de passageiros até 2030, elaborou um relatório de Mobilidade Global com o objetivo de trazer a igualdade por meio da mobilidade sustentável. Pessoas com deficiência visual enfrentam vários desafios no que diz respeito à mobilidade, refletindo-se na forma de realizar tarefas simples como chegar a um destino desejável. A dificuldade na percepção de espaço, segurança e orientação estão a levar ao isolamento deste grupo de pessoas, o que, consequentemente, pode levar à queda da economia, depressão, alfabetização, entre outros problemas. Tendo isso em mente, este projecto propõe uma aplicação móvel que engloba um algoritmo de roteamento que visa retornar o caminho mais adequado, considerando diversos critérios, com o objetivo final de promover um maior nível de independência e autonomia a este segmento de pessoas. A aplicação baseia-se no paradigma de crowdsourcing usando o OpenStreetMaps e OpenTripPlanner. A solução apresentada, com base nos resultados obtidos, revela-se uma solução viável para o problema abordado, facilitando a mobilidade dos invisuais e melhorando a sensação de segurança ao caminhar na rua, pois saberão com antecedência os obstáculos que o caminho possui e os lugares onde podem atravessar as ruas com segurança, o que lhes permitirá ter uma escolha informada entre os caminhos apresentados.

Keywords: Visually Impaired People. Inclusive Mobility. Crowdsourcing. Urban Mobility.

Contents

Acronyms

3D Third Dimension

AI Artificial Inteligence

API Application Programming Interface

ATM Automated Teller Machine

Ave Avenue

BLE Bluetooth Low Energy

DSR Design Science Research

DSRM Design Science Research Methodology

GeoJSON Geografic JavaScript Object Notation

GIS Geographic Information System

GPRS General Packet Radio Service

GPS Global Positioning System

GTFS General Transit Feed Specification

IBM International Business Machines Corporation

IT Information Technology

JOSM Java OpenStreetMap Editor

JSON JavaScript Object Notation

LA Los Angeles

NW North West

OR Oregon

OSM OpenStreetMaps

OTP OpenTripPlanner

PAVIP Personal Assistant for Visually Impaired People

PBF Protocolbuffer Binary Format

PDA Personal Digital Assistant

PHP Hypertext Preprocessor

POI Point Of Interest

RFID Radio Frequency Identification

SI System Information

SQL Structured Query Language

St Street

SW South West

UI User Interface

UN United Nations

URL Uniform Resource Locator

US United States

USA United States of America

USB Universal Serial Bus

UV Ultraviolet

VIP Visually Impaired People

W West

WHO World Health Organization

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Chapter 1

Introduction

Visually Impaired People (VIP) face several challenges when it comes to performing regular daily mobility tasks in urban environments. Although several applications already exist to guide citizens to desired destinations, most of them don't take into consideration the specific needs of VIP such as the most adequate streets.

This study proposes an optimized route recommendation system for VIP based on OpenStreetMap (OSM) and OpenTripPlanner (OTP) in order to return the most adequate path, considering several criteria, with the final purpose of promoting a greater level of independence and autonomy to this segment of people. OSM is an open-source collaborative mapping project to create a free and editable map for everyone to use and cooperate. For that, it provides an extensive list of tags that everyone can add to places (streets, under-ground stations, etc). Those tags include traffic light signals in a crossing road, tactile pavement, stairs, points of interest, ramps, indoor and outdoor information, among others.

In this project, these tags were used as criteria for recommending the most optimized routes. OTP, on the other hand, is open-source multi-modal software that provides route information about passengers and transportation networks.

The proposed route recommendation algorithm receives the current location and desired destination as inputs received from a mobile app, then will retrieve the possible solutions, order by the most relevant to the least, with turn by turn instructions and with detailed information about the obstacles that the VIP may found.

Such a solution has the potential to provide an easy and suitable solution for VIP users to walk safely and gain more independence in the scope of urban mobility.

1.1 Context

Taking a bus or a train may be a trivial task that most of us perform on a daily basis, particularly in big cities where most people use public transportation as their main means of transport. The population with sight disabilities such as visual impairment or blindness is growing over the past years and is expected to grow over threefold from about 36 million past in 2017 to 115 million in 2050 on a report made by Medical Express [19].

By the end of 2019, WHO claimed that it was expected that at least 2.2 billion people have a vision impairment or blindness of whom at least 1 billion have a visual impairment that could have been prevented or has yet to be addressed [76].

The use of public transportation is gaining more and more importance due to sustainability and environmental issues so their adequacy and support for people with visual impairment are fundamental. It is a common activity, mainly in larger cities, to use public transports, but for the reasons mentioned above, even small cities should aim towards higher usage of public transportation, including for people with visual impairment, contributing to a more inclusive transportation system which is an emergent topic within smart inclusive cities.

The use of public transport can become an arduous task for people with visual impairments because they need to gather information about their surroundings (location of the crosswalk, the direction of the nearest bus stop, among other information), to be able to use public transports to get to work, to public institutions, to supermarkets.

Nevertheless, some difficulties have been found among the existing applications, such as precision of GPS, recommendations systems based on the user needs, and still, some challenges regarding mobility underground are to be explored, since GPS does not work in such places. Radio-frequency needs proximity and other solutions require the user to have multiple devices, access to Wi-Fi, or the need of hardware installed in the subways or inside the public transportation, as the example presented in [21] that works with beacons installed in the London tube and the user needs Bluetooth access to receive the voice instructions.

Another challenge faced by VIP is to know when to get off the transport or to enter in the right one when there are multiple means of transport arriving at the same time [37]. Among the 17 sustainable development goals of the United Nations [47] related to social economic and environmental aspects, there are a few where mobility has an impact on, like the eradication of poverty, decent work, and economic growth, innovation and infrastructures, quality of education, especially when it comes to allowing mobility to everyone.

For the economy to grow, people have to move to work, to shopping centers. Likewise, growth in education allows people to have more jobs which increases their outcome, and thus the economic growth. Having that in mind, in 2017 the United Nations came up with a Global Mobility report [46], that aimed to promote equitable, efficient, safe, and green mobility through the Sustainable Mobility for All movement that intends, by the end of 2030, to improve the quality of lives of billions of people. In this report, it is highlighted that "by 2030 annual passenger traffic will exceed 80 trillion passenger-kilometer - a 50 percent increase compared to 2015" [46]. These statements enhance the importance of equal access to mobility and this report intends to show their global goals and how they intend to reach them by the end of 2030.

By allowing universal access to economics, increasing efficiency of transports, reducing deaths by improving safety in public transports and roads, and lowering pollution by shifting public transports systems to green energy, the United Nations believes in archiving their global goals.

Most of the people with these kinds of disabilities end up in social isolation because of the challenges they face in what comes to mobility, being that, the reason that these kinds of measures are so important and should aim for awareness.

This work aims to develop a route recommendation system that returns the most suitable according to VIP needs. This way, improving VIP mobility as long as their feeling of safety while walking on the streets. This improvement aims to fulfill the gap presented in the section 1.2.

1.2 Problem Statement

Mobile applications play an important role in our daily life and they can be a powerful help for people with disabilities such as VIP. However, the existing recommendation systems still lack on delivering the routes regarding the VIP needs, that alert them for possible obstacles, that consider their potential preferences for straight paths, along with other features.

Most of the developed applications do not take into consideration the challenges faced by VIP, regarding orientation, safety, and boosting their confidence while walking outside. This way, an application that fills this gap, showing the possible paths the VIP may take according to a difficulty range based on their preferences will enlarge their confidence, promoting inclusive mobility and therefore making VIPs more independent.

Recommendation systems are now being explored mostly in e-commerce and marketing campaigns to show the user options based on their research. In what concerns to mobility, there is still a large space for improvement to take into account the users' preferences and needs.

Considering the most usual systems that are now being used by Google, Apple, Waze, they all use route recommendation systems based on distance, time, cost of the travel, and traffic. However, different users have different needs, and in this particular case, the main users are a specific group of people with sight disabilities.

One of the biggest goals in promoting a better inclusive mobility is to diminish the social isolation of VIP. The biggest challenges faced by these users is how they orient themselves, being aware of the obstacles on the streets, increasing their feeling of safety, and increasing their independence. These obstacles could be a no sound traffic light, a fence, or even the existence of a platform for boarding public transports.

Regarding VIP needs on route recommendation system, some applications have been developed. Some [10] consider the width, inclination, turns, and the existence of trees and park routes. Others [69] [48] made extensive research on several guidance systems, using various machine learning algorithms, and compared several applications in terms of their guidance capabilities and quality of supported functionally. There is a unanimous conclusion of the amount of work yet to be done in this field, as said in [48] "There is a significant gap towards the developed solutions and actual needs of VIP in terms of richer and comfortable paths for safe and smooth navigation".

To fill this gap, a route recommendation system based on information that will help the VIP's mobility is presented along with this work. The next section will explain the objectives proposed in order to fulfill the purpose of this work.

1.3 Objectives

In a world where inclusive communities are increasing awareness, it is important that each one of us could be able to do something that will help others to improve their quality of life. With the growing technological evolution over the years, a large scale of cities is becoming smart cities helping us in almost every aspect of our life. Nevertheless, VIP still struggle to have an independent life where they can benefit from inclusive mobility. Although several works have already been proposed with the aim to improve their daily lives, there is yet a lot to be done.

With that in mind, and aligning my passion for technology with my willingness to help others, I embraced the idea of creating a new solution to overcome the challenge that VIP face every day, in order to simplify tasks such as catching a bus in a crowded city or reaching the desired destination.

Choosing crowdsourcing applications to work with, was not a difficult choice to make. Crowdsourcing applications can be powerful because people from different areas of interest work together with the same goal in mind, to deliver a solution to a problem, and when people work together things happen faster. In this particular case, it could take decades for a single company to tag every single building, route, traffic sign, etc. and with OpenStreetMap, every person from around the globe can make their contributions, making it easier to enlarge the world's information about traffic in general.

The specific goals defined for this project are as follows:

- Understand the challenges and needs for VIP when walking on the streets;
- Definition of the specific set of OSM tags that are more relevant for VIP;
- Development of an algorithm to recommend paths, having into consideration the

relevant tags that were defined in the previous step;

- Development of an app that uses the algorithm and returns the most suitable path for the VIP;
- Evaluation of the solution.

1.4 Methodology

In order to pursue this research, the Design Science Research (DSR) methodology was used. This research methodology is commonly used among information technology (IT) and system information (SI) researchers, aiming to solve identified problems or create new innovative solutions in problems already solved by designing methods, models, constructs even social innovations [31].

According to [60], this definition "includes any designed object with an embedded solution to an understood research problem". However, only in 2007, Peffers et al. came with a structured methodology that involved problem identification and motivation, the definition of the objectives, design, and development, demonstration, evaluation, and communication which is shown in Figure 1.1:

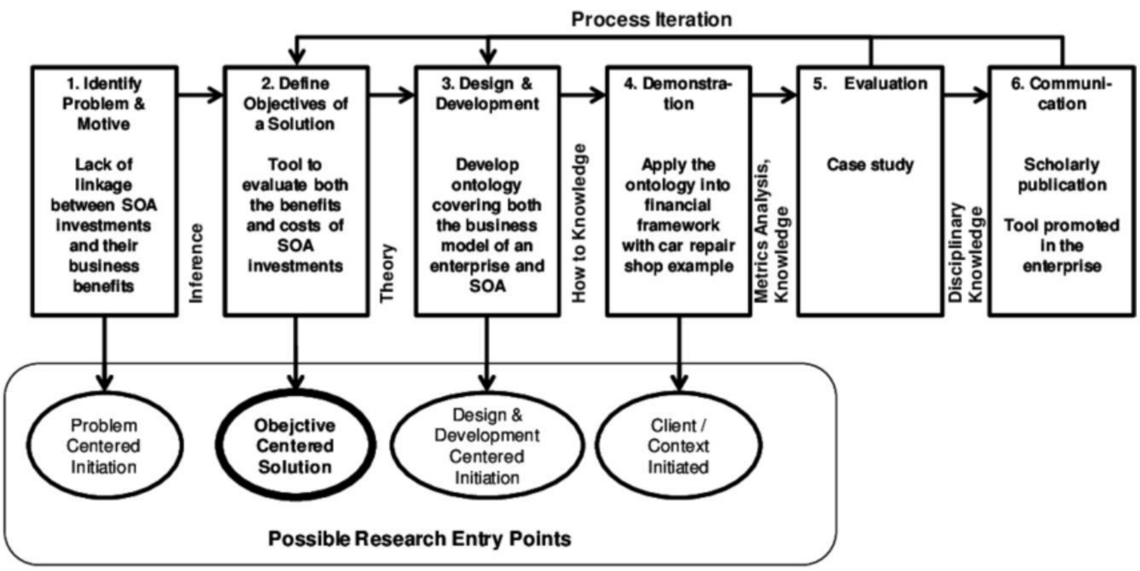

Figure 1.1: Nominal process of DSRM (Peffers et al., 2007) Objective [60]

The first stage - the identification of the problem - relies on previous research for the existing solutions concerning a better understanding of the problem, finding more solid knowledge to later propose a feasible alternative solution to the addressed problem. Thereon, the definition of the objectives for the addressed problem should be presented in quantitative or qualitative forms describing in a rational and reasoned way how the problem will be addressed and why this solution will have better results than the existing ones. These objectives must be well identified, to better accomplish the next steps.

The designing and development step is where the architecture of the solution will gain form. It is also in this step that the main functionalities must be fully described and implemented on an artifact in order to be tested.

The next step will be to demonstrate how the presented solution works either simulated or real user experience-based. After demonstrating how the solution may work, it will be necessary to evaluate the results and the accuracy of the presented solution. This activity is very important because it will decide if the presented solution works effectively or if any other relevant aspects must be improved in order to present a feasible solution.

From here the process can go back to the second or third step depending on the aspects where the solution failed. It may be only a question of usability, or it may be that in the end, the presented solution does not show feasibility enough to solve the existing problem, which will lead to a whole redefinition of the objectives.

The last activity relies on the communication of the presented solution in a conference, journal, or other appropriated research environment.

1.5 Organization

This work is divided into 6 chapters, first chapter belonging to the introduction presents a contextualization of the subject of the work, explains the problem statement, the objectives of this work as well as the methodology used, and last how this work is organized.

Chapter two refers to the conceptual background. Here, is presented an overview of the user's typology in order to understand who are they, what challenges their face that makes the reason for this work to be written, an explanation of the technologies used and their capabilities in a general overview. In this chapter is also presented an brief introduction to crowdsourcing and inclusive mobility.

In chapter three, is presented the literature review divided into two sections. The first section has a massive explanation of all the applications that address the problem statement described in chapter one, founded on research and a comparison between them. The second and last section of this chapter relies on the crowdsourcing solutions that also face the addressed problem.

A solution proposal is presented in chapter four. In this chapter first an explanation of the architecture and how the solution will work. Section two and three have an in-depth explanation of the implementation of the presented solution. Section four presents and explanation about the Backend processing and last, section five, presents the solution itself with an overview of the prototypes of the application screens.

After understanding the presented solution, an evaluation of the application described in the previous chapter is introduced in chapter five. This chapter is divided in two sections, first the test characterization is explained and last, the analysis of different results in real-time evaluation are shown, having into consideration several different conditions.

Last but not least, chapter six, contemplates the conclusions founded regarding the results explained in the chapter above and it is also presented what could be the future work of the solution proposed throughout this work.

Chapter 2

Conceptual Background

As already mentioned in the introductory chapter, VIP face some challenges that people who haven't these conditions are not aware of. In this section, it will be explained the conditions affecting this specific group of people and how it impacts their lives. It will also be mentioned the technologies used, explain their differences, what their functionality is, and also other technical aspects that will be mentioned during this work.

2.1 Blind and Visually Impaired People

Not all blind and VIP have the same amount of sight loss. While some blind people see nothing, others can see shadows, colors or even objects that are close [6]. According to WHO [76], the International Classification of Diseases divides these diseases into two groups: distance vision impairment and near vision impairment. The first one is yet fragmented into four stages (Mid, Moderate, Severe, and Blind).

Besides, this disease could come from different factors as described in [23], an analysis of this disease between 1990 and 2020. This analysis estimated that the main cause of blindness and visual impairment by 2020 will be cataracts. The main causes of blindness and visual impairment are enumerated below:

- Cataract
- Uncorrected refractive error (including aphakia)
- Glaucoma

- Age-related molecular degeneration
- Diabetic Retinopathy
- Corneal Opacity
- Thracoma
- Other

2.1.1 Aids for Visually Impaired People

As vision is one of our main senses, people with visual impairment can become more isolated easily. Besides the world is becoming increasingly aware of the problems these people face, there's always a lot of work to do in several different areas. With the lack of one of the senses, VIP use more often the other senses, like hearing, touch, and smell, to orient themselves.

The most common guiding support for VIP is the white canes and the guide dogs. The main difference between these two, according to [13], is that while white canes help avoid impediments, guide dogs are trained to avoid obstacles in the pathway even that the VIP may never be aware. There are some pros and cons about using each of these aids and each person should use the one that feels more comfortable and safer according to the pros and cons of each.

Braille has been for years the main reading aid for VIP besides the number of legally blind people who can read braille has dropped over the years from around 50% in the 1960s to 12% in 2010 [70]. This happened mostly because of the increase of technology like the voice readers devices, smartphones that already come with assisting technology for the blind and other devices that came to surpass the braille.

Nevertheless, on a survey made to 443 participants [66] who joined data from demographics and braille learning history with well being and employment outcome, was found out that despite the evolution of new technologies braille still plays an important role in VIP, especially because it is directly related with the VIP well being. In this study, the individuals were separated into three different groups. Those who learn braille early in life, those who used another reading medium in their childhood, and those who never have learned braille. Besides the most known products, there are a few others like alerting indicators for liquids, talking clocks, devices with larger numbers and letters in the case of people with low vision, protective glasses against blue light and sun, etc.

2.2 Technologies and tools to support navigation

2.2.1 Beacons

Beacons are small artifacts created by Apple in 2013 used especially for indoor geolocation. This device communicates with other devices (smartphones for example) by proximity, using Bluetooth Low Energy (BLE) to operate, and using radio waves to communicate between devices. This technology allows a higher reach with less energy spent than regular Bluetooth technology even when trespassing concrete walls. This way, the use of these devices helps to identify the location of people indoor.

These devices are cheap, which is an advantage for their massive use in several areas, not only for geolocation but nowadays they are being used for different purposes like location, engagement, navigation, analysis and data collection, asset and people tracking and iteration [5], payment, event management, content delivery, transportation, proximity marketing [67] to track the user's behavior in their stores and communicate with them to increase the sales [11].

There are some types of beacons, each one with different sizes and functions.

- Standard beacons: works like Wi-Fi and are very often used for indoor trackings like geolocation or retail purposes.
- Small beacons: These portable beacons are the size of a credit card and are often used for employment purposes.
- USB beacon: often used to deploy in-office related purposes and looks like a flash drive.
- Video beacon: usually it is a Bluetooth device plugged into the back of a screen and used for videos purposes for example to deliver customized customer experiences.
- AI beacons: used to detect movements using machine learning algorithms.

- Sticker beacons: these are the smallest ones and are very often used for tracking purposes.
- Parent beacons: these gather and manage the data from other beacons and store that in the cloud. Usually, they are about the size of a Wi-Fi router.
- Specific beacons: resistant to water, UV, shattering, dust, antistatic.

In terms of technologies, the following can be used:

- iBeacon (Apple)
- Eddystone (Google)
- AltBeacon (Radius Networks)
- GeoBeacon (Tecno-World)
- Bluetooth low energy (BLE)
- Wi-Fi Aware.
- Ultrasound.
- Combined technologies.

Speaking of the most relevant ones, iBeacon, created by Apple is the most commonly used beacon technology. However, although compatible with iOS and Android, it requires a license both for the manufacturing and for the logo. Google also created one competitor for iBeacon with Apache Open Licence, allowing more features than iBeacon and AltBeacon and also creates a better engagement by making it possible to send URLs. Last but not least, AltBeacon is a free alternative to the previous technologies, regardless of the variety of the operational customization, it is more difficult to implement than iBeacon for example [62] [67].

2.2.2 GPS

GPS stands for Global Positioning System, and it's a very common technology that is present in every smartphone, allowing people to know their current positioning. Nowadays, GPS is essential in several different areas, from different work areas to recreation, helping rescue people, to transport companies, everyone has at least used GPS once in their lives. GPS, owned by the United States government, started being used in 1973, but only in 1993 were set the current 24 satellites in orbit. Although GPS is a free technology, it is maintained by the US military and has been approved in 1996, a national policy where the US compromises to provide the use of this technology worldwide.

As been said in [35] the United States "will continue to provide the GPS Standard Positioning Service for peaceful civil, commercial, and scientific use on a continuous, worldwide basis, free of direct user fees. We will cooperate with other governments and international organizations to ensure an appropriate balance between the requirements of international civil, commercial, and scientific users and international security interests."

According to [26], there are three different segments of this technology: Space, Control, and User Segment. The first two segments are fully controlled by the United States Space force. The Space Segment is responsible for the satellites presented as constellations in space, transmitting the GPS signal to the Earth. The Control Segment is responsible for the maintenance and control of the satellites in orbit, being cared for by stations worldwide. The User Segment concerns the devices used to receive the information given by the satellites and then calculates the three-dimensional position (latitude, longitude, and altitude) for the user to know their exact location over time.

From the beginning of its use, GPS has evolved, being each day more accurate. However, in indoor spaces, mainly underground like metro stations it still lacks efficiency.

2.2.3 OTP

OpenTripPlanner (OTP) is open-source multimodal software that provides route information about passengers and transportation networks [57]. This software uses real-time updates on transportation and alerts and is used by a lot of applications worldwide. Examples of the standard deployments using OTP can be found at the TransitWiki website [71]. Next is shown a few of them all around the world:

- Trimet Portland (USA)
- New York State Department of Transportation (USA)

- Helsinki Regional Transport Authority (Finland)
- Municipal Transport Company of Valencia S. A. U. (Spain)
- SMTC (France)
- ZTM Lublin (Poland)
- ViaggiaTrent o & ViaggiaRoverto (Italy)
- Adelaide Metro (Australia)

Open Trip Planner has two releases, the first one is under development since 2009 and the second one was released in 2018. The first version is best to use under research or consulting, as a network analysis toolkit for urban planning and research. Due to its amount of experimental code, it is not viable for long-term maintaining which turns this version obsolete for product-oriented platforms. On the other hand, version 2 is still in testing, some components have been completely rewritten which translates to higher performance when speaking about larger transportation network [58].

2.2.4 OSM

OpenStreetMap (OSM) is an open-source collaborative mapping project to create a free and editable map for everyone to use and cooperate. According to [36] at the beginning of the current year (2021), OSM had more than 5 million users registered, and around 20% of them have already edited the map. For that, it provides an extensive list of tags that everyone can add to places (streets, underground stations, etc), to enrich global information for everyone to use. Those tags include traffic lights in a crossing road, tactile paving, stairs, points of interest, ramps, indoor and outdoor information, etc.

OpenStreetMap is commonly used by several top-rated companies like Amazon, Apple, Facebook, Microsoft, Foursquare, Uber, New York Times, but also for several Governmental and Humanitarian institutions, News and Media, educational institutions, navigation, and social companies, etc. Its use is not restricted to a base map, being able to use OSM data for routing, navigation, or GIS analysis, and more, for example, the PokemonGo game that uses these geospatial maps [53].

2.3 Crowdsourcing

Although crowdsourcing can be traced back to the 18th century it was by the words of Jeff Howe that, in 2006, the term crowdsourcing started to being used [12]. As he explains, in several areas, companies are using the knowledge of different people to upscale their developments, saving time and money. He explains, in the article entitled the rise of crowdsourcing, a sort of definition of crowdsourcing "The labor isn't always free, but it costs a lot less than paying traditional employees. It's not outsourcing; it's crowdsourcing." [32].

These groups of people can be attached to an organization or work as individuals who want to help in different kinds of causes. The good thing about crowdsourcing is that these groups of people can be all around the world, with different backgrounds, working in different time zones, making things happen faster and in a cheaper way. According to [29], who joins different points of view of the crowdsourcing activity, the concept can be defined as "the act of outsourcing tasks originally performed inside an organization, or assigned externally in form of a business relationship, to an undefinable large, heterogeneous mass of potential actors".

Crowdsourcing is emerging and can be found in several areas, helping foster the development of applications and innovations. Some crowdsourcing communities are more focused on fundraising for certain developments than the development of the product themselves.

Not a long time ago, with the recently pandemic situation of Covid-19, several crowdsourcing communities were raised in weeks, which helped foster the development of applications and data analysis to help the whole world, not only applications but the exchange of knowledge around the world to find treatment for this disease as fast as possible, reuse of technology to face several challenges, etc.

An example of that is the Portuguese Tech4covid19 community [45], with 34 projects ongoing and more than 5000 volunteers from different study fields, engineers, scientists, health professionals, markets, etc., that, last year, have developed the "Posso ir?" application [51] to provide information about the affluence of people in supermarkets. For that, each one of the people, who had the application, every time they went to the supermarket had to give some information like location, time and how crowded the place was. Several other application exists as the traffic application, Waze, where each driver can give some information like police, speed traps, hazard, cars stopped on the road, conditions of traffic, etc.

Applications based on crowdsourcing grow along with the growth of users, and that is crucial for their success.

2.4 Inclusive Mobility

As cities are becoming smarter, inclusive mobility has been an increasing discussion topic all around the world and there's an increase of measures taken to ensure mobility.

An example of that is the European Event that covers all transport modes and aspects of mobility [40]. This topic is not only about VIP but all kinds of people with disabilities. From a simple ramp to a sidewalk to ease access to elevators, or even tactile paving in metro stations to ease the mobility of VIP are measures that enrich inclusive mobility. A diversified language on advertising the current transport arriving and its destination is another example as well.

Inclusive mobility is about to decrease the challenges people face when moving from point A to point B giving to all people, despite their disabilities, equal opportunities. Sometimes the ramp exists but its amplitude is higher for a person in a wheelchair to be able to reach its top safely. Another example is the Automated Teller Machines (ATM) being placed too high, that people with motion disabilities can't reach them.

According to the World Bank, one billion people have some kind of disability, of which, between 110 million to 190 million suffers from severe disabilities being this number higher in places under development [4]. In America for example, around 16 million people use wheelchairs, canes, crutches, or walkers [3].

The existence of disabilities does not affect only the mobility itself but it has repercussions on the entire society, education, employment, mobility, economy, etc. That is why this is such an important topic that must be discussed and measures must be taken to improve the inclusiveness of people with disabilities in society.

John Morris, the founder of the wheelchair travel blog [44], points the difficulties encountered in every country for travel purposes and how people with disabilities could get around. From hotels, to transport either in America or all around the world, there is a lot of information that people with disabilities could use. One of the important things he points out is the challenges people may face when using a public bathroom in Europe. As the bathroom for people with disabilities is placed inside a door that gives access to all-gender bathrooms, and that first door may be locked with a European universal key to avoiding misuse. In these cases, people have to ask the waitresses for the key. Nevertheless, he explains how people with disabilities could get a personal copy of this European universal key. Apart from that, he states that almost all the information around the internet is unreliable and there's a lot of work yet to do regarding this topic [44].

First Mile Last Mile, a strategic plan for Los Angeles County [22] was made regarding the need of inclusion to everyone, making standard best practices to reach inclusive mobility in the city having the following guidelines:

- Provide a coordination tool and resource for Metro, LA Country, municipal organizations, community groups, and private institutions.
- Serve as a key source of direction for LA Metro when undertaking planning and design efforts aimed at improving first and last mile connections to transit.
- Clearly articulates the pathway concept including objectives, characteristics, and the role the Pathway plays in supporting transit access and regional planning goals.

Several other measures and laws were developed to help not only the people with disabilities but everyone in society. The North Carolina State University came with 7 principles called Universal Design that nowadays are used in almost every design and architecture University all around the world. These principals aim to ease and turn every space accessible to a wide range of people [72]:

- Principle 1: Equitable Use
- Principle 2: Flexibility in Use
- Principle 3: Simple and Intuitive
- Principle 4: Perceptible Information

- Principle 5: Tolerance for Error
- Principle 6: Low Physical Effort
- Principle 7: Size and Space for Approach and Use

Thinking about how the future mobility system could be accessible to everyone in an inclusive society, a conceptual framework for an inclusive mobility system was formulated combining these principles with mobility, accessibility requirements, competencies, and responsibilities of involved actors, involving several aspects of the society and technology and focusing on the need of development in areas like transports, digitization and automation enlightening the potential of this areas to improve accessibility, equality and inclusion [20].

A study about how the measures of inclusive mobility were taken in the European Union and a comparison between how several countries react to that issue [24], state that, besides this issue started to be pointed a long time ago, at the beginning of the new century, points the urge of this concern to be taken seriously for all countries and the importance of individual mobility "as a necessary prerequisite for people's participation in social activities".

As lack of mobility turns a risk for social exclusion, the topic that began being spoken in 1990 in Europe, although countries like France had already created special measures with the aim to help people with disabilities earlier on 1982. This way, the importance of the European Union to play a leading role in this aspect was enlightened in this study [24].

Chapter 3

Literature Review

The use of public transportation and inclusive mobility is an important topic that should aim for awareness all around the world. Over the years, the importance of this theme, and the evolution of the technology, conducted a lot of research and developed applications to help and ease the mobility challenges the VIP face.

The following subsections will focus on the developed research made over the years regarding the development of applications and systems that aid VIP with mobility challenges. The first section focuses on applications to help the VIP, how they work, and the challenges they still face. The second section concerns crowdsourcing solutions and the yet existing challenges on the current mobile applications available on the market.

3.1 Applications to help VIP on Public Transportation

Research on this topic is found in the literature for decades with the single purpose of helping VIP to use public transportation [30].

In order to fulfill the challenges VIP face, many solutions were created all around the world. Most of these solutions rely on the implementation of loudspeakers [52], radio-frequency solutions [42], buzzers and wireless transmission [75] and mobile applications based on GPS or RFID. In Panama, an app called Movidis [42] was created, which was made of 3 separate apps and one communication box, concerning communication with the bus stop and the bus driver. Firstly, the transmitter box communicates with the bus stop, and when the bus gets at a certain distance to the bus stop, the driver receives the information that a VIP wants to get on the bus. After the boarding, the box allows users to communicate with the driver their intention to leave the bus at a certain bus stop. For example, if a VIP is at the next bus station and with the communication box that works with radiofrequency, a VIP can alert the bus driver at the time the bus approaches the stop, their intention to board, and also when leaving the bus [64].

An indoor-outdoor position navigation app was developed for Austrian and German railway to fill the obstacle of underground areas [41]. This app allows people with sight disabilities to request a navigation route and timetable to use within public transport. Information about boarding and disembarkation is given to the user.

In Switzerland, a User Interface was investigated [63], and some interesting points were pointed about the needs of the VIP, regarding using the mobile phone to perform simple tasks like requesting a bus number. Solutions for the design of this kind of apps were formulated as speech recognition, screen reader software, gesture recognition, and screen magnifiers [63].

Likewise, PAVIP (that stands for Personal Assistant for VIP), a command with buttons and voice guidance, was developed in the same country [59] [75] [64]. These commands with voice recognition are used all over the world as they are cheap and easy to use.

In Prague, a personal command transmitter, made by Apex, ltd and called Tyfloset, uses GPS and GPRS digital radio monitoring and presents audio information and orientation for VIP [2] allowing the user, similarly to Movidis, to inform the bus driver of their intent to board, to know if the user is boarding the right bus and to check the number of the bus only by pressing a sequence of buttons [65].

Germany also has a solution made with RFID acoustic support called BusId, which helps users find the right bus, orientation inside the bus, and in underground areas where the GPS does not work [73].

In Brazil, the app called "busalert" helps VIP to get on the bus [9]. For that, the person has to first send a message with the number of the bus they want to catch and also the destination, in order to get a message back with information regarding where is the bus stop, waiting time, and also other information.

In Canada, an app called iBus [34], based on a customer-focus project, uses GPS and odometer data to give real-time information about all the buses in the city of Montreal allowing every citizen, including the ones with every kind of disability, to have the easiest way to use public transportation. With this app, bus drivers can change routes accordingly with traffic or accidents, and if that occur, the passengers are alerted in the app, in the panel's inside the bus and also buses communicates with transit lights to change to green when a bus passes by to arrive quicker to the bus stops.

In Finland, an app called Noppa was created in 2004 [50] with the aim of helping VIP with orientation both indoor and outdoor. This app provided indoor and outdoor positioning, warnings, route planning, and guidance using PDA, 3G phone, speech recognition, GPS all separated parts of the system. Nevertheless, today the app is only used as a research platform.

Although many countries developed at least one app regarding the needs of VIP, there are only a few that covers different public transports worldwide.

Movit is a regular app for public transport with Voice-Over and Talkback options [43].

BlindSquare is another app that works worldwide based on OpenStreetMap and Foursquare. Besides helping to plan the route, with time to leave reminders and route obstacles information, this app also provides information about the nearest POI's within the circle radios the user previously defined. This app uses third-party apps to provide turn-by-turn information such as Apple Maps or Google maps [8].

Probably the most famous app among VIP, is the one called Georgies Phone [61] made by Roger and Margaret Wilson-Hinds, a blind couple. Over the past years, the app has evolved and it aims to help the VIP with bus travels, read printed text, pointing location, color, and object recognition, among other features, that make a lot easier the life of people with such disabilities. The only two restrictions regarding the use of this app are the language that only is available in English and it's a paid app.

In Portugal, some research in this area has been made in a couple of cities. In Leiria, in 2011 an app based on GPS and available only for android was developed. This application aims to work without a network by having a local database (SQL lite) [65].

In Viana do Castelo, another app based on GPS and PHP was built in 2018. This app was made not only for transportation aid, to the VIP, but also as an outdoor navigation aid app [37].

Table 3.1 summarizes the above-presented information, namely presenting a comparison of the apps regarding the challenge they address and used approach.

Table 3.1: Summary of apps for Visually Impaired People

Study	Country	Challenge	Limitation	Approach
Movidis [64] [42]	Panamá	Creating a system that works in the underground when GPS does not.	The system relies on the auditory cues for alerting the visually disabled person about bus arrival and for guiding them to board the bus. Bus drivers must be trained.	Radiofrequency communication, GPS and PHP.
Indoor positioning [41]	Austria and German railway	Provide current position indoor and outdoor and appropriate user interface.	Accuracy of tracking position and necessity of walking a few steps before the app detects movement.	GPS, OpenStreetMap and project-specific database.
Design of an app to help VIP [63]	Switzerland-Bern	Improve information about public transportation for VIP for the Bernmobil company	Issues with sound alerts in crowded places were taken into consideration.	Only the design of the UI was made. Presents some solutions about crucial design needs for the apps.
Pavip [59]	Switzerland	Voice guidance for the use of transports	There isn't communication with the driver	Wireless

Tyfloset [2]	Czech Republic	Audio orientation for municipal, suburban and railway transportation.	Requires specific equipment (the box with buttons)	GPS/GPRS digital radio monitoring.
BussAlert [9]	Brazil	Navigation to the stop and informs when buses arrives		
iBus [34]	Canada	Real-time information about buses in Montroyal	It is a regular app	GPS and odometer data
BusId [73]	Deutschland	Finding single and multiple bus stops .	Restrictions in crowded places.	RFID
NOPPA [50]	Finland	Indoor and outdoor position and warnings to take the bus	Separated devices.	GPS, 3G phone, PDA
BlindSquare [8] [7]	Worldwide	Navigates user to the bus stop, send reminders, and inform nearest points of interest.	Needs the use of third-party apps.	GPS, Foursquare, OpenStreetMap
Moovit [43]	Worldwide	Read the train schedule and where to get the bus.	Relies only upon sound may be a problem in noisy environments.	Voice-over and talk-back options and GPS

Georgie Phone [61]	England - Worldwide	Perform day-to-day tasks with a text reader, bus finder, object recognition, etc.	Paid and only available in English	Object recognition, text reader, voice over.
Assistive mobile software [65]	Portugal	Find location while traveling on public transports without network.	Text to speech does not support the Portuguese language.	SQL lite, GPS, Android inbuilt voice over.
Outdoor navigation system [37]	Portugal	Walks in the city and take a bus.	GPS feasibility when the signal is weak.	GPS

Table 3.1 summarizes the above-presented information, namely presenting a comparison of the apps regarding the challenge they address and used approach.

3.2 Crowdsourcing solutions

Crowdsourcing platforms and apps have been emerging among people without disabilities and over the years people are trying to implement such practices to help VIP. Some apps were been developed with this model as the one presented in [18] made in Singapore. This Android application called Lend an Eye consists in using volunteers to help VIP "see" through their smartphones, by using video calls where the volunteer describes the surroundings to the VIP.

Google itself has been working on making the life of people with some disabilities easier, helping a nonprofit organization with money to develop better platforms using crowdsourcing [16].

Some apps regarding the use of OpenStreetMap (OSM) have been developed mostly for outdoor navigation mixing real-time navigation with information about points of interest (POIs) [39] [15] [14] [28].

VirtualWalk and VirtualLeap are two apps combined that allow users to explore and create memorable route planning with turn-by-turn instructions and with POI information using audio effects as described in [28].

NavCog, on the other hand, uses Bluetooth Low Energy (BLE) beacons and k-Nearest algorithm to get a higher localization accuracy as explained in [1].

Recently, in 2018, IBM Research and Carnegie Mellon University started to explore this app with the aim to redesign NavCog to help VIP to navigate through airports as this app has higher accuracy (1,62 mt) compared with other indoor solutions that can achieve errors from 5 to 10 mt according to [33].

Chapter 4

Solution Proposal

Collaborative applications can increase their data faster as the number of collaborating users increases. With the aim to create a feasible application with updated data and to help VIP increase their mobility, an application was created that makes use of an algorithm based upon collaborative applications.

The developed application has the main goal to provide a VIP with the most suitable route to a given destination.

The developed algorithm relies on OSM and OTP in order to obtain a graph combining real-time schedules of public transport routes with relevant tags for the VIP.

Research showed that most routing applications provide the faster or shortest path as the output. In our case, we intend that the application recommends the user the most suitable route according to VIP needs (existence of light traffic with sound, tactile paving, straight path, streets only for pedestrians).

Section 4.1 provides an explanation about the architecture of the proposed solution. Section 4.2 explains the use of OSM in the application. The use of the OTP and its setup is explained in Section 4.3. Section 4.4 shows the back office work, an overview of whats been done for the application produce the desired outcome, and an explanation of the path calculation. In Section 4.5, an overview of how the mobile application is made, then an explanation of the path calculation and in the last subsection the prototypes of the application are shown.

4.1 Architecture

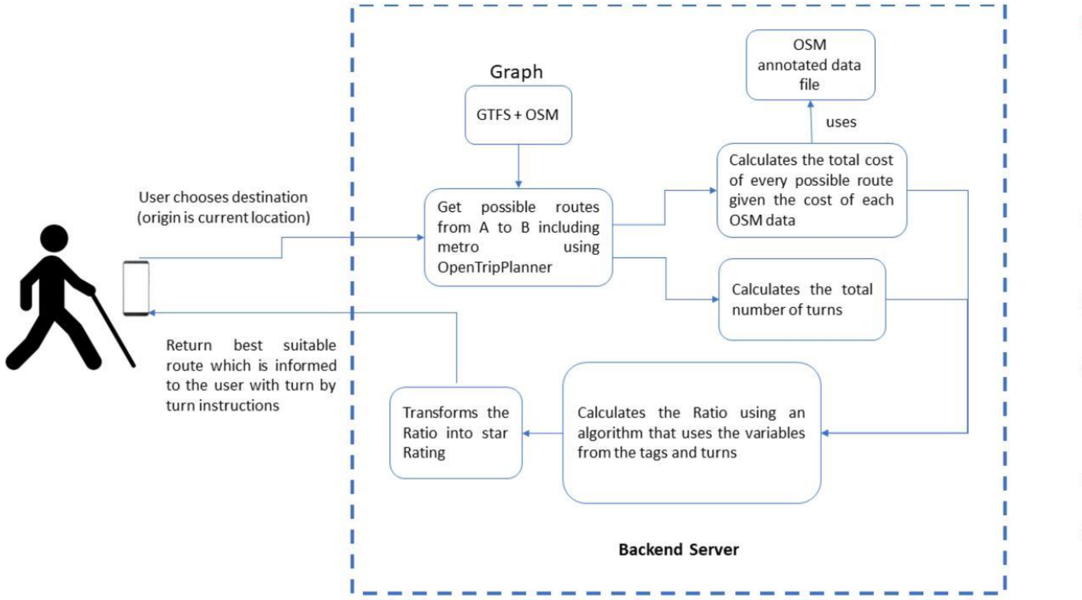

Figure 4.1: System Architecture

The diagram presented in Figure 4.1 summarizes the proposed system architecture. To determine the most adequate path for VIP, some information must be taken into consideration. For example, the preference of VIP for a straight path, sounds or light traffics instead of only zebra crossings [15].

The defined architecture uses an initial position and the desired destination (points A and B), inputted by the user, and returns to the user the safest and optimal path with turn-by-turn instructions.

Therefore, the user should start by entering the destination, and the application will use OTP to obtain all public transport network timetables and every possible route from Point A to point B.

For all possible paths, its ratio is calculated using an algorithm that combines the maximum weight of all OSM tags associated to the path and the minimum turns along the path.

This ratio is then transformed into a 5-star rating, which will translate the most suitable path as the one with the most rating stars and the least suitable with none or least stars.

The OTP and OSM are used on the backend of the solution. On the client side (mobile application), the user will receive the paths, ordered by suitability according to the ratio calculated with the algorithm, presented with turn by turn instructions.

4.2 OSM

This section is divided into three subsections: the first one, regarding OSM Data, will explain the data used on the prototype. On the Subsection 4.2.2, the criteria for the implemented tags is described. An explanation about how the classification of the tags was made is done on Subsection 4.2.3.

4.2.1 OSM Data

OSM presents data information based on Geographic Information System (GIS) with spatial referenced data. This type of data is then separated into three vector types, point, line, and polygon [38]. Polygons are usually used to represent buildings, lines to represent roads and streets, and points to represent singular information like points of interest. An example of the data format is shown in the Listing 4.1.

Listing 4.1: OSM Data Format

```
"geometry": {
                "type": "LineString",
                "coordinates": [
                    [
                        -122.67439850000,
                        45.52304660000
                    ],
                    [
                        -122.67427000000,
                        45.52305170000
                    ],
                    [
                        -122.67407150000,
                        45.52305630000
                    ],
                    [
                        -122.67353770000,
                        45.52306870000
                    ],
                    [
```

```
                        -122.67338600000,
                        45.52307220000
                    ]
                ]
            }
        },
        {
            "type": "Feature",
            "properties": {
                "crossing:barrier": "no",
                "railway": "tram_level_crossing"
            },
            "geometry": {
                "type": "Point",
                "coordinates": [
                    -122.67790540000,
                    45.52041400000
                ]
            }
        },
        {
            "type": "Feature",
            "properties": {
                "railway": "tram_crossing"
            },
            "geometry": {
                "type": "Point",
                "coordinates": [
                    -122.68174170000,
                    45.52059860000
                ]
            }
        },
        {
            "type": "Feature",
            "properties": {
                "crossing": "marked",
                "footway": "crossing",
                "highway": "footway"
            }
```

The tags used for the path calculation are inside the OSM data. Tags are key-value pairs that describe features inside the map [77]. There are a lot of possible tags and several combination of values. The detailed description of each tag can be found on Tagsinfo's website [54], a world map image that points to the places where each tag can be found, among other information.

In Listing 4.1, the content inside properties represent the existing tags on those coordinates. For example, the coordinates [-122.67790540000, 45.52041400000] have two tags: "crossing:barrier": "no" and "railway": "tram_level_crossing". The first tag ("crossing:barrier": "no") has the key "crossing:barrier" and the value "no" which means the street has a crossing without barrier. The second tag ("railway": "tram_level_crossing") has the key "railway" and the value "tram_level _crossing" meaning that this point has also a railway at tram level. Combining both tags means there is a crossing without barrier through a railway at tram level. Inside the OSM file, data is divided by lines, polygon, and points. A line is a set of points represented by coordinates. This file first presents all the coordinates corresponding to a specific line, and then, one by one, those coordinates are separated and presented regarding its properties.

It is possible to add the tags directly to the OSM file, however, it requires knowledge of all the coordinates where the new tags must be placed. On the other hand, with JOSM (see section 4.2.3), it's easier, since it is just needed to choose a point on the map where the user intends to add the tag.

4.2.2 Tags Analysis

The amount of tags presented on the OSM is very extensive [54]. For this study case, it was imperative to find the most relevant tags and those that could help the most the VIP, which will be the target audience of the application.

In order to understand the main needs and which features are more relevant, research was made that led to the conclusion that VIP feel safer in shorter, straight, and less crowded routes [48] [15] [49]. For that reason, tags like 'highway=footway' are preferred by VIP since this tag refers that the road is only for pedestrians, thus providing a safety feeling for the VIP who prefer routes where bicycles or motorcycles are not allowed [15].

Table 4.1 represents the list of the OSM tags that was found more relevant to be incorporated in the routing algorithm according to previous research on VIP preferences when walking. These tags may increase their sense of safety, or ease the way they perceive the obstacles. For example, sounds on traffic lights, the correct pronunciation of places, etc. For each tag, it is indicated if it relates to indoor or outdoor information, and also its meaning.

Table 4.1: OSM Tags

OSM Tags	Indoor	Outdoor	Observations	Might be applied to
Tactile_paving = Yes/No	X	X	Existence of tactile paving.	Paving of the streets or the underground.
Traffic_signals: sound = yes/no		X	Indicates that sound is emitted on tag when crossing is allowed.	Pedestrian traffic lights.
Crossing = Marked; Uncontrolled; Traffic_signals; unmarked; zebra; no		X	Types of crossing in roads: no traffic signals, unregulated level crossing, crossing with traffic signals, crossing without zebra, crossing with zebra marks, no crossing is possible, respectively.	Pedestrian crossing.
Name = pronunciation =*		X	Phonetic transcription of a name into the international phonetic alphabet.	Streets, POIs, buildings, etc.
Public_transport = platform	X	X	Place where passengers are waiting for the public transport vehicles.	Public transports stop or stations.
Elevator = yes; no	X	X	To describe if a feature has an elevator or not.	Metro stations.
Stairs = yes; level=*	X	X	Existence of stairs and information about the level (1st floor, 2nd floor, etc).	Stairs on the streets or stairs in underground areas.
Indoor = area; corridor; door; wall	X		Existence of indoor area not defined through walls, unwalled connecting passage, swinging or sliding barrier, and walls within a building.	Underground metro station.
Incline = up; down	X	X	Indicates the unevenness, slope or inclination.	Streets or metro stations.
Ramp = Yes; No	X	X	Existence of a ramp for wheelchairs, bicycles, strollers built into a stairway.	Streets or underground metro stations.
Step_count =*	X	X	Number of individual steps in a stair.	Stairs in the street or within metro stations.
Step: contrast = no/bad/-/yes	X	X	Existence of a step contrast (yellow or in metal) that helps VIP with the stick to climb stairs.	Stairs in the street or within metro stations.

For the purpose of path calculation, all tags were divided in three categories: positive, neutral, and negative. This classification was made based on studies that included VIP groups [15] [49] [48].

According to those, positive tags were given 2 points, neutral tags 1 point and negative tags -1 points as shown on Table 4.2.

Positive tags are the ones where the user will benefit from their presence. Neutral are the ones that could be left out without causing any harm to the user. Negative tags are the ones that its presence will impact negatively on the safety of the user. So these tags must alert the user to be aware of their presence.

For this particular case study, and considering the extensive number of OSM tags, only a small subset was considered, as shown in Table 4.2. Nevertheless, others that are not mentioned on this table could also be of interest to the VIPs in a real-life scenario.

Table 4.2: Tags weight

TAG:Value	Weight	Observation
railway:platform	2	Platform for accessing public transport
railway:tram_level-crossing	-1	Crossing at tram level in railway
crossing:traffic_signals;marked	1	Road where people can cross with traffic signals and marked
crossing:barrier:no	-1	Road where people can cross without barrier
crossing:marked	-1	Road where people can cross only marked
Crossing:zebra	1	Road where people can cross with zebra
crossing:uncontrolled:marked	-1	Road where people can cross uncontrolled but marked
crossing:uncontrolled	-1	Road where people can cross uncontrolled
crossing:traffic_signals	1	Road where people can cross with traffic signals
highway:crossing	1	Road where people can cross
highway:traffic_signals	2	Road where people can cross with traffic signals
highway:footway	2	Road only for pedestrians
tactile_paving:yes	2	Road with tactile paving
tactile_paving:no	1	Road without tactile paving
footway:crossing	2	Road for pedestrians where they can cross
wheelchair:yes	2	Road accessible for wheelchair
public_transport:platform	2	There is a platform in order to enter public transports
traffic_signals:sound:yes	2	Traffic signals with sound
traffic_signals:sound:no	-1	Traffic signals without sound
shelter:yes	2	There's a shelter on the public transport stop
button_operated:no	-1	Traffic signals without button operated
button_operated:yes	2	Traffic signals with button operated

4.2.3 Tags Classification

After defining the most relevant tags that will be used in this case study, it was necessary to classify tags in an OSM file, which will serve to evaluate the solution.

A portion of the world map was chosen, and some of the tags analyzed on Subsection 4.2.2, were inserted on the map to generate different evaluation paths. After some trials made with other cities, Portland city was chosen because it has a large transportation network which allows to have more itinerary options in shorter distances.

The software used to add tags on the file, Java OpenStreetMap Editor (JOSM), only allows editing on short fragments of the map at once, which was a factor to eliminate big cities or cities where the transportation network has more distance between routes.

JOSM allows the file to be saved in GeoJSON format. This specific format is more readable than the OSM format thus, regarding evaluation purposes, to compare the previously added tags with the points given to each tag, this format is preferred.

Nonetheless, it is also possible to download the OSM data from a specific country on Geofabrik website [25] and convert it on a small file, with just the wanted city, cut by geographic coordinates of bounding boxes, in PBF (Protocolbuffer Binary Format) file. PBF format will be necessary for the integration with OTP.

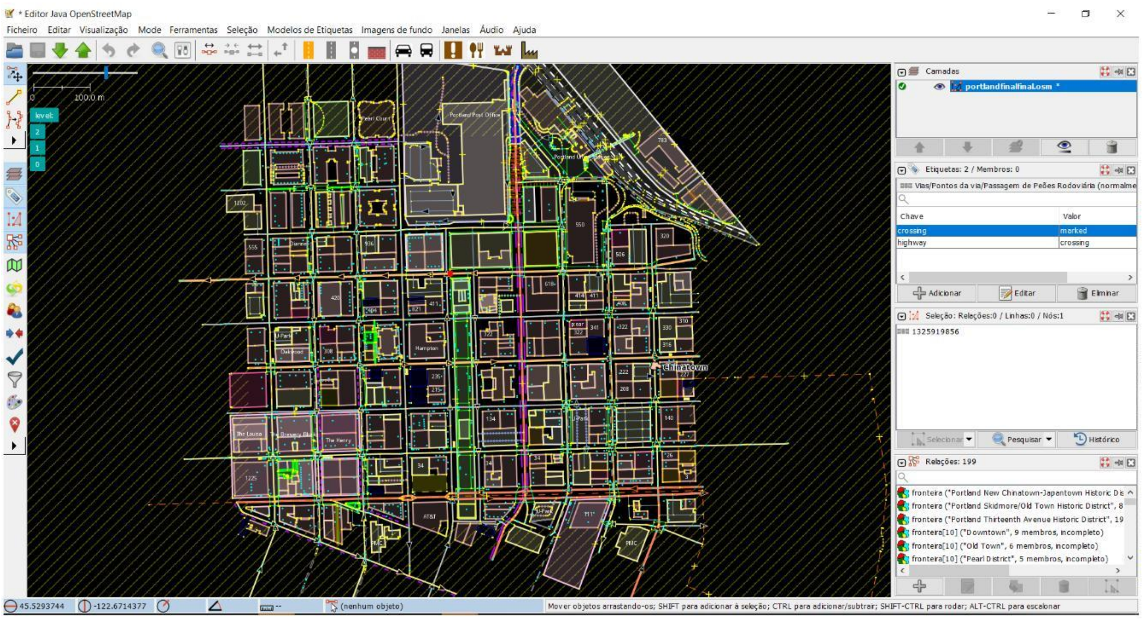

Figure 4.2: JOSM-software for taging the map

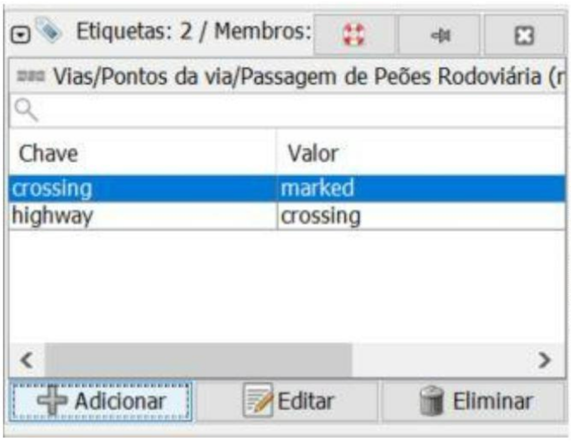

Figure 4.3: JOSM-Tags box

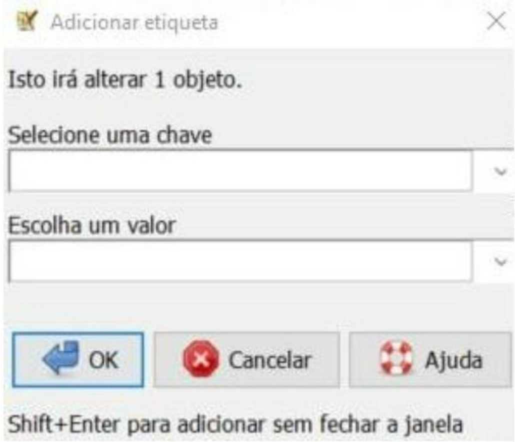

Figure 4.4: JOSM-Add Tag Popup

Figure 4.2, shows an example of the software used for tagging the map. This example represents the portion of the map edited for this proof of concept. It is possible to see polygons, lines and dots. In the center of Figure 4.2 there is a red dot, which represents the selected point. Using the middle box presented on the right side of the Figure 4.2 (see Figure 4.3 for more detail), it is possible to see the tags presented in that point as well as a button to add more tags. In order to add more tags, it is only required to insert a key and a value and press ok as shown in Figure 4.4.

In this map, several tags have been added mostly on the streets NW 10th Ave, NW Glisan St, W Burnside st, NW 9th Ave, NW Irving St, and other streets. The tags added to the map were the ones referenced in Table 4.2. After adding all the desired tags, the file saved in GeoJson format will look like Listing 4.2 which shows an example of some of the tags that have been added to the map. For example coordinate [-122.68123010000, 45.52298240000] represents the point with the following address: 1001-1029 W Burnside St, Portland, OR 97209, USA.

Listing 4.2: OSM Edited

```
"geometry": {
              "type": "Point",
              "coordinates": [
                  -122.68252880000,
                  45.52322600000
              ]
          }
      },
```

```
        {
            "type": "Feature",
            "properties": {
                "button_operated": "no",
                "crossing": "traffic_signals",
                "highway": "crossing",
                "tactile_paving": "yes",
                "traffic_signals:sound": "no"
            },
            "geometry": {
                "type": "Point",
                "coordinates": [
                    -122.68123010000,
                    45.52298240000
                ]
            }
        },
        {
            "type": "Feature",
            "properties": {
                "highway": "crossing"
            },
            "geometry": {
                "type": "Point",
                "coordinates": [
                    -122.68312820000,
                    45.52508370000
                ]
            }
```

4.3 OTP

4.3.1 Overview

OpenTripPlanner is the framework responsible for joining the information provided by OpenStreetMaps, and the routes timetable specified in GTFS (General Transit Feed Specification).

A comparison between several open-source routing services that also used OpenStreetMaps shows that "OpenTripPlanner is the only software with a safety parameter and has the most features" [17]. OpenTripPlanner allows combining the collected data from Open-

StreetMaps, where the information regarding the main needs for VIP was taken into consideration, with routing timetables from public transports in order to return the safest, suitable path allowing users to get from point A to B the easiest way.

OTP has two versions OTP1 and OTP2. OTP1 is the first version, stabler than OTP2, which was lunched in the third quarter of 2020 and is still under limited production use. At this point, OTP1 is still more widely used than OTP2. OTP2 has fewer features but it works more efficiently because public transit routing was completely rewritten when compared with OTP1.

OTP1 routing approach is obsolete, has large amounts of experimental data, and needs long time maintenance. However, it does not mean that it is not a good choice. For example, it is very useful for research or consultancy purposes as this version focus on passenger facing itinerary services over API's and network analysis toolkit. The benefits of choosing OTP2 over OTP1 stand on its efficiency over large or dense networks and its capability to handle even larger networks than OTP1.

Besides this comparison, a list of the main differences between these two versions can be found on the OTP website [55]. As this is a proof of concept involving research, OTP1 version was the chosen one.

4.3.2 GTFS

General Transit Feed Specification (GTFS) [68] is a data format used to represent time schedules for public transportation, allowing them to be used in several different applications. With this format is possible to provide real-time information about the transit schedules for every transit company around the world.

GTFS contains useful information such as schedule, fare, geographic transit information, arrival predictions, vehicle positions, and service advisories.

GTFS data are public, so everyone could download the file. For this work, the Portland city GTFS was downloaded in the Transitfeed website [27]. This website has information about GTFS around the world, and almost every main transport company of the most known cities of each country is available for download.

4.3.3 Setup OTP

For this implementation, OpenTripPlaner was launched via Docker [74]. However, it is always needed to have the OSM data and GTFS prepared. The OSM data was prepared as described in 4.2. Regarding the GTFS data, it has been downloaded as described in 4.3.2.

To join the OSM data with the real-time schedules it is necessary to build a graph. This Graph is a 3D representation of the world map, where the Tag's information will be combined with the real-time schedules for public transports. To build this graph, it is needed to put the OSM file and the GTFS (without unzipping it), in the same folder. The last step is to run the commands to build the graph and run the docker server [74]. In an alternative way, the instructions displayed on the OTP website can also be used [56] [78]. After the graph has been built, the map with the OSM data and the real-time schedules for public transportation can be found on localhost.

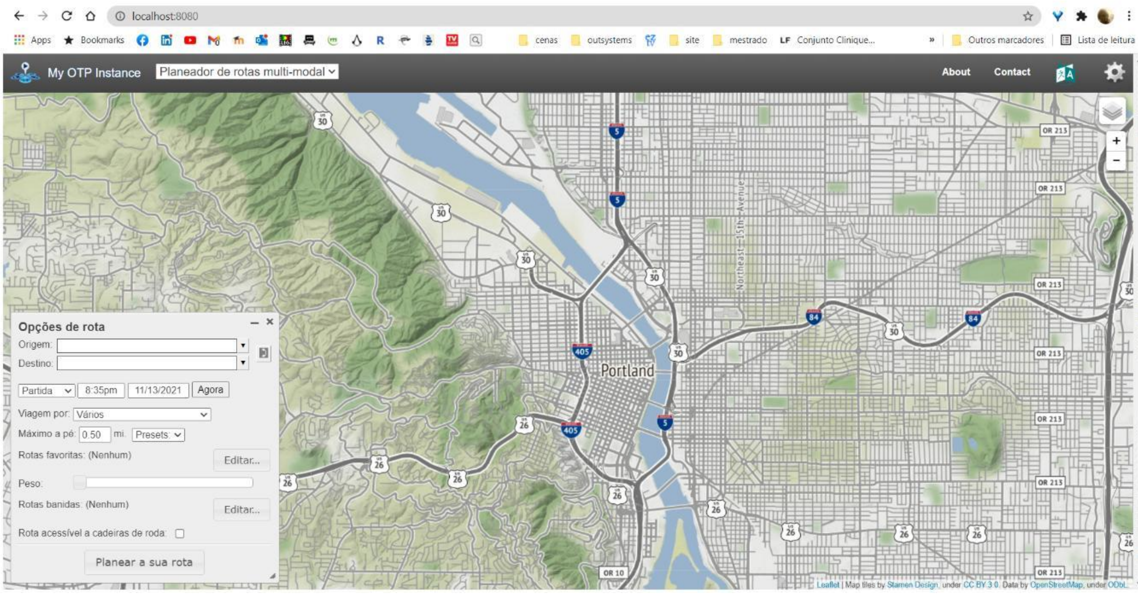

Figure 4.5: OTP running

For proof of concept purposes, the OTP created will be used as a web service that will be used by the application in order to get all the possible paths between location and desired destination. According to OpenTripPlanner resources, there is a list of resources that can use the URL to get specific information of the web service, for example only specific routes or only at a specific time of departure. In this case, it is only necessary to get routing information from the initial location to the destination, using the corresponding coordinates as shown on Listing 4.3.

Listing 4.3: URL to get the possible paths to the desired destination

```
http://localhost:8080/otp/routers/default/plan?fromPlace=" + fromCoordinates + " \&
    toPlace=" + toCoordinate
```

A translation from the address into coordinates is done using the Geocoder class. The link shown on Listing 4.3 will get the coordinates of both initial and destination locations from the names of the corresponding streets inputted by the user on the main screen of the application.

Figure 4.6 represents a brief sample of data (returned from the backoffice of the application) that will be used as the main resource in order to calculate the tags weighting and organized the routing plan returned to the user.

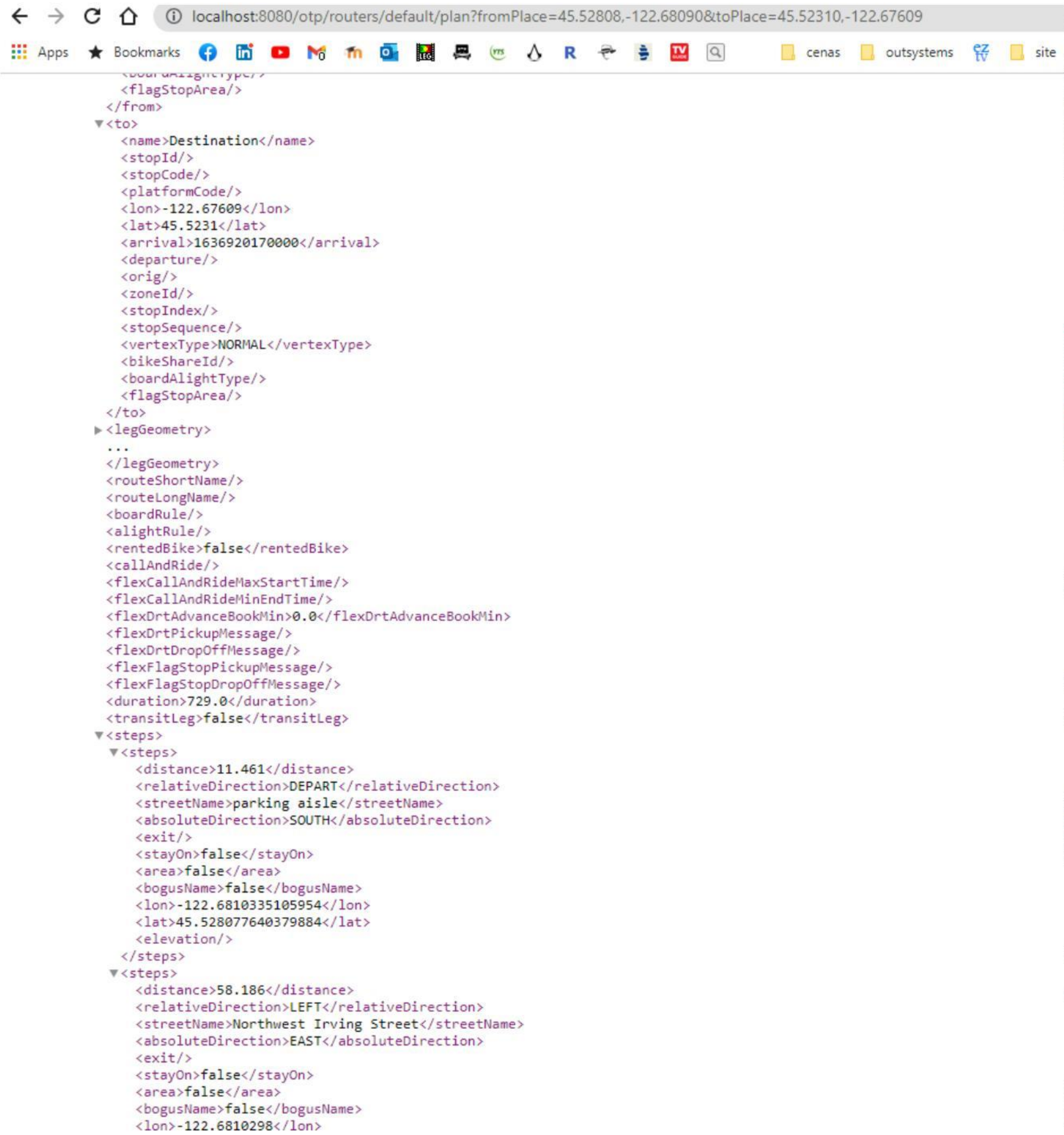

Figure 4.6: Brief sample of OTP response

4.3.4 Summary

In summary, in the proposed architecture, the user will input the location and desired destination on the application. In the backend server, via OSM and OTP, an algorithm will calculate the most suitable path according to the existing tags and will return the possible paths, sorted by suitability.

So far, explanation was provided regarding the data needed for OSM, the criteria used for the chosen tags, the implementation of tags in the city of Portland, the classification of the tags by relevance (positive, negative, and neutral), and the weight each one has. The Integration of the OSM data with GTFS using the OTP was also shown.

4.4 Backend Processing

4.4.1 Overview

The backend uses the OTP as a web service which has incorporated the OSM file with the inputted tags for this case study. The main functionality developed in the backend aims to calculate the path suitability according to the data given by the OTP and the OSM tags. This will allow to return the user all paths ordered by suitability with turn by turn instructions.

4.4.2 Path Calculation

The path calculation uses two main information: the sum of the weight per tag (as given in Table 4.2) and the sum of the total number of turns in each path. Figure 4.7 presents, in a flowchart, how the path is calculated in the backend. The blue shapes explain the calculus of the tag's weight per itinerary and the green shapes the calculus of the total turns.

The process assumes the OSM file (edited on Subsection 4.2.3), was inserted on the backend in GeoJSON format. An iteration through the result given by the OTP (1) (via web service invocation) compares that information with the one given by the OSM file (2).

When the coordinates of the previous comparison matches (3), another iteration will retrieve its tags (4) and the respective weight (6) previously categorized (see Table 4.2) retrieving the total tag's weight of each path (7).

To calculate the number of turns, and looking at the green side of Figure 4.7, another iteration is used through the same OTP result (1), to retrieve both the turn by turn instructions and the total number of turns (9) and save the latter (10).

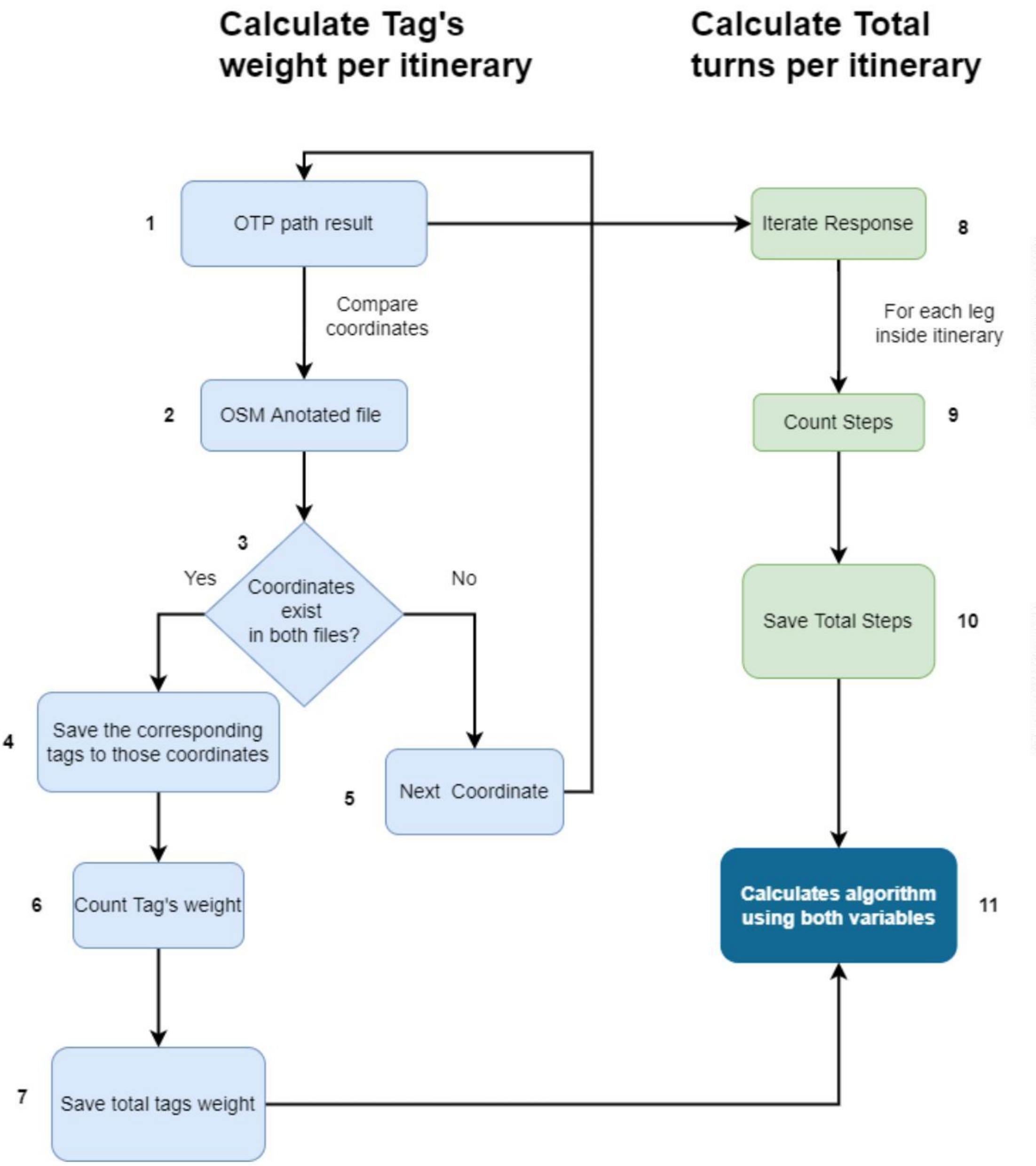

Figure 4.7: Path Calculation Fluxogram

These two values will then be used to calculate the Ratio. The Ratio is the final cost of the path having into consideration the weight of every tag and the total number of turns in the path. The algorithm used can be found in equation 4.1.

This final weight will be used to calculate the rating for the stars that will show how suitable a path is according to the VIP needs. This rating from the stars is calculated through an algorithm that assumes as the best path the one that has the maximum positive tags and the less possible turns according to the following equation.

$$Ratio = TagsWeight + (Turns * -2) \tag{4.1}$$

After that calculation there will be a translation of the ratio into a 5-star rating following the criteria shown below:

★☆☆☆☆ less or equal than 0;

★★☆☆☆ less or equal than 5;

★★★☆☆ less or equal than 10;

★★★★☆ less or equal than 15;

★★★★★ more than 15;

A brief visualization of the results given by the algorithm and the corresponding stars according to the total number of tags in a path and the total number of turns in the same path can be found on Table 4.3.

Table 4.3: Stars comparison based on the algorithm

Tags \ Turns	5	6	7	8	9	10	11	12	13	14
5	-5	-7	-9	-11	-13	-15	-17	-19	-21	-23
6	-4	-6	-8	-10	-12	-14	-16	-18	-20	-22
7	-3	-5	-7	-9	-11	-13	-15	-17	-19	-21
8	-2	-4	-6	-8	-10	-12	-14	-16	-18	-20
9	-1	-3	-5	-7	-9	-11	-13	-15	-17	-19
10	0	-2	-4	-6	-8	-10	-12	-14	-16	-18
11	1	-1	-3	-5	-7	-9	-11	-13	-15	-17
12	2	0	-2	-4	-6	-8	-10	-12	-14	-16
13	3	1	-1	-3	-5	-7	-9	-11	-13	-15
14	4	2	0	-2	-4	-6	-8	-10	-12	-14
15	5	3	1	-1	-3	-5	-7	-9	-11	-13

16	6	4	2	0	-2	-4	-6	-8	-10	-12
17	7	5	3	1	-1	-3	-5	-7	-9	-11
18	8	6	4	2	0	-2	-4	-6	-8	-10
19	9	7	5	3	1	-1	-3	-5	-7	-9
20	10	8	6	4	2	0	-2	-4	-6	-8
21	11	9	7	5	3	1	-1	-3	-5	-7
22	12	10	8	6	4	2	0	-2	-4	-6
23	13	11	9	7	5	3	1	-1	-3	-5
24	14	12	10	8	6	4	2	0	-2	-4
25	15	13	11	9	7	5	3	1	-1	-3
26	16	14	12	10	8	6	4	2	0	-2
27	17	15	13	11	9	7	5	3	1	-1
28	18	16	14	12	10	8	6	4	2	0
29	19	17	15	13	11	9	7	5	3	1
30	20	18	16	14	12	10	8	6	4	2

As shown on Table 4.3, vertically we have the total of the tag's weight according to the weights presented in Table 4.2 and horizontally we have the number of turns. The data presented in the middle is the total ratio given the weight of the tags and the respective number of turns. We can even visualize the table in several colors each corresponding to a level of stars. Red - 1 star, orange - 2 stars, yellow - 3 stars, light green - 4 stars, and last dark green - 5 stars.

The aim of an optimal path is maximize the number of positive tags and minimize the number of turns, so the heavier the tags and the smaller the number of turns, the more stars the path will have.

4.5 Mobile application

4.5.1 Overview

The mobile application developed aims to create a feasible solution for VIP in order to improve their mobility and increase their feeling of safety.

In the mobile application, the user will input the name of his location and desired destination within the city of Portland.

Although this wasn't the best option for the VIP to input location, it is of knowledge that the speech-to-text functionality is, nowadays, incorporated in almost every smartphone keyboard, and the main focus of this prototype relies on the development of the criteria for the developed algorithm. Nevertheless, for a final application, this functionality should be implemented.

The inserted origin and destination are translated into coordinates and used to create the URL shown on Listing 4.3 to call the web service that returns the possible paths for that origin/destination combination.

The result given by the web service (OTP) will then be used to feed the algorithm presented in Subsection 4.4.2 and finally translated into a star rating.

In the next section, the mobile prototype developed will be presented.

4.5.2 Prototype

The first screen, shown in Figure 4.8, was developed with minimal information to be user-friendly. In this screen, the user will input the initial location and desired destination and then click on the Go button to proceed to the next screen.

In the second screen (shown on Figure 4.9), it is possible to see the result right after the button Go was clicked on the first screen. This screen shows the possible itineraries, along with the number of the rating star corresponding to each path, and at the right, the minutes and meters that take to arrive at the destination.

Figure 4.10, shows the details of a given itinerary when clicked. The accordion opens and shows a turn-by-turn instruction with the name of the street, the meters to walk in that direction, the direction to take next, and an information button. When clicked, this information button displays a pop-up with all the obstacles that the user may face.

Figure 4.8: First Screen

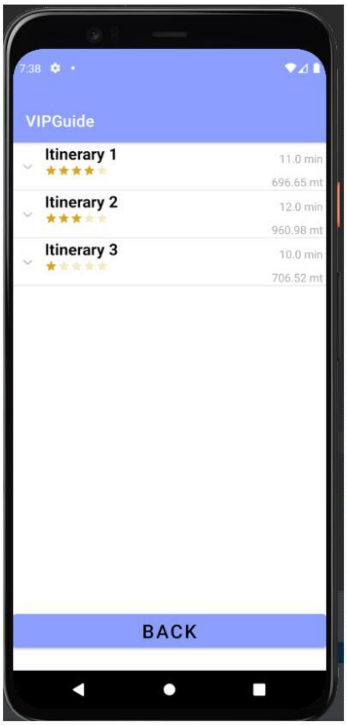

Figure 4.9: Second Screen

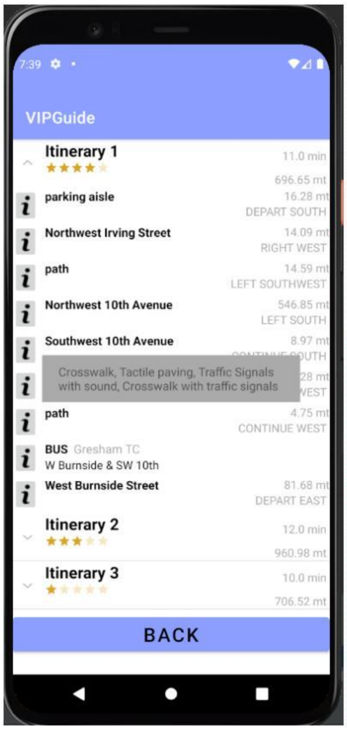

Figure 4.10: Second Screen With Second Level Opened

Chapter 5

Evaluation

The evaluation of the solution required the definition of four routes, each returning three possible itineraries. On the other hand, and so that it is possible to understand how the algorithm behaves in different situations, the paths were chosen to meet the following criteria:

1. a path with many tags and many turns;
2. a path with few tags and few turns;
3. a path with many tags and few turns;
4. a path with few tags and few turns.

This evaluation is divided into two sections: Test characterization and analysis. In Section 5.1, the characterization of the testes made is explained. Then, in Section 5.2, the analysis of the results returned in each test is presented.

5.1 Test Characterization

Figures 5.1, 5.2, 5.3, and 5.4 presents the four chosen paths, taking into account the three defined scenarios.

The first path, represented in Figure 5.1, goes from 710NW 10th Ave, Portland to 503W Burnside St, Portland. This path returns three different itineraries. Itinerary1 corresponds to the orange line (walking part) and a dark blue line that corresponds to the public transport part. This itinerary has 9 turns and 17 tags. Itinerary2 represented by a grey line is a walking path with 7 turns and 12 tags. Itinerary3 represented by the green line (walking part) and a dark blue line (public transport part) has 14 turns and 12 tags.

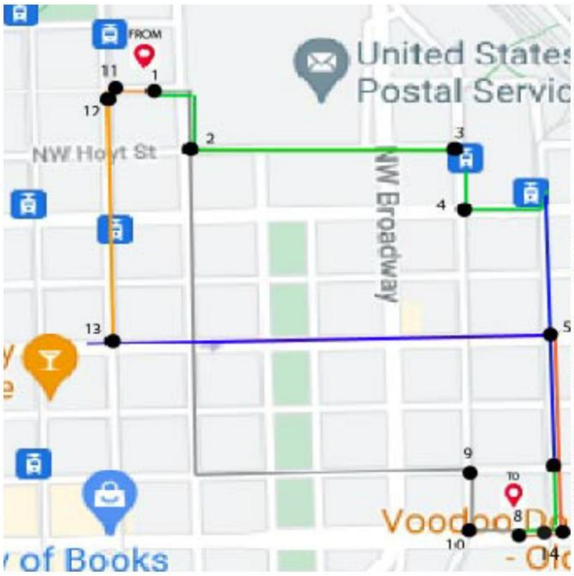

Figure 5.1: First Path

The second path, shown in Figure 5.2, starts at 419NW Broadway, Portland, and goes to 511SW 10th Ave, Portland. This path also has three itineraries. Itinerary 1 represented by a light blue line (walking part) and a dark blue line (public transport part) has 8 turns and 11 tags. Itinerary 2 is represented by an orange line (walking part) and a dark blue line (public transport part) and has 8 turns and 6 tags. Itinerary 3 is represented only by a green line which means it's a walking path that has 4 turns and 3 tags.

Figure 5.2: Second Path

The third path, shown in Figure 5.3, starts at 1106W Burnside St, Portland and goes to 309SW 6th Ave, Portland. The green line (walking part) and a dark blue line (public transportation part) represent Itinerary1 which has 6 turns and 6 tags. Itinerary 2 is represented by the same lines, it only differs in time. The purple line represents the Itinerary3, a walking path only, having 4 turns and no tags.

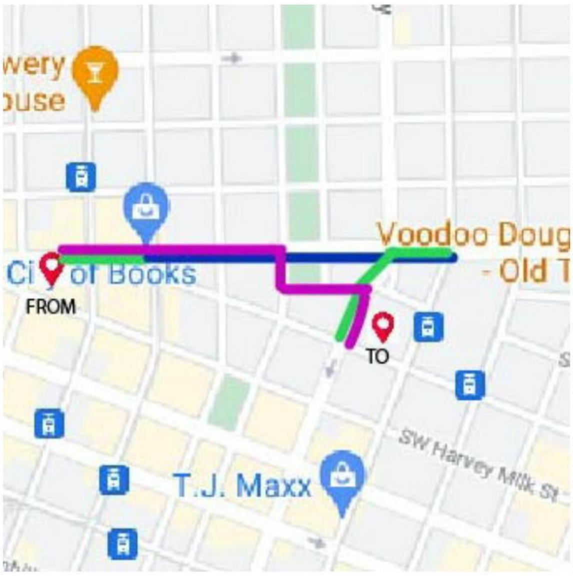

Figure 5.3: Third Path

The fourth path shown in Figure 5.4 starts at 511NW Broadway, Portland and goes to

402SW 10th Ave, Portland. Itinerary 1, walking path only, is represented by a green line and has 9 turns and 14 tags. Itinerary 2 represented by a purple line (walking part) and a dark blue line (public transportation part) has 6 turns and 5 tags. With 6 turns and 1 tag, Itinerary 3 is represented by an orange line (walking part) and a dark blue line (public transportation part).

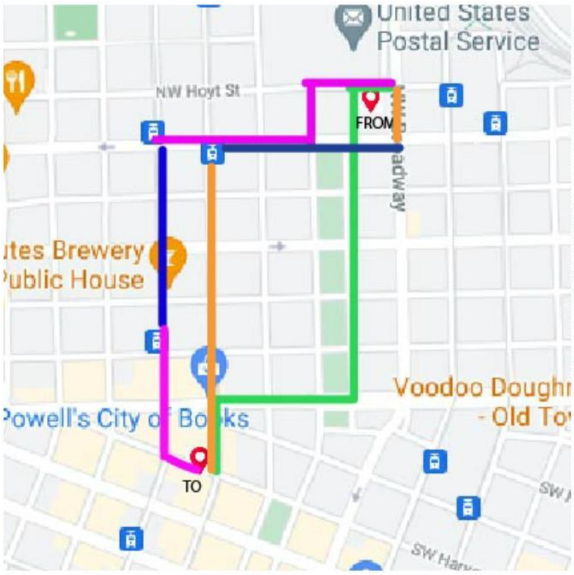

Figure 5.4: Fourth Path

5.2 Analysis

This section presents an analysis of the algorithm developed, having into consideration the four path scenarios described in Section 5.1. Besides this real-time analysis, a table with a wide range of possible scenarios and its outcome was presented alongside the explanation of the path calculation (see Table 4.3). This table presents the outcome of all the possible scenarios up to 14 turns and 30 tags.

Table 5.1 presents the comparison between the itineraries previous characterized on section 5.1.

Table 5.1: Path suitability Compairison

	Option	Distance	Time	Turns	Tags: Positive	Tags: Neutral	Tags: Negative	Suitability
First Path	Itinerary 1	696.65.mt	11min	9	14	2	1	11
	Itinerary 2	960.98 mt	12 min	7	10	2	0	8
	Itinerary 3	706.52mt	10 min	14	11	0	1	-7
Second Path	Itinerary 1	722.14 mt	11 min	8	9	2	0	4
	Itinerary 2	760.43 mt	11min	8	5	1	0	-5
	Itinerary 3	799,18 mt	10min	4	3	0	0	-2
Third Path	Itinerary 1	300mt	6min	6	4	1	1	-4
	Itinerary 2	300mt	6min	6	4	1	1	-4
	Itinerary 3	470mt	6min	4	0	0	0	-8
Fourth Path	Itinerary 1	696.67mt	11min	9	11	3	0	7
	Itinerary 2	534,40mt	7min	6	5	0	0	-2
	Itinerary 3	780.52mt	10min	6	1	0	0	-10

The first path presented in Table 5.1 has the three possible itineraries used for these results. The first itinerary, according to the star rating explained in chapter 4, Subsection 4.4.2, got 4 stars as it has suitability of 11 points. It can be concluded that, besides having 2 more turns than Itinerary2, Itinerary 1 is way shorter and has more positive tags. Itinerary3, besides having more positive tags than Itinerary2, has also a lot more turns which lower the suitability allowing just only one star, compared with the tree star from Itinerary2. In this set of itineraries, the one with more stars was shorter, with fewer turns and more positive tags.

The second path presented in Table 5.1 has 3 itineraries. In the last two itineraries of this path, it is possible to visualize that although both of them have one star, Itinerary 3, despite having fewer tags has also fewer turns. Itineraries one and two, both have the same number of turns but the first has more tags which makes it more suitable when compared with the second one. Here, the most suitable of the three is the one with more tags, but here the turns are not the least. The difference of tags from the Itinerary 1 to the others made it increase the suitability despite the number of turns.

The third Path, presented on the same table as the previous path, has only one-star itineraries, and two options are the same but with different times for public transport. These two first Itineraries, despite having a higher number of turns, have tags which increases the weight compared with the last itinerary. Itinerary 3 has no tags, meaning it's a path without information which easily becomes a dangerous one for a VIP, resulting in a one star rating.

For the last path, looking at the data on the Table 5.1 it is possible to say that, although the first path has more turns, it also has a lot more tags than the rest of the itineraries for this path, which allows it to have four stars when compared with the one star that each one of the other itineraries was rated. Itinerary 2 has five tags, and itinerary 3 has only one, making them inadequate for this purpose. In this path, it is also possible to verify that the most suitable itinerary is not the shortest one.

To summarize, it can be said that the algorithm presented in this work balances the number of tags and the number of turns. A suitable path will be the one with more information and fewer turns, however, a preference over an informed path is highlighted on these results, as the lack of information could be more dangerous than an extra turn.

Chapter 6

Conclusion and Future Work

In this work, a proof of concept of a mobile application that returns a suitable path for VIP according to the challenges they face. As referenced before in this work, the inclusion of everyone in the society, most specifically mobile inclusion is an important topic that everyone should be aware of and willing to make a change even that is small. It is known that using crowdsourcing solutions, the success of these applications rely on the number of users the application has, mostly regarding editing the maps, According to the evaluation made in the chapter above, it is possible to conclude that this is a feasible solution to implement to ease the life of VIP and it could be spread all over the world and displayed in multiple languages. However, is yet a lot of work to do. To turn this application even better, can be implemented a google maps screen that will work with GPS allowing the application to know the real-time location of the user and with voice over could read the turn-by-turn instructions also in real-time. This part was not implemented because the focus of this work was to create a feasible solution to return a suitable path as a proof of concept and it was assumed that as the implementation with real-time geolocation was not an invention, could easily be implemented in any application, and does not change the results presented on the algorithm developed here, thus could be ignored for this particular case. Another feature that was left aside, because it is also easily implemented with any application was the voice recognition for the input of the destination, as nowadays almost every smartphone keyboard comes with a speech to text feature. The solution presented here with the results obtained proves to be a feasible solution for the addressed problem, easing the VIP mobility and also improving their security feeling while walking on the streets, as they will know in advance the obstacles that the path will have and the places where they can cross the stress more safely, for example, allowing them to have an informed choice between paths.

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