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Multimodal Dynamic Routing for Wheelchairs and Pedestrians

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Abstract

There is a wide variety of navigation systems available on the market. Most of these systems offer the possibility to choose between different transport vehicles and routing options. However, these systems hardly offer the possibility for accessible routing, which is optimized especially for users of wheelchairs. Although, a lot of state-of-the-art navigation systems already offer multimodal routing capabilities, most of them use a static approach to calculate the route. In this case the route is determined before the route guidance starts and therefore depends on the precision of the a priori used schedule information. Thus these systems can not react properly to delays in public transits. This results in less precise guarantees for the estimated arrival time.

In this work an approach is introduced, which extends the eNav system to fully support multi-modal routing. Therefore, the approach reacts dynamically and adaptively to delays by using real-time data. Furthermore, it tries to automatically optimize the current route by using public transportations. The approach is designed as a modular system to offer the possibility to transfer it to other navigation systems. We show that the use of dynamic routing improves arrival times, especially in urban areas. Our evaluation shows that in most cases the presented approach outperforms static calculation of the route. On top of that, our approach brings a lot of social and user experience benefits, with which a static approach cannot compete these days.

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Keywords: eNav, dynamical multimodal routing, accessibility, navigation-system

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1. Introduction

A variety of navigation systems offer multimodal routes. There are several means of transport considered for the trip and they can just be selected by users at the beginning of the journey. Two important features are time and “walk energy”. Many users consider the time factor as a selection criterion. Between two routes where Route A is by foot and Route B is by bus, the user will select Route A if the changeover time at B takes too long. If the user decides for route A, it may happen that the bus, which he could have taken with a short waiting time, is there at the bus stop because the user arrived before the time or the bus was late. These moments are always annoying for a lot of users and at the end the journey takes longer and the walking is exhausting. This work presents a solution to this challenge.

The idea is to maintain a permanent connection between the navigation system and the public transport system, which is better illustrated by the following example (Fig.1). Assuming that the user in Figure 1a would like to travel from S to Z. The user has two choices: go by foot 26 minutes or by bus within 35 minutes. Due to the long transfer time the user decides to go by foot, which is represented in Fig. 1b. The usual pedestrian navigation systems normally don’t look for better alternatives after the route selection because the users can fill the means of transport just only at the beginning of the journey.

With eNav, the optimal alternative will be searched in secondary plan. Figure 1c illustrates such a scenario. During the journey, the user will pass the first bus stop. Once he is close enough to the bus stop, the navigation system checks the current position of the buses and tries to optimize the route. In case of the navigation system finds a different optimal route, the user will be informed of the new route during the approach time to the bus stop. In the case of Figure 1c, an alternative route results from a bus delay. Now the user can choose whether to stay on the old route of 26 minutes (see Fig. 1b) or to change to the new route of 19 minutes (see Fig. 1c fat line). In this example, the user decides for the route of 19 minutes, so that the time of his travel is shortened by eNav about 27%.

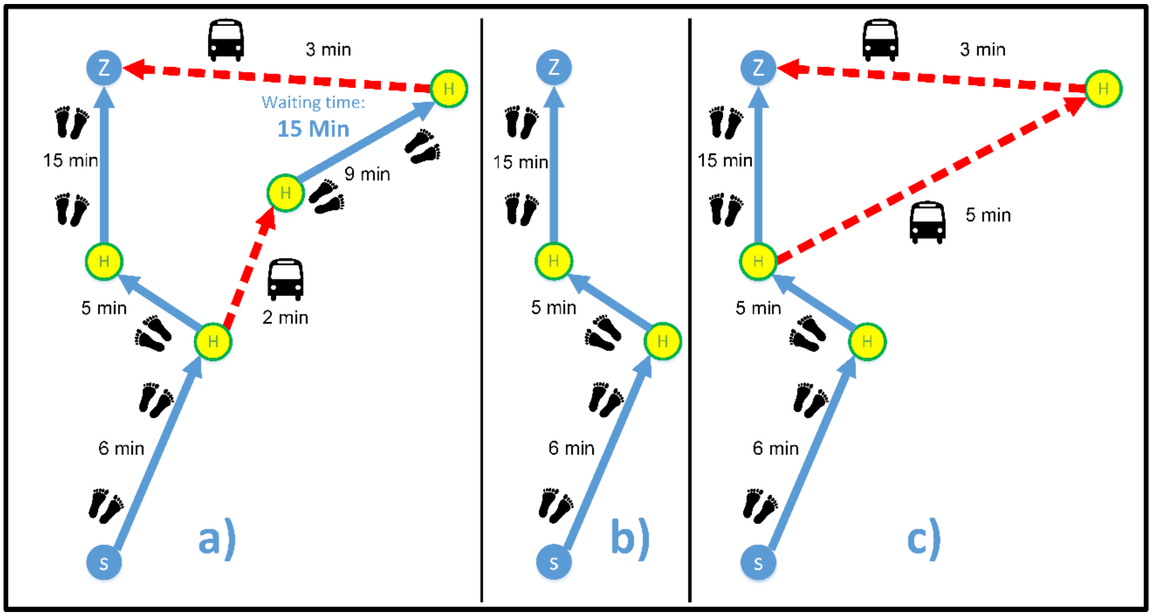

Fig. 1 Example

2. Basic

Before the go into the implementation, we present conceptual explanations and definitions which are important for the understanding of this paper. These are limited to a summary. For a deeper discussion, further literature is given.

2.1. Multimodal Dynamic Routing

The term **multimodal routing** means: “Routing in a given time interval, across different means of transport”. The term "direct routing" is defined as a static routing from start to destination point, which means a constant mean of transport with no change. Intermodal routing is a sub-concept of multimodal routing and refers to a switch between means of transport and wheelchairs and / or pedestrians as means of transport. (Ahrens et al., 2010)

The term **dynamic routing** is the simple idea that the routing algorithm always receives the position of all the means of transport considered and can react to it. In other words, the algorithm gets real-time data from these bus connections.

2.2. Real-Time of Public Transport

The eNav system requires real-time data about the position of the buses to be able to route dynamically “multimodally”. So eNav can optimize delays directly in the route. This can be done thanks to the partnership between eNav und the company ASEAG (Aachener Straßenbahn und Energieversorgungs-AG), which operates the public transport in Aachen and the region. The company has decisively shaped the development of Aachen, always with the aim of ensuring and promoting the mobility of people in the region through technical progress and further development. The real-time data is provided by the company IVU Traffic Technologies AG, which assumes the transport logistics of ASEAG. IVU provides eNav all the information of the buses via an API. In addition, all information about the bus lines is provided so that eNav only works with real-time data of relevant buses. This reduces both the volume of the data transfer and the energy consumption of the smartphone.

2.3. eNav

eNav is a navigation system that increases the mobility of the riders of electric wheelchairs by allowing them to make better use of the battery capacity by calculating energy-efficient routes. For this to happen, eNav also considers climb and roll resistance information to determine the energy consumption of the individual road sections. It is known from an investigation that the energy consumption is exponential relative to the slope (FRANKE et al. 2011). In addition, it is also possible to increase the comfort of the wheelchair users by means of the rolling resistance, since the wheelchair user has the possibility of choosing the surface, e.g. cobblestone (Dzafic et al., 2014, Franke et al., 2011). The integration of Wheelmap.org enables wheelchair users to access information on accessibility via Point Of Interests (POI) directly in eNav. eNav consists at the moment of a route planner and a navigational application, which will be discussed further in chapter 5.

2.4. Routing-Algorithm

The A-star algorithm with some modifications is used in eNav system to calculate modified routes. The A-star algorithm calculates the shortest route between two points, using a heuristic with which the route is found more quickly. In the case of eNav, there are currently three different modifications of the algorithm: (HART et al., 1968 & NORWIG, P., RUSSELL, S. 2011)

- The length of the edges is the weighting for the **shortest route**. The heuristic is the linear distance to the destination node.
- For the **most energy-efficient route**, the energy consumption of the edges is considered as weighting and the heuristic is a special eNav modification. See further Literatur. (Dzafic et al., 2014, Dzafic et al.,

2013).

- For the **multimodal route**, the time is considered as edge weighting since the consumption of an electric wheelchair during a bus trip is almost zero. In this case, the heuristic is the temporal linear distance.

3. Related Works

This chapter presents the concept of “Multimodal Dynamic Routing for Wheelchairs and Pedestrians” in relation to other similar projects. None of the known projects show a multimodal dynamic routing that is presented in our paper.

- **Google Maps** is a service provided by Google Inc., which was launched on February 8. It has a large amount of map data, representing virtually the entire earth. At the moment, Google Maps offers routing by car, bicycle, pedestrians and in some countries public transport but no wheelchair. Since 2008 Google Maps offers the possibility to route by means of real-time data. These relate, however, to current traffic conditions and not to public transport. Google compensates this gap through Google Transit and allows public transport companies to integrate information about their travel plans into the Google Maps network. (FLOEMER 2016).

- **Open Route Service (ORS)** is a free routing platform based on OpenStreetMap (OSM). ORS is available for download and can be freely implemented in many systems. The entire platform is built as RESTful API, in comparison to (RICHARDSON & RUBY 2008). For this purpose, OpenRouteService offers various modules, which can be used and configured independently of each other. On the website of ORS are currently car, truck, bicycle, wheelchair and pedestrian but no public transport routing options. The use of the map material is only based on OSM. The quality of the map material swung depending on the OSMComunity. For cars and trucks, ORS still uses information from TMC to inform about the transmission.

- **Open Trip Planner (OTP)** is also a free and available platform for finding and creating routes. A good number of services are essential to plan the route. To this end, OpenTripPlanner, as well as OpenRouteService, integrates OpenStreetMap’s map material. In addition, however, it also accesses real-time data via feeds according to the General Transit Feed Specification (GTFS). This is a standard that allows transportation companies, bus companies or railway companies to provide real-time information and timetables in a standardized way. Even though GTFS feeds are provided by many companies around the world, this is not a standard. Open Trip Planner is divided into the following three services [otp16].

4. Design

First the design objectives are presented. Second the general requirements for the implementation of the design are introduced. At the end, the architecture of the design is discussed.

4.1. Design objectives

The objectives, which the implementation of this work should fulfill, are briefly explained below.

- **Independent extension**: The developed extension of the eNav system should be as independent as possible, thus contributing to a better modular transferability to other systems. Further developments on the eNav system should be as independent as possible and the functionality of the extension should not be impaired.

- **Dynamic response to delays**: the task of this extension is not just only to provide multimodal routes in general, but also to dynamically response to delays in the public transport. For this purpose, delays are to be used if a faster route results from these. The route is therefore not planned, but it should be dynamically adapted to the current status of the means of transport. This is to guarantee the shortest time of arrival, that would not be possible by planning the trip in advance. The inclusion of public transport should not only lead to an improvement in the arrival time, but also to an improved consumption of the battery of electric vehicles.
- **Lightweight frontend**: Calculations and the selection of the possible routes should continue in the backend, so a lightweight Frontend can be used. Only the automated queries to the backend after improvements of the route, as well as the representation of these, should be added as one task for the lightweight Frontend.

4.2. Requirements

The following requirements must be fulfilled to be able to implement the design objectives mentioned before.

- **Availability of real-time data**: Since this work has as a goal the introduction of the implementation of dynamic multimodal routing, real-time data must be available. In addition to up-to-date information of the arrival times and / or the position of public transport vehicles, information on bus stops (e.g. location, availability) must also be provided.
- **Abilities of the Frontend light**: Although the Lightweight frontend is largely to be relieved, it must still have access to current GNSS / GPS data with the goal to determine the current position of the user. Furthermore, it must provide an existing Internet connection with the objective to make requests to the eNav server.
- **API in the navigation system**: The underlying navigation system must provide an API that allows the developed extension to route between any two end points. The duration and length of the route as well as all nodes must be provided. Furthermore, the navigation system must be based on a Cartesian system to allow a correct correlation between stops and nodes.

4.3. Architecture

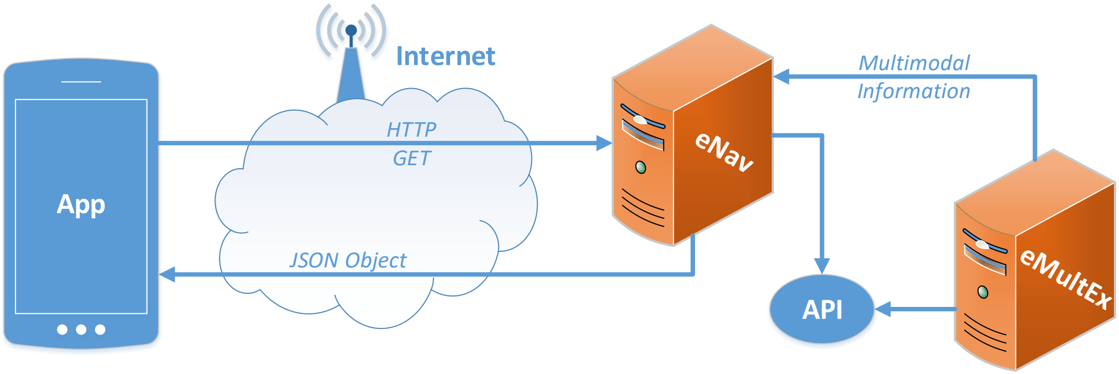

Fig. 2 eMultEx extension´s architecture

This section discusses the architecture of the eMultEx extension (eNav Multimodal Extension) (see Figure 2). The mobile frontend, referred to in the following as an "app", communicates with the eNav system via HTTP request and answer schemes, based on a stateless client server model. All important data and parameters are transferred from the app to the eNav system as an HTTP GET parameter in the URL. eNav calculates its own routing information, but also sends requests to eMultEx. EMultEx has access to graph data and routing information from the main system via an API provided by the eNav system. Processed information is finally returned to the app as JSON objects. These objects will be read and displayed graphically to the user. The eMultEx extension is almost completely resolved by the eNav carrier system and only uses the API provided by eNav to access the graph data. The main functionality of the API is the calculation of routes between any start and destination points.

4.4. Routing procedure

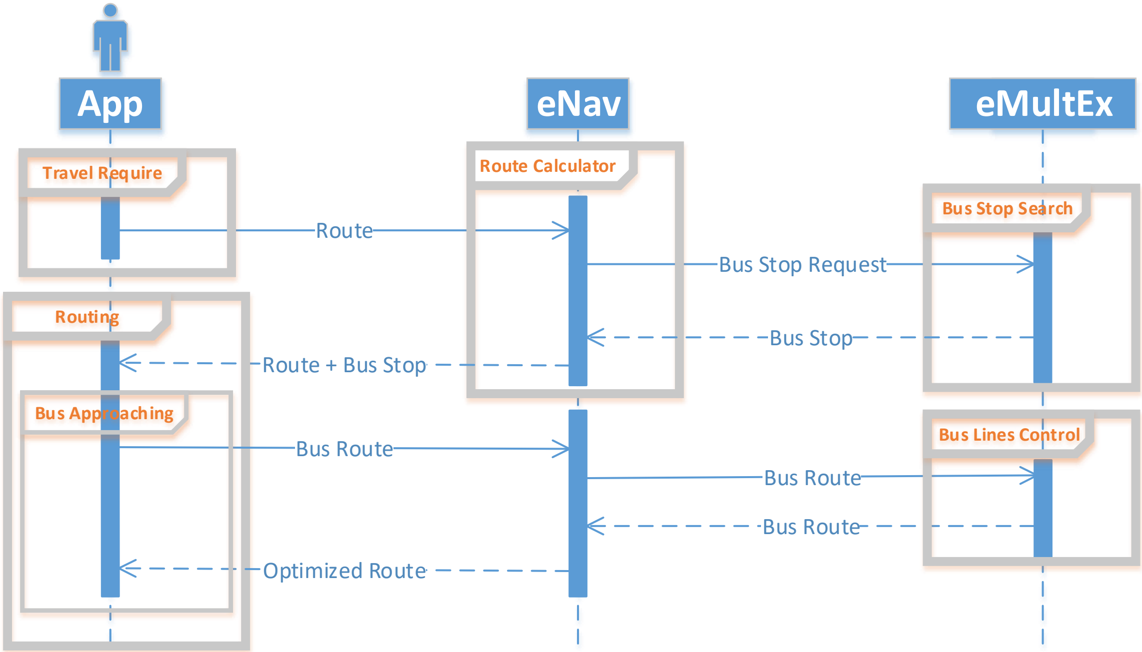

Fig. 3 Sequence of a routing request

The app displays an initial routing request (see Figure 3). A new route is calculated and returned to the app together with the bus stops near the user and its alternatives. The journey begins through the initial “by foot / wheelchair” route. When the user approaches a bus stop, a new request is made to the backend. This then checks for possible route improvements using real-time data. Only current local public transport departures are considered. This is limited to a few minutes to guarantee the best possible arrival time. In addition, temporal improvements are also considered for partial sections of the route, although routing over the entire route would be possible but more time-consuming. The user, if an improving optimization is calculated by eNav, is asked, if he wants to change his route. The adaption to the optimized alternative then requires a final confirmation from the user.

5. eNav-App

The app of the eNav system is already presented in the previous AGIT contributions. (DZAFIC et al., 2014). Figures 4 and 5 show the multimodal dynamic extension. At the beginning, the app shows all stops near the route, see Figure 4. The symbols of the stops have three options:

- **Red:** The stop is outside the relevant range of 200 m
- **Orange:** The stop is within the relevant range, and a better (faster) route is not (yet) available.
- **Green:** A better (faster) route was found, with a departure from this stop (Fig. 5).

If the app finds a better (faster) route, the user, apart from the green stop, is given a voice and visual notification about the existence of this new route and its duration. The visual notification uses a popup to give the user the option to accept or cancel this optimized route. If the message is ignored, it disappears as soon as the user moves outside the relevant range.

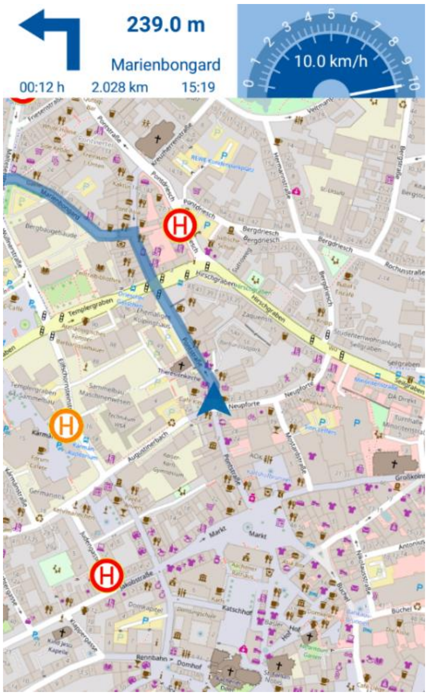

Fig. 4 GUI with bus stops

A better route, which saves 3 minutes, is available, accept?

Fig. 5 GUI with relevant routes

6. Evaluation

This chapter shows the advantages in using dynamic multimodal routing. Therefore, the approach presented in this work is compared to traditional static routing. For this purpose, travel time of routes, calculated by dynamic multimodal routing, is compared to the travel time of routes completely by foot and routes calculates by a static multimodal method. whereby static routing refers to a routing by predefined schedules or with real-time data only available at the beginning of the routing.

6.1. Setup Test

In order to gain empiric results, the evaluation was done using a simulation and a subsequent validation by real-life test runs. The simulator was implemented as a Windows application and executed on several machines to gain concurrent results. The simulation includes an interpolation of GNSS coordinates between nodes of the calculated route by a constant speed. Furthermore, it sends requests to the eNav server similar to how the mobile application does. The following parameters were set for the simulation:

- **Average speed**: 5 km/h
- **Maximum coefficient for the incline**: 20%
- **Allowed pavements**: all
- **Routing-Type**: most efficient one

6.2. Scenario

The evaluation was set on three different scenarios. The first one represents a route between two points, which are also directly connected by a bus connection. The second scenario also represents a route, which is connected by bus only. However, in the second scenario, the points are not connected directly, resulting in at least one switch from one bus to another. In the third scenario, a route, which cannot be completed passed by bus, is used. Moreover, these scenarios were combined with three different lengths (short, mid, long), thus resulting in nine test cases. Nevertheless, three of these test cases could be excluded in advance, since these test cases would result in useless evaluations. Thus, there are six test cases which a evaluated.

6.3. Results

The evaluation shows that the use of a dynamic multi-modal routing approach brings advantages with respect to the average travel time. Furthermore, the scattering of the travel times is distributed narrower around the average travel time, thus giving better guarantees for the estimated arrival time. The best estimated travel times were mostly achieved by a static routing via bus. However, the worst actual travel time was reached by the static routing by bus in every test case. Besides, the best arrival times of the multi-modal routing approach were maximally within 10% of the best travel time by the static approach. The advantages of a dynamic multi-modal approach are especially shown by scenario one.

However, too short routes in scenario two and three resulted in a 100% by foot decision of the eNav system. The comparison to the static only by bus approach cannot be done correctly, because modern navigation systems would always decide to use a route by foot, regardless of the schedules of the buses.

In scenario three (long route), there are few situations, where a static routing is advantageous over the dynamic approach, but there are also a lot of situations, where the actual arrival time of the static routing is a lot worse than the one of the dynamic routing. Hence, the estimated arrival time of the dynamic multi-modal routing is more accurate and more constant regardless of the current public transport delays.

Finally, in all test cases the average travel time of our approach was better than a static routing completely by foot. On top of that, in more than 70% of the routings, there was an optimization of the route found by our system, resulting in a relief of the traveling person regarding walking workload or driving energy consumption, respectively.

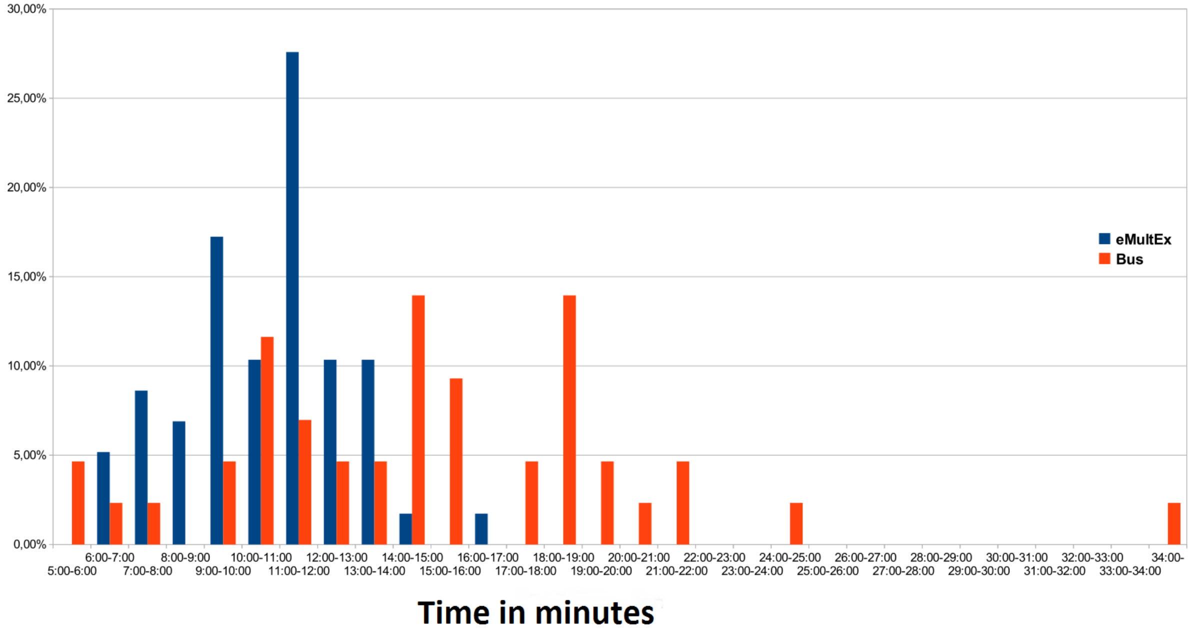

Fig. 6 Scenario 1 Mid Route

Figures 6 and 7 are examples for most of the test cases evaluated. Especially Figure 6 shows the distribution of arrival times throughout most of the test cases. It can be seen that the eMultEx system achieves better results, which are better concentrated around the average. However, there are few test cases with long routes, whereby the route which can be absolved by bus is relatively short, in which eMultEx cannot find optimizations through the bus. This is exemplarily shown in figure 7. The arrival times of the routing by bus are spread across several minutes, whereas the eMultEx system decides to travel by foot in 100% of the routings.

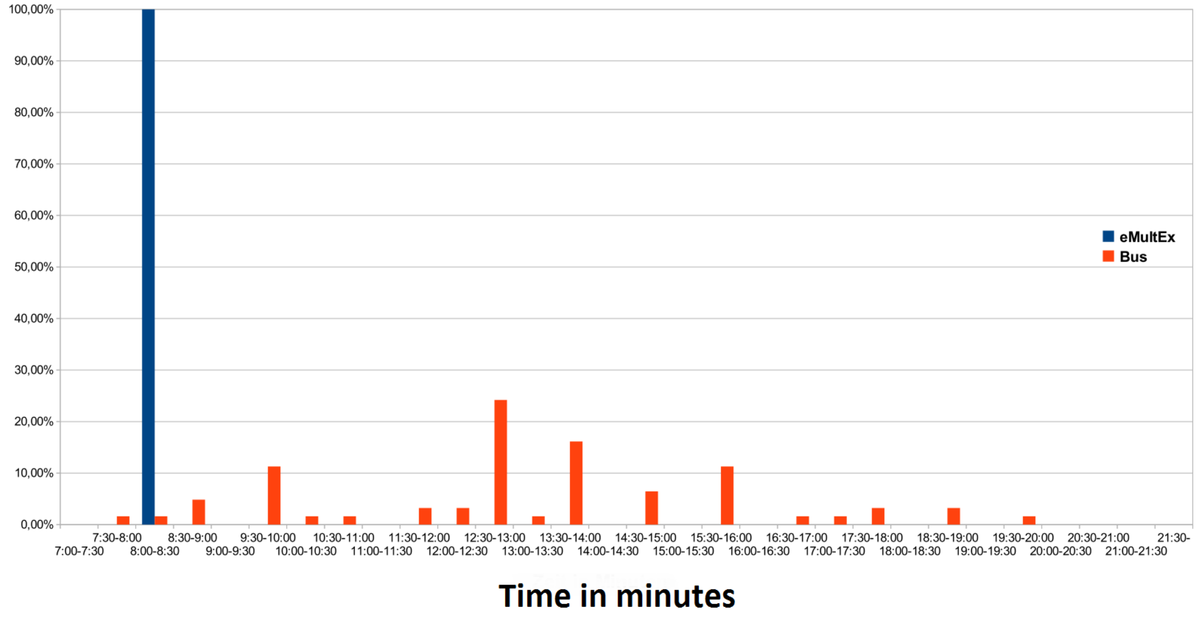

Fig. 7 Scenario 2 Mid Route

7. Conclusion

This paper presents a navigation concept, which informs wheelchair users and pedestrians when a faster route by bus exists during an ongoing route guidance. The navigation system is directly connected with public transport information systems and as such, can immediately react to e.g. bus delays. Enabling the user to be informed that the bus has not yet passed the bus stop. With this system it will be ensured that the user does not assume that the bus is already gone and continues to go by foot. The multimodal dynamic routing makes it possible to calculate a faster route in 70% of the cases in contrast to a multimodal static routing. This is the result of getting frequent information updates during the trip, evaluating them and including them into ongoing routing.

These results were developed within the CiTi Center for Integrative Traffic Investigation Project and are integrated into the eNav system.

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