Introducing a Navigation Algorithm for Reducing the Spread of Diseases in Public Transport Networks

Jens KLINKER[a,1], Mohamed Hechem SELMI[a], Mariana AVEZUM[a] and Stephan JONAS[a]

[a] Professorship for Digital Health, Technical University Munich, Munich, Germany

Abstract. Reducing passenger flow through highly frequented bottlenecks in public transportation networks is a well-known urban planning problem. This issue has become even more relevant since the outbreak of the SARS-CoV-2 pandemic and the necessity for minimum distances between passengers. We propose an approach that allows to dynamically navigate passengers around dangerously crowded stations to better distribute the passenger load across an entire urban public transport network. This is achieved through the introduction of new constraints into routing requests, that enable the avoidance of specific nodes in a network. These requests consider walks, bikes, metros, subways, trams and buses as possible modes of transportation. An implementation of the approach is provided in cooperation with the Munich Travel Corporation (MVG) for the city of Munich, to simulate the effects on a real city's urban traffic flow. Among other factors, the impact on the travel time was simulated given that the two major exchange points in the network were to be avoided. With an increase from 26.5 to 26.8 minutes on the average travel time, the simulation suggests that the time penalty might be worth the safety benefits.

Keywords. Physical Distance, Social Control, Social Distancing, COVID-19 Pandemic, Risky Health Behavior, Outbreaks, Prevention and Control

1. Introduction

Conventional navigation systems like Google Maps offer a number of fastest or shortest routes to get to a destination. While these options were sufficient in the past, the outbreak of the SARS-CoV-2 pandemic led to a new requirement. Since then, travelers have also been looking for safe routes through cities, that could lower the risk of an infection with the virus. In the case of SARS-CoV-2, one effective measure to reduce this risk is to keep a safe distance to other humans [1, 2].

In Germany, the minimal required safety distance in public places was set to 1.5 meters by the Federal Ministry of Health [3]. Any distance below that threshold is considered unsafe from a social distancing perspective.

Fulfilling these social distancing requirements turns out to be a challenging task for passengers in urban public transportation networks. This is mostly due to overcrowded transportation vehicles and exchange stations during rush-hour times that force people to break social distancing rules. Relatively in the beginning of the outbreak, public

---

[1] Corresponding Author: Jens Klinker, Technical University Munich, Germany, E-Mail: jens.klinker@tum.de

authorities in Germany took action to prohibit any events with more than 100 people. However, when considering that the average Munich subway has capacity for over 900 people, any public transportation ride operating at over 11% of its total capacity can already be considered a large event [4]. This issue is even more critical at the central exchange points in Munich's public transportation network.

In exchanges with city planners form the Munich Transport Corporation (MVG), it was explained that congestions rarely occur at most public transport stations. Instead, there is a small number of stations in Munich's public transportation network that get overcrowded reliably and predictably on a daily basis, due to their centrality in the network. Such stations, like "Sendlinger Tor" or "Hauptbahnhof", that are mainly used to change between public transport lines, pose a constant infection risk. At "Sendlinger Tor" for example, an average of 250.000 passengers board, alight or change public transport every day [5]. While this is an unusual threat during a pandemic, it is a constant threat to people in high-risk groups.

To solve this issue, new solutions have to be implemented that reduce the passenger load on central traffic nodes, so that safety distances can be established again [6]. The goal of such an optimization problem is to fulfill the safety requirement while causing the minimal necessary impact on other travel goals such as minimizing overall travel time to a destination.

2. Methods

To tackle this issue, we introduce a new routing algorithm that offers a safer route to a traveler's destination by avoiding highly congested stations in the public transport network. As the congestion level of a node is not constant, but depends on a large number of factors, a collaboration with the Munich Transport Corporation (MVG) was established. Using insights provided by the MVG, public transport stations can be dynamically toggled on and off before they reach a dangerously high congestion level in which safe distances can no longer be maintained. Currently, the assessment whether a station is considered safe or overcrowded is delegated to the MVG. To make this assessment as transparent and scientific as possible, it is advisable to take a closer look at parameters influencing the spreading risk in public transport stations. Due to its complexity, we haven't included this additional step in the scope of this publication.

The avoidance algorithm then uses the information about the available and unavailable stations to calculate a safer route with less congested exchange points, giving the control for social distancing back to the travelers. To simulate the impact on the travel time and other important features, the MVG provided a dataset containing the scheduled departure and arrival times of all public transport lines in Munich. Both the data and the congestion knowledge are used to simulate the results produced by an avoidance algorithm for safer routes.

To evaluate the performance the avoidance algorithm is compared to the results of the same algorithm without the avoidance feature. Core features like the change in travel time are then used to measure how the convenience of a route is impacted by the feature. As the convenience of a route is highly subjective, no final measure for the convenience could be produced. Instead, some underlying factors that partially correlate with a route's perceived convenience are presented.

As the proposed solution was developed with data from- and in cooperation with public authorities in Munich, the researched results and examples use cases are limited to the city of Munich.

2.1. Foundations

Public transportation has long been suggested as an alternative for road bottlenecks. During rush-hour, however, these are already overcrowded, and some cities thus prefer to limit passenger flow in bottleneck stations. In order to motivate passengers to consider going around an overcrowded station, two main reviews are presented: (1) Providing passengers with personalized multi-modal routing options and (2) calculating routes which have further advantages than a fastest travel time.

Review (1) is based on the work of Bucher *et al.* who describe how to integrate personal constraints on calculation of multi-modal routes [7]. To incorporate more travelling options into the multi-modal route calculation, the authors save a series of constraints in the form of a user profile.

As far as multi-modal routing goes, the state-of-the-art implementation is provided by OpenTripPlanner [8]. The open-source project uses public transportation schedules formatted as General Transit Feed Specification (GTFS) to calculate multi-modal routes that, among others, can combine cycling and public transportation segments. Since the consideration of multi-modal routes can be seen as an interesting approach to reduce the load of overcrowded public transportation intersection, OpenTripPlanner contains a "bannedStop" parameter that can be passed through a route request.

While the calculation of routes is a technical challenge, actually ensuring that the passengers use that route is a social one. Review (2) mentioned above relates to providing route advantages other than simply travel time. The basis for this is the work of Bunds *et al.* who analyzed how different route attributes were perceived by travelers and how these affected the choice of route [9]. Bunds et al. showed how air pollution, traffic, and noise level are the determining factors when deciding which route to walk through [9]. This allows us to infer that if a traveler can control for these variables during a route calculation, they can be more likely to accept longer walking segments. Furthermore, the fact that traffic and noise levels are directly correlated with overcrowded regions (even in public transportation), means that presenting this information to the traveler can serve as an important motivation for them to avoid these regions.

2.2. Constraint-based route personalization

OpenTripPlanner calculates multi-modal routes in the network based on a routing request that consists of a list of query parameters. In order to define the context of the route search, the request must specify the following information:

- **fromPlace:** Latitude and longitude of the start location.
- **toPlace:** Latitude and longitude of the end location
- **date:** Date on which the trip should depart.
- **time:** Time when the trip should depart.
- **mode:** Set of modes that a commuter is willing to use. The main modes supported by the system are walk, bike, car, and transit (buses, trains, trams).

In addition, the existing system supports multiple optional parameters that can be used to further manipulate the results. The most useful parameters for the problem at hand are:

- **bannedRoutes:** A comma-separated list of banned public transportation lines.
- **bannedStops:** Banned stations cannot be used to board or alight from a public transportation mode, but it is still possible to travel through them. This is achieved by blocking the pre-board and pre-alight edges that connect the transit network to the street network.
- **bannedStopsHard:** Stations that are removed from the network. It is no longer possible to board, alight or travel through these stations.

While the bannedStops parameter realizes the avoidance that the system aims to achieve for crowded stations, the time aware usage of this parameter to automatically avoid the stations during rush hour periods is still to be implemented.

2.3. Constraint integration in multi-modal routing

Similar to most state-of-the-art route planning services, OpenTripPlanner uses the A* algorithm to search for routes in the transportation network [10]. This algorithm keeps track of an ordered list of tentative routes and during each iteration the one with the smallest weight is extended. In order to achieve multi-modal routes, the algorithm is modified to loop over the available transportation modes during each iteration. For all outgoing edges of the last node, each mode that matches the type of the edge is used to traverse it. For instance, edges from the street network can be used for walking, biking, or driving, whereas edges of the transit network are restricted to a specific public transportation mode.

3. Results

3.1. Example use case

The following use case exemplifies how the avoidance algorithm calculates routes. We consider a trip in the Munich transit network and compare the route generated by the system with and without the automatic avoidance during rush-hour periods. For this demonstration, the experts from the Munich Transport Corporation (MVG) recommended to use the Sendlinger Tor, as it is one of the most congested stations in the network. In this case the routing request sent to the trip planner could, for example, use the following parameters:

- **fromPlace:** Nordfriedhof station with latitude 48.17312 and longitude 1.59686.
- **toPlace:** Theresienstraße station with latitude 48.15139 and longitude 11.56444.
- **date:** May 5th 2020.
- **time:** 08:00 am.
- **mode:** Walk, transit (buses, trains, trams)

This trip starts near a dorm for students and ends at a station used to access the technical university in the city, which makes it a realistic trip that students take on a daily

basis. The time of the request is within the morning rush-hour period from 07:00 am to 09:00 am.
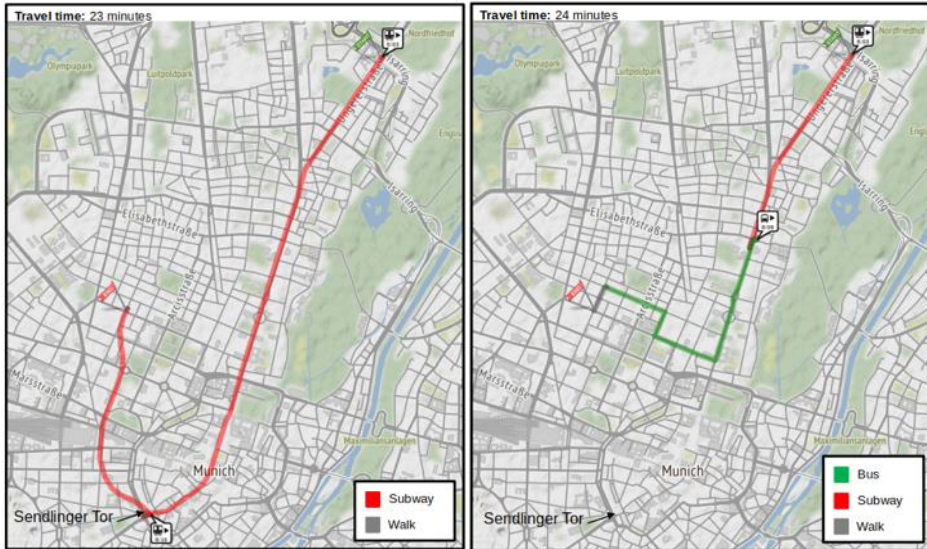
Figure 1. Route from Nordfriedhof to Theresienstraße. Left: Without automatic rush-hour avoidance. Right: With automatic rush-hour avoidance.

The route generated without avoidance can be seen in Figure 1 (left). It uses the subway from the origin, marked with a green flag, to get to Sendlinger Tor station. From there, a different subway line is used to get to the destination marked with a red flag. Including the time-aware avoidance results in a route that successfully avoids changing lines at Sendlinger Tor station as shown in Figure 1 (right). The new route cuts the subway part short before reaching banned stations and instead uses a bus to get to the destination. With activated avoidance, the travel time increases by one minute from 23 to 24 minutes.

3.2. General effect of avoidance on line changes

In this section we analyze how avoiding one station would affect the travel time and passenger distribution. The goals are to avoid overcrowding other stations in an attempt to scatter passengers to other stations and to maintain a reasonable travel time. To do so, we analyze the number of routes that use these stations to board, alight, or change lines. This can be considered as an estimation of the number of passengers at the stations. The analysis is based on a set of 1000 random routes located in the city of Munich. For each route, coordinates for the origin and the destination are sampled from an area centered at Sendlinger Tor with a radius of 4 kilometers. In addition, the following parameters are used for all routes:

- **date:** May 5th 2020
- **time:** 08:00 am.
- **mode:** Bicycle, walk, transit (buses, trains, trams)

The coordinates of the stops used to **board**, **alight**, or **change** lines are then extracted from each route and used to generate two heat maps. The first heat map shown in Figure 2 (left) summarizes the routes where no stops were avoided. The heat map in Figure 2 (right) considers the routes where Sendlinger Tor and Hauptbahnhof were automatically avoided during rush hour periods.
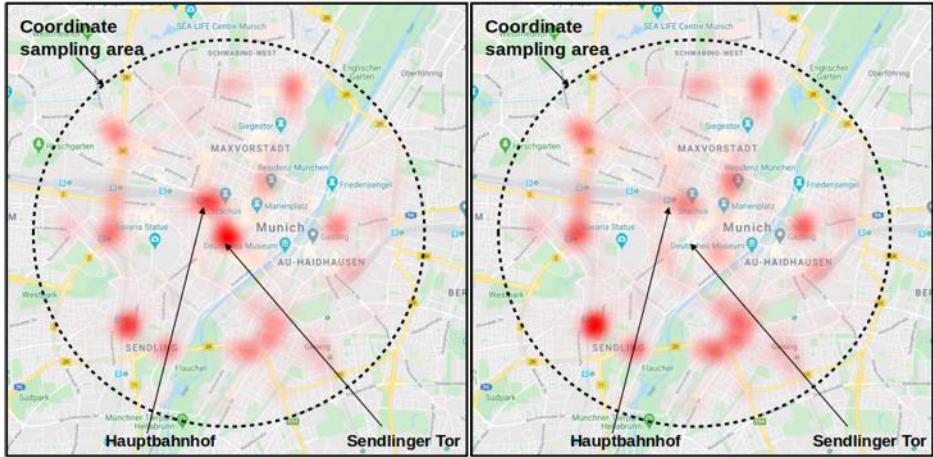
Figure 2. Heat maps showing how often transit stations are used to board or alight public transportation vehicles based on 1000 random routes. Left: Without activated avoidance feature. Right: With activated avoidance feature.

The left image in Figure 2 visualizes how Hauptbahnhof and Sendlinger Tor are originally the most used stations in the network, indicated through the dark red color of theses hot spots. While some areas on the outskirt of the network have similar size and darkness, they represent stations where commuters mostly board or alight a transit line but do not change them. With the automatic avoidance feature activated, the heat signature at the Sendlinger Tor and Hauptbahnhof both brighten up, while the direct areas around them darken slightly. This effect visualizes the distribution of the passenger load from these two stations to other nearby stations in the network. Instead of overcrowding a new station in the network, the load was distributed rather evenly over multiple surrounding stations located in close vicinity of the banned ones.

Aside the distribution of line transfers, the avoidance did not have notable effects on other route characteristics. The mean biking distance per route rose from 959 to 976 meters and the average walking distance slightly shrank from 469 meters to 468 meters. The mean waiting time at public transportation stations also remained unchanged at around 3.8 minutes per route. The mean runtime required to calculate a route decreased from 4.7 seconds to 3.7 seconds when the avoidance was activated. Finally, we consider the travel time of the routes used for the creation of the heat maps. The mean travel time increased from 26.5 minutes without avoidance to 26.8 minutes with avoidance.

3.3. Effect of avoidance on travel time

In this section we use isochrones to visualize the effect of the avoidance on the travel time in Munich's traffic network. Isochrones are graphs that measure location reachability from a specific origin. They consist of curves with equal travel time (Figure

3). OpenTripPlanner provides a service for generating isochrones out of the box by sending a request to the system similar to how routes are generated. In Figure 3 Sendlinger Tor was picked as the origin parameter for calculating the isochrones.

The generation of an isochrone starts by calculating a shortest path tree. OpenTripPlanner then builds a regular grid of samples covering the whole shortest path tree area. Finally, the sample points are connected based on their travel time to form the curves of the isochrones. The isolines are computed with the help of the Delaunay Triangulation Algorithm [11].
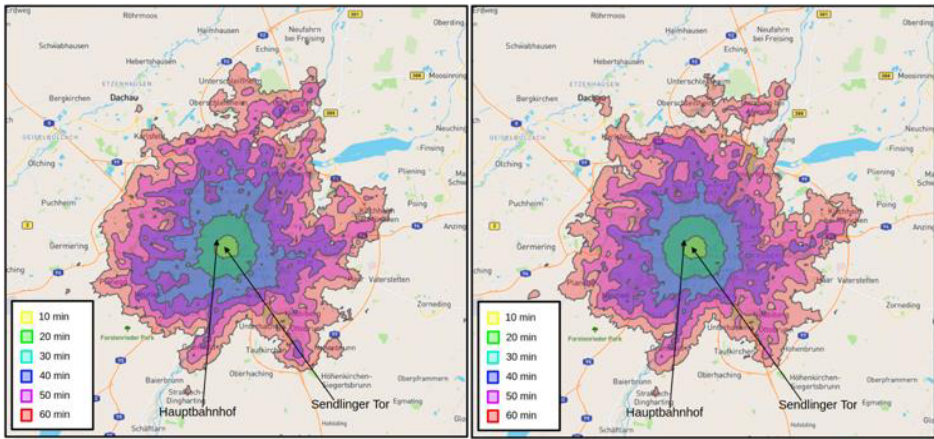
Figure 3. Isochrone of the travel time. Left: Without avoidance of Sendlinger Tor and Hauptbahnhof. Right: With avoidance of Sendlinger Tor and Hauptbahnhof.

Comparing the yellow and green areas in Figure 3 (left) and Figure 3 (right), shows that the avoidance of Hauptbahnhof and Sendlinger Tor did not have a noticeable effect on the area reachable within 20 minutes of the origin Sendlinger Tor. However, the curves that were affected the most are the ones from 30 to 40 minutes (blue and purple areas). When the crowded intersections are avoided, these areas became noticeably smaller. This reflects an increase in travel time for the destinations located within these areas. The last two curves that represent 50 and 60 minutes were also affected by the avoidance. In general, the areas reachable within 50 and 60 minutes are very similar in both isochrones, with a small decrease in reachability when avoidance is included.

4. Discussion

4.1. Result interpretation

Deleting two critical stations in the transportation network results in an overall increase in travel time, particularly for medium long routes. However, this increase is to be expected since the deleted nodes represent important connections in the transit network. Also, for most routes, the increase was so small that it is neglectable. This is specifically true for the random test set presented in Figure 2, where the average travel time for 1000 randomly generated routes only increased by 0.3 minutes. For longer routes, avoiding the central exchange points in Munich's traffic network usually results in less direct

routes with more line changes and an increase in waiting time. Regarding the travel time, the increase is rather small, when compared to the potential crowd reduction benefits presented in Figure 2. In contrast to our own expectations, passengers were evenly distributed by the algorithm, thereby preventing neighboring stations from overcrowding. However, this method could still pose a risk, if those neighboring stations are much smaller than the avoided station and therefore could be overloaded even by a comparably small number of passengers. Assuming that this is not the case, the changes to the overall travel time, as well as the stable physical activity level (walk/bike distance) required for a route, would be small enough to compensate for the potential health benefits. This is specifically the case for high-risk groups with a higher need for a safe passage.

4.2. Limitations

The greatest threat lies in the theoretical conception of the motivational aspects. Without real data from travelers, the true threshold for individuals to ignore a safe route can only be estimated. Also, a safety increase through the navigation around congested bottlenecks, can only be assumed but not measured yet. Hence, we do not know how effective such a measure could be unless it has been tested. Another bias lies in the selection of one single city to serve as a prove of concept. Even though the simulation produces promising results in Munich, there is currently no foundation on which the results could be compared to other cities.

4.3. Outlook

We suggest repeating the same evaluation with other cities in Germany, or even Europe, to understand how different transportation networks respond to the avoidance feature. With this measure, it could be determined whether the simulated results of this research are generalizable or whether they merely occurred due to the specific layout of Munich's traffic network. To reproduce these results in other cities, the public transport schedule data and position of traffic hot spots would be required. The format and accessibility of the public transport schedule data may vary between cities. During first investigations, we were able to obtain similar data sets for Nuremburg, Berlin and Duesseldorf. The second requirement for the extension of this work is to obtain the city specific knowledge about the most frequented nodes. For this knowledge a cooperation with local traffic experts would have to be established.

   The results presented in the previous sections leave room for a variety of subsequent research areas. As hinted before, our research so far focused on simulations with planned trips. Consequently, the next step could be a comparison of these results to the real travel behavior of Munich's citizens. Currently such a data set does not exist, as there is no technological solution yet that can reliably track the lines, change points and modes of transport a traveler used in a route. Given such a solution was implemented, it could be used to compare the schedule data to the real travel behavior of passengers who are given the chance to test the avoidance router.

   Finally, this router could not only be used to prevent infections with contagious diseases, but also to individualize routes to fit to the needs of physically impaired passengers. Firsts test with our algorithm have shown that it is possible to tailor the amount of physical activity through steps in a route to the settings of a passenger. Given that a passenger struggles with walking, it would be possible to generate routes that minimize the number of steps. Vice versa it is also possible to create routes that contain

a minimum number of steps for passengers who need or want to include more physical activity in their daily routines.

5. Conclusion

The presented approach simulated how safer routes that avoid overcrowded nodes in the traffic network of Munich could be generated, without causing the travel time to increase significantly. Even though it could not be determined how much safer such routes are, our simulations suggest that it could dissolve existing congestions without causing new ones at neighboring stations. This would allow passengers to maintain a safe distance to other passengers while they are in a public transport station. Determining when a node is at risk of being too congested was established through a collaboration with city specific transportation flow experts. In the here presented use case for the city of Munich, this knowledge was provided by the MVG who already monitor the public transportation network but required additional tools to steer the passenger flow and prevent congestions.

References

[1] C. Courtemanche, J. Garuccio, A. Le, J. Pinkston, A. Yelowitz, Strong Social Distancing Measures In The United States Reduced The COVID-19 Growth Rate: Study evaluates the impact of social distancing measures on the growth rate of confirmed COVID-19 cases across the United States, *Health Affairs* **39**(7) (2020), 1237-1246.

[2] K. Prather, C. Wang, R.T. Schooley, Reducing transmission of SARS-CoV-2, *Science* **368**(6498) (2020), 1422-1424.

[3] German Federal Ministry of Health, Novel Coronavirus SARS-CoV-2: Information and practical advice, https://assets.ctfassets.net/eaae45wp4t29/29lyMngJAvYypiWvqOTtVr/5707e9a6f5ea1681c4d0d1d5e0 9019f4/BMG_Corona_Information_englisch.pdf, last access: 31.01.2021

[4] Munich Transport Corporation, Aktuelle Zahlen und Fakten, https://www.mvg.de/dam/mvg/ueber/ unternehmensprofil/mvg_in_zahlen_s, last access: 02.01.2021

[5] Munich Transport Corporation, Modernisierung U-Bahnhof Sendlinger Tor, https://www.mvg.de/ ueber/mvg-projekte/bauprojekte/modernisierung-sendlinger-tor.html, last access: 13.03.2021

[6] T.R. Frieden, C.T. Lee, Identifying and interrupting superspreading events-implications for control of severe acute respiratory syndrome coronavirus 2, *Emerging infectious diseases* **26**(6) (2020), 1059.

[7] D. Bucher, D. Jonietz, M. Raubal, *A heuristic for multi-modal route planning*, in: Progress in Location-Based Services 2016, Springer, Germany, 2017. Pp. 211-229.

[8] C. Narboneta, K. Teknomo, OpenTripPlanner, OpenStreetMap, General Transit Feed Specification: Tools for Disaster Relief and Recovery, *CoRR*, arXiv:1609.01472 (2016).

[9] K.S. Bunds, J.M. Casper, J.A. Jonathan, J. Koenigstorfer, Recreational walking decisions in urban away-from-home environments: The relevance of air quality, noise, traffic, and the natural environment, *Transportation research part F: traffic psychology and behaviour* **65** (2019), 363-375.

[10] P.E. Hart, N.J. Nilsson, B. Raphael, A Formal Basis for the Heuristic Determination of Minimum Cost Paths, *IEEE Transactions on Systems Science and Cybernetics* **4**(2) (1968), 100-107.

[11] M. Duckham, L. Kulik, M. Worboys, A. Galton, Efficient Generation of Simple Polygons for Characterizing the Shape of a Set of Points in the Plane, *Pattern Recogn.* **41**(10) (2008), 3224-3236.