Collective Dynamics

Estimating Pedestrian Flows Using Route Distributions and Sparse Counting Data

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Abstract At metro station Münchner Freiheit in Munich soccer fans cause congestion before and after soccer matches on the shortest route to get from a bus station to the metro. Yet, an online survey suggests that, given the right information and incentive through a mobile app, fans are willing to take a detour. In this study we combine the survey results with passenger counts collected in a field study to quantitatively estimate the number of rerouted pedestrians in dependency of influx from a side entrance for which there is no data. We find a realistic range for the change in flow, despite incomplete measurement data, that we use as input for predictive simulations. The quantitative results are also helpful for traffic management.

Keywords Crowd management · count study · online survey · pedestrians · traffic

1 Introduction

At the metro station Münchner Freiheit in Munich soccer fans typically take the shortest route to get from the bus station to the trains. Especially near escalators and elevators this leads to jamming and poses a safety risk, so that traffic managers are looking for ways to nudge the fans towards two alternative, but longer routes. While one does not need full compliance with suggestions to improve pedestrian traffic situations, as we saw in [1], one still needs a certain level of cooperation that depends on the actual scenario. Hence, in a previous study, we conducted an online survey [2], to investigate the effect of app message design on how many fans take a detour. The message is communicated through a mobile application which is more and more explored by the pedestrian dynamics community for crowd management purposes [3–6]. Not only the medium, but also the communication

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strategy plays a crucial role on the crowd behavior, as investigated by Holly Carter et al. [7, 8] who examined the effect of information provision in decontamination trials. In our study, we also tested the provision of information and, we saw that the participants were quite willing to follow route instructions provided they were given a good reason. Indeed, when informed about the congestion ahead many of them opted for longer routes. Also, an appeal to their team spirit showed a positive effect as we expected from the social identity approach [9, 10]. The results of the study are distributions on three main routes for each message design. But the distributions do not tell us to which extend the safety risk and the travel comfort of the fans is improved, because this also depends on the actual number of passengers. Thus, we want to know concretely: How many fans are diverted from the short path? Since an app information such as ours does not yet exist in the field, we cannot measure the true flow. Instead we combine passenger counts collected in an independent field study, conducted as part of a student project and in cooperation with practice partner Stadtwerke München, with the survey outcome to answer this question.

This manuscript is structured as follows: We first list the results from the online survey that we need as input Sec. 2. Then we present the setup and results of the count study and estimate the unknown flow assuming a balance of flows and the route distributions in Sec. 3. We discuss limitations and give an outlook in Sec. 4.

2 Materials and Methods

Fig. 1 gives a schematic view of the routes at the underground train station. The shortest (red) way leads down an escalator and typically gets jammed. Without route recommendation 51% of the people arriving at the bus station take the short route, 27% take the medium route and 22% take the long route to get to the trains. We gained the route choice probabilities from an online survey that we conducted with over 1000 FC Bayern fans and about half as many students and faculty members from Hochschule München as control group [2].

In the survey we presented participants with pictures of the surroundings and with visual messages, also shown in Fig. 1. Information was visually or textually coded: An arrow always pointed in the desired re-direction. All other information was either present or not, in varying combinations with others. A top down view showed the route. On a second screen, congestion was depicted in orange and red. A text indicated that there was congestion and, another text appealed to the team spirit. Information on why one should pick an alternative route induced many fans to favor longer routes. However, providing more than one type of information at a time did not further improve compliance. Appealing to the team spirit showed an effect in some cases. The best re-direction results were achieved for the group of students and faculty for the designs highlighted in bold in Tab. 1. We use the identical distributions for the two best designs as input in our estimates in Sec. 3.

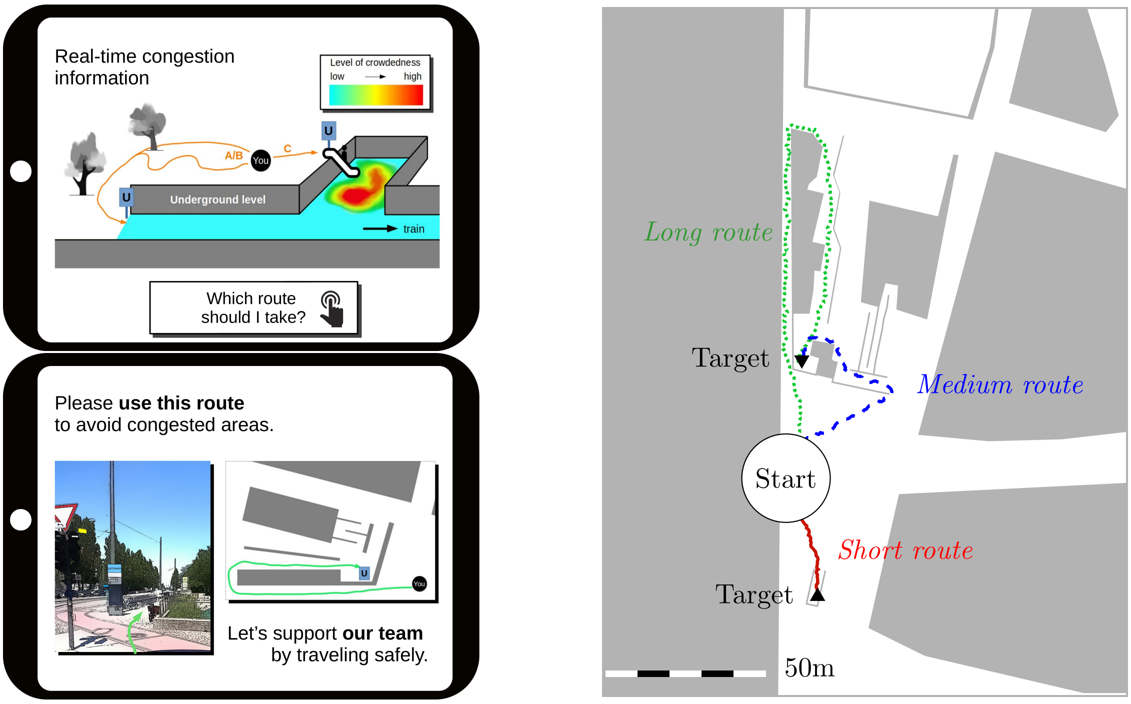

Figure 1 Visual incentives (left) are presented to survey participants through an app when they arrive at Munich's underground station (marked as "Start" on the schematic of the station (right)). The goal is to divert many of them from the shortest path between bus and trains (marked in red) to two longer alternatives (blue and green).

3 Results

3.1 Count study

Fig. 2 shows a map of the intermediate floor of underground station Münchner Freiheit and a simplified schematic. Students were strategically placed on that level to measure the flows labeled *big* and *small*. They clicked an app whenever a person crossed an imaginary line towards a certain direction. The count was conducted on 19.10.2020 during a lull in the Covid pandemic. The lines were also in view of surveillance cameras operated by the local traffic authority so that the students' counts were backed by video data. However, the video data was deleted after the check to ensure people's privacy and we use the students' counts for our estimates.

Fig. 3 shows the number of pedestrians over time for the two measurement lines marked in blue in Fig. 2. The measurements were taken within three time slots with intermittent breaks for the students.

3.2 Estimating flows using mass conservation

We are interested in the flow on the short path. Whether travelers walk along the medium or long route is of little interest for the practical application, as long as people can be

Message design	Percentage of persons on route		
	p_1 (short)	p_2 (medium)	p_3 (long)
Congestion info + arrow	25	35	40
Congestion info + arrow + top down view	25	35	40
Congestion info + arrow + team spirit	26	36	38
Congestion info + arrow + top down view + team spirit	28	32	40
Arrow	32	29	39
Arrow + top down view	33	27	40
Arrow + team spirit	33	29	37
Arrow + top down view + team spirit	34	28	38

Table 1 Route choice probabilities for students and faculty associates taken from [2]: The percentage of persons opting for a certain route in the online survey depends on the message design. The maximum number of diversions to the non-congested longer routes (medium and long) are achieved when informing the participants about the congestion and pointing an arrow in the desired direction. Whether or not the information was visually enforced by a top-down view on a red congested area in the app visualization, did not further improve the participants' choice. We use the most favorable distribution for our estimates.

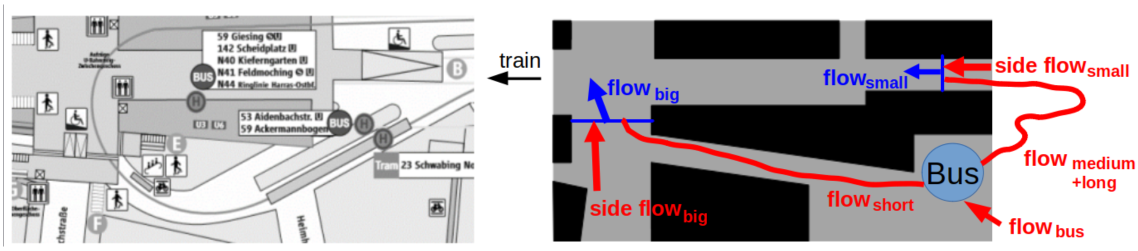

Figure 2 Intermediate floor of the metro station Münchner Freiheit (Munich): Map view (left) taken from `https://efa.mvv-muenchen.de/sta/muenchnerfreiheit.pdf` (16th Jan. 2023) and schematic of pedestrian flows (right). The big and the small flow were measured by counting the number of persons crossing the blue lines.

deviated from the short, congested route. Thus, we consider the flow along the alternative routes as one: $f_{medium+long}$. The side flows stem from travelers from side streets.

We also assume a steady and balanced flow. No passengers disappear in or reappear from shops. In view of the necessary crudeness of our estimates, we think this permissible. Thus, we average: $882.67 peds/h \approx (356+463+505) peds/1.5h$ for the big flow and $213.33 peds/h \approx (100+93+127) peds/1.5h$ for the small flow. We derive three equations

$$\begin{aligned} f_{short}+f_{medium+long}+f_{side,big}+f_{side,small} &= f_{big}+f_{small} && (1)\\ f_{short}+f_{side,big} &= f_{big} && (2)\\ f_{medium+long}+f_{side,small} = &= f_{big}, && (3) \end{aligned}$$

with two knowns f_{small}, f_{big} and four unknowns f_{short}, $f_{medium+long}$, $f_{side,big}$, $f_{side,small}$. From the survey we take the probability to select the short route p_{short} and harvest two further equations

$$f_{short} = f_{bus} p_{short} \qquad (4)$$

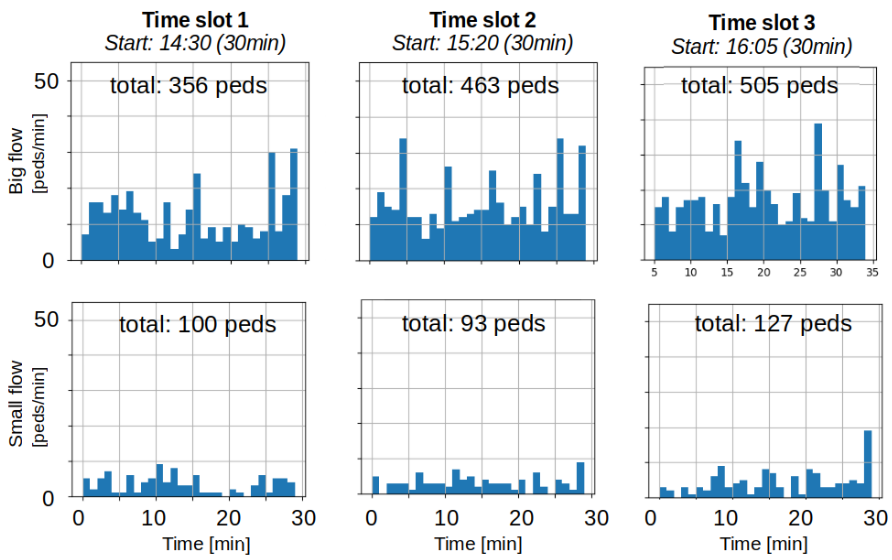

Figure 3 Number of pedestrians over time crossing the two (blue) measurement lines defined in Fig. 2. The measurements were taken in three separate time slots.

$$f_{medium+long} = f_{bus}(1 - p_{short}), \tag{5}$$

at the cost of introducing a new unknown f_{bus}. Unfortunately, despite the correct number of equations, the linear system is singular.

3.3 Number of redirected pedestrians

We use the small side flow $f_{side,small}$ as independent, or fixed, variable, arguing that it has the smallest influence in the system. Straightforward linear algebra then results in a solution that depends on the the size of the small side flow as seen in Fig. 4. Without redirection between 0 and 222 pedestrians per hour take the short route, where 222 corresponds to the case where there is no small side flow. When we nudge the travellers towards alternative routes only 71 pedestrians per hour remain on the short path in the case without side flow. Finally, we quantify the uncertainty in the number of redirected pedestrians r. The minimum value of redirected pedestrians is $r_{min} = 0$ when the side flow is maximal (see Fig. 4). The maximum value is $r_{max} = 151$. In the absence of more information, we assume a uniform distribution of the side flow. Then, due to the linear relationship, the number of redirected pedestrians also follows a uniform distribution. With that, we can analytically derive the expected value for the number of redirected pedestrians, $E = 75(= r_{min} + r_{max})/2$, as well as the standard deviation, $std = 44(= \sqrt{(r_{max} - r_{min})^2/12})$. This gives us an upper limit of the uncertainty in the result. However, in a pre-study we mostly observed very little flow from the side. Thus, we argue that a left-skewed distribution with expected value 75 and a small standard deviation might be a better model of the side flow and imagine the true number of redirections to lie close to 75.

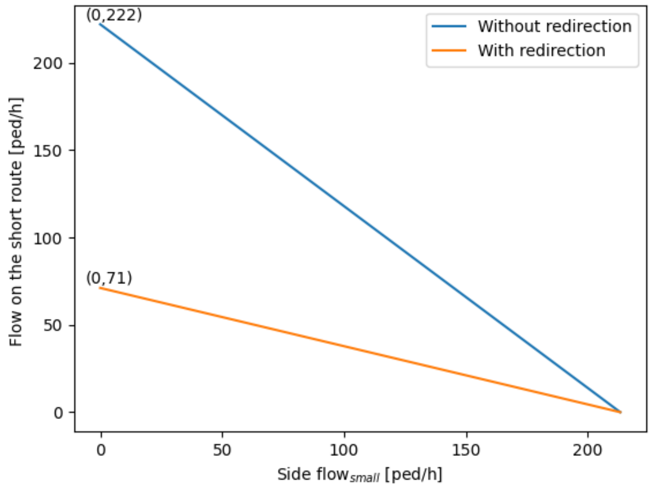

Figure 4 The estimated flow on the short route depends on the unknown side flow $sideflow_{small}$. A maximum of 151ped/hour (=222ped/hour - 71ped/hour) can be redirected from the short route to the medium or long route .

4 Discussion

We combined a survey on passenger reaction to redirection messages and a count study to estimate the number of soccer fans that can be nudged towards a less contested route at a metro station in Munich. We receive the flow in dependency of the influx at a side entrance that can be assumed minor in many cases. Assuming the concrete traffic situation and the best performing message design up to 151 pedestrians per hour from 222 pedestrians per hour could be redirected. The expected value is 75 with a small remaining uncertainty that stems from a mostly negligible side flow.

One should be aware that assuming mass conversation is not strictly true at all times, since people arrive in batches due to the bus schedule or may visit shops. Also early in the morning the station fills up while it empties at the end of the day. However, we think that during the time intervals that are of interest for congestion, the assumption does not introduce undue errors.

The count study took place during a lull in the Covid pandemic, so that the actual pedestrian traffic was weaker than normal. However, the simple method we present here, can easily be transferred to a full traffic situation or even simply be scaled up.

Also, survey participants may respond differently to the app information in real life. This opens a wealth of interdisciplinary research questions that should be addressed if guiding pedestrians with apps is to become a part of life comparable to guidance systems in cars.

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your student project as much as we do.

Ethics Statement This study is based on a previous online survey [2] for which we obtained ethical approval from the Hochschule München University of Applied Sciences (Munich, Germany). For more information, please find our journal article [2].

Author Contributions Christina Mayr: Conceptualization, Methodology, Software, Data curation, Visualization, Formal analysis, Writing draft / Gerta Köster: Conceptualization, Writing original, Supervision, Resources, Funding acquisition, Project administration.

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