Collective Dynamics

Estimating the Capacity of Railway Platforms and Stations

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Abstract In order to substantially design stations, it is key to know the capacity and the speed-density relation for different facility parts. To this end, having detailed data of pedestrian behaviour on railway platforms is essential. By using real-life tracking data from different Swiss railway stations, we derive a method to estimate the capacity for different facility elements and apply it to the data aiming at verifying or improving the existing design values.

We plot the speed-density-flow relation at different levels ranging from a whole platform section to areas covering only a few square meters. Waiting pedestrians are treated separately to reflect their specific behaviour. Afterwards, we fit the Kladek-curve proposed by Weidmann to the data using different parameter values.

The results show that the flow-density curves are a good fit to the mean of each density bin. However, there is a large scatter of the individual data points. Furthermore, the derived maximum flow is considerably different depending on the measurement location and the area size. It is generally lower than average values from literature. We assume that the complex behaviour of pedestrians has a significant influence on the observed differences.

Keywords Fundamental diagram · pedestrian tracking · railway station

1. Introduction

Planers design railway stations and platforms for a lifespan of several decades, which requires a sustainable design of its pedestrian areas. For this, the capacity and the speed-density relation for different facility parts are key components. However, the Swiss railway companies base their guidelines mainly on theoretical derivations and expert knowledge, as other sources were previously not available.

In literature, different speed-density-curves and fundamental diagrams, derived from measuring uni- or bidirectional flow, can be found, which showing relevant differences between the sources [1]. In comparison, the pedestrian flows on railway platforms are more diverse and include different behaviour such as standing or walking around while waiting for the next train. Hence, measuring a single uni- or bidirectional flow is hardly possible, compared to the classical fundamental diagram [2]. For these situations, macroscopic fundamental diagrams were introduced, covering a single multi-directional situation up to a whole network. By using simulation data, Daamen et al. [3] showed that the concept of macroscopic fundamental diagrams can also be applied to railway platforms.

Nowadays, real-life tracking data from railway stations allow better insight into specific situations [4]. Nevertheless, determining the capacity of different facility elements remains a challenge, as the design density for platforms is well below the density at capacity, which limits the real-life data at higher density to a few outliers. In addition, the platform is used for boarding and alighting as well as walking and waiting, which results in different densities and movements depending on the presence of trains [5]. Therefore, a method is needed to estimate fundamental diagrams for railway platforms based on tracking data.

In this study we estimate macro- and mesoscopic fundamental diagrams for platform areas based on real-life data. By looking at different areas within a platform, for example bottlenecks or queueing areas, we can evaluate differences in the fundamental diagrams. In addition, we expect the heterogeneity of the platform usage to influence the results. Therefore, it is essential to develop suitable methods to obtain comparable results.

2. Method

First, we defined area types (access, bottlenecks, $\cdots$) ranging from a whole platform section to areas covering only a few square meters (Fig. 1). Each area type corresponds to an expected behaviour pattern and therefore some of these areas can overlap as there is no clear border between these types. Based on these, we selected similar measurement areas for further analysis. For this study, we selected 8 tracking locations in 5 railway stations and used data from several days with high demand[1]. For each measurement area, we calculated the speed-density relation for each second using the classical density and the mean of the individual speeds obtained from the positions at each time step. To reduce the influence of the high amount of data at very low densities, we binned the data based on the density and calculated the bin-means (Fig. 2). We used the bin-means to estimate the speed-density curve by fitting the Kladek-curve proposed by Weidmann [6]:

$$v_i = v_f * [1 - e^{(-1.913*(\frac{1}{D*D_{fit}} - \frac{1}{5.4*D_{fit}}))}],$$

where v_i is the speed at a given density and D is the density. v_f and D_{fit} were used as fitting parameters, the maximum for D_{fit} was set so that D_{max} is limited to 10 P/m^2. The parameters $\gamma = -1.913$ and $D_{max} = 5.4$ were kept constant.

[1] SBB records anonymous tracking data for different locations within its railway stations.

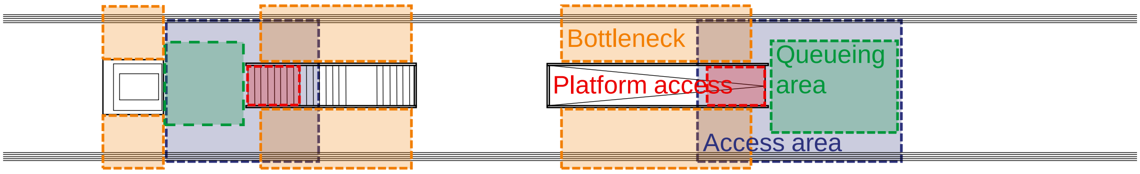

Figure 1 Area types used for the estimation of the fundamental diagram curves.

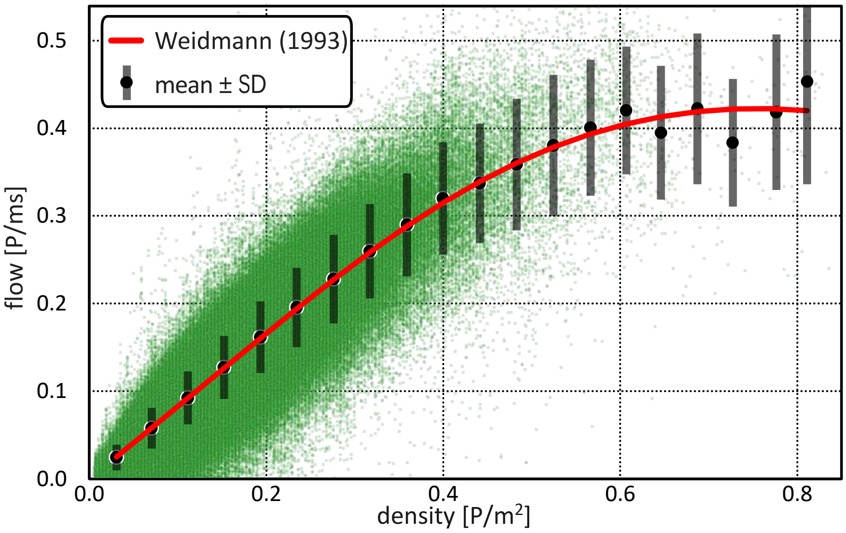

Figure 2 Fitted fundamental diagram based on tracking data. Due to the discrete values from the classical density calculation we added some random variation to the green data points for better visibility.

In general, speed-density curves are only useful for walking pedestrians. While waiting, the speed is independent of the density and is roughly zero (apart from stochastic movements and measurement errors). Thus, the influence of waiting has to be considered separately when calculating speed-density curves. A comparison of different methods (running average, random forest, $\cdots$) showed that waiting can be best identified by using the average mean speed as indicator and using a mean speed of 0.25 m/s over 9 seconds. The comparison was done in an unpublished study by comparing the results of the methods to manually labelled tracking data. For the density calculation, we included waiting pedestrians just like walking pedestrians, but for the speed calculation we considered only walking pedestrians. We then obtained the flow and hence the capacity by using speed and density. Therefore, it is assumed for this value that only walking pedestrians are present. This method to include waiting pedestrians does not consider the different space demand of walking and waiting pedestrians and does not reflect the waiting pedestrian in the flow calculation, but still allows to obtain comparable results for different shares of walking and waiting pedestrians.

In general, as we used the bin-mean speed, we obtained very high R^2-values. But as the goodness of fit does not reflect the small number of high-density values, we made a visual comparison to the data, especially at higher densities, and excluded bad fits for further analysis. For the remaining data, we calculated the capacity values and compared the curves as well as the capacity values within and between different area types.

3. Results

In comparison, the different area types show significant differences (Fig. 3). In general, the capacity values are the highest for platform accesses and the lowest for the total measurement areas. This is also in accordance with the expected outcome, as platform accesses show uni- and bidirectional situations with a high desired speed and whole measurement areas also include pedestrians who almost reached their destinations or just stroll around and areas which are hardly used. Compared to the platform access and bottlenecks, the queueing areas in front of the access generally show lower specific capacities, which we assume to result from the limited capacity of the platform access. In comparison with literature values, the estimated maximum densities are higher and, apart from the platform access, the densities at capacity are lower.

Although the obtained data is limited to lower densities, most measurement areas show a handful of observations at or little below capacity. This provides some reliability for the capacity estimation, as in general we found a good fit for lower densities. Nevertheless, as data at densities above capacity is missing, the goodness of fit for higher densities and possibly changes in the shape of the curve cannot be observed.

The results show that the flow-density curves provide a good fit to the mean of the data. However, a large scatter of the individual data points is visible. The derived maximum flow is considerably different depending on the measurement location and the area size and ranges roughly between 0.4 and 1.2 P/ms. It is suspected that due to the less goal-oriented behaviour of boarding passengers before train arrival, the presence of obstacles and waiting pedestrians, and the multidimensional flows in railway stations, the capacity values are generally lower than average values from the literature.

4. Influences on the fundamental diagram estimation

As mentioned previously, the estimation of capacity based on the observed density-speed relationship is influenced by various factors. To begin with, the accuracy of the Kladek formula's fit varies across different types of areas. Generally, we observe a more accurate fit of the data to the Kladek formula in areas with a lower percentage of waiting passengers, as one would expect. This because the classification of passengers into either walking or waiting categories is determined by a 9-second running average. Consequently, stop-and-go behaviour is not accurately captured, and the initial and final segments of a passenger's trajectory are inadequately modelled. In addition, the space occupied by walking and waiting passengers is not equal, which we do not take into account.

Furthermore, we notice that areas with a high variance in walking angles, indicating a multi-directional flow, tend to exhibit a poorer fit compared to areas with unidirectional flow, such as bottlenecks on the platform. However, there are also factors that are less straightforward to describe using simple state variables. For instance, areas close to the platform edges tend to yield poorer fits, likely due to the dynamics associated with entry and exit manoeuvres when boarding and alighting from the train. These dynamics can include clustering, queueing, and mutual hindrance.

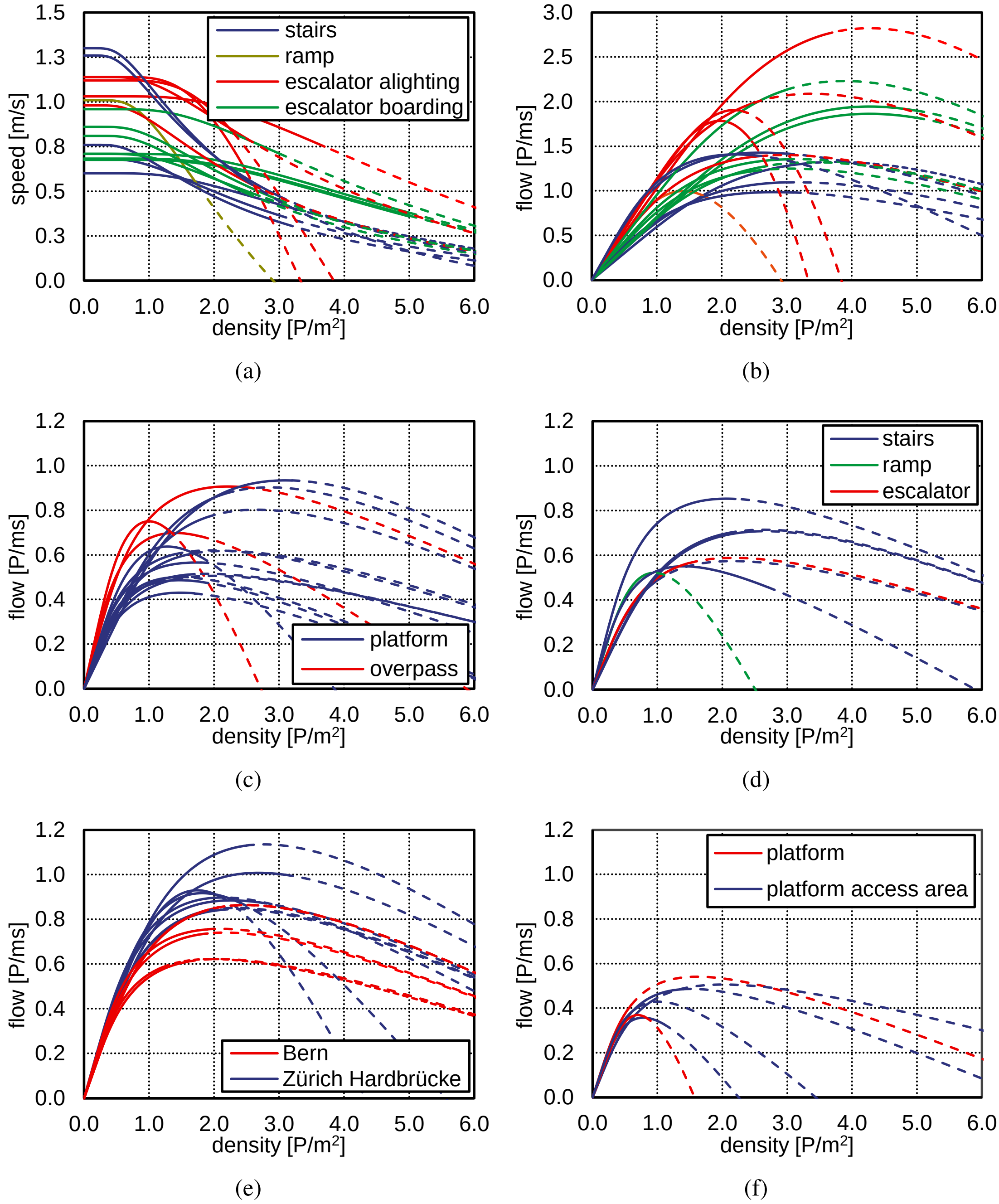

Figure 3 Fitted fundamental diagram curves for (a, b) platform accesses, (c) queueing areas, (d) access areas, (e) bottlenecks and (f) total platform (observation) areas. For the area definitions see Fig. 1. Solid lines represent the available data range, whereas dashed lines are estimates for higher densities. Each line represents a different measurement area.

Additionally, when using a larger area, the observed peak densities will generally be lower than in smaller areas. This introduces more uncertainty into the capacity estimation since only a fraction of the parameter space is actually observed. Conversely, using an excessively small area may result in observed densities that are near or even exceeding capacity. In such cases, the number of data points (bins) decreases, making the fit less robust. The comparison for areas with different sizes also showed a negative correlation between the observed area and the calculated capacity, although the causes remain unclear. Possible reasons are a selection bias, as only parts of the platform are selected for the smaller areas, or the presence of hardly used spaces in bigger areas.

Especially in queueing areas, it is essential to keep in mind that capacity and the speed-density is not solely a local phenomenon. Passengers may slow down not necessarily because of capacity limitations in their immediate vicinity but due to capacity constraints outside the selected area, such as in railway cars or at the platform access. As the platform must be viewed as a holistic system, which also interacts with neighbouring systems, a selection of sub-areas is not always feasible. For example, if the flow at a bottleneck is mainly influenced by its narrow width, a fundamental diagram for this area also reflects the behaviour within the selected area. But if the bottleneck is close to a platform access, the queueing in front of the access might influence the behaviour at the bottleneck. Hence the comparability between these two is limited.

5. Conclusion

Although several questions remain open and a considerable scatter is visible in the results, the performed approach was found to be useful and allowed a better insight into the platform behaviour. A fit between the data and the Kladek-curve was found for the data. Fundamental diagrams at different scales allow to estimate the capacity of different elements within railway stations and highlight the differences between different area types. In general, the estimated capacities are within the expected range, but closer reflect the local dynamics on the platforms.

Still, some results need further studies. We observed that curves for similar areas show considerable differences. These can be due to differences in behaviour, but also due to the definition of the exact measurement areas and sizes. For example, the influence of the area size and location and the pedestrian behaviour was observed, but only simple methods were used to integrate the effects into the calculation. Using a more complex density calculation method, for example the calculation of Voronoi cells, will likely improve the density calculation, but on the other hand increase computation times.

Finally, we conclude that modern technology allows for better evaluating and designing railway stations. Albeit it introduces also further uncertainty and demands a good understanding of the data available.

Author Contributions Ernst Bosina: Conceptualization, Investigation, Writing – Original draft preparation / Raphael Roth: Investigation, Software, Writing – Original draft preparation / Jonas Meli: Validation, Writing - review and editing.

References

[1] Bosina, E.: A New Generic Approach to the Pedestrian Fundamental Diagram. Doctoral Thesis, ETH Zurich (2018). doi:10.3929/ethz-b-000296226

[2] Bosina, E., Weidmann, U.: Defining the pedestrian fundamental diagram. In: Hamdar, S.H. (ed.) Traffic and Granular Flow '17, pp. 383–391. Springer International Publishing, Cham (2019). doi:10.1007/978-3-030-11440-4_42

[3] Daamen, W., den Heuvel, J.v., Knoop, V.L., Hoogendoorn, S.P.: Macroscopic Fundamental Diagram for Train Platforms. In: Hamdar, S.H. (ed.) Traffic and Granular Flow '17, pp. 365–372. Springer International Publishing, Cham (2019). doi:10.1007/978-3-030-11440-4_40

[4] Thurau, J., Keusen, N.: Influence of Obstacles on the Use of the Danger Zone on Railway Platforms. Collective Dynamics **5**, A84 (2020). doi:10.17815/CD.2020.84

[5] Küpper, M., Seyfried, A.: Analysis of Space Usage on Train Station Platforms Based on Trajectory Data. Sustainability **12**(20), 8325 (2020). doi:10.3390/su12208325

[6] Weidmann, U.: Transporttechnik der Fussgänger - Transporttechnische Eigenschaften des Fussgängerverkehrs. No. 90 in Schriftenreihe des IVT. Institut für Verkehrsplanung, Transporttechnik, Strassen- und Eisenbahnbau, ETH Zürich, Zürich (1993). doi:10.3929/ethz-b-000242008

A. Data

The data used for this study can be obtained from the authors after signing a confidentiality declaration and usage agreement.