An Investigation of the Influences on Train Dwell Time

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***Abstract*—Station dwell time is a key parameter of rail service quality and reliability. Longer standing times induce headway variability and reduce the overall rail system performance by generating delays. Delays are unattractive and uneconomic. This research interrelates station dwell times with possible root causes and influencing factors. Based on passenger and dwell time data of a railway station in Zurich observed by the Swiss Federal Railways (SBB), this study focuses on factors influencing stopping time at stations. In addition, a model to estimate passenger dwell time is developed from own counts and measurements.**

Keywords—Dwell Time, Passenger Dwell Time, Boarding and Alighting Process, Train Delays, Zurich Hardbruecke

I. Introduction

Switzerland's railway system is known for its high service quality and constantly increasing passenger numbers. However, this is an opposing trend. More people in the network can lead to delays and therefore to a reduction of service performance. One way to improve timetable stability is a precise operation planning, such as an accurate estimation of the station dwell time. Since train delays often originate or grow around stations, it is essential to understand the factors influencing the actual train standing time. Studies worldwide indicate the importance of an accurate dwell time estimation. However, findings about the type of influencing factors and their effects differ from country to country and mostly also depend on the rail system analysed. In Switzerland, train dwell time was mostly analysed with descriptive analytics and on-field observations. However, little analysis to eventually predict the variability of dwell time was done so far.

It can be expected that rail passenger numbers will increase further in Switzerland, which is why the system will be operating closer to capacity. This explains the general interest in a better understanding of the processes influencing train stopping time. Online available data as well as data received from SBB allows to interrelate train dwell times at the station Zurich Hardbruecke with possible root causes. Among other things, this is done in this study.

II. Literature Review

A. *Theory on dwell time*

Train dwell time is the time a train stops in the station. Therefore, the total travel time is the sum of the running time plus all station dwell times. Obviously, the main reason for the necessity of stopping at a station is to exchange passengers. This is the main determinant of the total train dwell time. The dwell time for a whole trip is the sum of all dwell times per station. However, the dwell time for an individual station is the maximum time needed at one door for passengers to alight and board (passenger dwell time) plus some additional technical time for the doors to open and close and the train to get ready to leave the station again [1]. The reason for this is that normally passengers are not distributed uniformly on the platform.

$$DT_k = t_0 + max\ t_i \tag{1}$$

DT_k *dwell time of station k*
t_0 *fixed technical time*
t_i *passenger dwell time per door*

As shown in Fig. 1, station dwell time can be divided into five sub-processes [2]. The effective train dwell time is then the longest time needed at one door for all the sub-processes to be finished.

B. *Summary of preliminary work on train dwell time and its influences*

Over the years, many researchers studied dwell time at railway stations and tried to identify and quantify influential parameters. Some developed dwell time models are introduced below. The following summary is not concluding. However, it shows what was done so far in this specific research field.

Reference [3] showed that train dwell time is related to the maximum number of passengers alighting and boarding at a door as well as to the friction between the number of boarders and alighters. They produced three separate equations for 1.1 m doors with a middle bar to estimate train dwell time that take these factors into account (Table 1).

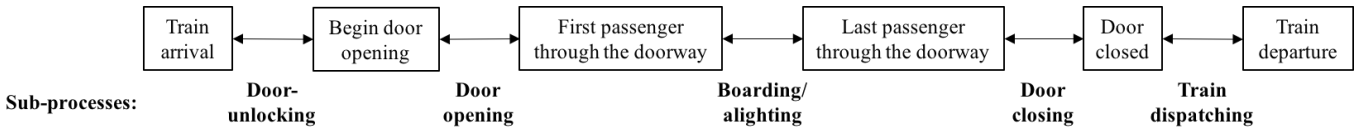

Fig. 1. Sub-processes of train dwell time according to [2].

TABLE I. EQUATIONS TO ESTIMATE TRAIN DWELL TIME [3].

Group description	**Predictive equation** $t = l + \lambda(a) + \mu(b)$
Exclusive or dominant alighting $\psi \leq 0.32$	t = 2 + 1.0(a) + 2.4(b)
Alighting and boarding $0.33 \leq \psi \leq 0.66$	t = 2 + 0.4(a) + 1.4(b)
Exclusive or dominant boarding $\psi \geq 0.67$	t = 2 + 1.4(a) + 1.4(b)
ψ = fraction of boarders l = lost time [s] λ = time per person to alight [s/P] μ = time per person to board [s/P]	a = number of alighters [P] b = number of boarders [P]

In 1992, [4] analysed train dwell time based on data collected for light rail systems in Boston. Without including crowding on board, the following linear model to estimate train dwell time was developed.

$$DT = 11.73 + 0.49\,a + 0.42\,b \qquad (2)$$

where DT = train dwell time [s], a = total number of alighters [P] and b = total number of boarders [P].

In the survey of Lam et al. [5], data of three railway stations in Hong Kong was used to study the relations of train dwell time and crowding situations at stations. Only including the total number of passengers alighting (a) and boarding (b) per train, a model for dwell time prediction was determined with the data of all three stations together (equation (3)). They used a fixed time of 10.5 s for doors to open and close. Further, they pointed out that train dwell time will not increase infinitely with more boarders and alighters, since the headway defines the maximum possible dwell time in a station.

$$DT = 10.50 + 0.021\,a + 0.016\,b \qquad (3)$$

In 2000, [6] developed a model based on the results found by [4]. However, he had a closer look at the influence of the number of doors per train and crowding effects on dwell time. Data, namely the total number of boarders and alighters as well as the total number of through standees was collected in Massachusetts. With a regression analysis, the following model was developed to estimate dwell time of an individual car.

$$DT = 12.22 + 1.82\,a_d + 2.27\,b_d + 6.2\,10^{-4} \cdot TS_d^3\,b_d \qquad (4)$$

where DT = train dwell time [s], a_d = alighting passengers per door [P], b_d = boarding passengers per door [P] and TS_d = through standees per door [P].

As reported by Harris and Anderson [7], Weston deviated a formula for London Underground Ltd to calculate the station stop time dependent on a great number of variables. He defined a lost time of 15 s for the doors to open and close. This predictive model incorporates additional time needed in case of mixed passenger flow (boarding and alighting at the same time) and indicates that the increase of dwell time with more passengers is declining.

$$SS=15+\left[1.4\cdot\left(1+\frac{f}{35}\cdot\frac{(t-s)}{d}\right)\right]\cdot\left[\left(\frac{f\cdot b}{d}\right)^{0.7}+\left(\frac{f\cdot a}{d}\right)^{0.7}+\left(0.027\cdot\frac{f\cdot b}{d}\cdot\frac{f\cdot a}{d}\right)\right] \qquad (5)$$

where SS = station stop time [s], a = number of alighters [P], b = number of boarders [P], d = number of doors, f = peak door / average door factor, s = number of seats and t = number of through standees [P]. All parameters are for the entire train.

Harris and Anderson applied Weston's formula to a set of metro stations in the world and found that the model structure in general is applicable worldwide without undertaking significant adaptions. However, some parameters have to be fit to other situations, especially when station characteristics, the used trains or passenger demand are different. In general, Weston's formula shows deviations when passenger loads are very high [8].

In 2012, [9] reviewed static and dynamic approaches to calculate train dwell time and also developed a model to estimate dwell time for double deck trains in Sydney. To do so, two types of surveys were conducted. In a first step, live data was collected at three stations as in a second step, an experiment with 300 fieldworkers boarding and alighting a train was conducted. For his prediction model, Douglas combined the data of both surveys and additionally added a functional time (doors opening and closing) to calculate the total dwell time.

$$DT = 10 + 1.9a_d^{0.7} + 1.4b_d^{0.7} + 0.007(a_d + b_d)\,(Std_d) + 0.005(a_d b_d) \qquad (6)$$

where a_d = number of alighters per door [P], b_d = number of boarders per door [P] and Std_d = estimated number of standing through passengers per door [P]. He concluded that statistically based dwell time models that were estimated for a specific type of rolling stock, are not generally applicable for other type of trains. To develop a more general model, not only train characteristics but also platform conditions would have to be included.

Concluding, it can be said that all researchers agree on the importance of dwell time as a key parameter for system performance and reliability in passenger rail traffic. It makes sense that dwell time is mostly influenced by passenger volume. However, the above-mentioned studies were

TABLE II. EXISTING DWELL TIME ESTIMATION MODELS[a].

		Input variables				
		Passengers			***Rolling stock***	
Lit.	***Location***	***Number of A & B***	***Interaction of A & B***	***Number of S***	***Number of doors***	***Door width***
[3]	Canada	√	√	-	-	-
[4]	USA	√	√	√	NA	-
[5]	Hong Kong	√	-	-	-	-
[6]	USA	√	-	√	NA	-
[7]	UK	√	√	√	√	√
[9]	Australia	√	√	√	√	-

[a.] A = alighters, B = boarders, S = standees in the train, "√" = included, "-" = not included, NA = not applicable.

conducted in different countries, for different rail operating systems, different rolling stocks and used different analytical methods. The problem is generalisability. Table 2 summarises the mentioned dwell time models and lists used input variables.

III. Methods

This study focuses on train dwell time analysis at the station Zurich Hardbruecke in Switzerland. The station is mainly used by the Zurich suburban railway (S-Bahn). According to the number of passengers boarding and alighting per weekday, Zurich Hardbruecke is the fifth largest railway station in the canton of Zurich and the eleventh largest in Switzerland. The average daily number of passengers during weekdays was 56'000 in 2016 [10]. It is fair to assume that the station is mostly used by commuters. Not only is it located in the industrial area of Zurich with many workplaces, it is also a node to change to the local public transport. The station Zurich Hardbruecke is suited to analyse train dwell times, because each train is unambiguously assigned to a track and because trains only stop for passenger exchange. Tickets are collected before entering the platform. The Zurich suburban railway uses four different train types. All used vehicles are double-decker coaches. Except for additional trains that are only used during rush hours, all trains at least have some at level entrances. Door widths of all types are around 1.4 m.

A. *Dwell time analysis with passenger numbers per train*

The investigation of train dwell time at the station Zurich Hardbruecke is divided into two parts. In a first step, information about the total number of boarders and alighters per train is received from SBB. The data includes trains between January and mid-March 2018. Passengers boarding and alighting are counted with sensors at each door. About 35% of all trains stopping at the regarded station are equipped with this automatic counting system. Together with data from other sources, one dataset containing more than 14'000 trains is created and analysed. Fig. 2 shows the sources of all available variables. It is tried to identify and quantify influences on train dwell time with multiple linear regression analysis (MLR).

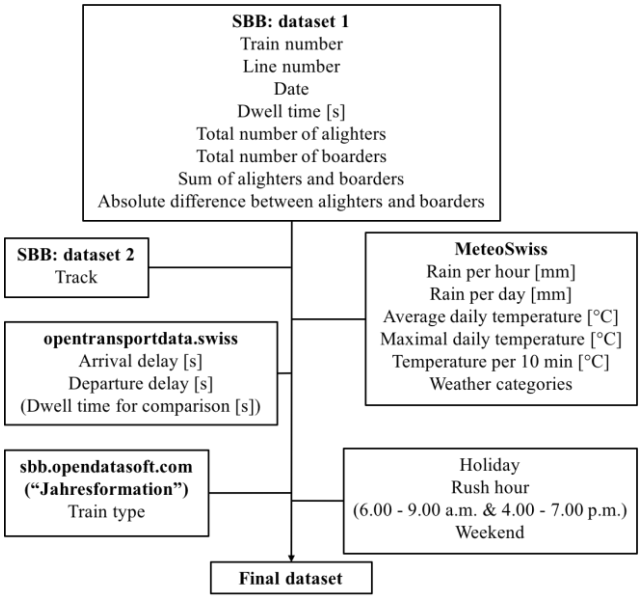

Fig. 2. Variables used in the train dwell time analysis and their sources.

B. *Passenger dwell time analysis and link to train dwell time*

In the second part, own measurements conducted on-site during June 2018 are analysed. Goal is on the one hand to investigate on the passenger exchange sub-process and on the other hand to verify the results of the previous investigation. The analysis of the passenger dwell time at a micro level (one door), can make a significant contribution to the development of a model for estimating the total train dwell time. Data is collected on three weekdays during the morning and evening peak hours. The number of boarders and alighters is separately counted for a randomly selected door. The total duration of this process is measured. Only persons moving in a cluster are considered. A person belongs to a cluster if the time interval between the predecessor and him- or herself is less than 3 s. This means that if a person subsequently runs onto the train, he or she is not counted as a boarder. The duration of the passenger exchange process is measured as the time when the first passenger passes through the door (mostly a person alighting) until the time when the last person passes through it (mostly a boarder). It is also measured if the passenger exchange process at another door takes substantially longer. In addition, the following attributes are noted for the selected door: Number of standing persons in the door area in the train, stairs / railings (yes / no), do passengers of two trains influence each other on the platform. A total of 324 trains was observed.

First, passenger dwell time as such is analysed and an estimation model is developed with MLR. Using door-specific data from SBB, it is then possible to calculate the time needed for passenger exchange at the critical door. In a second step, it is therefore tried to improve train dwell time estimation with this additional information.

Train dwell time analysed in both parts of this study does not represent the actual stopping time of the train. It is the difference between the timestamp when the engine driver unlocks the doors and the train reaches the zone of the station (~ arrival time) and the timestamp when the train leaves the zone of the station with locked doors (~ departure time). Therefore, train dwell times are longer than the actual stopping times. Actual train dwell times were not available in the datasets analysed in this study.

IV. Results

Since separate analyses were performed, the results are presented in corresponding subchapters.

A. *Results of train dwell time analysis with total passenger numbers per train*

Firstly, parts of the dataset are visualised and selected relationships highlighted. In the second section, results of inferential statistics to estimate train dwell time dependent on different variables are illustrated. For the whole analysis only trains with total dwell times between 30 and 300 s are included. It is assumed that a stopping time shorter than 30 s is not possible. If a train waits longer than 5 min at a station, the passenger exchange is most likely not the critical process.

The average dwell time at the station Zurich Hardbruecke is circa 95 s with a standard deviation of around 25 s. Fig. 3 shows a typical distribution of train dwell time over the time of the day. It is visible that they increase during the morning and evening peak hours. Similarly to dwell time, the number of boarders and alighters also shows peaks over the time of a

weekday. The number of boarders grows during the day and reaches its peak during the evening rush hour. The number of alighters is higher during the morning rush hour, but also indicates a peak in the evening.

Comparing train dwell time and the total number of passengers boarding and alighting, different interactions can be determined (Fig. 4). S3 trains on track 4 indicate a rather linear interrelation between dwell time and the total number of passengers per train. However, something else influences the same trains that stop on track 1. Dwell times longer than 125 s happen with rather low passenger numbers between 25 and 150. Similar observations can be made for other lines.

Comparing departure delays and train dwell times, it becomes clear that longer dwell times induce delays.

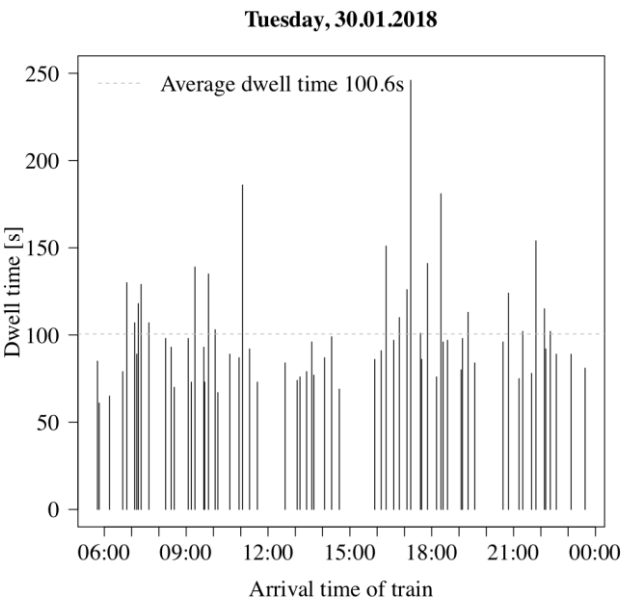

Fig. 3. Typical variation of dwell time during a weekday.

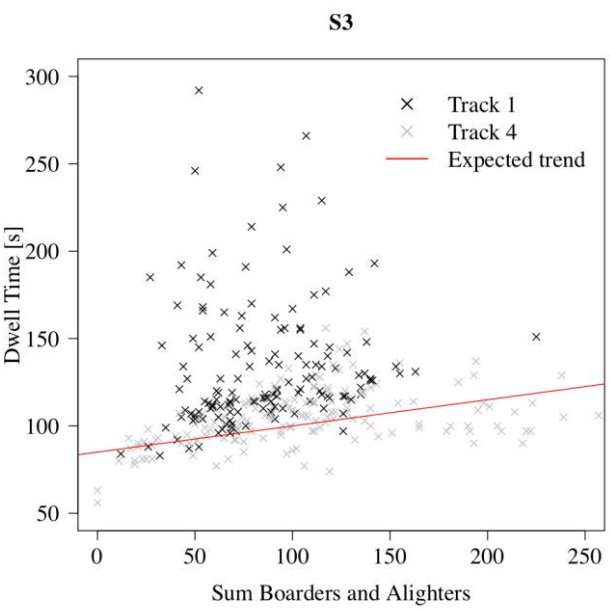

Fig. 4. Interaction of dwell times and passengers during rush hour on S3.

Analysing various MLR models with the total number of passengers per train, train dwell time significantly increases with more boarders and alighters. However, the effect is rather low. The estimated parameter (β_i) of the total number of boarders or alighters per train is circa 0.15. This means that if there is one more passenger e.g. boarding, train dwell time increases by 0.15 s, given that all other independent variables stay constant. This is also indicated through the small slope of the trend line in Fig. 4. The results also indicate that holidays and weekends have a negative effect on the station dwell time. This is probably due to less passengers boarding and alighting on such days. The opposite is the case for trains during rush hours. Finally, rain also seems to influence train dwell time. In all MLR models the estimated parameter for the dummy variable RAIN (was it raining during the hour of train arrival? 1 yes; 0 no) is evaluated significantly different from zero and with a positive value.

Various assumptions were made to develop a model that describes the variability of the train dwell time as accurately as possible. For example, only trains with an arrival delay larger than 90 s or only trains during rush hours were included in the different regression models. However, also by varying the data included in the model, a R^2-value larger than 30% cannot be achieved.

B. Results of passenger dwell time analysis

The time needed for boarding and alighting dependent on the total number of passengers moving in a cluster is shown in Fig. 5. It is well visible that the time needed increases linearly with more passengers. The slope of the trend line is almost 1 (0.97). The constant term of 1.05 is as expected close to zero and can be neglected. The larger the total number of passengers, the more the passenger dwell time scatters around the trend line. The passenger dwell time does not seem to be limited upwards.

Using the total number of passengers boarding (IN) and alighting (OUT) separately to describe passenger dwell time (PASS_DT), the following model can be developed:

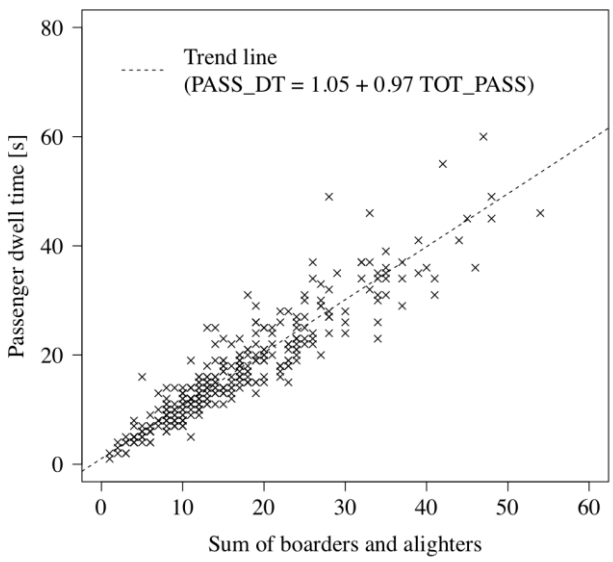

Fig. 5. Passenger dwell time dependent on sum of passengers.

$$PASS\_DT = 0.50 + 1.17\ IN + 0.88\ OUT \qquad (7)$$

This model indicates that boarders need more time (1.2 s/P) than passengers leaving the train (0.9 s/P). The R^2-value is 88%. According to MLR analyses, steps instead of at level entrances do not appear to have a significantly negative impact on passenger dwell time. The influence of standees in the entrance area could not be investigated directly. Although this variable was collected on site, only three observed doors had more than seven persons standing in the entrance area.

C. *Results of train dwell time analysis including passenger dwell times*

Since door-specific passenger data is available from SBB for the period own measurements were conducted, it is possible to calculate the maximal passenger dwell time from the number of boarders and alighters at the door with maximal passengers. This is done using formula (7). Not each door of a train is equiped with sensors to count boarders and alighters. Therefore, it is possible that the critical door is not measured and that the calculated passenger dwell time does not belong to the crical door with maximal passengers.

Fig. 6 shows the interrelation of calculated passenger dwell times at the critical door and total train dwell times at the station Zurich Hardbruecke. It is assumed that passengers behave similar on the different platforms and also during off-peak hours. Therefore, the graph includes all trains on three weekdays that are equipped with sensors to count passengers (690 trains). A trend line with a total fit of $R^2 = 23\%$ is drawn through the points with train dwell times between 30 s and 125 s. The constant term describing train dwell time independent of the passenger exchange process is 80 s. Additionally, the identity line is illustrated.

With the complete data set consisting of own measurements and SBB data (N = 139), another regression analysis is carried out. It is tried to develop a model that describes train dwell time variability amongst others with the number of boarders and alighters at the maximal door. Since no measurements of off-peak hours, weekends or holidays exist, these variables are not included into the model. Table 3 shows the estimated parameters of this regression analysis.

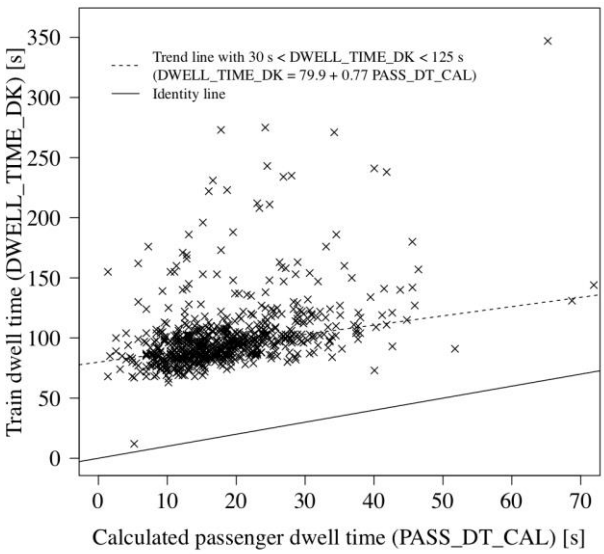

Fig. 6. Train dwell time and calculated maximal passenger dwell time.

TABLE III. RESULTS OF MLR MODEL

Coefficient	Estimated parameter	Significance
(Intercept)	54.26	*
Boarders_at_critical_door	1.45	**
Alighters_at_critical_door	1.55	***
Delay	1.68	
Morning_peak	-13.61	*
Track_2	6.26	
TT_1	27.63	
TT_2	17.94	
TT_3	7.38	
Rain	9.14	
$R^2 = 0.32$		
*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, '.' $p < 0.1$		

Delay is the one shown on the platform display in minutes when the train arrives. Morning_peak and all following coefficients are categorical variables. TT_i are the different train types. Rain characterises if it was raining during the train arrival.

V. DISCUSSION

The fact that boarders are slower than alighters was also shown by [6] and [11]. Reference [12] found the same for the passenger exchange process on buses. A possible explanation is that alighters wait in a cluster for the doors to open and then know exactly where they have to go. Boarders however, eventually have to walk to the nearest door. In general, it was observed that boarders stand less close to each other than alighters. The inside door widths of all train types are similar. Comparing the estimated parameters with the literature, [13] found a value of 0.9 s/P for similar door widths. Own measurements of [14] resulted in 0.77 s/P for at level entrances and 1.03 s/P when there are steps. The results of the measurements of this thesis are therefore in line with results of earlier studies.

Using the time needed for passenger exchange at the critical door instead of total passenger numbers, slightly improves train dwell time estimation. This is understandable, as it is important how passengers are distributed on all doors of the train. Fig. 6 illustrates that short stopping times are practically impossible with long passenger dwell times. However, long train dwell times occur although the passenger exchange process is rather short. For such measurements, the train has to wait at the station for other reasons. This is one of many possible explanations, why the variance can still only be explained to about one third with the available variables. The consistently small model accuracies are an indication that further influences are present. Which they are and whether it would be possible to include them in a regression model can only be speculated. The main restriction probably is that operational effects cannot be excluded in these analyses. It is always possible that a train stops longer due to effects not related to the passenger exchange process. An estimation model therefore would have to take uncertainties into account. This in turn would make a prediction practically meaningless. This is why, such a model is not developed in this thesis. Generally, it might make more sense to examine further sub-processes of train dwell time individually.

Deviating from the first analysis, rain seems to have no influence on train dwell time in the second MLR model (Table III). It is possible that passengers behave differently when it rains. However, the magnitude of the influence must be further investigated.

Lastly, the assumptions of multiple linear regression have to be discussed. This study assumes that there exists a linear relationship between train dwell time and the number boarders and alighters as well as the other used independent variables. Although this connection is hinted at in various Figures, its correctness cannot be definitively proven. Multicollinearity was considered by analysing the correlation matrices that compare all independent variables before each regression. Residuals of the regression model should be normally distributed which can be checked with QQ-plots. In the middle of the QQ-graphs, points mostly fall on the identity line, but in the extremities, they curve off. This is an indication that the data includes more extreme values than would be expected for a Normal distribution. Therefore, this condition is not fully met. For passenger dwell time (Fig. 5), observations form a cone shape. This shows that the variation of observations around the regression line is not constant, which means that another condition of MLR is not fully met. This must also be taken into account when interpreting the results.

VI. Conclusion and Outlook

The analyses carried out in this study provide important information on train dwell time and the behaviour of passengers at the station Zurich Hardbruecke as well as the boarding and alighting process. The main findings are listed below.

- Long train dwell times induce delays at the station Zurich Hardbruecke.
- Train dwell time at the station Zurich Hardbruecke is influenced by total passenger numbers. Additionally, weekday/weekend, rush hours and holidays influence the average stopping time. The influence of rain remains questionable.
- Passenger dwell time can be estimated through the number of boarders and alighters. Whereby the effect of boarders seems to be slightly greater. Steps do not prolong the process.
- Including passenger dwell time at the maximal door of the train instead of total passenger numbers improves the estimation of train dwell time.

In a further analysis signal data could be used to include operational effects into the regression model. It would also be interesting to analyse more different types of trains (different door widths and interior layouts) and lines, as well as different stations. Although there will always be uncertainties in the estimation of train dwell time, an improvement in the prediction accuracy seems possible.

Railway passenger numbers are expected to continue to rise in Switzerland. Moreover, it cannot be ruled out that capacities will be reached on individual lines and stations. This makes further dwell time analyses interesting. If the effects on train dwell time are understood, timetables can be planned more accurately. This in turn would reduce delays and lead to a higher quality of passenger rail services.

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