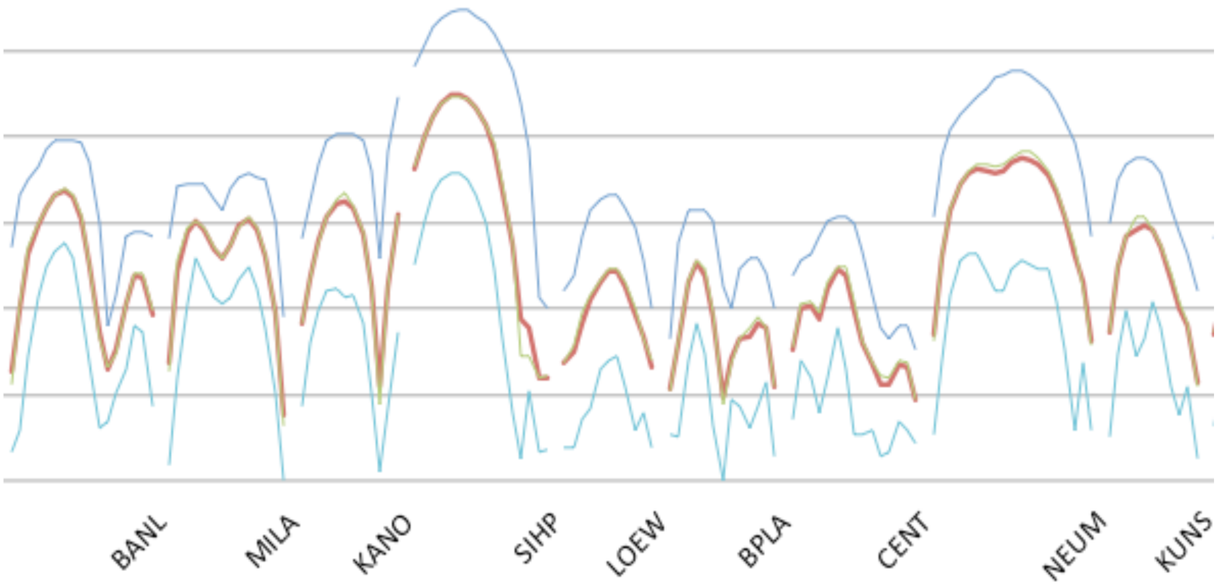

Quantifying public transport reliability in Zurich

Nelson Carrasco, ETH Zurich

Conference paper STRC 2011

STRC | 11th Swiss Transport Research Conference
Monte Verità, Ascona, May 11 - 13, 2011

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Nelson Carrasco
IVT - ETH
8093 Zurich

Phone: +41 44 633 3087
Fax: +41 44 633 1057
nelson.carrasco@ivt.baug.ethz.ch

May 2011

Abstract

Public transport operators aim to provide higher levels of reliability for their users because reliable services are more attractive, and can also reduce operating costs for the agency. This work addresses the issue in a context where high-quality public transport is the norm. An on-going study makes use of Automatic Vehicle Location data (AVL) of bus Line 31 in Zurich to estimate quantitative operational reliability measures. A number of in-vehicle observations during peak periods, and aggregate operational data reports complement the detailed AVL data. The main objective is to shed light on the major causes of reliability problems in Line 31 by first identifying where the problems are located and how performance varies throughout the day. Initial results indicate that intersections contribute most to delays, even with the presence of active priority for vehicles at traffic lights. In Zurich, high reliability levels are achieved with a limited level of segregation and exclusive lanes. Together with priority measures, holding strategies and timetables with sufficient recovery times are considered to contribute most to a stable operation. It is not expected that reliability can be significantly improved without a higher degree of segregation from the rest of the traffic. The results of this work provide a quantitative benchmark to which further improvements in the service can be compared. It can also prove useful to cities looking for ways to improve the reliability of their urban bus services. Further work will deal with the analysis of timetable design, buffer time allocation and holding strategies.

Keywords

Reliability – Public Transport – Zurich – AVL Data

1. Introduction

Reliability is a key element of any public transport service. Considerable effort is being made by public transport agencies and operators to improve the reliability of their operations and consequently the quality of their services. Improvements in service reliability benefit both users and operators, as less variable services decrease waiting time for passengers and allow for an efficient use of resources by operators. It's a win-win situation.

This work is a first attempt at quantifying reliability in Zurich using recorded data from the Operator, including Automatic Vehicle Location (AVL) data. The first section deals with performance, reliability, its relevance, and a description of the metrics used describe the reliability of service using bus Line 31 as a case study. The following chapter describes the Line, its characteristics, metrics and demand, identifying some of the most important points along it. Chapter 4 describes the aggregate and disaggregate data made available for this study, and draws a first picture of performance using a small sample of field observations made during peak hours. Chapter 5 contains the results of the travel time, speed, punctuality and regularity analysis. Chapter 6 and 7 draw some conclusion on the work and describe limitations and future work.

2. Performance and reliability in Public Transport

Performance of a public transport system refers to how well the system achieves its intended goals and objectives. Measuring performance is very important because it provides information on how well the service is being provided, and when it is not, it helps in diagnosing problems and finding solutions.

In the past, estimating performance measures in public transport was difficult and expensive due to the lack of comprehensive performance data. However, these limitations have slowly been overcome by advances in technology, which allow the use of automatically collected data systems (ADCS), thus providing large amounts of high quality data for this purpose.

The focus of public transport performance measures has traditionally been on attributes of service supply, such as capacity, passenger loads, frequency, regularity and reliability. However, a number of studies have also focused on performance measures from the demand side. For example, [1] focused on the measuring the attractiveness of travel by public transport, [2] worked on connectivity measures; and the unpublished work by [3] developed reliability indicators for transfers from the passenger's perspective. In [4], eight performance measure categories for public transport are defined: availability, service delivery, safety and security, maintenance and construction, economic, community, capacity and travel time.

This work addresses the performance of public transport service delivery from the perspective of travel time and service reliability, estimating and analyzing a number of operational performance metrics for bus Line 31 in Zurich.

2.1 The multiple dimensions of reliability

Reliability is a term that can be defined differently, depending on the context or discipline in which it is being treated. Synonyms to the word "reliability" are: dependability, accuracy, constancy, fidelity and security. Public transport users experience reliability mostly through punctuality (with the associated additional waiting time at the stop) and travel time (reliability provides and idea on the consistency and variability of travel times). However, a public transport operator will focus on a number of features of the system to characterize reliability, such as schedule adherence, headway regularity, and percentage of completed trips.

A strict definition of reliability is "one minus the probability of failure" [5]. However, in public transport systems failure is complex and hard to define. It can relate to different elements and be of different types. Usually, reliability is measured by its consequences: number of persons affected, lost time, time between breakdowns, recovery time, etc. It must be stated that reliability takes place over a long period of time, i.e. it is not punctual.

Travel time reliability can be defined as the consistency or dependability in travel times, measured from day to day for the same trip. Travelers on well-known routes learn to adapt to the possible unexpected events and adjust their travel time budget accordingly. Their experience will vary day-to-day for the same trip in services with unreliable travel times.

Public transport service reliability can be understood in different ways, as summarized by [6]. It can be understood as the "variability in performance measured over time" [7]; as the "variability of service attributes and its effects on traveler behavior and on transport agency performance" [8]; or mostly as "schedule adherence and keeping schedule related delays (on-time performance, run time variation, headway delay and headway delay variation) to a minimum" [9], [10]. Reliability issues of public transport services are often attributed to the dynamic nature of the operating environment [11]. According to [9], to provide a reliable service means "keeping buses on schedule, maintaining uniform headways and minimizing the variance of maximum passenger loads".

2.2 Operational stability and reliability

In general, operational stability refers to capable and reliable processes and equipment. In the public transport industry, this translates into high levels of reliability for both scheduled and frequency based services (but also vehicles, supporting systems, and processes). In places where scheduled services are predominant, such as Switzerland, schedule adherence is normally the (only) indicator used by transport agencies to measure operational stability. However, the use of this metric implies that schedules are already realistic and achievable; therefore it can be misleading where sub-optimal schedules are in use.

In places where very frequent services are predominant (headways equal to or under 10 minutes, according to [12]) the focus tends to change towards regularity. The main reason is the assumption that most users of such services ignore the timetable and arrive randomly at the station, though a number of studies exist where this restriction is relaxed, for example in [13], or [14] where it was found that some passengers in Zurich consult the timetables and do not arrive randomly, even for 5-minute headway services. An even spacing between vehicles then becomes the main priority, in order to distribute passengers evenly on the vehicles and avoid overloading that may lead to the accumulation of delays which in turn results in package building, or "bus bunching".

2.3 Importance of reliability in Public Transport

The characteristics of a public transport system (frequency, travel time, etc.) and the level of reliability of public transport services influence the mode choice of travellers. The value placed on reliability by these, relative to other service attributes, will determine the level to which their travel choices are influenced. Attitudinal surveys have shown reliability to be among the most important public transport service attributes for all travellers under certain conditions [8]. In this study, reliability was considered more important than average travel time and costs for both work and non-work trips. Moreover, unreliable services lead to higher operating costs for the operator, as well as decreased ridership by unsatisfied users.

Improvements in reliability have the potential to enhance the mobility of public transport users and induce car users to switch mode. Therefore, by reducing waiting time variability, total travel time variability and mean waiting time (sources of trip disutility, or unattractiveness), the attractiveness of public transport increases. Moreover, reliability influences departure time decision for the trips travellers intend to take. Often, these decisions are made with the objective of reaching the trip destination at a specific time. This is particularly relevant for work trips, where lateness is considered to have very high disutility values. When deciding on departure travel time, the traveller will seek to minimize his or her travel time related disutility. A trade off takes place between mean travel time components and travel time variability components. Because total travel time (and its variability) must be considered by each traveller when deciding to depart (by any mode), total travel time variability will directly influence the time of arrival at the destination. Variability in travel times just means that extra time must be planned for, as travellers have to leave earlier, adding a buffer to their planned travel time to account for possible delays, or, in other words, absorb the unreliability of their travel time. The additional time a traveller must add to his travel time can be considered as a cost for the person traveling. This extra time is at least as costly as regular travel time, and is more sensitive to schedule reliability than service frequency [13].

The discussion above shows how reliability influences travel behavior. However, reliability is not only an issue for the user, it is also of utmost important for the operators, who must devote part of their resources to dealing with the consequences of unreliability. The lack of reliable services can have a significant impact on the operator’s costs and may also affect system ridership and consequently revenue. An increase in reliability allows the operator to optimize the use of the resources. By reducing the amount of recovery time built into the schedules, the operators can increase the availability of drivers and vehicles. Reduction in vehicle breakdowns and schedule adherence allows the operator to reduce the number of spare vehicles and drivers kept on stand-by. Improving headway regularity will reduce the probability of bus bunching, lowering the mean passenger waiting times and improving the efficiency in vehicle capacity utilization.

By taking advantage of the increased availability of vehicles and drivers, an operator can translate the improved reliability into other kinds of benefits (either cost savings with the same service, or improvements in service with the same amount of resources). In summary, as pointed out by [12], public transport service reliability is “an important measure of service quality and directly affects both passenger demand and level of service”.

2.4 Service reliability measures

Users often perceive public transport service reliability as merely its punctuality. However, service measures are the set of aggregate metrics used to characterize overall bus service, measure performance and evaluate service delivery [15]. Service measures are required to compare planned (promised) and actual (delivered) level of service, and are an essential part in characterizing service reliability. They are basically summaries of individual trip outputs (at the route or stop level, for a specified period of time), such as calculated running time, schedule deviation, dwell time, headway deviation and passenger loads. Operators make use of them to assess the delivered service and establish both the level of actual level of reliability and its variation (improvement or not) over time.

The previously mentioned importance of public transport reliability to both users and operators, justifies the need to identify and develop eloquent measures of reliability in public transport that describe the variability in service and reflect its impacts on both users and operators. As mentioned in [8], such measures would help transportation planners and the public transport industry to:

- Identify and understand reliability problems
- Identify and measure improvements
- Relate improvements to strategies
- Modify strategies, methods and design to achieve greater reliability improvements

Early studies of on-time performance were generally concerned with either the shape of the probability distribution of observed versus scheduled arrival times, or with evaluating service reliability, namely: running times, run time variation and headway variability. In [16], these are reviewed, and an attempt is made to bridge the two approaches.

Furthermore, as reviewed and summarized by [17], contemporary methods to analyze performance in the public transport industry are classified in two types:

- Parametric (such as stochastic frontiers and econometric models), and
- Non-parametric (like Data Envelopment Analysis and analysis through indicators)

This work seeks to assess public transport service reliability by performing route and stop-level analysis of running times, schedule deviations and headway regularity, as well as estimating measures of their variation.

In general high frequency services are considered to offer headways equal to, or below 10 minutes. In Zurich, all services are scheduled regardless of their frequency, for this reason both schedule adherence and regularity analysis are done to evaluate performance in the line.

As mentioned by [12], bus performance should be measured at intermediate locations along the line and not only at terminal stations. In this work, bus performance is measured at the route level for running times, and at the route and stop level for schedule deviations and headways regularity. Additionally, an on-time performance indicator, defined as the percentage of trips departing punctually is calculated at the stop level. Punctuality is defined as a bus leaving no more than 30 seconds before, or 60 seconds after the scheduled departure time. Table 1 below, summarizes the measures used in this study to describe reliability quantitatively.

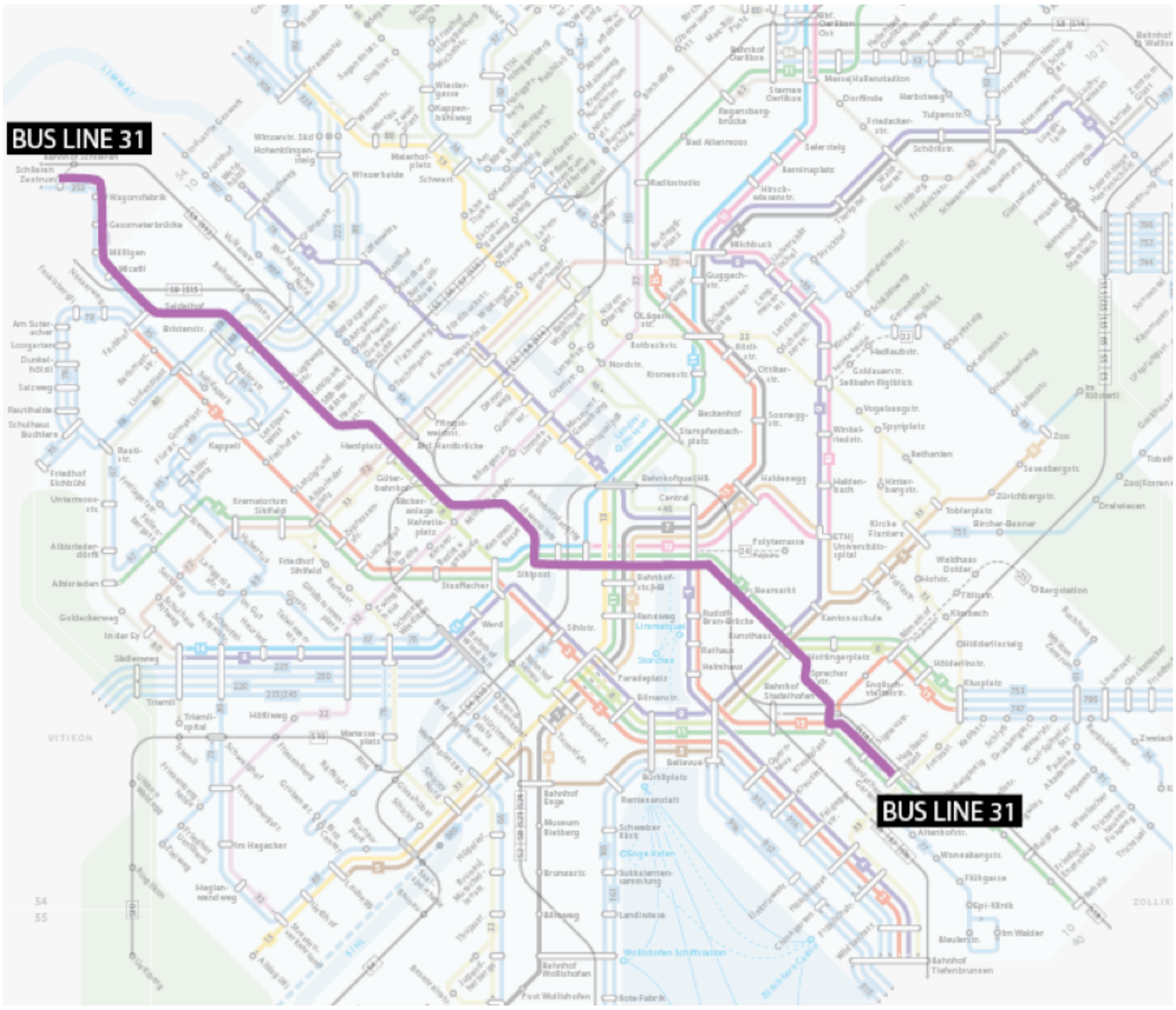
Table 1 Summary of performance measures and indicators included in this study

Travel time	Speed	Punctuality	Regularity
Mean distribution for all trips	Mean distribution for all trips	Schedule deviation frequency distribution at route level	Actual headway frequency distribution at route and stop level
Percentiles 5 and 95	Percentiles 5 and 95	Mean schedule deviation at stop level	Mean actual headway at stop level
		On-time performance (% of departures on time)	Coefficient of variation (CV) of actual headways at stop level
		Std. dev, from scheduled departures at stop level	
		Coefficient of variation of schedule deviation at stop level	

3. Case study

This section describes bus Line 31 in Zurich, which is used as a case study to assess the reliability metrics mentioned previously. Bus Line 31 runs from Schlieren station (SZEN) at the west of Zurich to Hegibachplatz (HEGI) in the south east of Zurich city (Figure 1). It connects with important stations along its way, such as the end stop of tram 2, Farbhof (FARB), the busy train station Altstetten (BALT), a large shopping mall, Letzipark (LETP), the densely populated area around Kanonengasse (KANO), Zurich main train station (BPLA), and the busy tram node, Central (CENT).

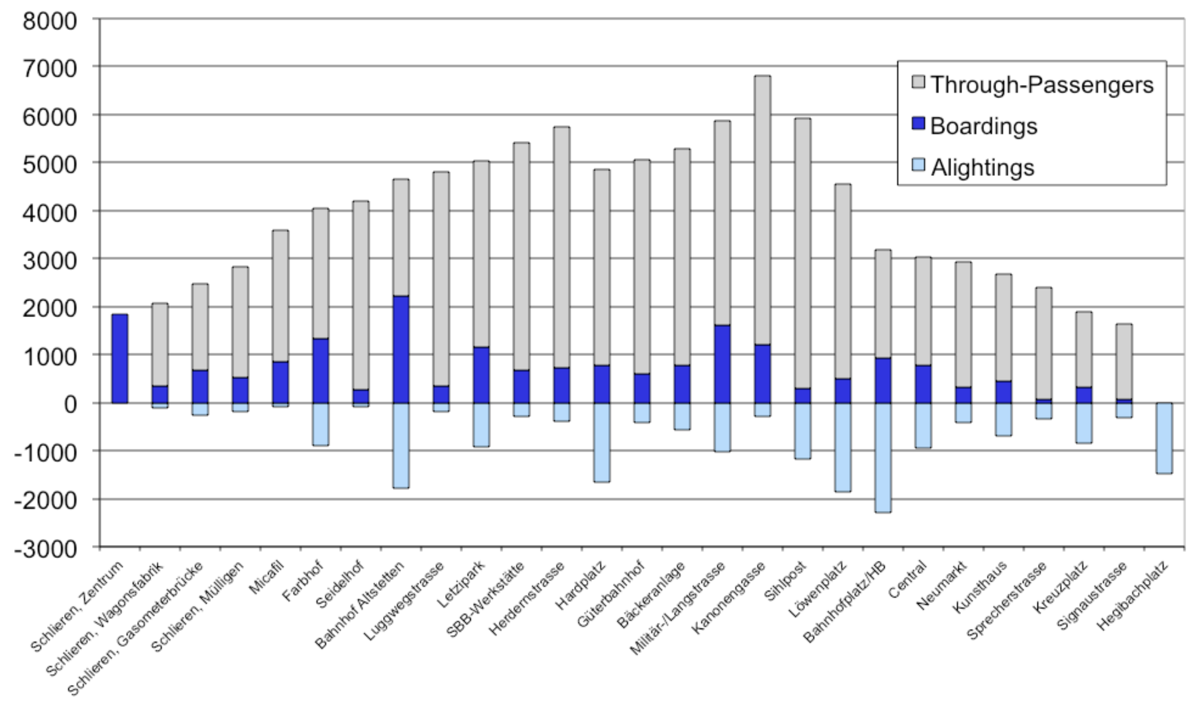
Figure 1 Topological map of Zurich's public transport network. Bus Line 31 highlighted



Source: www.zvv.ch

Line 31 is 10.9 Km long, with an average distance between stops of 415 m. It provides service every day of the week, from 5:12 to 1:00, with a frequency of 8 vehicles per hour on a 7.5-minute headway all day long until about 20:00. Service during the weekend is somewhat less frequent. Line 31 serves 27 stops, and transports around 20'000 passengers every working day[1] (see Figure 2). Since 2008, service is provided with double articulated, 25-m electric (trolley-buses), 100% low-floor, air-conditioned vehicles, with 60 seats, 5 doors and a technical capacity of 202 passengers (4 persons /m2). These vehicles were introduced due to capacity problems with single-articulated vehicles that were reaching their service life. A study was undertaken in which current and expected passenger growth trends were evaluated in two scenarios: higher vehicle frequency or higher-capacity vehicles. The results clearly favored the introduction of larger vehicles, which are more cost-effective and provide a higher level of service. Most passenger activity can be recognized to take place in the stations Farbhof, Altstetten, Letzipark, Militär-/Langstrasse and Zurich main train station (Bahnhofplatz/HB). See Figure below.

Figure 2 Average daily passenger demand distribution (Monday to Thursday) in 2009



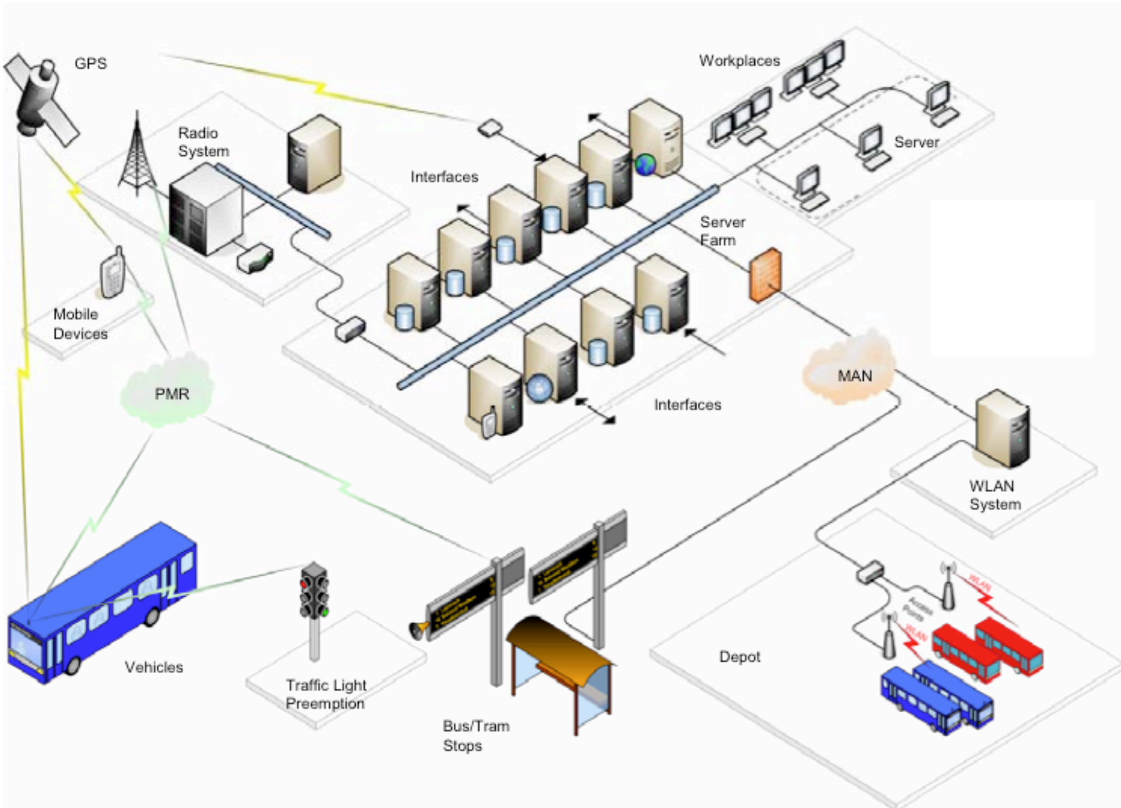
Source: Verkehrsbetriebe Zürich (VBZ)

Zurich has been a pioneer in vehicle detection technology and traffic control management since its citizens voted against the construction of an underground subway in the early 70's, and a large amount of resources was invested in improving the quality of the surface public transport. For a comprehensive review from the planning and technical perspective, see [18]

[1] 2009 figure.

and [19]. Since around 2006, a new Automatic Vehicle Location (AVL) system has been deployed (see Figure 3), involving all the operators providing services in the greater Zurich region and regulated by the transport authority, the Zürcher Verkehrsverbund (ZVV). The project involved not only real-time location and communication technology linked to a modern control centre, but also high-quality information for the passengers and the subsequent collection of large amounts of operational data that can be used for off-line analysis and planning.

Figure 3 Schematic AVL system architecture in Zurich



Source: Trapeze ITS

For this work, the AVL data kindly provided by the VBZ corresponds to stop-level data for all recorded trips along Line 31 in working days (Monday to Friday) of February 2011. Only the direction Schlieren Zentrum (SZEN) - Hegibachplatz (HEGI) is considered in the analysis (East bound). Four day time profiles are established: (1) AM Peak (7:30-8:00), (2) between peaks (9:30-11:00), (3) PM peak (16:30-18:00), and (4) late evening (21:00-22:30).

4. Data preparation and exploration

In this study, several sources of data were available. First, a set of observations was made during the AM and PM rush hour of two working days on a week in March 2010. During this time period, 50% of the vehicle trips were captured. The main objective was to register events at, and between stops. Events captured at stops were: observed schedule deviation (from the driver display), arrival and departure time, and the frequency of events that may contribute to delay during dwell time (passengers with luggage, baby buggies or bicycles). Events between two stops were the second objective of this observation, in which the observers recorded the frequency of events they perceived to have contributed to any delay (construction sites, congestion, pedestrian crossings and traffic lights at intersections). Additionally a subjective measure of passenger load was recorded (1 to 3). This sample data is not statistically representative.

The second source of data was a set of spread sheets containing aggregate information and basic statistical measures on schedule deviation (at stops and every 25 meters), vehicle speed records between stops (every 25 meters), and aggregate vehicle travel time for all working days (Monday to Friday) in March 2011.

Finally, original AVL records were made available by the VBZ in the form of a relational database containing detailed stop-level operational data for Line 31 in February 2011. The most relevant variables included in the database are summarized below:

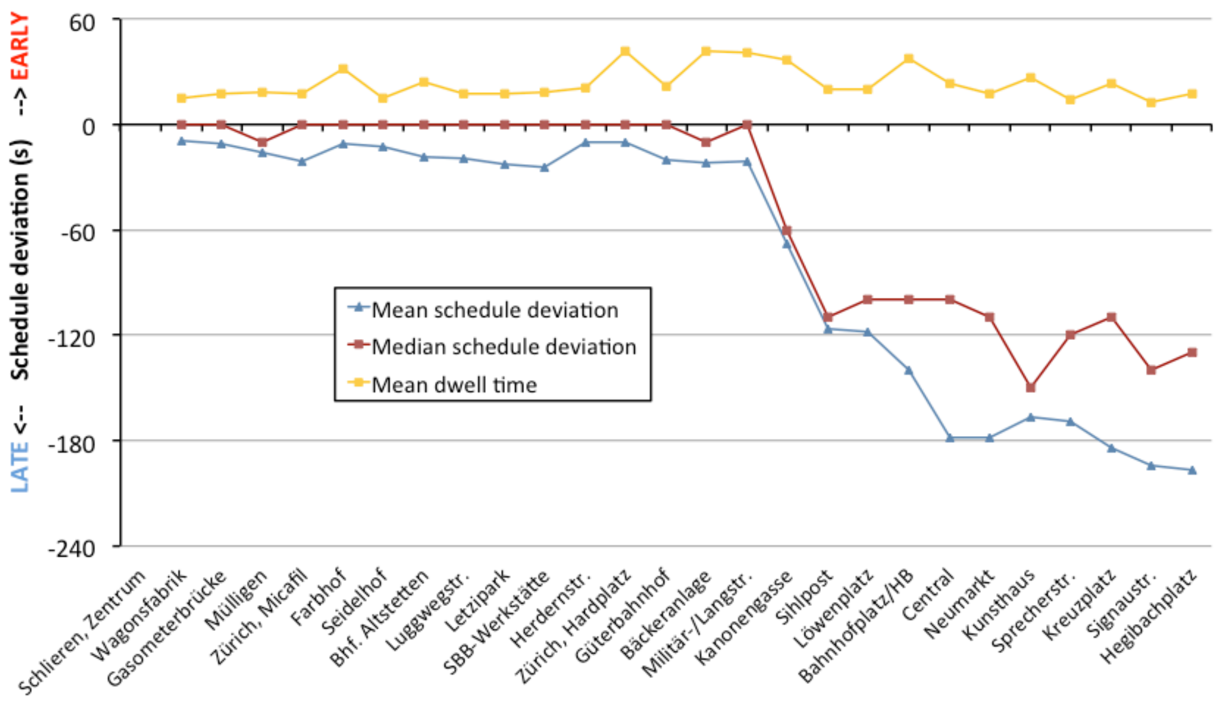
Table 2 Main variables of interest included in the relational data base (SQL)

Variable	Description	Variable	Description
[Id]	Primary record key	[Stop_Seq_No]	Sequence of stop in pattern
[Date]	Calendar day of planned arrival	[Service_Date]	Operational day of scheduled trip
[Block_Id]	Block identifier	[Planned_Arrival]	Planned at stop in seconds after midnight
[Trip_Id]	Trip identifier	[Planned_Departure]	Planned at stop in seconds after midnight
[Route_Id]	Route identifier (e.g. 31)	[Actual_Arrival]	Measured at stop in seconds after midnight
[Pattern_Id]	Sequence of stops for a trip	[Actual_Departure]	Measured at stop in seconds after midnight
[Direction]	Direction of trip (1 or 2)	[Day_Type_Id]	Day type identifier
[Stop_Id]	Stop identifier	[Month_Part]	Calendar Month
		[Year_Part]	Calendar year

No passenger counts or driver information were available for this study.

Even though the first data set does not allow the calculation of any statistical measures due to its subjective nature and small sample size, it nevertheless provides a first picture of events taking place along Line 31. It must be mentioned that at the time the observations were made, road construction was taking place between Militär-/Langstrasse & Kanonengasse, which is clearly visible in Figure 4 below.

Figure 4 Schedule deviation at stops and dwell time for all observations

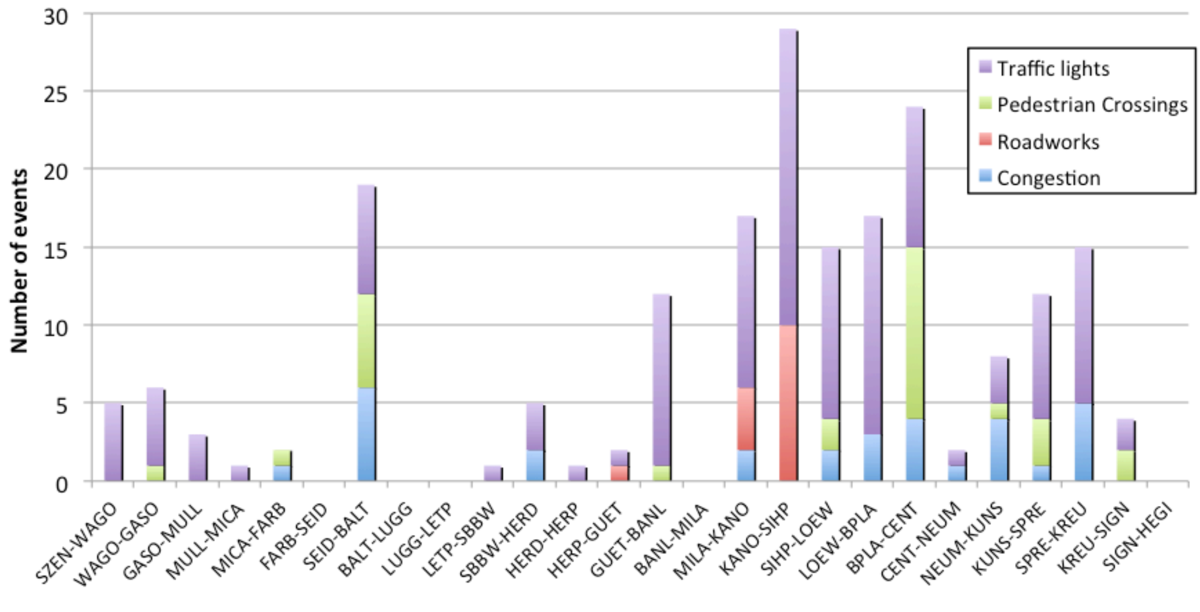


For the observed sample at the stop level, mean schedule adherence is remarkably good (below 30 seconds) until the point where road construction begins. At this point, a systematic delay can be observed, leading to up to 2 minutes of delay that is not recovered in the rest of the run. Dwell time peaks are observed at Farbhof, Hardplatz, and at the main train station.

Between stops, all events that subjectively contributed to delay along the line were aggregated in Figure 5. The influence of congestion and pedestrian crossings can be clearly seen as vehicles approach Altstetten train station, even though this does not show in the schedule deviation. It is assumed that the systematic delay is absorbed by buffer time in the schedule.

Construction works are also clearly visible in the section mentioned before, as well as delays due to pedestrian crossings arriving to Central. Surprisingly, even though line 31 is allocated with priority at all traffic lights, these were perceived to be a consistent source of delay more or less along the entire line, specially closer to the city centre.

Figure 5 Perceived delay causing events between stops. All observations.



This section has provided an overview of the available data for this study, and a first impression of performance using a small sample of subjective observations.

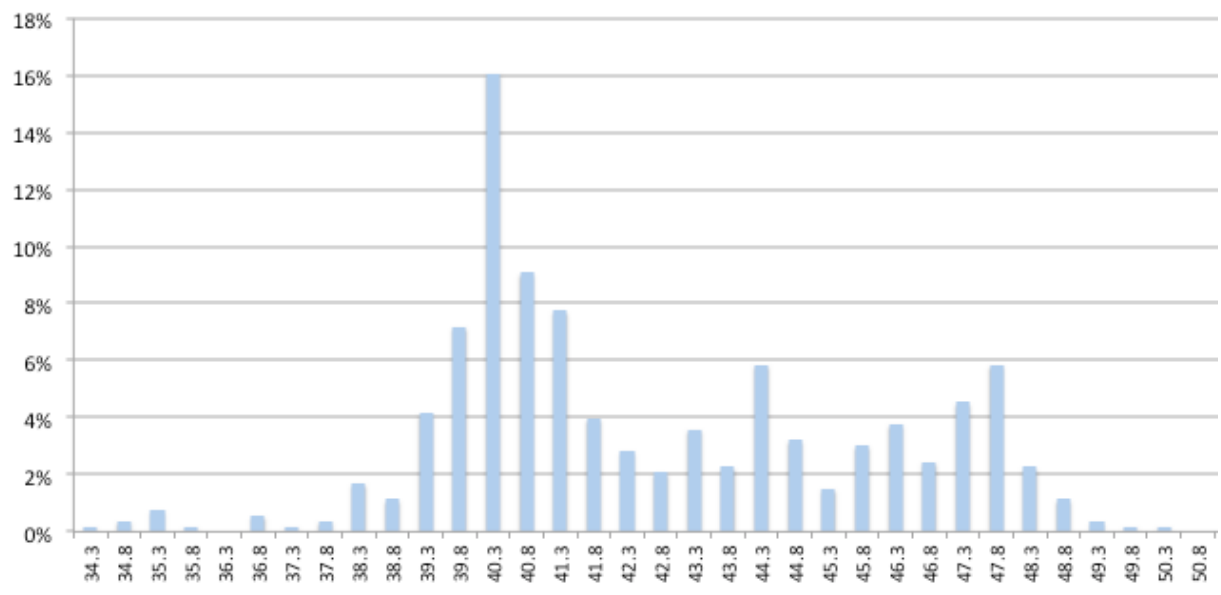
5. Reliability analysis

The second (aggregate spreadsheets) and third (AVL) sources of data provided the opportunity to evaluate performance in detail using the entire sample of trips in working days of March 2011 for the first set and February of 2011 for the second. Although the two data sets do not correspond to the same period of time, they still provide an insight into the behaviour of Line 31.

5.1 Travel time and speed

All-day aggregate data from the spreadsheets was used to analyse travel time reliability and vehicle speed along the line. The figure below shows the frequency distribution of the travel times for all working days of March 2011. Three peaks can be observed, around 40, 44, and 47 minutes. The shape of the distribution reflects the different travel time experienced by different time of day.

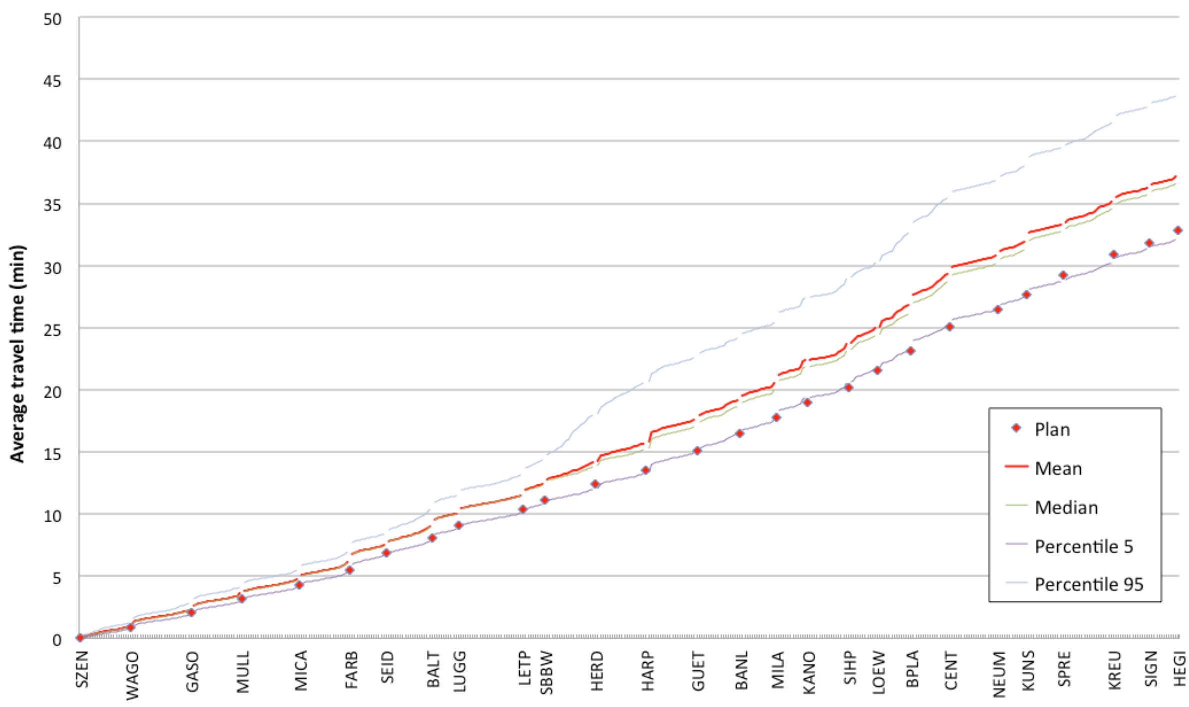
Figure 6 Total travel time distribution for all trips (Mo-Fr) in March 2011



Source: VBZ aggregate data set N = 529

Trip time deviation can be observed in Figure 7, where the 5th and 95th percentile of the sample start to spread from the mean around Altstetten (BALT), incrementing at Herdernstrasse (HERD) and remaining mostly stable for the rest of the run. Records are aggregated for all runs every 25 meters from the departing station. The dots at the bottom represent expected travel time, which is assumed to be the planned travel time for the fastest time of day. Again, because the graph includes all day runs, the average is above the planned travel time depicted.

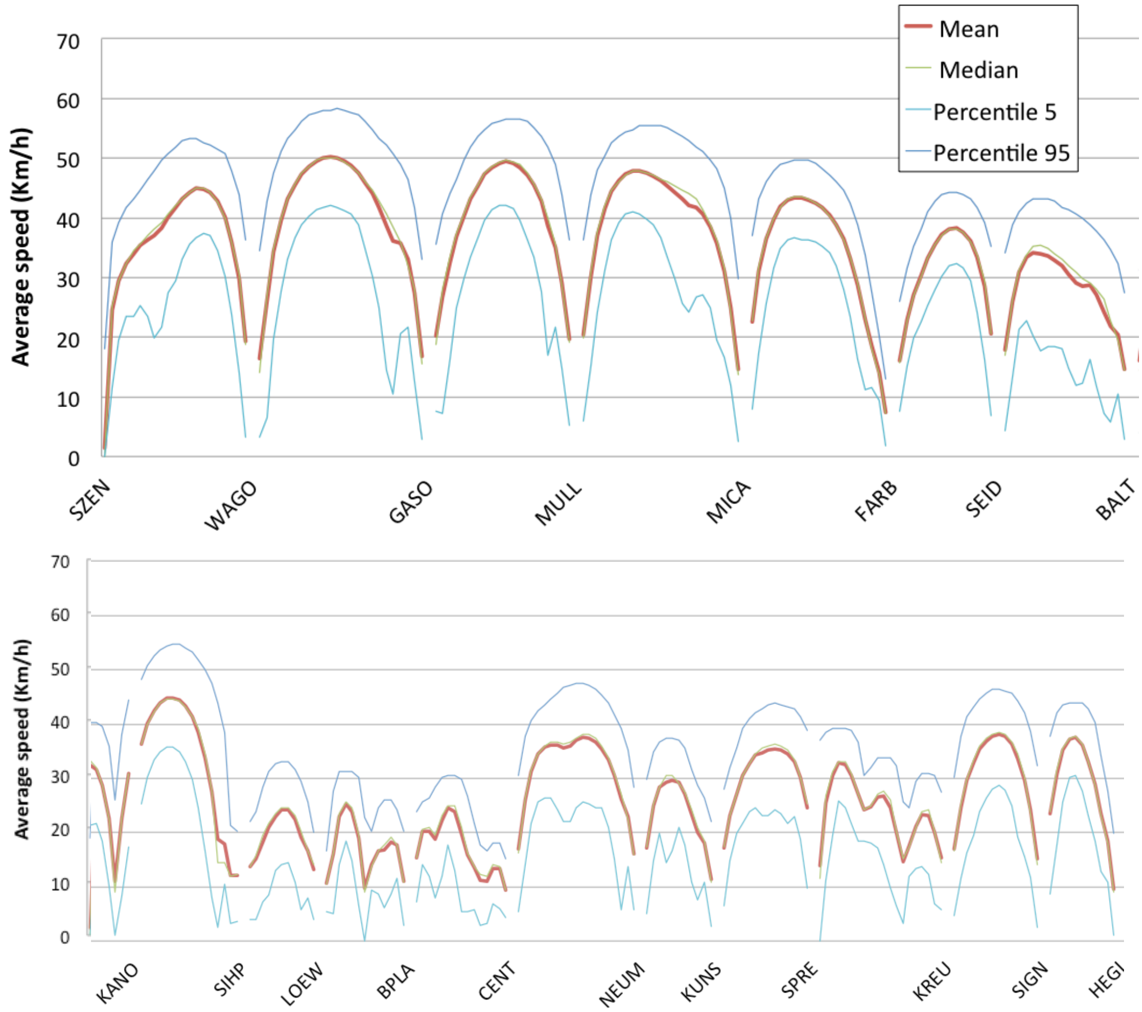
Figure 7 Average travel time distribution for all trips (Mo-Fr) in March 2011.



Similar records were available for vehicle speed along the line, with aggregate mean, median and percentile values every 25 meters starting at the departing point (distance = 0). Figure 8 shows the mean (darker line), median, as well as the 5^{th} and 95^{th} percentile of speed along the lines for all trips in March 2011. Only the first and last sections of the line are included, or 19 out of 27 stations. The graph clearly shows relatively smooth runs at average speeds between 45 and 50 Km/h from the start of the run until about Farbhof (FARB). This station is the terminal of tram Line 2. After this point peak average speed between stops only exceeds 40 Km/h between Luggwegstrasse and Letzipark (not shown), and between Kanonengasse (KANO) and Sihlpost (SIHP), in the lower section of the graph. From SIHP until Central (CENT) Line 31 shares the road with tram Lines 3 and 14. Just before the stop at Zurich main train station the vehicle merges into mixed traffic until CENT, where a roundabout and a set of pedestrian crossings require careful manoeuvring before the vehicle reaches the stop.

Between CENT and Kunsthaus (NEUM) Line 31 shares an exclusive lane with tram Line 3, which is reflected on average vehicle speed. Between Sprecherstrasse (SPRE) and Kreutzplatz (KREU) a set of traffic lights clearly have an impact on the average speed.

Figure 8 Average speed distribution for all trips (first and last section of Line 31).



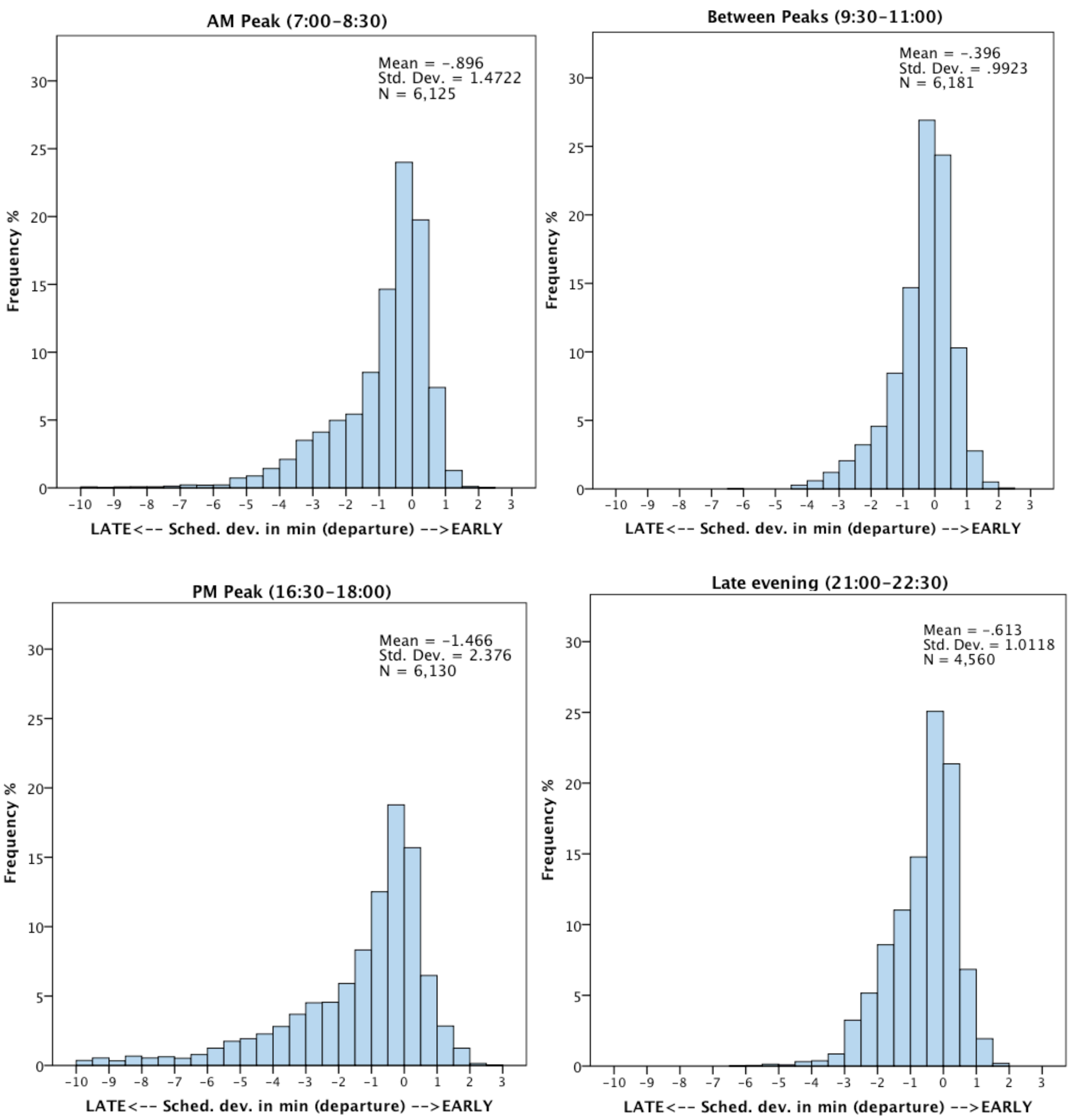
The previous analysis provides a clear picture of where the buses have a harder time getting from one stop to the next. The slowest average section is between SIHP and CENT, a section where a total of 8 bus and tram lines converge, significant vehicle traffic is present, and large amounts of pedestrians coming from and to the main train station are constantly crossing the street. Peak average vehicle speed is about 25 Km/h along this section. Another clear example is between SPRE and KREU, where two traffic lights and 90-degree turns systematically slow down the vehicles.

5.2 Punctuality

For the following analysis, the stop-level AVL data was used. A general filter was set to select only complete trips on one direction (from SZEN to HEGI) taking place on working days (Monday to Friday). Additionally, missing values were filtered out. A total of 59’616 records were left from the filtering process.

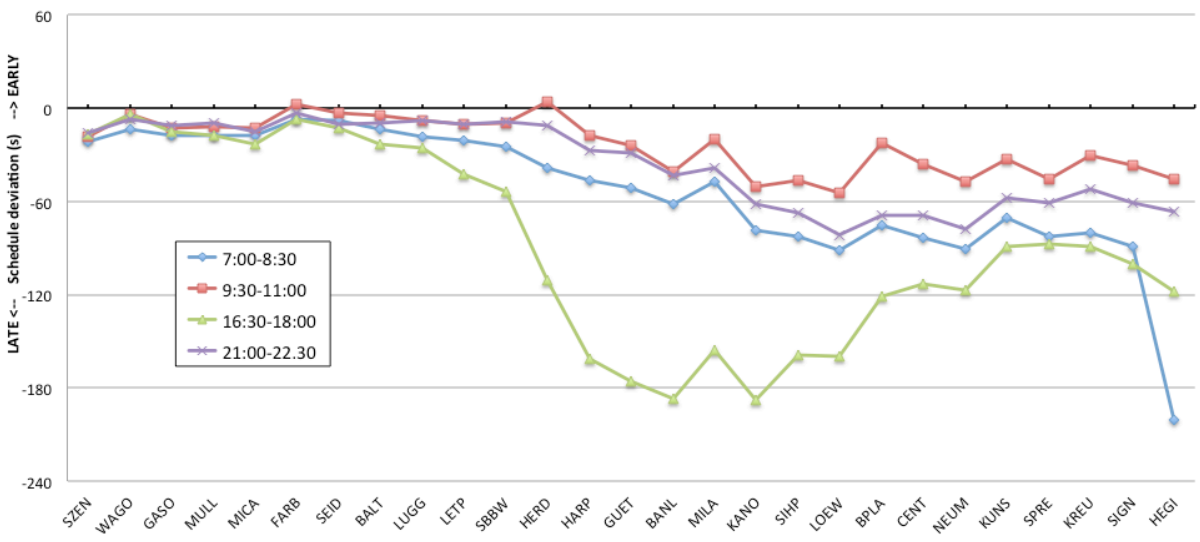
Because performance varies with time of day, a total of four time profiles were selected to assess route and stop level reliability metrics for schedule adherence and headway regularity. These are: the morning peak (7:00-8:30); in between peaks (9:30-11:00); afternoon peak (16:30-18:00); and late evening (21:00-22:30). Figure 9 below includes the route-level schedule deviation frequency distribution for all time profiles, using the same vertical and horizontal axis scales. The bars are 30-second wide and a clear difference can be observed between peaks and other periods, with a skewed distribution to the left (late departures). The most compact distribution is for the period between peaks (Std. Dev. = 0.9923 min), the highest distribution is observed for the PM peak (Std. Dev. = 2.376 min).

Figure 9 Schedule deviation distribution by time of day at route level (Mo-Fr, Feb 2011)



At the stop level, the mean schedule deviation is depicted in the Figure below for each time profile. A systematic recovery is observed for all time profiles between the stops Micafil (MICA) and Farbhof (FARB). Courses remain largely on time until Altstetten (BALT) for the morning period, with another systematic schedule recovery until the following stop. From that point on until the end of the line, the buses remain approximately with the same schedule deviation. An exception is the PM peak period, where vehicles deviate (in average) up to 3 minutes from the schedule, but recover (most likely by large buffers in the schedule) until being (in average) below 2 minutes late by the end of the line. Surprisingly, the services in the in between peaks are (in average) punctual along the entire line, with higher average schedule adherence than the late night services

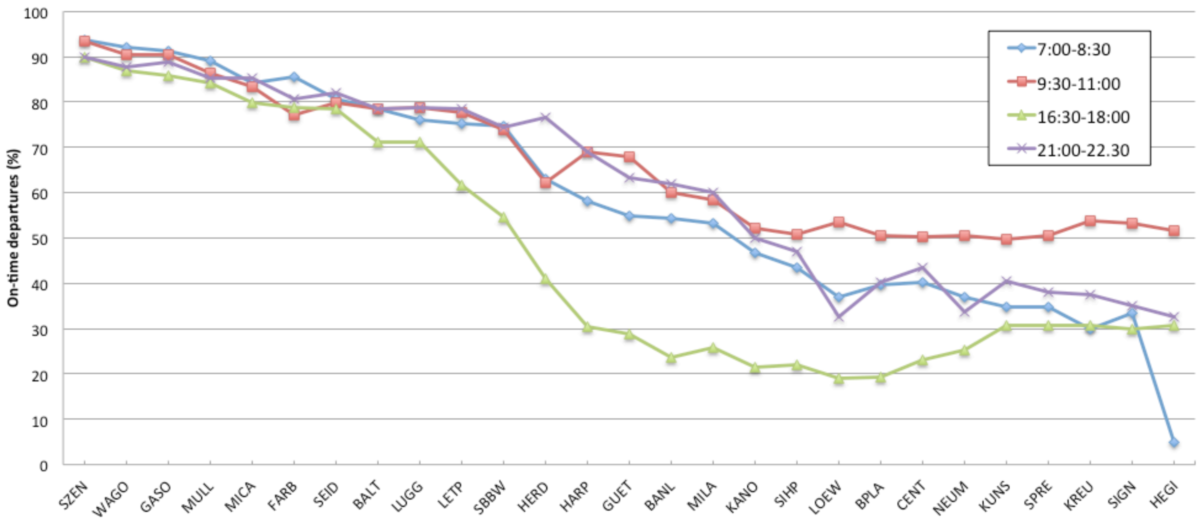
Figure 10 Mean schedule deviation per time of day at stop level. (Mo-Fr in Feb 2011)



Additional to the average schedule deviation, the on-time performance (OTP) index defined in Table 1 was estimated at the stop level. It corresponds to the percentage of departures taking place “on-time” according to the VBZ punctuality standards (between 30 seconds before, and 60 seconds after the scheduled departure from the stop).

Figure 11 summarizes the results for the OTP indicator for all time profiles at the stop level. Consistent with the previous Figure, the PM peak performs the worst, with a sharp decline after Luggwegstrasse (LUGG) down from over 70% of on-time departures, to just below 20% by the time vehicles reach Loewenstrasse (LOEW). Services during other times of day are quite similar, with the AM peak slightly underperforming the non-peak periods, and the in between peaks remaining above 50% OTP along the entire line. Sharp peaks are observed for the last section of the line during the late night services, which might be explained by a less strict schedule adherence behaviour from the drivers, possibly waiting for passengers at stops, at a time where services are less frequent.

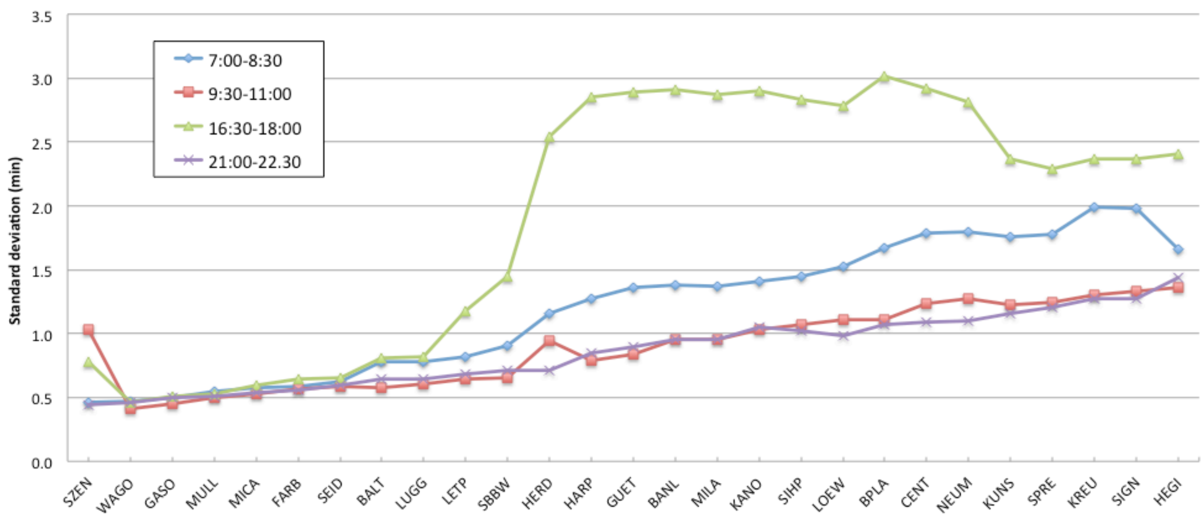
Figure 11 On-time performance per time of day at stop level (30 s early – 1 min late)



The distribution of the observations can be seen in the Figure below. It is consistent with Figure 9, where off-peak time periods display less variation. The AM peak deviation slightly underperforms the in-between periods, however the PM peak deviation surges after the stop SBBW to almost 3 minutes, and remains fairly constant, slightly declining after Central (CENT), where buses share an exclusive lane with tram Line 3.

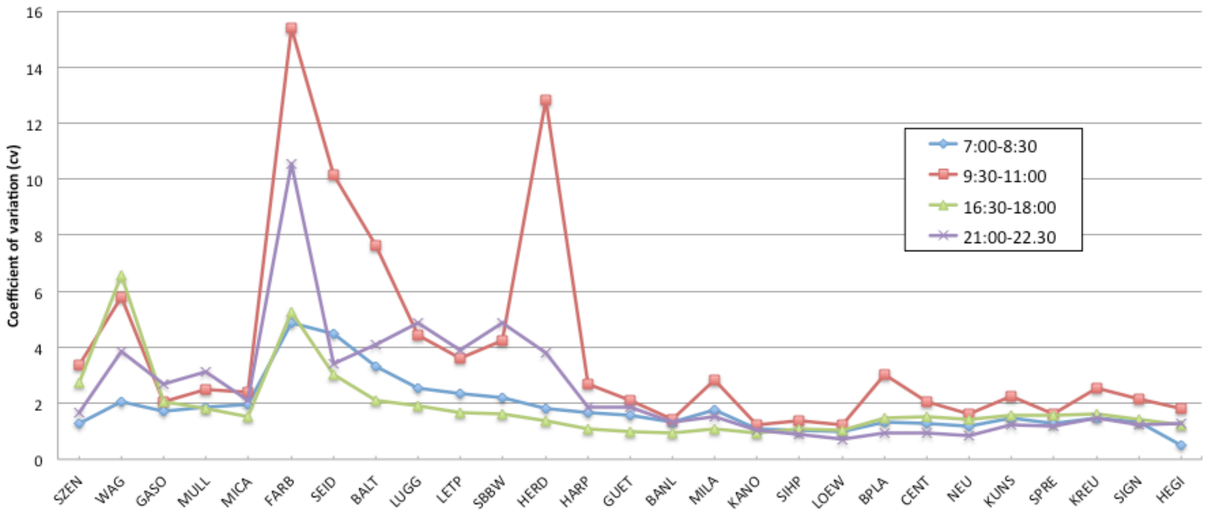
Deviations for the off-line periods increase slowly but constantly, remaining below 90 seconds by the end of the line.

Figure 12 Standard deviation from scheduled departure times per time of day at stop level



A final graph depicts the coefficient of variation (CV) for mean schedule adherence at the stop level for all time profiles. The CV is a useful measure because it normalizes the effect of standard deviation relative to the mean. Large peaks are observed for services in between peaks, which might reflect a driver relay, as most likely during this time the morning shift ends for the drivers. A similar peak is observed for the late night services at the same location.

Figure 13 Coefficient of variation of mean sched. deviation per time of day at stop level



In this section, punctuality of Line 31 was described quantitatively using schedule deviation metrics at the route and stop level, as well as an OTP indicator at the stop level. As expected, services outside of the peak time periods exhibit better punctuality metrics and less deviation from the mean that services during peak-periods. Services during the PM peak greatly underperform when compared to those during the AM peak, especially in the mid-section of the line, after which punctuality improves.

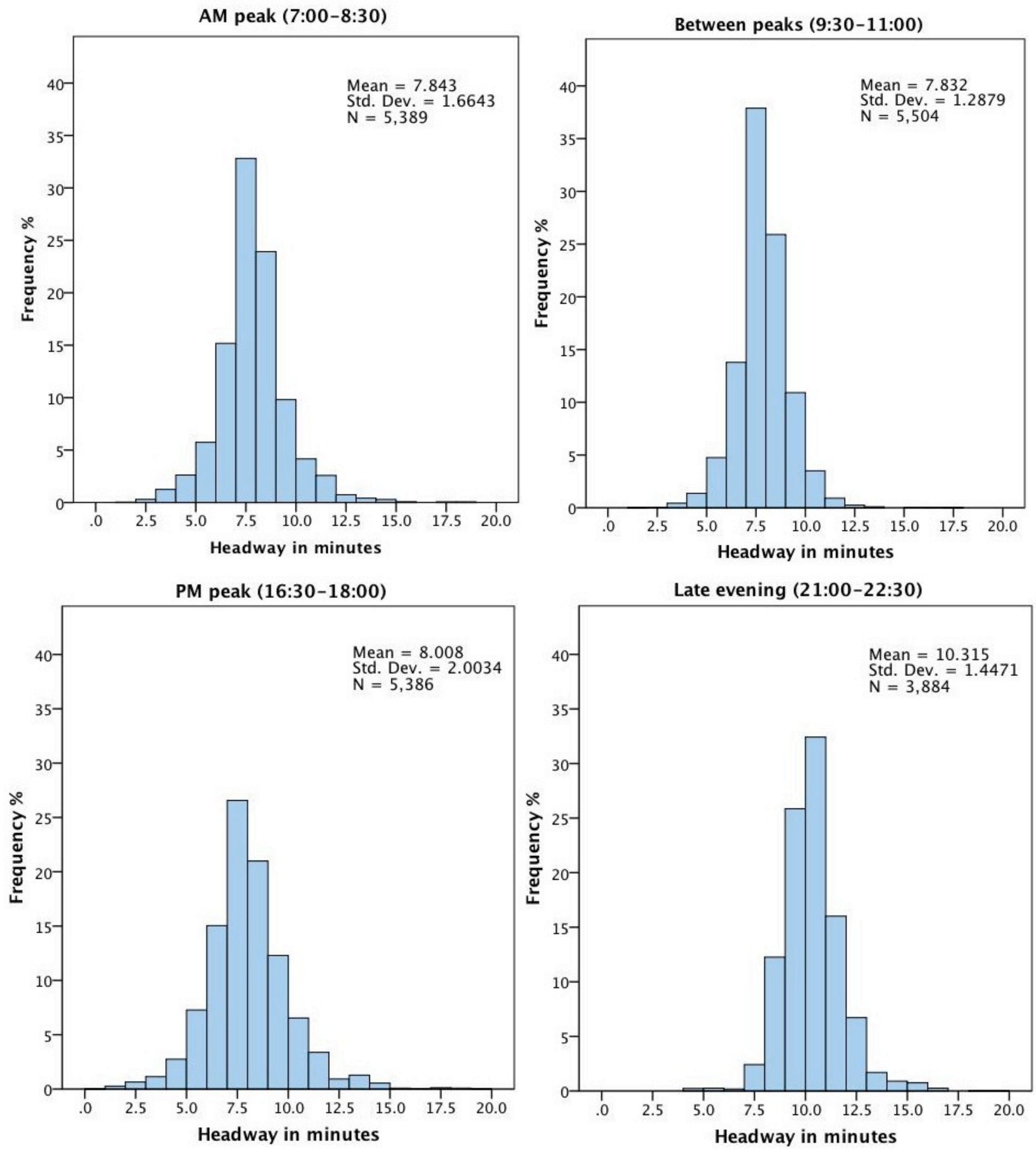
5.3 Headway regularity

Using the actual departure time stamps for the sequence of trips [Actual_Departure], headways were calculated at the route and stop level for all time profiles. Headway deviation was also included, knowing that all services run with a planned 7.5-minute headway, except for the late night services, which operates with a planned 10-minute headway.

Figure 14 summarizes the results for the actual headway frequency distribution at the route level for all time profiles in the working days of February 2011, using the same vertical and horizontal scale in each graph.

The two off peak-time profiles exhibit more compliance to the planned headway, however the in-between peak period displays a lower deviation from the mean (Std. Dev. = 1.2879 min) than the late evening period (Std. Dev. = 1.4471 min). As expected, the PM period shows the largest variability (Std. Dev. = 2.0034 min) and highest mean headway (8.008 min) of all time periods.

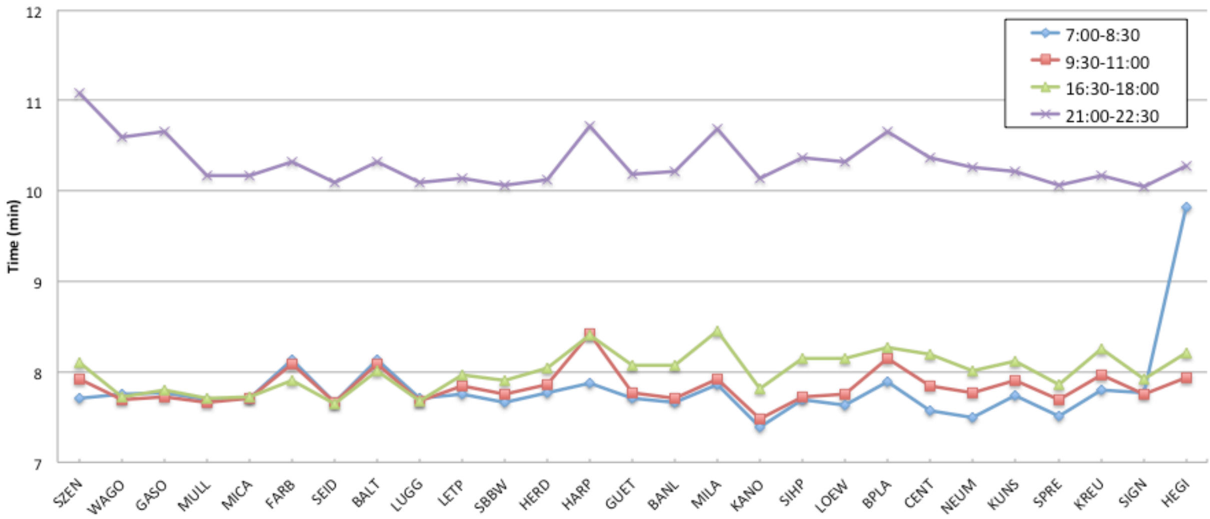
Figure 14 Actual headway distribution by time of day at route level (Mo-Fr in Feb 2011)



A stop level representation of the actual headways per time profile can be found in Figure 15. Three points along the line stand out, where increases in headway can be observed at all times of day. These points are Hardplatz (HARP), Militär-/Langstrasse (MILA), and the stop at

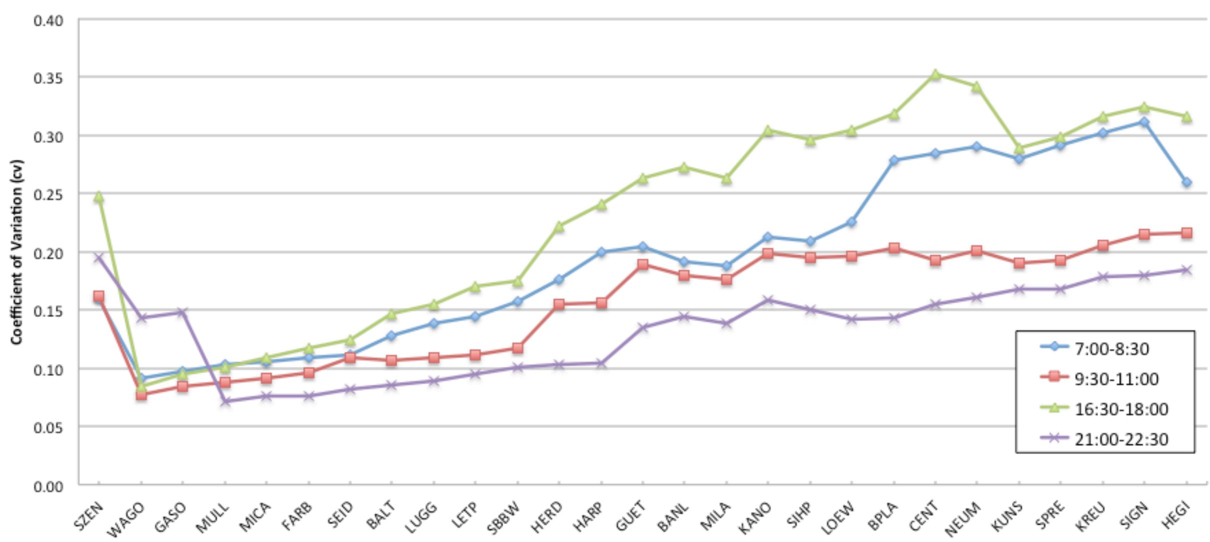
Zurich main station (BPLA). Mean headways remain fairly constant for all 7.5-minute headways services, but an increase can be observed after HARP for the PM peak period.

Figure 15 Mean actual headways per time of day at stop level



Similar to the schedule adherence, the CV was calculated for the mean headway at the stop level for each time profile and displayed in the Figure below. In this graph, it can clearly be seen that the late evening time profile exhibits the lowest variation. The PM peak period services are the most variable in terms of headway regularity. Interesting is the decrease in the CV for the PM peak along the exclusive tram/bus late between CENT and KUNS.

Figure 16 Coefficient of variation of actual headways per time of day at stop level



6. Conclusions

Public transport agencies are increasingly realizing the benefits of collecting and analyzing operational data recorded by AVL systems, and using it to increase the quality of their service. This work represents a first attempt at quantifying public transport service reliability in Zurich. Using the available data, combined with a small set of observations, some measures of reliability and their variability were calculated. Data for vehicle travel time and speed along the line was available on a whole day basis, while punctuality (measured as deviation from the schedule) and regularity (measured as headway variation) were more deeply analyzed thanks to the availability of detailed AVL records. The average speed distribution along the line clearly shows considerable speed reductions as the vehicles travel along the city centre, between Sihlpost (SIHP) and Central (CENT), where additional to car traffic, a number ofpublic transport lines converge, and many pedestrians cross the street between Zurich main train station and the busy Bahnhofstrasse..

The detailed AVL records allowed punctuality and regularity to be analyzed at a more detailed level. Four time profiles (2 peaks and 2 non-peaks) were defined and compared throughout the study. As expected, the PM peak time profile describes the highest mean deviation from schedule, as well as the highest variation, ad the lowest on-time performance. The most critical section appears to be between Altstetten train station (BALT) and the tram node Central (CENT), after which the vehicles consistently recover time and reduce delay. Contrary to expectations, the best performing profile was that between peak hours, and not during the late evening. In average it departs from stops around 24 seconds “late”, with a standard deviation of less than a minute. It is assumed that traffic congestion and passenger activity is lower than during the peaks, but not lower than during late night services. One explanation may be that for the operator it is more important to be on time at 10:00, during conventional productive working hours, than at 22:00, when services are less frequent and most passengers are likely to be returning home from a previous activity.

Headway averages for the different time profiles depict a similar picture, with the services between peaks outperforming the rest in term of deviation from the mean (Std. Dev= 17.3 s), but the late night services showing the best measure for mean headway, only 18.9 s above the scheduled headway. Systematic increases in average headway were observed in a number of stations along the line, particularly at Farbhof, Altstetten, Hardplatz and Militar-/Langstrasse. A large number of passenger transfers take place at these stations.

It has been shown that a rich depiction of reliability can be achieved using AVL data. Direct causes of unreliability along the line could not be specifically pointed out, but a much clearer picture was drawn and it remains a task to relate the events taking place to the detailed operational records captured by the system.

7. Limitations and future research

A number of limitations can be pointed out in this study. First, the three different data sources do not correspond to the same period of time. However, this work is a first approach to understanding the AVL data structure from the VBZ and attempting to extract valuable information. Future work will make use of the AVL data to a larger extent.

Second, available data was limited, as no passenger or driver (level of experience) data was made available. These additional data could enrich the analysis and give the opportunity to make regressions in order to observe the impact of such variables on different measures of reliability. It remains future work to obtain and integrate such information.

A third limitation is the selection of adequate indicators and measures that fit to the Zurich context, but are transferable and comparable to those in other places. These should include the view of both the operator and the passenger, and provide important, useful, and clear information that can aid in improving the quality of service. Examples of these indicators are those related with passenger arrival and waiting times, congestion, system crisis, etc.

An additional limitation is the focus of the study, which is limited to only one direction of one bus line in Zurich. It would be interesting to extend the analysis to more lines, including tram lines, and evaluate the effect of different route characteristics on travel time and service reliability. Route and network level reliability metrics would be of interest as well. Moreover, a comparison within and between the different levels of the public transport hierarchy in Zurich would be of interest for strategic and tactical planning of the service.

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