


# Monitoring a road system's level of service

## The Canton Zurich floating car study 2003

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## **Monitoring a road system's level of service: The Canton Zurich floating car study 2003**

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### **Abstract**

This paper presents the results of the first large-scale assessment of the service quality of the road network of the Canton Zurich. Three GPS-equipped floating cars were deployed for three weeks on a set of three randomly selected, representative measurement circuits of circa 500 km length. Vehicle coordinates were logged each second for over 2.5 million data records. The experimental approach, data gathering, data reduction, map matching, and speed results are described. A newly developed map matching algorithm is outlined, as particular difficulties with the available GIS network models made the application of commercial software impossible. The results are summarized categorically by type of road, time period and road owner. In addition to the calculation of the standard deviation, an assessment of the measurement error was performed to provide a complete measure of the variability. The main substantive results are the high speeds and large speed variances on the motorways, in contrast to the lower speeds and higher reliability of the minor road network.

### **Keywords**

Floating car, GPS, level of service, road system, speed, Canton Zurich, map matching

### **Preferred citation style**

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# 1 Framework and measurement strategy

Canton Zurich is the most populous of 26 administrative areas in Switzerland. It has an estimated 1.23 million residents (2001) with the main city Zurich (pop. 341,000) near its physical center and suburban development northward to another urban center, Winterthur. It occupies 172,875 hectares of hilly terrain and is divided by a large lake. The Amt für Verkehr (Transport Agency) of the Canton Zurich has the responsibility to regulate, plan and monitor the quality of the transportation systems of the Canton. As part of this work, measurements of the speed of traffic on the roads of the Canton were made on behalf of the Amt by the Institute for Transportation Planning and Transportation Systems (IVT). This study is the counterpart to earlier work on the quality of service of the public transport system. The measurement of traffic speeds has a long tradition for many highway administrations, for example London (TfL, 1999, DfT, 1997) or in Germany for motorways only (Heidemann and Hotop, 1990). This is the first known study in the German speaking area which includes all types of roads during a representative time period.

The measurements were made by IVT according to the floating car principle on three randomly chosen road circuits covering the territory of the Canton. A driver of the floating car adapts to the speed of traffic by ensuring that he is overtaken by as many cars as he overtakes himself. This driving technique corresponds to the average speed of the flow (Leutzbach, 1988). Each circuit of roughly 500km begins and ends at the same point and is composed of 50 linked road segments between randomly chosen traffic planning zones within the Canton: the segment from zone A to zone B is followed by a segment from zone B to zone C. The zones and their sequence were drawn using a Monte Carlo technique, in which the probability of choosing a zone is proportional to the traffic volume on that OD relation in the workday average demand matrix of the Canton. The route of the driven segments between each pair of zones is the shortest-time path according to a high-resolution network model.

The measurements began at 6:00am and ended at 9:00pm, and resumed at the point in the circuit where measurement had stopped the evening before. The measurements were taken during a period of three weeks except on Sundays. The sample size (number of desired measurements of the circuits) had been established using prior information on speed variability from a national travel diary survey. The location and speed of the vehicle was recorded every second with a GPS logger. The trips driven to and from the measurement

circuit, or to bring the vehicle to a point at which the drivers could change shifts, were also recorded. The drivers were primarily students recruited from the engineering departments.

In order to place the measurements in a context relevant to transportation policy, the GPS points were matched to links in the Canton's road network model (Jenni and Gottardi AG 1998). The speeds were calculated for these links, and then for classes of these links. The road network model incorporates all national and cantonal roads, as well as the most important municipal roads in Canton Zurich.

## 2 Constructing the circuits

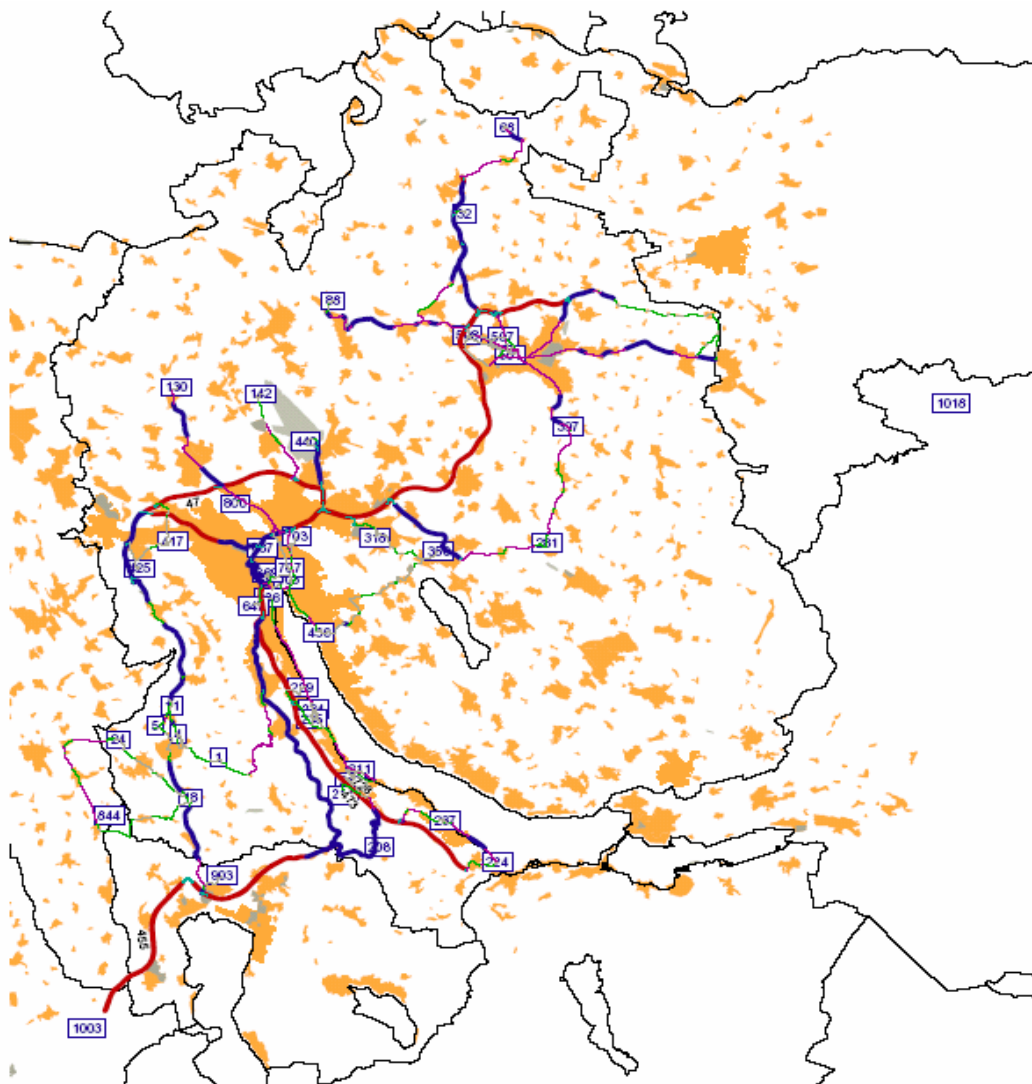
A statistical method was used to establish a representative subset of the road segments in the Canton. A series of origin/destination relations between the 808 planning zones in the cantonal traffic assignment model (KVM98) were chosen which are representative for the flows in the Canton and the immediate vicinity (Tiefbauamt Zürich, 2002).

The origin and destination zones and their sequence were chosen concurrently in a Monte Carlo procedure. The probability distribution for choosing a destination zone B from an origin zone A is the normalized distribution of the number of trips from zone A to all zones in the KVM98 workday average demand matrix. Zone 1 of the assignment model was chosen arbitrarily as the starting point. From here, an integer  $b$  between 1 and 808 is chosen randomly along with a random number  $p$  between 0 and 1. If  $p$  is less than the probability of choosing the destination zone B with the index  $b$  from zone 1, then B is chosen as the destination zone. If it is not,  $b$  and  $p$  are redrawn. In the next step, zone B becomes the new origin zone and the search for the following destination is repeated. A chain of zones is formed and the circuit is closed when the 50th zone is assigned again to zone 1, the starting point.

The procedure described above was repeated to make a set of circuits. Three circuits were chosen for their complementary spatial coverage of the Canton's area and the diversity of the road types. The measurement circuits are each between 550-700km long (Figure 1). The numbers appearing in boxes indicate the zone centers from the KVM98. The color and thickness of the roads indicate their different types. This circuit length yields a sample size at 40 km/h and 18 measurement days of approximately 20 measurements per segment.

Figure 1 Example measurement circuit: Circuit 3

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The zone centers are statistically-based abstractions and in most cases cannot be driven to. The three nearest street addresses to each zone centroid were determined in a GIS-Databank of buildings as the basis for driving instructions.

### 3 Field measurements and raw data

Three vehicles were in use simultaneously with GPS data loggers provided by GeoStats, Atlanta. Each was dedicated to a measurement circuit. The drivers were alone in the vehicle.

The drivers were initially given paper maps and driving instructions which were prepared by hand using the mapping website MAP24® ([www.map24.ch](http://www.map24.ch)) with the street addresses of the zone centers. The route instructions were detailed and correct, but in practice difficult to follow. The paper maps and the print were not legible in the dark. The challenge of navigating with these maps in real time, combined with the assignment to drive as fast as traffic, which some drivers also felt was too fast for conditions anyway, was too difficult for the drivers. The data yield in the first days was too low for the scheduled expectation and the number of driving/navigating mistakes was too high. Drivers had the feeling that the job was too dangerous without a navigator and were frustrated at not being able to make good measurements.

After three and a half days of measurements, new vehicles with on-board navigation systems were obtained. The next destination address could then be entered into the navigation system of the vehicle at each origin zone, after which the driver was guided by an electronic voice along the shortest-time path to the destination. This step not only raised the data yield, but also greatly reduced the stress on the drivers.

The measurements began at 6:00 am and ended at 9:00 pm. After any interruption, measurement resumed at the point of interruption. The measurements were taken for three weeks daily except Sundays from 11/03/2003-11/22/2003, in order to concentrate on representative work day traffic. The location, direction, altitude and speed of the vehicle were recorded each second with the GPS data logger.

The drivers alternated after 4- to 6-hour shifts at meeting points which they organized themselves. To avoid exchanges late nights and early mornings, the last driver of each day brought the measurement vehicle home and continued with the first measurements the next day. The drivers only turned the logger off overnight to avoid their turning it off during a break and forgetting to turn it on again. This means that the trips made to switch drivers, as well as trips to and from home, for refueling, and for personal breaks the drivers took, were all recorded in the data. Most of these trips were not on the measurement circuits.

The technical equipment worked without problems except for an antenna wire which was accidentally broken by a driver, which resulted in half a day's lost measurements. Routing the antenna cable via the car window and closing the window on the cable caused this failure, and also allowed rain into the vehicle which destroyed one of the navigation maps. Gently closing the cable in the door proves to be a better method, as the weather seal does not damage the cable.

The loggers can record roughly 75 hours of measurements at 1 second intervals. The data were downloaded every 4 days, and at special intervals when drivers were not certain how to interpret the diagnostic LED signal on the logger, and suspected a problem. The difficulty in navigation at the beginning resulted in some non-useful data. Additionally, some drivers forgot to turn on the logger a couple of times. GPS measurements are not possible where the satellite reception is blocked or distorted: in tunnels, parking garages or under bridges. More than 2.6 million seconds of data over 33,000 km were collected. About 30% of the measurement time the vehicles were not on the measurement circuits. According to the onboard journals, each segment of the planned measurement routes was measured at least 12 times despite the unexpected difficulties. The GPS raw data show a very high consistency and are in sufficient quantity to enable the desired comparisons of the system speeds.

## **4 Matching GPS points to the network models**

An original matching program was written to match the GPS points to the links on the network model of the Canton (See also the companion paper by Marchal, Hackney and Axhausen, 2004 for details). This new program has made a large step in quickly matching large volumes of GPS data to network models. The program utilizes the network topology to force a match of the GPS points based on the connectivity of the network. This approach ensures that the GPS points are always matched to the nearest road that could have been reached over the nodes in the network model via the upstream links. The first GPS point is matched to the nearest links and the perpendicular distance to each link is calculated. As GPS points are read, the distance between the stream and the connected model links that follow the first matched link is remembered for each possible path through the network from that link. Only  $N$  paths are retained as candidates for the match, where the  $(N + 1)^{\text{st}}$  path with the largest distance is dropped from the list. At the end (or at a suitably defined interruption) of the data stream, only the path with the smallest average distance is fixed as the match for the GPS point stream.

An incorrect match can occur if fewer path candidates are kept in memory than are necessary in order to check all the possible routes through dense network areas. This problem can be solved if enough paths are kept in the list. In fact, after raising the number of paths in memory beyond a certain number, the total deviation of the GPS points and the model links decreases to a minimum. It is a sign that no improvement in the match can be achieved for the network topology. The number of paths to search through in order to achieve this minimum deviation was tested with this dataset on two network models of

the Canton with different resolutions.  $N$  ranges from 10 to 50. The speed of the matching calculation scales with  $\text{Log}(N)$ . While a coarse network is matched faster than a fine one, if the vehicle drives on small roads that are not represented in the network model, matches will be made to links that were not driven, causing distortion of the average speed on that link. This is a common challenge to all matching algorithms and solutions were not addressed in this analysis.

The matching program writes out a table which includes the following variables:

- Vehicle number
- Observation date
- Link number in the network model
- Link length in the network model
- Time of entry into the matched link (seconds after Midnight)
- Travel time on the matched link (seconds)
- Average deviation of matched GPS points from the link (meters)

Calculations proceed on the basis of the model links, not the GPS data. Link-based characteristics are the building blocks of the analysis of the system speeds. The speed for every trip on every link is defined as the model link length divided by the travel time on the link during that trip. This results in a speed per link per trip.

## **5 Cleaning the data and checking the match**

Besides measurement error, there are two types of errors which must be cleaned from the data and the match: the non-traffic related breaks of the drivers and the discrepancies between the network geometry and the real paths of the roads.

### **5.1 Filtering the drivers' break time out of the raw data**

The most important distortion in the data is caused by GPS points which were driven outside the measurement protocol. The main challenge is how to handle the breaks that the drivers made for personal, navigation, or technical reasons (refueling, exchanging drivers, eating, reading a map, etc.). 33% of the GPS points have speed = 0. Figure 2 shows the distribution of the total stopped time by stop duration for all observations. The traffic-

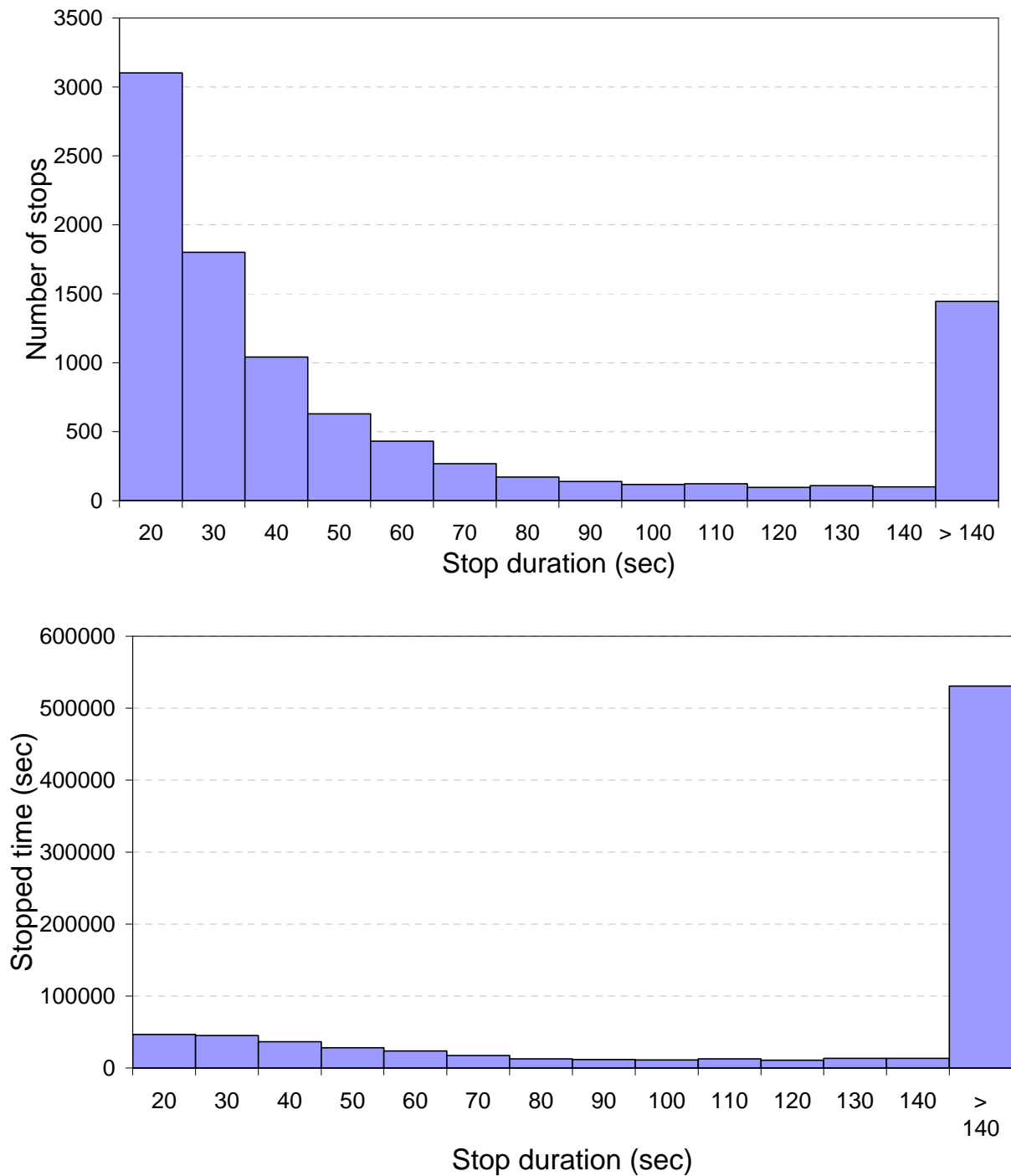


related stops and the non-traffic-related stops are mixed together. It also shows the number of such stops.

Even though it is possible in large cities that the road traffic is stopped for 30% of the time (Transport for London, 1999), this is not the case in this dataset. Examination of the onboard journals shows long pauses outside the traffic flow to eat, refuel, or to exchange drivers, which lasted up to a half an hour each and which coincided with GPS speed = 0. Stops to navigate lasted several minutes. Meanwhile, journal entries marked, “traffic jam” coincide with prolonged periods of creeping speeds interspersed with short stops. Figure 2 shows that the longest stops, which have the largest effect on the link speeds, make up the majority of the stopped time. If there is a strong relationship between the reason for stopping and the duration of the stop, the duration of the stop would be an important criterion for screening measurements, leading to greatly improved speed estimates. The validity of this assumption was evaluated.

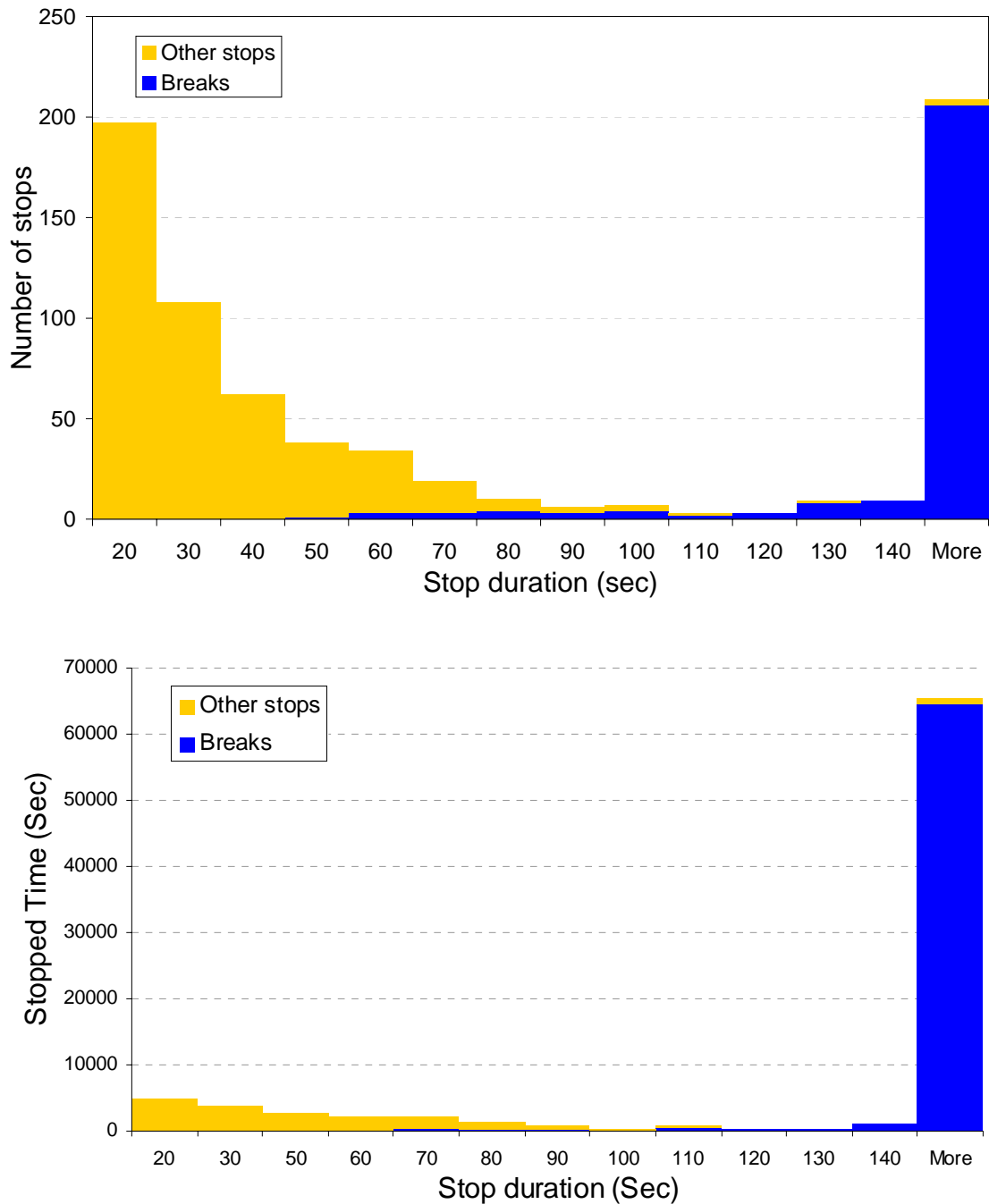
With the onboard journals which every driver was asked to fill out, one can attempt to identify and flag each stop and other maneuvers in the GPS data which did not have to do with the flow of traffic on the roads, but which had to do with navigation or other needs of the drivers. This time-consuming step could not be completely carried out, but a 10% sample of the data was used to evaluate the precise distribution of the reasons for stopping. The journal and the GPS data for measurement circuit 2 between 11/7 and 11/13 were examined by stop reason. GPS points during stops with non-traffic-related reasons were flagged “break”. Points during stops for traffic-related reasons (“traffic jam/road construction”) or without comment in the journal were flagged “other stops.” Figure 3 shows the relationship in the 10% sample between the stop duration and the stop reason in a distribution analogous to Figure 2.

Figure 2 Length of stops (sec) > 20 seconds, number of stops and total stopped time, all measurements.



The stops between 0-10 seconds are omitted for clarity due to their large number.

Figure 3 Relationship between reason for stopping, duration of stop, and number of stops, Measurement Circuit 2, 11/7-11/11.



The stops between 0-10 seconds are omitted for clarity due to their large number.

Although there is some overlap of the two distributions, “other stops”, and “breaks”, the analysis shows that the GPS data can be screened based on the single parameter “stop duration” in order to provide greatly improved estimates of the system speeds relative to using the raw data. Filtering on a simple threshold value accepts small errors as a consequence. The choice of threshold must take into account the relative influence on the sys-

tem speeds of the loss of too many stops that are traffic-related, versus leaving in too many non-traffic-related stops which one would rather filter out.

In both figures a stop duration between 90 and 110 seconds appears to be a sensible threshold, shorter than which are found mostly traffic-related stops, and above which the stops are mostly for personal, measurement-related, automobile maintenance, or navigation reasons. 100 seconds was chosen as a threshold value for the entire dataset. It is longer than a typical red phase at a traffic light while being shorter than most navigation stops.

Stops with duration longer than 100 seconds were removed from the GPS data before matching to the network links. This removed subset is 5% of the stops and 61% of the stopped time (582,000 seconds, or 22.3% of the raw data). After matching the cleaned GPS data, the representative sample of measurements contains 55738 link speed measurements. The total stopped time of the measurement vehicles in the retained data is 29,300 seconds, or 14.5% of the measurement time and can be considered with few exceptions to be entirely traffic-related.

## 5.2 Filtering the matched links in steps

Several filters were implemented after matching, at the link level, to address other measurement and matching problems. First, links were filtered out which were only matched once. It is likely that these links were not part of the planned measurement routes or were the ad hoc adaptations that the drivers made to approximate the prescribed route. These trips could be good data which reflects normal driving behavior, or they could be trips where the driver was lost and looking for a landmark, in which case the data would not be desirable for processing.. Second, there are very short links which, when combined with the imprecise spatial representation of reality in the network model and the measurement period of a single second, have a travel time of zero seconds and thus an undefined link speed. These observations were also removed from further analysis. Finally, those link measurements were filtered out which had an average speed after matching of over 176 km/h, the highest speed recorded in the GPS point database. After these three filters at the link level, 93% of the matched observations and, respectively, kilometers, remained for analysis.

Further, possibly erroneous link speeds in the first and last few hundred meters of each segment were treated separate from other links in the analysis. There are several reasons why measurements at the beginning and end might not represent real driving behavior.

The drivers were instructed to take all breaks either at the beginning or end of the segment, only in zone centers. The non-traffic-related stops not removed in the 100sec filter are to be expected there, as far as the drivers followed instructions. The main reason for stopping was to enter the address of the next destination zone into the navigation computer, which took from 25 seconds to several minutes (the latter already filtered out of the raw data). This portion of the driving segments also include the most difficult navigation on the route to the zone center, and the drivers were prone to getting lost. Yet the first and last meters of a trip are very important in measuring the level of service of a road network, and it could be that the drivers, after some practice, provided good data in these zone centers, in which case leaving them out would lose potentially meaningful data.

In the Canton traffic model, there is a road type 90 called “zone connector” which makes the connection between the zone center and the network model. There is one zone connector per zone. The problematic first and last meters of measurement will conveniently often be matched to this link type in the model. Accordingly, two different analyses were carried out, first with, then without the type 90 roads. The final judgment of the quality of the data at the end and beginning of the measurement segments near zone centers will rest with more detailed studies of individual cases. Type 90 roads make up 4% of the road links and 2.5% of the kilometers driven.

There were also errors as mentioned in matching the GPS data to the network model which are fundamental to this methodology and which have to do with the representation of reality in the network model. GPS points were matched to model links which are indeed closest to the points and which are reachable from the previously matched links over model topology. Despite this, some of the matched links are otherwise not similar to the actual road that was driven. This occurs when the roads actually driven are not represented in the network model, while the algorithm is forced to match the points to the closest road in the model topology. Usually these cases are trips on very small lanes in fields, small villages, or industrial zones where the slow speed is matched to a nearby higher speed road and causes a distortion of the average speed on that link. This problem is not yet solved, though using higher density and more accurate network models would help. The magnitude of the influence of such cases on the system speeds has not been analyzed fully.

The number of speed observations per link is varied, depending on the position of the link in the network and according to the corresponding outcome of the quality filter. Key links in centrally located, important intersections were driven several hundred times, while some lonely links at the edge of the measurement routes were driven around a dozen times,

which corresponds to the number of times a circuit was driven in the 18 measurement days.

## 6 Calculation of speeds: space mean speed

The system speeds are summarized in the context of the Canton Network Model and are calculated on the basis of the smallest element in the model, the link. In order to calculate the system speeds according to different road types and traffic conditions, the matched links were grouped into exclusive categories and the category statistics were calculated. The “system speed” is defined as the space mean speed of the links by category. The speed on each model link is treated like a random (independent and equally likely) observation of the mean speed on the set of the links of a category. The total length of all links in the group is determined and then divided by the total driving time on the links (Leutzbach, 1988). The space mean speed is a useful measure because it is also equal to the traffic flow divided by the traffic density (Gartner et al., 1992). This measure can be considered to be the speed on the link which a driver could expect to encounter under certain traffic conditions, and is therefore a link-based concept. Space mean speed for a classification of links (a subset) is calculated by:

$$\bar{V} = \frac{(v_1 t_1 + v_2 t_2 + v_3 t_3 + \dots + v_n t_n)}{(t_1 + t_2 + t_3 + \dots + t_n)}$$

with

$v, t$  the speed and the travel time of link  $i$  in the given subset (for example, a certain link type, measurement segment, or travel period)

$n$  is the number of links in the subset.

This gives:

$$\bar{V} = \frac{(x_1 + x_2 + x_3 + \dots + x_n)}{(t_1 + t_2 + t_3 + \dots + t_n)} \quad \text{or, equivalently,} \quad \bar{V} = \frac{(x_1 + x_2 + x_3 + \dots + x_n)/n}{(t_1 + t_2 + t_3 + \dots + t_n)/n},$$

an expression which will be useful for the calculation of standard deviation.

## ***Estimation of variance and measurement error of $\bar{V}$***

The error term is a combination of non observable or non controllable variables on travel behavior on the link (standard deviation) and of the technically-related measurement error in the GPS logging methodology.

### ***Standard deviation (variance)***

The reliability of the estimate of the system speed is bounded by the uncontrollable or unobserved influence of the traffic situation and the definition of the term “system speed.” The standard deviation of  $\bar{V}$  results from the distribution of the lengths,  $x$  and travel times,  $t$ , in a subset of links belonging to a category for which a system speed is calculated. Travel time varies because each observation is a measure of travel time on a link under specific conditions which were constantly changing, even during measurement, and not controlled for in every respect. The characteristics of the links (for example length, curviness, steepness) and the traffic conditions (weather, proportion of trucks, traffic flow) are similar but not the same, which produces randomness in the average time (speed) across the links. The variability in the link lengths is part of the standard deviation because the system speed is defined as the average over a set of links of varying length. If each link is a sample of the average link in the system, the variation about this average has to be taken into account.

The standard deviation of the mean of a subset of links is calculated for the average distance and time measure, an assumption that these two values are “best estimates” of the quantities:

$$\bar{\sigma}_{\bar{X}} = \frac{\sigma_{\bar{X}}}{\sqrt{n}} \quad \text{and} \quad \bar{\sigma}_{\bar{T}} = \frac{\sigma_{\bar{T}}}{\sqrt{n}}$$

with  $n$  = number of valid links in the subset and  $\bar{X} = \sum x_i / n$  (average length of links in the subset),  $\bar{T} = \sum t_i / n$  (average travel time per link in the subset).

The variances of  $\bar{X}$  and  $\bar{T}$  are independent. The standard deviation of  $\bar{V}$  is the sum of the standard deviations of  $\bar{X}$  and  $\bar{T}$ , in quadrature and weighted with the corresponding average value (Taylor, 1982, eq. 3.18):

$$\sigma_{\bar{V}} = \bar{V} \sqrt{\frac{\sigma_{\bar{X}}^2}{\bar{X}^2} + \frac{\sigma_{\bar{T}}^2}{\bar{T}^2}}$$

### Measurement errors

To this uncertainty are added the measurement errors of the GPS technology used to record the location of the vehicles. The measurement over the links in the subset is subject to measurement error in both space and time. The estimated spatial measurement error of the GPS logger is 15 meters per GPS point (GeoStats, 2003). This error affects the matching of the GPS point to the network but it does not have a direct impact on the calculation of the link speeds, because this is derived from the model link length and not from the GPS points. The meaning of “spatial error” in this methodology is therefore in the correspondence between the link ID (length, location) and the length of the actual track of the road in reality. It is assumed for the sake of calibrating the travel times between zones in the Canton model that this difference is zero. With this assumption there will be no analysis of spatial error. The measurement period of one second has direct influence on the calculation of the link speed. The total measurement error is added proportionally in quadrature (Taylor, 1982).

When the continuity of the network is used to match the GPS points to the network model, only the time measurements at the beginning and end of the link are relevant. Correspondingly, they are considered twice per link. They are also independent and they add in quadrature (Taylor, 1982, eq. 3.16):

$$dT = \sqrt{(2dt_1)^2 + (2dt_2)^2 + (2dt_3)^2 + \dots + (2dt_n)^2}$$

The average error per link is also averaged over  $n$  links (Taylor, 1982, eq. 3.9), where the measurement error is in this case the same for every point ( $dt = dt_i = 1$  second):

$$d\bar{T} = \frac{dT}{n} = \frac{\sum_{i=1}^n 2\sqrt{dt_i^2}}{n} = \frac{2n \sum_{i=1}^n dt}{n} = \frac{2n(dt)}{n} = 2dt = 2 \text{ seconds per link.}$$

The magnitude of this error depends on the speed and the length of the link. The order of magnitude of this effect on an average link can be estimated with the average link length and travel time. These values are 458 meters and 36 seconds, respectively, which result in  $\bar{V} = 46$  km/h. The estimate of measurement error  $dT/T = 2 \text{ sec}/35.5 \text{ sec}$  is 5.6% and con-



tributes a measurement error of  $\pm 0.056 \times 46 = \pm 2.6$  km/h. This will be lower for longer link travel times and vice versa.

### **Total error**

The total error term for the analysis of the subsets of links is summed in quadrature (Taylor, 1982, eq. 3.18):

$$\sigma_{\bar{V}} \sim dV = \bar{V} \sqrt{\left(\frac{d\bar{T}}{\bar{T}}\right)^2 + \left(\frac{\sigma_{\bar{T}}}{\bar{T}}\right)^2 + \left(\frac{\sigma_{\bar{X}}}{\bar{X}}\right)^2} .$$

The symbol  $\sigma_{\bar{V}}$  is used for the total error because this term is the best approximation of the standard deviation of  $\bar{V}$ .

## **7 Speeds on the cantonal road network**

The classifications embedded in the canton traffic assignment model are directly utilized to frame the speeds in a context familiar to local decision makers. The system speeds were evaluated separately for the following subsets:

- Road type (the model designation of road type)
- Road owner (Municipality/Canton/Federal government, which did not own the roads at the time of the experiment but will in a matter of months)
- Time period
  - Mon.-Fri. Peak [6:30-8:30 and 16:30 to 18:30]
  - Mon.-Fri. Off-peak [8:30 to 16:30 and 18:30 to 20:30]
  - Mon.-Fri. Other
  - Saturdays.

The definitions of the road types and their coding in the Canton model are (Tiefbauamt Zürich 2002): High capacity roadways (HLS, Hochleistungsstrassen), Main trunk roads (HVS, Hauptstrassen and Hauptverkehrsstrassen), Collectors (SS, Sammelstrassen), Distributors (ES, Erschliessungsstrassen), Zone Connectors and Other roads (projected roads at the last model update of 1998).

Table 2 presents the averages by type of road and time period. Note the separate values for the zone connectors. The total by road type includes the zone connector links (speeds

are 1-2 km/h higher without). Figure 4 shows the directional mean speeds of the links on the measured part of the network.

The analysis by road owner (Table 1) shows the substantial impact of the zone connectors on the speeds on municipal roads and of course less effect on higher ranked roads.

Table 1 System Speed by Road Owner [km/h]

Data	Municipality	Canton	Federation	Total
All road types				
Average	29.5	43.4	86.5	46.4
Standard Deviation	1.4	2.3	8.1	2.6
Number of Observations	4916	37543	9452	51911
Km driven	1964.3	17190.6	4954.5	24109.4
All roads, but without Type 90 zone connectors				
Average	33.4	43.8	86.5	47.9
Standard Deviation	1.8	2.3	8.3	2.7
Number of Observations	3433	36797	9378	49608
Km driven	1498.2	16974.5	4800.0	23272.8

Table 2 System Speed by Road Type and Traffic Demand Period, km/h

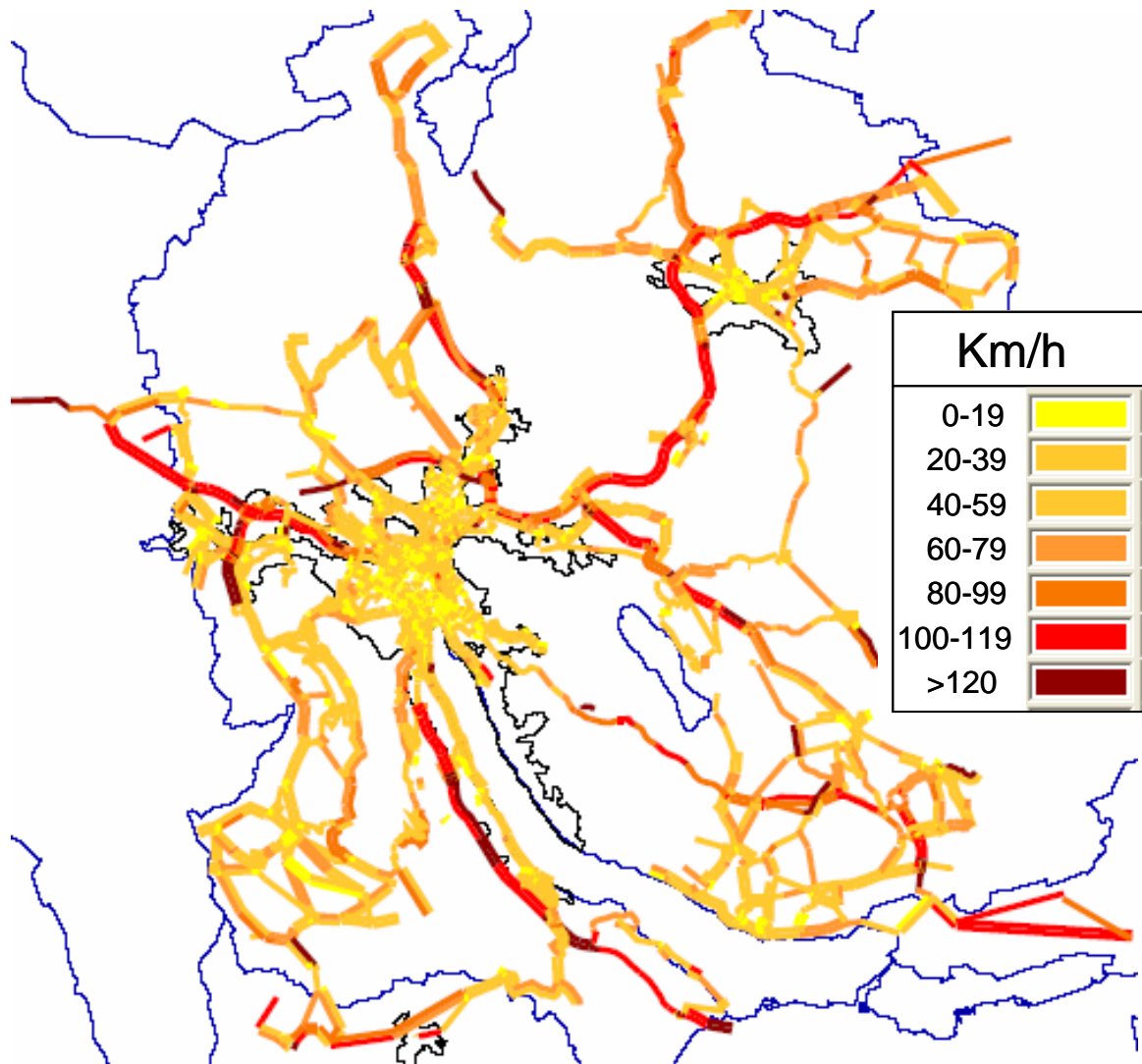
Road type	Data	Saturday	HVZ (Peak)	NVZ (Off-peak)	RVZ (Other)	Mo.-Fr.	Total
HLS (motorway and similar)	Average	101.2	85.3	101.5	93.0	96.1	97.1
	Standard Deviation	8.3	5.5	8.3	7.0	6.8	8.1
	Number of Observations	2495	2235	6306	991	9532	12027
	Km driven	1475.9	1359.4	3703.2	628.4	5691.0	7166.9
HVS/HVSII (trunk roads)	Average	40.5	35.0	39.0	41.6	38.1	38.6
	Standard Deviation	2.1	1.5	1.9	2.8	1.8	2.1
	Number of Observations	5696	5246	14732	2648	22626	28322
	Km driven	2159.5	2244.9	5808.1	846.8	8899.7	11059.2
SS (collector)	Average	50.9	41.7	46.1	48.3	45.0	46.1
	Standard Deviation	3.0	2.2	2.1	4.7	1.9	1.8
	Number of Observations	1118	1195	3052	258	4505	5623
	Km driven	753.0	728.1	2057.0	185.5	2970.6	3723.5
ES (distributor roads)	Average	30.4	26.5	28.7	30.7	28.3	28.7
	Standard Deviation	2.1	1.7	1.4	2.7	1.3	1.3
	Number of Observations	724	647	1874	391	2912	3636
	Km driven	259.1	255.0	689.4	119.7	1064.0	1323.1
Typ 90 Zone connector	Average	22.4	21.3	21.9	22.0	21.7	21.8
	Standard Deviation	1.8	1.6	1.2	3.1	1.1	0.9
	Number of Observations	424	478	1093	110	1681	2105
	Km driven	127.2	148.0	339.1	30.9	518.0	645.2
Other Types	Number of Observations	48	59	81	10	150	198
	Km driven	50.6	79.5	54.7	6.7	140.8	191.4
Total (including zone con- nectors)	Average	49.5	41.8	46.8	50.1	45.7	46.4
	Standard deviation	3.1	2.1	2.6	3.6	2.5	2.6
	Number of Observations	10505	9860	27138	4408	41406	51911
	Km driven	4825.3	4814.8	12651.4	1817.9	19284.1	24109.4

The results show the expected means with low variances due to the large sample sizes. This will allow the Canton to compare the results over time and to detect the relevant changes in the transport system. There are strong differences by type of road and by road owner, but this is no surprise due to the correlation between ownership and road types.

The differences by time period follow the expected patterns, except for the motorway network, where the extreme early and late periods (“Other”) have lower average speeds than the off-peak period. This is probably due to the measurement period in November, during which these times are completely dark. The drivers were also likely alone on the roads and it could be that they were driving closer to the speed limit rather than attempting to match the speed of other drivers. The difference between peak and off-peak is also strongest on motorways, indicating that the speed limits on the other road types constrain the speeds more strongly than the volume differences.

The speed variances of the motorway system are the largest, both in absolute and in relative terms. This is contrary to prior opinion, which has held that the faster parts of a system are also the most reliable. This might only be true until the system reaches capacity. Some parts of the motorway network are known bottlenecks. The high level of variability observed is also compounded by incidents, construction sites (one, in particular), and vehicle breakdowns that the drivers noted in the logbooks.

Figure 4 Link mean speeds during the peak hours (Mo.-Fr.)



## 8 Conclusions and outlook

The study has shown that it is possible with reasonable effort to measure the level of service of a regional road system with sufficient accuracy to permit temporal analysis. GPS map matching algorithms will become more robust in the future, further speeding up the process. Improvements are necessary in reconciling the GPS tracks along the actual roadway relative to the generalised alignment of links in the navigation, GIS, or assignment models. In addition, the matching needs to find intelligent ways to cope with existing roads not available in the network representation used for the matching.

The key substantive results are the comparatively large variances of the speeds on the motorway system and the still large speed differential between the motorways and the remaining roads. While the high speeds attract the users, the increasing unreliability reduces the value of it to the users.

The results presented so far could be improved in a number of ways, all of which unfortunately require substantial effort. The link length could be measured from the GPS points, rather than taken from the GIS records. Some initial tests indicate notable differences, which in turn will affect the speed estimates. The speeds could be volume weighted after a successful calibration of the assignment model. The filtering of driver breaks could be improved by including the type of road or location into the filter, as well as the information contained in the field notes of the drivers.

The data opens up avenues for further work. We are planning to estimate models to generalise the results to the links not covered in the survey. The models will relate the speed of a link to a series of explanatory variables such a time-of-day, day-of-week, type of road, population density, network density, density of motorway access points, distance to the main centres in the region. These models will also allow an analysis of the tempo-spatial correlations between the observations and the respective residuals. It also planned to employ the results to the on-going calibration of the regional and national assignment models.

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