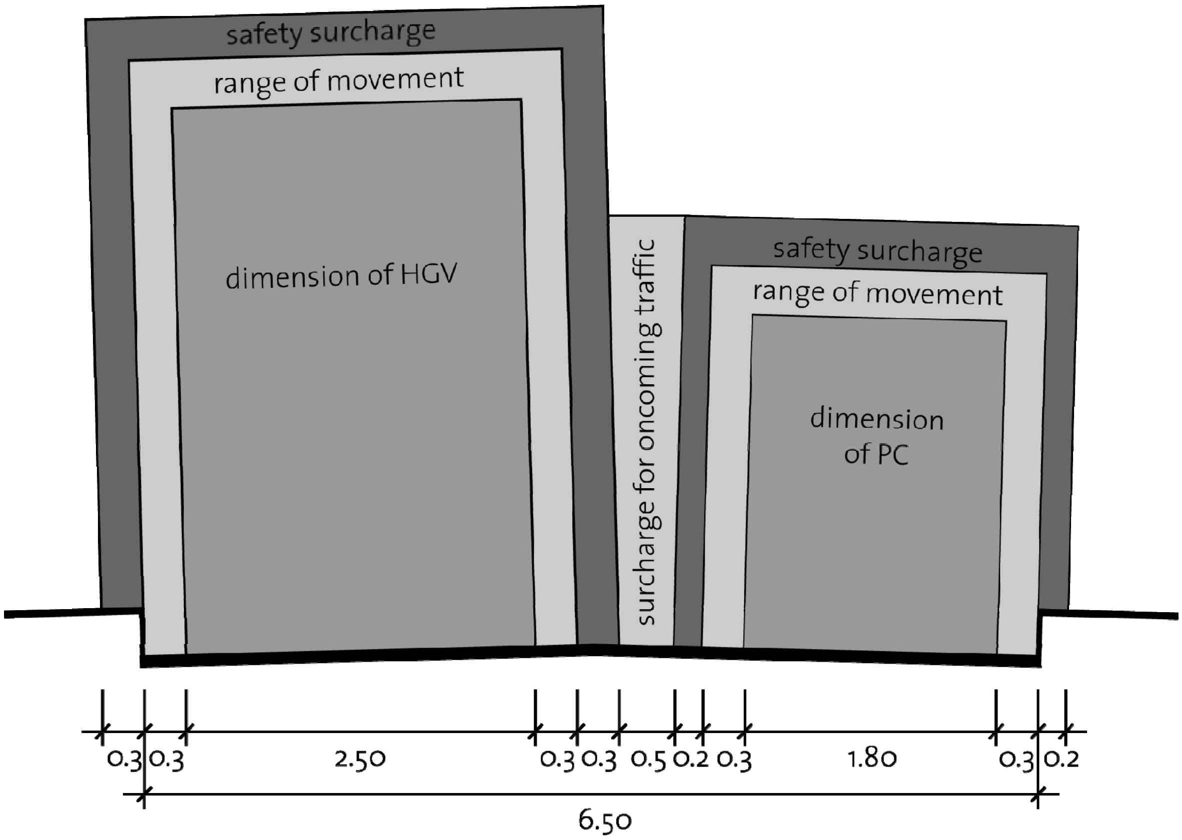

Standard-profile of cross sections

G. Santel, IVT – ETH Zurich

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Gerko Santel
Institute for Transport Planning and Systems (IVT)
ETH Zurich
CH – 8093 Zurich

Phone: +41 44 633 66 58
Fax: +41 44 633 10 75
email: santel@ivt.baug.ethz.ch

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Abstract

The examination of the Swiss standard SN 640 201 (basic measurements) is in the foreground of this research. A focus is placed on the statistically firm investigation of dimensioning elements of the standard-profile of cross sections. The corresponding reference values are derived from empirical data. The acquired data contains individual vehicle trajectories, vehicle speed, passing distance between two vehicles and time gap between vehicles.

Keywords

Geometrisches Normalprofil GNP – geometric standard profiles of cross sections – lateral movement range – lateral passing distances – speed-dependent reference values – driving behaviour

1. Initial situation

The Swiss standard group of geometric standard profiles of cross sections (Swiss: Geometrisches Normalprofil – GNP) from the year 1992 consists of three standards. In these standards the individual elements of the cross sections are defined and indications for the regulation of the measurements are given.

The examination of the Swiss standard SN 640 201 (basic measurements) is in the foreground of this research. It contains quantitative reference values to the assessment of the elements of the streets clearance. Most of these elements, such as range of lateral movement, additional clearance for oncoming traffic and clearance for overtaking are speed-dependent. Therefore the research also has a high relevance for road safety.

Back then, the specification of these reference values was carried out without field researches. So these are largely empirical values which are not supported by measurements of real traffic flow. Only a rough and incomplete categorization for these speed-dependent reference values is contained in the standard. This is leading to uncertainties applying the Swiss standard.

1.1 Aims

The aim of the research is to provide a scientific base for a possible revision of the Swiss standard SN 640 201. A focus is placed on the statistically firm investigation of speed-dependent dimensioning elements of the standard-profile of cross sections. The corresponding reference values are derived from empirical data.

The range of lateral movement is regarded as the amplitude of a vehicle trajectory on a straight track section caused by steering clearance, road unevennesses, wind influences etc. The lateral passing distances between the vehicles contains the contraflow traffic allowance (streets with oncoming traffic) or overtaking allowance (streets with directional traffic) according to the existing Swiss standard.

The question arises, to what extent the range of movement is influenced by the traffic volume. Possible differences between the conditions "individual vehicle" (unhindered) and "vehicle group" are to be examined here.

For this purpose approximately 50 measurements have been carried out on roads, motorways and urban streets with speed limits of 30 km/h and 50 km/h. On average, 1000 vehicles could be measured at every single track section examined. The acquired data contains individual vehicle trajectories, vehicle speed, passing distance between two vehicles and time gap between vehicles.

2. Method of investigation

It has to be determined which values and relations must be established, how they can be quantified and how these values correlate with each other.

2.1 Values and relations

It has to be distinguished between the sought-after values and the influence variables. Relations between these have to be derived in real traffic flow.

The sought-after values are

- the range of lateral movement of an unhindered individual vehicle
- lateral distances at crossing cases between road users.

The dimensioning elements depend on several criteria to be taken into account during measurements. In real traffic flow the influences mentioned above often overlap. During measurements, the separate recording of the single influences and their superposition must therefore be ensured.

The most important technical criteria consist of:

- carriageway width
- operation mode (road with directional or oncoming traffic)
- obstacle distance and characteristic
- passing type of different road user groups
- passing speed

For the measurements, flat or at the most slightly inclined track sections were required. The roads (with directional and oncoming traffic) were divided into the categories “narrow”, “regular” and “wide”. Regarding to the lateral obstacle distance obstacles got distinguished into categories of distances with more or less then one meter. The obstacle characteristics are attributed as either "dot-like" or "elongate".

To detect the range of lateral movement, passenger cars (PC), heavy goods vehicles (HGV) and buses as well as bicycles (BC) were surveyed. Motorcycles are not included, because they are not relevant for the assessment of the standard profile.

For the lateral distances on the roadway the following five passing cases were examined:

PC/PC, PC/HGV, HGV/HGV, PC/BC und HGV/BC

The influence variable “speed” can be interpreted as a dispersive influence value. The extent of velocity is influenced by the choice of measurement track section according to the category of street and signalised speed limit.

Besides this influence variable, environmental conditions have an effect on the road performance also. In this examination the measurements are carried out at the following conditions:

At daytime, with no rain, on roadways without unevenness.

The described influence variables result in a large number of combinations. A first estimate from previous experiences and conclusions from literature shows that approx. 20 measurements are required for non urban roads with oncoming traffic in order to gain statistically safe statements. Therefore, the measurement sections had to be selected so that many of the combinations could be covered at one place. The evaluation of suitable track sections therefore was of great importance.

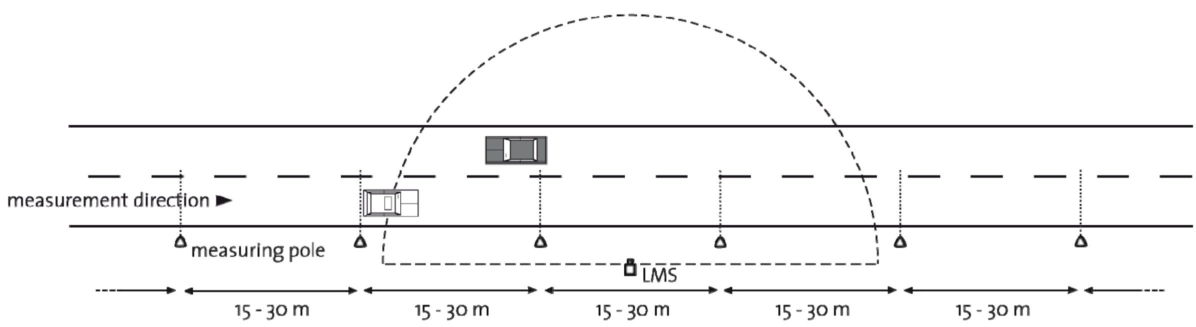
3. Measurements

The recording of the sought-after variables is carried out with a measuring device of the IVT (measuring poles) which was already used for several research projects. This device enables the detection of lateral distances of individual vehicles at several cross sections as well as traffic direction, vehicle length and passing speed. A special sensor system is used for recording the passing cases and for the detection of the range of lateral movement. This system is based on laser scanning and is able to acquire and follow the position of mobile objects.

An advantage of this type of measurement over the also conceivable video image processing is due to the precision and primarily to the flexibility (no increased camera position is needed). The collected data can be interpreted directly. The extremely time-consuming video evaluation is rendered unnecessary.

The general measuring set-up on a track section is represented in the following figure. The distances between the measuring poles vary according to the expected speed level. The distance between the single measuring poles varies between 15 meters (sections on urban roads) and 30 meters (sections on highways). So the length of the measurement sections varies from 165 m on urban roads to 330 m on highways.

Figure 1 General measuring set-up



The measuring poles, arranged in a row, only measure the trajectories and velocities of the vehicles driving into the direction of measurement. For the assessment of vehicle width as well as for passing cases a match with the data acquired by the laser measuring system (LMS) is necessary.

3.1 Analysis

From the complete sample of the measurements at a section, several subsets are formed in the following steps:

- *Classification according to road users*

  Vehicles get allocated into the three groups PC, HGV and BC. Then a classification is carried out for the events without oncoming traffic or overtaking (measurement for range of lateral movement) and with vehicle passing (measurement for lateral passing distances.)

- *Classification according to velocities*

  For the sorted subsets, speed distributions are calculated and velocity classes are formed. In case of a passing event, the velocity of the faster vehicle is regarded as passing speed.

- *Determination and distribution of the range of lateral movement*

  For the different speed classes, the individual range of lateral movement is derived from the traces of the unhindered road users. Their distribution forms the base for the specification of the speed-dependent standard reference values.

- *Determination and distribution of the surcharge for oncoming traffic and overtaking*

  The lateral passing distances are determined one by one from the trace courses of the road users involved in passing cases. Their distribution forms the base for the specification of the speed-dependent standard reference values. After the subtraction of lateral movement range, the results show the corresponding oncoming traffic or overtaking surcharges.

In a separate evaluation the question of the influence of the traffic volume on the range of lateral movement is pursued. Larger groups of vehicles are evaluated and compared to the results of unhindered moving individual vehicles.

The evaluation of the individual measurement sections is followed by the comparison of measurement sections of different width as well as the comparison of measurement sections with and without lateral obstacles. A possible influence of these variables shall be shown and quantified.
Furthermore statistical evaluations of the vehicle measurements are carried out in order to consider structural changes in the Swiss vehicle fleet.

3.2 Measurement track sections

For the examination, urban roads with a speed limit of 50 km/h, non urban roads and highways were distinguished. All these types are traffic oriented streets. In addition to these, measurements on urban roads with a speed limit of 30 km/h were carried out. Besides the requirements mentioned in chap. 3.2.1 pp., a relative geographical proximity to the domicile of the research institute was always aspired.

For the choice of measurement tracks, besides the mentioned requirements, it was also paid attention to the road surface being in a good condition. Particularly a significant influence of road roughnesses, such as pavement rutting, can therefore be excluded. Major gradients and crossfalls as well as inhomogeneities in the road surface could be avoided by the choice of measurement sections.

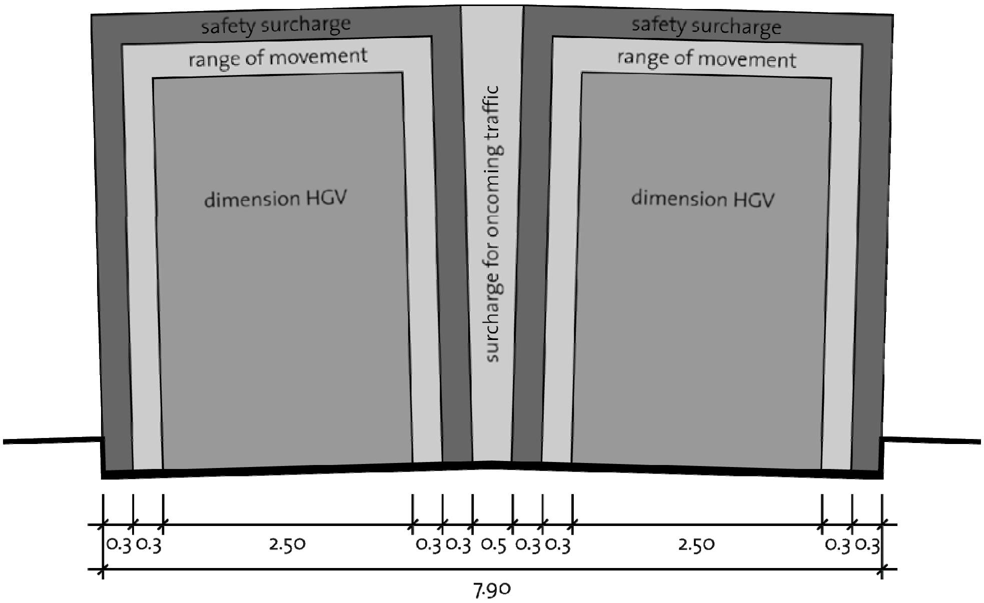
As important influence factors the lane width, the road width, the lateral obstacle clearance and possible specialities were documented.

3.2.1 Sections on non urban roads

Altogether, 21 measurement track sections on non urban roads in the cantons of Zurich, Thurgau, Argovia and Schaffhausen with a signalled maximum speed of 80 km/h were surveyed. These can be put into different categories in order of road width. For the examination on hand the categories were “narrow”, “regular” and “wide”.

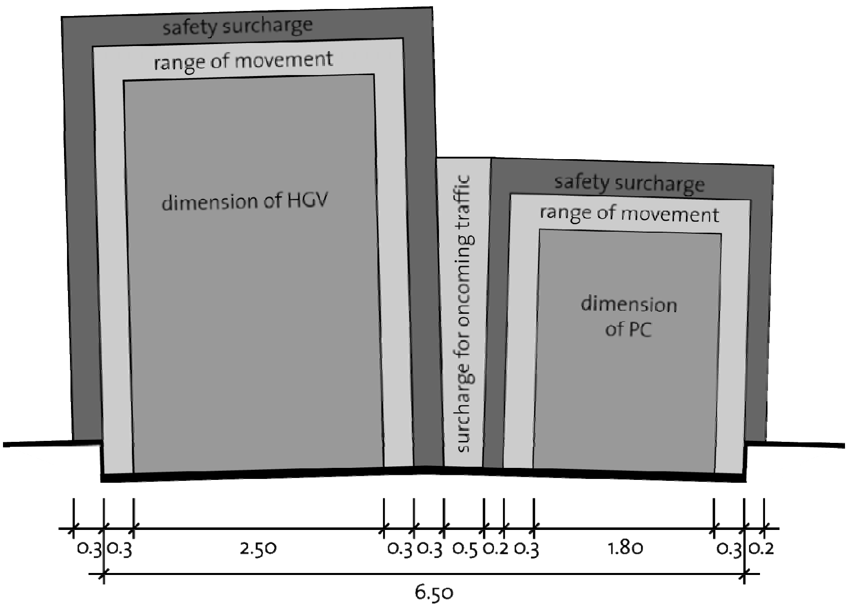
A cross section is considered to be regular if it is dimensioned (according to SN 640 201) for the passing case of two HGV (with the outer safety surcharge beyond the carriageway). The cross section consists of the basic measurement of two HGV (2.5 m each), the range for lateral movement (0.3 m each) on the right and on the left at each lane and the surcharge for oncoming traffic (0.5 m). This yields a total clearance of 7.9 m (cp. figure 2).

Figure 2 Cross section HGV - HGV [m]



At the minimal passing case HGV – PC, it is assumed that the surcharges for safety are beyond the carriageway. For the basic measurements of a PC (width. 1.8 m) and a safety surcharge for PC of 0.2 m, a minimal road width of 6.50 m results (cp. figure 3).

Figure 3 Cross section HGV – PC [m]



The following classification therefore gets applied at speed limit of 80 km/h:

- Narrow carriageway: < 6.50 m
- Regular carriageway: 6.50 m to 7.90 m
- Wide carriageway: > 7.90 m

In all three categories the measurement sections were subdivided in categories according to type and distance of lateral obstacles (cp. table 1).

Table 1 Sections on non urban roads, speed limit 80 km/h

obstacle	(distance)	carriageway width < 6.50 m	carriageway width 6.50 m - 7.90 m	carriageway width > 7.90 m
no obstacle		Künten	Aarau1, Dielsdorf3, Wehntalerstrasse	Affoltern2, Thayngen
dot-like	> 1 m	Steinmaur	Dielsdorf1	Affoltern1, Beringen
dot-like	< 1 m	Embrach, Unterneerach	Aarau2, Dielsdorf2	Paradies
elongate	> 1 m	Flaach	N4Bülach	Diessenhofen
elongate	< 1 m	Hüntwangen	Kreuzlingen	

Compact obstacles which only extend over a short part of the track section and wich do not have a line-type character are regarded as dot-like obstacles. This includes individual trees, lights and over-country electricity pylons as well as single bushes.

Safety barrier, retaining walls as well as thick and high street accompanying hedges belong to the line-type obstacles. The different manner of the obstacle expression lets expect a more continuous influence on the driving performance.

Another measurement section was selected for the simulation of conditions in tunnels and galleries with a massive line-type obstacle. For reasons of safety for the measuring staff as well as for avoidance of an essential intervention into the traffic flow, measurements in tunnels had to be renounced. To substitute for his measurements were carried out on day time and in the dark at a track section with a lateral retaining wall at Mumpf (AG).

3.2.2 Sections on urban roads

The track sections on urban roads can be divided into three groups. The distinguishing factors are the section characteristic speed limits on the measurement track sections.

The measurements for the assessment of the passing or overtaking surcharge of PC and BC take place at comparatively shorter track sections. These are characterized by traffic islands (refuges) of different length or stop islands of the public traffic. The urban road sections are distinguished according to the speed limit (50 km/h or 30 km/h) and the length of the traffic island.

Track sections on urban roads, speed limit 50 km/h

Analog to the assumption for the track sections at speed limit 80 km/h the sections with speed limit 50 km/h are subdivided in “regular” and “wide” sections.

The following seperation therefore gets applied at speed limit of 50 km/h:

- Regular carriageway: ≤ 7.30 m
- Wide carriageway: > 7.30 m

Five measurement track sections were determined in the canton of Zurich. Two are allotted to the category “wide” and three on the category “regular” (cp. table 2).

Table 2 Sections on urban roads, speed limit 50 km/h

obstacle	(distance)	**carriageway with** ≤ 7.30 m	> 7.30 m
no obstacle		Bachenbülach	Schöfflisdorf, Nänikon
elongate	> 1 m	Schweighofstrasse ZH	
	≤ 1 m	Maur	

When choosing the track sections, locations in the area of city limits were preferred. This serves the purpose to avoid excessive disturbances of the measurements by pedestrians and bicycles. At these sections, disturbances of the traffic flow by parking search traffic or parking events happened sparsely.

Track sections on urban roads, speed limit 30 km/h

For observations in urban roads with a speed limit of 30 km/h, two sufficiently long sections could be found in the city of Zurich.

Both track sections have a carriageway width of 5.50 m (cp. table 3). Analog to the above assumption this corresponds to narrow roads. The passing case HGV - PC with the outer safety surcharge beyond the carriageway for a speed of 30 km/h is assumed with a width of 5.70 m in the Swiss standard. This passing case can be accepted as assessment basis since the sections are moderately frequented by the delivering traffic. Even the Zollikerstrasse is element of the public transport network and therefore regularly used by broader vehicles.

Table 3 Sections on urban roads, speed limit 30 km/h

obstacle	**carriageway width** 5.50 m
no obstacle	Sonneggstrasse (ZH), Zollikerstrasse (ZH)

Track sections with traffic island (refuges)

The observations of the overtaking behaviour and the lateral overtaking distances between motor vehicles and bicycles were realized on track sections with long or short traffic islands. Two questions are in the focus of this measurement. On one hand the lane width which is needed by a vehicle driver to overtake a bicycle between traffic island and sidewalk shall be derived. On the other hand the dependence between island length and readiness to overtake should be derived. Therefore the carriageway widths, as well as the traffic island lengths are the characteristic variables for this examination. A carriageway width of 3.4 m was assumed as a maximum for regular wide lanes. This width arises from the assessment of lanes with traffic islands in the area of road junctions, according to SN 640 262. Table 4 shows the track sections looked at. All sections are found in the city of Zurich.

Table 4 Sections with traffic island

traffic island length	carriageway width ≤ 3.40 m	> 3.40 m
< 15 m		Irchelstrasse, Wehntalerstrasse
15 to 30 m		Altstetterstrasse
> 30 m	Limmatstrasse, Weinbergstrasse	Hofwiesenstrasse

An important factor when choosing these sections was a high frequentation by cyclists. The measurements at short traffic islands were taken at pedestrian refuge islands on walkways. The track sections with a traffic island length of over 30 m are sections in the area of tram stops. A speed limit of 50 km/h is valid at all sections.

3.2.3 Sections on highways

The traffic flow on highways could be measured on seven track sections in the cantons of Zurich, Thurgau, Grisons, Lucerne and Argovia. Five of theses sections were motorways with structurally separate carriageways. Another two measurements were carried out at the "Umfahrungsstrasse" at Littau (LU).

According to the ASTRA guideline "Nationalstrassenprojekte" roads on two-lane highways exceeding a total a width of 7.75 m can be termed "wide".

Table 5 Sections on two-lane highways

hard shoulder	carriageway width ≤ 7.75 m	> 7.75 m
with	Wigoltingen A7	Horgen A3, Frauenfeld A7
without	Kloten A51, Thusis A13	

Table 5 shows the track sections on two lane highways distinguished by lane width and the criterion "with or without hard shoulder for emergency use". Since an existing hard shoulder must be counted as part of the driving clearance, effects on the driving behaviour have to be expected.

Due to the restricted cross section in Thusis, a speed limit of 100 km/h is imposed on this section. On all other section tracks the limit is 120 km/h.

Table 6 Further sections of highways

obstacle	**lane width** 3.90 m
no obstacle	Littau1
elongate	Littau2

The sections “Littau1” and “Littau2” (cp. table 6) differ regarding to lateral obstacle clearance. While the track section Littau1 is limited by a safety barrier, an up to 10 m tale retaining wall is placed at the track section “Littau2” at a distance of 2.6 m to the right lane edge. Both sections each have one lane per direction with a width of 3.9 m.

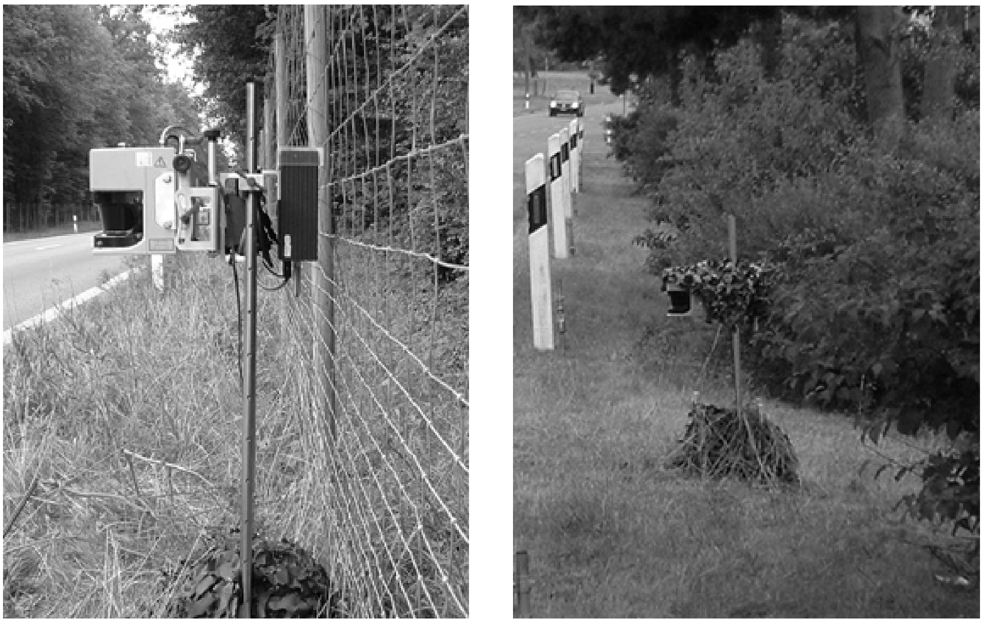
3.3 Measurement devices

For measuring the driving behaviour, two different measurement devices are used. On one hand a laser measuring system has been developed in connection with this research project. Further, a system consisting of twelve measuring poles, approved in several previous projects has been used.

3.3.1 Laser measuring system

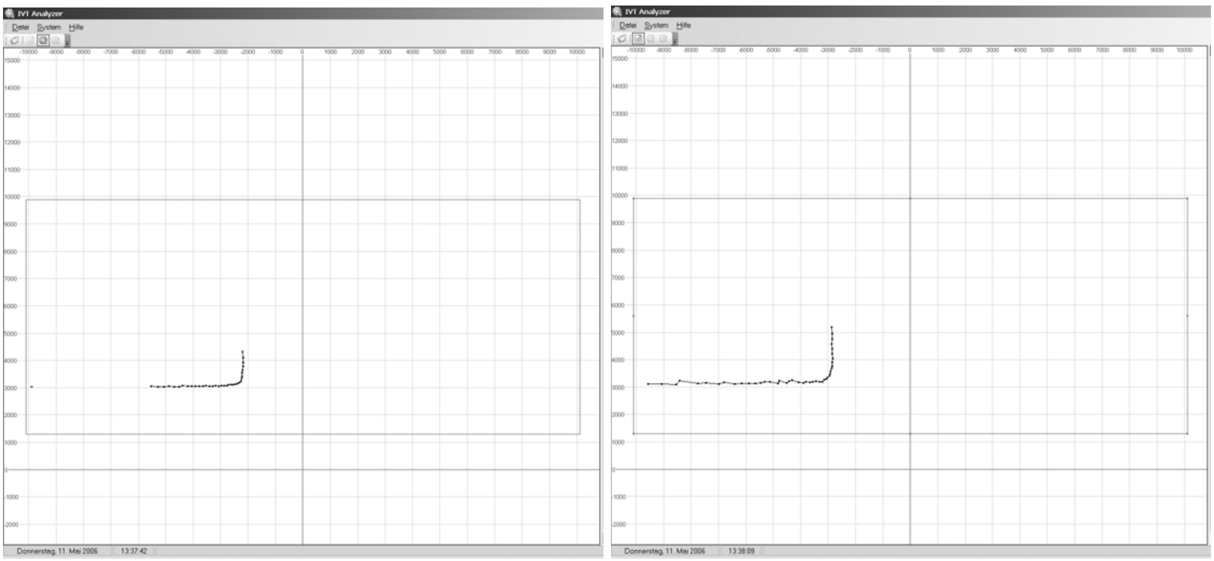
The laser measuring system (LMS) was developed to acquire the position of moving objects and to follow them. Vehicles in the sensor area of the LMS are recognized with the vehicle flanks turned towards the LMS. Besides the current position, vehicle data such as length and width as well as the vehicle speed can be derived. The system consists essentially of the laser sensor and a recording computer (cp. figure 4).

Figure 4 Laser measuring system (LMS)



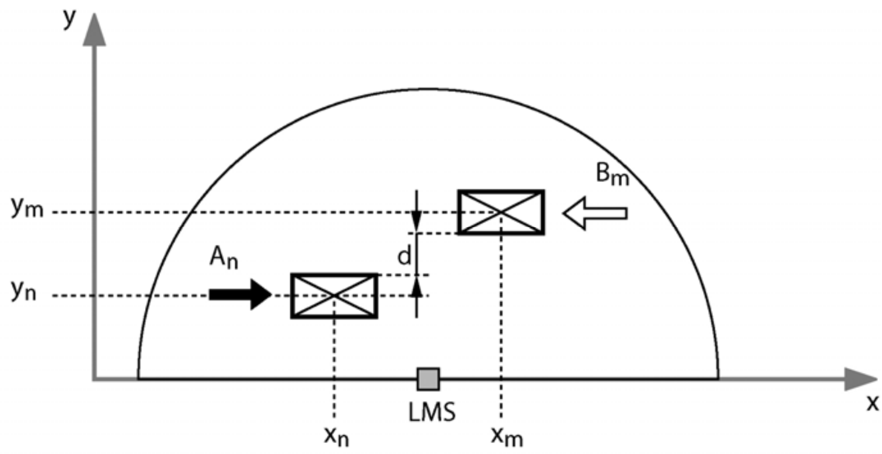
The measured raw data consists of XY coordinates. These points represent the object surface related to the sensor location in an arch distance of one degree. In a first step the data is filtered and the sets of points of the moving objects get separated from background points (cp. figure 5).

Figure 5 Vehicle detected by the LMS, PC (left) and HGV (right)



Besides the localization, the recorded objects also allow the definition of the vehicle measurements (average width and length) and therefore the division into vehicle classes. A recorded vehicle is pursued in the sensor field. Data like vehicle speed, vehicle trajectories and range of lateral movement can be quantified over the time.

Figure 6 Coordinate system of the LMS

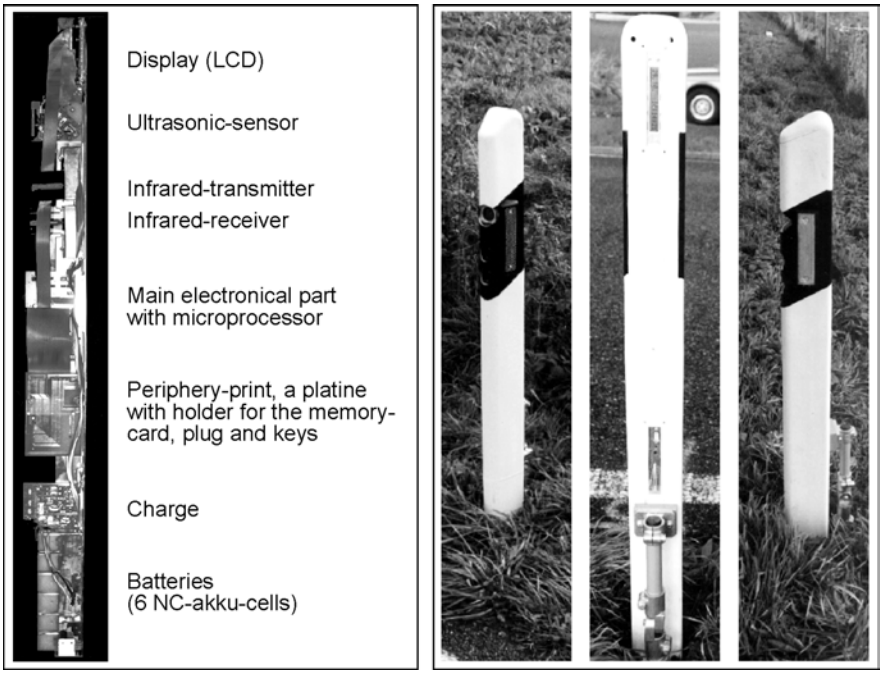


Moreover, the LMS can distinguish, whether a vehicle was influenced by oncoming traffic. In the case of overtaking or oncoming traffic in the sensor field, the passing distances between the vehicles can be determined (cp. figure 6).

3.3.2 Measuring poles

Measuring poles were used in the field trials as well. This equipment consists of autonomous measuring poles, disguised as regular delineator poles (cp. figure 7). The individual measuring pole, configured by a special control unit, can detect the pass-trough of the vehicles, their driving direction, the vehicle length and the lateral distance between the vehicle and the pole.

Figure 7 Views of the measuring pole



The speed of the vehicle is determined by analyzing the measured pass-through times in relation to the distances between the measuring poles. Each pole stores the collected data on memory cards, which are subsequently exported to a computer for further analysis.

Up to 12 measuring poles were used for the acquisition of the driving behaviour at track sections on non urban roads. The number of poles at the track sections on urban roads was reduced due to the length of available section.

Among other things, the software developed at the IVT, enables the evaluation of speed distributions as well as the evaluation of the trace distributions. Besides this speed sequences and trajectories can be drawn about the complete measurement section.

3.3.3 Combination of the measuring devices

The laser measuring system and the measuring poles run synchronously. A time stamp is assigned to every recorded object in the respective data sets. A vehicle, which is detected by the laser measuring system, can clearly be identified in the data surveyed by the measuring poles.

So the attribute “unhindered” or “hindered” is assigned to every identified vehicle based on the data surveyed by the laser measuring system. For every vehicle identified by the measuring poles, the corresponding LMS data reveals, whether a passing has taken place with one or several oncoming vehicles. To this it is necessary to extrapolate the driving course of the oncoming traffic, which only is surveyed by the LMS, to the complete measurement section. A vehicle passing can therefore also be indexed at the beginning and at the end of the track section covered by the measuring poles.

Detailed examples for the measurement setup according to the different categories of measurement track sections are shown in the appendix.

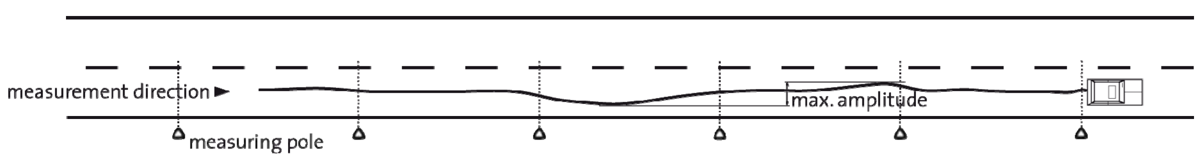
3.4 Sought-after values

Despite the different section characteristics the same sought-after values are respectively in the focus of all measurements. These describe the range of the lateral movement and the passing distances between two vehicles (cp. chap. 2-1).

3.4.1 Range of lateral movement

The data acquired by measuring poles is used for the determination of the lateral movement range. The detected distances between the vehicles and the individual poles are considered. With these bases the driving trajectory is reconstructed for every vehicle by using a cubic spline interpolation. The range of lateral movement arises from the maximum amplitude of the calculated trajectory (cp. figure 8). To exclude systematic failures at this consideration, a straight track section is a prerequisite.

Figure 8 Schematic view of the range of lateral movement



To be able to represent the trajectory regarding the vehicle longitudinal axis, the dimensions of the individual vehicles also must be ascertained. For this the LMS detects width as well as length of every moving object. Furthermore the dimensions are necessary to be able to carry out a classification of the vehicles. The vehicles are subdivided into the categories passenger car (PC), heavy good vehicles and busses (HGV) and bicycles (BC).

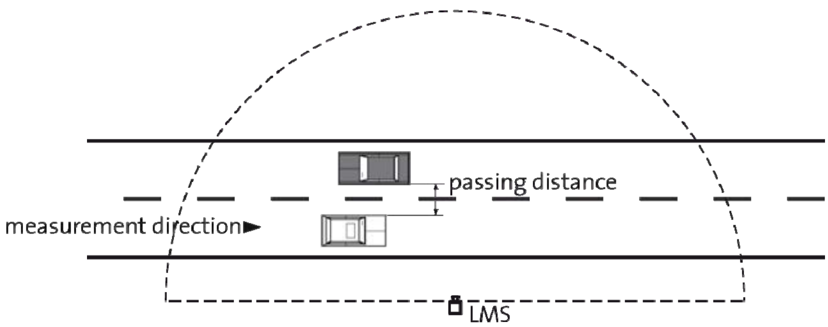
3.4.2 Lateral passing distances

Lateral passing distances between two vehicles or a vehicle and a bicycle are recorded in the sensor area of the LMS (cp. figure 9). The distances are measured between vehicle flanks turned towards each other during the passing. Three passing cases are distinguished:

- Overtaking
- Passing oncoming vehicle
- Overtaking of a bicycle

The passing case "overtaking" is only ascertained for measurements on two-lane highways. Unlike the measurements on non urban roads with speed limit 80 km/h and on urban roads, this case represents the decisive passing case here. Despite that, overtaking manoeuvres appear also at the other roads, they are no assessment basis in the VSS standards.

Figure 9 Schematic view of the passing distance



In the passing case "passing oncoming vehicle" the lateral distance between two contra flowing vehicles is measured. The amount of samples is a subset from the amount raised for the derivation of the range of lateral movement of individual vehicles. It consists of the vehicles which pass an oncoming vehicle in the sensor area of the LMS.

4. Status quo

At this time all measurements have been concluded. Actually the raw data is beeing transformed into analysable datasets.

Next is the evaluation of sought-after values for all measurement track sections regarding the above mentioned methods.

The research will presumably be concludet in the beginning of the year 2009.

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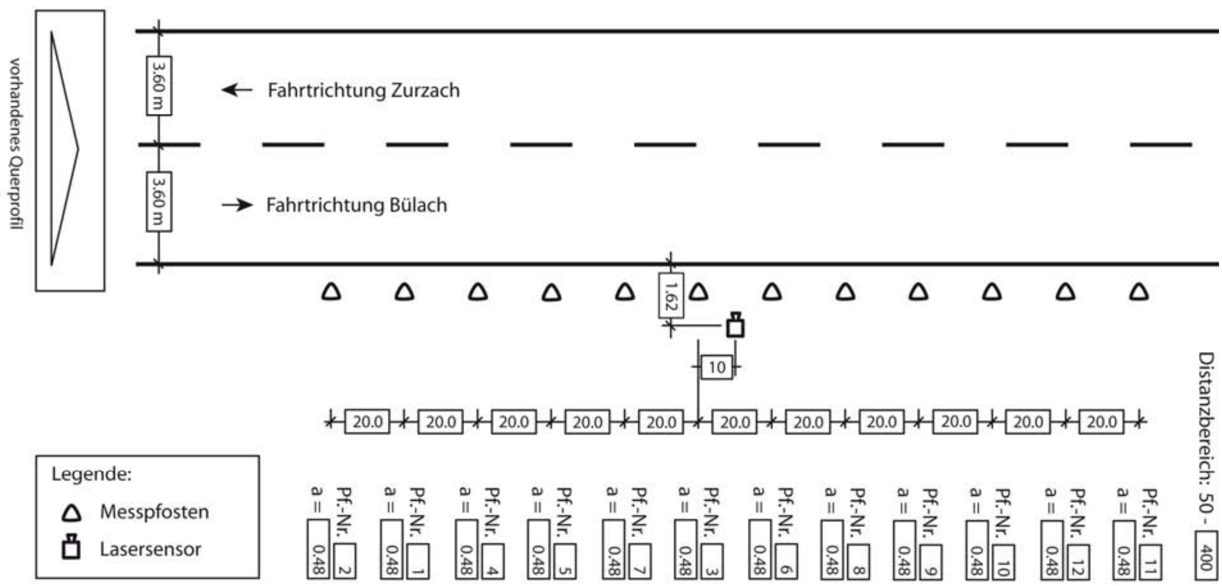
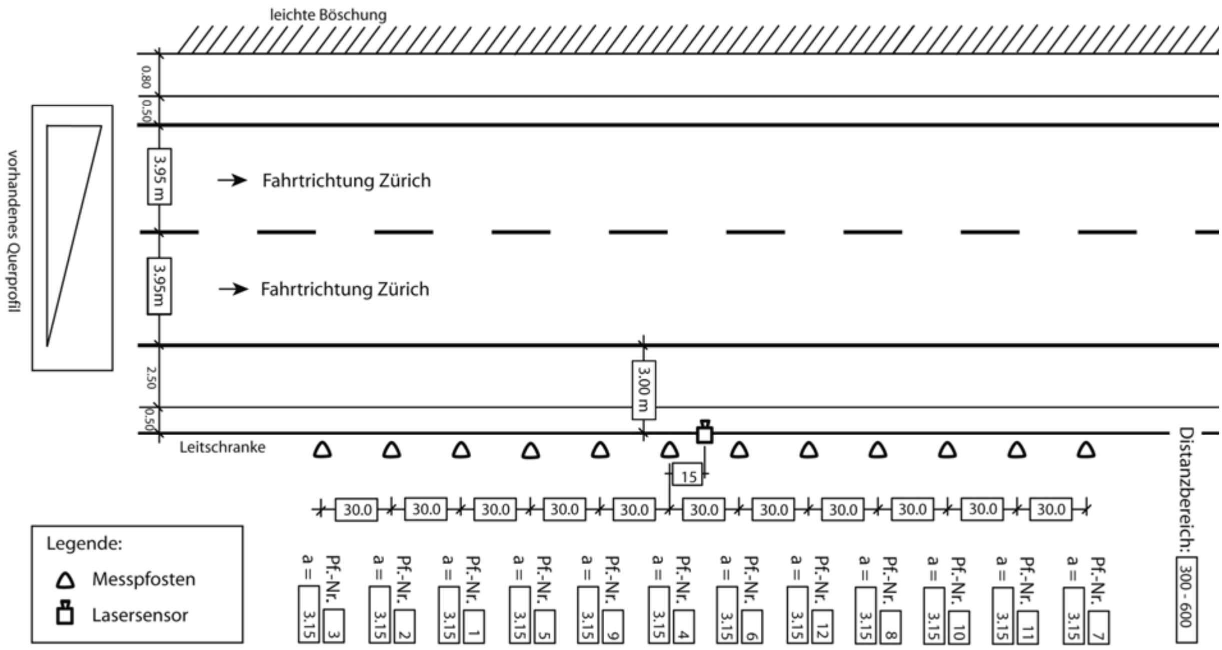
Appendix

Appendix 1 Schematic view of the measuring set-up on a non urban road



Appendix 2 Schematic view of the measuring set-up on a highway



Appendix 3 Schematic view of the measuring set-up on an urban road with traffic island