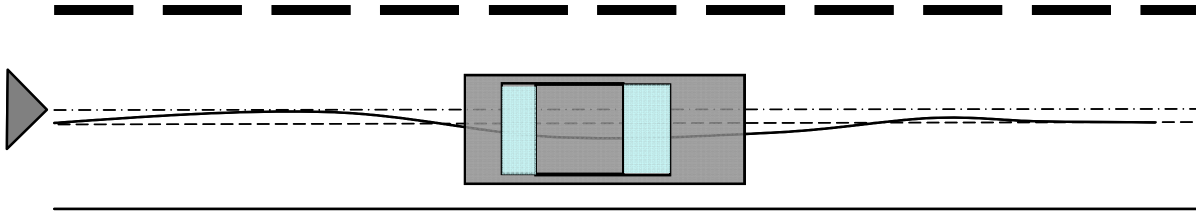

Lateral driving behaviour

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Lateral driving behaviour

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Abstract

The aim of the research is to provide a scientific base for the derivation of reference values for the range of lateral movements in road traffic. The range of movement is regarded as the amplitude of a vehicle trajectory on a straight track section. The movement can be caused as a result of the steering clearance, road unevennesses, wind influences etc. The corresponding reference values are derived from empirical data.

Keywords

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

1. Preamble

This work bases on the research concerning the standard profile of cross section for all vehicle types [Santel, Spacek, 2010] and the research work on lateral driving behaviour [Santel, 2010]. It builds up on the presentation at the STRC08 regarding the standard profile of cross sections [Santel, 2008]. Important points are represented and summarized.

2. Initial situation

Up to now there is no or only few knowledge of the lateral driving behaviour of vehicles. Especially the influences of several criteria, such as the vehicle speed, the carriageway width, the vehicle status (individual vehicle / vehicle groups) and whether there is a passing vehicle or not, are extensively unknown.

The aim of the research is to provide a scientific base for the derivation of reference values for the range of lateral movements in road traffic. The range of movement is regarded as the amplitude of a vehicle trajectory on a straight track section. The movement can be caused as a result of the steering clearance, road unevennesses, wind influences etc. The corresponding reference values are derived from empirical data.

The range of lateral movements depends on several criteria to be taken into account. The most important technical criteria consist of:

- the vehicle speed
- the carriageway width
- the vehicle status (individual vehicle / vehicle groups)
- the operation mode (road with directional or contraflow traffic)
- possible passing of contraflowing or overtaking vehicles

In real traffic flow the influences mentioned above often overlap. During measurements, the separate recording of the single influences and their superposition therefore were ensured.

3. Measurements

The described influence variables result in a large number of combinations. A first estimate from previous experiences and conclusions from literature shows that for example approx. 20 measurements are required on 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.

3.1 Measurement track sections

The lane width, the speed limit and the lateral obstacle clearance are the main characteristics which may influence the driving behaviour. Therefore measurement tracks were looked after which differ regarding to these criteria.

For the examination, five urban roads with a speed limit of 50 km/h, 23 non urban roads and five sections on highways were distinguished. All these types are traffic oriented streets. In addition to these, measurements on two urban roads with a speed limit of 30 km/h were carried out. Besides all other requirements a relative geographical proximity to the domicile of the research institute was aspired.

For the choice of measurement tracks it was 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.

3.1.1 Sections on non urban roads

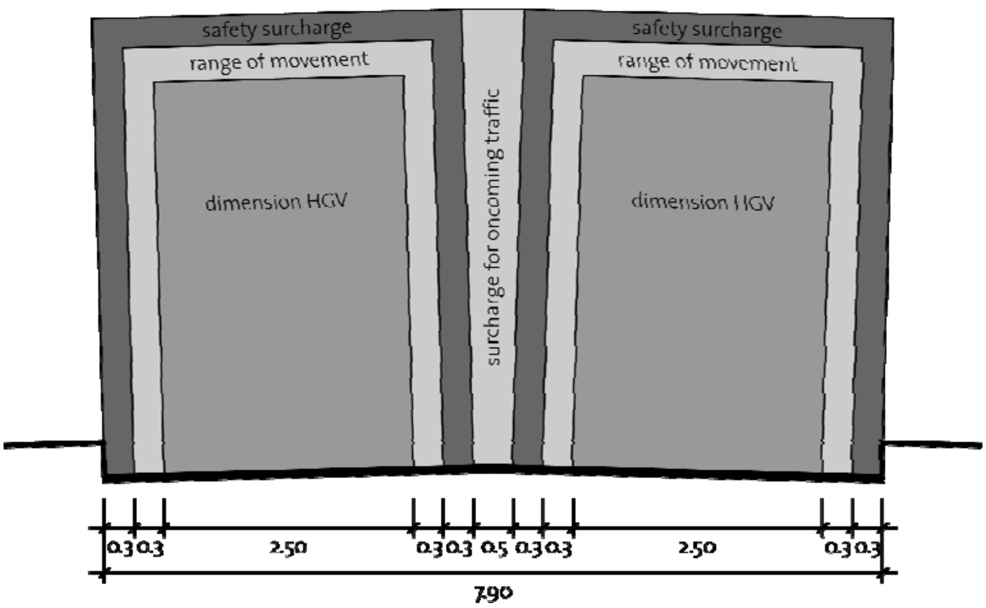
Altogether, 23 measurement track sections on non urban roads in the cantons of Zurich, Thurgau, Argovia and Schaffhausen with a signalled maximum speed of 80 or 100 km/h were surveyed. These can be put into different categories in order of road width. For the examination on hand the categories were “narrow”, “regular” and “wide”.

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

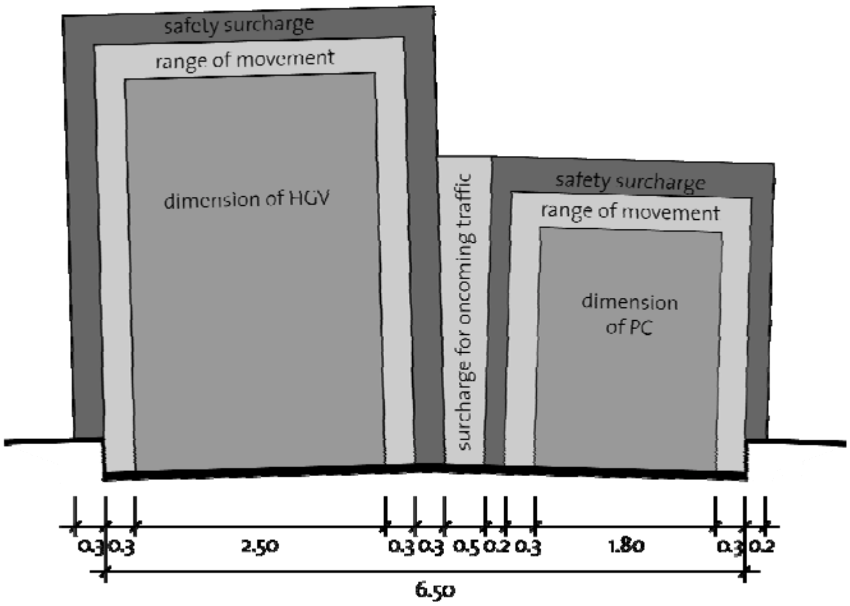
A cross section is considered to be regular if it is dimensioned (according to SN 640 201) for the passing case of two heavy goods vehicles (HGV) (with the outer safety surcharge beyond the carriageway). The cross section consists of the basic measurement of two HGV (2.5 m each), the range for lateral 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 1).

Figure 1 Cross section HGV - HGV [m]



At the minimal passing case HGV – passenger car (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 6.5 m results (cp. figure 2).

Figure 2 Cross section HGV – PC [m]



3.1.2 Sections on urban roads

The track sections on urban roads can be divided into three groups. The distinguishing factors are the section characteristic and 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 separation therefore gets applied at speed limit of 50 km/h:

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

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. Analog to the above assumption this corresponds to regular wide 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 5.20 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.

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. All sections are found in the city of Zurich.

3.1.3 Sections on highways

The traffic flow on highways could be measured on five track sections in the cantons of Zurich, Thurgau, Grisons, Lucerne and Argovia. All sections are motorways with structurally separate carriageways.

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

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 a 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.

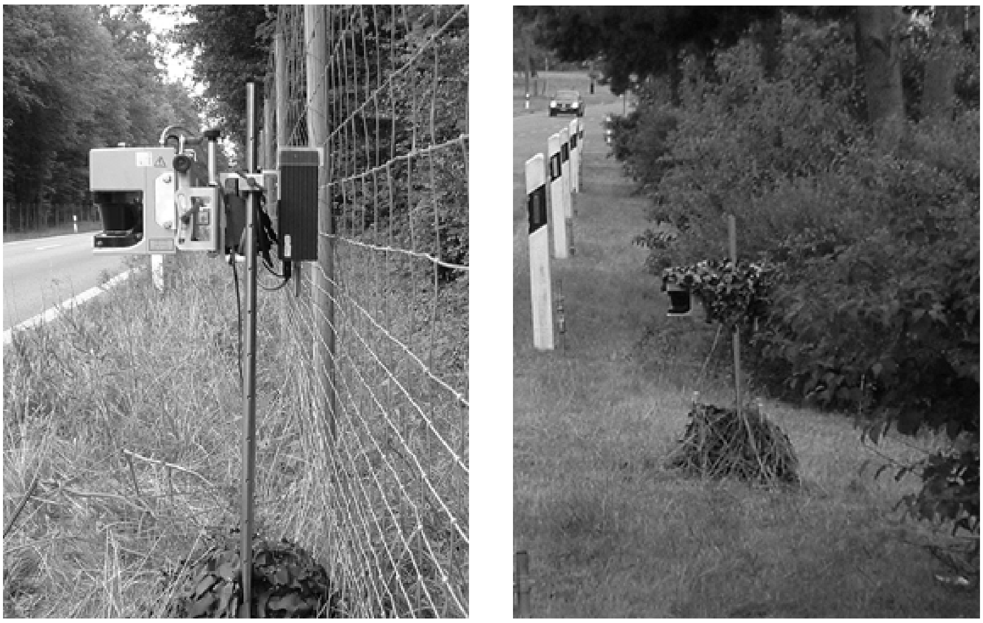
3.2 Measurement devices

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.

3.2.1 Laser measuring system

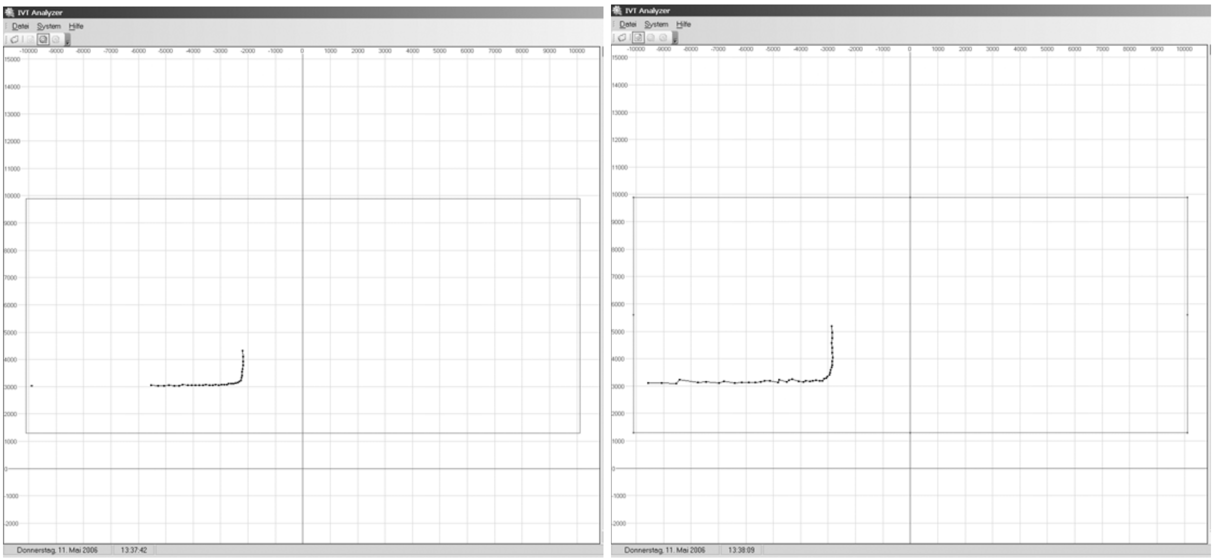
The laser measuring system (LMS) was developed to acquire the position of moving objects and to follow them. Vehicles in the sensor area of the LMS are recognized with the vehicle flanks turned towards the LMS. Besides the current position, vehicle data such as length and width as well as the vehicle speed can be derived. The system consists essentially of the laser sensor and a recording computer (cp. figure 3).

Figure 3 Laser measuring system (LMS)



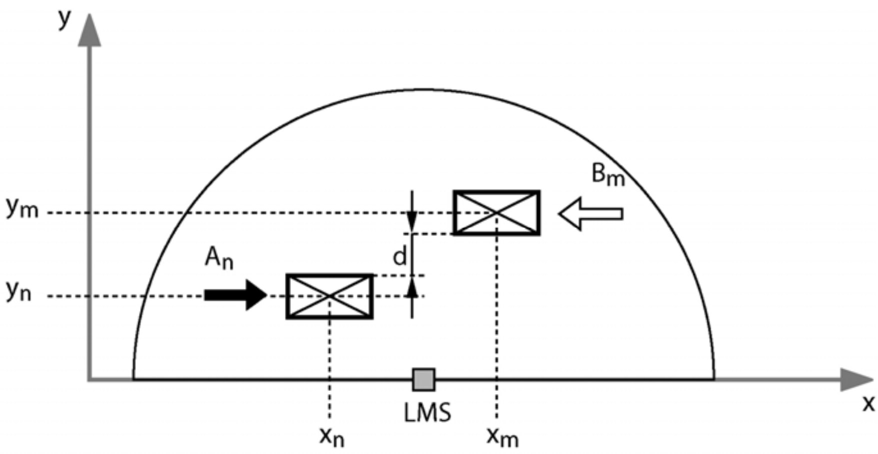
The measured raw data consists of XY coordinates. These points represent the object surface related to the sensor location in an arch distance of one degree. In a first step the data is filtered and the sets of points of the moving objects get separated from background points (cp. figure 4).

Figure 4 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 5 Coordinate system of the LMS

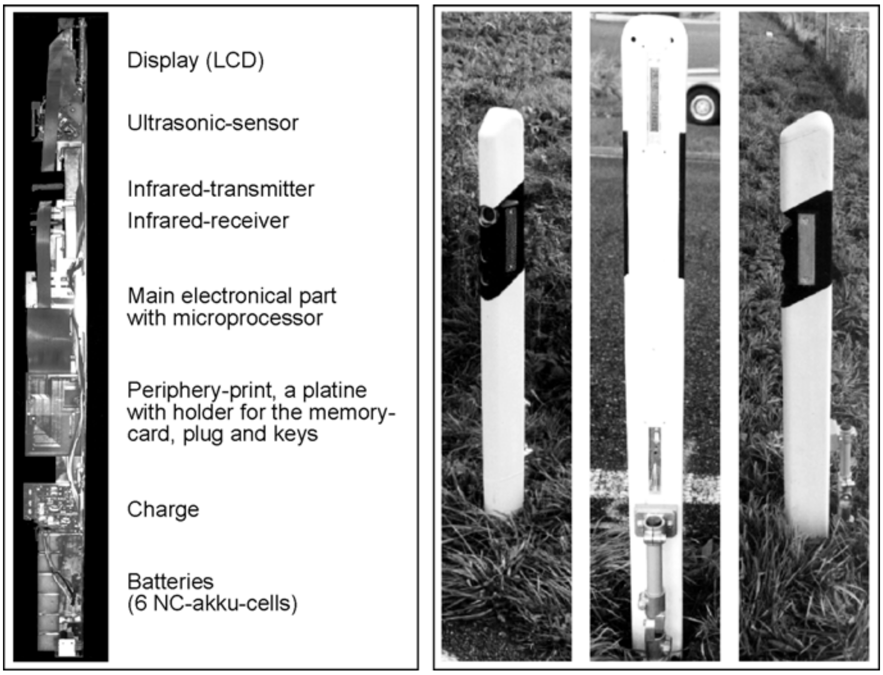


Moreover, the LMS can distinguish, whether a vehicle was influenced by oncoming traffic. In the case of overtaking or oncoming traffic in the sensor field, the passing distances between the vehicles can be determined (cp. figure 5).

3.2.2 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 6). 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 6 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.

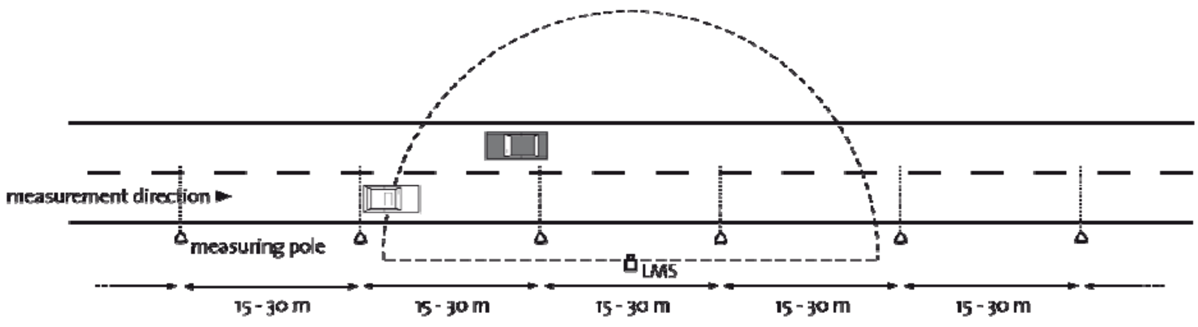
Up to 12 measuring poles were used for the acquisition of the driving behaviour at track sections on non urban roads. The number of poles at the track sections on urban roads was reduced due to the length of the available section.

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.

3.2.3 Combination of the measuring devices

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 7 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.

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.

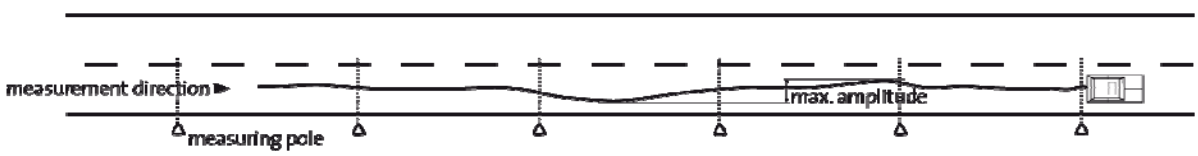
On average, 1000 vehicles could be measured at every single track section examined. The acquired data contains individual vehicle trajectories, vehicle speed, passing distance between two vehicles and time gap between vehicles.

3.3 Sought-after value

The range of lateral movement is regarded as the amplitude of a vehicle trajectory on a straight track section caused by unconscious reactions, steering clearance, road unevennesses, wind influences etc.

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).

Regarding to the Swiss Standard [SN 640 200a] the range of lateral movement is defined as a speed dependent surcharge. It is a cross section related parameter. Related to the research into lateral driving behaviour, this definition is inadequate. For measuring of the lateral amplitude a minimum track section length had to be determined. This has been done in the research work on lateral driving behaviour [Santel, 2010]. The results are shown in Table 1.

Table 1 Minimum section length

speed limit	minimum section length
50 km/h	87 m
80 km/h	128 m
120 km/h	185 m

Referring to this, all chosen measurement tracks possess the required length to determine the amplitude of lateral movement.

4. Results

The evaluation of the individual measurement sections was followed by the comparison of section groups with different characteristics. So it was possible to quantify the influences of the factors given by the traffic situation or the properties of the track sections.

In the following sub chapters the influences and correlations for the factors

- vehicle status (individual vehicle / vehicle groups),
- passing vehicles,
- type of vehicle,
- the vehicle speed and
- the carriageway width

are shown.

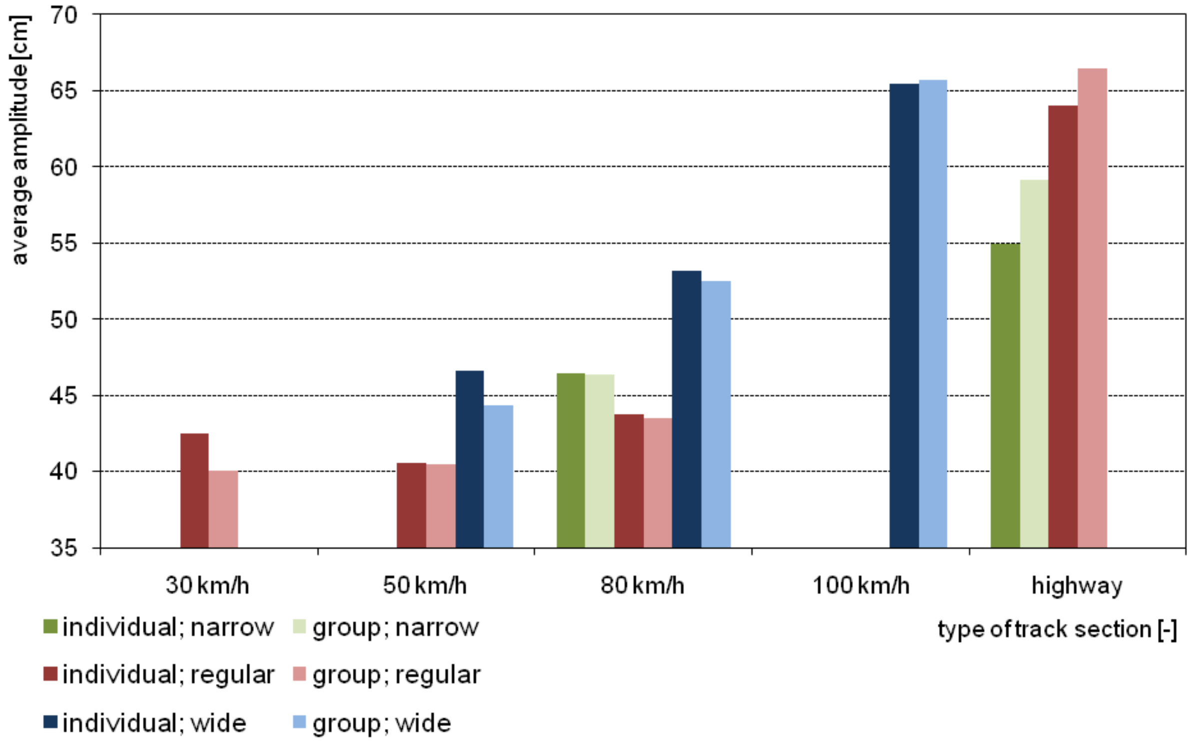
In the research work concerning the “Standard profile of cross section for all vehicle types” [Santel, Spacek, 2010] the influences on the lateral movement were determined and tested for statistical significance at a significance level of 1 % by single- or multi-factorial ANOVA.

4.1 Influence of vehicle status

In this evaluation 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 decision whether a vehicle is an unhindered, individual vehicle or not, was done by the time gap to the forerunning vehicle. According to the research on “Standard profile of cross section for all vehicle types” vehicles with time gaps of over 2 seconds at speed limit 50 km/h, 4 seconds at speed limit 80 km/h and 6 seconds on highways are individual vehicles.

Figure 9 shows the average amplitude of lateral movement for individual vehicles and vehicle groups. These amplitudes are subdivided into three groups of carriageway widths (narrow, regular and wide) and four types of track sections (speed limit 30, 50, 80, 100 km/h and highways).

Figure 9 Influence of the vehicle status



The values for the average amplitude (μ), standard deviation (σ) and the number of measured vehicles (n) are shown in table 2.

Table 2 Influence of the vehicle status

type of track section	carriageway width narrow n [-]	μ [cm]	σ [cm]	regular n [-]	μ [cm]	σ [cm]	wide n [-]	μ [cm]	σ [cm]
average amplitude of individual vehicles									
30 km/h				517	42.5	20.8			
50 km/h				1568	40.6	17.4	1119	46.6	19.6
80 km/h	1175	46.5	20.8	3146	43.7	21.4	1684	53.2	22.9
100 km/h							689	65.4	27.9
highway	1185	54.9	26.8	584	64.0	34.4			
average amplitude of vehicle groups									
30 km/h				66	40.1	14.4			
50 km/h				277	40.5	18.0	196	44.4	19.9
80 km/h	222	46.4	19.6	3879	43.5	22.0	841	52.5	21.4
100 km/h							677	65.7	27.6
highway	1414	59.1	31.4	882	66.5	36.9			

The analysis and the statistical test show coherences between the vehicle status and the amplitude of lateral movement only for highways. In all other cases the vehicle status has no influence on the range of lateral movement.

For further considerations only vehicles on highways were divided regarding the vehicle status. For all other types of track sections individual vehicles and vehicle groups were combined.

4.2 Influence of passing vehicles

Besides the vehicle status, the passing of contraflowing or overtaking vehicles might have an influence on the lateral movement as well. So in a second step this factor was considered. The table 3 shows the average amplitudes of lateral movements for PCs and HGVs with and without passing vehicles and the differences between both cases. Again the values are subdivided into three groups of carriageway widths (narrow, regular and wide) and six types of track sections (speed limit 30, 50, 80, 100 km/h, highways individual, highways groups). The additional division between individual vehicles on highways (hw individual) and vehicle groups on highways (hw groups) is the result of the previous consideration (cp. 4.1).

Table 3 Influence of passing vehicles

type of track section	carriageway width: narrow, passing: without	with	difference	regular, passing: without	with	difference	wide, passing: without	with	difference
average amplitude of passenger cars [cm]									
30 km/h				40.5	42.0	1.4			
50 km/h				40.4	40.1	-0.3	47.0	46.3	-0.7
80 km/h	46.8	49.7	2.9	48.0	43.3	-4.7	53.3	53.9	0.6
100 km/h							68.3	65.0	-3.3
hw individual	56.9	62.7	5.9	64.6	77.6	13.0			
hw groups	62.4	64.5	2.1	68.8	72.1	3.3			
average amplitude of heavy goods vehicles [cm]									
30 km/h				42.9	31.5	-11.4			
50 km/h				34.3	35.2	0.9	38.5	37.2	-1.3
80 km/h	37.2	45.2	8.0	37.9	33.6	-4.2	48.5	38.7	-9.8
100 km/h							54.5	51.5	-3.0
hw individual	40.8	48.8	8.0	53.9	43.8	-10.1			
hw groups	44.9	42.6	-2.3	47.3	54.4	7.2			

For both types of vehicles (PCs, HGVs) the considerations and statistical tests do not show any significant influence of passing vehicles. This applies for all types of track sections as well for all carriageway widths and for all combined influences. However there is a systematically influence of passing vehicles. On narrow track sections the amplitude is larger in cases with passing. On wide track sections the amplitude turns to be little smaller in cases with passing vehicles. This can be explained by the intentional dodge in case of an oncoming vehicle on narrow sections. On wide sections the driver aim for directional stability to keep a safety distance to the oncoming vehicle.

4.3 Influence of vehicle type

To test the influence of different vehicle types on the lateral movement, vehicles got allocated into the three groups PC, HGV and two-wheeler (TW). Figure 10 shows the average amplitude of lateral movement for these types of vehicles itemised by types of track sections and the carriageway widths.

Figure 10 Influence of the vehicle types

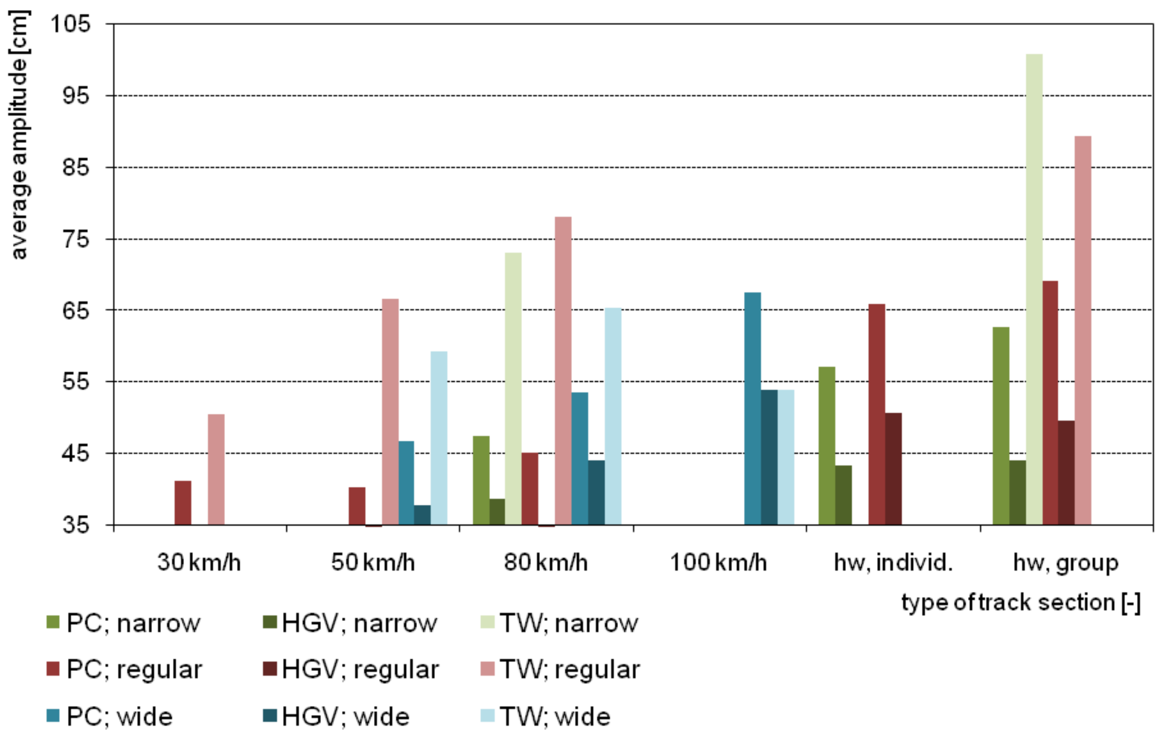


Table 4 shows the related values for the average amplitude (μ), standard deviation (σ) and the number of measured vehicles (n).

Table 4 Influence of the vehicle types

type of track section	carriageway width								
	narrow			regular			wide		
	n [-]	μ [cm]	σ [cm]	n [-]	μ [cm]	σ [cm]	n [-]	μ [cm]	σ [cm]
average amplitude of PCs									
30 km/h				437	41.1	20.5			
50 km/h				1376	40.3	16.8	1039	46.7	19.1
80 km/h	1119	47.4	20.5	5317	45.0	22.0	2099	53.5	22.4
100 km/h							1092	67.5	28.1
hw individual	909	57.1	27.5	447	66.0	35.4			
hw groups	1071	62.7	32.6	706	69.2	37.9			
average amplitude of HGVs									
30 km/h				10	34.9	15.1			
50 km/h				86	34.7	15.2	57	37.8	16.1
80 km/h	41	38.6	21.0	465	34.8	15.8	82	44.1	19.5
100 km/h							82	53.9	20.6
hw individual	84	43.3	21.6	44	50.7	26.0			
hw groups	101	44.0	18.8	55	49.6	22.3			
average amplitude of TWs									
30 km/h				49	50.5	18.0			
50 km/h				39	66.5	23.7	8	59.2	41.9
80 km/h	9	73.1	28.6	19	78.1	30.0	20	65.4	21.8
100 km/h							-	-	-
hw individual	-	-	-	-	-	-			
hw groups	3	100.7	54.3	1	89.4	-			

While examining the influence of the vehicle type on the lateral movement the low number of two-wheelers (TW) has to be taken into account. The considerations and statistical tests show a statistical significant influence of the vehicle types for all types of track sections and all carriageway widths. HGVs have significant smaller amplitudes than PCs and TWs. This can on the one hand be explained with HGVs having a smaller amount of space to their disposal than PC because of the different vehicle dimensions. On the other hand HGVs have a higher dynamic stability because of their greater axis-centre distance, and greater weight.

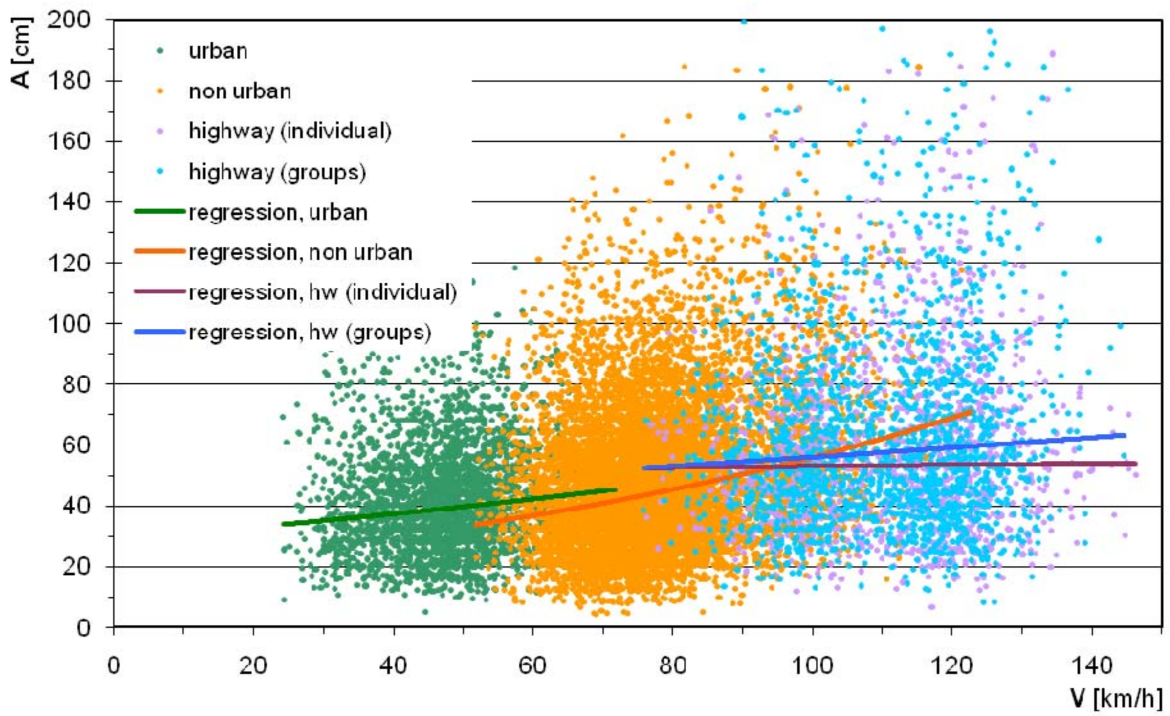
Therefore for the interpretation of the range of lateral movement it has to be differed between the various types of vehicles. Two-wheelers are not considered in the further analysis.

4.4 Influence of vehicle speed

The previous analyses already showed an influence of the various groups of speed limits. The influence variable "speed" can be interpreted as a dispersive influence value. The extent of velocity is influenced by the choice of measurement track sections according to the category of street and signalised speed limit.

Figure 11 shows the speed (V) and the amplitude of lateral movement (A) for all passenger cars divided into different groups of track sections. The lines represent the exponential regression for each group.

Figure 11 Influence of the vehicle speed for PCs



By increasing speed also the range of lateral movement increases. This fact does apply for all types of track sections and for PCs as well as for HGVs. PCs show an average amplitude of ca. 35 cm at the speed of 25 km/h and an average amplitude of over 70 cm at non urban roads at the speed of 123 km/h.

Besides the general dependency of the vehicle speed on the amplitude of lateral movement, differences between the track section types are obvious. The according values for the average amplitude (μ), standard deviation (σ) and the number of measured vehicles (n) can be seen in table 4.

Statistical test by an analysis of co-variances (ANCOVA) shows a statistical proof coherence between the speed and the lateral amplitude especially for the non urban roads.

4.5 Influence of carriageway width

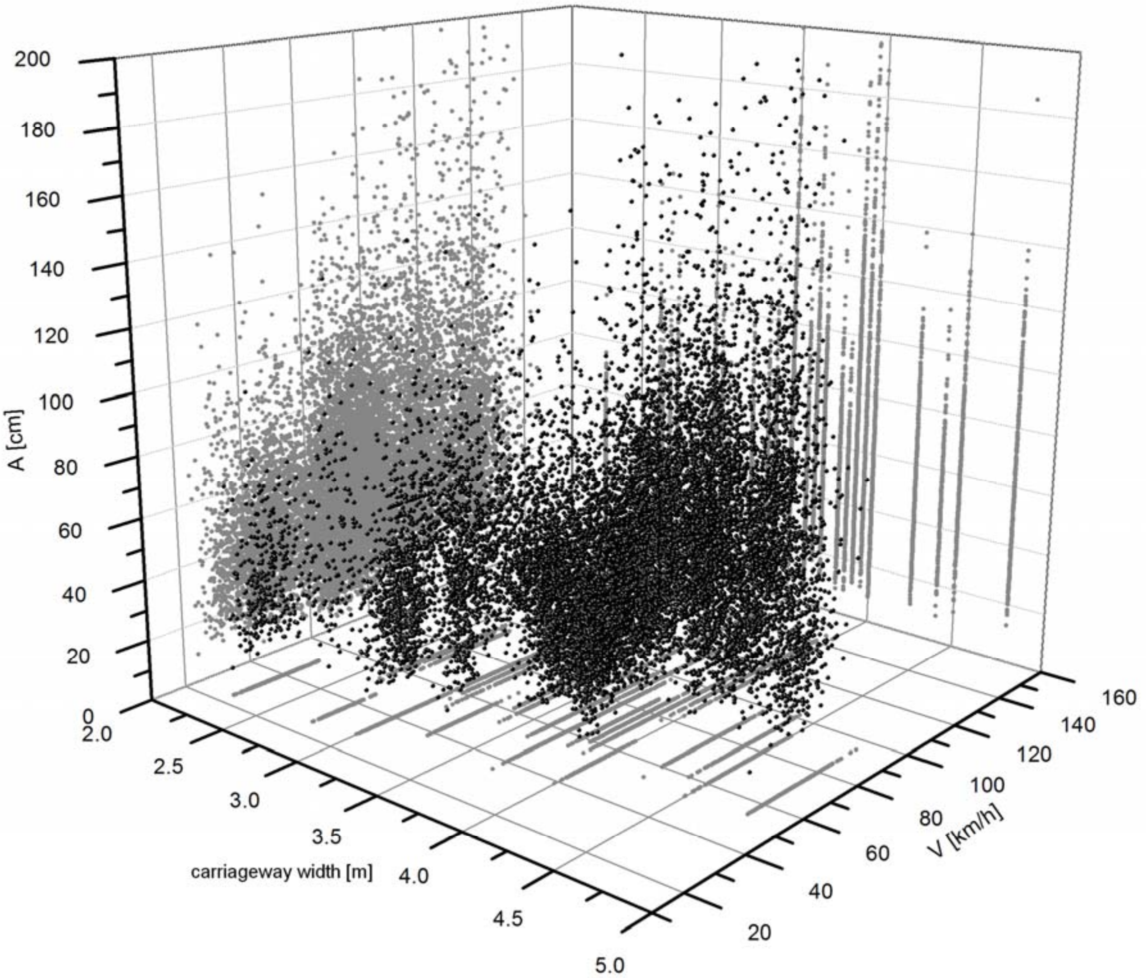
At the previous influence considerations the different carriageway widths were already taken into account as an essential factor. At the considerations the track sections were subdivided due to their carriageway width into the categories "narrow", "regular" and "wide".

At the examination regarding the influence of the vehicle status the category of the carriageway widths was already introduced as a broader factor. The coherences represented in figure 9 clearly show different average lateral amplitudes for narrow, regular and wide carriageways. At track sections with speed limit 50 and 80 km/h lower average amplitudes appeared on narrow carriageways than on regular or wide carriageways.

The figure 12 shows the combined influences of driven speed (V), carriageway width and lateral amplitude (A) for passenger cars. The illustration confirms the mentioned dependences of the lateral movement of the driven speed and the carriageway width. Besides these dependences the figure also shows coherences between the carriageway width and the driven speed. These are based on the project planning according to the Swiss standard [SN 640 200a]. It contains quantitative reference values to the assessment of the elements of 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 streets with a higher design speed have wider carriageway than streets at a lower speed level.

The considerations and statistical tests show a significant influence of the categories of carriageway widths for all types of track sections for PCs as well as for HGVs. Such as shown in figure 12 the lateral amplitude rises with the carriageway width.

Figure 12 Combined influence of the vehicle speed an carriageway width for PCs



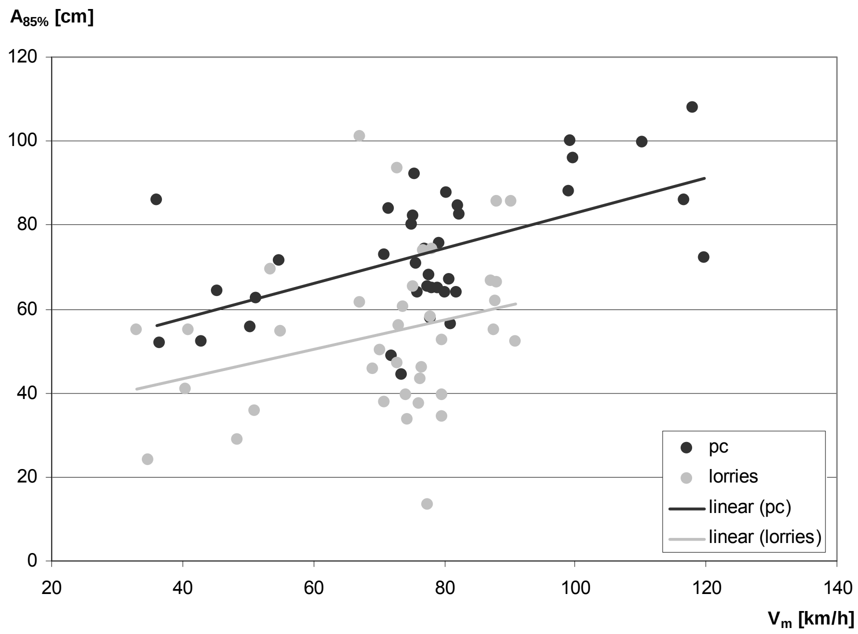
5. Conclusions

The analyses of the lateral movement shows more or less definite influences of the factors mentioned above. Further on these influences can be quantified and therefore base for the derivation of reference values for the range of lateral movements in road traffic.

The research work on the Swiss standard for the geometric standard profiles of cross sections [Santel, Spacek, 2010] includes this quantification of reference values. The lateral movement for example is considered by the value of the 85 %-Amplitude in the range of movement or in the surcharge for overtaking and oncoming vehicles.

The figure below exemplarily shows the influence of the average speed on the range of lateral movement (85 %-amplitude) at single examination stretches for passenger PCs and HGVs (lorries).

Figure 13 Influence of average speed (Vm) on range of lateral movement (A85%)



This already indicates that the existing standards are insufficient. They do not distinguish between the different vehicle types regarding the range of movement. A revision of the existing standard seems to be necessary.

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