Speed on upgrades and downgrades

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Abstract

It has been more than 20 years since the speed behavior of passenger cars and heavy vehicles on upgrades and downgrades was last investigated in Switzerland. At that time rural highways were subject to a general speed limit of 100 km/h. No comprehensive surveys were undertaken after the introduction of the general speed limit of 80 km/h. In the case of heavy vehicles, new surveys were also necessary in view of the intention to allow vehicles of up to 40 metric tons in weight (instead of 28 tons).

The aim of this research project is to determine the changes in the relationship between vertical alignments and vehicle speed and thus to enable any desirable modifications to the relevant design standards to be made. The speed on upgrades and downgrades relates, directly or indirectly, to several geometric design standards and in particular to the standard for "auxiliary lanes on upgrades and downgrades". The results of this study are based on approximately 40 surveys in traffic flow on freeways and main rural highways, and upon complimentary simulation calculations.

Keywords

speed diagramm – standard truck – speed behavior – upgrades – downgrades – Swiss design standards – heavy vehicles – STRC 2005 – Swiss Transport Research Conference

1. Background

Speeds are fundamental for the design of highways that have to be aligned according to the principles of driving dynamics. The speed model in the existing Swiss design standards is based upon physical calculations. The effective running speeds serve only as comparative values for the model. These running speeds are mainly influenced by road geometry and by speed limit. Regarding the road geometry, the driven speeds primarily depend on curve radii but the speed behavior of heavy vehicles is also influenced by the vertical alignment.

It has been more than 20 years since the speed behavior of passenger cars and heavy vehicles on upgrades and downgrades was last investigated in Switzerland. The existing design principles for upgrade sections are based on that research carried out in the 1980s. At that time rural highways were subject to a general speed limit of 100 km/h. No comprehensive surveys were undertaken after the introduction of the general speed limit of 80 km/h. Aditionally the legal mimimum power-to-weight ratio was 10 hp/t (7.5 KW/t) for heavy vehicles with a limit of 28 tons for the gross weight at that time.

In the case of heavy vehicles, new surveys were also necessary with regards to allowing vehicles of up to 40 metric tons in weight. The heavy vehicle quotas agreed in the bilateral negotiations with the European Union came into effect on 1 January 2001[1], therefore one of the aims at the start of this study in 1999 was to undertake surveys in the "before" situation (weight limit of 28 tons). The effects of the increased weight limits (or of the thus reduced legal mimimum power-to-weight ratio for heavy motor vehicles to 6.8 hp/t resp. 5.0 KW/t) on speed behavior were investigated through corresponding measurements in the summer of 2002, which represent the "after" situation.

2. Research aim

The aim of this research project is to determine the effects of the adjusted regulations and therefore the changes in the relationship between vertical alignments and vehicle speed. Therefore, this enables any desirable modifications to the relevant design standards to be made. The speed on upgrades and downgrades relates, directly or indirectly, to several Swiss geometric design standards and in particular to the standard for "auxiliary lanes on upgrades

[1] Limited annual quotas of HVs were approved between 2001 and 2004; from 2005 there are no longer any limits to the number of HVs with 40 t allowed in Switzerland.

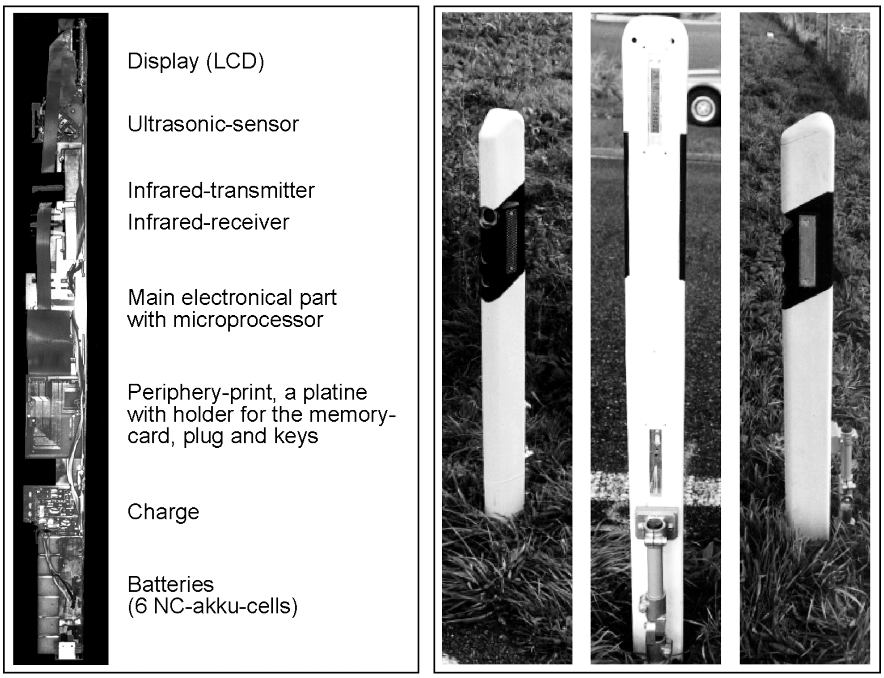
and downgrades" (SN 640 138a). The results of this study are based upon approximately 40 surveys in traffic flow on freeways and main rural highways, and upon complimentary simulation calculations.

3. Measurements and simulation calculations

The selection of appropriate stretches for the conduction of the speed measurements in downgrades and upgrades had to fullfill several criterias. These include constant vertical alignment between 2% and 10%, straight and long enough horizontal alignment, no influence of junctions and curves and no local speed limitations. With regard to these requirements, 12 stretches on main rural highways and 7 stretches on freeways were suitable to be used for speed measurements. The stretches on freeways were located on the “North-South-Axis” which is used by transalpine freight traffic and therefore the effects of the new weight limit of 40 tons would have to be recognizable.

The measuring equipment allows recording speed progression along the stretches. The measuring equipment consists of 12 autonomous measuring poles, which are built into regular delineator poles. The delineator poles serve as housings for instruments and as a camouflage. The individual measuring pole, configured by a special control unit, can detect the pass-through times of the vehicles, their driving direction and the vehicle length (see figure 1).

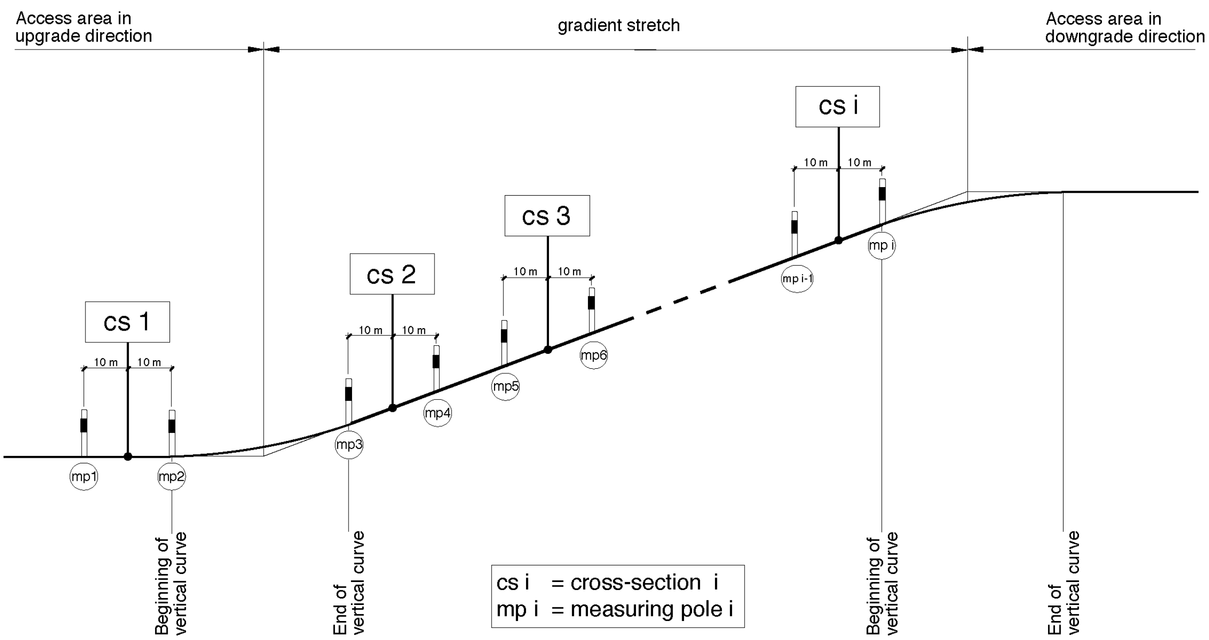
Figure 1 Various views of the measuring pole



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

The measuring set-up along the gradient stretch depended on its length. The length of the upgrade sections enabled to measure the crawl speeds V_D dictated by the gradients. This crawl speed is defined through the $V_{15\%}$ value and is usually representative for loaded vehicles traveling without hindrance. 3 to 6 measuring cross-sections were normally used in upgrades, 1 to 4 in downgrades. One measuring cross-section consisted of two measuring poles in a distance of 20 m. The first measuring cross-section included the access area before the gradient stretch, where speed is not yet influenced by vertical alignment. The following figure shows the principle of the measuring set-up in upgrade direction.

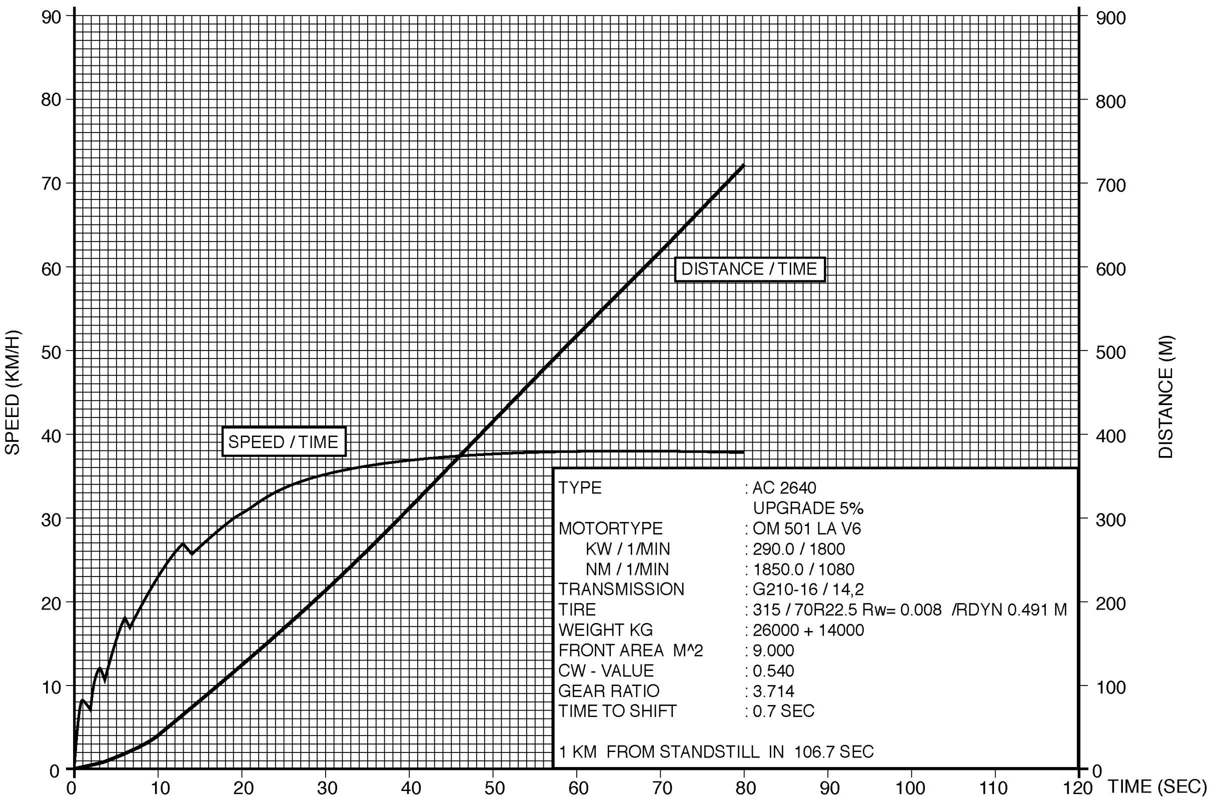
Figure 2 Principle of the measuring set-up in upgrade direction



During the two series of measurements in 1999 (“before” situation) and 2002 (“after” situation) data was collected of several thousand vehicles. As only vehicles traveling without hindrance were of interest (according to the time gap to the vehicle ahead), the amount of heavy vehicles to be analyzed per cross-section was between 120 to 300 on freeways and between 40 to 160 on rural highways.

To verify the measured speed progressions along the gradient stretches, additional simulation calculations were carried out. These simulation calculations included deceleration and acceleration processes of heavy vehicles with different power-to-weight ratios (7.2 / 9.9 / 13.3 / 14.4 hp/t) on various downgrades and upgrades (4% to 8 %). The following figure shows an example of a heavy vehicle with 40 tons in weight and a power-to-weight ratio of 7.2 hp/t accelerating from standstill to crawl speed in a 5% upgrade.

Figure 3 Example of a simulation calculation



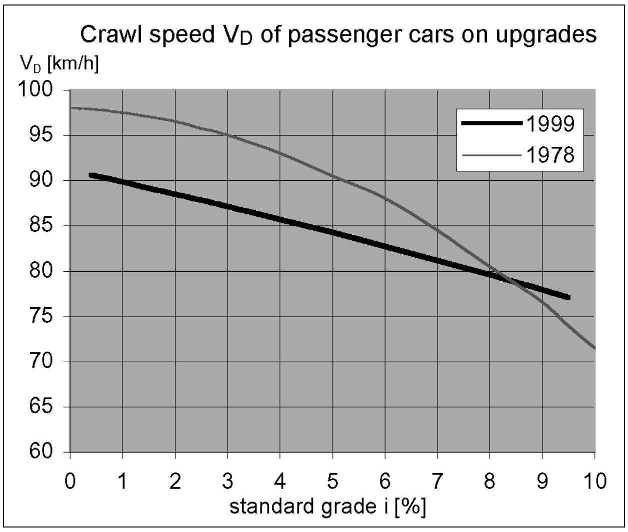
4. Results of the speed measurements

4.1. Passenger cars (PCs)

The speeds of passenger cars have only been evaluated on main rural highways where the speed limit of 80 km/h came into effect. Therefore the measurements on speed behavior of PCs were carried out in 1999 only. According to the speed distribution of passenger cars, which is an indicator of traffic safety, an increased homogeneity was evident in the results from 1999 compared with the ones from 1978. The speed difference between the fast ($V_{85\%}$) and slow ($V_{15\%}$) PCs is about 20 km/h, irrespective of vertical alignment. In 1978 it was approximately 5 to 10 km/h greater than that.

Moreover, on upgrade stretches, in contrast to downgrade stretches, a slight dependence between vertical alignment and speed became apparent. The increased homogeneity referred to above is due to a reduction in the speed of fast PCs above all. It was also established that the sustained speed of passenger cars on upgrades of up to 8% is below that of 1978 – by as much as 8 km/h on low upgrades. Only in the case of very considerable upgrades was a slight increase in speed recorded. These changes may be explained by the reduced speed limit on rural highways from 100 to 80 km/h. Only from upgrades with more than 8% onwards, crawl speed of PCs falls below speed limit (see figure 4).

Figure 4 Comparison of crawl speeds of PCs on upgrades in the years 1978 and 1999



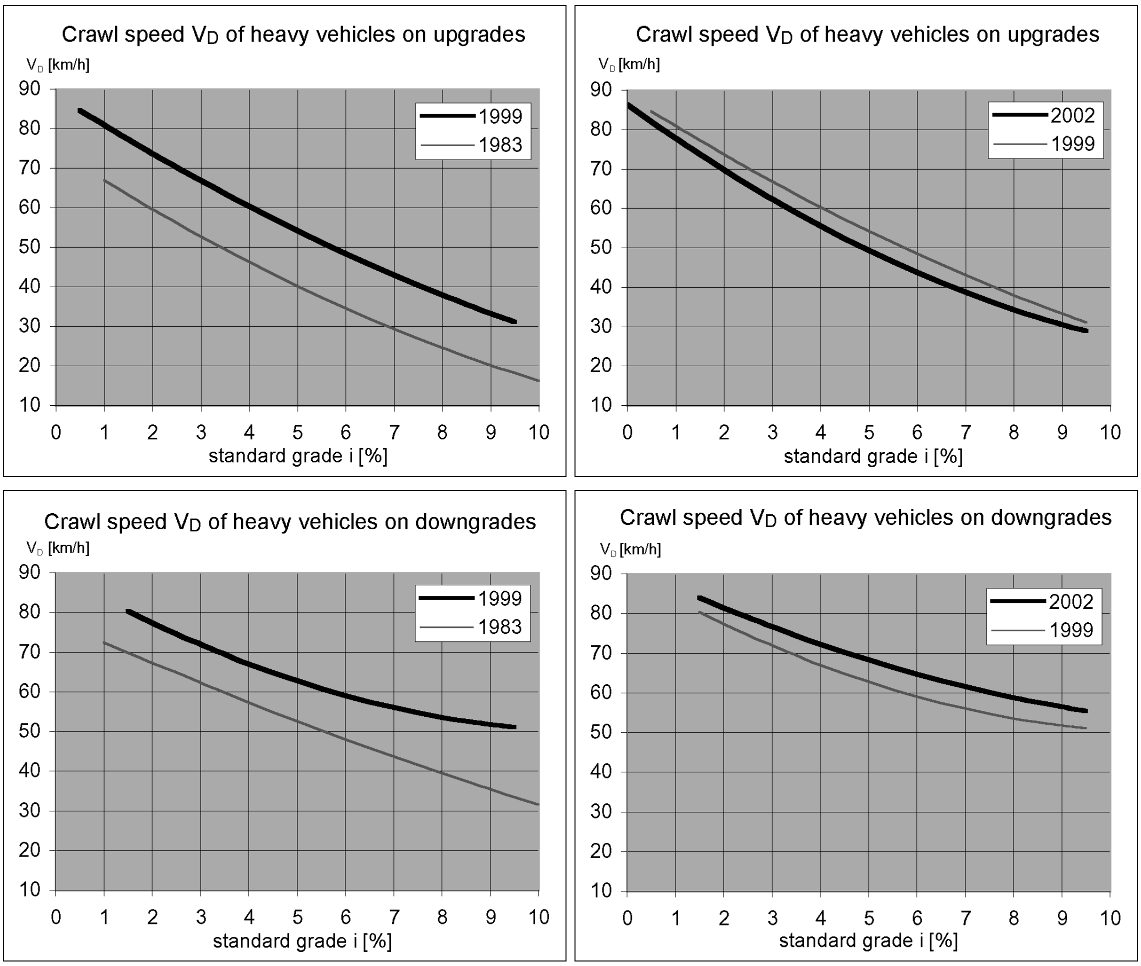
4.2. Heavy vehicles (HVs)

The speeds of heavy vehicles (HVs) have been evaluated both on main rural highways and on freeways (with a speed limit of 80 km/h on both types of roads). As mentioned above, the stretches on freeways were located on the "North-South-Axis" on the A2 from Basle to Chiasso (via Gotthard) and on the A13 (via San Bernadino). These routes are used by transalpine freight traffic and therefore the effects of the new weight limit of 40 tons and the reduced legal mimimum power-to-weight ratio to 5.0 KW/t for heavy motor vehicles would have to be recognizable.

The surveys of 1999 reflected a clear tendency towards a lower speed of HVs as vertical alignment increases, and thus shows a clear correlation between those two parameters. The speed distribution for HVs turned out to be slightly less homogenous than that for PCs. Nevertheless, the speed difference between the fast ($V_{85\%}$) and slow, loaded ($V_{15\%}$) HVs has also markedly declined between 1983 and 1999, resulting in more homogenous speed behavior. The surveys of 2002 showed a slight increase in speed difference on upgrades compared to 1999, while a further reduction was observable on downgrades.

In the case of the $V_{15\%}$, which is representative of the crawl speed of loaded HVs, some very large increases were recorded in both 1999 and 2002 compared to 1983. The measurements of the $V_{15\%}$ on upgrades were slightly lower in 2002 than in 1999, while on downgrades a further increase was recorded (see figure 5). The decrease in crawl speed of heavy vehicles on upgrades in 2002 was less than expected by Swiss authorities before the authorization of HVs of up to 40 tons in weight.

Figure 5 Comparison of crawl speeds of HVs on upgrades (above) and downgrades (below) in the years 1983, 1999 („before") and 2002 („after")



The crawl speed of unhindered heavy vehicles was markedly higher in 1999 than in 1983 both on upgrades (on average +13.7 km/h) and on downgrades (between +10 km/h on low downgrades and +16 km/h on steep ones).

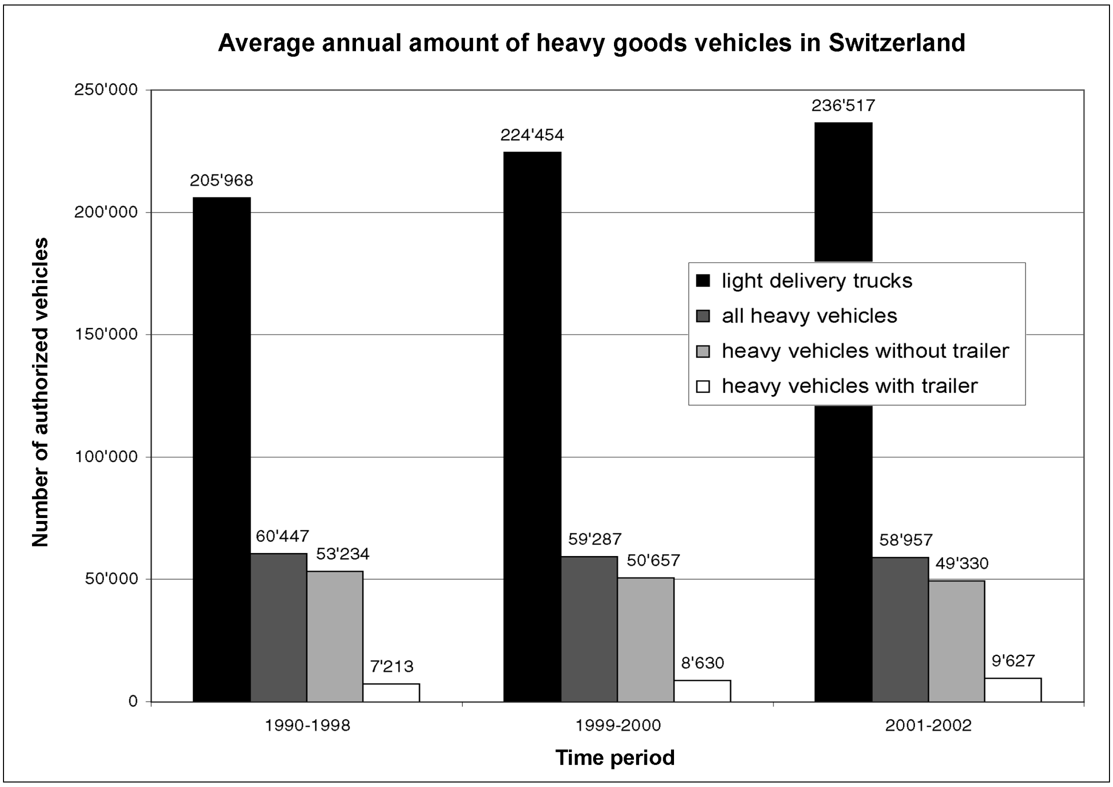
Regarding the effects of the altered power-to-weight ratio and the new weight limit of 40 tons, the surveys of 2002 revealed a slight reduction in crawl speed (-3.8 km/h on average) on upgrades compared to 1999. On downgrades a further increase of the crawl speed (+4.8 km/h on average) was recorded. Nevertheless, the crawl speed of heavy vehicles on upgrades today (2002) is about 10 km/h higher than the results from 1983. Since the speed limit applicable to HVs has not been changed, the increased speed is partly due to technical improvements in the heavy vehicle fleet and partly due to the increased supply by haulage companies of vehicles with superior engines for transalpine freight traffic. This means that they greatly exceed the legal minimal power-to-weight ratio of 5.0 kW/t. That hypothesis was confirmed by analysis of the Weigh-in-Motion (WIM) measurements on the Gotthard route.

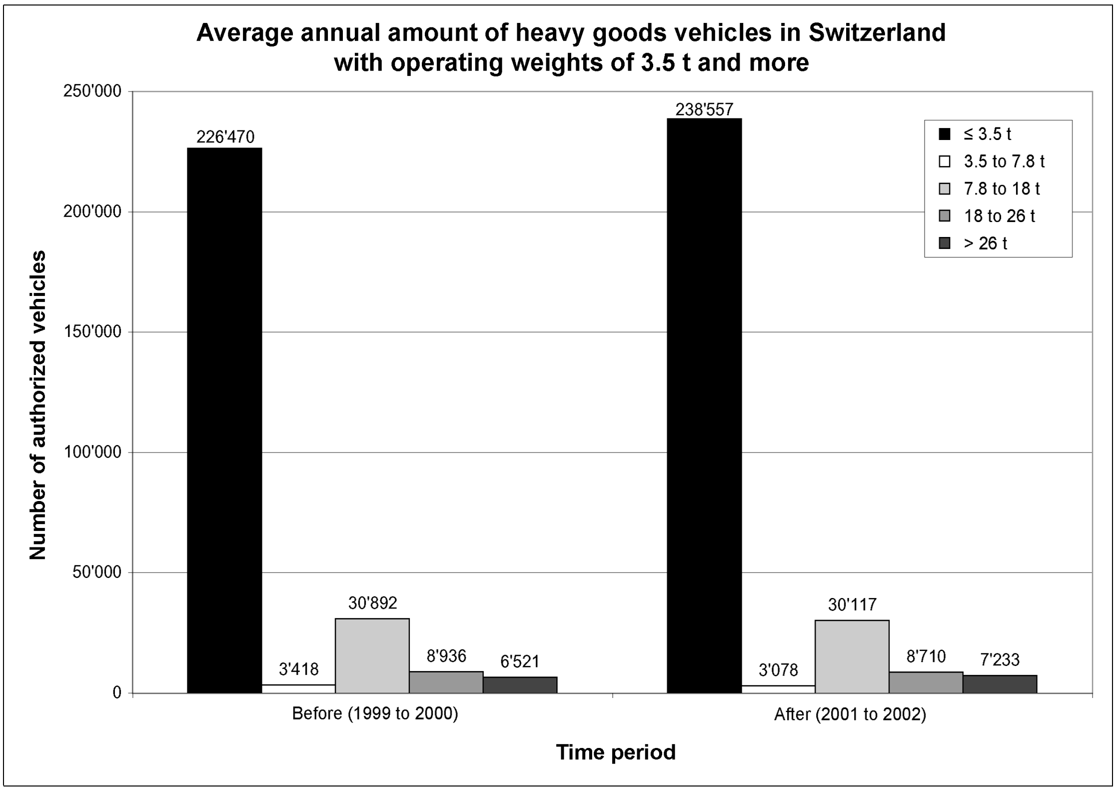
5. Statistical analyses

As mentioned above, the comparison of heavy vehicles on upgrades in the years 1999 and 2002 showed a slight reduction in crawl speed. Furthermore, the heavy vehicle fleet in Switzerland has been statistically analyzed since 1990 for a better understanding of these results (see figure 6).

The analyses have shown that since the introduction of the distance-based heavy vehicle fee (LSVA) in 2001, there have been significant increases in the numbers of light delivery trucks (+5.4%) and particularly of heavy vehicles with trailers (+11.6%). With regard to operating weights (total weight of the vehicle and its load during the journey), an increase of nearly 11% in HVs of over 26 tons was recorded following the introduction of the LSVA, but decreases were evident in the lower weight categories.

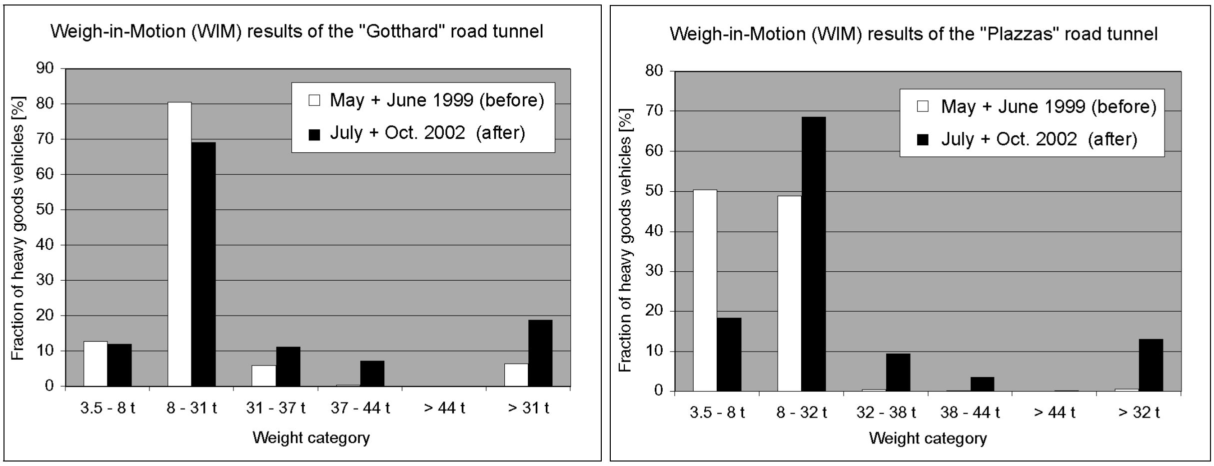
Figure 6 Average annual amount of heavy goods vehicles in Switzerland regarding to category (above) and operating weight (below) before and after the introduction of the distance-based heavy vehicle fee (LSVA)





More important than the changes in the heavy vehicle fleet in Switzerland regarding to operating weights is the situation on the roads where heavy vehicles from all over Europe are traveling. For this purpose the results of the WIM (Weigh-in-Motion) measurements have been analyzed in detail (see figure 7). The analyzed time periods correspond to the time when the speed measurements have been done.

Figure 7 Results of the WIM analyses for north-south traffic via A2 (Gotthard, left) and A13 (Plazzas, right) before and after the introduction of the distance-based heavy vehicle fee (LSVA)



The WIM analysis for north-south traffic in the summer of 2002 revealed a significant increase in the number and quota of commercial vehicles with operating weights above the old weight limit of 28 tons (resp. 31 tons due to fault-tolerance of the WIM measuring system), compared to the corresponding period in 1999. At the Gotthard, the increase was from 6.5% to 19% and at Plazzas from 0.6% to 13%.

Despite the clear increase of the amount of heavy vehicles with more than 28 tons in weight, the crawl speeds on upgrades have been reduced only slightly while on downgrades a further increase of the crawl speeds was recorded. This means that haulage companies supply vehicles with superior engines for transalpine freight traffic.

The upcoming question at that point of the study was the longterm reliabilty of the measured crawl speeds in 2002 on which the design standard to be modified will be based. Therefore the effects of several contradicting influences had to be balanced against each other:

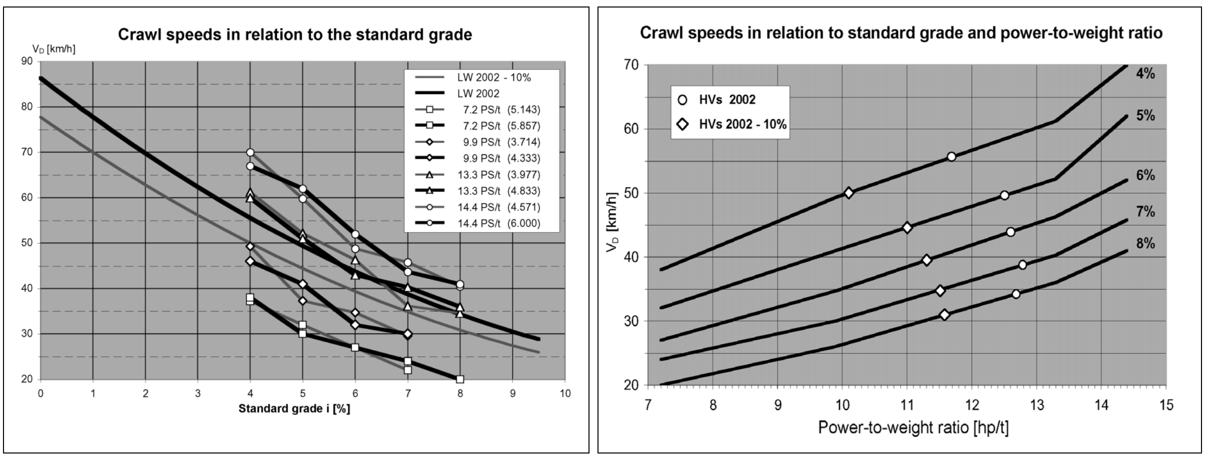
- From 2005 there are no longer any limits to the number of 40t HVs allowed in Switzerland.
- At the same time the full fees of the LSVA apply.
- The political intention to shift the HVs from road to train is still ongoing.
- The higher operating weights do not affect the speeds proportionally

Regarding the portions of HVs with 40 tons in weight in Switzerland from 2005, it is likely that the distribution of the operating weights will adapt to the situation in the surrounding countries of the EU. For example, the analysis of an Austrian WIM measurement on the important north to south Brenner freeway showed clearly that the fraction of HVs over 32t is about 44% and therefore more than twice as high as on the Gotthard. Because of this fact, for the new design standard the crawl speeds on upgrades – measured in 2002 – were reduced by 10%, where as, for downgrades no adjustments needed to be made.

6. Speed diagramm of the new standard truck

The investigations of the speed progressions along the gradient stretches provided the basis for designing the speed diagram of the new design truck. As mentioned before, additional simulation calculations were carried out to verify the empirical measurements. First the specific power-to-weight ratio of the new design truck had to be defined. Therefore the simulated crawl speeds were compared to the reduced results from 2002 (see figure 8).

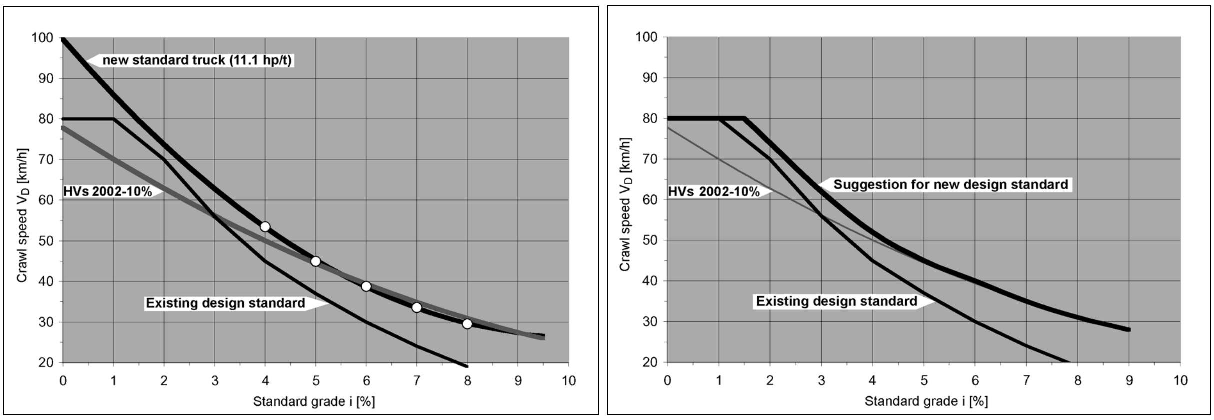
Figure 8 Comparison of the simulated and empirical crawl speeds in relation to standard grade (left) and power-to-weight ratio (right)



The comparison of the simulated and empirical crawl speeds in relation to the standard grade has shown that the specific power-to-weight ratio of the new standard truck lies between the simulated curves for HVs with 9.9 and 13.3 hp/t. This range was further limited by comparing the crawl speed in relation to the specific power-to-weight ratio. From here it becomes evident that the empirical results, reduced by 10%, lie within 10.1 and 11.6 hp/t. On the average a specific power-to-weight ratio of 11.1 hp/t resulted for the new standard truck.

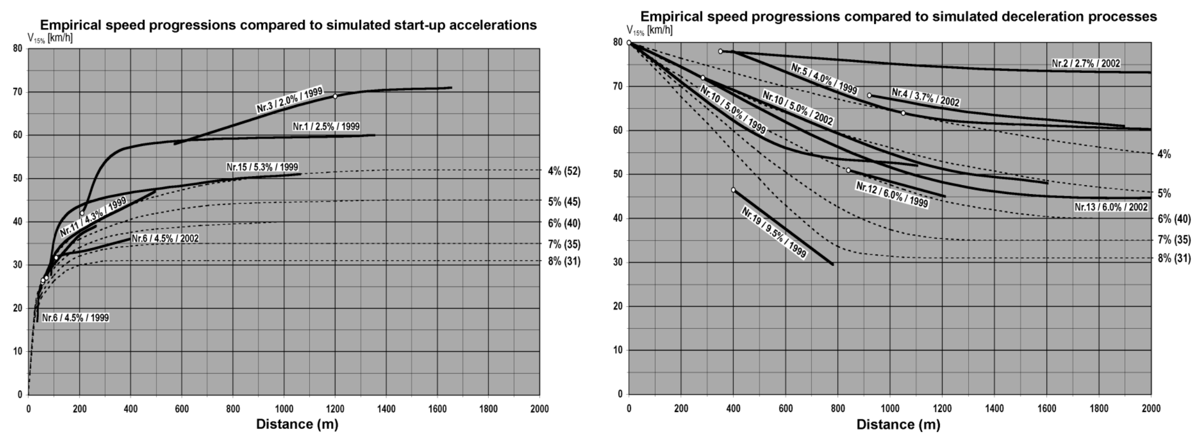
On the basis of 11.1 hp/t, the corresponding crawl speed has been determined by interpolation of the standard grades between 4% and 8%. Standard grades between 0% and 4% have been extrapolated by a square function. The extrapolated crawl speed between 0% and 4% is higher than the empirical results. This can be explained by the fact that the existing engine power is not fully used on lower gradients and that the simulation calculations were carried out under optimized conditions. Based on these findings a new design standard of crawl speed has been suggested.

Figure 9 Comparison of crawl speed of the existing design standard, empirical results and new standard truck (left) and suggested crawl speeds for modified design standard (right)



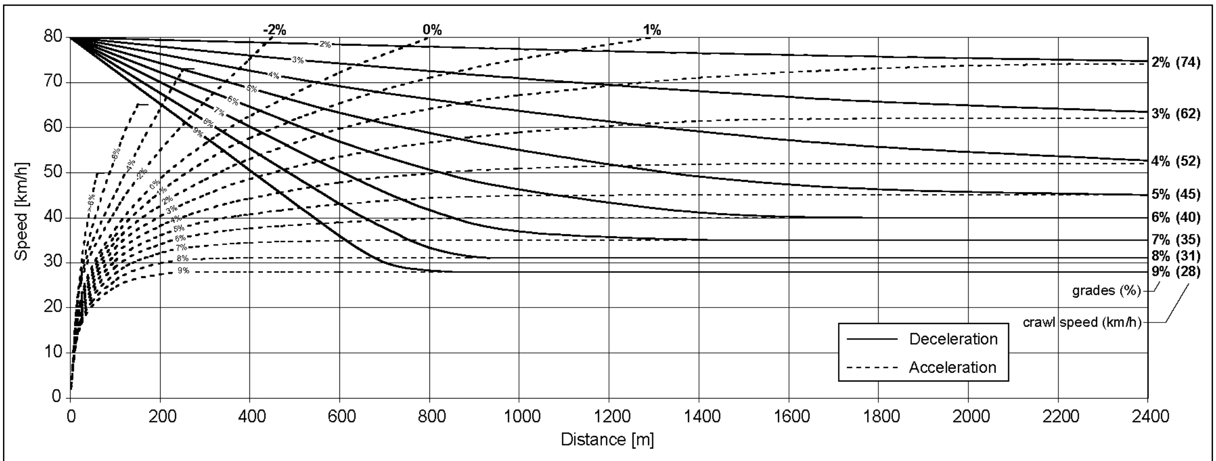
In addition to the suggested crawl speed a new speed diagram (speed profile) of the new standard truck had to be worked out. For this purpose the simulated speed progressions of the heavy vehicles with 9.9 and 13.3 hp/t have been interpolated within gradients between 4% and 8% (dotted lines in figure 10). The range between 1% and 4% was derived by the empirical speed progressions. The following figure shows the adjustment of empirical and simulated speed progressions of deceleration processes and start-up accelerations for heavy vehicles.

Figure 10 Adjustment of empirical and simulated speed progressions of start-up accelerations (left) and deceleration processes (right) for heavy vehicles



Finally the new speed diagram has been created. Compared to the speed diagram of the existing design standard it is noticeable that loaded HVs accelerate faster and therefore crawl speed is reached earlier than before. Concerning deceleration processes, the decrease in speed is less rapid because of the higher power-to-weight ratio.

Figure 11 Speed performance of the new design truck for the new standard



The final stage of the study involved preparing further foundations for modifying the existing Swiss standards for "auxiliary lanes on upgrades and downgrades". With regard to the driving-dynamics criteria for assessing the need for auxiliary lanes, adjustments of the ratios between V_{PC} and V_{HV} are certainly necessary. Regarding to the traffic engineering criteria there is also an evident need to make adjustments. The recommendation for a new model is based on fundamental diagramms of the German manual for highway measurements (HBS 2001) and takes various grading categories, degrees of curvature and levels of service into account.