Estimating the Effects of Reducing the Speed Limit on Main Roads in Urban Areas from 50 km/h to 30 km/h on NO_X Emissions

N. Toenges-Schuller[1], Chr. Schneider[1], A. Niederau[1] ,W. Scholz[2]*

[1] AVISO GmbH, Am Hasselholz 15, 52074 Aachen, Germany, nicola.toenges-schuller@avisogmbh.de
[2] LUBW, Referat 33 Luftqualität, Großoberfeld 3, 76135 Karlsruhe, Germany

Abstract

To quantify the effects of reducing the speed limit on main roads in urban areas from 50 km/h (T50) to 30 km/h (T30) on air quality, in 13 German towns test runs were performed by AVISO GmbH (Niederau et al., 2011) and TÜV Nord (Kleinebrahm, Steven, 2011) on behalf of several regional councils in Baden-Württemberg and the LUBW (State Agency for Environment, Measurements and Nature Conservation Baden-Württemberg). For these test runs, NO_X and PM10 emissions were calculated at TU Graz by the model PHEM (Passenger Car and Heavy Duty Emission Model, Hausberger, S., Luz, T., 2010). To derive an "initial estimation scheme" to estimate the effect of T30 on the air quality for a selected track before the performance of test runs, test run data from 10 towns were evaluated at large (Toenges-Schuller, N. et al., 2012). As a result, T30 may have positive effects on traffic induced NO_X-emissions depending on longitudinal road gradient, fraction of steady driving and fraction of heavy duty vehicles. The effect of T30 on exhaust gas particulate matter (PM10) in nearly all situations is negative. However, the effect on total PM10 (exhaust gas, resuspension, abrasion) can also be positive.

Introduction

Given limit exceedances of air pollutants at a number of traffic influenced measurement stations, in Germany it is widely discussed whether a reduction of the speed limit on main roads in urban areas from 50 km/h to 30 km/h would reduce emissions and thus improve air quality. On behalf of several regional councils in Baden-Württemberg and the LUBW, test runs in 13 German towns were performed by AVISO GmbH (Niederau et al., 2011) and TÜV Nord (Kleinebrahm, Steven, 2011). Since individual test runs for each track are expensive to perform and to evaluate, all available data were evaluated at large to allow general statements about the effect of T30 before the performance of test runs. This resulted in the derivation of an "Initial estimation scheme", which is introduced in the following paper.

Test Tracks and Data Base

The tracks where the test runs were performed differ with respect to track length, road gradient and crossroads. Properties of 12 tracks in 9 towns in Baden-Württemberg, where AVISO did test runs, are listed in Table 1.

Altogether, more than 1.000 PC (passenger car) test runs (T50, T30 virtual, T50 HD (heavy duty) tracking) were performed by TÜV Nord (Kleinebrahm, Steven, 2011) and AVISO (Niederau et al., 2011). Driving parameters (velocity, acceleration, gps coordinates) were recorded every second, in total about 225.000 measurement points. For these, emissions of NO_X, PM10 and fuel consumption were calculated at TU Graz by the model PHEM (Passenger Car and Heavy Duty Emission Model, Hausberger, S., Luz, T., 2010). Evaluation for all relevant vehicle sections of PC, LDV (light duty vehicles) and HDV (heavy duty vehicles) resulted in more than 15 million data sets. To develop a general scheme for estimating the direction of effect of T30 on traffic emissions on a certain track before the performance of test runs, data from 10 towns (twelve tracks by AVISO shown in Table 1 plus three tracks in Stuttgart by TÜV Nord) were evaluated at large (Toenges-Schuller, N. et al., 2012).

Table 1 : Test track characteristics (AVISO tracks)

town	track length	road gradient	light signal systems	synchro-nized	pedestrian lights	round-abouts
Mühlacker	600 m	4% - 8%	2	yes	1	-
Urbach	1.200 m	0% - 2%	-	-	3	2
Freiberg A	800 m	0% - 2%	-	-	3	-
Freiberg B	700 m	0% - 10%	-	-	2	-
Ingersheim	1.100 m	0% - 4%	1	-	3	-
Pleidelheim A	900 m	0%	1	-	4	-
Pleidelsheim B	450 m	0%	1	-	1	-
Schamberg	600 m	0% - 10%	1	-	-	-
Ulm A	1.100 m	0%	5	yes	-	-
Ulm B	450 m	0%	3	yes	-	-
Unterjesingen	1.500 m	0% - 2%	2	yes	3	-
Tübingen	2.000 m	0%	11	yes	9	-

NO_X Emission Factors T50 and T30 for Steady Driving, Acceleration and Deceleration

The datasets were grouped into run type (T50, T30 virtual, T50 HD tracking), driving condition (stop phases (v < 0.5 m/s), acceleration (a > 0.125 m/s^2), deceleration (a < 0.125 m/s^2), steady) following the PHEM definitions and road gradient (following HBEFA3.1). For these groups, mean emissions factors (EF) were calculated, assuming the vehicles to be distributed according to the mean fleet composition of Baden-Württemberg 2010 (Schneider, Chr. et al., 2009). For the stop phases, as expected, no difference between T50 and T30 emissions could be found. For steady driving, acceleration and deceleration, depending on road gradient, T30 emissions are frequently higher than T50 emissions. In Figure 1, this is shown for PC and HD steady driving NO_X emissions, in Figure 2 (left hand side), for PC this is also for acceleration and deceleration phases.

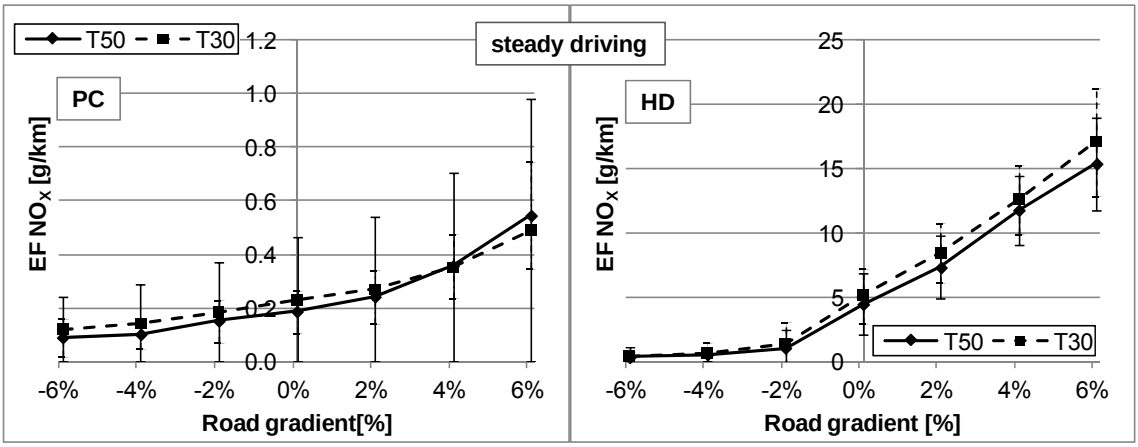

Figure 1 : PC and HD steady driving NO_X EF evaluated with the model PHEM as a function of road gradient for T50 and T30; error bars correspond to one standard deviation (fleet composition Baden-Württemberg 2010).

In Figure 2 (left hand side), you can also see that while EF for acceleration are higher and EF for deceleration are lower than EF for steady driving, the combined EF for acceleration and deceleration are higher than those for steady driving.

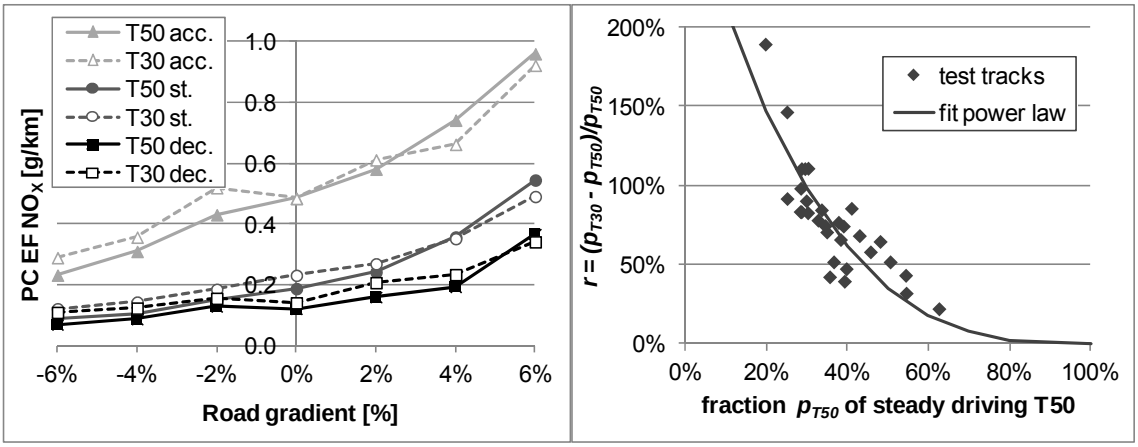

Figure 2 : *left:* PC EF NO_X T50 and T30 for acceleration, steady driving and deceleration depending on road gradient (fleet composition Baden-Württemberg 2010); *right:* increase of the fraction of steady driving induced by T30

Effect of T30 on the Fraction of Steady Driving

While a separated evaluation of steady driving, acceleration and deceleration phases for nearly all road gradients shows an increase of NO_X emissions for each phase due to T30, evaluations of complete tracks often show a decrease of NO_X emissions due to T30 (Niederau et al., 2011). This can be explained by the following two effects:

- **Effect 1**: EF for steady driving, acceleration and deceleration for most road gradients are higher at T30 than at T50
- **Effect 2**: After a disruption, the intended speed is obtained faster at T30 than at T50, there is no acceleration phase from 30 km/h to 50 km/h. Thus, for an equal number of disruptions at T30 and T50, the fraction of acceleration and deceleration is lower and of steady driving is higher at T30 than at T50. Since the combined EF of acceleration and deceleration is higher than for steady driving, increasing the fraction of steady driving in general reduces emissions.

Depending on the local conditions, effect 1 (increasing emissions) or effect 2 (reducing emissions) can dominate. Therefore, for all test tracks, the mean change of the fraction of steady driving at T30 with respect to T50 was determined. To ensure comparable data collectives, for each test track, a selection of test runs was chosen with equal number and kind of disruptions.

In Figure 2 (right hand side), for each track, the relative change r of the mean fraction of steady driving at T30 w. r. t. T50 is shown as a function of the fraction of steady driving at T50 p_{T50}. To these data points, a power law

$$r = a \cdot (1 - p_{T50})^b \qquad a, b\text{: fit parameters}$$

was fitted, which is shown as solid line in Figure 2 (right hand side). For the fraction of steady driving p_{T30} at T30, this yields

$$p_{T30} = p_{T50} \cdot (1 + a \cdot (1 - p_{T50})^b) = p_{T50} \cdot (1 + r) \qquad \text{(Eq. 1)}$$

It fulfils the following boundary conditions:

- $p_{T30} = 0$ for $p_{T50} = 0$ stop&go: no difference between T50 and T30
- $p_{T30} = 1$ for $p_{T50} = 1$ without disruptions, there is 100% steady driving
- $p_{T30} > p_{T50}$ else

EF as a Function of the Fraction of Steady Driving at T50

EF for stop phases do not depend on the speed limit, neither do their mean durations. Therefore, in a comparison of T30 and T50 EF, stop phases may be neglected.

As an approximation, EF not containing stop phases can be expressed as a product of the mean emission factors $EF_{T50/T30}^{s,a,b}$ for steady driving (*s*), acceleration (*a*) and deceleration (*d*) derived above and the respective fractions $p_{T50/T30}^{s,a,d}$. With $p_{T50/T30}^{s} + p_{T50/T30}^{a} + p_{T50/T30}^{d} = 1$ and $p_{T50/T30}^{b} / p_{T50/T30}^{v} \approx 1{,}16$ (derived from the test runs) follows

$$EF_{T50/T30} \approx p_{T50/T30}^{s} \cdot EF_{T50/T30}^{s} + (1 - p_{T50/T30}^{s})\,(0{,}54 \cdot EF_{T50/T30}^{a} + 0{,}46 \cdot EF_{T50/T30}^{d}) \qquad \text{(Eq. 2)}$$

for each air pollutant and each road gradient. Given the mean $EF_{T50/T30}^{s,a,b}$ for steady driving, acceleration and deceleration and the relation of p_{T50} and p_{T30} from Eq.1, *EF* for a complete track can be approximated as a function of the fraction of steady driving at T50 on that track. This fraction must be determined for each track individually. For the test tracks, we found a range from 20% up to 63% with a mean value of 37%.

In Figure 3, the EF_{T50} and EF_{T30} for NO_X and a road gradient of 0% approximated by Eq.2 are shown as a function of the fraction of steady driving at T50.

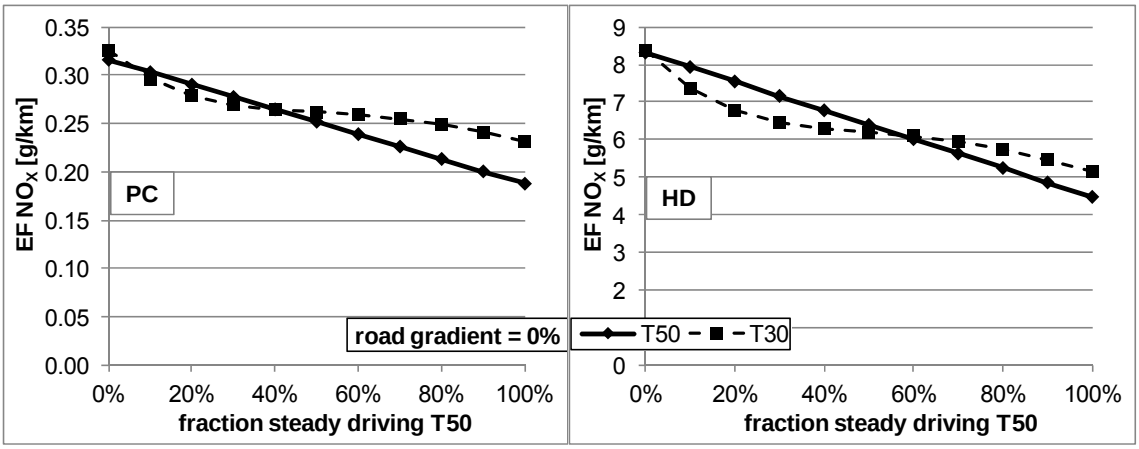

Figure 3 : EF NO_X for PC and HD depending on the fraction of steady driving at T50[1] on even test tracks, (fleet composition Baden-Württemberg 2010).

You can see the following:

- For p_{T50}^{s} = 0%, EF_{T30} is slightly higher than EF_{T50}.
- With increasing p_{T50}^{s} up to $p_{T50}^{s} \approx 40\%$ (PC) and $p_{T50}^{s} \approx 60\%$ (HD), respectively, EF_{T30} is lower than EF_{T50}. In this range, the emission reducing effect of shorter acceleration phases at T30 dominates.
- For $p_{T50}^{s} > 40\%$ (PC) and $p_{T50}^{s} > 60\%$ (HD), respectively, EF_{T30} is higher than EF_{T50}. In free traffic flow, accelerating phases cannot be shortened much more, the effect of higher steady driving emissions at T30 dominates.

Initial Estimation Scheme

In Figure 1, NO_X EF for steady driving ($p_{T50/T30} \approx 0\%$) are shown depending on road gradient. In Figure 3, EF for a complete track with road gradient = 0% (consisting of fractions for steady driving, acceleration and deceleration phases) are shown depending on the fraction of steady driving at T50. In a two-dimensional diagram, the influences of both road gradient and fraction of steady driving at T50 can be visualised together.

[1] The corresponding fraction at T30 was calculated by Eq. 1

For PC, NO_X EF (without stop phases) depending on road gradient and p_{T50}^{s} were determined according to Eq. 2. The difference yields the direction of the effect of T30.

For HD, based on the existing data collective, the direction of the effect of T30 cannot be determined for each road gradient. It is only possible to distinguish between even tracks and tracks with absolute gradient ≥ 2%.

Since for LD the data base of the model PHEM is weaker than for PC and HD, they were not considered here. Their fraction in the fleet composition is low, they do not contribute highly to the total emissions. If they were considered, the effect of T30 would get slightly better.

Altogether, the estimation of the direction of the effect of T30 on NO_X emissions for the total fleet of vehicles can only be done depending on the absolute gradient. Therefore, also for PC the direction of the effect of T30 was determined for the cross sections of the tracks for absolute gradients of 0%, ±2%, ±4% and ±6%.

In Figure 4, the resulting directions of the effect of T30 on NO_X emissions are shown for fractions of HV from HD=0% (only PC) up to HD = 5% (95% PC).

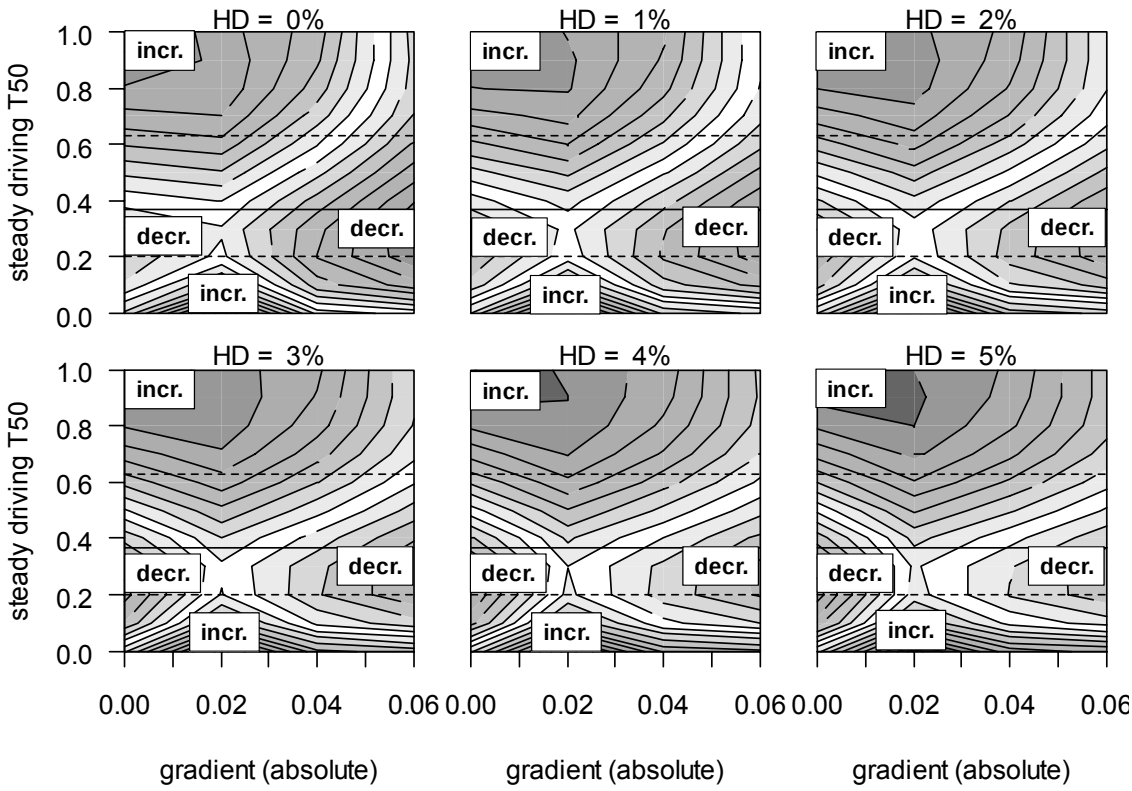

Figure 4 : Direction of the effect of T30 on NO_X emissions depending on fraction of steady driving at T50, absolute road gradient and fraction of HD vehicles in the fleet; solid lines: mean fraction of steady driving of all test tracks, dotted lines: range of the mean fractions of steady driving within the test tracks; colour scheme: white: no change of NO_X emissions caused by T30, dark grey: strong change of NO_X emissions caused by T30, direction (increase, decrease) noted in diagram.

Given the track parameters “HD fraction”, “absolute gradient” and “fraction of steady driving at T50”, from these diagrams, an initial estimation regarding the direction of the effect of T30 on NO_X emissions on a certain track can be read.

With a HD fraction of 3% and a road gradient of ±2% for example, no positive effects can be achieved by T30: There are only white (no effect) or grey areas which are labelled as increase. At all other gradients, there is a range for the fraction of steady driving between ca. 20% (lower values were not found) and ca. 40%, where the effect of T30 is positive. For high road gradients, the range of positive effects reaches up to 55%.

With increasing fraction of HD, the positive effect on even tracks increases while the positive effect at high road gradients decreases.

For tracks with a high fraction of steady driving, as for example in Stuttgart ($p_{T50} \approx 60\%$), negative effects of T30 dominate.

PM10 Emissions and Fuel Consumption

In addition to NO_X emissions, also PM10 emissions (exhaust gas) and fuel consumption were evaluated by PHEM. For these, in nearly all cases T30 leads to negative effects. PM10, however, is predominantly caused by abrasion and resuspension. Düring, I. et al. (2010) found that, depending on the density of disruptions, T30 may cause reductions of abrasion and resuspension of up to 10%. Thus, the effect on total PM10 (exhaust gas, resuspension, abrasion) can also be positive.

Estimating the Fraction of Steady Driving at T50

To apply the ”initial estimation scheme” to a certain track, information about road gradient, HD fraction and the fraction of steady driving at T50 is necessary. The latter quantity is not commonly used and therefore typically not known. It mainly depends on disruptions of the traffic flow. These can be caused internally by mutual interference of the vehicles with increasing traffic volume or externally by influences like light signal systems, strong changes of direction on the layout of a road etc. Depending on the dominating cause for disruptions, for the “initial estimation scheme”, two methods were developed to estimate the fraction of steady driving at T50. For both, local knowledge of the place is necessary.

1. For part of the collective of test tracks, the majority of test runs were done at heavy to saturated traffic volume. Traffic-induced (internal) disruptions prevail. From this, a proportionality of fraction of steady driving at T50 and traffic volume can be derived.

2. For other test tracks, disruptions mainly were caused externally. For these cases, a procedure to estimate the fraction of steady driving at T50 by weighted disruption was developed

Both methods are described in detail by Toenges-Schuller, N. et al. (2012). In Figure 5, the fractions of steady driving for all AVISO test tracks estimated by methods 1 and 2 are shown in comparison with the corresponding values derived directly from the test runs.

From the figure, the following can be read:

- The estimation for the fraction of steady driving at T50 based on traffic volume contains fewer extreme values

- Both estimations differ by less than 10 percentage points and agree well in most cases.

- Agreement between estimation and measurement is also good. Exception: Schramberg

- For Schramberg (road gradient up to 10%, fraction of HD: 8%), the fraction of steady driving at T50 can be explained by neither of the methods.

The fraction of steady driving at T50 can always be determined by measurement runs.

Preconditions

Before applying the scheme shown in Figure 4, one has to consider the following limitations. They result from the range of values of the test track parameters, which were used as a base to derive the scheme.

- The track length should not be shorter than 400 m.

- The traffic volume should be within the range of 4.000 and 8.000 vehicles per day and per lane.

- The road gradient should not be larger than 10%.

Outside these ranges, the estimations read from the scheme are of limited value.

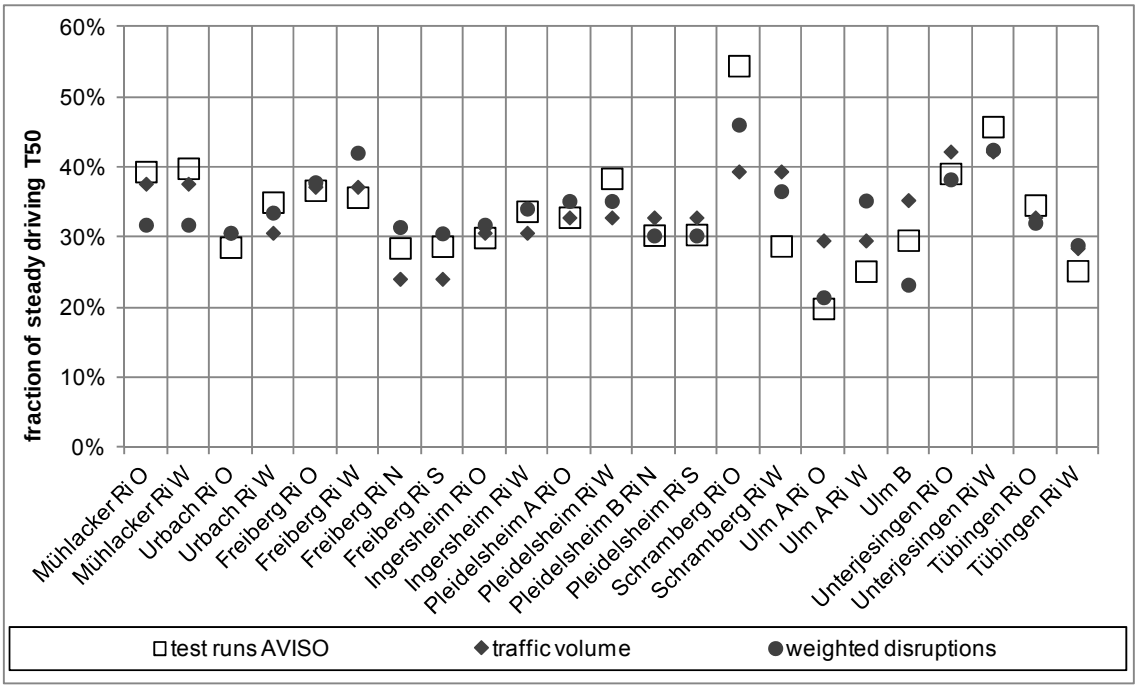

Figure 5 : Fraction of steady driving at T50 for the AVISO test tracks, derived from the test runs and estimated by proportionality to traffic volume and by weighted disruptions

Application to Test Tracks

When the preconditions listed in the former passage are fulfilled, the values for the input parameters “mean road gradient”, “HD fraction” and “fraction of steady driving at T50” must be determined. In Figure 4, the expected direction of the effect of T30 on NO_X emissions can be read. The scheme is not suitable to predict quantitative values how large effect of T30 on a certain track will be. This can only be determined by measurement runs on the track in question. On those tracks, where a positive effect of T30 was found, the reduction of NO_X emissions was between -1% and -10%.

In Table 2, for the AVISO test tracks, the direction of the effect of T30 on NO_X emissions as read from Figure 4 is shown in comparison with the direction found in the individual evaluations of the test runs. The fraction of steady driving was determined both via the traffic volume and via weighted disruptions.

For the majority of test tracks, both estimations agree well with the individual evaluations of the test runs.

Additional to the tracks listed in Table 2, measurement runs were performed by TÜV Nord on several tracks in Stuttgart. For these tracks, detailed information about the track parameters are not available. Therefore, the fraction of steady driving at T50 was not estimated by one of the described methods but derived directly from the measurement runs. On these tracks, due to partially tunnelled crossroads, the fraction of steady driving at T50 is very high (>60%). The effect of T30 on these tracks is negative. This results both from individual evaluations of the test runs and from the scheme shown in Figure 4.

Table 2: Direction of the effect of T30 on NO_X emissions by the initial estimation scheme (fraction of steady driving p_{T50}^{s} estimated via the traffic volume and via weighted disruptions) in comparison with the individual evaluations of the test runs on the AVISO test tracks

town	test runs	Initial estimation scheme	
		p_{T50}^{s} by traffic volume	p_{T50}^{s} by weighted disruptions
Mühlacker	positive	positive	positive
Urbach	positive	slightly positive	slightly positive
Freiberg A	positive	positive	positive
Freiberg B	positive	positive	positive
Ingersheim	positive	positive	positive
Pleidelheim A	positive	positive	positive
Pleidelsheim B	positive	positive	positive
Schamberg	slightly positive	positive	positive
Ulm A	positive	positive	positive
Ulm B	positive	positive	positive
Unterjesingen	slightly positive	slightly positive	neutral
Tübingen	positive	positive	positive

Conclusions

T30 on main roads in urban areas influences the NO_X emissions by two effects, one increasing and the other reducing the emissions. It depends on the characteristics of the track in question, which one of the effects dominates. Therefore, a general statement about the effect of T30 is not possible. However, depending on road gradient, HD fraction and the fraction of steady driving at T50, the direction of effect of T30 on NO_X emissions can be estimated ("Initial estimation scheme"). If there are limit exceedances and if the scheme shows a positive effect, test runs can quantify the possible emissions reductions. The effect of T30 on fuel consumption and exhaust gas particulate matter (PM10) in nearly all situations is negative. However, the effect on total PM10 (exhaust gas, resuspension, abrasion) can also be positive.

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