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DRIVING SPEED ON THOROUGHFARES IN MINOR TOWNS IN DENMARK

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ABSTRACT

It is well documented that speeding increases the risk of injury accidents significantly. Earlier studies have found that there is significant speeding on thoroughfares (TF) where speed-calming measures such as speed bumps are not used. Speed-calming measures have local effect, but little is known about the effect of varying intervals between speed-calming measures on driving behaviour. In this study, Floating Car Data covering 579 trips on 14 TF are used to measure the effect of various speed-calming measures. The main results show that visual speed-calming measures (town entrances and speed limit signs) as well as physical measures (bumps, elevated areas, braking islands, and roundabouts) have an effect on speeding. The visual measures reduce speed somewhat although the mean speed continues to be well over the speed limit. On roads with 50km/h speed limit with physical speed-calming measures implemented at more than 225m intervals mean speeds up to 58km/h were recorded. With lower intervals (130-200m) speeding is limited. A model across all trips on the TF shows that more than 70% of the driving on TF is above the speed limit. The intervals between speed-calming measures affect the extent of speeding significantly. Also the proportion of densely built-up roadsides affects driving behaviour considerably, although this variable has limited effect on the highest speeds. For an appropriate speed to be kept on TF, physical speed-calming measures should be placed at intervals of about 150m.

BACKGROUND

Road safety is one of the most important issues regarding loss of years of life. In 2004, it was estimated that more than 1.27 million people globally died in road accidents (World Health Organization 2009). Despite significant improvements within the last five years in Denmark, the road safety statistics still show 167 fatalities and 3,600 injured in 2012 (Statistics Denmark 2013). Due to a significant number of dark figures the problem is much bigger than indicated in the official statistics. Only 14% of the injured were recorded here – a share which is declining (Plovsing, Lange 2009). In addition, this problem is particularly challenging regarding vulnerable road users (Schepers et al. 2013), who are often the victims of traffic accidents in built-up areas. It is well documented that inappropriate speeds lead to a higher number of road fatalities, as represented by the Power Model developed by Nilsson (2004). Elvik too carried out a large-scale study. He generally agreed with the model and found that the most adequate value of power in relation to fatal accidents is 3.5 (Elvik 2009). That means that even minor speed violations affect the road safety significantly negatively. E.g., if the mean speed increases from 50 to 55km/h, the number of fatal accidents increases by 40%. Also, it is found that increased mean speed on a road network increases the speed variation substantially, and that higher speed variation clearly affects road safety negatively (Finch et al. 1994, Salusjärvi 1981).

Speeding as a problem on thoroughfares

Speeding is a significant problem on most roads outside built-up areas (Eksler, Popolizio & Allsop 2009, Elvik et al. 2009). This is particularly the case in Denmark, where 71% of the drivers are speeding outside built-up areas and the mean speed is 85km/h (Eksler et al. 2009). This pattern also reflects the accident distribution on the Danish roads; while above 60% of all injury accidents are registered in urban areas, 70% of all fatal accidents are registered outside built-up areas (Statistics Denmark 2013). New and older Danish studies found that speeding is a key challenge regarding road safety on thoroughfares (TF) in minor Danish towns (Danish Road Directorate 1996, Wellis et al. 2004). TF are main roads running through small towns and villages. Outside built-up areas, the speed limit is normally 80km/h while it is reduced to 50 or 60km/h inside built-up areas.

Measures to reduce speeding on thoroughfares

Traditional solutions to prevent speed violation comprise enforcement, information, and enhanced road design. Enforcement is a central solution to prevent speeding. The risk of getting caught if speeding has a considerable effect on the number of speed limit violations. However, in a number of references Várhelyi (1996) found that the effect is considerable but transient in space and time. Also, the risk of getting penalised for speeding is low. In Denmark in 2008, it was found that the average driver would drive for approximately 13 years before being fined for violating the speed limit (Agerholm 2011). Information can reduce speed violation. However, the baseline level upon which a campaign has to build influences the potential effect. The less speed violation in baseline, the less effect can be expected (Elliott 1993). A markedly higher impact can be reached through a combination of campaigns and enforcement. (Elliott 1993, Vaa et al. 2004). Campaigns against speed violations have been carried out for many years, probably with significant effect. However, it is not obvious that further significant effects can be achieved concerning speed violations. Speed-calming measures have shown significant safety effects. In a meta-analysis, area-wide urban speed-calming schemes were found to reduce the number of injury accidents significantly (Elvik 2001). Also speed-calming measures on TF in minor towns and villages in Denmark have shown significant effects on road safety due to reduced speed (Wellis et al. 2004). Older Danish studies carried out in connection with establishing traffic calmed TF likewise show significant positive effects on driving behaviour (Danish Road Directorate 1996). Figure 1 shows selected speed-calming measures used in Denmark. Also, new measures based on Intelligent Transport Systems (ITS), such as speed reminders, have become widespread in small Danish towns. Research on the effect of these measures has not been found, but while they generally have a good effect locally, it is plausible that the effect is transient in space and time.



Figure 1. Example of speed-calming measures suitable for TF (Danish Road Directorate 2013).

Research question

As a number of measures are suitable for reducing speeding on TF, it is tempting to believe that the speeding problems on TF are nearly eliminated. However, as shown above, there are considerable problems and the effects of the speed-calming measures are not well documented. Therefore, the research question in this study was:

What are the effects of speed-calming islands, bumps and town entrances on driving behaviour on TF in minor Danish towns?

METHOD AND DATA

Overall method

The normal driving behaviour on TF in minor towns in Denmark was studied using the approach of comparing facts about the roads in question: routing, built-up facade next to the TF, and speed-calming measures, with the speed of the passing vehicles on the various sections of the roads. The speed is recorded by GPS-loggers installed in the vehicles driving on the TF. The advantage of using this type of data, called Floating Car Data (FCD), rather than the traditional speed measurement in one particular spot is, that knowledge about the speed on all sections of the road in question is gathered. On the other hand, with FCD the speed measurements are based only on a small proportion of the drivers on the road segment. On the basis of traditional spot speed measurements it is often assumed that the speed found is typical of the whole road. On TF with speed-calming measures and the resulting speed variation, the measured speed is hardly representative of the whole of the TF. Hence speed measurements based on FCD show a more accurate view of the speed.

Selected thoroughfares

Location	Speed limit	Direction	Trips	Unique cars	Speed reducing measures
Brovst	50km/h	To the east	9	4	Speed reducing traffic island, Roundabout
		To the west	14	9	
Halvrimmen	50km/h	To the east	25	11	Speed reducing traffic island
		To the west	35	14	
Hundelev	50km/h	To the north	4	4	Bump, Speed reducing traffic islands
		To the south	4	4	
Saltum	50km/h	To the north	13	9	Speed reducing traffic islands
		To the south	14	10	
Sæsing	50km/h	To the east	4	2	Bump
		To the west	4	2	
Sønder Rubjerg	50km/h	To the north	3	3	Bump, elevated road area
		To the south	6	5	
Tornby	50km/h	To the north	7	6	Bump
		To the south	12	6	
Vebbestrup	50km/h	To the north	26	12	Speed reducing traffic islands
		To the south	30	11	
Vittrup	50km/h	To the east	6	6	Speed reducing traffic islands, Bump
		To the west	8	7	
Ålbæk	50km/h	To the north	26	8	Roundabout
		To the south	24	8	
Biersted	60km/h	To the east	13	3	None
		To the west	20	2	
Melholt	60km/h	To the north	5	2	None
		To the south	5	2	
Nielstrup	60km/h	To the north	53	9	None
		To the south	55	8	
Stenild	60km/h	To the east	80	9	None
		To the west	76	8	

Table 1. The TF and the number of trips included in the study.

The TF selected are located in the northern part of Denmark, because the FCD were mainly collected here. The study includes the major TF of minor towns and villages. Outside the built-up areas, the speed limit is 80km/h whereas inside it is 50 or 60km/h. Due to some only partly built-up areas or special safety problems a few roads outside the TF have a speed limit of 60km/h over a few hundred meters. Only TF in minor towns form part of the study as driving in major urban areas tends to be influenced by the various functions of such areas. Hence they would not give a reliable result on the effects from speed-calming measures. Furthermore, it is essential that the TF of the study are almost straight so that the chosen driving speed is not affected by, for example, sharp bends. 14 TF form part of the study, 10 of which have a speed limit of 50 km/h while 4 have a speed limit of 60 km/h. They vary regarding speed, the building facades, and the types and intervals of any speed-calming measures. See table 1.

The trace of the road and the width of the majority of TF invite speed limit violations. This is in particular the case in the non built-up parts of a TF, while on road sections with densely built-up facades near the centres of small towns, there might be a speed-calming effect. This might be because many road users consider these locations more like built-up areas, which justifies a lower speed. Examples appear in figure 2.



Figure 2. Examples from Halvrimmen. Left: road with low-density built-up facade. Right: road with denser built-up facade.

Used Floating Car Data

FCD are data, which are recorded during driving and can be used for a number of purposes afterwards or in real time (Jamson et al. 2006, Lahrmann et al. 2007). In FCD, the current position and a varying number of attributes are recorded. Commonly used attributes are speed, direction and time. The position is normally registered by GPS, but the cell phone net can likewise be used although with some limitations (Holstrøm 2006). FCD positions are normally registered with 1Hz. However, GPS-based positions might have fluctuating precision due to e.g. the quality of the GPS logger and software; hills, trees, and buildings obscuring satellites; the moving speed of the GPS logger; and the positions obtained from the GPS satellites.

The reliability of the positions can be improved with map matching (MM), which means an algorithm that compiles the GPS position in question with e.g. a digital road map. In the Danish Intelligent Speed Adaptation (ISA) project, Pay As You Speed (PAYS), it was found that despite various types of terrain, over 95 % of the positions had been map matched to the right road segment. (Tradisauskas et al. 2009). ISA are systems, which in various ways support the driver in keeping an appropriate speed while driving (Carsten, Tate 2005, Lahrmann et al. 2012). In general, tall buildings do not surround the TF of this study. Also, the fact that the study focuses on major roads minimises the risk of satellites being obstructed by trees and hills. Hence the level of precision here is reasonably higher than 95%. Tradisauskas et al. also found that where the uncertainty of the GPS position was high, it is mostly displaced geographically, while the speed registrations are not significantly affected. Identical effects are found in another research project with FCD, called ITS Platform, although it is yet to be documented (ITS Platform 2013). FCD from PAYS were used to measure the driving speed on the TF. PAYS comprised 153 mainly young drivers'

driving with ISA for up to 2,5 years (Lahrmann et al. 2012). However, to measure the effect of ISA on driving behaviour, the first 1,5 months formed a baseline with ISA deactivated but with driving behaviour recorded (Agerholm et al. 2008). To ensure that the results reflect the actual driving behaviour in TF as well as possible, only FCD collected in baseline were used. In total, baseline data consist of 26.5 million observations of which only a minor part are used in the present study. Although data were collected while the drivers were not influenced by ISA, it should be noted that drivers who took part in the test committed fewer speed violations than the average driver. Hence FCD from PAYS might be biased towards less speed violation than would be found if FCD from the average young drivers were used (Harms et al. 2008). Therefore it is plausible that if data are biased, the results will understate the speeding. Hence any speeding problems from ISA are highly reliable. The overall assessment is that FCD can describe the speed pattern on the TF.

Data treatment

The FCD were selected by this procedure:

1. FCD near a TF are selected on the basis of their position,
2. Sequential FCD, which are positioned on/near the TF only, are included,
3. FCD for each vehicle are sorted timewise
4. Trips are identified (sequential FCD without holes > 10 sec. due to GPS errors),
5. Trips which do not pass the entire TF are deselected (to avoid turning trips),
6. Trips with long stops are deselected (stop at bakery, shops etc.), and
7. Trips are ordered by direction.

When the FCD of the trips are identified and each single trip has to be defined, the FCD are weighted so they represent an identical distance driven. Failing that, the FCD with low speed would be weighted too much, because the slower a GPS-collecting unit is driving, the more FCD will be collected per distance driven. Analyses based on GPS positions which are not linked to other GPS positions or, for example, road sections, do not make much sense. The linking can be done in at least two ways; by map matching FCD to the correct road section or on the basis of the distance to any relevant point. If the calculations of driving behaviour are to be based on more than one position, they must consequently be distributed according to road intervals. In addition, with a view to making a speed profile, it is necessary to relate each observation to a specific road segment. In the present study, every TF was divided into 12.5m road segments, each segment thus yielding one position at a speed of 45km/h. If the recorded speed is higher than 45km/h, the speed will not be recorded for a number of road segments. By contrast, low speeds are recorded as more than one FCD observation per road segment. If more than one FCD position is located on one road segment the latest is selected and the remaining observations are removed. If there are no FCD located on one road segment, the previous FCD observation is used. These principles appear in figure 3. By using this method for all TF any bias due to deselection of FCD is minimised.

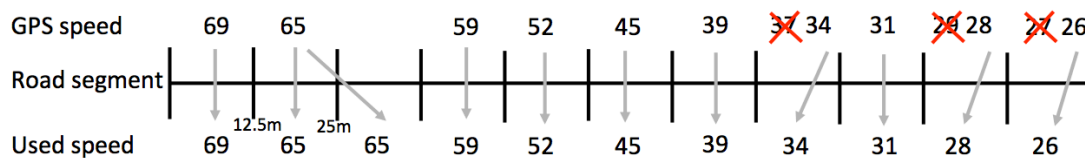


Figure 3. The use of FCD in speed profiles.

When data treatment for all trips on a road segment in one direction is completed, a speed profile can be set up. See figure 4 for an example.

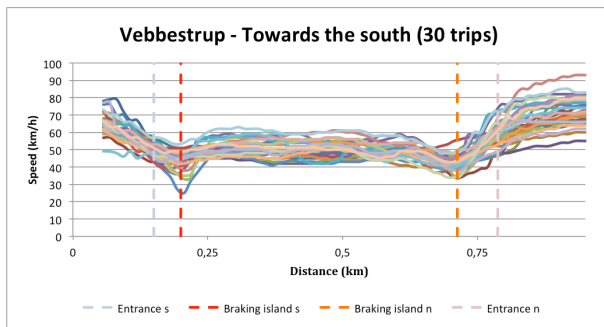


Figure 4. A speed profile example.

Methods of analysis of driving behaviour and speed-calming measures

The results found are presented in two ways; Selected results for single TF with typical characteristics are highlighted and correlated with other similar TF. In addition, a statistical model including driving behaviour and its correlation with the characteristics of the TF is developed. Mean speed, 85 percentile speed (85% speed), and maximum speed are used to describe driving behaviour. There are three principal ways of calculating the mean speed and the 85% speed: 1: Mean speed is calculated for one passage of a TF. 2: Mean speed is calculated for all passages of the TF. 3: Mean speed is calculated for all passages of a particular road segment. The same applies to 85th percentile speed. The last procedure is used when the results are presented as speed profiles.

Model of driving behaviour and the characteristics of a thoroughfare

The statistic software SPSS was used for the development of a model which included 579 trips. A multi-linear regression analysis was used for the model. First, a correlation test was made of the variable, which could be part of the model. Subsequently, regression analyses were carried out on the basis of the variable, which fits the model best. The following variables were included in the model:

- 'Speeding share' is the dependent variable (Y), the share of each trip on the TF, which has been driven faster than the speed limit,
- 'Speed limit' is a categorical variable, which refers to the speed limit on the TF in the built-up areas with the value 50 or 60km/h,
- 'Rural area' is outside built-up areas, but inside the town signs on one or both roadsides. This and the two next variables describe the share of the roadside regarding urbanisation level,
- 'Extent buildings' means roadsides where single-family houses are secluded.
- 'Dense buildings' means roadsides where the facades of the buildings are near the trace of the TF,
- 'Length' is the length of the TF (m),
- 'Speed-calming' is a categorical variable, with the value 0 and 1.
- 'Urban' is the sum of 'Extent buildings' and 'Dense buildings',
- 'Interval' means the length of the TF/the number of speed-calming measures. For TF without speed-calming measures this value was put arbitrarily at 2,000m.

RESULTS

Typical thoroughfares

50km/h speed limit and only town entrances

In Ålbæk, which has a 50km/h speed limit, town signs are located at the town entrances. No speed-calming measures are placed here. In the centre of the town there is a roundabout. At the town entrance, the mean speed is approximately 10km/h above the speed limit and drops towards the roundabout. The 85% speed is about 20km/h above the speed limit at the entrance and continues above the posted speed limit until 100 m before the roundabout, which reduces the speed significantly. Hence speeding takes place on most of the TF. Mean

and 85% speed appear in figure 5. Regarding single trips (not shown) the speed distribution is significant, and the highest speeds found at entrance and exit are 88 and 87km/h, respectively. With the exception of the roundabout, the TF in Ålbæk has many similarities with the TF with a 60km/h speed limit.

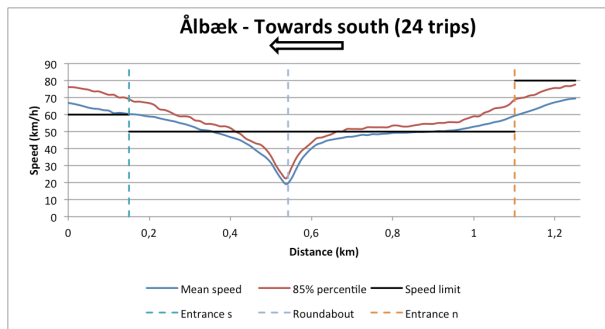


Figure 5. Speed profile for Ålbæk.

60km/h speed limit and speed limit signs only at the town entrances

In Stenild, with a 60km/h speed limit, which is the TF studied with most trips included, the mean speed at the entrances is above 67km/h and 64km/h where it is lowest. The 85% speed is about 76km/h at the entrances and is reduced to 71km/h where it is lowest. See figure 6. The fastest recorded trip was above 108km/h and the speed was virtually unchanged on the entire TF. An identical driving pattern can be found for the other three TF with a 60km/h speed limit. Where the speed limit is changed the mean speed is 5-12km/h above the speed limit, and it is generally above the limit on all parts of the TF. On the TF in Nielstrup the fastest trip has a minimum speed above 100km/h while the speeds of the fastest trips are not under 77 and 83km/h in Biersted and Melholt, respectively.

50km/h speed limit and braking islands near the town entrances

The TF in Halvrømme has a speed limit of 50km/h and braking islands just inside the entrances. See figure 6. No further speed-calming measures are made. Next to the braking islands, the mean and the 85% speeds are below the speed limit. 50-300m inside the braking island near the entrance, the mean speed is about 50km/h. On the identical part towards the exit, the mean speed is about 54km/h. On the central part of the TF it is 46-50km/h. The 85% speed is generally 5km/h higher than the mean speed. The highest speed inside the town signs (except near the braking islands) is 69km/h and is above 60km/h continuously. An identical driving pattern, although with slightly higher speeds, is found in the other direction. In Saltum and Vebbestrup, there are likewise braking islands near entrance and exit but no other speed-calming measures. The speed profile of Saltum bears great similarity to that of Halvrømme. There is a higher speed towards the south than towards the north, with 57 and 50km/h as the highest mean speed, respectively. Also, the speed is higher on the southern part of the TF. The increased speed towards the south is reasonable because the TF slopes towards the south here. On the TF in Vebbestrup, the mean speed is slightly higher than 50km/h, and it is not reduced on the central part of the TF. The fourth town in this group, Brovst, differs slightly because it has a signalised intersection in the town centre and the eastern roundabout replaces a braking island. Apart from the signalised intersection, where speed is considerably lower, mean speed is slightly lower than 50 km/h and on most of the TF, 85% speed hardly differs from that. Brovst is slightly bigger than the other towns in the study (2,700 inhabitants), and has a denser building facade.

50km/h speed limit, braking island, and other speed-calming measures

Speed-calming measures of various types and at varying intervals have been made on the TF in Sønder Røbjerg and Vittrup. In Vittrup, the mean and 85% speed is below 50km/h around the braking islands.

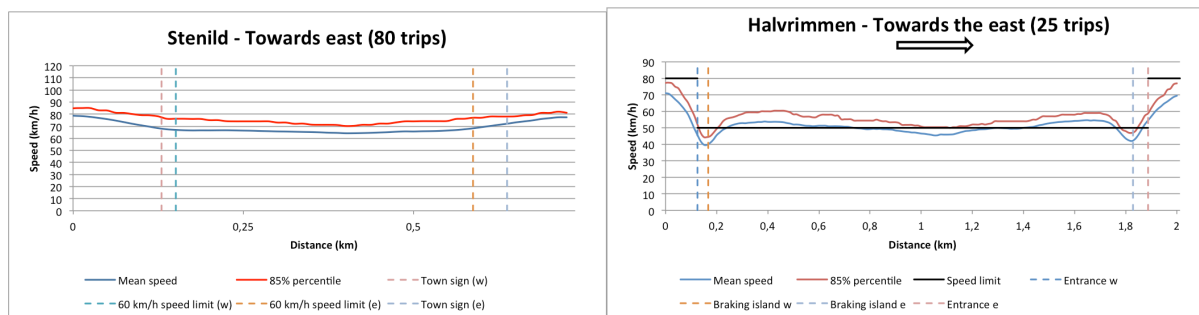


Figure 6. Left: speed profile for Stenild. Right: speed profile for Halvrømmen.

At all speed bumps, mean speed is reduced to below the speed limit, while it is only at the easternmost bump that 85% speed is also below the speed limit. The intervals between the speed-calming measures in Vittrup are 155, 233, 210, and 285m, respectively. Except for the first segment inside the braking island, higher intervals result in higher speeds. In general, the 85% speed is 58-61km/h, culminating between the speed bumps. An exception is between the 2nd and 3rd speed bumps, where speed is just above 50km/h. The latter is reasonable due to dense facade on this part of the TF. An identical driving pattern can be recognised towards the west. The highest speed measured inside the braking islands is 66km/h. See figure 7. An identical driving pattern can be found for Sønder Rubjerg with intervals between the speed-calming measures of 3-400m. One of these measures is an elevated area, which seems to have less speed-calming effect than the other measures (speed bumps). The highest speed on the TF is 69km/h (not shown).

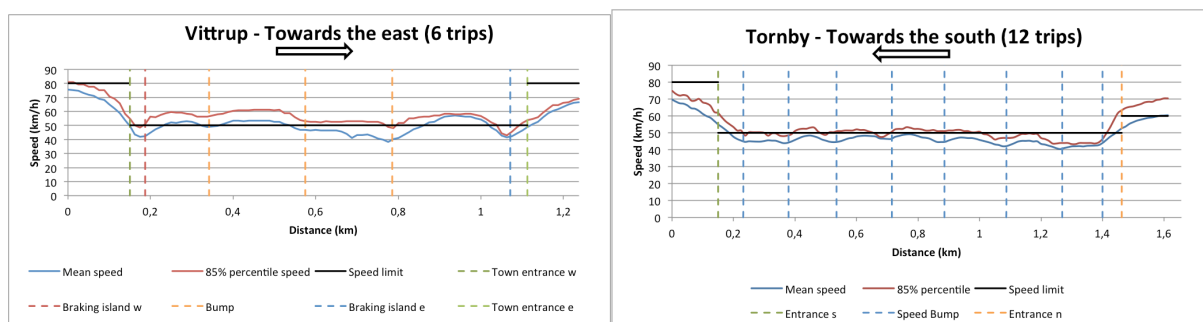


Figure 7. Left: speed profile for Vittrup. Right: speed profile for Tornby.

50km/h speed limit, speed bumps at short intervals

In Sæsing, Hundeleiv, and in particular Tornby, the speed-calming measures are placed at short intervals and roughly in accordance with the recommendation in the Danish Road Guidances (intervals of 150m). In Tornby, the intervals between the speed bumps are 130-200m. The mean speed here is below 50km/h and this is also the case for virtually all 85% speed registrations. See figure 7. The highest speed on the TF is 61km/h (not shown). Almost identical driving patterns can be found for the TF in Sæsing and Hundeleiv. In Sæsing, the intervals between the four speed bumps are 170-200m, while in Hundeleiv they are 110-140m. Also, it should be noted that speed increases substantially outside the outermost speed bumps in Tornby and Sæsing, where there are no braking islands near the entrances. In Hundeleiv, there are braking islands in addition to speed bumps, and the speed limit is almost kept on the entire TF.

Model based on driving behaviour and town/village characteristics

Additional conditions than speed-calming measures affect driving behaviour on TF. The 14 TF of this study differ significantly and FCD from these can't offhand be compiled. To estimate the effect of speed-calming measures on driving behaviour a statistical model with 579 trips was developed. The two variables 'Speed limit' and 'Speed-calming' were offhand remo-

ved from the model, because they are completely correlated with the two types of TF. After which 'Interval' had the highest coefficient of determination. 'Rural area' and 'Urban' are the only variables, which do not correlate with 'Interval'. 'Urban' was selected because these two variables have the same levels of explanation. 'Urban' together with 'Rural area' describe the entire roadside facade. Hence it is of minor importance, which of the variables are selected. The regression analysis shows a justified R^2 at 0,221. This low level of explanation could either be due to relevant variables not being included in the model or the number of trips being too low. The model found that 71% of the driving in the TF was carried out above the speed limit. The level of dense buildings on the roadsides contributes statistically significantly negatively to the speeding share; the more densely built-up roadsides, the less speeding. Likewise, increased intervals between speed-calming measures will result in increased speeding. The model found is this:

$$Y = C + \beta_A \cdot X_A + \beta_B \cdot X_B + e, \text{ where}$$

Y is the share of the distance driven above the speed limit,
 X_A is the weight of the share of the roadside, which is densely built-up areas,
 β_A is the share of the roadside, which is densely built-up areas,
 X_B is the interval between the speed-calming measures (m),
 β_B is the weight of the interval between the speed-calming measures,
C is a constant, and
e is the standard error.

The correlation is: $Y = 0,712 - 0,24\beta_A + 0,396\beta_B + e$

SUMMARY

Earlier studies have shown that speeding is a problem on Danish TF. Speed-calming measures such as speed bumps and braking islands have been implemented at varying intervals. However, it is uncertain if they resulted in sufficient speed reductions. In this study the driving behaviour on 14 TF is studied on the basis of FCD from a number of drivers. FCD from 579 trips are included in the study. Visual speed-calming measures (town entrances and speed limit signs) as well as physical measures (bumps, elevated areas, braking islands, and roundabouts) have an effect on speeding. By comparison with the driving outside built-up areas, the visual measures reduce the speed somewhat, although the mean speed continues to be well over the speed limit. On TF with speed-calming measures at higher intervals than 225m mean speeds up to 58km/h were recorded. Where the interval was 130-200m speeding was limited. The majority of the TF however, seem to share a kind of 'centre effect' related to the built-up facade. The main results from the model are that more than 70% of the driving on TF is above the speed limit. The intervals between speed-calming measures affect speeding significantly. Also, the shares of densely built-up roadsides affect driving behaviour considerably, although this variable has limited effect on the highest speeds. For an appropriate speed to be observed on TF physical speed-calming measures such as speed bumps should be placed at intervals of about 150m.

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