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Monitoring change in cycling with the Danish bike-traffic index.

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Abstract

The Danish Road Directorate has long experience in planning for cycling and the use of bicycle data and indexes. A national cycling index, a bike-traffic-index, was established in 1985, based on bike-flows continuously counted in locations all over the country. The number of counting stations included in the index has been increased over time to improve reliability and allow support for the development and assessment of policies aiming to maintain and further increase cycling. The index is partly fed by the Road Directorate and partly by the municipalities. With its current 61 counting stations in operation, the bike-traffic-index is still 'thin' compared to the equivalent car-traffic index, but it does provide consistent evidence on changes in cycling on Danish roads. The paper compares the bike-traffic-index with travel-survey data as indicators of changes in cycling, it presents the methodology and accuracy of the bike-traffic-index, and finally, it discusses its desirable improvements to increase accuracy and detect changes in cycling beyond the fluctuations in weather conditions that are generally important to cycling but also beyond policy reach.

Keywords: travel survey, index, counting, indicator, cycling, trend

Introduction

The Danish national bike-traffic-index was initiated in the mid-1980s as an index based on a small number of continuous counts of bikes and mopeds (<30 km/h or 19 mi/h) distributed across the country. It was pre-dated by the launch of a car-traffic-index from 1978 onwards (Christensen and Hansen, 2001), but the 1970s and early eighties was characterized by an increasing attention towards softer modes of travel as well as road planning that was more sensitive to the needs of bicycles and pedestrians – thus creating the need for a targeted bike-traffic-index.

Starting from a limited 12 permanent counts in 1985, the reliability of the index has been improved at several occasions: by increasing the permanent counting stations to 28 in the 1990s, to 54 counting stations in 2008, and recently, from 2014, a further expansion to 61 permanent counting stations.

As the bike-traffic-index is maintained by the Danish Road Directorate its development may be said to reflect the degree to which cycling falls within the Road Directorate's domain – as well as the general interest in cycling among policy-makers and planners. The Danish Road Directorate builds and operates 'national roads' including limited access motorways, but (from 01-01-2007) also a large number of regional roads and their urban segments which naturally include a mix of motorized traffic, bicycles and pedestrians. Paralleling this shift in the Road Directorate's road portfolio, national policies have been put in place with the aim to reverse what was generally a negative trend in cycling and to further increase cycling for its environmental, congestion and public health benefits. Efforts include funding for bike-infrastructures along national roads, support for municipal projects, as well as a general emphasis on planning for bicycles that include e.g. an annual cycling conference and wider communicative efforts – all hosted by the Danish Road Directorate and developed in collaboration with the various stakeholders of the field.

Monitoring progress towards increased cycling can be based on the bike-traffic-index representing bike-traffic – on existing roads as well as on the Danish National Travel Survey (TU) which represents the general travel behavior of residents of Denmark year-by-year. Preliminary experience suggests that both are needed and that each has its pros and cons.

Changes to the bike-traffic-index from 2008 and 2016, including a recent 2015 adjustment to include additional counts, has greatly improved the sensitivity of the index (Hansen, 2016). But there are still a range of improvements that would be desirable: to improve validity for monitoring and policy assessment as well as to address evolving policy issues, e.g. tourism oriented bicycle networks (Vejdirektoratet, 2016a).

The purpose of this paper is to present the Danish bike-traffic-index as an experience in practice with a well established methodology. The paper compares and highlights uncertainties in trend analysis based on the index and, based on the Danish National Travel Survey data (TU), it continues to present the bike-traffic-index with respect to statistical methodology, the underlying stratification, and its accuracy. The paper finally discusses desirable improvements to the index as well as to the National Travel Survey from the perspective of supporting policy discussions with reliable indicators.

Denmark is Europe's second most cycling nation after the Netherlands (Nielsen et al. 2015; Haustein and Nielsen, 2016) and the average Dane bikes approximately 530 km/year (329 mi/year) (Vejdirektoratet, 2011). The Danish Road Directorate has, what – from an international perspective – is a comparatively lengthy experience with the use of bicycle data and indexes, and as the interest for bicycle data is now growing internationally (see: Griffin et al., 2014; Ryan et al., 2014), it is suggested that bringing the Danish experience forward may contribute to the international knowledgebase.

Use of the Danish bike-traffic-index

The bike-traffic-index is updated quarterly to present change per month compared to the same month the previous year – as well as annually to present an annual index figure. The Danish Road Directorate’s website (www.vejdirektoratet.dk) provides the main communication channel with pages presenting the general changes in bike traffic in Denmark based on the index, change per month compared to the previous year (Figure 1) as well as the possibility of data download (*Vejdirektoratet, 2017*).

The impact of the bike-traffic index is not monitored in detail. A total of 2200 page visits to the two bike index pages (Figure 1) was counted in 2016 (2400 in 2015). A review of web-pages referring to the bike-traffic-index data suggests high usage among professional organizations, professional and popular media, as well as municipalities communicating trends and efforts in cycling promotion.

The bike-traffic-index is also included in the Road Directorate’s press-releases and article communications on changes in vehicle as well as bicycle traffic. Over time, this has included radically different messages ranging from the conclusion of 2001 (Vejdirektoratet, 2016b) where bike traffic according to the index had dropped 24% from 1989 to 1999 – to the more positive view of 2015 (Clausen, 2015) where the bike-traffic-index showed that it was at its highest level since 1995. Recent trends, as can be seen in figure 1, appear less encouraging and points to decreasing cycling in 2015 and first quarter of 2016. Bike advocates currently makes reference to the bike-traffic-index to argue for a revival of the national cycling promotion efforts (Bondam, 2016). The index points to a marked effect from weather conditions on cycling, and the degree – to which the winter conditions can explain the observed trends – is often discussed. For example, the decrease in the first months of 2016 was likely contributed by colder weather conditions compared to 2015.

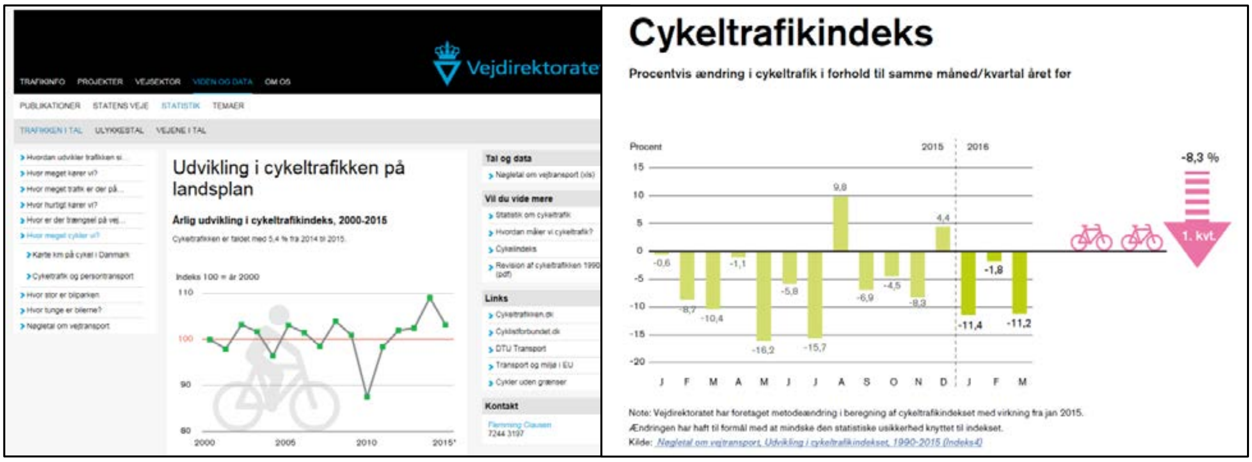

FIGURE 1. Web display of general changes (left) and monthly changes (right) to bicycle traffic in Denmark based on the national bike-traffic-index (Vejdirektoratet, 2016c; Vejdirektoratet, 2016d).

As the bike-traffic-index represents the longest available continuity for Danish bike statistics with national coverage, it has provided substantiation for national policies and policy documents – including the recent national bicycle strategy ‘Denmark – on your bike!’ (Ministry of Transport, 2014) where the index provided a basis for summarizing trends and derived challenges.

Monitoring change in Danish cycling

Given the national policy-objectives to promote cycling and considerable investments to achieve this aim, reliable data to monitor progress and adjust strategies is crucial. Both the Danish National Travel Survey (TU) and the bike-traffic-index are generally employed as supplementary resources for this purpose.

The Danish National Travel Survey (TU) (Christiansen, 2012) is being delivered by the Technical University of Denmark to represent the travel behavior at all seasons and week-days of all residents of Denmark above the age of 6 (from 2016 onwards). Earlier versions of the survey (the survey ran continuously from 1992-2002 and again from 2006 till present) targeted age groups 16 to 74, and in the recent decade age 10 to age 84. Practice with respect to short trips and access/egress trips have been adjusted over time and with the current principle of recording all trips and trip-stages, the survey is probably as close as ever to being able to reflect bike traffic as it should be observable on the street. But its basis in respondent recall of trips as well as its survey population of residents of Denmark will always maintain some gap between the surveyed transport behavior and the traffic. Additionally the origin-destination survey format does not include information on the use of the road or path network.

The survey has been used for general studies of change in bike mode share and trend analysis covering longer time spans (see: Nielsen et al. 2013; 2016), but it remains a challenge arriving at sufficiently specific conclusions with respect to the magnitude of changes and where and when they took place.

Cycling is a widely available mode of travel and its use is more varied than motorized transport and thus puts extra requirements on the sample sizes for statistical analysis (mean daily travel in km per person and standard errors of the estimate, 2016; bike: 1.55 +/- SE 0.052; motorized modes 38.47 +/- SE 0.75). The current sample of the travel survey is slightly less than 10,000 interview sessions per year (independent samples/repeated cross-sections) – where one session accounts for one respondent's travel behavior during one day (travel diary/origin-destination survey). At previous occasions a higher sampling rate has been employed (e.g. 2009-2012 with some 20,000 interviews/year) leading to considerably higher certainty of cycling estimates, but the current rate significantly limits the sensitivity of the survey to shorter terms and smaller changes which may also, from a policy perspective, be important to get insight into.

The bike-traffic-index has some advantages when it comes to detecting change and especially changes in network demand. Firstly, bike-counting includes all traffic across the screenline irrespective of residence, age or recall and therefore can provide more adequate measures of flow and demand; secondly, the counted locations are specific and well described, and measures of demand can therefore be assigned to network segments and types; and thirdly, when making repeated use of continuous counting stations, the result is a data set which is highly sensitive to actual changes in the demand.

Of course, there are also some challenges. One being that the regions or network types, which it is desirable to represent with the index, should be covered with a number of randomly selected bike-counts – the more, the better. Additionally, significant changes to infrastructures and/or behaviors may challenge the stratification of the network, requiring a revision and possibly new or additional counting stations to remain sensitive to changes in demand.

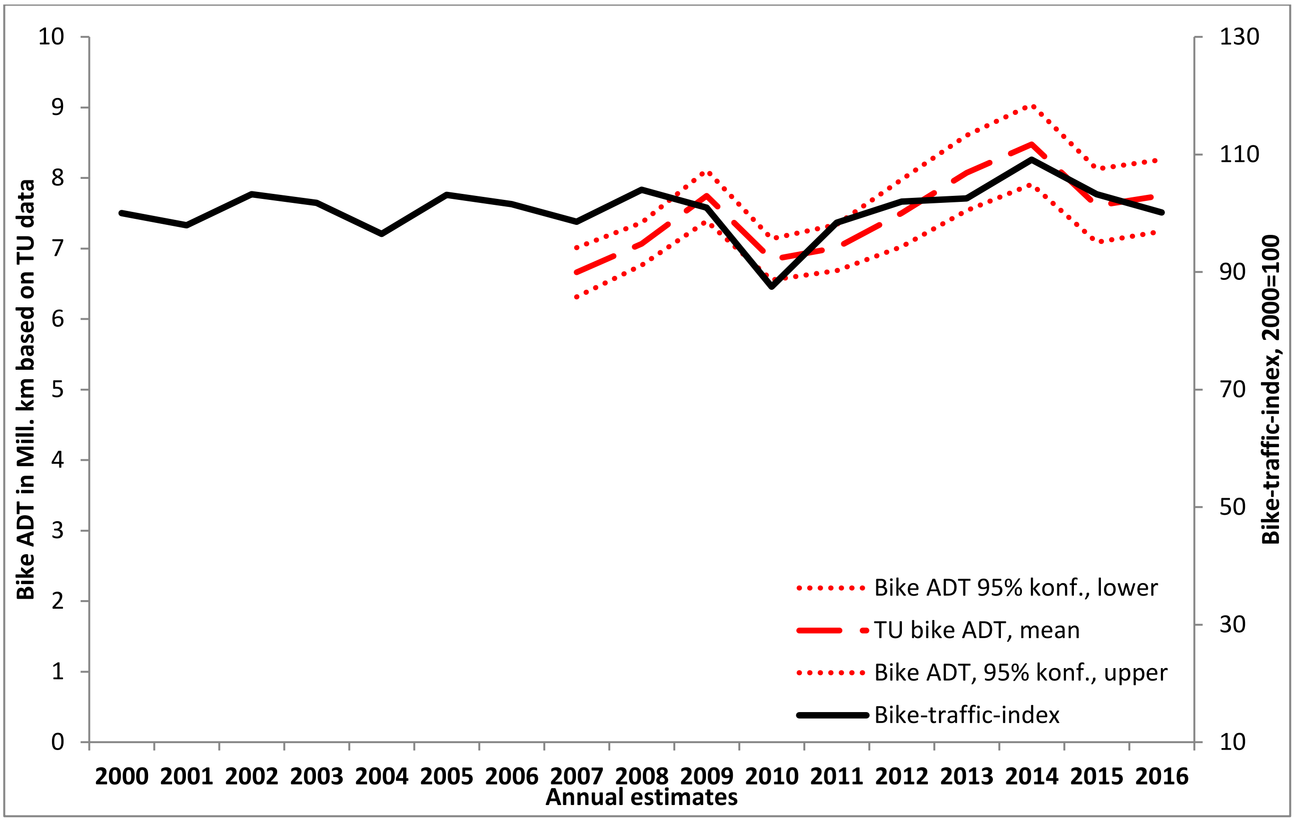

FIGURE 2. Annual bike-traffic-index 2000-2016 (right axis) and bike ADT estimates (Mill. km/day) based on the Danish National Travel Survey (TU) 2007-2016 (left axis).

Figure 2 overlays the annual bike-traffic-index values from 2000 to 2015 with the national bike AADT (Mill. bike km on Danish roads per day) calculated based on the National Travel Survey (TU) most recent and consistent data series from 2006 onwards. Dotted lines indicate the 95% confidence intervals of the AADT estimates and vary in width over time due to differences in annual sample sizes.

In a general way, the two indicators display the same trend, e.g. an increase in cycling from 2011 to 2014 and a largely negative trend from 2014 to 2016. But as can be seen from the confidence intervals, the uncertainty is very high.

Figure 3 highlights the difficulty of change and trend reading in the shorter term by overlaying the monthly bike-traffic-index with bike km per person per day estimated based on the National Travel Survey (TU) from January 2014 to December 2016.

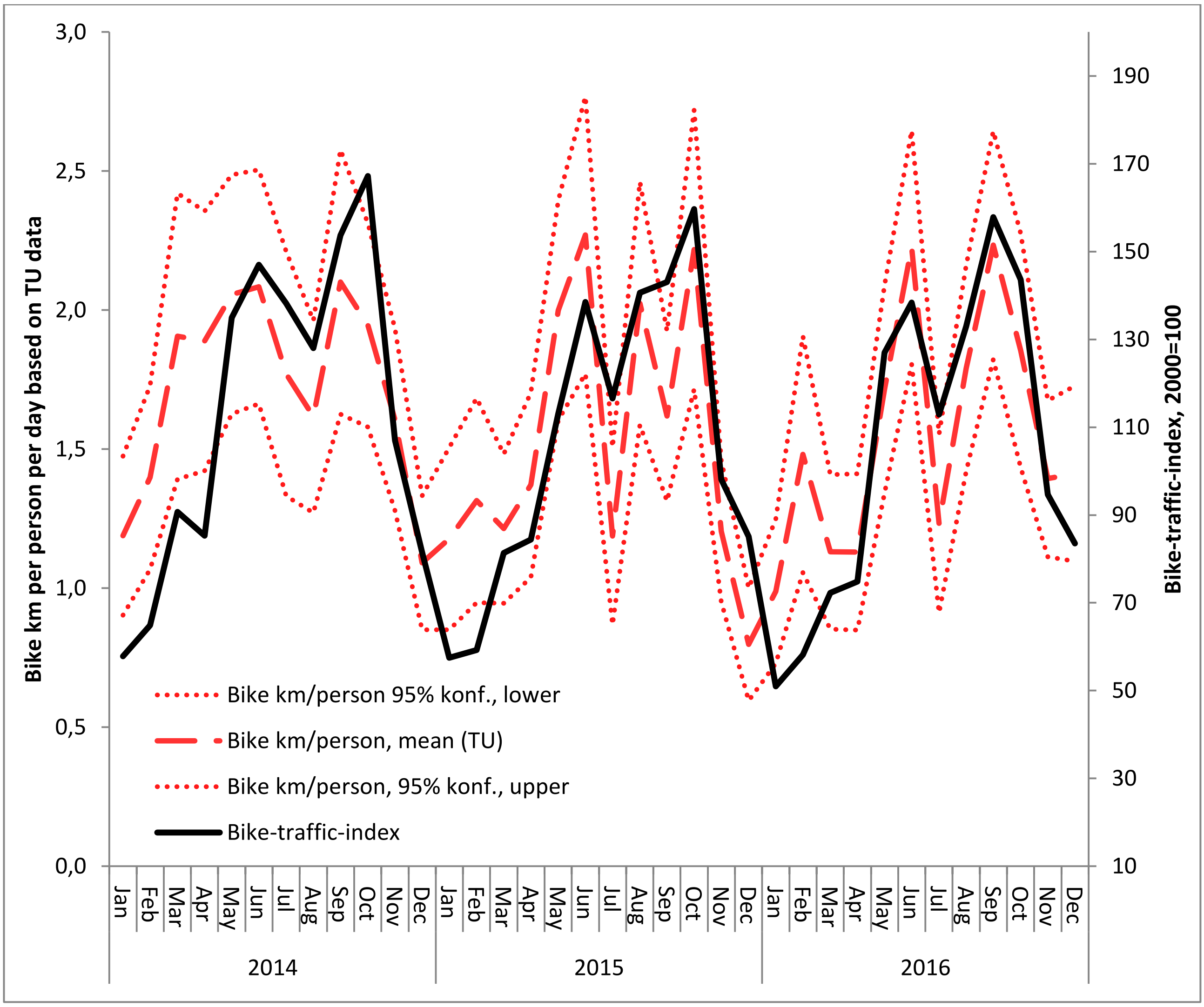

FIGURE 3. Monthly bike-traffic-index 2014-2016 (right axis) and monthly estimates of bike km per person per day based on the Danish National Travel Survey (TU) (left axis).

Turning to the declining trend in Danish cycling after 2014, the travel survey data set (TU) with its current sample size does not support a detection of change by month or quarter. Only by comparing the full 2014 sample with the full 2015 or 2016 sample one can conclude, based on a 95% confidence interval, that bike-km per capita has declined. The reduction in bike km per person per day was between 30 meter and 350 meter from 2014 to 2015 (corresponding to between minus 2% and minus 20%). No significant change in cycling from 2015 to 2016 can be detected based on travel survey data.

The bike-traffic-index with its publication of monthly change/differences (Figure 1) may make up a more certain indicator, especially when it comes to short-term changes, but is of course sensitive to the overall representativity and relevance of this index.

Statistical methodology of the bike-traffic-index

The bike-traffic-index is defined as the ratio of mileages R = Y/X, e.g. between two successive years. Let us assume that a cycling network consisting of N links is divided into H strata, N = N = N_1 +...+ N_H. The sample sizes within the strata are denoted by $n_{1,}$ …., n_H, respectively. The estimate of the population ratio is,

$$\hat{R} = \frac{\hat{Y}}{\hat{X}} = \frac{1}{X}\sum_{h=1}^{H}\frac{\bar{y}_h}{\bar{x}_h}X_h \quad \text{where } \bar{x}_h = \frac{1}{n_h}\sum_{i=1}^{n_h} l_i x'_i \text{ and } \bar{y}_h = \frac{1}{n_h}\sum_{i=1}^{n_h} l_i y'_i \qquad (1)$$

where x'_i and y'_i are counts on link i which has a length of l_i. The milage X_h is used to weight the estimates from the individual stratum and it is assumed to be known (approximately). Figure 4 shows the distribution of total cycling mileage of 3.06 Billion bike-km in 2015 by month, estimated based on TU and count data. The most frequent use of bicycles is in August and September, whereas it is less used in January and February due to winter weather. Figure 5 also includes the estimated distribution of mileage per stratum in the national bike-traffic-index.

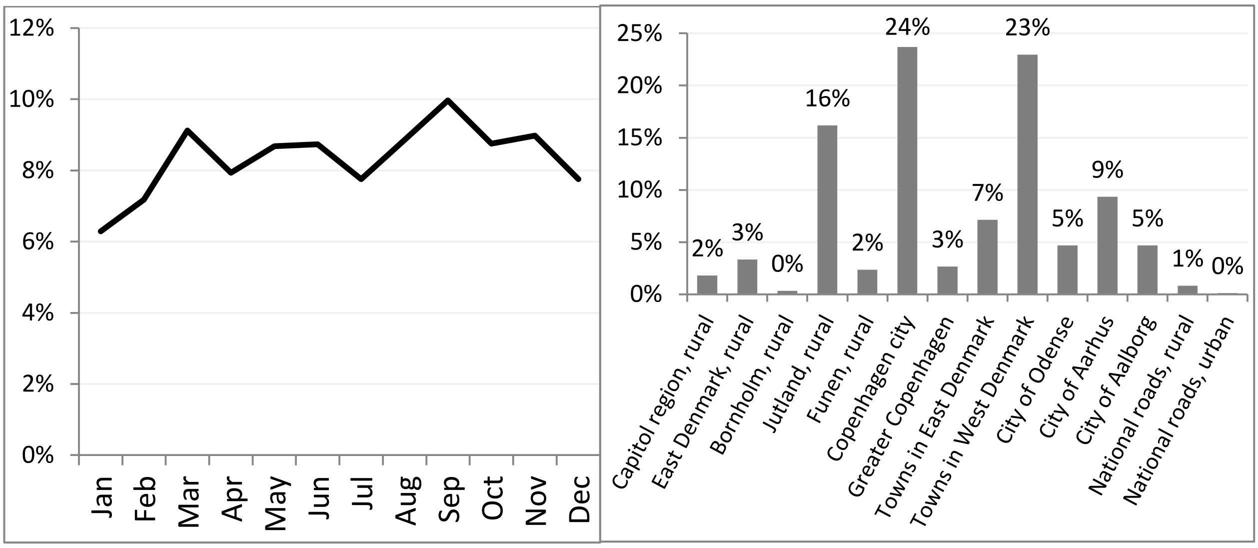

FIGURE 4. Total bicycle mileage by month (left) and strata (right) that are used as weights in the national bike-traffic-index.

In a survey with many strata and small samples (a small number of permanent counts) in each stratum, the ratio may be subject to a small bias. Methods are available to remove or reduce the bias. We use Beale's (Beale, 1962) estimator,

$$\hat{R}_{Bh} = \hat{R}_h F_{Bh} = \hat{R}_h \frac{1+\left(\frac{1-f_h}{n_h}\right)c_{hxy}}{1+\left(\frac{1-f_h}{n_h}\right)c_{hxx}} \qquad (2)$$

where c_{hxy} and c_{hxx} are the sample relative covariance and relative variance of x within the strata, respectively.

The mean square error of the sample estimate (2) is,

$$MSE(\hat{R}_B) = \frac{1}{X^2}\sum_{h=1}^{H}\left(V(\hat{Y}_h) + X_h^2(E(\hat{R}_{Bh} - R_{Bh}))^2\right) = \frac{1}{X^2}\sum_{h=1}^{H} X_h^2\left(V(\hat{R}_{Bh}) + (E(\hat{R}_{Bh} - R_{Bh}))^2\right) \qquad (3)$$

The variance of the estimated ratio is,

$$V(\hat{R}_B) = \frac{1}{X^2}V(\hat{Y}) \approx \frac{1}{X^2}\sum_{h=1}^{H}\frac{N_h^2(1-f_h)}{n_h}s_{dh}^2 \qquad (4)$$

where $f_n = n_h/N_h$ is the sampling fraction. The estimated variance is (Cochran, 1977),

$$s_{dh}^2 = \frac{1}{n_h - 1}\sum_{i=1}^{n_h} l_i^2\left(y_i - \hat{R}_{Bh}\, x_i\right)^2 = s_{hy}^2 + \hat{R}_{Bh}^2\, s_{hx}^2 - 2\hat{R}_{Bh}\,\rho_{hxy}s_{hy}s_{hx} \qquad (5)$$

where s^2_{hx} and s^2_{hy} are sample variances of x and y, respectively, and ρ_{hxy} is the sample correlation coefficient between x and y within stratum h. The bias of (2) is found by a Taylor approximation:

$$E(\hat{R}_{Bh} - R_h) \approx \frac{1 - f_h}{n_h \bar{X}_h^2}\left(\hat{R}_{Bh}\, s^2_{hx} - F_{Bh}\rho_{hxy} s_{hx} s_{hy}\right) + \hat{R}_{Bh}(F_{Bh} - 1) \qquad (6)$$

The confidence limits of the ratio estimate is,

$$R \;:\; \hat{R}_B \pm z\sqrt{MSE(\hat{R}_B)} \qquad (7)$$

Assuming a normal distribution and confidence probability of 95%, z = 1.96.

Stratification in the bike-traffic-index

The Danish bike-traffic-index is developed to represent change in cycling on Danish roads and paths based on a set of permanent counting stations across the country. As a core element of the methodology the counting stations are selected and located to represent different strata/stratifications.

The aim of the stratification is threefold:

i) To meet the user objectives of the bike-traffic-index
ii) To minimize the mean square error of the ratio estimate
iii) To utilize existing counting sites most efficiently

Hence, it involves a multidisciplinary mixture of policy aspects, technical skills and cost issues and has been developed in a multistep procedure with iterations between the different objectives and aims. One objective of the bike-traffic-index is for example to monitor bike-traffic for different uses of land or for different types of bike paths. Additionally, the Danish Road Directorate is often required for distinguishing between rural and urban areas, national and municipal roads and/or between the different regions of the country, and therefore these also have to be identifiable based on the stratification.

The equations (5) and (6) reveal that the mean square error (MSE) depends on the sample variances and correlation coefficients. Therefore, the strata should be developed with the aim of grouping network links with similar traffic volumes. Ideally, this is done on the basis of the cycling network. Often, however, only proxies of cycling volumes are available for the grouping of links. Experience shows, that accuracy will benefit by grouping residential streets and main urban roads into different strata. Residential streets may have less than 20 in bike AADT, whereas main urban roads can easily reach hundreds or even thousands of cyclists per day. The rural network available for cycling is very large and most links carry close to none or very few cyclicts per day. The few frequently used bike paths outside urban areas, e.g. cycle highways and similar links used for commuting, are radically different and should be separeted from other rural networks by the stratification.

The correlation coefficients between x and y are estimated from a sample of continuous counting sites within each stratum – for two consecutive years. In practice, estimation is limited to the available number of counting sites, often with few sites per stratum as well as stratas that are currently not covered by permanent counting stations. This has implications for the estimation of accuracy of the bike-traffic-index, but the estimation may be improved as the number of available counting sites increases further. In the current Danish bike-traffic-index, the number of counting sites for estimation of correlation range from 4 to 20 per stratum and 2/3 of the strata are covered with sample data. The correlation coefficients will, with a proper stratification, be very close to 1 because the main drivers of traffic growth are generic, including e.g. population growth, weather, and economy. In the national bike-traffic-index, the correlation coefficients are estimated to be in the range from 0.981 to 0.999. Similar levels of correlation are found in estimations based on more detailed strata for local bike indexes. A comparison with index-data for motor-vehicles indicates that the coefficients, in general, are higher for motor-vehicles than for cycling.

In theory, the counting sites must be randomly selected within each stratum. But a number of permanent counting stations have been established over the years for different reasons. Establishing and maintaining new counting stations is costly, so to reduce costs, counting stations representative of each stratum generally have to be sought within the selection of existing stations. There are around 100 permanent counting stations available for the bike-traffic-index. They have been manually inspected and 61 have been selected for the bike-traffic-index (see Figure 5). Figure 6 illustrates the problem in using existing counting sites, as there are few sites available on Funen and in West Jutland. This is solved in the stratification of Funen and Jutland.

Thus, the bike-traffic-index is based on a pseudo random sample of permanent counting stations used in the current version of the bike-traffic-index. However, all new counting sites added to the index are randomly selected by drawing from the ‘population’ of network links.

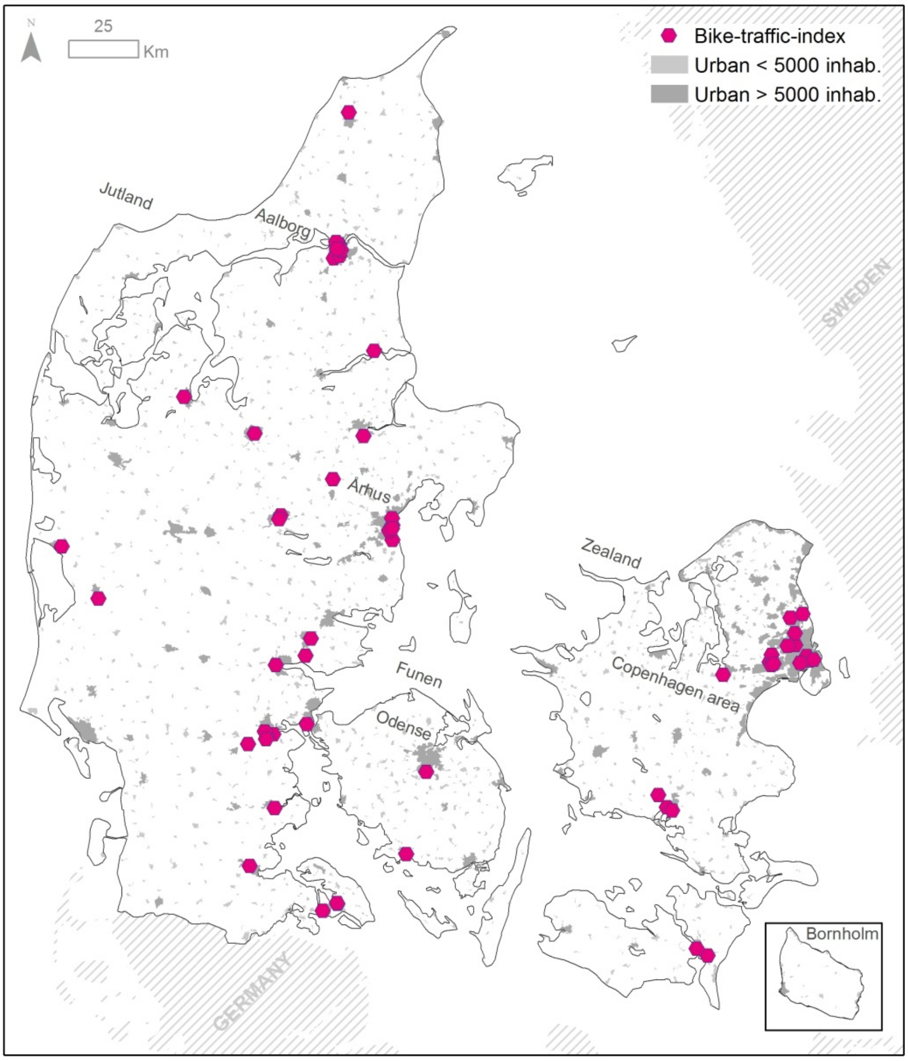

FIGURE 5. Map of permanent counting stations included in the Danish bike-traffic-index.

The current version of the bike-traffic-index includes 14 strata divided into 2 strata for national cycling network (urban and rural paths) and 12 strata for municipality network. The municipal network is stratified into 5 rural areas and 9 combinations of city sizes and street types (e.g. local streets in Copenhagen). The stratification will be refined and improved as the number of counting sites available for the index increases.

Municipalities such as Aarhus and Kolding develop their own local bike-traffic-indexes based on permanent counting stations which of course provide a resource for the national bike-traffic-index as well. Figure 6 illustrates the stratification of the cycling network for Kolding municipality. At this geographical level the stratification can be developed to consider location in specific neighborhoods and connectivity in the local network. For example, the northern part of Kolding city has an individual stratum, because an urban development is taking place in this part of the city.

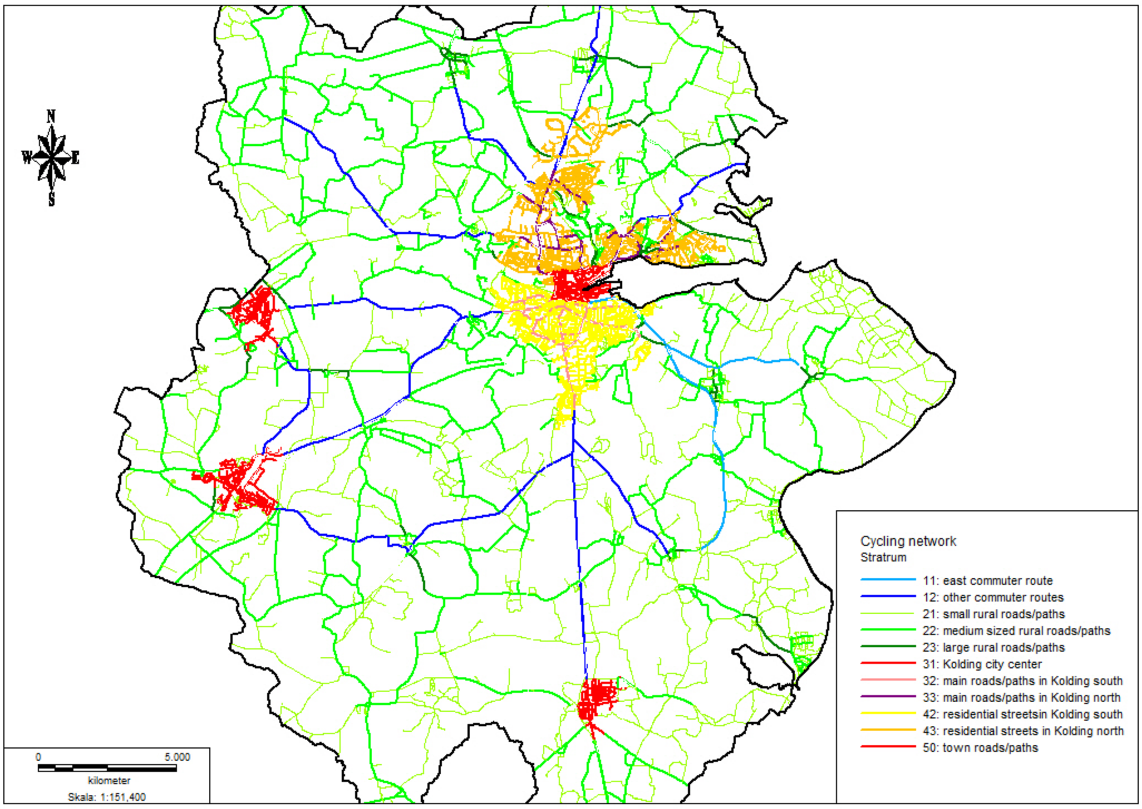

FIGURE 6. Stratification of the cycling network for a local bike-traffic-index.

Accuracy of the bike-traffic-index

The accuracy of the bike-traffic-index is estimated on assessments of annual average daily traffic (AADT) in the strata, whereas the index is applied for average monthly traffic. AADT is used to assess the level of accuracy as AADT estimates are available in larger numbers than monthly volumes. While data may be missing for a few months, it is still possible to estimate AADT sufficiently accurate. The accuracy assessed, based on monthly volumes, is not necessarily less than one based on AADT estimates, since traffic is counted continuously. Actually, the correlation coefficients may be higher since the general trends can be stronger for a short period due e.g. to the general weather conditions. This postulate has been verified for selected months.

Calculated based on available counting data, the current version of the Danish bike-traffic-index which is based on 61 permanent counting stations, will be able to detect the true growth in cycling within ±4% (95% confidence level). In comparison, the national index for motor vehicles is estimated with a 95% confidence of ±0.5% partly due to a larger sample size. The sample size is among the key parameters for improving the bike-traffic-index. Figure 8 shows the size of the 95% confidence interval limits for different sample sizes of the bike-traffic-index.

The stratification and the sample size are mutually dependent and with few counting stations the number of strata will be less. With an increased sample size, the stratification can be refined and counting stations allocated more optimal to the strata using for example Neyman allocation (Neyman, 1944). Therefore, the accuracy increases rapidly for sample sizes from 30 to about 90 counting stations. As Figure 7 is based on the effect of using an increasing number of counting stations to represent the existing 14 strata, the contribution from an improved stratification cannot be fully assessed. An additional 'leap' in accuracy should be expected at the point where the sampling allows the stratification to be further detailed, i.e. from approximately 90 permanent counting stations.

For comparison, Figure 8 also shows the dependency between accuracy and sample size for a local (municipal) bike-traffic-index. As one would expect, much fewer sites are required to provide accurate estimates representative of the local area. The steep increase in accuracy is due to an improved and refined stratification and optimal allocation of new counting sites to strata.

Equation (2) uses the Beale estimator to correct for small sample sizes in the strata. Experience from the national and local index shows that the role of this correction is very marginal, the mean square error (MSE) is reduced by less than 1%. The need for a bias reduction factor in the index will decrease as the number of counting stations increases per stratum. In addition to the number of stations this also (2) depends on the covariance compared to the variance within the stratum – and therefore the quality of the stratification which may also be improved with a larger sample size.

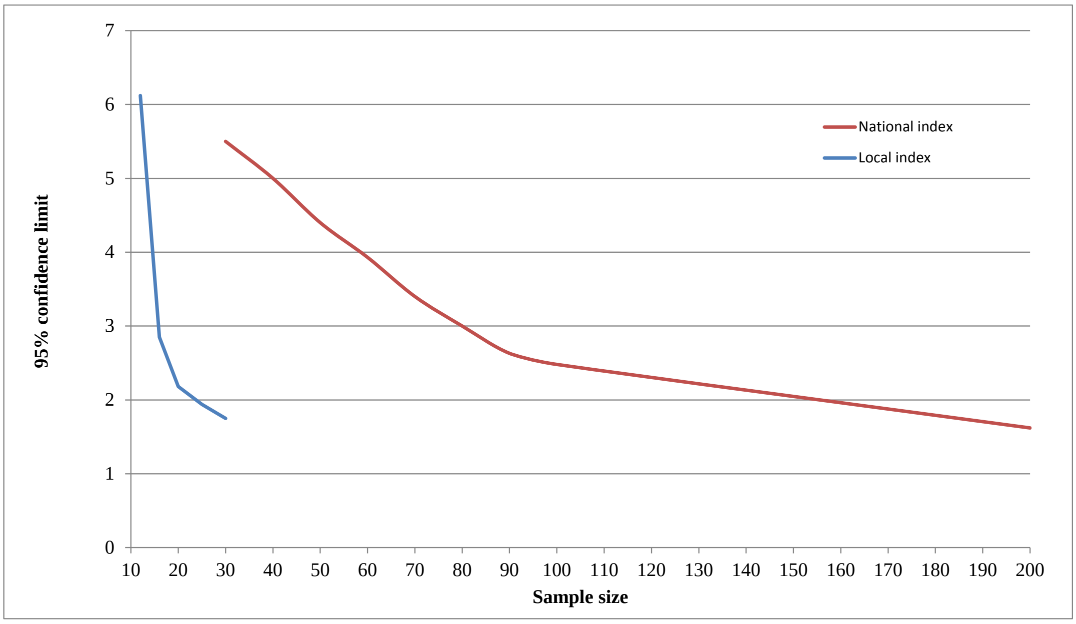

FIGURE 7. Estimated 95% confidence interval limits in %-change for different sample sizes of the national bike-traffic-index as well as in a local (municipal) index.

The future of the Danish bike-traffic-index

The Danish bike-traffic-index is already undergoing a 'development program' with some elements that are expected to unfold in the short term. This includes targetting the role of the weather for changes in the index. The year 2010 provides a prominent example of a steep temporal decline in cycling due to harsh winter weather which makes it hard to identify a general trend which goes beyond the weather. Solutions may involve a sub-index based on less weather sensitive seasons or more advanced weather-based stratification to ascertain that only days with comparable weather are compared to assess change in cycling from year to year. Development plans also include an intensification of dialogue with the municipalities to create interest and 'recruit' permanent bike counts to the national index. And finally, efforts to update correction factors for short-term counts into AADT may indirectly benefit the bike-traffic-index, as it will improve and create knowledge on the uncertainty of this correction, and thus the consequences for reliability of depending on short-term counts.

In the longer term it may be relevant to reconsider the stratification of the index from the perspective of securing homogeneous and relevant strata for measuring bike-traffic – as well as from the perspective of policy relevance. The current stratification may not capture the relevant breaks and areas of attention in the development of cycling, including e.g. cycle highways and tourism/recreational cycle routes. As the index rely on inputs from many data owners creating interest by answering, the right questions will be increasingly important. This includes bearing in mind that the stakeholders in cycling promotion are diverse and the transportation planners often are marginally represented among them.

Additionally, the current national bike-traffic-index as well as a new index may benefit substantially from a better metric of the bikeable network in the strata. Standardized GIS layers of bikepaths and bikeways with national coverage have generally not been available. Efforts have now been made to collect these and bike-network metric can be made for all parts of the country but some methodological development will also be required to employ this in the index calculation.

Lastly – and naturally – more permanent bike-counts controlled by the Danish Road Directorate (or by the needs of creating a reliable/valid index) is desirable. The Danish Road Directorate has the ambition to be able to expand the bike-traffic-index to 200 permanent counting stations, partly based on counting stations in operation in the municipalities. The challenge that we face, when representing the national change in cycling based on the municipal counting stations, is that they are generally located in connection with new key infrastructures and/or may serve the purpose of being visible and create public awareness. Thus, these highly selective locations need to be supplemented with counting stations on smaller and more rural roads to secure that the 200 counting stations will adequately represent bike-traffic on Danish roads.

Improving the Danish National Travel Survey (TU), either by increasing its sample size or by introducing panel-based approaches to assess temporal variation in cycling, would of course also make a valuable contribution to the monitoring of cycling in Denmark. In general, the TU and the bike-traffic-index are treated as supplementary sources, bearing in mind that the TU is devised to fulfill multiple other objectives than measuring just bike-traffic – in contrastto the bike-traffic-index which is devised to measure bike-traffic and should do it better in the future.

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