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Note

Estimating Annual Average Daily Traffic (AADT) based on extremely sparse traffic counts

A study of the feasibility of using satellite data for AADT estimation

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Abstract

The current primary source of traffic statistics in Norway is measurement stations based on induction loops counting vehicles that pass a given point in the road system over time. The basis curve method is then used to estimate the annual traffic volume for count sites where counts are unavailable parts of the year. The estimate is usually given as AADT; Annual Average Daily Traffic.

A satellite image is covering a large area instantanesouly and can thereby be an alternative source of information. This requires that the number of vehicles in the image can be counted automatically, and the average speed of the vehicles in the image can be estimated. However, due to the nature of the satellite system in question, and the dependence on cloud free conditions, only a few useful images can be expected every year.

This report documents a set of experiments that were made in order to assess the quality of AADT estimates based on extremely sparse traffic data. More specifically, the chosen input data sets have been designed to simulate satellite data, with resepect to frequency of counts, the amount of information in one count, and what time of the day and the year counts can be obtained from optical satellites. The results indicate that counting data representing as little as one five minute interval – corresponding to a satellite image covering roughly seven kilometres road with an average speed of 80 km/h - may produce useful AADT estimates. Thus, further work to improve the analysis of the satellite images, i.e., the vehicle detection method, is worthwhile.

Keywords	AADT, traffic monitoring, satellite images, basis curve method
Target group	Road traffic authorities
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Contents

1 Introduction

Estimation of Annual Average Daily Traffic (AADT) is usually based on counts of the number of vehicles that pass a road during a certain period of time. The ground-based equipment that is applied for making such measurements is relatively expensive, both to purchase and operate. For some highways, continuous measurements are made throughout the year. Most commonly, however, the counting period lasts for a few weeks, or even less. For most Norwegian roads, no counts are made at all, hence AADT can not be estimated.

The basis curve method, developed by the Norwegian Computing Center ([1],[2], and [3]), is used to estimate the annual traffic volume for count sites where counts are available for only a limited part of the year. The method is based on a statistical model, the complexity of which is adapted to the amount of data available. The method is currently in use by the Norwegian Public Roads Administration. The required input data is obtained from ground-based sensors.

We have been investigating the possibility of using satellite images to obtain information about the traffic situation. The idea is that automatic image analysis methodology based on pattern recognition, in combination with high resolution satellite imagery (today available e.g. by the commercial Quickbird and Ikonos satellites), can be used to count the number of vehicles in a larger area. In the "SatTrafikk" project, which is a continuation of the "Road Traffic Snapshot" project (2006-2007), it has been shown that this is indeed a promising alternative ([4] and [5]). Assuming that the number of cars on a section of the road at a given point in time can be detected from the satellite image, and the average speed of the cars is known, the traffic that pass a single point in the road over a short period (a few minutes) can be calculated. If satellite images can be used for estimation of AADT, then much larger areas and a much larger number of roads can be covered as compared to today's situation, where in-road measurements are the only alternative.

Assuming that satellite data may be used for reliable traffic counts, there would still be a very restricted amount of data available for input to the basis curve method. Detecting vehicles from space requires very high resolution imagery, taken on a cloud free day, preferably during the snow free season of the year. The elevation of the sun in the sky also plays an important role for the quality of the images. With the commercial satellites of today, this means that we could expect from one to a few useful images per year. One image covering a five kilometer road section where the average speed is 60 kilometres per hour could hold the information equivalent to five minutes long in-road (i.e., a single point in the road) count. The question now is whether a few counts of only a few minutes each is sufficient for the basis curve method to make an acceptable estimate of AADT.

This document describes the work that has been done in order to assess the quality of the AADT estimates that are generated by the basis curve method when the input data is fictive satellite traffic counts. The work has been performed as a part of the SatTrafikk project in 2008, with funding from the Norwegian Space Centre (Norsk Romsenter) and the Norwegian Public Roads Administration (Statens Vegvesen Vegdirektoratet).

2 Methods, experiments and data

2.1 Data

The main idea of the experiments is to compare "true" AADT to the approximate AADT estimates made from simulated satellite counts, i.e., AADT estimates made from extremely short term data. More specifically:

- By true AADT estimates, we refer to the AADT calculated by the basis curve method using (more or less) continuous hourly in-road counts, i.e., with minimum 80% of the year covered.
- By approximate AADT, we refer to the AADT calculated by the basis curve method, using only a few selected five, ten, or 15 minute intervals (see below for how the selection was made).

The counting data is from 18 in-road counting stations. It is provided by the Norwegian Public Road Authorities. For each counting station, vehicles are counted at two different time resolutions; hourly or per five minutes. The data is collected between 2003 and 2007. We only consider years where the hour data is at least 80% complete. The coverage of five minute data is very poor in comparison. A consistency check between the five minute data and the hour data only makes sense at hours that are covered in the hour data and where all twelve five minute intervals are covered in the five minute data. This matching is only occasionally fulfilled, and for this reason, many of the five minute intervals can not be checked against the hour data. Nevertheless, checking possible situations revealed that the five minute data and the hour data do generally not agree completely. In other words, the sum of cars over the twelve five minute periods of one hour does not in general equal the corresponding hour count. Lack of consistency between the data at the two different time resolutions is unfortunate. However, the inconsistency is relatively small (usually around 2%), and we have ignored the problem in our experiments, assuming that the contribution to the error is negligible.

Table 1 gives an overview of the data that was used for the experiments. The counting stations are divided into three classes depending on the amount of traffic on the corresponding road;

- small AADT : < 10,000
- medium AADT : 10,000 – 20,000
- large AADT : > 20,000

The AADT given in the table is based on the hour data for the respective counting station. At some counting stations, data is available for one year only, while others have data from up to five years. The table shows the average AADT over the given years for stations with data from more than one year.

2.2 The basis curve method

As mentioned above, the basis curve method is a method for calculation of yearly traffic volume. Based on hourly traffic counts for a part of the year, the number of cars per hour is estimated for those hours where counts are not available. AADT, together with an uncertainty estimate, is then calculated from the collection of true and estimated data.

The basis curve method supplies the precision of the traffic volume estimates as a function of the sampling design, i.e., when and for how long the traffic is counted. In general the uncertainty will decrease as the counting period becomes longer, but it also depends on what time of the day or week the counts are done. The method uses a set of predefined basis curves, which describes the trend variation in traffic volume. If the available amount of data is small, then the estimated curve describing traffic will not follow the pattern of the data very closely, but instead rely more heavyily on the predefined assumptions, except that the level will be adjusted to the true data. On the other hand, if there are much data available, then the fitted curve will follow the data more closely. With moderate amounts of data, say a few days, weeks, or months, the basis curve method is more precise than the traditional factor curve approach, or equivalently, it needs less data than the factor curve to achieve the same precision. On the other hand, with extremely sparse traffic data, as in our situation, the basis curve method behaves like the factor approach, i.e., only the first basis curve is used.

The basis curve method has three sets of basis curves, depending on the ratio between the traffic volume in the summer compared to the rest of the year. Here we use the set of curves corresponding to the medium ratio.

	Counting station	AADT	Years
Small AADT	Veggli	2254	2007
	Nyhus	2681	2007
	Flå	3872	2007
	Vrengen Bru	5241	2003, 2004
	Stokkebakken	8486	2003
Medium AADT	Sollihøgda	10281	2007
	Lanner	12970	2003
	Solum	13023	2003, 2004, 2005, 2006
	Strømsåstunnelen	13382	2003, 2004, 2005, 2006, 2007
	Bolstadtunnelen	14991	2005, 2007
	Brekketunnelen	15102	2005, 2007
	Nygård	15991	2003, 2005
	Herstrøm	16958	2007
Large AADT	Ringdal	21860	2005, 2006
	Klinestad	22947	2003, 2004, 2005, 2006, 2007
	Skoger	23224	2003, 2004, 2005, 2006, 2007
	Holmane	24180	2004, 2005, 2006, 2007
	Lierskogen	39145	2003, 2005, 2007

Table 1 Overview of counting data used for experiments. At counting stations with data from more than one year, the average AADT is given.

Vehicle counts may be obtained at various levels of detail, and the AADT estimate can be given with the same degree of detail as the counts, as well as for aggregated levels. More specifically, the counts may be available for each lane, for each driving direction, or as a sum of two directions. Furthermore, the vehicles may be divided into five length classes – one class for light vehicles (up to 5.5 metres), and four classes for heavy vehicles. In this study, we have focused on the level of maximum aggregation, i.e., the total sum of vehicles of any size and in both directions, thus we will only report AADT estimates and errors at the total level.

The basis curve method has not yet been developed for use on data with time resolution less than one hour. We therefore had to modify it for the use in our experiments. First, all five, ten, or fifteen minute counts were rescaled to hourly counts, for instance, a five minute count were multiplied by twelve. Second, it turned out that the method was too flexible with respect to adapting to the data when the amount of data was extremely sparse, yielding unstable results. We therefore modified the method such that only the first basis curve was used when applied to extremely sparse data sets.

2.3 Experiments

The approximate AADT is calculated as follows:

- Since the available five minute data is sparse, we require that we have at least 1000 five minute intervals with data within the time of the year and the day when it is likely to acquire useful satellite images. We assume that useful images can be acquired from April through September, and between 10:00 and 14:00 hours local time.
- We assume that it is likely to obtain between one and six useful images per year, and that each image gives the equivalent information of five to 15 minutes of single-point (traditional) measurements. Hence we did experiments using from one up to six counts, and with one, two, or three contiguous five minute intervals per count, i.e., with duration five, ten, or 15 minutes. With an average vehicle speed of 80 km/h, this corresponds to road segments of length 6.7 km, 13.3 km, and 20 km, respectively.
- For each combination of counts, the counting intervals are drawn pseudo-randomly from the pool of useful intervals, until we get a useful data set. The typical satellite repetition cycle and ground swath for very high resolution optical satellites makes it impossible to acquire images with less than around three days of separation. Estimation is made only in the case that the time lapse between any two intervals was at least 60 days divided by the number of counts, i.e., when using two counts, the minimum separation between the two counts had to be 30 days, when using three counts, the minimum separation between each couple of counts was 20 days, etc.
- For each combination of counts, 1000 data sets are constructed, and each data set is used to make an AADT estimate.

For each data set, the approximate AADT, $\hat{\alpha}_i$, is compared to the true AADT, α, by calculating the relative error,

$$\hat{\varepsilon}_i = \frac{\hat{\alpha}_i - \alpha}{\alpha}.$$

For each counting station and year, denoted c and y, respectively, the mean absolute error , $\hat{\varepsilon}_{abs}^{c,y}$, is then calculated as

$$\hat{\varepsilon}^{c,y}_{abs} = \frac{1}{1000}\sum_{i=1}^{1000}\left|\hat{\varepsilon}_i\right|,$$

and the root mean square (RMS) error, $\hat{\varepsilon}^{c,y}_{rms}$, by

$$\hat{\varepsilon}^{c,y}_{rms} = \sqrt{\frac{1}{1000}\sum_{i=1}^{1000}\hat{\varepsilon}_i^2}\ .$$

Hence, these errors are calculated for each counting station and for each year. Then, the total error over all years and counting stations is calculated. Each counting station is given the same weight in the total sum, and each year is given the same weight to the counting station. More specifically, the total error is given by:

$$\varepsilon^{total}_{type} = \frac{1}{n_c}\sum_{\text{all } c}\left(\frac{1}{n_y^c}\sum_{\substack{\text{all } y\\ \text{available}\\ \text{for } c}}\hat{\varepsilon}^{c,y}_{type}\right),$$

where n_c denotes the number of counting stations, n_y^c denotes the number of years with available data for counting station *c*, and *type* is either *abs* or *rms*. The total error is also calculated class-wise, i.e., for each class of counting stations: small, medium, or large AADT.

3 Results and discussion

Figure 1 and Figure 2 below present plots of the absolute error and the RMS error, respectively.

As could be expected, the general picture shows that the error gets smaller the more counts are used in the AADT estimate, and the error is also smaller when each count represents a longer time interval (e.g. 15 minutes) than a shorter time interval (e.g. 5 minutes).

The time lapse between each car that passes the station is greater for stations with small AADT than for those with large AADT. (For a five minute time interval, the number of cars passing a counting station with large AADT is typically several tens, while at a counting station with small AADT, the number might be 0-10). Thus, within a few, short, randomly selected time intervals we expect to get less statistical material to build our AADT estimate at roads with less traffic. Therefore, it is natural to assume that counting stations with small AADT are more sensitive to estimation error. This assumption was indeed verified by our experiments. For one single five minute interval, the absolute error was on average 36% for counting stations with small AADT, 27% for medium AADT, and 22% for large AADT. The corresponding RMS error was 55%, 34%, and 27%, for small, medium and large AADT, resepectively. Nevertheless, this indicates that the basis curve method is stable; the AADT estimate does not get totally out of proportion, even with a minimum amount of input data.

The results also indicate that the smaller the AADT, the more there is to gain on adding more counts. This can be seen as the error curves, as expected, are steeper for smaller AADT than for larger. However, using six counts, the absolute error measures around 15-17%, no matter which

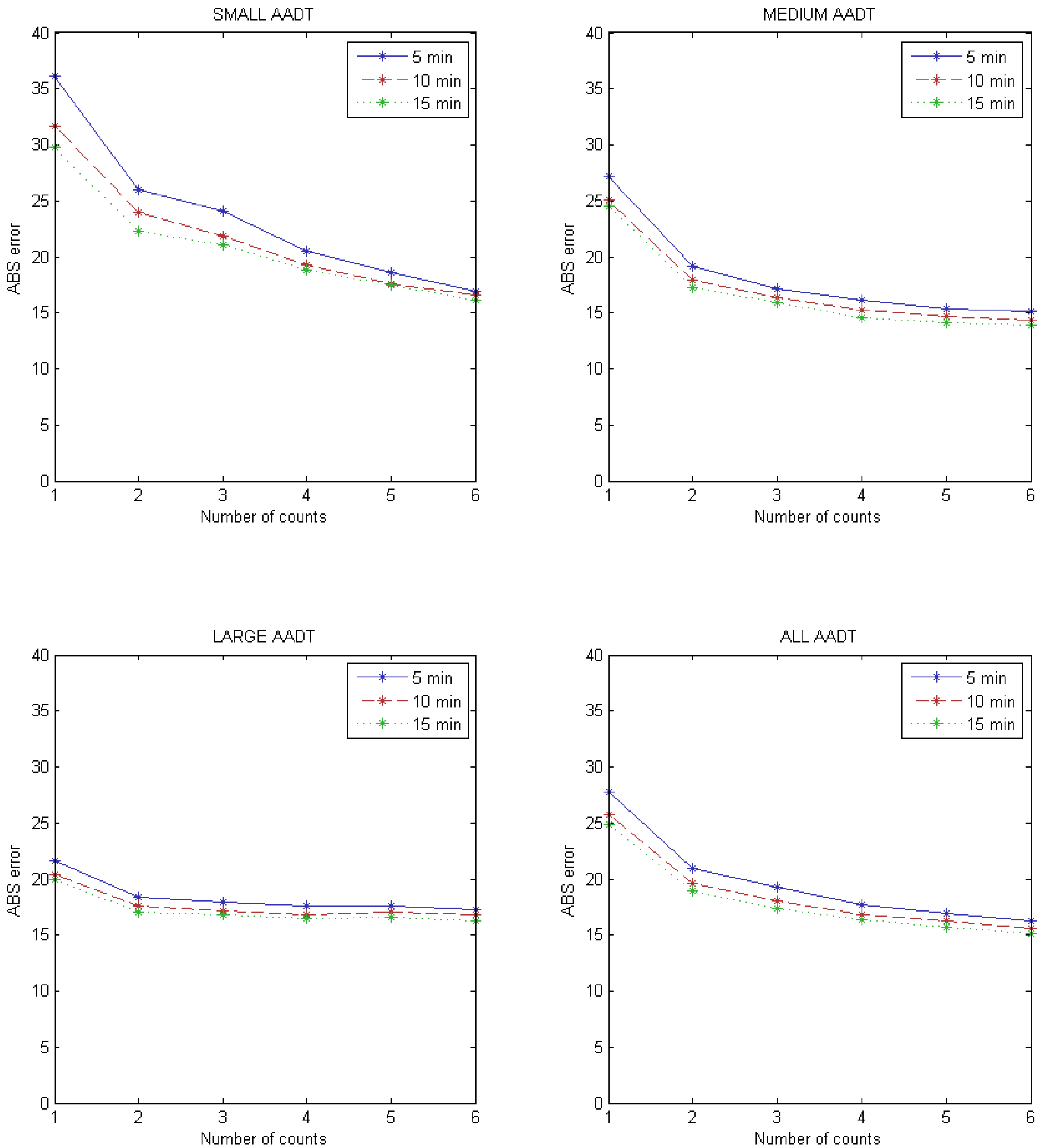

Figure 1 Absolute error.

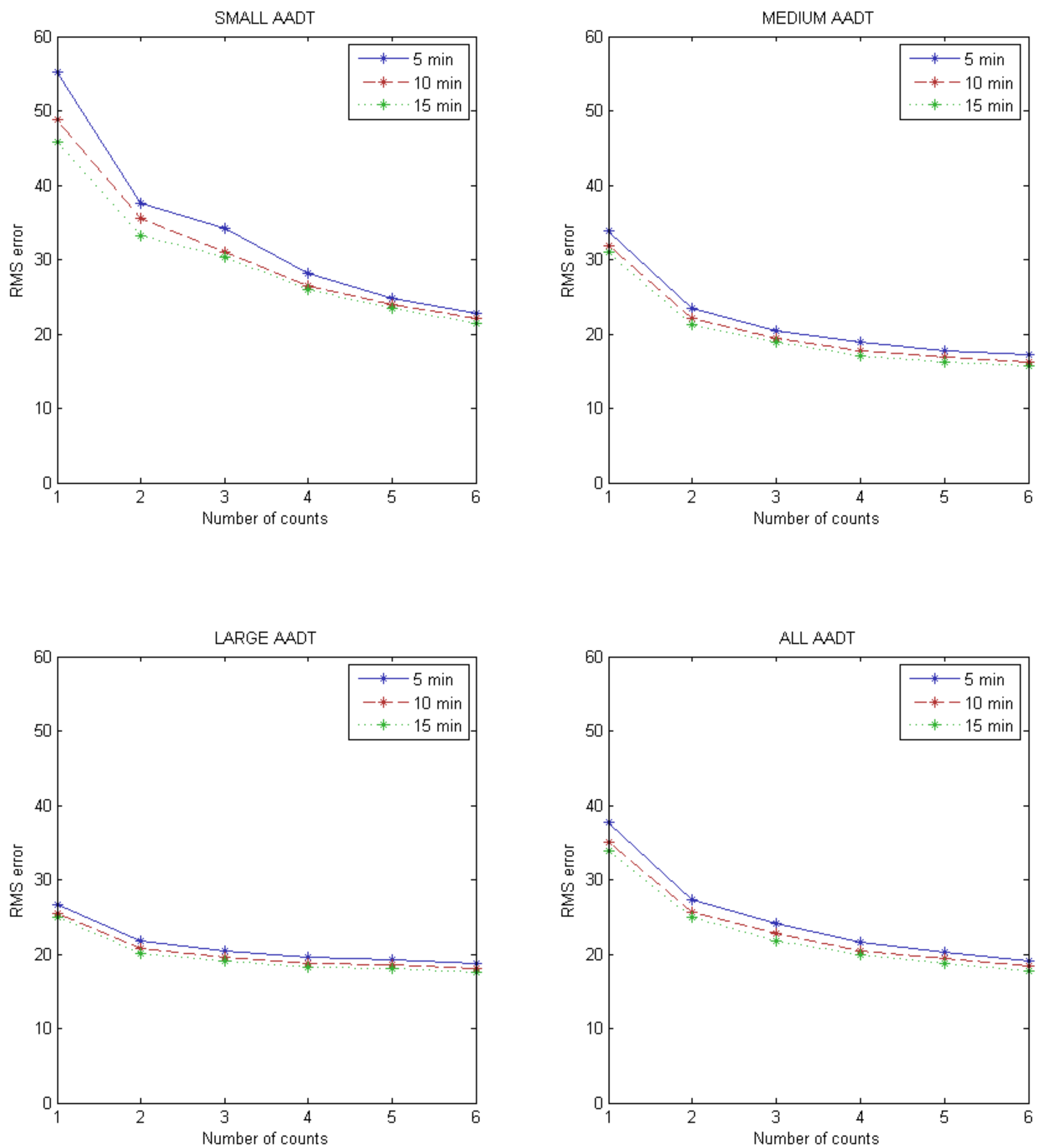

Figure 2 Root Mean Square (RMS) error.

AADT we look at. It is surprising that the curve is more or less flat above three counts in the large AADT case. This may be explained by contingencies in the data. The amount of experimental data is limited, with only five examples of large AADT counting stations.

Now, it is likely to get at least two to three satellite images per year, in which case the situation will look much better. If each satellite image covers the equivalent length of a road to 15 minutes of single-point measurements, and we have three satellite images per year, the absolute error is 21% for small AADT and 17% for large AADT, while the RMS error is 30% and 19%, resepectively.

Although at present it is not likely to have six useful satellite images over the same area in the same year, perhaps, with the rapid development in the field of remote sensing, the market of new remote sensing satellites will increase, and this is not unlikely in the not-so-far future. It is worth mentioning, that with six counts, the absolute error is around 15% for all classes of AADT.

A related study by McCord et al. [6] focuses on some American highways in Ohio. They suggest using satellite or aerial imagery in combination with ground-based sensors. They present results of using one single 1-m resolution image (with information equivalent to a few minutes of ground-based counts) for AADT estimation based on the factor approach. The reported relative difference, $\hat{\varepsilon}_i$, is - although notingly better - comparable to our results, especially when taking into consideration the fact that the roads in their study have much larger traffic (AADT between 30,000 and 180,000) than the roads in our study, i.e., the error is expected to be smaller since the AADT is larger. Interestingly, McCord et al. found that the mean of the relative error distribution is close to zero. This indicates that averaging the AADT estimates of two or more images may lead to even better results.

4 Summary and conclusions

In this report we have presented a study of whether it is feasible to calculate AADT based on extremely short term traffic data. The intention behind the study was to see if satellite images can be used as an alternative source of traffic information to the current system of in-road equipment. Traffic counts with five minutes time resolution was collected from a set of traffic stations, together with continuous (or, at least 80% complete, that is) hourly traffic counts throughout the year. The hourly counts were used to estimate the reference, or “true”, AADT, while the five minute data was used to construct data sets that were meant to represent the different combinations of counts one would expect to obtain from satellite data from within one year. These data sets were then one by one used to estimate AADT, and the results were compared to the true AADT. The absolute and RMS errors were calculated.

We defined three traffic volume classes; small (<10,000), medium (10,000-20,000), and large (>20,000) AADT. The results were presented in class-wise and total error plots, which showed some clear trends:

- The error was smaller the more counts that were used in the AADT estimate, and the error was also smaller when each count represented a longer time interval (e.g. 15 minutes) than a shorter time interval (e.g. 5 minutes).

- Comparing the error between the classes, the result was worst for counting stations with small AADT, and then got increasingly better for counting stations with medium to large AADT.

With three five minute counts or more, the class average RMS error is less than 30% in our case. It should be noted that the error may be larger for individual counting stations, and the error will also most likely be larger if we include roads with even less traffic (say, AADT < 1000) than in our example (Table 1). Yet, the question is now – is this result good enough? Since we had no predefined limit on what is an acceptable error, this is hard to answer. However, the perhaps most important result shown by these experiments is that the method is stable; even with only five minutes of data, the AADT estimate does not get totally out of proportion. As mentioned above, in many roads, the alternative is no AADT estimate at all, since ground-based measurements are too expensive. The information from two-three satellite images would then be valuable, even if it comes with a relatively high uncertainty measure.

In this report we have assumed that our methodology for vehicle detection in satellite images is as reliable as the in-road five minute counts. As of today, this assumption does not hold. In [5], automatic vehicle counts were compared with manual vehicle counts in six satellite scenes. The automatic method found between 68% and 157% as many vehicles as the manual count. This uncertainty is much larger than the uncertainty found in the ground-based sensors (see Section 2.1). However, this report shows that using very short term traffic counts in combintation with the basis curve method is feasible. Hence, it encourages further research aimed to improve the image analysis based vehicle detection methods. Furthermore, if we are going to use satellite images to make estimates of AADT, we are not only required to count the number of vehicles in the image. We must also find the average speed held by the vehicles in the image. So far, the average speed measured at the counting stations at the time of satellite image acquisition, has been used. Thus, one important aim of future research should be to develop methods for estimating average speed of the vehicles in the image. This method could be based on a function of distance between cars, speed limits, and other information.

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