FLOATING CAR DATA: TRAVEL TIME ESTIMATION IN URBAN NETWORKS

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ABSTRACT

Floating Car Data (FCD) is becoming a more and more popular technique for travel time measurements in road networks. Nevertheless, FCD is a sampling technique which requires controlling the statistical properties of link travel times to obtain accurate estimations. Based on microsimulation outputs, this paper shows which parameters play a key role in the travel time estimation accuracy, particularly in the case of urban networks. Among them, aggregation period and link definition are the most critical ones. They must be properly chosen according to the equipped vehicles ratio.

INTRODUCTION

Due to the vital need of accurate real time traffic data for supplying ITS applications, many a lot of research has been done, and is still ongoing in order to improve the efficiency of data acquisition techniques and data treatment methods. Among this data, travel time has been recognized to be one of the most valuable ones, particularly for ATIS (Advanced Traveller Information System) or ATMS (Advanced Traffic Management System). Travel time acquisition techniques are commonly divided into two groups: the indirect (e.g. deducted from loop detectors) and the direct acquisition (e.g. using AVI). Belonging to the second one, the Floating Car Data measurement is becoming more and more popular due, among other reasons, to the mobile communication development and the fact that no road-based infrastructure is needed, reducing significantly maintenance cost and traffic disturbances.

A wide range of studies has therefore been done on FCD based travel time estimation. The efficiency of this method is directly linked to the accuracy level with which estimated travel time calculated with sampled data (FCD) can match the “real” travel time experienced by the overall vehicles data set. Usually, travel time is calculated for each link of the network as being the average of the individual travel time recorded during the $[t;t+\Delta t[$ period, Δt being the aggregation period. Consequently, the estimation error is generally defined as the difference between the sample and the full data set averages. Nevertheless, this accuracy indicator is not the most relevant as will be discussed in this paper.

To be able to determine which estimation accuracy can be expected, individual travel time measurements evolution between and within the aggregation periods must be well identified. This evolution is significantly dependent on the type of network. Indeed, if the variability of a freeway link travel time data set (within an aggregated period) is generally low, it isn't the case for urban ones. Furthermore, bias problems have been highlighted (Sen & al. (1)) in urban network link travel time samples when the probe vehicles ratio isn't equal for the different turning flows leaving the link. Hellinga and Fu (2) have clearly demonstrated how the influence of traffic signals and platoon effects are basically responsible for these phenomena. The impact of this link travel time data set variability on optimal routes calculation has also been partially described by Sen & al. (4). Considering these observations an important reflection has to be made on the real sense of using only the aggregated travel time average to describe a data set with a wide variability. Indeed, Josias Ziestman and Laurence R. Rilett (3) have plainly shown the advantages of a disaggregated-based travel time estimation facing an aggregated one.

Using field trial data allows only studying sampled travel times but not the corresponding full data set. Combining FCD measurements with AVI (Automatic Vehicle identification) on some links could be a solution but would be costly and limited to some individual and local applications. This is why this research relies on microsimulation outputs, using a well calibrated urban model of the Lausanne (Switzerland) downtown network. The latter has been built using the AIMSUN software (5) developed by the Polytechnic University of Catalunya, Spain. All the individual link travel time are recorded during the simulation process (a five hours period around the evening peak hour) and analysed to be able to describe the data set structure properties. This approach allows obtaining a totally disaggregated picture of link travel time measurements and not a limited one only based on averages.

Relying on these microsimulation results, this paper underlines the specific travel time's statistical properties for urban links and explains why decreasing the variability of data sets is essential to obtain a more accurate travel time estimation. Different techniques to achieve this goal are then suggested. The important problem of measurement lacks when the equipped vehicle ratio is too low is also described and implications on estimation preciseness are demonstrated. Different performance indicators for the travel time estimation accuracy assessment are then presented. Lacks of relevance induced by the use of the sample average to represent link travel times are also commented. Finally, further research orientations and conclusions are given.

TRAVEL TIME VARIABILITY

Figure 1 gives an example of individual link travel time records provided by the simulation for a major avenue of the downtown area. It shows an important data set variability which is typical for urban links. The red line represents the aggregated travel time averages calculated on the basis of 15 minutes aggregation periods.

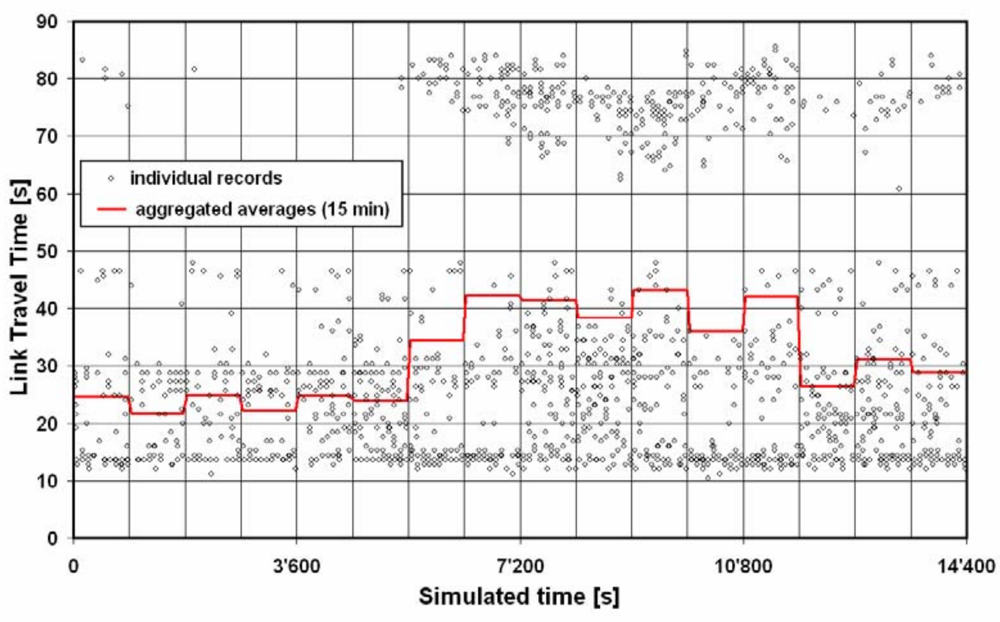

Figure 1: Individual and aggregated link travel time

Urban link travel time variability is mainly due to two different phenomena. The first one is the medium-term evolution of traffic conditions. Indeed, changes in traffic flow according to the day time implies a change in queue length and in congestion level, those having a direct impact on travel time. This variability can easily be shown by the temporal evolution of the red line in Figure 1. It represents the general trend of the travel time evolution during the day. In the other hand, short-term variability is due to non continuous traffic conditions that vehicles face during their journey through the link. Traffic lights, stops and give way signs are the main causes of these flow disturbances. Short term variability can be deduced from the data included in-between the aggregation period limits. It represents the major difference between urban and freeways or highways travel time. Indeed, vehicles usually find continuous traffic conditions during an aggregation period in the latter case. Short term variability plays an important role within the travel time estimation process as probe vehicle based link travel time estimation generally aims to match the aggregation period data set average with a limited sample one.

It can be shown that the larger the data set variability, the larger the sample size (in percentage) must be to reach a predetermined matching level. This phenomenon highlights the importance of the short-term variability of link travel time. Consequently, to obtain a more accurate averages matching with a fixed probe vehicle percentage, the data set variability has to be reduced. Different techniques allow this variability to decrease. Among them, a more detailed definition of "link" is suggested.

A "classical" link is indeed frequently defined as the arc linking two road intersections. Nevertheless, cars crossing a "classical" link controlled by traffic lights experience different traffic conditions according to the different turnings possibilities at the end of the link and also according to the link they are coming from. This is especially the case when the upstream junction is also equipped with traffic lights. By subdividing the "classical" link into sub-links, joining each possible link entrance with each exit, the variability of the corresponding data sets is, most of the time, smaller than the one with the "classical" link definition. An exploratory study made by Chen and Chien (6) has already underlined the necessity of distinguishing the travel time measurement according to the exit link, but for freeway networks only where the potential seems much lower than in urban ones. An example of how this sub-division is done is shown in Figure 2 and 3.

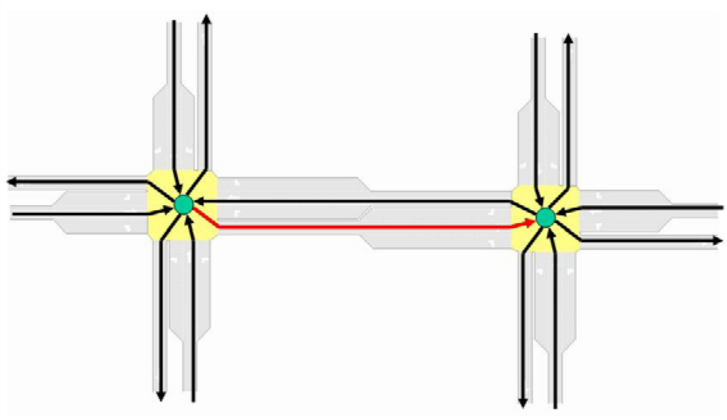

Figure 2: Classical link representation

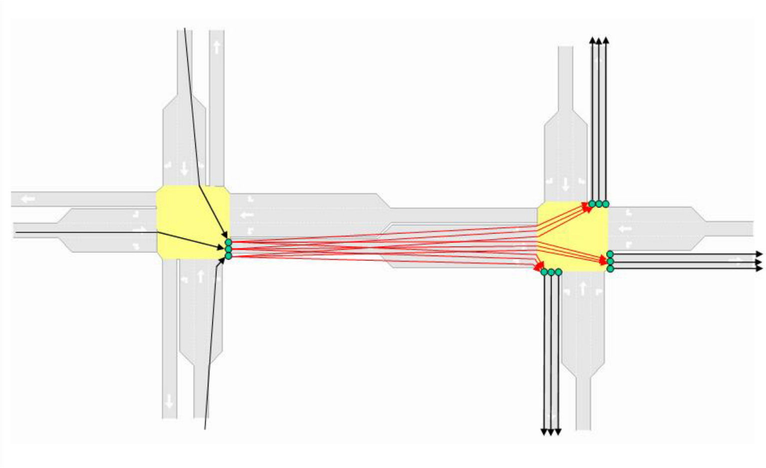

Figure 3: Sub-divided link representation

Figure 4 shows the four different (two entrances and two exits) data sets obtained by the subdivision of the link travel time measurements illustrated by Figure 1. As vehicles driving through the same sub-link face similar traffic conditions (green time cycle and timing in this case) data distribution is less extensive. In this example, the sub-link’s standard deviations (or variability) are, in three cases, clearly smaller than by using the classical approach. Only the sub-link “1 to 4” keeps an important variability due to the fact that some vehicles can cross the sub-link without stopping while others have to wait a full red cycle (the last vehicles of the platoon entering the sub-link).

Distribution of the “1 to 4” sub-link travel time records is, after simulation second 5400, a typical bimodal one with very few records in between the upper and lower group. This fact leads to some reservations about the real meaning of using the data set average as representation of the travel time experienced by the drivers during the different aggregation period. Indeed no records are equal or close to the average value. The latter is only giving an indication about the probability to belong to the upper or the lower group but is not a travel time possible to experience. Even if it is not expressed in this paper, taking into account not only the average but also other parameters of the statistical distribution of records should lead to a more accurate estimation of travel time.

One important disadvantage of this subdivision technique is the significant increase in complexity of the network representation. It has a direct impact, for example, on computational time needed for shortest time calculation as the number of links to take into account is much bigger. In the case of the Lausanne downtown network the number of links has been multiplied by 3.6 by using the subdivided representation in comparison to the classical one. Nevertheless, this disadvantage is only a technical and not a fundamental one. Consequently it could be quickly compensated by a future increase in computer performance.

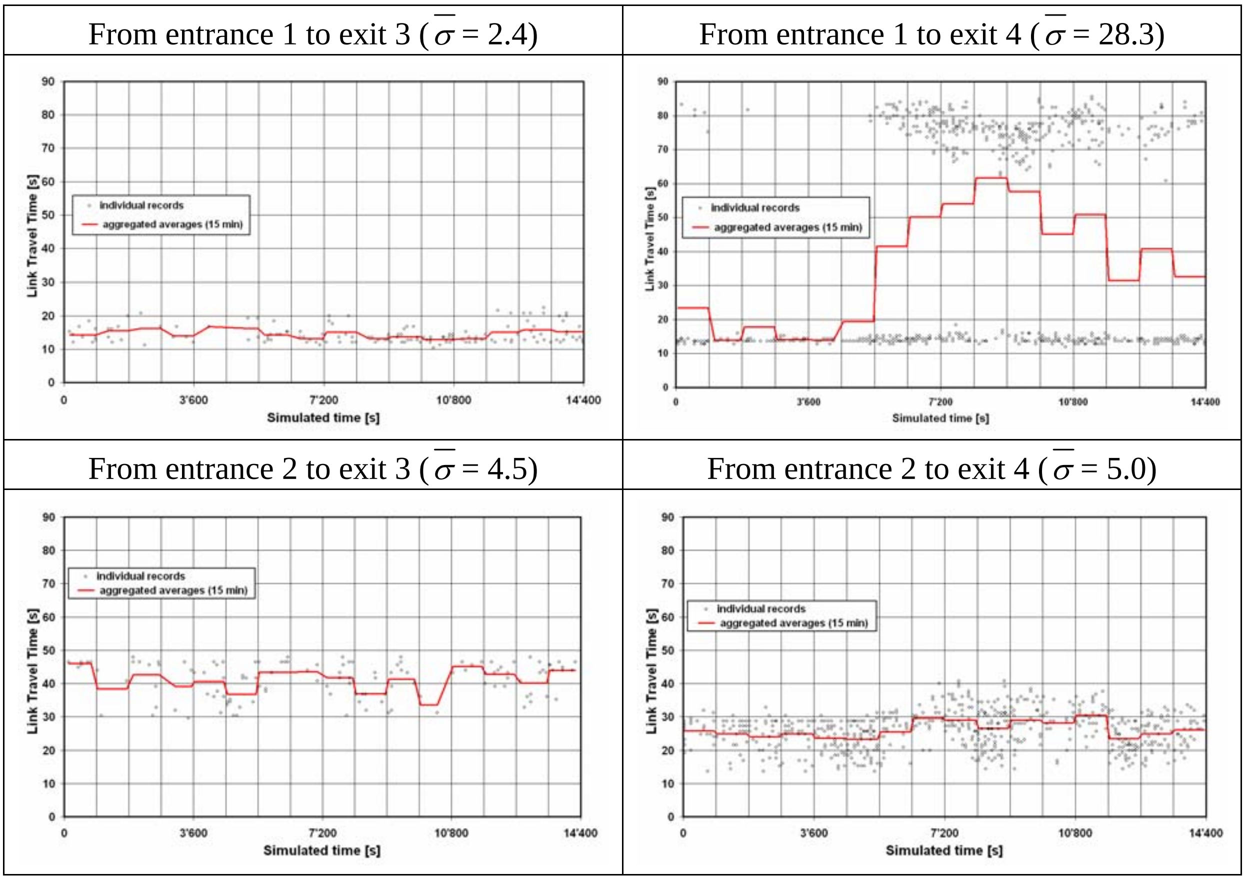

Figure 4: Link Travel time with sub-divided links

Short-term variability can also be reduced by decreasing the duration of aggregation periods. Indeed, the shorter this period, the less important the impact of medium-term variability (general trend) on the sort-term one becomes. The aim of this approach is to isolate the non-continuous traffic condition as the unique cause of the variability. However, this duration must be longer than the traffic lights cycle to keep representative data sets. Experimental results show that choosing an aggregation period duration being a multiple of the traffic light cycle (if constant) increases the positive effects.

The combined influence of the link definition and the aggregation period on the data set variability has been studied for the whole Lausanne down town network (532 classical links and 1934 subdivided links). Global results shown in Table 1 confirm the decrease in variability by using both techniques.

	120	300	600	900	1200	1800
Classical	5.71	6.73	7.43	7.81	8.15	8.58
Sub-divided	3.75	5.16	6.33	7.05	7.56	8.40

Table 1: Average link travel time standard deviation [s] according to the aggregation period [s] (in column) and the link definition

LACK OF MEASURMENTS

Even though both techniques allow reducing the link travel time data set variability, they have a common disadvantage affecting negatively the link travel time estimation. Indeed, subdivision of links as well as aggregation period shrinking implies a decrease in the absolute number of records per data sets. Consequently, even if the percentage of probe vehicles remains the same, the probability of having a lack of probe record per data set (corresponding to one link and one aggregation period) is higher. This statement is confirmed by Figure 5 which shows the percentage of data sets without probe records according to the probe percentage and the aggregation period (AP).

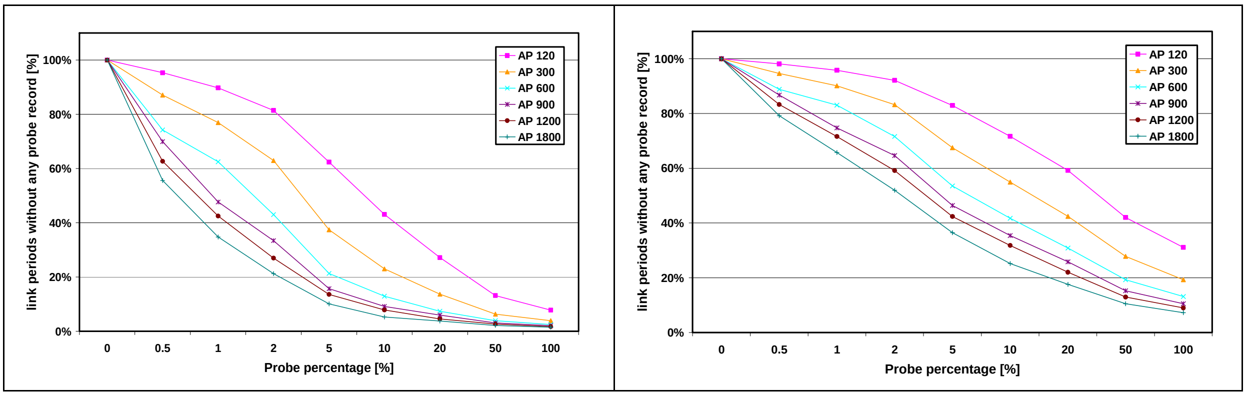

Figure 5: Lack of probe record in [%] per link and per aggregation period (AP) for a classical link definition (left) and a subdivided one (right)

When no probe record is available, a method has to be applied for substituting the missing link average travel time with a calculated one, this entailing generally a decrease in the global estimation accuracy. A lot of different methods can be applied for replacing missing data and the choice of one of them has, obviously, a direct impact on the estimation performance. In addition, the choice of the most adapted method is also linked to the probe vehicle percentage.

Among the simplest substitution methods, replacing the average by the free flow link travel time is easy to implement and can give satisfactory results when the probe ratio is very low. This technique has been used to obtain the results shown in the following paragraphs. Another simple method is using the travel time average obtained during the previous aggregation period, making the hypothesis of a provisional stability of the medium term travel time trend.

However, more relevant techniques must be adopted in most of the cases, particularly when the probe ratio is higher than 1%. Regression tools, time series analysis (ARIMA, SARIMA), Kalman filtering and even neural networks can be used be used to estimate the missing data on the basis of previous ones. Methods based on using historical profile may also give interesting results.

ACCURACY INDICATORS

By using different sort of accuracy indicators applied to the whole simulation outputs, optimal choices of link definition and aggregation period duration can be obtained for each probe vehicle percentage. The average error between estimated and "real" travel time could be used as it is done in many studies. However, a different indicator is proposed in this research. It is the Average Individual Path Travel Time Error (AIPTTE). This indicator is obtained by, firstly, calculating for each vehicle the time difference between its real travel time experienced during its journey and the one obtained by summing the probe vehicle based travel time estimation of each link belonging to its path. Then, an average over the 52'000 vehicles that drove through the network during the simulation process is calculated and divided by the average path travel time.

This indicator is quite relevant for ATIS application as link travel time estimation accuracy is not the final objective. Indeed, for route guidance systems, only the path travel time accuracy is relevant for the end user. Note that currently this type of indicators can only be provided by simulation-based studies, data coming from field trials being too limited. Indicator values according to the probe percentage and the AP is shown in Figure 6 and 7.

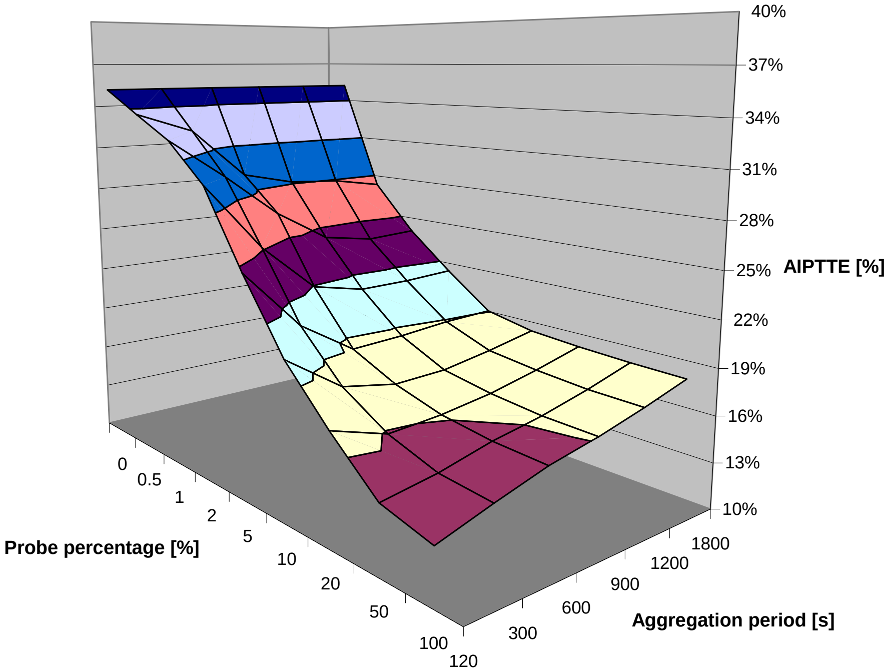

Figure 6: AIPTTE according to the aggregation period and the probe percentage for classical link definition

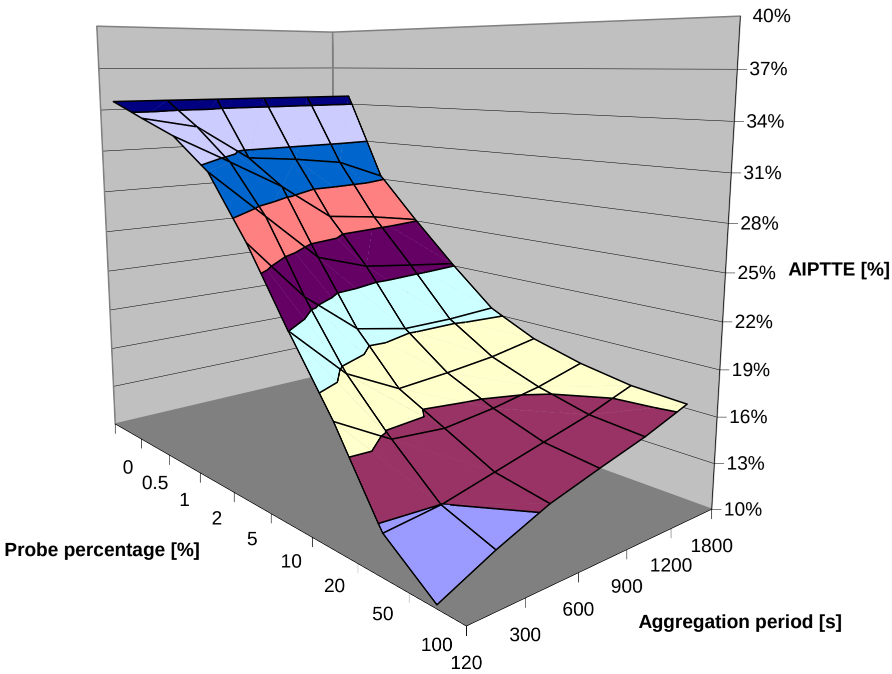

Figure 7: AIPTTE according to the aggregation period and the probe percentage for sub-divided link definition

The summary of these results is shown in Table 2. For each probe percentage, the combination of link definition and AP which give the lowest AIPTTE is thus given. One of the interesting conclusions is that the subdivision of links is efficient only for a probe percentage higher than 5% which is still an important one for real life applications. Nevertheless, it is vital to remember that these results are based on the "free flow" lack replacing method. More relevant methods will allow obtaining a lower limit of efficiency for the subdivision technique.

	0.5	1	2	5	10	20	50	100
Link déf.	Cl	Cl	Cl	Cl	SD	SD	SD	SD
AP	1800	1200	900	600	600	600	120	120

Table 2: Optimal combination of aggregation period (AP) and Link definition (CL = classical, SD = Sub-Divided) according to the probe percentage

For a better understanding of the AIPTTE evolution according to the link definition and the probe percentage, Figure 8 shows the graphs for a particular AP (900 seconds).

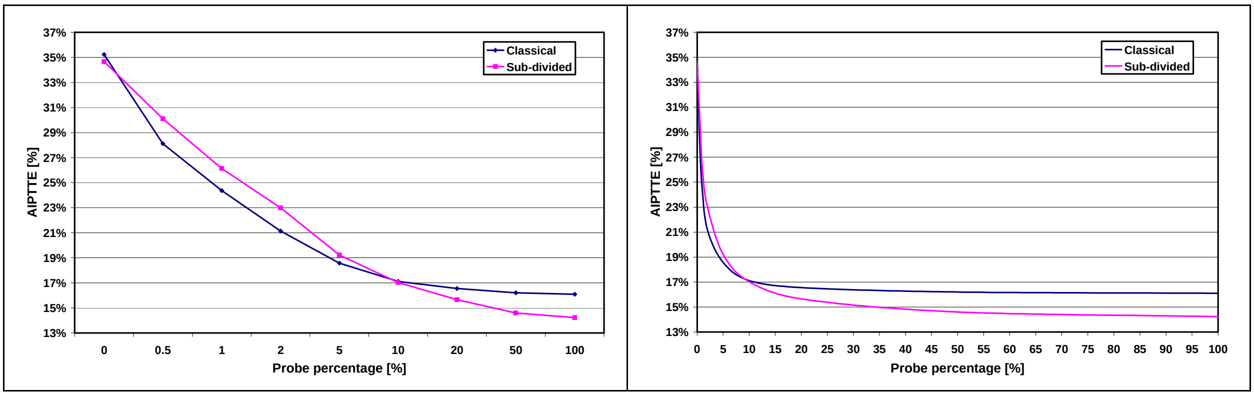

Figure 8: AIPTTE according to probe percentage with distorted (left) and real (right) scale

FURTHER RESEARCHES

One of the following steps of this research will obviously be to determine which of the lack replacing methods described above is the most performing one in function of the different probe ratios.

Furthermore, the detailed study of the difference between the path travel time really experienced by vehicles and the one obtained by the simple addition of the estimated link travel times leads to conclude that an important work has to be done to avoid using the hypothesis (too frequently accepted in past studies) that travel times of consecutive links are independent. It could then be useful to include the covariance factor in the path travel time calculation. This justifies once more the need to avoid aggregating travel time measurement to a simple average and to take into account a more disaggregated vision (distribution shape, variability, etc.). Also, it could be interesting to use these statistical values not only to improve the path travel time estimation accuracy but also to calculate path travel time variability. This could be an interesting new feature for route guidance systems.

If this paper has demonstrated, among others, the advantages of a more detailed link definition with a differentiation according to the possible link entrances and exits, more research must be done to determine if a differentiation only according to the exits or only to the entrances could give a better advantages/disadvantages ratio.

Finally, link travel time prediction based on FCD has also to be analyzed in order to determine which level of accuracy can be expected taking into account the particularities of FCD records. Indeed, travel time prediction is necessary, particularly for dynamic route guidance systems, because time dependent shortest path algorithms need these predictive data.

CONCLUSIONS

This research has shown that even if a lot of research has been done on FCD, there is still a lot to do for improving the performance of the applications using such type of data. The results described above underline that not only the probe vehicle ratio is a parameter to take into account for the estimation accuracy assessment.

Indeed, other parameters like aggregation period, link definition or lack replacing method also play a key role in the improvement of the estimation accuracy.

It has also be proven that using only link travel time averages is too restrictive and doesn't allow to calculate the path travel time variability estimation or to take into account consecutive link travel time dependency.

Finally, a relevant performance indicator has been proposed for travel time estimation accuracy calculation. It is not only based on link travel time but also on path travel time which is, in fact, the most important value to be estimated for ATIS applications.

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