Link travel time estimation with probe vehicles in signalised networks

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Abstract

One of the more useful dynamic data used by ATIS (Advanced Traveller Information Systems) and ATMS (Advanced Traffic Management Systems) applications is the link travel time, in particular for the DRGS (Dynamic Route Guidance Systems) case. Among the different methods for collecting these data, the use of probe vehicles is one of the most efficient and promising method. However, accuracy issues have to be solved, above all, from the statistical point of view. This paper presents an analyse of the individual link travel time records distribution shape of a typical urban network link. The influence of this analysis on the probe vehicles-based estimation accuracy is also described. A division of the overall records in sub-samples according to the upstream and downstream link used by the vehicles is proposed. Advantages and disadvantages of this approach are commented. The necessity of integrating the link travel time estimation accuracy in a path context instead of treating it as an individual entity is demonstrated. Finally, some conclusions are given and further research needs are highlighted.

Keywords

Link travel time – Dynamic Route Guidance – Probe Vehicles – Floating Car Data – 3rd Swiss Transport Research Conference – STRC 2003 – Monte Verità

1. Introduction

As shown by the extensive literature on this topic, a lot of research has been done on link travel time estimation and prediction. This can be easily explained by the significant utility of such type of dynamic data for ITS applications like ATIS (Advanced Traveller Information System) and ATMS (Advanced Traffic Management Systems) Furthermore, the considerable complexity of link travel times statistic and stochastic properties leads to a need of shrewder developments. DRGS (Dynamic Route Guidance Systems) is, for example, a typical application relied on the availability of up-to-date link travel times, providing users with optimal paths before and during their trip. Nevertheless, the quality of the services offered by such systems depends clearly on the reliability and accuracy of available data, those ones being influenced by the methods used for the data acquisition.

Among others, the use of probe vehicles (also know as floating car) to obtain link travel time is considered as one of the most efficient and promising method. On this topic, a wide range of studies has also been done. One of the major problem of this approach is to determine the accuracy level with which an aggregated travel time based on sampled data (for a given probe vehicle ratio) can match the aggregated travel time experienced by the overall vehicles data set. To answer this question, the 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 has been highlighted by Sen & al. (1997) in urban network link travel time samples if the probe vehicles ratio isn't equal between the different turnings flow leaving the link. Hellinga and Fu (1999) have clearly demonstrated how the influence of traffic signals and platoon effects are basically responsible for these phenomena. The implications of this link travel time data set variability for optimal routes calculation has also been partially described by Sen & al. (1999). considering these observations an important reflection has to be made on the real sense of using an aggregated average to describe a data set with a wide variability. Indeed, Josias Ziestman and Laurence R. Rilett (2000) have plainly shown the advantages of a disaggregated-based travel time estimation facing an aggregated one.

This article explains how a more detailed definition of network links in urban and signalised area can lead also to reduce the variability of the travel time data sets and, consequently, improve the accuracy of probe vehicles-based estimation. This has been done by differencing the link travel time data according to the downstream and upstream link used by the recorded vehicles. An exploratory study made by Chen and Chien (2001) has already underlined the necessity of distinguishing the travel time measurement according to the exit link, but for freeway networks only. Disaggregated travel time data coming from field operation test being rare, a microsimulation-based analysis was carried out using the AIMSUN simulator (Barcelo & all. (1995)).

This research also highlights the importance of integrating link travel time in a path context as it is done when shortest paths are calculated and not of considering it as an isolated entity. Based on simulations using the Lausanne (Switzerland) city centre model, some examples demonstrate that the link travel time experienced by the same driver during his trip isn't always independent one to each other.

2. Differentiation according to the upstream and downstream link

Queuing theories can easily explain how vehicles using different turning options on the downstream intersection of a signalised link can experience different waiting time. The evolution, during the day, of this waiting time depends mainly on the ratio between the different fixed green time cycles for each turnings and its corresponding demand volume. This has been clearly demonstrated by numerous authors like, for example, Todd Graves & al. (1998). This waiting time disparity implies a rise of the link travel time data set variability within an aggregation period. Furthermore, this phenomenon can lead to a biased estimation of the average link travel time using probe vehicles if the ratio of such vehicles is different in each turning sub-set as explained by Bruce Hellinga and Liping Fu (2002).

Many studies on traffic light delays influence on link travel time are based on the hypothesis of a uniform or random link arrival rate that is not appropriate in a realistic urban network. In such case, the arrival rate is directly dependent on the upstream intersection signal cycles, vehicles entering the link in platoons. That's why link travel time data set variability is also partially dependent on the distribution of the global entering volume between the various upstream turnings possibilities.

It is known that the smaller the data set standard deviation (variability indicator), the better the probability of matching satisfactorily the data set average with a fixed ratio (probe vehicles percentage) sample average is. As shown before, the overall data set variability is partially due to different traffic conditions for the same link. Consequently, the better way to group travel time measurements of similar traffic conditions is to divide the overall data set into sub-sets, each one regrouping the records provided by the vehicles coming from the same upstream link and going to the same downstream link.

The following example based on the observation of a fully calibrated urban network microsimulation model is illustrates this finding. Travel time measurement of all the vehicles crossing an important link in the Lausanne city centre during a simulation run (from 6 to 10 o'clock in the morning) have been recorded. The upstream and downstream intersections of this link are equipped with synchronised but non-adaptive traffic signals. Each intersection group together three road sections as described by figure 1. Travel time is measured from the link entrance to one of the downstream link entrances.

Figure 1 View of the link studied (in blue) and the up an downstream intersections (in yellow)

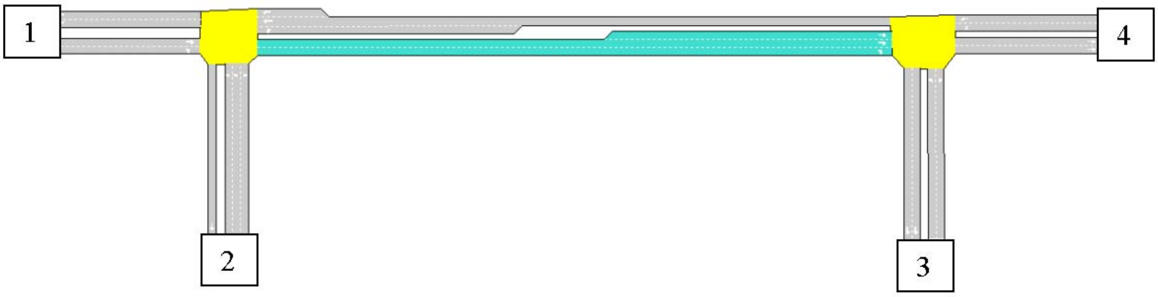


Figure 2 Link Travel Time records without distinction between origin and destination links

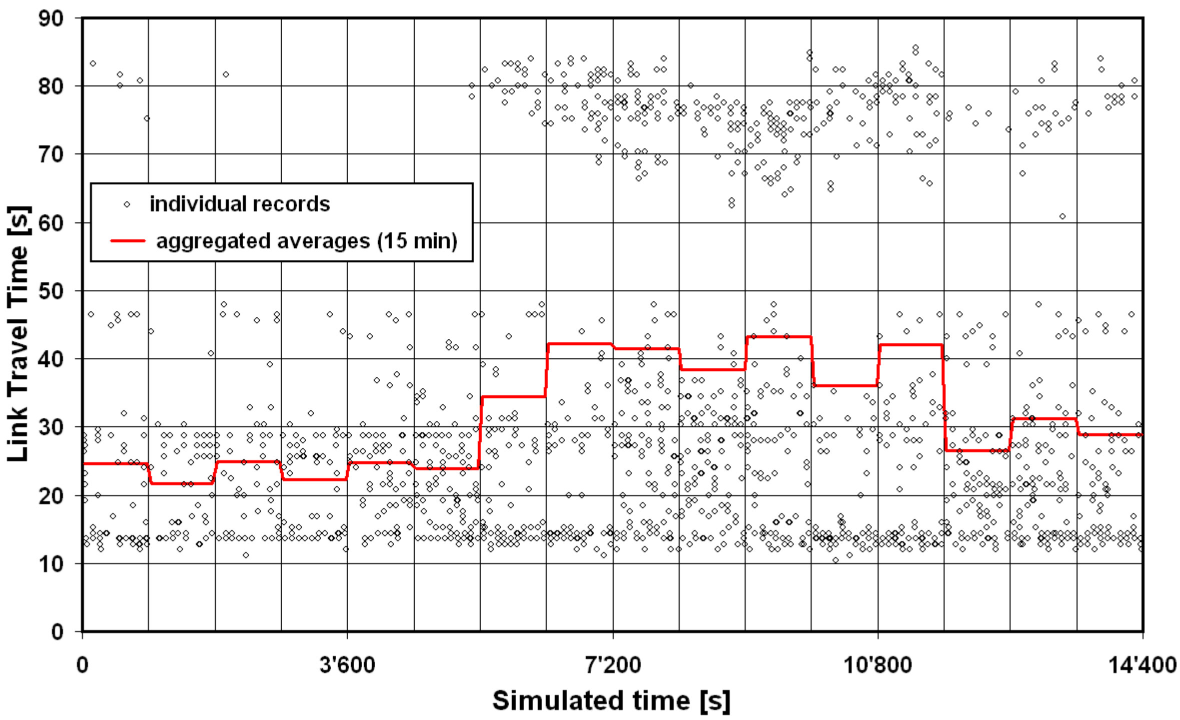


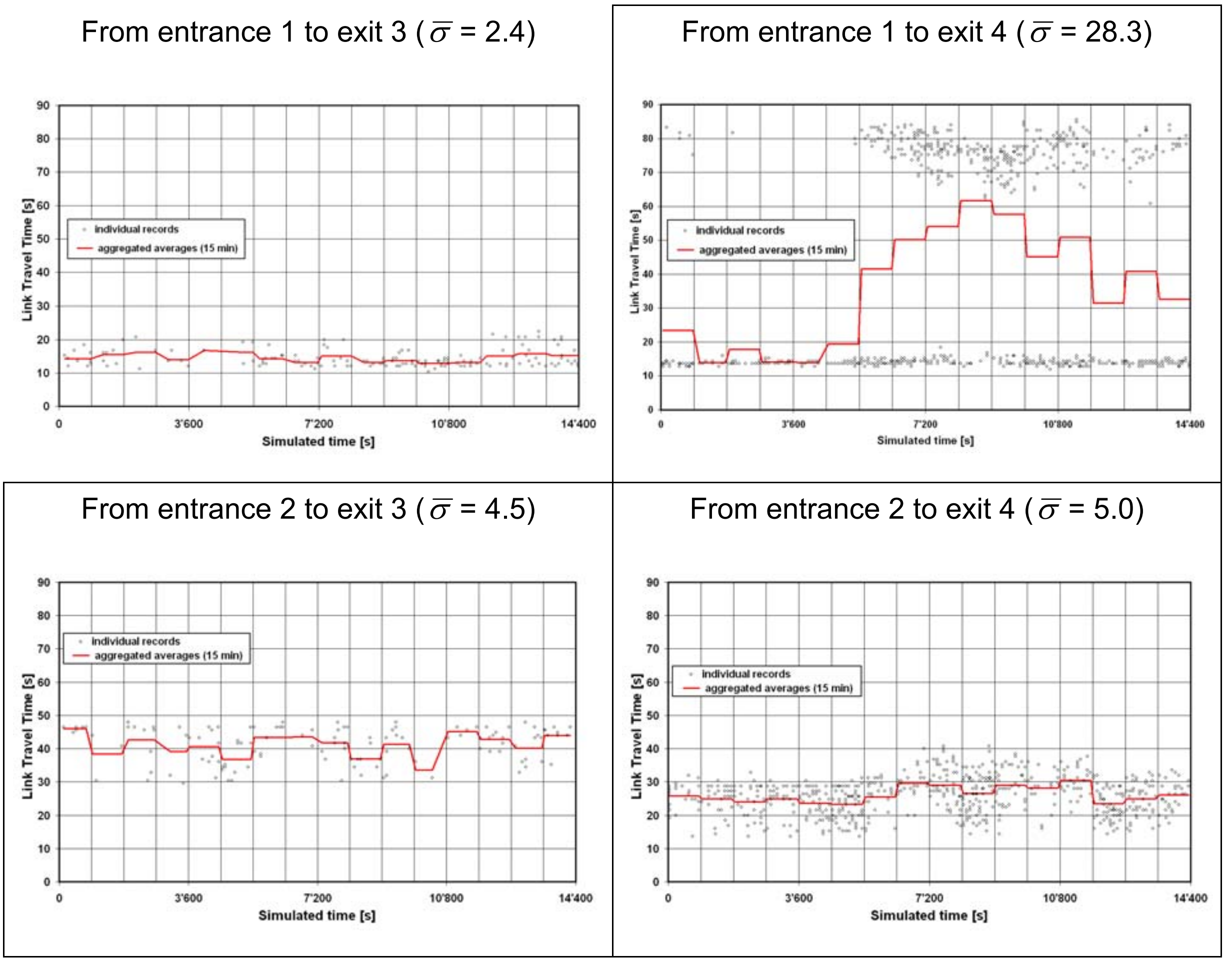
Figure 2 shows the link travel time individual records. The simulated time is divided into sixteen 900 seconds aggregation periods. For each period, the link travel time average and standard deviation is calculated. The red curve represents the evolution of these averages throughout the 6h00 (0 [s]) to 10h00 (14'400 [s]) simulation period. A large spread out of the data set is noted, particularly after 7h30 when some vehicles have to wait one traffic light cycle before leaving the link (implying travel time from 60 to 90 seconds). The standard deviations average ($\overline{\sigma}$ = 22.0) confirms this observation. Due to this important variability of the recorded data set a significant probe vehicle ratio would be necessary to match with satisfaction the data set averages with the sample averages.

The result of the upstream – downstream link pair sub-set division process is shown by figure 3 where the four combinations diagrams are presented. For each sub-set, the standard deviations average (as defined above) has been calculated and is indicated on the heading of each diagram. This records grouping according to the entrance and exit link highlights the perception of the link travel time evolution. For three combinations (1 to 3, 2 to 3 and 2 to 4), a more or less stable evolution is observed as shown by the red curves. In addition, the spread out of these sub-sets is very limited. The small standard deviations averages (2.4, 4.5 and 5.0) confirm this observation.

Consequently, a sub-set link travel time estimation based on probe vehicles (only those being part of the sub-set) would be more accurate even if the probe vehicles ratio was low. On the contrary, the forth sub-set (entrance 1 to exit 4) spread out remains large with a standard deviations average of 28.3. It is now clear that only the vehicles of this sub-set lead to a significant variability of the overall data set. For this sub-set only, the matching of the link travel time averages by the probe vehicles records remains difficult.

Nevertheless, a global increase of the link travel time estimation accuracy can be expected by using this differentiation method. Indeed, more vehicles link travel time are represented by a more accurate average than in the overall data set approach. On the other hand, it is important to emphasize that dividing a probe vehicle reports sample into sub-samples implies a significant decrease in the absolute number of records to be used for the assessment. That means that the risk of not having probe vehicle reports in an aggregation period rises (it is a sort of data dissolution). The out coming increase in the use of extrapolation methods to estimate link travel time can lead to a decrease in the estimation accuracy. So, further research must be carried out to determine what is the efficiency of the approach, advantages and disadvantages explained above being taken into account.

Figure 3 Link Travel Time records divided in upstream – downstream link pair sub-sets



More information can be extracted from the 1 to 4 sub-set diagram. Indeed, the records distribution after 07h30 (5'400 [s]) is definitively a bipolar distribution, all the measurements being grouped between 10 and 20 seconds and between 65 and 85 seconds. This is due to the fact that the first vehicles of the platoon coming from the entrance #1 can leave the link without stopping (first pole) and that the last ones (second pole) have to wait a complete red cycle before. Therefore, aggregated link travel time averages (being between 30 and 60) are values that none of the vehicles has experienced in reality! They represent only the records distribution ratio between the two groups.

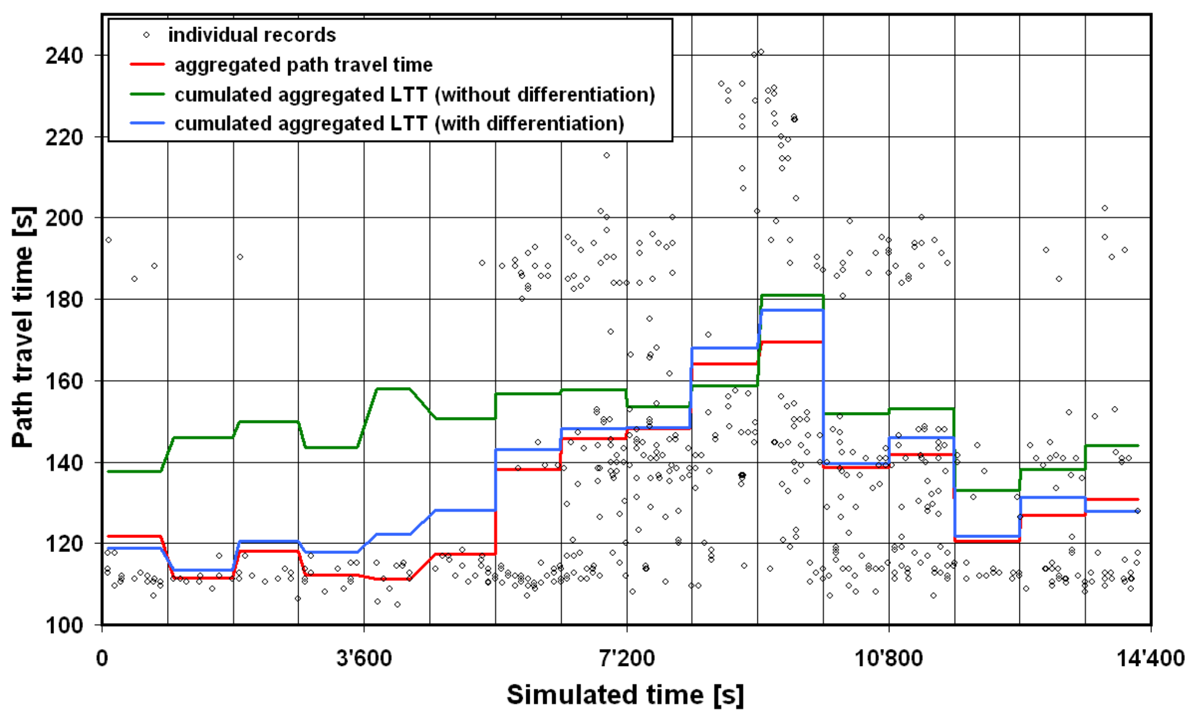
On this basis, it is reasonable to wonder if the link travel time data set (or the sample) average is a relevant value to be used for ITS applications, in particular for DRGS. So far, it seems that this question has not been studied as it should be. For that reason, more research on this topic should be carried out. However, it's necessary to emphasize that the link travel time estimation accuracy in DRGS (for example) don't have a significant role in itself, only his influence on the accuracy on the path travel time estimation being important. That's why link travel time estimation must be analysed in a path context and not only as independent entity.

3. Link travel time in the path analysis context

A particular path has been defined within the Lausanne city center network model for analysing path travel time. It is composed of 7 links (including the one studied in the previous section), each one being equipped with synchronized but non-adaptive traffic signals. During the 6h00 to 10h00 simulation period, the path travel time of all the vehicles having covered consecutively the seven links have been recorded (0). The horizontal coordinate of the records is the first link entrance time (= path entrance time) of the vehicles.

The overall path travel time data set is spread over a band between 100 and 240 seconds, even in the same aggregation period. It means that vehicles entering the path under similar traffic conditions can experience significantly different path travel time according to the traffic signal synchronization interplay. The red curve represents the evolution of the aggregated period averages throughout the simulation period.

Figure 4 Individual path travel time records and different aggregation methods comparison



In ITS applications, these path travel time are calculated by cumulating the link travel time. Figure 4 presents these cumulated curves obtained by using both link travel time calculation method, as they are described in the previous section.

The green one corresponds to the sum (done for each aggregation period) of the link travel time averages calculated on the basis of all the vehicles that have covered the link. The blue one is obtained by using the link travel time averages taking into account the vehicles coming from an upstream link and going to a downstream link belonging to the path link set only. It is the application of the differentiation method.

The visual comparison between both curves leads clearly to notice that the blue one match significantly better the red curve than the green one. It is particularly the case for the period between 6h00 and 7h30 (5'400 [s]) were a systematic difference of more or less 30 seconds is recorded between the "real" values (red curve) and the green curve values. That's means that the approach without differentiation leads to a systematic overestimation of the path travel time during this period. During the rest of the simulation period, the differentiation method continue to give better results than the other one but with less difference.

It is important here to remind that these calculations are dealing with the records data set and not with sampled records, as it would be the case for a probe vehicle based-estimation. But the conclusions about the accuracy of the different cumulating approaches as described previously are obviously also valid for sampled records. However, a complete study based on a larger path and with different probe vehicle ratio should be done to confirm these findings.

Based on the observation mentioned in the previous section, particularly about the "entrance 1 to exit 4" diagram, a "risk" approach could be developed. It is a question of cumulating the maximum travel time records (for each aggregation period) throughout the path to determine which maximum path travel time a vehicle would experience. Such approach could lead to add interesting new services to DRGS, but a careful analysis has to be carried out. Indeed, cumulating maximum and not averages means that the different link travel times experienced by a vehicle throughout the pass are independent among them, a statement which is clearly not correct.

That is the reason why dependency between link travel times should be assessed in detail. An integration of this phenomenon in the estimation process may lead to a better accuracy.

4. Conclusions and research needs

The knowledge of the overall records data set evolution throughout the time is necessary for evaluating the accuracy with which a probe vehicles-based approach can match the "real" link travel time, as it has been proven in this article. It permits to understand what are the statistical problems facing a sample-based approach.

The positive effects of dividing the overall data set (or sample) in sub-set according to the upstream and downstream link covered by the vehicles have been described and the potential increase in estimation accuracy using this differentiation method has been established. Nevertheless, some disadvantages have to be taking into account. Indeed, this division implies a decrease in the absolute number of probe vehicle reports. It means that a greater number of aggregation periods will not have probe vehicles records, implying a rise of extrapolation processes.

The necessity of integrating the link travel time estimation problematic within a path context has also been commented. In this path analysis framework, the link travel time differentiation approach has clearly been shown as being a better one than the normal one. Furthermore, problems coming from the dependency of the travel time evolution measured on two consecutive links of a path have been highlighted.

Further research needs have been identified like, for example, the necessity of studying the accuracy of path travel time assessment based on a larger path and with different probe vehicles ratio. A more theoretical approach is also necessary to support the findings described in this article.

5. References

Sen A., Thakuriah, P., Zhu, X., and Karr, A. (1997) Frequency of probe reports and variance of travel time estimates, *Journal of Transportation Engineering* published by the American Society of Civil Engineers, Volume 123 No. 4. ASCE, pp. 290 – 297.

Hellinga B. and Fu L. (1999) Assessing the Expected Accuracy of Probe Vehicle Travel Time Reports, *Journal of Transportation Engineering* published by the American Society of Civil Engineers; Nov./Dec., 1999 Volume 125 No. 6. pages 524 – 530.

Zietsman J. and Rilett L. R. (2000) Aggregate- and Disaggreagte-Based Travel Time estimation, *Transportation Research record*, Volume 1725, Paper No 00-0708.

Sen A., Thakuriah, P., Zhu, X., and Karr, A. (1999) Variance of link travel time estimates: implications for optimal routes, *International Transactions in operational research*, 6, 75-87.

Barceló J., Ferrer J.I., Grau R., Florian M., Chabini I. and Le Saux E. (1995) A Route Based variant of the AIMSUN Microsimulation Model, *Proceedings of the 2nd World Congress on Intelligent Transport Systems*, Yokohama.

Chen C. and Chien S. (2001) Dynamic Freeway Travel Time Prediction Using Probe Vehicle Data: Link-based vs. Path-based, *Proceedings of the 80th Transportation Research Board Annual Meeting*, Washington DC, January 7-11.

Graves T., Karr A. F. and Thakuriah P. (1998) Variability of Travel Times on Arterial Links: Effect of Signals and Volume, *National Institute of Statistical Science (North Caroline) technical report*.

Hellinga B. and Fu L. (2002) Reducing Bias in Probe-Based Arterial Link Travel Time Estimates for ITS Applications, *Transportation Research Part C - Emerging Technologies* Vol. 10 No. 4, pp. 257-273.