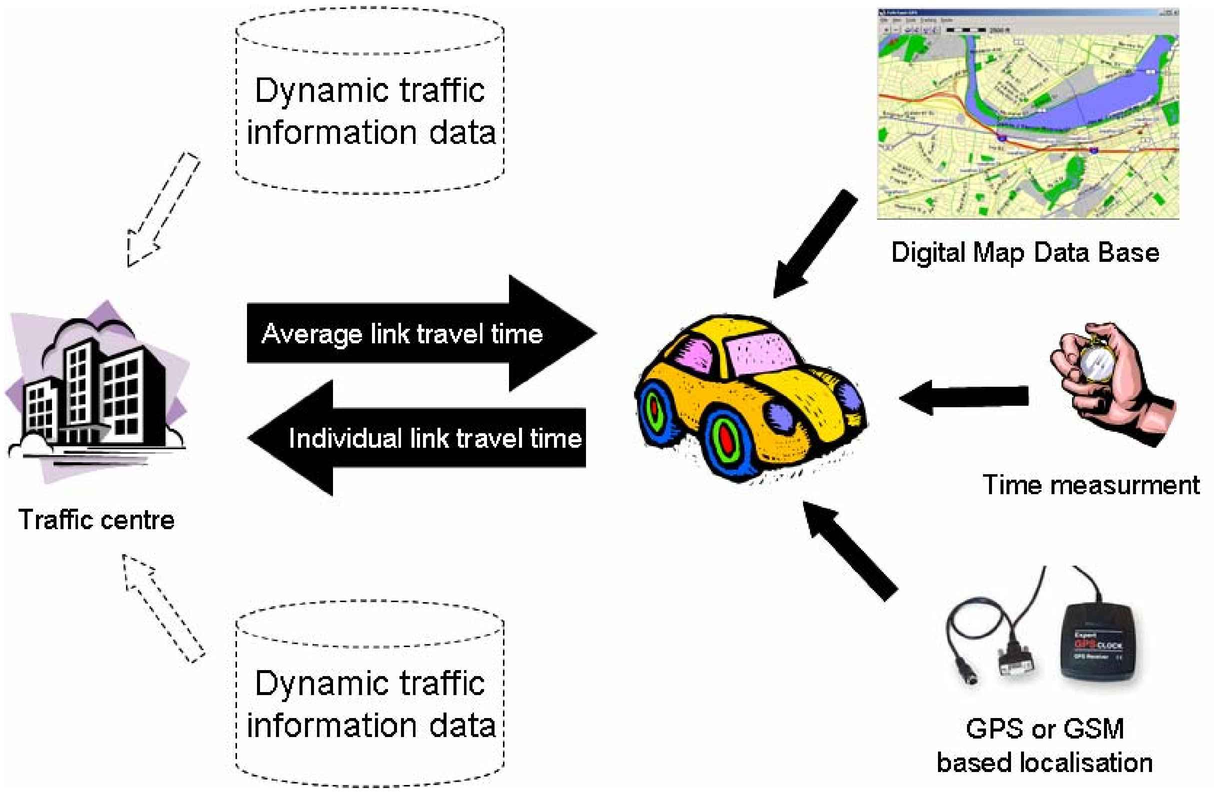

Self supplied navigation systems: microsimulation-based performance assessment

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Abstract

The self-supplied navigation concept is based on the combination of the floating car data technique and the dynamic route guidance service in the same vehicles. The gains obtained by the users of such system are, obviously, closely related to the percentage of equipped vehicles. This study shows concretely this relation relying on the use of a large scale microsimulator urban model, the Lausanne city case. Finally, limitations due to the fact that the same vehicles are providing and exploiting the traffic information are clearly emphasized.

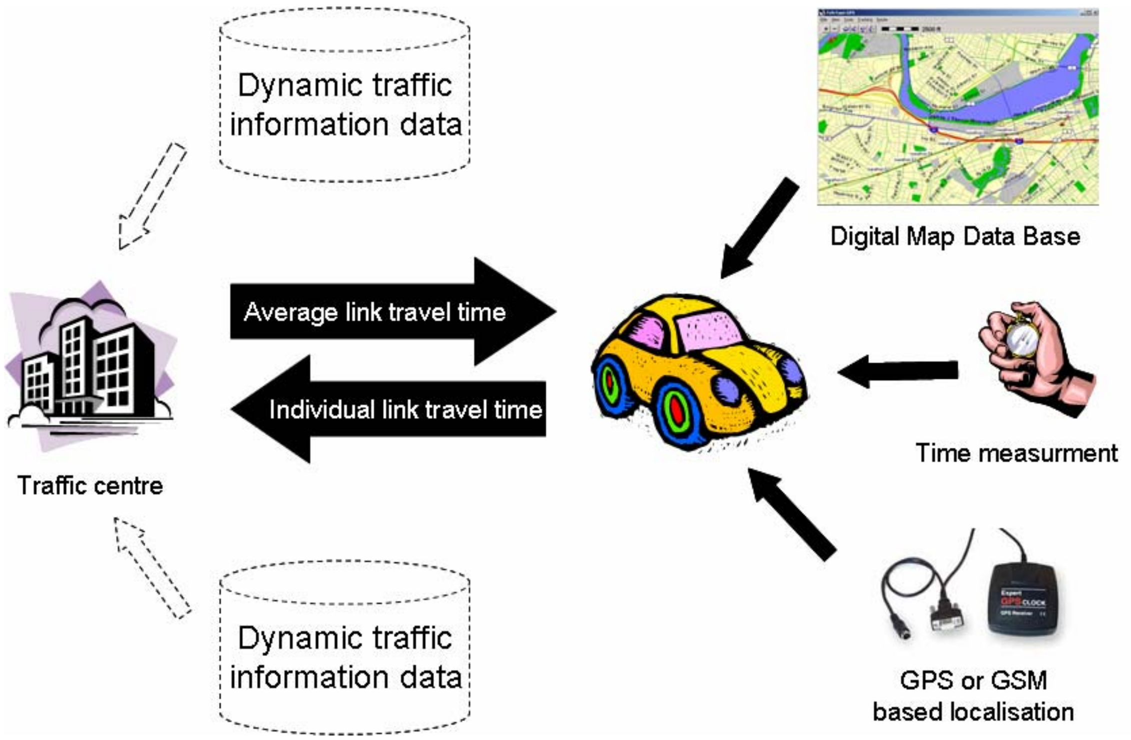
Keywords

Floating Car Data – Dynamic Route Guidance – Microsimulation – Travel Time Estimation

1. Introduction

The self-supplied navigation system concept (SNA), illustrated by Figure 1, is based on the merging of dynamic route guidance (DRG) system and the floating car data (FCD) ones. In other words, cars equipped with this system are dynamically guided during their journey based on the real-time traffic data delivered by the cars themselves, playing the role of probe vehicles. Consequently, these vehicles are forming a closed and self supplied users club. If DRG and FCD are widely studied topics in the literature, their combination appears to be a quite original approach that hasn't been considered until now. Indeed, the particularities of this concept cannot be tackled just by summing the knowledge of both individual components as the fact that the same vehicle plays both information provider and user roles leads to specific consequences. However, the recent launch of the Honda InterNavi Premium Club service in Japan shows that private companies are already starting to promote this concept which seems well tailored for their type of business.

Figure 1 Self-supplied navigation concept



Nevertheless, many questions concerning the performance of such systems are still open. One of them is obviously how many equipped users are needed to offer a satisfactorily performing service justifying its cost. To partially answer this question without tackling subjective and economical aspects of the problem, a comparison between journey travel times of equipped vehicles and non-equipped one is done in order to determine the expected benefits according to the equipment ratio which is the main goal of this study.

After a brief review of existing researches in the DRG and FCD fields (section 2), explanations about how microsimulation is used for the assessment process are given in section 3. In order to point out the real potential of the system, some improvements of the FCD techniques are suggested in section 4. Comparison between performances of non-guided and guided vehicles is then presented in section 5. Finally, further researches (section 6) and conclusions (section 7) close this article.

2. Literature review

During the eighties and nineties, various field operation tests have been undertaken to demonstrate the potential of the FCD technique. In the framework of the European project SOCRATES [1], first off-line measurements have been recorded relying on a seventy vehicles fleet. Based on this project knowledge, the German company Manesman launched in 1996 a 850 vehicles on-line (SMS) measurement experiment. This project, called VERDI [2], showed encouraging results especially in areas where no other measurement devices like inductive loops where available. In United States, the largest project that has been done on this topic is the ADVANCE [3, 4] one. A five thousand vehicles fleet was initially planned and many theoretical researches were supporting this field test. However, due to economical limitations only fifty vehicles were finally used. Even with this small fleet, technical feasibility of the FCD technique was clearly demonstrated.

Nevertheless, such field operation tests could only make hypothesis about what would be the travel time estimation accuracy level when a larger fleet is used. Relying on these technical and economical limitations of field tests, the simulation approach becomes the best alternative to evaluate the link between equipment ratio and estimation reliability. For example, Sandwal and Walrand [5] demonstrated that a 4% ratio was sufficient to obtain accurate travel times on highways links. Other researcher [6-8] used simulation tools to show the relation between the equipment ratio and the closeness of the sample average (estimation) compared to the population one (targeted). However, Sen et al. [9, 10] warned that these apparently obvious relationships weren't always correct due to statistical dependencies between link travel times, particularly in urban networks.

On the dynamic route guidance side, limitations of field operation tests have been highlighted like in the case of FCD. In Europe, the well known Ali-Scout [11] project (followed by the Autoguide [12] and Euro-Scout [13] ones) suggested an approach based on real-time data transmission through infrared beacons. If potential benefits were detected, most of the users identified them in non-recurrent congestion cases. This fact has been confirmed by the ADVANCE project's findings. However, reliability of travel times provided to users was too limited to allow a generalization of such conclusions. That is one of the reasons why simulation-based project became popular for DRG assessments. By this way, different conclusions were obtained like the fact that beyond a certain level of DRG penetration level, user's benefits are decreasing [14]. Adler et al. determined this equipment ratio being around 10% [15]. Concerning the benefits, Wunderlich [16] estimates that a 10% travel time can be saved in average by using DRG with important differences between scenarios (accident, recurrent congestion, bad weather, etc.). On their side, Sengupta Hongola [17] identified a 6 to 20% travel time decrease potential.

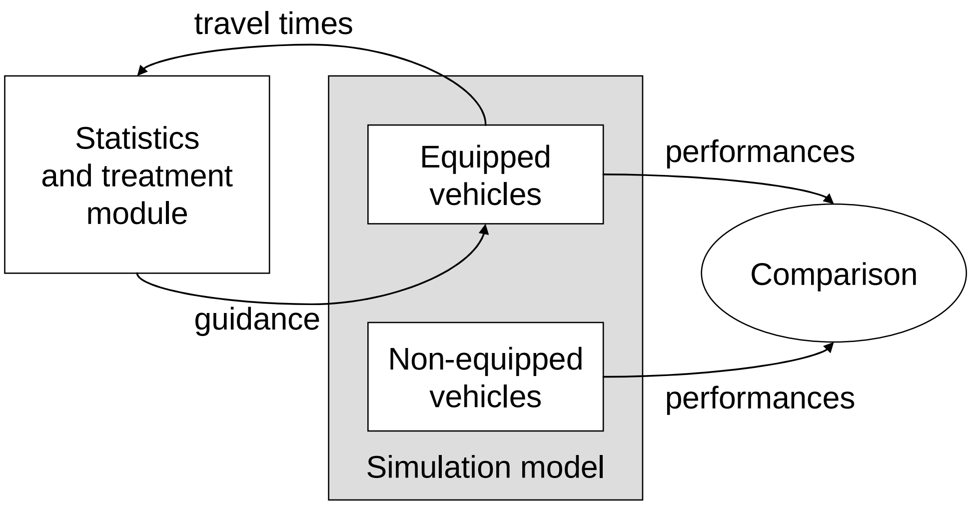
Finally, no concrete combination of FCD and DRG based on the same vehicles fleet has been found by the authors in their literature review excepted the TravTek [18, 19] case. The latter suggested an experiment relying on DRG services provided to renting cars in Florida. The dynamic travel time provided where provided, among other sources, by the vehicles themselves used as probe vehicles. This very interesting experiment was accompanied by simulation studies based on the INTEGRATION microsimulator [20]. Valuable findings were emphasized by this project. However, technical limitations on the computer side (experiment done in 1993) implied admitting numerous hypotheses that the project's authors themselves considered as debatable.

3. Microsimulation as assessment tool

As shown in the previous chapter, field operation test for the evaluation of DRG and particularly FCD performances are not really suitable due to the large economical investments they imply. On the other hand, the quantity of parameters playing an important role in this assessment process makes analytical approach inappropriate. For this reason, relying on traffic simulation tools has been identified as the most adapted one for this research.

Among the different simulator types, microsimulation is the only one that offers possibilities of obtaining individual travel times (for FCD) and allows individual route assignment (for DRG). Hence, the AIMSUN microsimulator [21] has been chosen for the assessment process which is described by Figure 2.

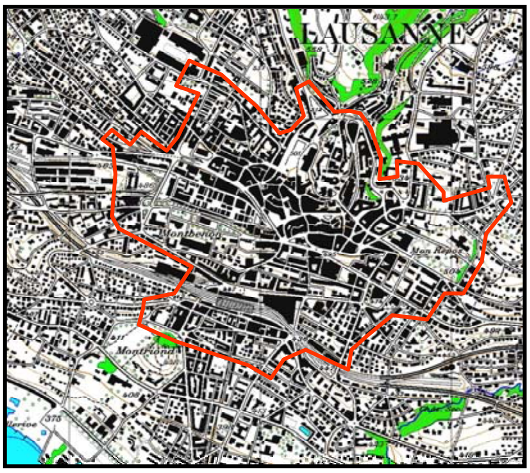
Figure 2 Used approach for simulation-based performances assessment



It shows, in grey, the simulation model in which non-equipped and equipped vehicles are represented. The latter ones send individual travel times (FCD) to an external module. This module reproduces the tasks that a traffic centre would be in charge of. Individual data are processed in order to obtain average link travel times that will are used to compute the up to date itineraries provided back to the equipped vehicles. The performances of both vehicle categories are recorded during the whole simulation process and, finally, compared.

The simulation model which is used on this study is the Lausanne centre area. It has been chosen because of his complexity and link density. The good authors' knowledge of this network has also been well appreciated for the model’s calibration task. Finally, the fact that most of the researches have been focused on highway networks has led the selection of a totally urban one in order to enlarge the field of experimentation.

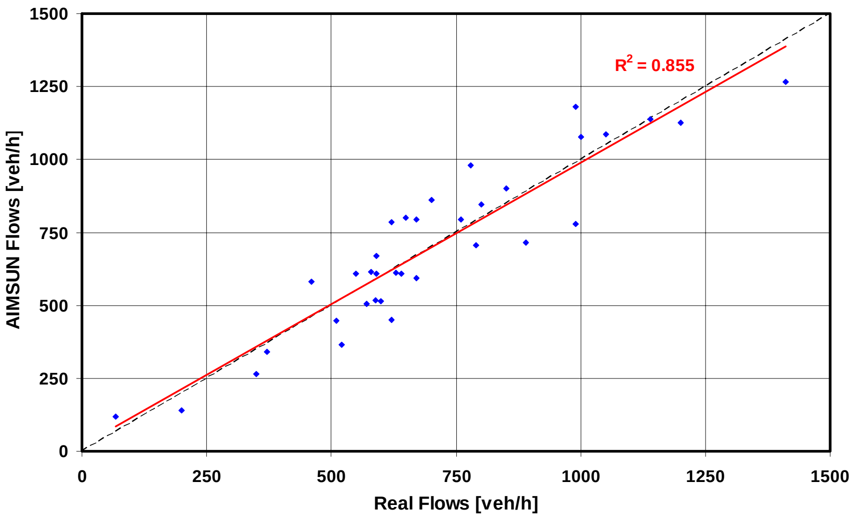
Figure 3 Area of the Lausanne simulation model



The simulated area, shown by Figure 3, includes 524 links and 241 nodes. Among the latter ones, 49 are controlled by traffic signals. Even if, in reality, the control plans are actuated, fixed plan have been simulated because no interface was ready for the integration of the VS-Plus [22] plans. The traffic demand is represented by a 80 per 80 OD matrix and the simulation period runs from 15h00 to 20h00. During the peak hour, a 16'500 veh/hour flow is recorded on the network.

The calibration of the Lausanne centre model rely on the flows recorded by around 35 loop detectors widely distributed over the network. The matching between real and simulated flows is shown by Figure 4.

Figure 4 Matching between real and simulated flows



4. Travel Time estimation using Floating Car Data technique

The present chapter gives a quick overview on the key elements playing a role in the FCD techniques and is mainly inspired from the author's previous works already described in [23].

Basically, this technique consists in estimating the link average travel time calculated by taking into account all the vehicles that crossed the link during an aggregation period relying only on a sample of these vehicles. The fundamental problem is the determination of the relationship that exists between the equipment ratio (sample size) and the estimation accuracy (difference between population and sample average).

As commented in the previous chapter, most of the researches that have done on FCD technique were using highways network. However, urban networks are much more challenging due to the non continuous conditions induced by stops, yields and traffic signals. These particularities lead to individual link travel time populations with high variability. Indeed, situation in which the population standard deviation is larger than the population average is not rare. From a statistical point of view, the problem is that higher is the variability of a population more limited is the accuracy of a fixed size sample based estimation. Concretely speaking, it means that a larger FCD fleet is required to obtain a satisfactory estimation process.

Based on this fact, the present research suggests different ways of improving the FCD travel time estimation technique.

4.1 Potential improvements

4.1.1 Link definition

A first possibility is to decrease the population variability. In order to do this, a new link definition has to be used. Indeed, the classical link representation is the arc linking two intersections. The suggested approach relies on the fact that vehicles experience quite different travel time between both intersections depending on the link the used to access the initial one and the link they used living the final one. A subdivision of a *classica*l link in *in-out* sub-links allows a decrease of population variability as shown in [23].

4.1.2 Aggregation period

In order to decrease this variability, adopting shorter aggregation periods (AP) is also effective. Indeed, two type of variability have to been taken into account. The medium term and the short term one. The latter is due to the non continuous conditions and the difference between driver behaviours. The medium-term one is induced by the evolution of traffic conditions over the time (congestion level, queue length, etc.). By adopting too large aggregation periods, both type of variability are summed in the same link travel time measurements population.

4.1.3 Substitution methods

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, sub-division 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. Substitution methods have then to be applied. For this research the following ones have been evaluated:

Static
It represents the most basic one and consists in substituting the lacking values by the free flow travel time ones. In other words, when no information is available, use the link travel time provided by a static navigation system (data recorded in the digital map CD-Rom).

Stationary
The stationary method relies on the hypothesis that without up-to-date information, link travel time has to be considered equivalent to the latest recorded one. It means that during the period for which not data is available, traffic conditions are supposed to be stationary.

Historical
Based on past days FCD records, historical profiles can be obtained. Thus, in the case of lacking data, the historical travel time for the corresponding link, day and aggregation period can be used as a substitution value.

Forcasting
In addition to travel time estimation, travel time forecasting is very useful in Advanced Traveller Information Systems (ATIS) like DRG. Based on FCD estimated travel times, forecasted values can be obtained for the future aggregation periods. Thus, when no data is available for a data set, the forecast that have been done previously can be used as substituted value. For this research, a forecast based on neural networks approach has been used but no description is provided in order to keep the focus on the main objectives of this paper.

4.1.4 Combined estimation

The idea of the combined estimation relies on the fact that, in some cases, the historical travel time is more accurate than the daily travel time estimation. Smaller the equipment ratio is more frequently it happens. A combination of both values with a relative weighting parameter could be, consequently, a more accurate estimation. However, the determination of the weight is depending on various parameters and an analytical approach is not able to catch this complexity. Thus, the calibration of a neural network model have been done to improve the performance of this combined estimation method.

4.2 Estimation accuracy assessment

As explained in the previous paragraph, many parameters are influencing the accuracy of travel time estimation. Some of them have contradictory effects and compromises have to be found for each equipment ratio (FCD fleet size). However, before assessing (using the simulation model) the estimation’s accuracy related to these parameters choice, a definition of accuracy has to be given.

4.2.1 Indicator

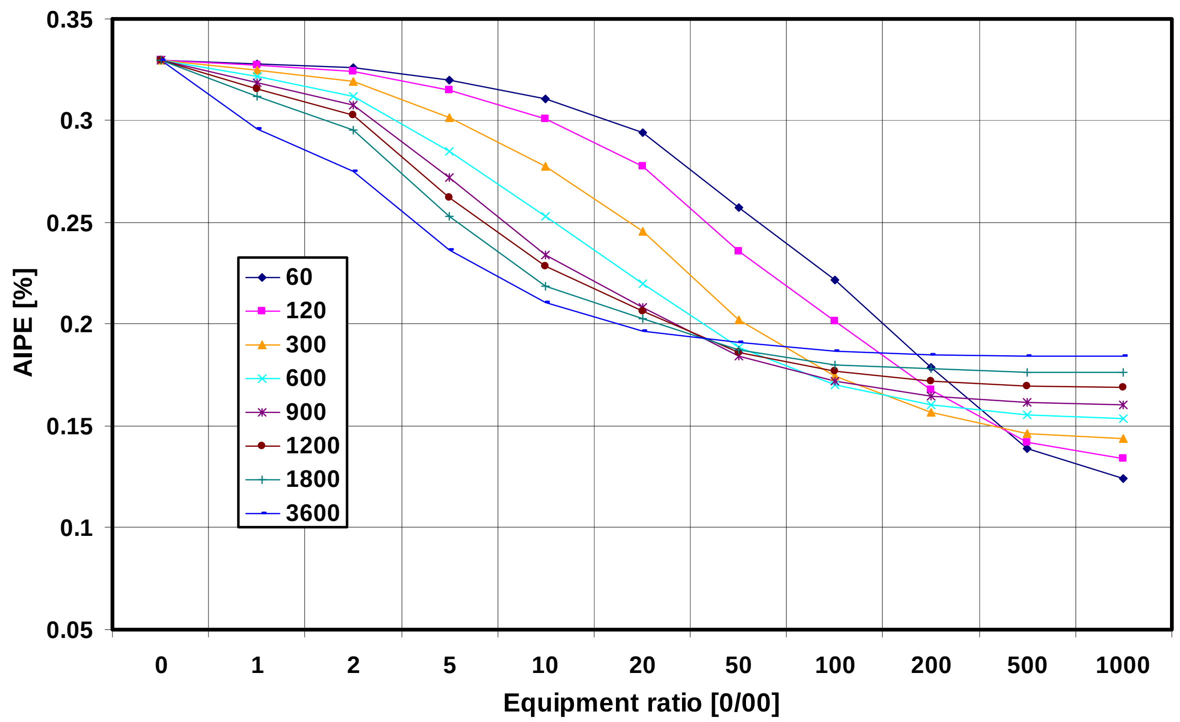
By using different sort of accuracy indicators applied to the whole simulation outputs, optimal choices of link definition and aggregation period duration can be obtained for each probe vehicle percentage. The average error between estimated and “real” travel time could be used as it is done in many studies. However, a different indicator is proposed in this research. It is the Average Individual Path Travel Time Error (AIPE). 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.

$$AIPE = \frac{\sum_{p=1}^{P}\sum_{\tau=1}^{T}\sum_{n=1}^{N_{p,\tau}} \frac{\left|PT_p^n - EPT_{p,\tau}\right|}{EPT_{p,\tau}}}{\sum_{p=1}^{P}\sum_{\tau=1}^{T} N_{p,\tau}} \qquad \textbf{Equ. 1}$$

4.2.2 The Lausanne case

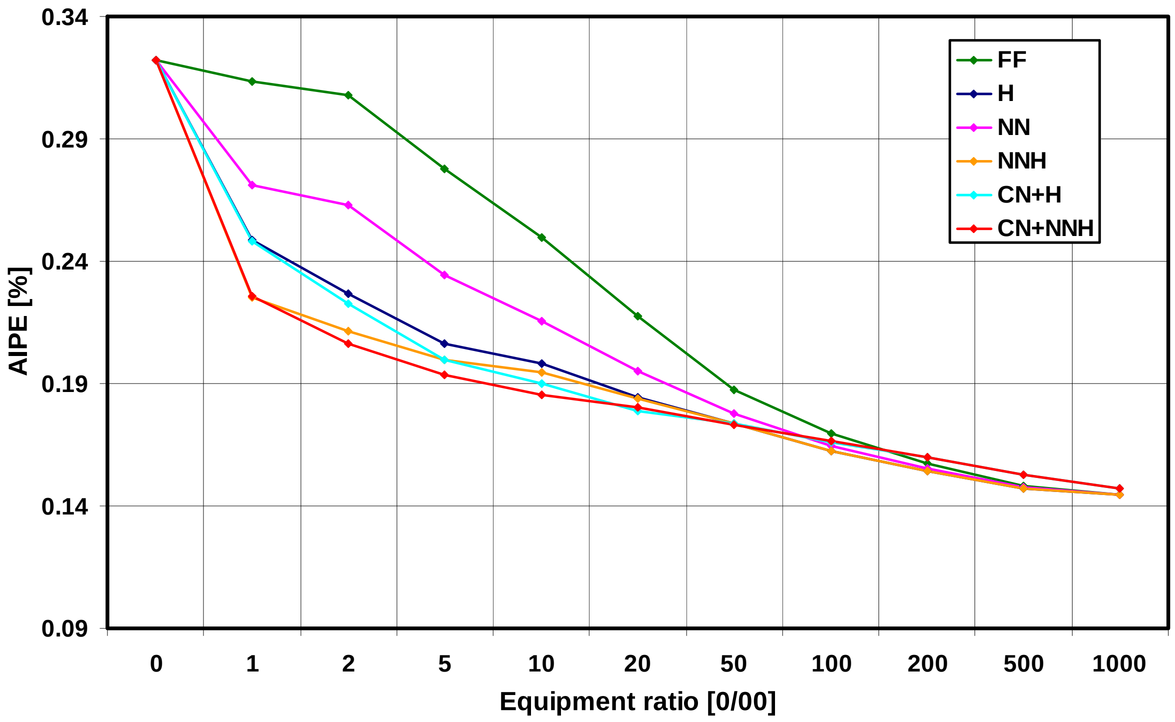
Based on the simulation runs of the Lausanne network model, various findings can be highlighted. Firstly, as shown in Figure 5, the effect of the aggregation period choice on the AIPE indicator can be clearly identified. This figure emphasize the fact that higher the equipment ratio is, smaller the AP has to be in order decrease the estimation error. In this particular case, a classical link definition and the static substitution method have been used.

Figure 5 Equipment ratio and aggregation period (in seconds) influence on AIPE indicator for a *classical* link definition



Knowing the set of parameters implying the lowest AIPE for each equipment ratio is, however, the most interesting results of this assessment process. Figure 6 shows these results. Indeed, for each substitution method, the best AIPE value possible (coming from the adequate use of aggregation period and link definition) are reported on the graph. The latter leads to identify two important findings. Firstly, the combination method (CN) added to the forecasting one (NNH) is the most performing choice. Then, Figure 6 also shows that with an equipment ratio of only one per thousand, the potential estimation error (AIPE) can be decreased by a half which is a quite encouraging result in the field of FCD. Obtaining such result has been possible by adapting the key parameters to the corresponding equipment ratio.

Figure 6 Influence of the substitution method on AIPE indicator



5. Performances assessment

This chapter aims to evaluate the benefits, mainly in travel time saving, that SNA users can expect. This assessment relies on the Lausanne network simulation experiment where performances of non-guided and guided (SNA) vehicles are compared. Both standard and with accident scenarios are analysed.

5.1 Assignment of non-guided vehicles

As explained in a previous work undertaken by Torday and Bert [24], the AIMSUN per default traffic assignment model is not sufficiently realistic for the particular needs of this research. Thus, an improved one has been developed. Its major particularity is the division of the non-guided vehicles in three categories:

Tourists
These users have a limited knowledge of the network (only main streets) and no information about usual traffic conditions.

Standards
Standards drivers represent the majority of the non guided one. The have a variable (random) knowledge of the whole network and traffic conditions. It means that they have a better familiarity with some part of the network (in term of geometry and traffic conditions) than with others.

Experts
The drivers being part of this category can be described as taxi drivers. They have a perfect knowledge of the network and know perfectly what the usual traffic conditions are.

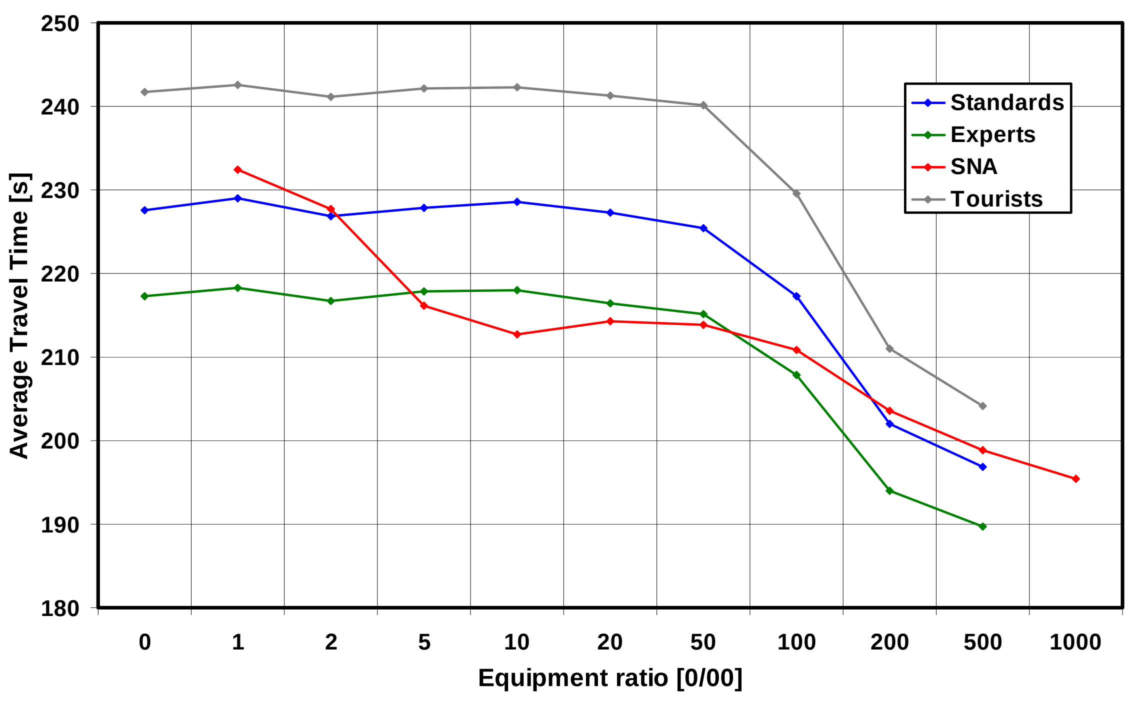
The notion of traffic conditions knowledge is representing the experience that drivers summed over previous days. Concretely, it’s an historical profile that is calculated on the basis of 10 or twenty simulation runs. However, none of the above described categories are using travel time information recorded during the simulated day, this contrasting with the reactive model offered by AIMSUN in the per default configuration.

5.2 Global performances

Under usual traffic conditions, the average travel time from origin to destination of all the vehicles that drove through the network has been obtained for the four different drivers categories. These results are reported in Figure 7 according to the equipment ratio.

It shows that even with a very limited number of equipped vehicles (ER around one or two per thousand), performances of SNA users are similar to standards ones which represents the typical commuters performances. Beyond five and up to fifty per thousand, equipped vehicles are experimenting lower travel times than expert drivers, clearly emphasizing the potential of this system. Nevertheless, beyond fifty per thousand, performances of SNA drivers (compared to others) are decreasing. This can be explained by the fact that too many vehicles have the knowledge of the current traffic conditions and are using the same streets in order to avoid congested areas. In this case, anticipatory route guidance concepts [25-27] have to be applied. However, it is important to notice that the global performances (all categories included) are improving with the equipment ratio increase.

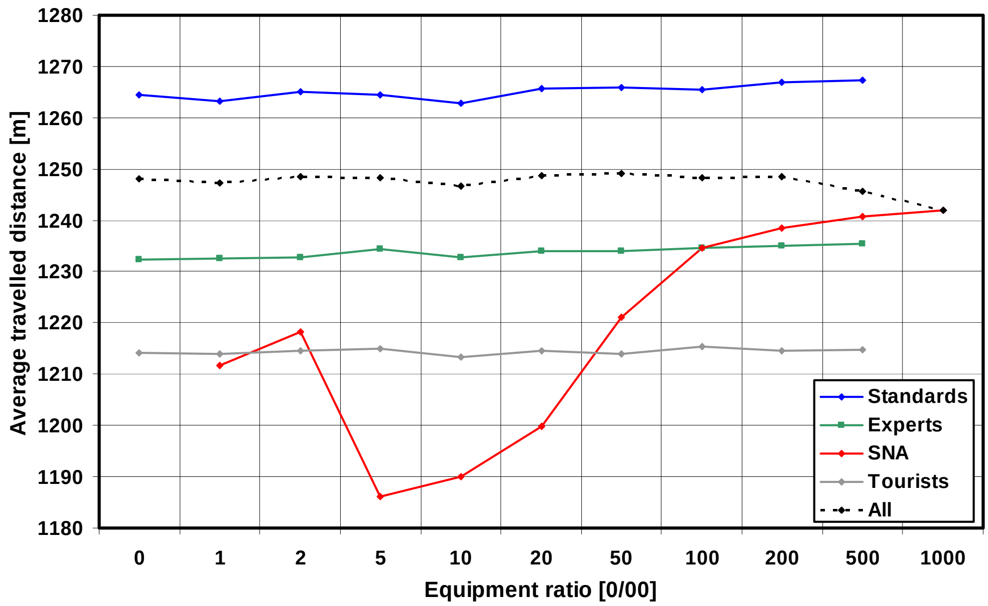
Figure 7 Evolution of the average travel time according to the equipment ratio



The shortcutting behaviour of the SNA drivers is clearly identified with Figure 8, the latter representing the average distance travelled by the four different categories. Indeed, for equipment ratio values between five and fifty per thousand (representing the best travel time performances) the SNA drivers are using the short routes, travelling similar distances as tourists' drivers but using much less time to do it. The optimization is consequently obtained.

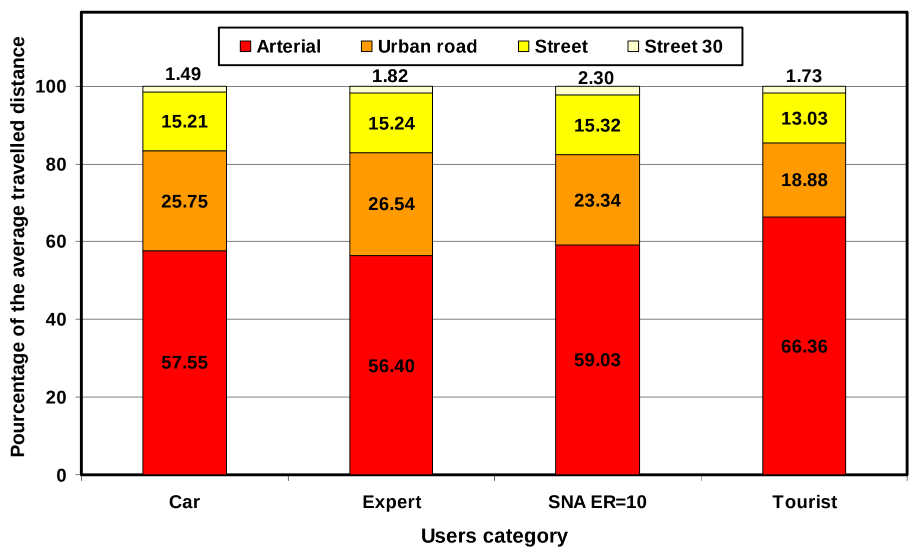
As for travel time, beyond fifty per thousand equipment ratios, SNA drivers' behaviour is coming back to more usual one.

Figure 8 Evolution of the average travelled distance according to the equipment ratio



Shortcuts taken by equipped vehicles could lead to think that they use more local and residential streets than other vehicles. Figure 9 confirms this fact, but also shows that this increase is quite limited. It even demonstrates that SNA vehicles use more frequently main streets than the non-tourists ones which is an additional proof of the optimization process obtain through the use of this system.

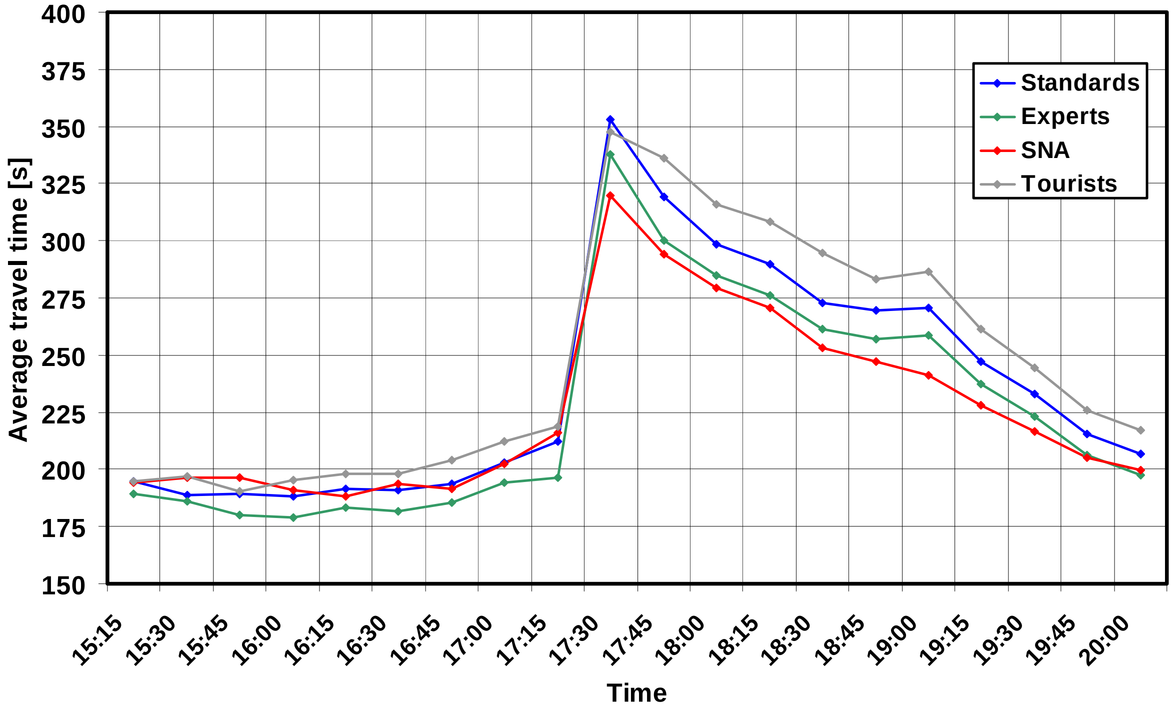
Figure 9 Distribution of the travelled distance over the different road types



5.3 The incident case

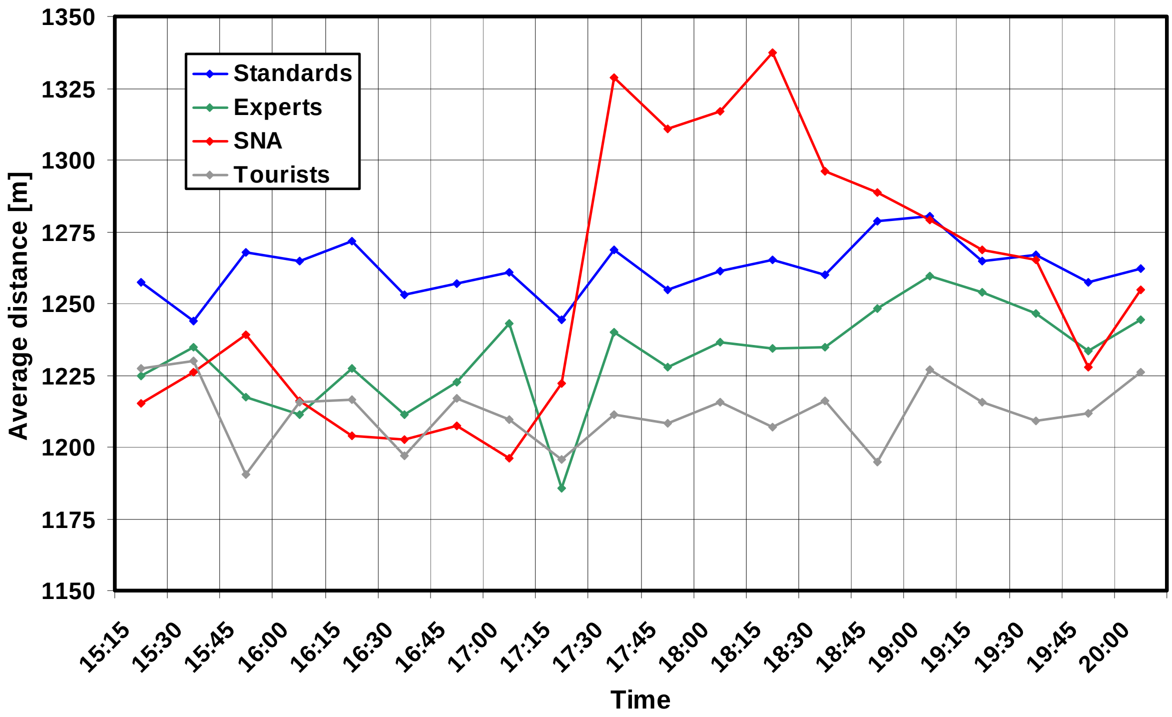
The accident scenario has been obtained by blocking the central street of the network at 17h00 and during 15. The effects of this simulated accident are clearly shown by Figure 10 with an important peak of travel time recorded after 17h15. It also demonstrates the benefits that can expected from SNA users in such case. Indeed, travel times of equipped vehicles are always behind experts' one after accident occurrence.

Figure 10 Average travel time evolution for an incident scenario



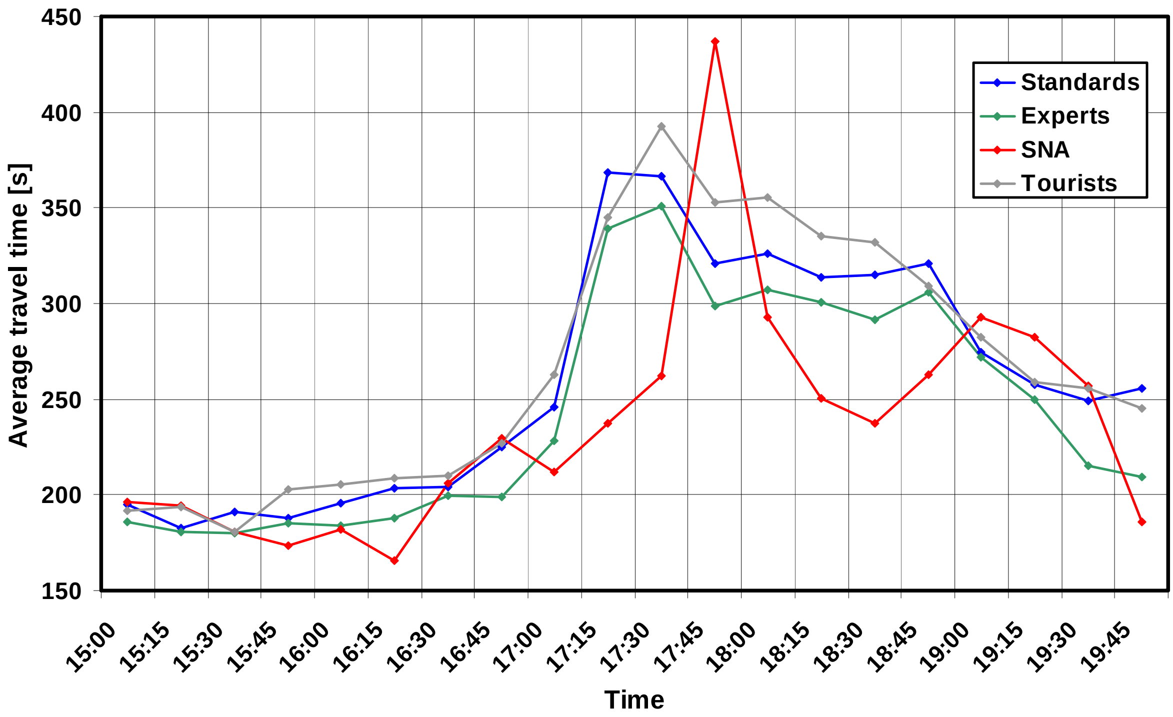
Looking to the travelled distances reported on Figure 11 allows a better understanding of the behaviour of guided vehicles. While non-guided vehicles continue to use their usual routes (because they don't receive current traffic conditions information), SNA drivers are informed of the congested situation in the centre of the network and avoid this area by choosing alternative routes that are longer in term of distance but faster in term of travel time.

Figure 11 Average travelled distance evolution for an incident scenario



However, limitations on the concept of self supplying have to be admitted. A particular simulation run of the accident scenario illustrate them. Indeed, Figure 12 shows the evolution of travel time of each driver categories during the simulation process. After accident occurrence, immediately SNA drivers start saving time by avoiding the accident area. However, a very important peak of travel time is recorded for SNA users at 17h45. What happens is that all the guided vehicles avoiding the network centre, no more information were available for this area. Consequently, after a certain time, substitution methods tend to push SNA drivers to come back to city centre and to discover that… the congestion is not finished! They react to this new information by, once more, avoiding this area implying a new decrease in travel time. This phenomena is direct consequence of the fact that vehicles using the information and providing it are the same.

Figure 12 Particular case of avergae travel time evolution for an incident case



6. Further researches

This research has pointed out numerous fields where research is still needed:

Instead of using a deterministic approach, based on average travel time, a probabilistic one with travel time distribution should provide much more information about reliability of route guidance provided by the SNA.

A direct consequence of the latter aspect is that dependencies between link travel time measurement populations have to be studied in order to obtain, not only link travel time distribution, but also path travel time ones.

Assessment of the SNA performances should be done on a larger network (the whole Lausanne area) in order to confirm the findings that the city centre network offers.

The DRG guidance method used for this research should be improved by the use of anticipatory route guidance and (for larger networks) time dependent shortest path algorithms [28-30].

7. Conclusion

This paper presented the concept of the self-supplied dynamic navigation system (SNA), a combination of the dynamic route guidance (DRG) and the floating car data (FCD) travel time acquisition technique.

After a brief review of the existing research on both fields, it emphasized that FCD based travel time estimation accuracy was depending on a lot of elements. Among them are the aggregation period, the link definition and the substitution method. It has been demonstrated (relying on an accuracy indicator based on path travel time) that FCD technique can be quite accurate if these elements are correctly chosen according to the equipment ratio.

On a second step, an assessment of the SNA users' performances has been proposed, based on the Lausanne network simulation runs. It shows that with an equipment ratio between five and fifty per thousand, equipped vehicles experience faster journeys than other drivers' categories and particularly expert ones. This phenomenon is amplified in the case of non recurrent congestion like an accident scenario. Indeed, being the only vehicles to have information about the current traffic conditions, SNA users are able to avoid the congested area and saving time even if the travel longer routes that the others.

In some special accident cases, however, it has been shown that the fact that vehicles using the information and providing it are the same can lead to complicate situation where guided vehicles are sent back to congested area to notice that situation hasn't changed yet.

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