

**DACCORD:**  
**ON-LINE TRAVEL TIME ESTIMATION/PREDICTION RESULTS**

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**SUMMARY**

This paper deals with part of the achievements of the European project DACCORD. Within the framework of DACCORD a number of methods for on-line travel time estimation and prediction have been developed, implemented, validated and evaluated. This paper provides an overview of the methodologies involved, but focuses on the evaluation results. Evaluation results and cross site comparisons are presented for a number of different methods that were demonstrated at three test sites which participated in DACCORD. Results show that on-line (i.e. real time) travel time estimation using induction loops can be achieved with errors around 10 % (up to moderate congestion levels). The results also show that on-line methods require a substantial effort to deal with the operational performance of the currently available monitoring systems.

## INTRODUCTION

Up-to-date travel time information plays an important role in Dynamic Traffic Management. This paper presents the results achieved with the methodologies used for the on-line estimation / prediction of travel times using induction loop detectors within the Telematics Application Programme project DACCORD.

Travel time —the time to travel from one location to another— is a primary form of information representing the traffic condition. Based on induction loop data alone several methods exist to estimate and predict travel time. DACCORD has investigated and continued the development of these methods, see (1). These methods have been implemented, validated and evaluated. Due to three test-sites and their corresponding test site owners that were part of the project consortium a considerable number of methods could be validated and evaluated cross-site. This paper summarises the results presented in (2) and (3).

The paper will start with some background on the DACCORD project. The following sections will briefly describe the test sites, provide an overview of the methods evaluated, explain the evaluation methodology, clarify the collection of reference data, and present the evaluation results. The paper concludes with a summary of the results and conclusions from the DACCORD project.

## DACCORD

DACCORD has been one of the main projects, within the Transport Sector in the Telematics Applications Program from the European Commission that focused on dynamic traffic management and control on inter-urban motorways (1996-1999). DACCORD stands for *Development and Application of Co-ordinated Control of Corridors*. Its main objective was to design, implement and validate a practical Dynamic Traffic Management System (DTMS) for integrated and co-ordinated control of inter-urban motorway corridors. An additional objective was to further develop an open system architecture for inter-urban traffic management.

Within DACCORD the problem of developing a DTMS as been approached in two very different and complementary ways: a pragmatic “bottom-up” approach geared towards practical experimentation with a large number of traffic management and motorway control tools, and a “top-down” approach oriented towards the development of an open system architecture for DTM systems in general.

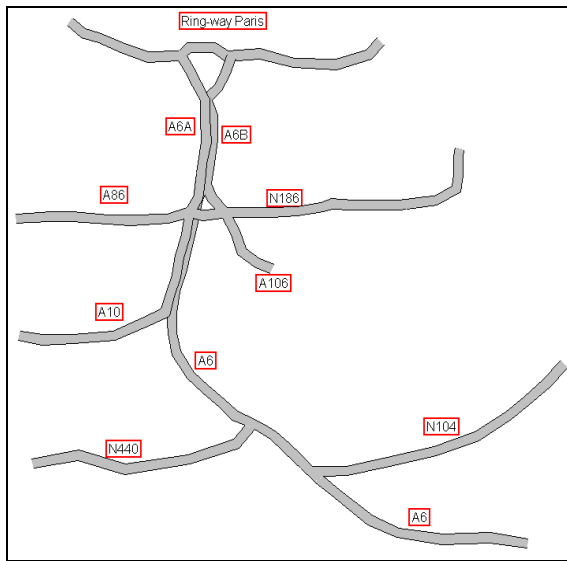
The activities carried out within DACCORD cover a very broad range, from development of new methods, enhancement and/or integration and/or field evaluation of previously developed tools, to application and evaluation of methods and tools at different test sites. The DACCORD project has built on previous experience from the DYNA project, the EUROCOR project, the GERDIEN project and the SATIN Task force, all former European projects.

The DACCORD consortium consisted of 22 partners from 8 different European countries, and included site owners, research institutions, universities, consultants and software developers.

The DACCORD project has benefited greatly from the presence of three well-equipped test sites (Amsterdam, Paris, and Brescia-Venice) and the commitment of the authorities in charge of the sites. The three site owners share similar operational objectives, and their respective interests in particular technical solutions and in integration issues overlap to a great extent. This places the project in a good position to gain practical operational experience with the tools involved, and to carry out a comprehensive evaluation.

## DACCORD TESTSITES

### PARIS TEST SITE

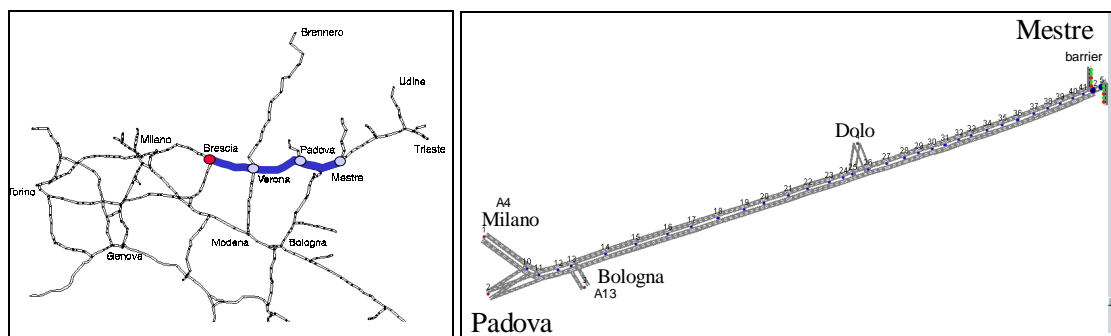


The Paris test site is located to the south of Paris. The topmost horizontal road in Figure 1 is the Boulevard Peripherique. The road running from north to South is the A6 motorway. The A6 motorway is fully equipped with induction loops measuring traffic volume, occupancy and speeds.

The A6 motorway is heavily used for commuting, and the traffic density can be very high.

**Figure 1. The Paris Test Site (F)**

### ITALIAN TEST SITE



**Figure 2. The Padova-Mestre Site (I)**

The Italian test site consists of the motorway between Padova and Mestre. The location of the motorway is shown on the left in Figure 2, an expanded view of the motorway is shown on the right. In Mestre the motorway ends in a Toll barrier. The stretch of the motorway leading into the barrier is well equipped with monitoring devices, and most of the experiments at the Italian test site have been carried out on this part of motorway.

## AMSTERDAM TEST SITE

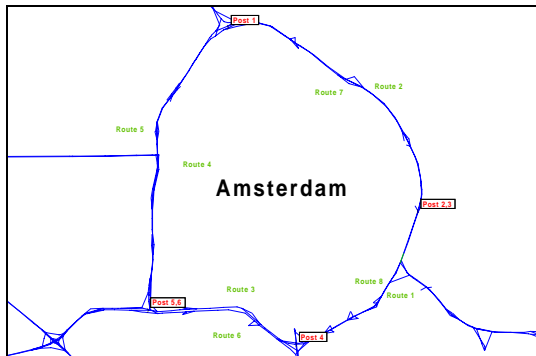


Figure 3. The Amsterdam Site (NL)

The Amsterdam test site consists mainly of the Amsterdam Orbital Motorway (A10), but includes the A9 leading up north and the connecting motorways that feed into the A10, as shown in Figure 3.

The A10 is well equipped with induction loops, which are installed about every 500 meters. The A10 has been used for demonstration within DACORD.

## ON-LINE TRAVEL TIME ESTIMATION AND PREDICTION

### SOME DEFINITIONS

#### Section versus route

A section  $k$  is a part of the road-network between induction loop detectors. In contrast, a route  $R$  is a pre-defined path in a network over a number of connecting sections  $k_1 - k_n$ .

#### Section-level travel time versus network-level travel time

With the assumption that the traffic conditions (speed, flow and density) are stationary during a time period and homogeneous across a section, time may be discretised in periods, while space is discretised in road-sections. The realism of this approximation depends on the duration of a period and the length of a section and the variability of the traffic conditions. Based on the discretisation in time and space, section-level travel time (SLTT) can be defined:

*The Section-Level Travel Time (SLTT) on section  $k$  for period  $p$  is defined as the time it takes to traverse road section  $k$  during period  $p$ .*

In the DACCORD project, travel time over a route is understood as the “network-level travel time (NLTT)”, which is defined as follows:

*The Network-Level Travel Time (NLTT) at time  $t$  between points  $A$  and  $B$  is the amount of time required for a traveller departing from point  $A$  at time  $t$  to arrive at point  $B$ , when travelling through the network over a pre-defined path  $R$  between  $A$  and  $B$ .*

By definition account is taken of prevailing traffic conditions and other influences on the travel time.

#### Instantaneous versus dynamic travel time

Instantaneous versus dynamic NLTT represents the way the NLTT is calculated from

SLTT's. The instantaneous NLTT is computed as the sum of the SLTT's of the same time period.

$$NLTT_R^{inst}(p) = \sum_{k \in R} SLTT_k(p) \quad (1)$$

The dynamic travel time on the other hand is defined by following a vehicle along its trajectory. The dynamic NLTT is computed as the sum of parts of the SLTT's of multiple time periods depending on the time moment a traveller enters a section, or on the point a traveller is at a new time period (1).

#### Estimation versus prediction

Estimation techniques calculate a travel time based on data representing the most recent time period. This data is directly measured during this period.

$$NLTT_R(p) = f(SLTT_{k \in R}(q)) \quad (q < p) \quad (2)$$

Prediction techniques calculate a travel time based on data representing both the most recent as future time periods. This data is computed using a prediction model calibrated with measured data.

$$NLTT_R(p) = f(SLTT_{k \in R}(q)) \quad (q \geq p) \quad (3)$$

### **TRAVEL TIME TECHNIQUES DEVELOPED IN THE DACCORD PROJECT**

This section in short describes the different travel time techniques in the DACCORD project. More detailed descriptions are given in (1) and (3).

#### Section-level travel time estimators

Two techniques have been developed and implemented for the computation of the section-level travel time:

- Section-level travel time estimator based on measured speeds. SLTT's are computed using the speeds at the start and end of each section.
- Section-level travel time estimator based on a mass-balance. SLTT's are computed using a mass-balance of the flows at the start and end of a section to compute the number of extra vehicles on the section due to congestion. The dissipation rate together with the number of extra vehicles leads to an estimate of the time losses on top of the free-flow travel time.

#### Network-level travel time estimators

These estimators use SLTT's from all sections of a route from the previous time period. Two techniques have been developed and implemented to aggregate these SLTT's to a NLTT. In DACCORD three NLTT estimators have been developed and evaluated:

- Instantaneous network-level travel time estimator based on section-level travel times estimates (equation 1).
- "weighted" instantaneous network-level travel time estimator based on section-level travel time estimates. The weighted instantaneous NLTT is computed in a similar

way as the instantaneous NLTT estimator computed from measured speeds, but using a weighting factor for each section level travel time that is proportional with the use of that section compared to the use of other sections in the route.

$$NLTT_R^{weight\ inst}(p) = \sum_{k \in R} \gamma_k SLTT_k(p) \quad (4)$$

#### Section-level travel time predictors

Two main models have been developed and implemented resulting in two predictors:

- Section-level travel time predictor of the Statistical Traffic Model (STM); The STM is a macroscopic traffic flow model in which traffic is represented by its macroscopic properties, density, flow and speed.
- Section-level travel time predictor of the Behavioural Traffic Model (BTM). The BTM is a dynamic framework including dynamic OD estimation and prediction models and the Multiclass Dynamic Assignment model (MIDA).

#### Network-level travel time predictors

The predictors use traffic data from all sections of a route from a future time period. Most prediction models, which have been developed and implemented, can compute both instantaneous and dynamic network-level travel time. Since dynamic travel time is expected to perform better, these models rely on dynamic travel times. One of the prediction techniques can only predict instantaneous travel times.

- Dynamic network-level travel time predictor based on SLTT predictions;
- Instantaneous network-level travel time predictor based on predicted flows. This model predicts the traffic performance on each section for a future time period. It then computes an instantaneous network-level travel time.

### **TRAVEL TIME TECHNIQUES IMPLEMENTED AT THE DACCORD TEST SITES**

For section level travel times, different estimation and prediction techniques were developed and tested during the lifetime of DACCORD.

Table 1 shows the types of travel time estimation and prediction techniques implemented at the test sites.

On-line travel time estimation and prediction techniques		Instantaneous NLTT	“Weighted” instantaneous NLTT	Dynamic NLTT
Estimation techniques	Speed-based SLTT	NL, F, I	NL, F	
	SLTT based on mass-balance	NL		
Prediction techniques	STM			NL, I
	BTM	I		I
	Predicted flows	F		

**Table 1. Travel time techniques at the different test sites in DACCORD**

## **METHODOLOGY OF TRAVEL TIME EVALUATION**

The objective of the evaluation of travel time estimation and prediction techniques is to assess their performance compared to the true travel times. Additionally the influence of traffic conditions, weather, and other ambient conditions on the performance of the tools has been investigated within DACCORD. Finally, a cross-site performance comparison has been carried out.

In addition to the comparison of the DACCORD travel time tools against real data, a further comparison was carried out against a pair of "reference estimators", based on the same induction loop data as is used by the DACCORD system.

Of the two reference estimators one is a quick-and-dirty estimator called the "lower reference". Comparison of the performance of the DACCORD tools with the lower reference shows the improvement one can obtain by using the DACCORD tools.

The other is an off-line estimator called the "upper reference". Comparison with the "upper reference" indicates how much improvement one could reasonably expect from further development of the DACCORD tools.

Both the DACCORD tools and the reference systems are evaluated by comparing them to true observed travel time as, experienced by travellers on the network.

Two reference systems used are:

- naïve travel time estimator as the minimum reference system;
- off-line dynamic travel time estimator as the maximum reference system.

### **DEFINITION OF THE NAÏVE REFERENCE SYSTEM**

The minimum reference system aims to give an estimate for the travel time for different moments of the day if no on-line estimation or prediction techniques would be available. The minimum reference system is determined by taking a historic average of the instantaneous NLTT for a certain period of time (a number of weeks). The speed-based SLTT was used to determine the instantaneous NLTT because this estimator is present at all three sites. The naïve reference system is assessed for each route based on five-minute intervals.

### **DEFINITION OF THE OFF-LINE DYNAMIC REFERENCE SYSTEM**

The maximum reference system aims to give the theoretically best possible estimate of travel time. The maximum reference taken in the evaluation is the so-called off-line dynamic travel time estimator.

The maximum reference system is determined with an off-line dynamic NLTT estimator using the speed-based SLTT, as this estimator is present at all three sites. The off-line dynamic reference system is assessed for each route based on the smallest possible time interval.

## TRAVEL TIME OBSERVATIONS

All three test sites used different methods to measure the true travel times:

- at the Amsterdam site a license plate survey was undertaken. At several locations in the network license plates of vehicles with a certain colour were recorded, along with the time of sighting. From the resulting database, the true travel time could be determined. This method is labour intensive, and thus expensive. It did however provide a considerable amount of observations.
- at the Paris test site a floating car survey was undertaken. Specially equipped cars departed at regular intervals and “floated” on the traffic stream. By clocking passage time at fixed locations the travel time could be determined. This method is also labour intensive and thus expensive and the amount of observations is very limited. As the cars “floated” on the traffic stream, individual observations should be more representative of the true travel time than those from a license plate survey.
- at the Italian test site the motorway tolling system was used to estimate travel times. Travel times were calculated from the difference in entry and exit times of toll tickets. The method is easy to implement and inexpensive to operate. The post processing is somewhat more labour intensive, but small compared to the other methods. Unfortunately this data collection system seems to be best suited for longer distances than the one to which it was applied, so that resulting travel times are not of the best quality. The total travel time is in the order of a few minutes and the resolution of the ticketing system itself is one minute. Together with a yet unexplained systematic error, and the absence of congestion, this compromised the usability of the travel time estimates from this site for the purpose at hand.

## RESULTS

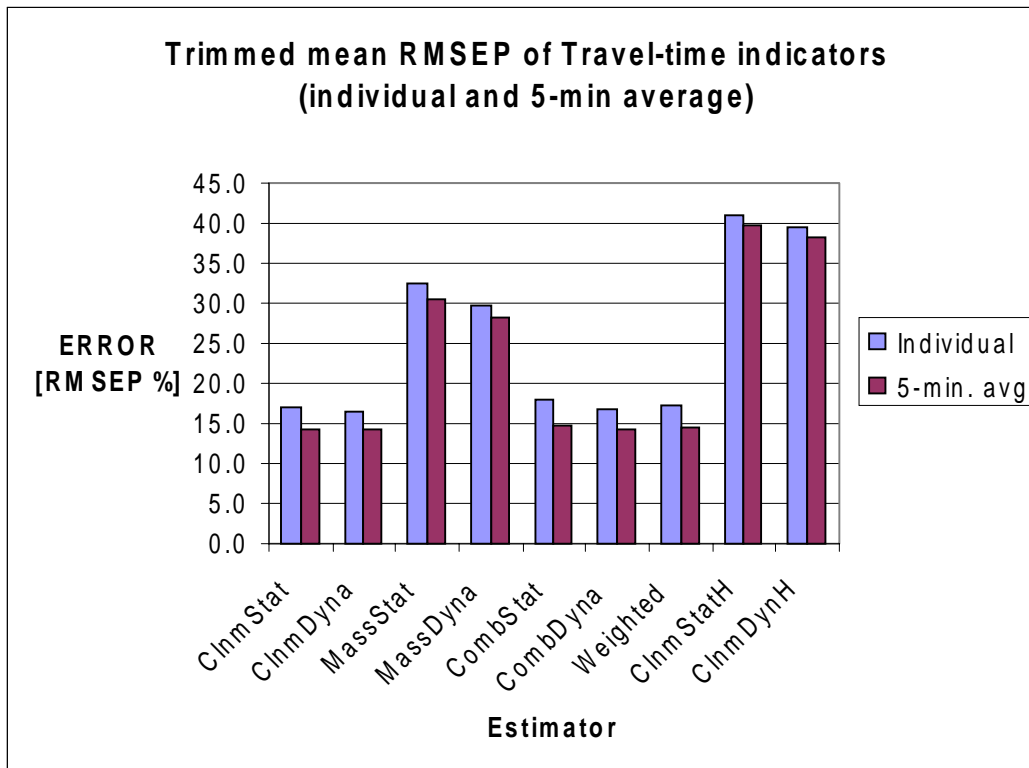
In this chapter results of the evaluation of DACCORD are shown. A large number of evaluations have been carried out within DACCORD, so that only a few results can be shown here (a complete overview is given in (3)). Only the overall comparison for the different methods is shown. The designations in the figures are:

<i>ClnmStat</i>	:	<i>instantaneous NLTT based on speed measurements</i>
<i>MassStat</i>	:	<i>instantaneous NLTT based on mass balance method</i>
<i>WghtStat</i>	:	<i>weighted Instantaneous NLTT based on speed measurements</i>
<i>PredStat</i>	:	<i>instantaneous NLTT based on Predicted flows</i>
<i>BtmDynXX</i>	:	<i>dynamic NLTT predictors based on the BTM for 0, 5, 15, 30 and 55 minutes ahead</i>
<i>ClnmDyna</i>	:	<i>off-line dynamic NLTT based on speed measurements</i>
<i>MassDyna</i>	:	<i>off-line dynamic NLTT based mass balance method</i>
<i>CombYYYY</i>	:	<i>combination of methods (MassYYYY and ClnmYYYY)</i>
<i>ClnmStatH</i>	:	<i>historical average of ClnmStat</i>
<i>ClnmDynaH</i>	:	<i>historical average of ClnmDyna.</i>

*ClnmDyna* and *MassDyna* represent the upper reference system, while *ClnmStatH* and *ClnmDynaH* represent the lower reference system.



In Figure 4, Figure 5 and Figure 6 the performance of the different methods is set out against the reference system using the RMSEP (Root Mean Square Error Percentage).



**Figure 4. Comparison of RMSEP at the Amsterdam test site**

In Figure 4 the RMSEP-results are shown for the Amsterdam test site. Both the RMSEP of the individual observations and the 5 minute average are shown. In both cases ClnmStat shows the best results of the on-line estimators. ClnmStat is very close to the upper reference, thus indicating that only a minor improvement would be possible with the available data. ClnmStat performs much better than the lower reference, thus showing the value of this on-line method. It must be added that the performance of the methods in Amsterdam strongly depends on the congestion levels: higher congestion levels show a disproportionate growth of the errors. One likely cause for this is the inability of a number of induction loops to measure speeds below 18 km/hour.

In Figure 5 the RMSEP-results are shown for the Paris test site. The results show that ClnmStat is not better than the lower reference. This was quite surprising, since the lower reference completely ignores the current traffic situation. The main reason for this seems to be the stability of the congestion pattern (for the 4-day demonstration period). At this site the best travel time estimator is WghtStat although it is very close to ClnmStat The Prediction appears to show a similar quality, but currently the travel time predictors do not show sufficient stability to permit their unrestricted use in a production environment.

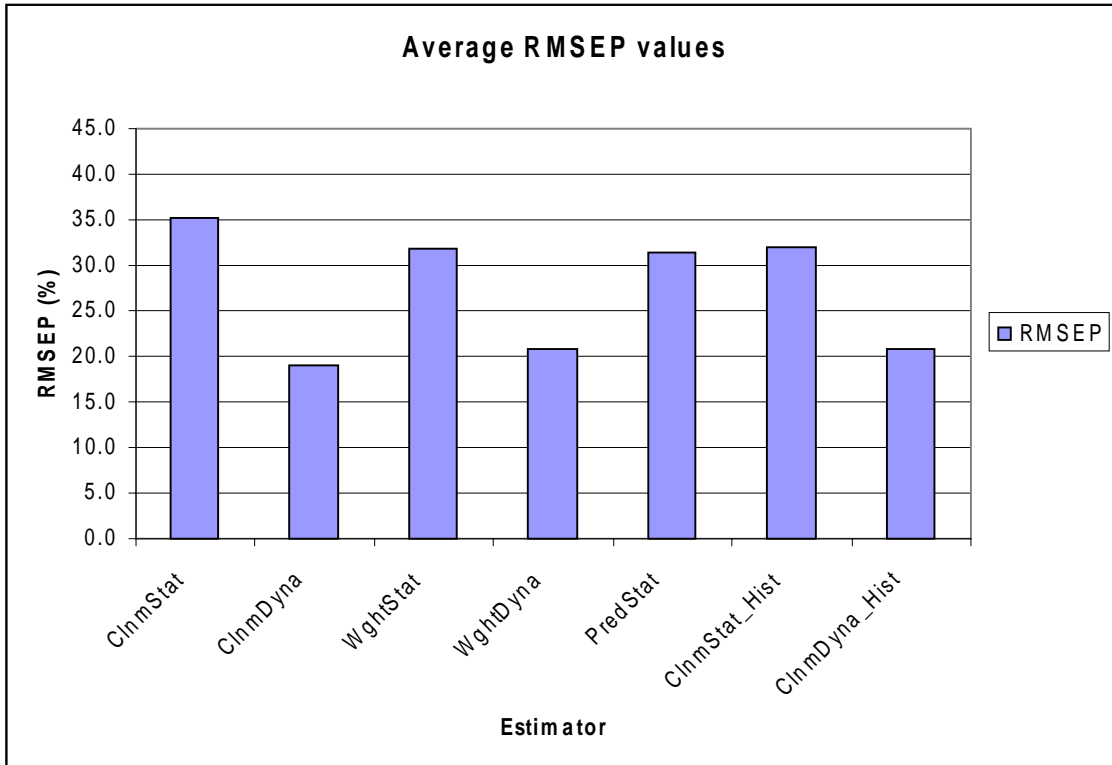


Figure 5. Comparison of RMSEP at the Paris test site

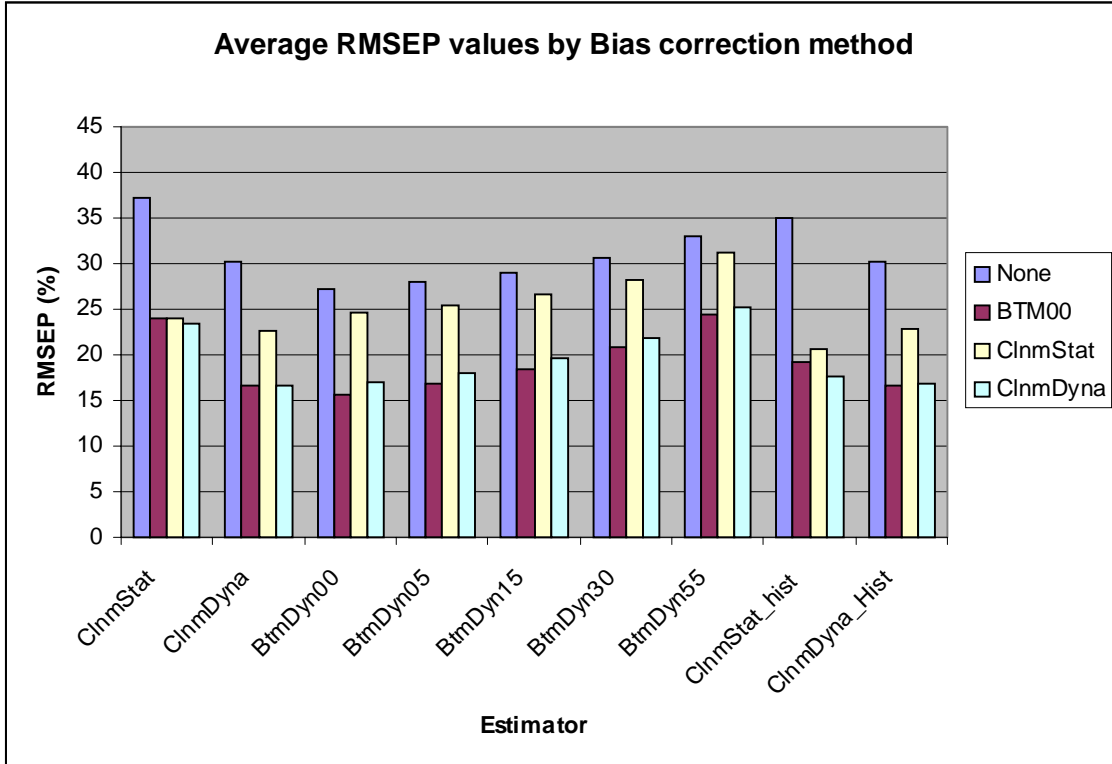


Figure 6. Comparison of the RMSEP at the Italian test site

In Figure 6 the RMSEP-results are shown for the Italian test site. As already explained, the travel time observations at the Italian test site show a considerable systematic error. In this figure four different methods for bias correction have been applied. Results show that the prediction model used (BTM) is the best estimator, even better than the upper reference. ClnmStat on the other hand does not seem to perform very well in comparison. However, to put this in perspective, the performance of the BTM benefited from the chronic lack of congestion during the period of demonstrations..

## CONCLUSIONS

### TRAVEL TIME ESTIMATION

The travel time estimators appeared to be reasonably accurate (circa 15% error) up to moderate congestion levels, at all sites (which is not surprising, because at low congestion level the travel time is close to the free-flow speed). From moderate congestion levels and up, the situation starts to diverge by site. At the Amsterdam site the estimators fail to capture the level of travel time on the network, and show considerable errors, where congestion level is the most important factor determining the level of the estimation error. A promising development is that, at the Paris site, travel time accuracy was maintained up to the highest congestion levels observed.

Other external factors such as visibility, weather conditions, and day of the week were seen to play a subordinate role as far as the accuracy of the travel time estimators is concerned.

Two artificial reference estimators were used: a “*lower reference*”, also called the “*naïve reference*”, and an “*upper reference*”. The lower reference simply consists of taking the average of the measured traffic conditions over the past few days. The upper reference consists of an *off-line* dynamic travel time estimator (ClnmDyna). This estimator gives the best travel time estimates (within the class of estimators evaluated) that can be achieved on basis of the available traffic measurements.

The overall result is that of the *on-line* methods, the simplest travel time estimator: instantaneous travel time estimation on basis of traffic speed measurements (ClnmStat) was seen to perform best. It generally outperformed the lower (naïve) reference estimator. This implies that such estimators will be of considerable support to traffic operators.

The upper reference estimator however performs a little better, notably in tracking sudden surges in travel time and generally being less “noisy” than ClnmStat. For this reason, a limited performance improvement of the instantaneous travel time estimator can still be sought.

### TRAVEL TIME PREDICTION

At present the travel time predictors either seem to be insufficiently stable to be used in a production environment, or showed great instability but could not be properly tested due to a lack of congestion at the test site.

Due to delays in the implementation and the calibration the results of the STM could not be assessed within the framework of DACCORD. Results of the STM are unstable and show that the STM is quite sensitive to the quality of the monitoring system, and the quality of the predictions of traffic entering and leaving the network under simulation.

The BTM on the other hand gives very stable travel time estimates/predictions. This is not wholly conclusive as no congestion occurred during the demonstration at the site where the BTM was tested. Furthermore, the accuracy of the BTM seems to degrade gracefully with increasing prediction horizons; for 5 and 10 minute-ahead predictions good agreement was seen between the estimated and predicted BTM travel time values.

In summary we can state that under those conditions where good travel time predictions would be helpful to traffic operators and road users (i.e. during the onset of congestion) the travel time predictors tested within DACCORD do not yet show satisfactory performance. Unfortunately, due to the current state of development and the circumstances of the evaluation definitive conclusions about the performance of travel time prediction methods cannot be drawn.

### **OVERALL CONCLUSIONS**

The DACCORD project gained a lot of experience with the operational use of induction loops for travel times estimation. In general the results are promising, but further work is still required.

This paper has shown mainly the results using RMSEP. Although it is a very useful method, its use has certain drawbacks and it is not the only way to evaluate the results. The DACCORD evaluation has analysed the results in a number of ways, which could not be presented here.

Accurate estimation of travel times based on induction loop data turn out to be a difficult undertaking, so that travel time prediction can therefore be expected to be even more difficult. One promising way of improving the results is to increase the quality of the data used, for instance by adding floating car data by means of mixed estimation techniques.

### **ACKNOWLEDGEMENTS**

The authors gratefully acknowledge the support of the European Commission in funding the DACCORD project. The content of this paper does however in no way represent the views of the European Commission.

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