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DACCORD: ON-LINE TRAVEL TIME PREDICTION

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Abstract

Travel time information --representing traffic conditions at network level-- plays an important role in Dynamic Traffic Management. This paper examines methodologies used within the Telematics Application Programme project DACCORD for on-line estimation/prediction of travel times using induction loop detectors. A classification of available on-line methods within DACCORD is presented as well as the DACCORD test sites at which they are applied. It is argued that the choice of methodology in a particular situation depends on two criteria. The simplicity of the methodology is weighed against the quality of the travel time. The quality of the travel time in turn depends on the traffic conditions.

INTRODUCTION

Up-to-date travel time information plays an important role in Dynamic Traffic Management. This paper deals 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— together with queue length are primary forms of information that represents traffic conditions. Other traffic variables, such as flows, densities and speeds also describe the traffic conditions, but only at a local level. Travel times and queue lengths can be seen as an aggregation of these local traffic conditions and represent the traffic conditions at a network level. That travel times need to be determined as accurately as possible, speaks for itself.

Experienced travel times can either be estimated directly from, for instance, induction loop data or predicted using traffic prediction models. Whether estimation suffices depends on the required accuracy as well as the variability of the travel time, and is thus location and situation dependent. Rather than estimating / predicting the travel time for an entire route as a whole, the network level travel time is based on the estimation / prediction of the travel time on the sections the route is composed of, the section level travel times.

This paper will first of all provide some information about the project DACCORD. In the following sections the estimation / prediction of network level travel time will be discussed for the general case and for on-line use. Additionally an overview of the methods used within DACCORD will be given. Furthermore, some details will be provided about the prediction and estimation of section level travel times. A brief discussion will finalise this paper.

DACCORD

This paper concerns work done within the context of the so-called DACCORD project. The DACCORD project is one of the projects in the Telematics Applications Program (TAP) from the European Commission, see Kroes *et al.* (1998).

The Telematics Applications Programme of the Fourth Framework is an initiative of the European Commission. Within the Transport sector of this initiative, DACCORD is one of the main projects focused on dynamic traffic management and control on inter-urban motorways. DACCORD stands for *Development and Application of Co-ordinated Control of Corridors*. Its main objective is 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 is to further develop an open system architecture for inter-urban traffic management.

Within DACCORD the problem of developing a DTMS is 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 builds upon the earlier experience within the DYNA project, the EUROCOR project, the GERDIEN project and the SATIN Task force, all former European activities.

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

The DACCORD project benefits greatly from the presence of three well equipped test sites (Amsterdam, Paris, and Brescia-Venice) and the commitment of the corresponding responsible authorities. 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 provides the project with unique possibilities to gain practical operational experience with the tools involved, and to carry out a comprehensive evaluation.

ESTIMATION AND PREDICTION OF NETWORK-LEVEL TRAVEL TIMES

Although the term 'travel time' seems to be well defined by itself, a more detailed definition is required, especially for network level travel times and section level travel times.

> *The Network Level Travel Time (NLTT) at time t between point A and point B is the total 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 A-B.*

Time t may be any time, points A and B can be any location in the network, and path A-B can be any feasible route (=path) through the network leading from point A to B. By definition account is taken of prevailing traffic conditions and other influences on the travel time.

The question is how to determine this travel time.

Measuring the NLTT

The NLTT as it is defined above represents the average or mean travel time for a specific route at a specific departure time. The mean travel time can only be measured indirectly. This is different in case of the travel time for an individual traveller; his or her travel time can be measured directly. An individual traveller may register his/her time using a stop watch. More generally applicable methods —that do not involve the individual traveller to determine the travel time— make use of for instance license plate recognition, toll-gates, in-car systems.

To conclusively determine the mean travel time for a particular route, all individual travel times would need to be determined. However, letting all travellers register their travel time is impractical, and most automated systems (except possibly for toll-gates) are not watertight. In practice the mean travel time would need to be determined from a subset of all individual travel times. In that case care should be taken that the subset is representative for the total population of individual travel times. This seems to be obvious, but automated systems may be biased.

A limited, but more controlled form of measuring the mean travel time is by means of floating cars or probe vehicles. Due to the cost involved, this form of data collection is rarely used at this moment for large scale application. However, in future, the availability of automated vehicle tracking facilities may increase and this will form a good way of measuring the actual NLTT for large numbers of vehicles at relatively low cost.

When direct measurement of the mean travel time is not possible, an alternative and relatively cost-effective way to determine travel time is by using the widely available induction loop detector systems. Induction loop detector systems generally provide measures of intensity, speed and sometimes occupancy. Travel time is a function of the speed along the route. More specifically, the mean travel time is the inverse of the space mean speed on the route multiplied by the length of the route. It is obvious that the speed measurements can be used directly for the computation of travel time. However, induction loop detector systems provide point measurements and the speed measurements are often time mean speeds over a certain period (e.g. 1 minute). Unless the variance of the speeds is nil, the time mean speed is somewhat higher than the space mean speed, see Wardrop (1952). This means that any form of travel time based on induction loop data can be no more than an estimate of the real travel time as it was defined above. To arrive at a consistent method of computing NLTT some approximations are required.

Discretisation of time and space — section level travel time

As the traffic measurements often represent traffic conditions during periods in time and at locations in space, a natural form of approximation is by a discretisation in time and space. If travel time is not computed from induction loop data, but from traffic models this form of approximation is even more natural, since most traffic models already use this form of discretisation. To be more specific, time is discretised in periods and space is discretised in road-sections. The assumptions associated with this discretisation is that the traffic conditions (speed, flow and density) are constant during the period and homogeneous across the section. The justification of this approximation depends on the duration of a period and length of a section and the variability of the traffic conditions.

Based on this discretisation in time and space a definition of a section level travel time can now be formulated.

> *The Section Level Travel Time (SLTT) is defined as the time it takes to traverse a road section during a certain period of time. This travel time can be determined by dividing the length of the section by the average speed for that period on the section.*

The above definition is less intuitive than the definition of NLTT. This is due to the fact that the section level travel time can be larger than the duration of the period. In that case a single SLTT can only be the best estimate of the time it takes to traverse the section at a certain time, especially when the SLTT's (and thus the speeds) for the following periods are unknown.

Computation of NLTT from SLTT

Given the assumptions that are associated with the discretisation there is only one way to correctly determine the best estimate of the NLTT based on SLTT for any given departure time and any path A-B.

The correct procedure to determine the travel time cannot be captured in one equation. An example of this procedure is given in Figure 1.

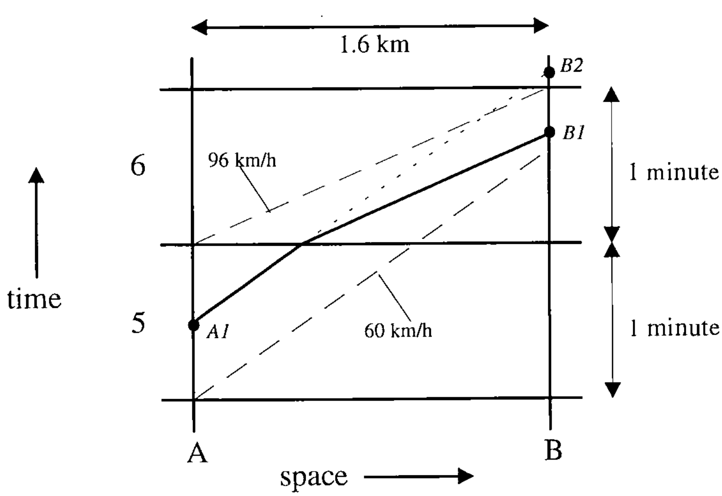

Figure 1 - Illustration of the computation of the NLTT from SLTT

Figure 1 shows the traffic conditions on a section in two periods, periods 5 and 6. The duration of one period is 1 minute. The section is 1.6 km long. The (average) speed in the first period is 60 km/hour, while the (average) speed in the second period is 96 km/hour (this is indicated by the dotted lines). When the departure time from location A is A1, then the arrival time at location B is B1.

Using the arrival time at each successive section in the network the NLTT is calculated. The Network Level Travel Time calculated according to this procedure, is sometimes called a dynamic travel time (because it captures the dynamic traffic conditions), or experienced travel time (because it is an estimation of the travel time a traveller actually experiences).

In a more simple way of computing the NLTT only the SLTT for the period of departure is used, in which case the arrival time at location B would be B2. In this case a basic principle is violated, the First In First Out (FIFO) principle. A driver departing from location A at the start of period 6 would arrive at location B prior to the former driver.

This violation would become more severe for longer sections and shorter periods, because in that case even more than 2 periods may be covered when the section is traversed. To show that this is not just a hypothetical problem Figure 2 shows the same situation calculated correctly and incorrectly.

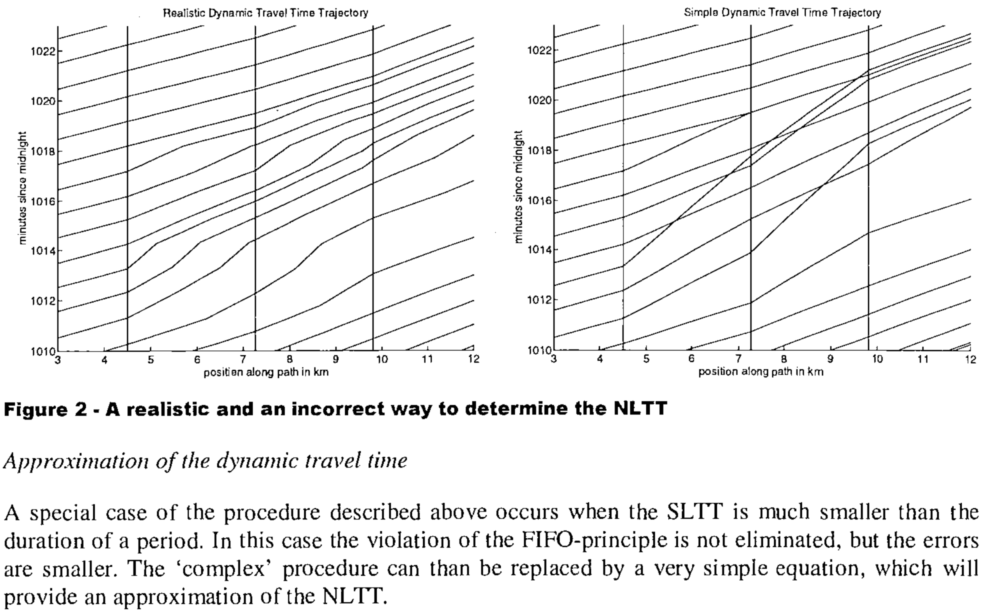

Figure 2 - A realistic and an incorrect way to determine the NLTT

Approximation of the dynamic travel time

A special case of the procedure described above occurs when the SLTT is much smaller than the duration of a period. In this case the violation of the FIFO-principle is not eliminated, but the errors are smaller. The 'complex' procedure can than be replaced by a very simple equation, which will provide an approximation of the NLTT.

The NLTT from node 1 to node n for departure time t, $T_n(t)$:

$$T_n(t) = T_{n-1}(t) + \tau_{n-1,n}\left(\text{int}\left(\frac{t + T_{n-1}(t)}{T_{period}}\right) + 1\right) \qquad (1)$$

In which T_{period} is duration of a period and *int()* the integer value in order to determine the period. The SLTT of the section between location n-1 and n during period p, is expressed by $\tau_{n-1,n}(p)$.

Approximation by the instantaneous travel time.

An even rougher approximation of the dynamic travel time is the instantaneous travel time. When the travel time to traverse the entire path is smaller than the duration of a period, an even easier method can be applied.

The travel time is then calculated by:

$$T_n(t) = \sum_{i=1}^{n-1} \tau_i \left(\text{int}\left(\frac{t}{T_{period}} \right) + 1 \right) \qquad (2)$$

In which $T_n(t)$ is the NLTT from node 1 to node n. The SLTT for the section i is expressed by $\tau_i(p)$. Given n nodes, there are $n-1$ sections.

This travel time is called the *instantaneous travel time*, as it seems to traverse the entire path in one 'instant' (during the current period). Again, when the assumptions are violated, the procedure provides only a rough approximation of the dynamic travel time.

Instantaneous travel times are generally used when the SLTT's for the periods following the departure period are unknown. In this case the instantaneous travel time forms the best available estimate.

ON-LINE ESTIMATION AND PREDICTION OF NLTT IN DACCORD

The estimation of NLTT has been discussed in detail for travel time estimation in general. To obtain up-to-date travel times the estimation needs to be done on-line and the available options change.

As mentioned earlier, the best way to estimate the NLTT off-line (apart from a direct measurement by the traveller) is by the use of individual vehicle observations (floating cars, license plate recognition, etc.). However, when it concerns the on-line estimation (and even more so prediction) this form of travel time measuring looses its benefits very quickly, because by definition these travel time measurements are only available after the journey is finished. Unless the traffic conditions are completely stable, —in which case the importance of on-line travel time estimation itself is questionable—, this estimate is not valid for a traveller currently departing.

NLTT based on predicted SLTT's

To obtain an up-to-date estimate of network level travel time it is better to base it on predictions of section level travel times and to use the method explained in an earlier section to determine dynamic travel time. An approximation, in case the sections are sufficiently short and the periods sufficiently long, can be obtained with equation (1).

On-line predictions of SLTT's for a certain horizon can only be determined by a traffic forecasting model. In DACCORD two such models are used; a macroscopic traffic flow model, the STM (Statistical Traffic Model), and a dynamic assignment model, MIDA. The main differences are the accuracy of modelling the traffic itself and the prediction horizon. These two prediction models will be discussed in some more detail later in this paper.

NLTT based on estimated SLTT's

In case no predictions of SLTT's are available, an instantaneous travel time may be computed based on estimations of the SLTT using equation (2). Two ways of estimating the SLTT, as they are developed (further) within DACCORD will also be discussed in following sections.

The first method is based on the average speed measured at the ends of the sections. This method generally gives good results provided that the sections are short. The second method is based on the time it takes for a certain amount of vehicles to leave the section. This amount of vehicles on the section is estimated using a mass-balance.

ESTIMATING THE NLTT AS A WHOLE

The basic assumption to justify the use of instantaneous travel time is that the traffic conditions on a stretch of road remain unchanged between the instant a vehicle enters the stretch and the moment it reaches the end. If the stretch is not too long and the traffic conditions do not vary over this distance (no change in speed), the instantaneous travel time forms a good estimate of the experienced travel time. However, when there is a considerable change in traffic conditions the calculations frequently underestimate or overestimate the travel times. This is mainly due to the summation of individual section level travel times. When the section level travel times are summed no account is taken of the fact that each of these sections has a specific traffic flow, which varies in the course of the journey across the stretch of road.

In the procedure that is suggested here the travel time for each section is weighted by a factor which varies in space. Account is taken of the varying traffic conditions over the stretch of road. The procedure determines two quantities: the total distance covered by all vehicles (veh×km) and the total time taken by all vehicles (veh×hour). The ratio between these values multiplied by the length of the entire stretch of road then represents the NLTT for that stretch of road.

The total distance covered is the sum of the individual section lengths multiplied by their individual section-flows, while the total time taken is the sum of the SLTT multiplied by their individual section-flows:

$$T_n(t) = \sum_{i=1}^{n-1} l_i \cdot \frac{\sum_{i=1}^{n-1} q_i(t)\tau_i(t)}{\sum_{i=1}^{n-1} q_i(t) l_i} = \sum_{i=1}^{n-1} l_i \cdot \frac{\sum_{i=1}^{n-1} \frac{q_i(t) l_i}{v_i(t)}}{\sum_{i=1}^{n-1} q_i(t) l_i} \qquad (3)$$

In which l_i is the length of section i, q_i is the traffic flow on section i and v_i the speed on section i. Since there are n nodes there are n-1 sections. In relation with equation 1 and 2, the SLTT $\tau_i(t) = l_i/v_i(t)$.

When the flows and speeds used in these computations are current measurements then this procedure provides an estimate of the travel time. By using projected flows (projected into the future) or predicted flows, also predictions of the NLTT can be determined.

It is easy to show that instantaneous travel time NLTT (equation 2) is a harmonic average of the speed of the n sections (see also the definition of SLTT). In this case every section is only weighted by the length of this section or in other words a static factor. In the procedure suggested here (equation 3) every section is weighted by the traffic flow on this section or in other words a dynamic factor.

Overview of methods used in DACCORD

Within DACCORD a large variety of methods is used. The purpose is to determine up-to-date traffic information. The complexity of the method used mainly depends on the required accuracy and the variation in the traffic conditions. Table 1 provides an overview of the methods used within DACCORD (on-line predictions and on-line estimations), supplemented by methods for travel time measurements. Table 2 shows at which DACCORD test sites the methodologies presented in Table 1 are actually used. Table 1 and Table 2 do not provide insight in the use of these methodologies. The choice of methodology in a particular situation depends on a number of criteria, but for practical implementations the following two are the most important ones. The simplicity of the methodology is weighed against the quality of the travel time. The quality of the travel time in turn depends on the traffic characteristics. In an area with relatively stable traffic conditions a fairly simple method may be used. Especially when the current travel time is only slightly different from the travel time in 20 minutes time then there is no need for predictions. In areas with rapidly changing conditions were the current travel time may be completely different from the travel time in 20 minutes a prediction model is essential.

Table 1 - Methods used by DACCORD for on-line estimation and prediction of network level travel time (NLTT) and section level travel time (SLTT)

method / level	travel times based on measurements	on-line predictions	on-line estimations
NLTT determined at network level	floating cars, toll gates	*weighted* instantaneous using flow *predictions*	*weighted* instantaneous using flow *measurements*
NLTT based on SLTT	*instantaneous* travel time	*dynamic* travel time	*instantaneous* travel time
SLTT long sections	floating cars	traffic flow models	mass balance
SLTT short sections		assignment models	speed averaging

Table 2 - Application of the methodologies presented in Table 1 at the DACCORD test site: Padova Mestre (IT), Amsterdam (NL) and Paris (FR)

method / level	travel times based on measurements	on-line predictions	on-line estimations
NLTT at network level	(IT)	FR	FR, NL
NLTT based on SLTT	-	NL	FR, IT, NL
SLTT long sections	-	NL, IT	FR, IT, NL
SLTT short sections			FR, IT, NL

When placed in parenthesis it means that it is not part of the DACCORD project.

PREDICTION OF SECTION LEVEL TRAVEL TIMES

To determine the NLTT on-line, the SLTT for future periods are required. The only way to obtain these future SLTT's is by means of prediction models.

In the DACCORD project two traffic models are used. The first is a macroscopic traffic flow model, which is called the STM, the Statistical Traffic Flow model. The second is a dynamic traffic flow model, which is called MIDA, MultIclass Dynamic Assignment. Both models will be discussed briefly. The basic difference between these types is that the former mainly models the supply side of the traffic system while the latter models both the demand, the supply and the behavioural side. For general background information of both models see van Grol *et al.* (1997). For the STM see also Whittaker *et al.* (1994, 1997).

STM — Statistical Traffic Model

The STM is a macroscopic traffic flow model, which means that the traffic condition on a road section is represented by the macroscopic properties density, speed and flow rather than the properties of individual vehicles as is the case with microscopic traffic flow models. The traffic conditions are considered constant over the length of a section and constant for a certain period of time.

The STM consists of a tracking and a prediction part. Basically the tracking part estimates the current state —as close as possible to the observations— to provide the prediction part with the best possible starting point to do the prediction.

The STM is formulated as a state-space model. The traffic conditions —the above mentioned properties— are represented by a so-called internal state-vector, x_t. The state vector thus holds the flows and densities that determine the network conditions at time t. To relate the internal state vector to the observations from traffic detectors (in this case often induction loops) a translation is made of the state vector into a vector of observable properties, y_t.

This relation is given by the observation equation:

$$y_t = C x_t + R \qquad (4)$$

In which C is a matrix relating the estimates to the observations.

The evolution of traffic through time is modelled by the transition equations.

$$x_{t+1} = A_t x_t + B\, u_t + Q \qquad (5)$$

In which A_t is the time dependent matrix by which the new state is expressed in terms of the old state, B is a matrix that determines the way in which the inflows u_t enter the traffic process, and R and Q are uncorrelated disturbances with zero mean.

On congested sections the traffic flow is determined by a queuing model. The assumption is that the 'queue' (traffic in a state of forced flow) dissipates at a fixed rate. In other words there is a so-called congestion-flow which is the flow realised by all sections within one congestion. The queuing model forms a constraint to the state-space model.

State estimation — Tracking

The tracking part of the STM provides the prediction part with a representation of the current situation in the traffic system, which compared to the current measurements is consistent and complete. By consistent it is meant that it complies to the observations (systematic errors however are omitted). By complete it is meant that the tracking part is able to estimate states for which the observations are missing. Thus, if a limited number of induction loops have broken down, the STM is able to compensate (at the cost of losing some accuracy).

The tracking is done by comparing the observable state y_t. with the measurements. The difference is then used to correct the current internal state x_t. The correction process is done using Kalman filtering.

State prediction — Prediction

The estimated or tracked state is the basis on which the prediction takes place. The prediction is the repeated application of equation 5. This means that the future u_t are thus required by the models. The main difference between prediction and estimation is that the result cannot be verified (immediately).

The Transition Equation

Equation 5 is the transition equation. This part of the model attempts to capture the 'physics' behind the traffic process. It consists of a vehicle conservation law, which implies that vehicles entering a section must also exit it (no vehicle may get lost) together with a flow equation based on the fundamental diagram. The fundamental diagram characterises the traffic conditions corresponding to the amount of traffic on the network.

Boundary conditions

For a section in the middle of a corridor with only a main input and a main output the above approach is completely defined, since what comes in to the section is wholly determined by what comes out of the upstream section, and what flows out is constrained to the capacity of the section and the available space in the downstream section. In reality the general situation is somewhat more complicated. Sections have on-ramps and off-ramps, and a mainline needs to start somewhere.

For optimal operation of both the tracking as well as the prediction the following information is required:

- fundamental diagram (for each section),
- road capacities (for each section),
- on-ramp flows (including motorway cut-offs),
- turning fractions.

Clearly the on-ramp flows need to be determined on-line. The on-ramp flows need to be both estimated and predicted. Also for the turning fractions it seems obvious to estimate and predict these on-line (they both have a direct influence on the volume of traffic and are the result of the behaviour of the road-users). For the fundamental diagram and the road capacities this is less obvious. One might wish that the road characteristics do not vary in time, but in reality they do change. The road characteristics change with the seasons, with the weather, by incidents, etc. For this reason both the fundamental diagram and the road capacities are estimated on-line as well.

Practical application

The STM has been tested on motorway stretches of 10-20 kilometres and the implementation on the test site around Amsterdam in the Netherlands is planned for the near future.

MIDA — Dynamic Traffic Assignment

MIDA stands for MultIclass Dynamic Assignment. An assignment model in general assigns traffic to routes in a network, and thus determines the traffic conditions on all of its parts. A *dynamic* assignment model, such as MIDA, also takes into account the time dependent traffic conditions. Routes therefore become trajectories, that not only describe a route in space but also in time. Time is discretised into periods. Within the periods the traffic conditions on a road section are presumed constant and homogeneous.

An essential input to an assignment model is an origin destination matrix. In case of a dynamic assignment model this is actually a three-dimensional origin destination matrix, because the origin destination flows may be different over subsequent periods in time. The origin destination matrix is predicted on-line. Another input to the model is formed by the speed density functions for the individual sections of the motorway.

The assignment is an iterative process in which the traffic is assigned to different routes in the network until a convergence condition has been reached.

The prediction system to which MIDA belongs consists of four components:

- Input generator,
- OD demand estimator,
- OD demand predictor,
- Dynamic Traffic Assignment (MIDA).

Input generator

The input generator prepares the scenarios related to the traffic situation. The scenarios are used as input by the OD Estimation and Prediction model and by the Dynamic Traffic Assignment model. A scenario consists of geographic information, static and dynamic section level features, measurements, etc., as well as historical OD (Origin Destination) information.

OD demand estimator

This function provides the assignment model with the best estimates of the OD-matrices of past periods, based on a historical database, but more importantly on the basis of current measurements.

OD demand predictor

In order to predict future traffic conditions, the expected demand needs to be determined for use by the assignment model. The OD prediction model is based on a filtering approach which combines historical and estimated OD information with predicted inflows at the motorway ramps.

Dynamic Traffic Assignment

Using the estimated and predicted traffic demand, the time varying traffic conditions are determined for all road-sections during a certain simulation period (one hour).

Practical application

MIDA has been applied within the DGXIII project HANNIBAL for the Sestrière '97 World Skiing Championship.

STM versus MIDA

The comparison between the STM and MIDA needs to be focused on a number of aspects, such as accuracy, prediction horizon, flexibility. The STM can provide more accurate predictions of the very near future (1-15 minutes) than MIDA provided that the traffic demand does not change in relation to historic patterns. The STM can in general model traffic flows and congestion's more accurately and in more detail. However, if the traffic demand changes relative to historic patterns, than the results become less accurate than what would be possible with MIDA. Because MIDA models both the traffic demand as well as the route choice behaviour MIDA is better able to deal with the problem of changing traffic demand (compared to historic patterns). MIDA has a prediction horizon of about an hour.

ESTIMATION OF SECTION LEVEL TRAVEL TIMES

An assumption made in this section is that each road section is enclosed by two measurement points. At each of these measurement points the speed and the intensity is measured. For the different methods used within the DACCORD project a distinction needs to be made between short and long road sections. Short road section are sections with a length smaller than approximately 1.5 kilometre while long road section are sections longer than approximately 1.5 kilometre. For both methods see Haj Salem (1997).

Within the DACCORD project two main methods are applied for travel time estimation:

- speed averaging for short road sections,
- mass-balance for long road section.

Travel time estimation by speed-averaging for short road sections

For short road sections one of the most simple but effective methods of travel time estimation is based on the averaging of speeds, see Brocken and de Haes (1990). In order to determine the travel time for the section it is assumed that the first half of the section is travelled with the speed at measurement point A, while the second half of the section is travelled with the speed at point B.

The section travel time $\tau_{A,B}(t)$ at time t is computed by:

$$\tau_{A,B}(t) = \frac{L}{2v_A(t)} + \frac{L}{2v_B(t)} \qquad (6)$$

In which L is the length of the section, and v_A and v_B the speeds at point A and point B.

Travel time estimation with a mass-balance for long road sections

When a road section is long the method using equation 6 cannot estimate the travel time accurately because the speed at the ends of the section are no longer representative for the speed on the section (the probability of an undetected congestion holding up traffic in the middle of the section increases). In this case a method based on a mass-balance provides better results. This method keeps track of the amount of vehicles present on the section and then determines the delay caused by it.

A problem with this is that the mass-balance is not accurate enough to track the number of vehicles continuously (the measurement system knows statistical as well as systematic errors). To overcome this problem, the mass-balance is only used when delays are expected, or in other words during congestion. In between congestion's the mass-balance is not used.

In the current procedure the mass-balance is initiated when congestion is detected using an ARMA model. Each minute an ARMA model is estimated for each section. Based on a combination of three criteria the congestion is then detected:

1. the size of the surface under the impulse response,
2. the weighted average impulse response time, and
3. the speed at both ends of the section.

During the congestion the mass-balance determines the 'number of vehicles to many', or in other words the accumulated sum of the difference between in- and out-flow of the section. The resulting amount of vehicles divided by the effective capacity then gives an estimate of the delay caused by these vehicles. The delay added to the free-flow travel time is an estimate of the travel time for a vehicle entering the section in the current period.

$$\tau_i = \frac{N_i(t)}{C_i^{eff}(t)} + \tau_i^{freeflow} \qquad (7)$$

In which $N(t)$ is the 'number of vehicles too many', $C^{eff}(t)$ the effective capacity, and $\tau^{freeflow}$ the freeflow travel time.

DISCUSSION

Up-to-date travel time information plays an important role in Dynamic Traffic Management. This paper deals 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 can be measured in several ways, but none of these methods is suitable for the on-line estimation/prediction of experienced travel times. Experienced travel times can either be estimated directly from, for instance, data from the currently widely available induction loops or predicted using traffic prediction models. A classification of available on-line methods within DACCORD has been presented including the DACCORD test sites at which they are applied.

It is argued that the choice of methodology in a particular situation depends on two criteria. The simplicity of the methodology is weighed against the quality of the travel time. The quality of the travel time in turn depends on the traffic characteristics. In an area with relatively stable traffic conditions a fairly simple estimation may be used, but in areas with rapidly changing conditions a prediction model is essential.

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