

DMOTION –TRAVEL TIME AND LOS ESTIMATION ON SLIP ROADS AS A PART OF AN INTEGRATED ROUTE GUIDANCE SYSTEM

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Abstract:

The objective of the German research project Dmotion is the development of an integrated traffic management system for Greater Düsseldorf. Currently, each road authority is responsible for traffic control within its own territory – the City of Düsseldorf operating the urban road network, the Federal State of NRW operating the motorways.

As two different operators are holding traffic data, modelling of travel time or LOS for slip roads between urban roads and motorways is a missing link. For an integrated route guidance system based on a consistent report on traffic conditions and travel time analysis, it is necessary to develop a model in order to estimate these values on slip roads.

INTRODUCTION

Dmotion is a German research project within the VM 2010 (Traffic Management 2010) research initiative funded by the German Ministry of Economics and Technology (BMWi). The aim of Dmotion is to develop and implement an integrated traffic management system for the conurbation of Düsseldorf. This system is based on a comprehensive data, information and strategy network for regional and local authorities as well as for private service providers.

Thus, one major objective of Dmotion is to generate a consistent and comprehensive report on traffic conditions for the Greater Düsseldorf area. Providing an overview of the current traffic situation is a prerequisite for deciding on corrective actions such as alternative route guidance. Therefore, all authorities involved have to agree and collaborate on a data network. This data network includes all relevant information for the traffic reports and makes it accessible to the partners within the traffic management network. Road users will be provided with the information via different sources: roadside information systems (VMS), the internet and, through on- and off-board navigation by private service providers.

The City of Düsseldorf has to cope with an extremely high level of commuter traffic. More than 400,000 people commute by car to the city every day, mostly for occupational reasons. A motorway ring surrounds Düsseldorf comprising the motorways A57, A44, A46 and A3.

The majority of commuters enter the urban network via motorway on slip roads. The slip roads can be identified as one bottleneck in the network of the conurbation area. High traffic volumes in peak hours cause traffic congestion (and corresponding delay times).

At present, each road authority is responsible for traffic control within their sovereign territory, using different control and information systems. The motorways are operated by the Federal State of North Rhine Westphalia with the traffic control centre located in Leverkusen. The urban road network is operated by the City of Düsseldorf with its urban traffic management centre. So far, congestion on slip roads cannot be identified because it is part of the geographical interface between these two authorities.

To establish a consistent and comprehensive report on traffic conditions for Greater Düsseldorf, it is essential to close this gap. Therefore an algorithm has to be developed which calculates the increase in travel time caused by traffic jams on slip roads. This report is the necessary basis for an integrated traffic management system and for dynamic navigation systems. One part of necessary data is provided in the motorway control centre, the other part in the urban control centre. So a comprehensive data network forms the base for the traffic condition analysis on slip roads.

COMPONENTS OF AN INTEGRATED TRAFFIC CONDITION ANALYSIS

One major topic of Dmotion is hybrid data fusion. It solves a network-wide report of traffic conditions, which is the base of an integrated traffic management system. The strategy of the hybrid data fusion is to collect all data available from different sources and to calculate a network-wide report on traffic conditions based on these sources, which are divided in model data and raw data. The idea is to run many different models at a small scale estimating travel times and LOS. The calibration is not as complex as for network-wide models and the results are provided on a more confirmed level. The hybrid data fusion adds the results and reconciles them. In the following, data sources of the data fusion are listed:

- Models to estimate traffic flow
 - Slip road model
 - Traffic jam estimator
- Floating car data (FCD) model
 - Public transport FCD
 - Private transport FCD
 - Taxi FCD
- Observation point data on
 - Primary roads
 - Motorways

This paper focuses on the slip road model as an essential element of the report on traffic conditions. Another essential component is the traffic jam estimator. This model provides the operator with information about the estimated congestion length at inner urban intersections. The location of the observation point and the available raw data are the main differences between the slip road model and the traffic jam estimator. The traffic jam estimator needs

observation points located close to traffic lights (< 30 meter) and the input of the estimator consists of move-up times.

SLIP ROAD MODEL REQUIREMENTS

The following figure shows the given infrastructure of a typical slip road.

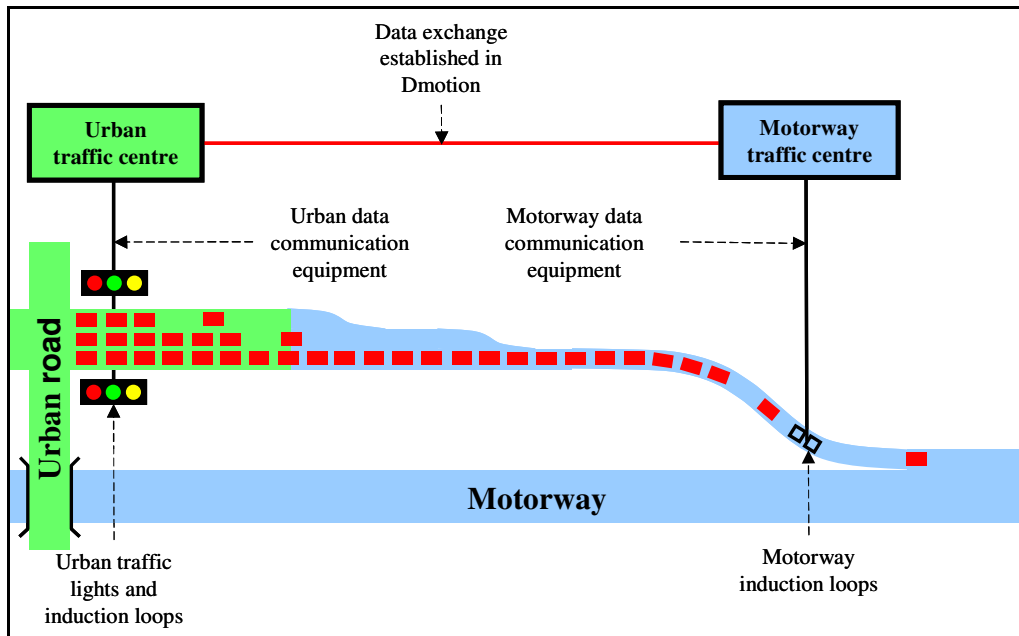


Figure 1. Infrastructure of a typical slip road

A car leaving the motorway network usually passes an induction loop at the beginning of the slip road. This data is collected at the motorway management centre. The data of the traffic light programmes and detection units close to the stop line are transferred to the urban traffic centre. As a result of Dmotion, both centres are connected and the motorway traffic centre sends its slip road data to the urban centre.

At the end of slip roads accessing the urban network, junctions are usually signalised. In Germany only traffic lights with adaptive control are equipped with a static detection unit close to the stop line. Signal control units with fixed green and circle time do not provide induction loops near the intersection. In case of adaptive control, the urban traffic centre receives information about signal times and traffic data based on the static detection. Otherwise only the signal time information is available.

The following input data provides the basis of the slip road model:

- Data of the urban traffic light at the end of the slip road including
 - signal times
- Traffic data of the urban static detection including nearby the stop line
 - number of vehicles
 - occupancy per vehicle

- Traffic data of induction loops collected by the motorway traffic centre aggregated in time intervals of one minute including
 - number of vehicles (normal and heavy vehicles) leaving the motorway
 - vehicle speed (normal and heavy vehicles)
 - occupancy

REQUIREMENTS

The challenge in closing the gap of travel time estimation between the motorway and the urban network is to get an exact overview of the congestion length and the delay on slip roads. In the process chain of modelling, traffic conditions at the slip road near the signalised junction can be seen as the bottleneck. The first requirement is to identify an existing algorithm, which offers best adaptation for calculating travel times, congestion length and LOS at the signalised junction at the end of the slip road. The second requirement is to adapt this algorithm on the given topology and carry out a further development of the algorithm itself, if necessary.

The stakeholders and their user needs in the Dmotion project have been identified for the further model specification. These needs have been taken into consideration to meet the enlarged requirements of the Dmotion project. These requirements are:

- Calculation of travel time and LOS at least every five minutes
- Providing public traffic centres and private service providers with travel time and LOS
- Providing georeferenced data using Alert-C (RDS-TMC)
- Data exchange between urban and motorway traffic centres
- Applicable to slip roads with different geometric conditions
- Automatic model calibration
- Low effort on model configuration

SELECTION OF AN ALGORITHM

The neuralgic element in the topology of the slip road for the motorway intersection is the signalised junction with its quality of services. The congestion at the waiting queue area is a result of that service. Therefore, the major challenge in terms of integrated model development was to identify the best adapted algorithm for travel time and LOS estimation at the signalised junction. The existing algorithms of the authors Schnabel/Lohse (3), Kimber/Hollis (2), Webster (4) and Akcelik (1) were tested anent to the major requirement of exact travel time estimation in discrete intervals of five minutes. Field tests have been carried out to collect real data on congested slip roads. This data was used as an input for the different algorithms.

The algorithm for calculating the tailback of Schnabel/Lohse has been developed to evaluate the capacity of signalised junctions offline. One disadvantage is the aggregation on hours,

which means that short term fluctuations will not be considered. This model is not suitable due to its inability to calibrate the reduction of traffic jams.

The Webster algorithm calibrates queue length closely to the saturation flow. At a saturation flow above 0.95, queue length and travel time increase in an extremely and implausible high manner. Due to this implausible high queue length, the algorithm was excluded.

At the beginning of every calculation period of the Akcelik algorithm the queue length starts at zero. The algorithm is incapable of transferring the estimated queue length from one discrete time interval to the next discrete time interval. This is the reason why the Akcelik algorithm is not useful for the requested online approach.

The algorithm of Kimber/Hollis describes the growth and decay of queues for major and minor priority junctions. The programming of an online algorithm is not too time-consuming. The two outputs of the algorithm are queue length and delay time (travel time). This leads to the conclusion that only the Kimber/Hollis algorithm fulfils the major requirements of accurate travel time estimation. This is the reason for choosing the Kimber/Hollis algorithm for the further development of the slip road approach.

EXPANSION OF THE ALGORITHM

The Kimber/Hollis (2) algorithm is divided in two functions. One function f_1 calculates the *delay time* D and the other f_2 the *queue length* L .

- $D = f_1 (\mu, \rho, L_0, C)$
- $L = f_2 (\mu, \rho, L_0, C)$

These algorithms are a function of the following values as the essential input:

- Traffic intensity ρ (traffic demand q divided through available capacity μ)
- Traffic demand in a stream q
- Available capacity μ
- Initial queue length L_0
- Arrival and service pattern constant C (for random arrivals and service $C=1$)

To realise low efforts on model configuration for different geometric preconditions it is necessary to provide an intelligent framework for the base algorithm. The idea was to compare the output of the Kimber/Hollis algorithm with real data on a complex slip road and to indicate all necessary parameters.

One field test was carried out at the slip road *Stockum* at the motorway A44 north of Düsseldorf on the 26th of April 2006. The slip road *Stockum* (two lanes) connects the motorway A44 with an arterial road (*Danziger Straße*). This urban road has a transverse profile of two lanes in each direction. It can be seen as an inner urban motorway.

The slip road *Stockum* is one of two major accesses from the Ruhrgebiet area to the City of Düsseldorf. So there is a high traffic demand in peak hours, especially in the morning peak. Every morning, the tailback from the junction causes a delay for traffic on the motorway. The pictures below show a peak traffic flow in the morning and an aerial view of the slip road and the main direction to the city centre of Düsseldorf.

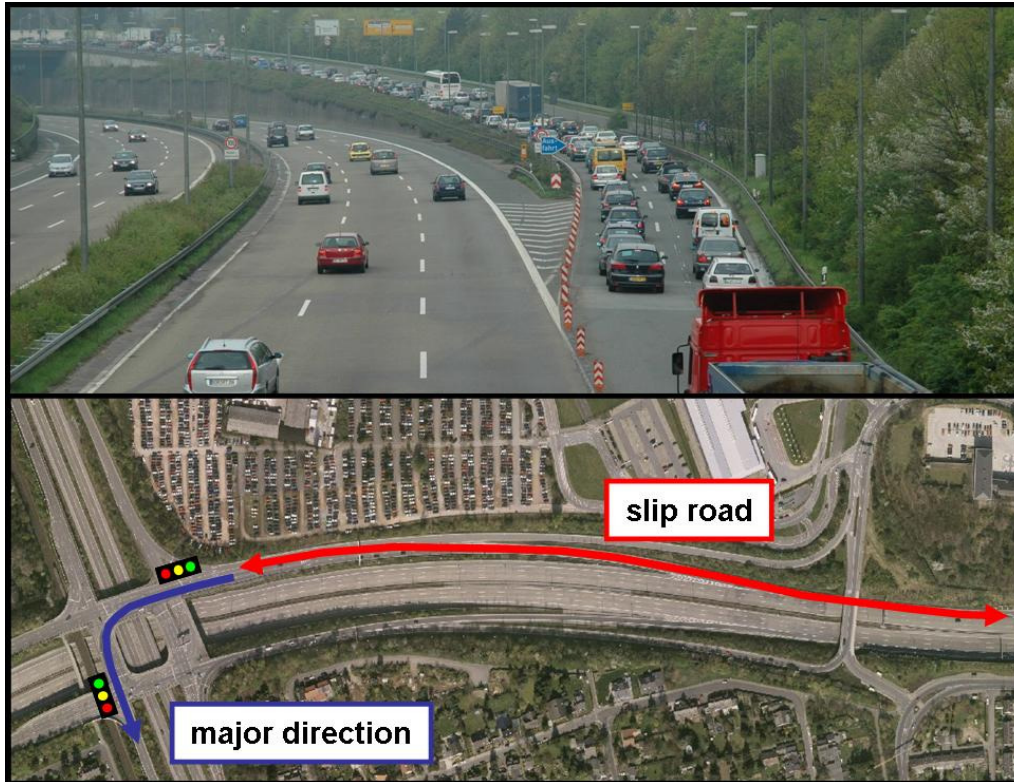


Figure 2. Peak traffic flow in the morning and an aerial view of the slip road “Stockum” at the motorway A44

After the analysis of the field test, the necessary parameters were indicated to estimate the algorithm values.

The entire traffic demand in a stream q is detected from the motorway loops but there is an undetected secondary influx from a minor road. So a multiplier called *increase factor of the entire stream* (A_{zu}) was found. This factor increases the detected main stream based on the relational traffic volume corresponding to the access volume at the induction loop.

The main direction stream makes a left turn at the signalised junction and needs to merge with the traffic on the arterial road Danziger Straße. The outward flows to the north and west are of minor importance, because these traffic flows never reach the capacity. The Kimber/Hollis algorithm needs to be focussed on the main stream. Therefore the capacity of this direction and the percentage of the main stream have to be estimated. To calculate the important main stream volume from the entire stream volume, the *reduction factor of the entire stream* (R_{zu}) was established.

Referred to the existing field actors there are two possibilities to estimate the capacity of the junction. If there is a static detection unit at the junction, the capacity is calculated online by using the number of vehicles per green phase. But in Germany, as described before, induction

loops near the stop line are sometimes missing. In that case the signal times are based on fixed circles. Therefore the capacity of the junction can be estimated offline, and for each phase change of the traffic light the model has to be parameterised with these offline data.

One major calibration parameter was derived from the observed traffic conditions in the field test. As the weaving section at the Danziger Straße was identified as a second bottleneck, the signalised junction was blocked by an upstream queue. This effect could be identified by an upstream data detection unit at the Danziger Straße. Here an indicator based on the occupancy is established to spot this traffic jam. If the occupancy on the Danziger Straße exceeds a predefined threshold value, the capacity of the junction needs to be reduced by multiplying a fixed factor. This *reduction factor of the junction capacity* (R_{ab}) is a global parameter for the calibration of the model.

Finally, an automatic calibration procedure has been established. By exceeding a threshold value of the occupancy at the motorway induction loop at the beginning of the ramp, the “real” congestion length is measured. This congestion length is being compared with the estimated congestion length in order to calculate the global *adjustment parameter for the modelled tailback* (K_t).

After setting the necessary parameters the real data was confronted with the model output. The following two figures show travel time on the one hand; and main traffic demand and capacity available at the signalised junction on the other hand.

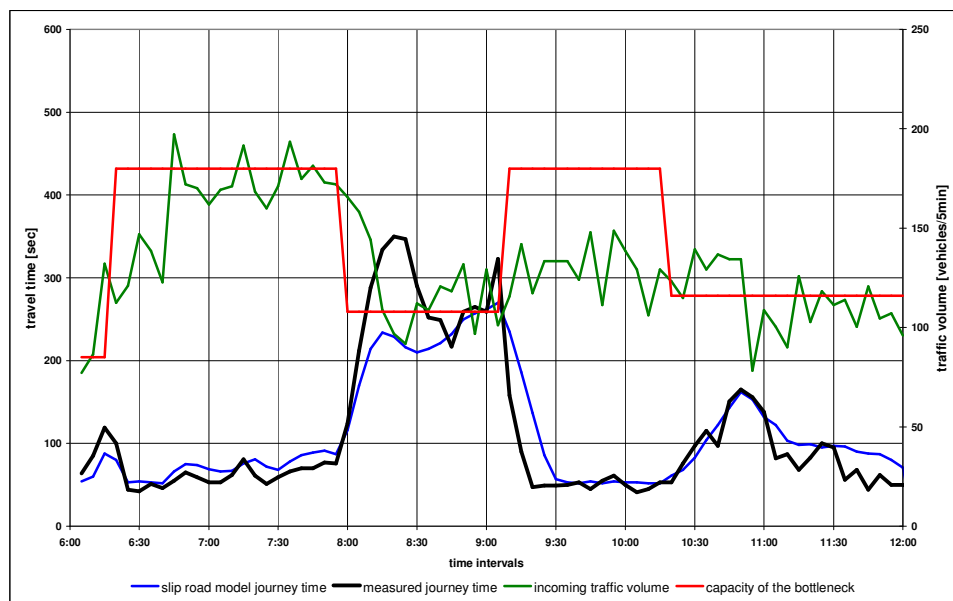


Figure 3. Slip road model travel time and real queue length of the field test at the slip road “Stockum” motorway A44

The positive differences between the main traffic demand (green line) and the available capacity (red line) at the signalised junction are the reason for the queues. The capacity depends on the signal times and on the traffic jam on Danziger Straße from 8:00 to 9:15 a.m. The slip road model output (blue line) compared with the measured values (black line) taken of the field tests describes the real situation in a highly detailed manner. The correlation coefficient between the time series of the travel time is 0.94.

The LOS is derived from the travel time. The different ranges of LOS are determined by defined thresholds of the travel time.

Conclusion

The basic idea is to develop a model identifying travel time and LOS on slip roads by comparing the number of incoming vehicles and the capacity of the junction. The number of vehicles is counted by a motorway induction loop.

Field tests have been carried out to collect real data of congested slip roads. This data was used as an input for the different algorithms of the authors Schnabel/Lohse, Kimber/Hollis, Webster and Akcelik, which have been tested and evaluated. As a result, the most suitable algorithm which best meets the major requirement (calculation of travel time every five minutes) was the Kimber/Hollis algorithm. Therefore, the developed slip road model is based on this algorithm. In extension to the algorithm four fundamental factors to upgrade the algorithm were indicated and adapted:

- Increase factor of the entire stream (A_{zu})
- Reduction factor of the entire stream (R_{zu})
- Reduction factor of the junction capacity (R_{ab})
- Adjustment parameter for the modelled tailback (K_t)

The slip road model provides good results in comparison to collected data. The correlation coefficient between slip road model output and collected data is above 0.9. This correlation between reality and model output can be seen as an excellent quality for travel time estimation.

The cooperative strategy management within the Dmotion project is based on a general analysis of traffic conditions. As two public authorities (motorway and urban) are involved in the strategy management, the slip road is the missing link in the coherent analysis of traffic conditions. It is important to close this gap in order to be able to integrate the routing algorithm and to develop an alternative route guidance system. The slip road model closes that missing link.

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