Applying StreamLine DTA model on the Amsterdam beltway

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Samenvatting

Deze paper presenteert een applicatie van een nieuw dynamisch toedelingsmodel uitgevoerd in opdracht van de gemeente Amsterdam. Deze applicatie omvat een mix van zowel hoofdwegen als onderliggend wegennet. Het onderliggend wegennet bevat verder geregelde als ongeregelde kruisingen om vertragingen op kruispuntniveau te modelleren. Het hybride karakter van de applicatie stelt hoge eisen aan het toe te passen model. De huidige modellen zijn niet goed in staat dergelijke, gemixte netwerken te simuleren. Om dit toch te kunnen doen is een nieuwe benadering nodig. Onze uitdaging was om een dynamisch toedelingsmodel te ontwikkelen voor een dergelijk netwerk inclusief kruispuntsimulatie en dynamisch verkeersmanagement (DVM) maatregelen. Het hier gepresenteerde dynamisch toedelingsmodel ondersteunt wat hiervoor beschreven is. De basis van het model is gebaseerd op het werk van Papageorgiou (METANET). Op deze basis zijn aanpassingen doorgevoerd om het model ook geschikt te maken voor stedelijk verkeer. Het bevat een ander - meer realistisch - fundamenteel diagram, ondersteuning voor stedelijke wegvakken, kruispuntmodellering en DVM. De simulatieresultaten zijn vergeleken met verschillende bronnen waaronder meetlussen, bekende knelpunten en trajectreistijden afgeleid van kentekenregistraties. De uitkomsten hiervan laten zien dat het gepresenteerde macroscopisch dynamisch toedelingsmodel (StreamLine) zeer geschikt is voor verkeerssimulaties zoals de Amsterdam case study.

1 Introduction

This paper deals with the simultaneous application of various DTA components, such as junctions, interacting urban and highway networks and dynamic traffic management measures, to a real life situation, namely the city of Amsterdam, the Netherlands.

All techniques are implemented in the "StreamLine" DTA framework. It provides basic building blocks for all the common DTA tasks such as route generation, route choice behaviour, propagation, management of custom dynamic traffic management controls, persistence of data etc. A number of these building blocks have been custom implemented to provide the functionality needed for this specific goal.

In this paper it shall be shown that using the proposed framework, such medium to large projects can be effectively modelled using macroscopic modelling techniques, the case study will verify the model results with loop detector data and recorded travel time data provided by the city of Amsterdam. The study does use some new DTA techniques to achieve this; the outline of this paper is therefore structured to first deal with the theory and techniques used and conclude with the case study and results.

1.1 Outline

The propagation model used in StreamLine is based on the well known macroscopic METANET propagation model, but is adapted and extended with several modifications and features to be more versatile compared to the original algorithm and to take away some of the drawbacks of the original model. These modifications will be discussed first. Another important aspect of this research is the use of a new type of junction modelling (XStream). Both signalled and unsignalled junctions are modelled in this, on cell transmission model (CTM) based, approach. Next to last, an architecture to implement generic controls is proposed. This architecture is applied in the Amsterdam case study to model a specific type of ramp metering controls used in this area. We conclude with the case study on Amsterdam which incorporates all the aforementioned methodologies.

2 The DTA framework

In the DTA field there are many macroscopic models, all using their own concepts. The proposed framework tries to break with this "tradition" in providing basic building blocks for each component of the DTA model which can be reused while still allowing for the construction of specialised blocks for specific purposes.

A paper solely on this subject is due for future publication, however it is not the principal focus of this paper. In order to allow the reader to follow further discussion some aspects of the propagation model, junction model, dynamic traffic management control architecture shall now be introduced and discussed in limited detail.

2.1 Propagation and junction model

The junction model and propagation model are two separate building blocks. StreamLine contains its own propagation model building block as a means of traffic propagation, while XStream is the junction model, solely responsible of taking care of the simulation of junctions. Currently, each propagation/junction model is obliged to support at least one of the three ways of mapping routes onto the network during dynamic network loading (DNL):

- Full route based
- Turn fraction based
- Macro route based (Raadsen et al. (2009)).

The *Full route* method allows for tracing back all traffic streams to the routes traversed, which is computationally expensive, but provides the most realistic results. The *Turn fractions* method is a computationally friendly solution but this comes at the cost of precision. Each node has static splitting rates for its turns and these splitting rates are based on a static assignment applied at one or more moments during DNL. Finally, the *Macro routes* method is a hybrid form of the other two approaches which utilises information on regional aspects of the network.

Both StreamLine traffic propagation and XStream support all three types, however for the remainder of this paper we shall focus solely on the turn fraction variant, as the case study has been conducted using this route mapping type to limit simulation run times.

2.2 Turn fractions and route choice

Although during DNL the routes are not traced, StreamLine does keep track of the original routes that its turn fractions are based on, thereby enabling route choice during simulation. Whenever a route choice moment is requested a new layer of turn fractions is applied to the DNL, this ensures that vehicles already on the network will only be affected by the original fractions. The newly departing traffic will only deal with the additional layer of fractions that is based on the updated route choice behaviour.

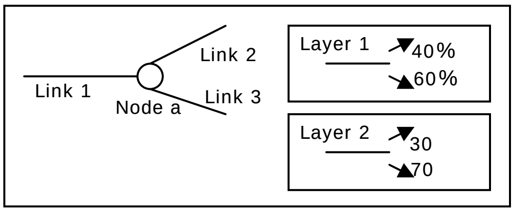

Figure 1: Schematic example of turn fraction layering to support pre-trip route choice

Using this technique of layering, route choice is possible, although it is limited to pre-trip route choice only.

3 The StreamLine propagation model

The basic traffic propagation building block in StreamLine is a METANET based macroscopic dynamic traffic model with some modifications to make it also suitable for inner city road networks rather than just motorway networks. Note that StreamLine propagation only incorporates the link propagation formulae of METANET (for the most part), the junction modelling of METANET is not adopted, but replaced by a separate module; XStream, which is discussed later in this paper.

3.1 Origins of StreamLine traffic propagation

Based on the kinematic wave theory the CTM model is a derivative of the so called LWR model introduced by Lighthill and Whitham (1955) and Richards (1956). The LWR model is based on the following basic conditions:

$$\frac{\partial f}{\partial x} + \frac{\partial k}{\partial t} = 0 \tag{1}$$

and

$$f = F\left(k, x, t\right) \tag{2}$$

with,

$f = \text{flow}$

$k = \text{density}$

$t = \text{time}$

$x = \text{distance}$

Typical implementations use the fundamental diagram to approximate *F*. This theory, originally adopted from fluid dynamics, is not well suited to computerization. Payne (1971) combined the theory of LWR with a car following model and made the model discrete to become computationally friendly. Further research by Daganzo (1994,1995) resulted in the CTM model, a first order cell based model. The METANET model developed by Messmer and Papageorgiou (1990), also a cell based model, is a second order model.

A cell based model is built on the idea that every link is divided into equal length cells. Each cell holds information on its relevant variables (e.g. density, speed, (out)flow). Vehicles move from one cell to another. It is assumed that each cell has a uniform density over the entire length of the cell and all vehicles travel at the same speed, ensuring the FIFO principle.

METANET is a more complex model compared to CTM as it is a second order model based on the following basic formulae for flow, density and speed

$$f_{m,i}(t+1) = k_{m,i}(t) \cdot v_{m,i}(t) \cdot \lambda_m \tag{3}$$

$$k_{m,i}(t+1) = k_{m,i}(t) + \frac{T}{L_m \cdot \lambda_m}\left(f_{m,i-1}(t) - f_{m,i}(t)\right) \tag{4}$$

$$\begin{aligned} v_{m,i}(t+1) = v_{m,i}(t) + & \underbrace{\frac{T}{\tau}\left(V^e\left(k_{m,i}(t)\right) - v_{m,i}(t)\right)}_{\text{relaxation term}} + \\ & \underbrace{\frac{T}{L_m} v_{m,i}(t) \cdot \left(v_{m,i-1}(t) - v_{m,i}(t)\right)}_{\text{convection term}} - \\ & \underbrace{\frac{\upsilon \cdot T \cdot \left(k_{m,i+1}(t) - k_{m,i}(t)\right)}{\tau \cdot L_m \cdot \left(k_{m,i}(t) + \kappa\right)}}_{\text{anticipation term}} \end{aligned} \tag{5}$$

with,

$v_{m,i}(t+1) =$ speed at link m segment i at time $t+1$

$T =$ time step size

$V^e(k) =$ fundamental diagram function based on density

$L_m =$ length of link m

$\lambda_m =$ number of lanes on link m

$\tau =$ control variable

$\upsilon =$ control variable

$\kappa =$ control variable

The control variables can be used to tune the model for specific conditions. The speed equation consists out of three components (relaxation, convection and anticipation), on the relaxation part a fundamental diagram calculation is used. To cater for specific situations additional speed terms will be added to mimic lane drops, merging effects or a combination of the two.

METANET also proposes its own fundamental diagram.

3.2 Extensions and modifications

StreamLine propagation model is a second order model based on METANET. Using this second order model instead of the less complicated first order counter parts is based on our belief that second order models can mimic real life situations better. The ongoing debate on theoretical soundness and applicability of first order versus higher order models is an interesting one, with Daganzo (1995) and Papageorgiou (1998) at the centre of it. The StreamLine propagation model is an adapted second order model which aims to addresses some of the criticisms of higher order models that are highlighted by this debate. This is discussed in detail in this section.

Negative flows and speeds

One of the qualitative criticisms expressed by Daganzo (1995) is the possibility of creating negative speeds. This can occur because speed is not just a derivative of the density and flow. Also, because the flow is a result of multiplying density and speed in METANET it is possible for the flow to become either negative or higher than the capacity of the link. This effect can be mitigated by the incorporation of safety nets proposed by Papageorgiou (1998) and is implemented in the StreamLine propagation model.

Turn fractions
StreamLine supports various route mapping types, while METANET is based on turn fractions only. This allows users to choose between a fine grained or a more coarse grained simulation depending on the purpose of the study. As stated previously, the Amsterdam case study shall utilize only the turn fraction variant to increase computational efficiency.

Fundamental diagram
The METANET fundamental diagram is not overly realistic. The speed drop is very steep as the density is increased in density. At the same time the density itself is relatively low in comparison to real life situations. Therefore, StreamLine incorporates support for the more complex, yet more realistic Van Aerde (1995) car following model based fundamental diagram. The realism of the Van Aerde model is verified by Rakha and Crowther (2002) and the following relationship

$$\frac{1}{k} = c_1 + c_3 \cdot v + \frac{c_2}{v_{free} - v} \tag{7}$$

from which we derived the related fundamental diagram equation, shown in (8)

$$0 = (c_3 \cdot k) \cdot v^2 + (c_3 \cdot k \cdot v_{free} - c_1 \cdot k + 1) \cdot v + (c_1 \cdot k \cdot v_{free} + c_2 \cdot k - v_{free}) \tag{8}$$

The positive solution for v is the result of the fundamental diagram calculation during DNL, where

$$c_1 = m \cdot c_2 \tag{9}$$

$$c_2 = \frac{1}{k_j \cdot \left(m + \frac{1}{v_{free}} \right)} \tag{10}$$

$$c_3 = \frac{-c_1 + \frac{v_c}{f_c} - \frac{c_2}{v_{free} - v_c}}{v_c} \tag{11}$$

and

$$m = \frac{2 \cdot v_c - v_{free}}{(v_{free} - v_c)^2} \tag{12}$$

with,

v_c = speed at capacity

Cross node modeling
METANET was especially designed for motorway network and hence it only supports merge and diverge nodes; nodes with multiple entry and multiple exit links are not part of the model. StreamLine propagation proposes a cross node with multiple entry and exit links to overcome this limitation. This is not a junction model like XStream (see section 4), it merely combines the characteristics of both the merge and diverge nodes, although the additional terms for lane drop and merging effects are ignored. this approach is useful for unsaturated unsignalled junctions with little delay. However, if this is not the case a junction should be modelled using a proper junction model like XStream to improve the level of realism of the generated results.

To deal with a situation where one or more of the exit links of the cross nodes become over saturated Bliemer (2007) proposes a method to scale down outflow on all entry links based on the intensity capacity ratio on the largest bottleneck of the cross node. This procedure is also applied in the StreamLine propagation model, although it is extended. The problem with the aforementioned solution is that it fails to cope with situations where there is traffic on an entry link which does not flow to an over saturated exit link at all In this case the outflow of this entry link would be scaled down, which in this case is undesired. This method is adapted in StreamLine propagation to solve this problem by using a modified flow calculation equation as shown in (13) and (14).

$$\alpha_{ij} = \begin{cases} 1 \Rightarrow f_{ij} = 0 \\ \min\left(1, \dfrac{c_{exit,j}}{f_{exit,j}}\right) \Rightarrow else \end{cases} \tag{13}$$

with,

α_{ij} = scale factor for entry link i to exit link j

$c_{exit,j}$ = capacity of exit link j

$f_{exit,j}$ = total offered flow to exit link j

f_{ij} = offered flow from entry link i to exit link j

The α_{ij} is the scale factor for the flow for a certain turn. From this formulation it can be seen that the scale factor α_{ij} is only applied when there is actual flow offered regardless of whether if there are exit links which are over saturated. Also note that the flow on exit link *i* will never be zero as in this case the first option will be chosen (no offered flow on turn).

When the scale factor is known the resulting flow is calculated according to the following

$$\tilde{f}_{i,j} = f_{i,j} \cdot \min\left(\alpha_{i,j}\right) \tag{14}$$

with,

$\tilde{f}_{i,j}$ = allowed flow from entry link i to exit link j

Macroscopic Urban DTA modeling

Before looking into the way StreamLine propagation model incorporates urban DTA modelling the reader is presented some theory on the subject. In his work, Payne (1971) showed that the derivative of speed to time, has three different aspects. A convection term describing how the speed changes due to the arrival and departure of vehicles, a relaxation term describing how vehicles adept their speed according to the fundamental diagram and an anticipation term describing how vehicles react to the concentration conditions downstream of the road.

One of the difficulties a propagation model faces, is the difference of vehicle behaviour on highways and on urban roads. On highways people tend to anticipate slowly to changes on the network, resulting in gradual increase and decrease of speed, density and flow. Conversely, people in city conditions tend to drive a lot more aggressively, resulting in bigger fluctuations in speed, density and flow in a shorter period of time. Knowing that the loss in travel time at junctions is modelled via a speed decrease at artificial links on the junction turns (see section 4), a test network was constructed to examine how the basic StreamLine propagation model behaved under such circumstances.

The test network consists of five road sections each consisting of 11 links, all links except the center link have a length of 300 meter, the middle link has a length of 20 meter. The maximum velocity on the middle link decreases by section from a maximum speed of 50 km/h on the first section to 10 km/h on the last section. This is done to examine the changes in mean speed over distance on the model, which gives a reliable indication on how fast or slow traffic accelerates and decelerates (in the following diagram traffic runs from the top to the bottom).

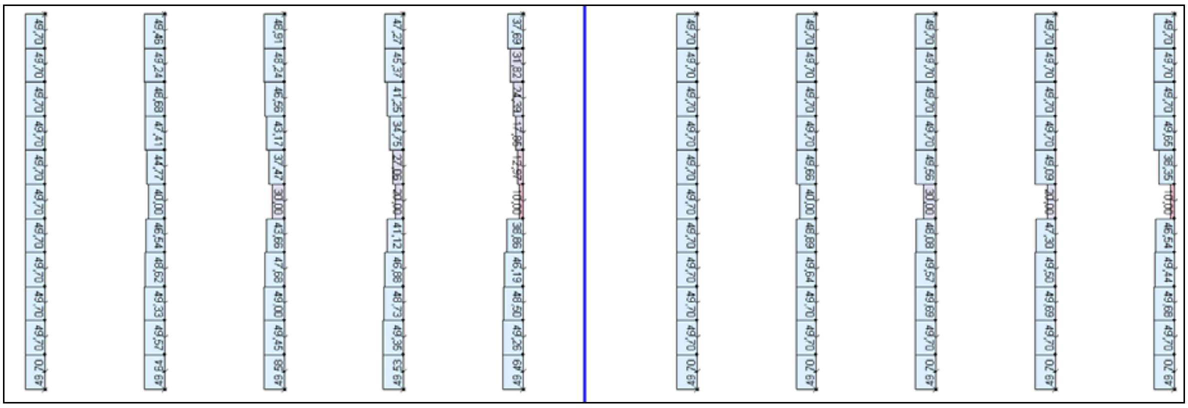

Figure 2: Comparing Acceleration and deceleration; Messmer & Papageorgiou anticipation term (left) and urban anticipation term (right)

Figure 2 depicts the average speed on the links when a demand of 600 vehicles/h is placed on each zone at the top. In the case of the original anticipation term the traffic starts the slow down as early as 1.5 km in front of the link with a designated speed of 10 km/h. To slow down to a speed of 30 km/h, depicted in the middle section, the traffic starts decelerating at approximately 900 meters before the given segment. This type of behaviour is does not accurately reflect conditions in urban road networks and hence, a new anticipation term is proposed in the propagation model when dealing with urban links:

$$T\frac{\zeta}{2\tau\cdot\Delta x}\frac{V^e\left(k_{m,i+1}\right)-V^e\left(k_{m,i}\right)}{\left(k_{\max}-k_{m,i+1}\right)} \tag{15}$$

with,

$k_{\max}$ = maximum density
ζ = control parameter
τ = control parameter

The propagation model with this new anticipation term gives the results depicted in ***Figure 2*** on the left hand side (with τ = 2, ζ = 40 and k_{max}= 180). When a constant deceleration is assumed the flow starts decreasing its speed around 300 meter before the link with a maximum speed of 10 km/h. In the less constrained cases the deceleration starts just before the bottleneck. With this assumption it takes slightly more than 10 seconds to decelerate from 50 km/h to 10 km/h. The modelled acceleration is also a lot more realistic for urban situations restoring the mean speed within 300 meters after the biggest bottleneck.

Giving ζ a value of 40 is a conservative choice, a smaller value of ζ will lead to even faster acceleration and deceleration, this choice, however, gives a smooth interaction between urban and non urban links which proved to provide the most realistic results, as a whole, over the range of link types available in the Amsterdam model.

4 XStream junction model

The combination of junctions and a dynamic traffic assignment model is not a novel concept; both Lo (1999) and Aboudolas (2008), for example, use a dynamic traffic assignment model in their search for optimal signal control strategies. In other studies however, the signal control is an input rather than an output, as is the case with the proposed framework. Both Lebacque (1999) and Jin (2010) propose a system in which the effects of junctions are integrated in the dynamic traffic assignment model, especially Lebacque points out that modelling junctions within a macroscopic model is a difficult task. Streamline acknowledges the challenges of modelling (especially signalled) junctions and therefore tries to circumvent the main problems involving junction propagation by proposing an additional layer of abstraction. This approach entails the conversion of the junction input (i.e. the junction type and opposing traffic) to a reduction of speed and capacity on a turn bases, resulting in “normal” propagation links with almost the same behaviour as all other links in the network.

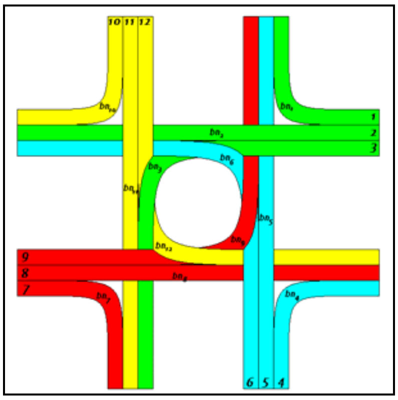

Figure 3: Schematic view of an XStream junction

In Figure 3 all possible turns of a four way junction are depicted. Every turn *i* has some kind of bottleneck bn_i, which has a given length, capacity and maximum speed depending on the intensities of the conflicting flows and the specifics of the junction. The schematic view is always the same, whether the junction has traffic lights, is an all stop junction, roundabout or another type of junction. The only difference is the formula for the bottleneck bn_i. This extra layer of abstraction introduced in XStream to be able to deal with all junctions in the same way while still being able to mimic the junction specifics defined by its bottlenecks.

4.1 *XStream Static junction model theory*

The mean waiting time of a vehicle at a junction to a certain direction depends on a large number of factors. The principal of these is that a vehicle generally has an obligation to give way to other flows (vehicles, public transport or slow traffic), the rules governing this obligation are dependent upon the junction type. Also playing an important role is the physical geometry of the junction its self, e.g. the number of lanes on the entry links to the junction and the way they can be utilised (left, through, right or a combination) and the width of a verge. This section shall describe how these factors are interpreted in both signalled and unsignalled junctions and also provide a reference to the static junction delay calculation originally proposed in HCM2000.

Theoretical Background

Over the years extensive research has been done on the subject of give way junctions by Tanner (1962), Hardes (1968), Siegloch (1973), Catling (1977), Kimber & Hollis (1978,1979), Akçelik & Troutbeck (1991) and Brilon(1995). In general most proposed methods of static junction modelling involve the calculation of a mean delay and corresponding exit capacity for a turn; in order to calculate the delays the exit capacities must already be known. In general one can say that exit capacities are either determined based on a gap acceptance approach, Troutbeck(1984), Brilon(1995) or on traffic flows, Bovy (1991).

Unsignalled junctions

There are three different unsignalled junctions supported by XStream: equal, give way and roundabouts.

XStream adopts the traffic flow methodology as proposed by Bovy (1991) when it comes to determining the exit capacity of the turn. To be compliant with current international standards the formulas stated by the Highway Capacity Manual 2000 (2000) are implemented to provide this delay. The formula for the calculation of the mean delay is divided into three parts: the uniform, incremental and geometric delay. Calculation of the incremental delay is a function of exit capacity, the load of the direction and the duration of the period of interest.

Signalled junctions

The methodology for signalled junctions is the same as for unsignalled junctions and also based on the theory of the HCM2000, however in this case only the green time and cycle time shall influence the capacity. The calculation of the green time is a non-trivial problem; finding the optimum order of green times for the different directions and determining which directions are allowed to have green at the same time can be time consuming. XStream uses the approach proposed by Van Zuylen and Wilson (1981) also known as the technique of KRAAN to solve this problem.

4.2 Converting to a dynamic environment

Using the static calculated delays and capacities directly into a dynamic model such as the XStream junction model would lead inevitably to problems. First and foremost of these is that the incremental part of the calculated delay represents the additional waiting time of a vehicle due to queue build up upstream of the junction. In a proper DTA model spillback is integrated in the propagation model and therefore to prevent taking the same delay into account twice, this part of the static delay is ignored in XStream.

Another point of interest is the conversion from delay to a new free speed on the turn which can potentially lead to very low free speeds around junctions. Therefore it is important to use urban link modelling (as proposed in 0) which allows for rapid acceleration and deceleration to localise the effects to the immediate vicinity of the junction.

In XStream, a turn is a normal propagation link it is simulated as such; as a turn gets “congested” the speed will drop and density increases. In early versions of simulation this could cause unrealistic and undesired flip-flopping of these turns. Looking at the methodology one can argue that the calculated free speed is the static mean speed of the turn over a certain period, which enables a simplification of the turn modeling to use simple “store and forward” links. This entails that all traffic on the turn will flow at free speed as long as there is capacity left. The result is a more coherent traffic flow on the turn, no flip-flop effects and improved run times. Preliminary results on the Amsterdam case study also demonstrate that the generated travel times over junctions are comparable to other micro-simulation packages such as VISSIM.

5 Dynamic Traffic Management: Controls

Along with the various building blocks (propagation model, route choice, route cost, junction model, etc.) StreamLine also includes a generic DTM architecture, and a number of DTM controls[1] are provided out of the box. In the Amsterdam case study the default ramp-metering DTM control is used, however in future publications results including a wider variety of controls shall be presented.

Ramp metering specifications

Ramp metering actuators constrains the amount of traffic allowed to enter the last section of a motorway on ramp. The actual value of this limit will vary depending on both the algorithm used and the network situation at hand. In the case study (reference year 2007) all ramp metering systems use the Dutch RWS ramp metering strategy; a comparison between various algorithms used in the Netherlands including RWS is performed by Taale et al. (2000). The RWS algorithm is converted from its original cycle time based origin to a macroscopic form using capacities only as is shown in (24).

$$Cr_k = C - I_{k-1} \tag{24}$$

with,

Cr_k = available capacity on the the on ramp r on time interval k

C = pre-specified capacity (per lane) on the link downstream of the on ramp

I_{k-1} = measered smoothed flow upstream of the on ramp in interval k -1,

The pre-specified capacity on the link down stream of the ramp is collected from the relevant link in the network, while the flow upstream is collected from a sensor with a user defined interval. Based on the interval the measured flow is smoothed and passed as input to the ramp metering actuator. To prevent negative capacities for Cr_k, a minimum capacity must be provided to check against whenever the ramp metering is enabled. Each ramp metering actuator is activated and de-

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[1] Currently the following controls are available in StreamLine: ramp metering actuator with various implementation strategies, fundamental diagram actuator, number-of-lane-change actuator, outflow limit actuator.

activated using a speed based activator implementation, capable of switching state at certain thresholds. Each ramp metering control is therefore dependant on the configuration supplied by the user.

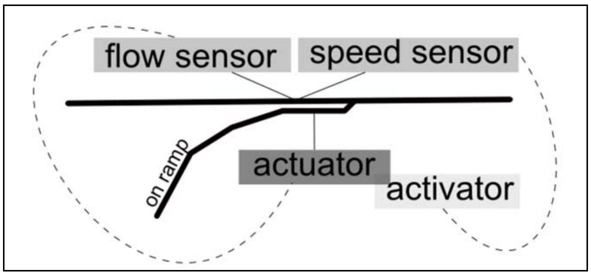

Figure 4 schematic representation of ramp metering implementation

6 Amsterdam case study

The beltway A10 is a major highway around the city of Amsterdam and plays an important role in the import and export of traffic in the metropolitan area of Amsterdam. This beltway has been researched in many studies and validation reports of dynamic models, such as Zijpp et al. (1998), Kotsialos et al. (2003) and Wang et al. (2006).

This particular study focuses on the urban area of the city, surrounded by the beltway A10, and in particular in modelling the traffic lights as realistically as possible. The traffic behaviour on the A10 influences behaviour within the urban area, and as such has been included in the traffic model. A large amount of count data is available that has been used for calibration and validation of the model.

6.1 Traffic model specification

As already specified, only the urban area surrounded by the beltway A10 is part of the traffic model. The specifications of the network are shown in *Table 1*:

Number of links	**Number of nodes**			
	Total	**Zones**		**Signalled junctions**
		Origin	***Destination***	
6.736	3.716	272	270	254

Table 1 Network characteristics Amsterdam model.

Some figures on the simulation itself are shown in *Table 2*:

Model year	**Timing**				**Number of Route choice moments**
	Start time	***End time***	***Output aggregation***	***Simulation time step***	
2007	14:00	19:30	5 minutes	1 second	24

Table 2 StreamLine simulation characteristics on the Amsterdam Model

The duration of a single run (single iteration) takes about 45 minutes on a standard business PC (Intel i7, 2.8 GHz, 8GB RAM, Windows 7).

6.2 Traffic lights

Within the study area, 254 traffic lights are defined using the actual phase schedule available from the city council. These phase schedules have been converted from a COCON file to an OmniTRANS junction definition. XStream is capable of collecting the junction definitions from OmniTRANS when reading the network and uses them as input for the calculation of the delays and exit capacities as discussed in Section 4.

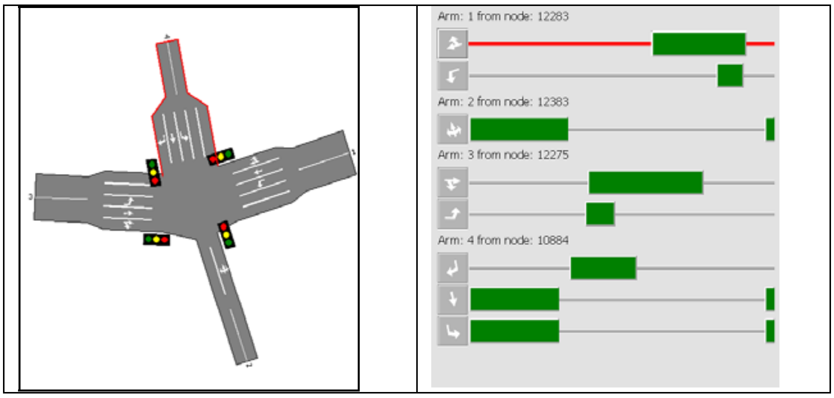

Figure 5 partial example of an OmniTRANS junction definition imported from COCON

The remainder of junctions in the city are a total of 535 unsignalled junctions. Instead of modelling them as actual junctions it was chosen to apply a static delay on these junctions based on information from the Amsterdam city council. This is supported by StreamLine in the form of static junctions and reduces computational times at the cost of some realism. This is a far better option than to just model them as cross nodes (see section 0), as cross nodes can trigger unrealistic route choice behaviour by neglecting delay altogether during DNL. Using static delays makes sure the junctions have suitable delays for both route choice and during DNL.

6.3 Ramp metering

In 2007 the A10 beltway had four ramp metering installations. These ramp metering installations worked according to the RWS algorithm which is described in Section 0. configurations applied in the Amsterdam network are shown in *Table 3*. The ramp meter regime determines the number of vehicles allowed to pass the traffic light when green. This is monitored using a red-light-camera.

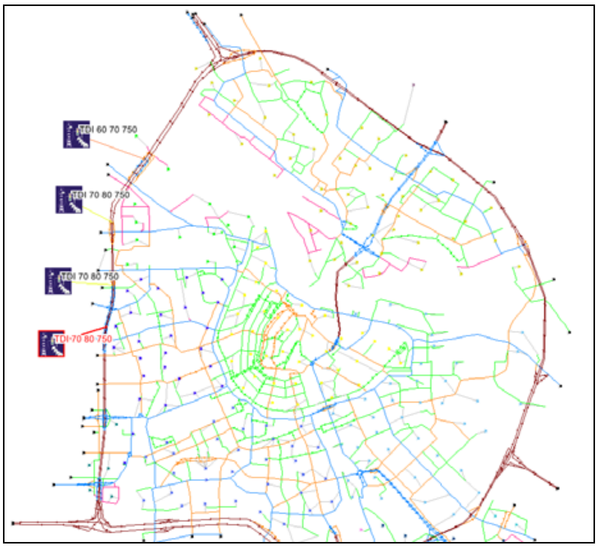

Figure 6 Amsterdam model including ramp metering controls

Ramp meter regime	**Activation speed**	**Deactivation speed**	**Min. Capacity**
One vehicle per green	60	70	750 veh/hour/lane
Two vehicles per green	60	70	1000 veh/hour/lane
One vehicle per green	70	80	750 veh/hour/lane
Two vehicles per green	70	80	1000 veh/hour/lane

Table 3 Ramp metering configuration available in the Amsterdam case study

6.4 Results

The Amsterdam city council provided the study with measured, average speed data on 20 selected trajectories including traffic lights. On these trajectories the travel times have been measured using license plate cameras. These travel times have been converted to mean speeds (per hour) resulting in average speed values during evening peak hours. From the model, the same trajectories have been identified and mean speeds have been calculated based on the simulation results. *Table 4* shows the comparison of the measurement data and the model data.

Trajectory	**Measurement data**			**Model data**		
	Speed (km/h)	**Speed (km/h)**	**Speed (km/h)**	**Speed (km/h)**	**Speed (km/h)**	**Speed (km/h)**
	16:00–17:00	**17:00–18:00**	**18:00–19:00**	**16:00–17:00**	**17:00–18:00**	**18:00–19:00**
S103 In	21	22	23	22	21	23
S103 Out	16	15	17	15	15	18
S105 In	12	13	13	14	19	20
S105 Out	16	15	17	20	20	21
S106 In	10	11	11	16	15	15
S106 Out	n.a.	n.a.	n.a.	14	15	14
S108 In	11	12	12	14	14	14
S108 Out	13	13	14	12	10	10
S109 In	10	11	11	19	15	14
S109 Out	15	15	14	18	13	12
S113 In	12	14	13	18	15	16
S113 Out	13	13	14	12	12	13
S103-S105 CW	14	16	16	22	18	17
S103-S105 CCW	18	17	18	21	19	16
S105-S106 CW	10	11	12	10	9	9
S105-S106 CCW	11	14	18	15	14	15
S106-S108 CW	9	9	10	9	9	9
S106-S108 CCW	5	6	6	12	9	10
S108-S112 CW	12	13	13	18	15	14
S108-S112 CCW	9	10	11	19	18	14

Table 4 Comparison between measured travel times and StreamLine travel times on various trajectories in the Amsterdam area

As the table shows, the simulation results are comparable to the real world measurements and importantly they fall within the tolerance levels stipulated by the city council.

7 Conclusions

The Amsterdam case study shows that it is possible to use a complex set of DTA components on a medium to large network, such as the Amsterdam model, to yield realistic and reproducible results. It also shows that macroscopic models like the StreamLine propagation model are capable of modelling urban networks using novel approaches like the XStream junction model and the proposed urban anticipation term.

Several novel techniques, the XStream junction model, multiple adaptations to the METANET propagation model and a new anticipation term to deal with urban scenarios, have been proposed. Testing on a large scale model of Amsterdam has demonstrated the suitability of these methods to modelling mixed urban/motorway networks within a macroscopic framework.

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