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Network Transmission Model: Application to a Real World City

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ABSTRACT

Traffic flow can be modelled at different levels, of which the vehicle level and the link level are mostly used. Recently, traffic relationships at a higher, network level are found, and a dynamic traffic flow model has been introduced. This paper tests such a model, the Network Transmission Model (NTM), for the city of The Hague. In this model, for each zone (i.e., parts of a network, neighbourhoods in this case) the number of vehicles in the network as well as the outflow is determined in each time step. The basic information from the city planners and the network is taken (OD, road lengths and capacities), and used as input to the NTM. Afterwards, the model parameters are adapted with input from practitioners of municipality. The parameters in the model had an understandable effect on the traffic congestion patterns. After adaptation, the model predicted a traffic patterns in line with the expectations of experts of the The Hague municipality. Generally the model predicts the congestion in the right zones and the propagation is predicted correctly. Moreover, the parameters have an interpretation so tuning is done. Finally, the model is quick enough to serve as on-line support for traffic management decisions. As face validation two different cases (adapted OD matrix and a modelled incident) were assessed with the model without adapting model parameters. The predicted traffic patterns were assessed as reasonable. The test also revealed further improvements in including traffic waiting for parking spaces and the inabilities to include turning restrictions.

1 INTRODUCTION

Transport and traffic models have been developed to work for large areas. Traditionally, their aim is to support decision making in the field of urban and regional planning (infrastructure) and traffic management policies. More recently, the application of traffic models in on-line decision support has been gaining more interest. To control traffic optimally in both normal situations and in case of specific situations such as incidents or events, information on the actual traffic situation and the ability to produce predictions for the short time, i.e., ten to twenty minutes, is essential. This requires a dynamic traffic model. On-line traffic management in a traffic control centre requires that information is provided almost instantly. This limits the possibilities to implement traditional dynamic assignment or micro-simulation models, due to the fact that the running times of these models are too large to provide instant information about short term traffic predictions. An operational manager in a traffic control centre requires real time information, with a time lack of some minutes at most, to decide which operations need to be taken.

For planning purposes, currently static models are used which provide a reasonable indication of the parts of the network which are heavily loaded. However, these models have a poor description of congestion and notably of spillback. These are features which are preferably included in a traffic model for short term predictions. In this context of urban traffic flow, planning purposes also include the planning of road works, in which case also traffic jams (and spillbacks) occur. The Traffic Management Division of the The Hague municipality would like to know what the negative impacts of a road closing are and to which extent traffic measures, like for instance rerouting, can help reducing these impacts.

In this paper, we consider the Network Transmission Model (NTM) (1) as one of the elementary components to support real time traffic control and the planning of road works. This is a dynamic model, which is able to describe changing traffic patterns in time and predicts the spillback of traffic to upstream roads or zones. It builds on the recent and large research effort about traffic dynamics at large scale using the concept of network macroscopic fundamental diagrams (2, 3, 4). It hence is better able than static models to capture the traffic dynamics. The basis of the model are zones (rather than vehicles or roads, see also section 2), so the whole city can be described by a low number of interacting elements. This makes the model very quick to run.

The Traffic Management Division of the municipality The Hague formulated the following requirements for a useful model:

1. The model needs to predict congestion at the right location at the right time.
2. The tuning of the model should be intuitive so it can be carried out by operators of the traffic control center.
3. The model needs to run quick – a single run for 30 minutes simulated time should not cost more than 10 seconds.

Requirement (1) follows from the goal of the model. If the large scale model predicts congestion in a zone, the idea is that this zone can be considered separately in a more detailed description (simulation), and not the whole city needs to be simulated at that level of detail. Therefore, the large scale model only needs to point at the zone where congestion occurs. Requirement (2) follows from the same modular approach. If on a street level the situation changes, a traffic operator needs to be

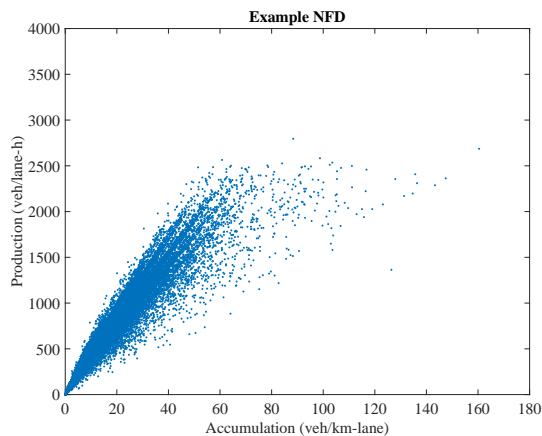


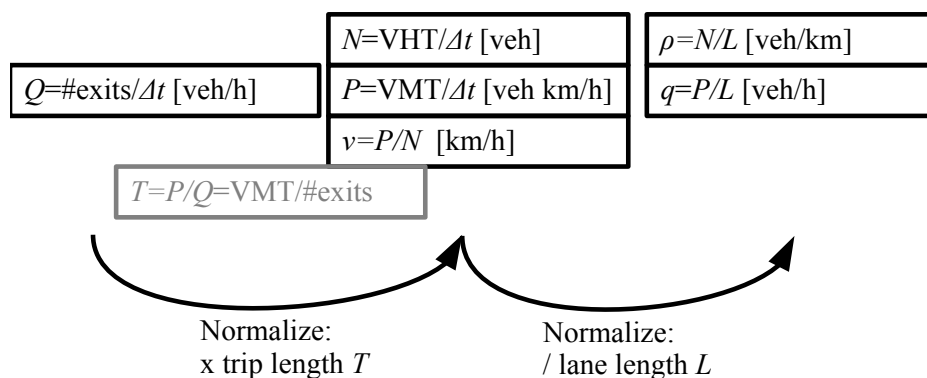
FIGURE 1 Example of a MFD for one of the zones

able to input these changes on the local level into the large scale model to assess the consequences on the city wide level. Requirement (3) is based on the assessment of control scenarios. Several settings for traffic management (traffic lights, routing schemes) can be implemented, and tested in the model. This can be activated by the traffic operator once an event happens. In order to assist the traffic operator, several scenarios should be run within the time (not more than 1 minute) the operator has to activate a scenario.

The NTM has been proposed based on theoretical considerations. It is unclear up to now to which extent the model predicts the traffic realistically. Thus, the main question discussed in this paper is: can the NTM describe urban traffic realistically? We test this by modelling the city of The Hague, the third largest city of the Netherlands, with over 500,000 inhabitants. The dynamics of the network form an important aspect of the experienced network conditions, and moreover, they influence to a large extent the control actions which can be executed.

In this paper, we model an evening peak for the city of The Hague. For comparing the NTM with reality, one would ideally have all data available so the MFDs could be measured and speeds of the model could be compared with reality. Unfortunately, there are some data, but not close to sufficient to get an indication for an MFD. The problem is not only the amount of data, but also the type (average travel times over longer road stretches; loop detector data providing counts upstream of traffic lights, influencing the estimations (5)). The data are mainly from the major roads, and the location of the measurements also influences the measurements. The available data has been analysed, but no stable MFDs were found (see also figure 1). Therefore, another approach was chosen where the traffic states were judged by experts of the Traffic Management Division of The Hague. These experts have the knowledge of the network and the typical traffic conditions. As background for the reader typical traffic states according to Google Maps are indicated in fig. 3. The main question is whether the NTM can represent the traffic. There is a calibration step involved, and in this calibration step the model is tuned towards the desired outcome. These main steps are the same regardless of the fact whether data or expert views are used. The expert views are preferred over the data since the very sparse data cannot provide a view of traffic states, and the state at the road is known not to be representative for the whole zone.

The remainder of the paper is set up as follows. First, we discuss the principles of large scale traffic simulation. Section 3 describes the implementation of the model for an initial run.

**FIGURE 2 Relationships between the different variables****TABLE 1 The symbols used**

Symbol	Meaning
N	Accumulation: the number of vehicles in the zone
P	Production: the amount of flow in the zone
k	Density: number of vehicles per lane kilometer
q	Flow: vehicular flow per lane kilometer
v	Speed: speed of the vehicles in the zone
L	Lane length: total length of the lanes in the zone
Q	Performance: the outflow out of the zone per time interval
u	Speed at a link
\mathcal{L}	Links in a zone
S	Length of a link
C	Capacity of a link
p	Nr of lanes of a link
T	Trip length: average length of a trip in the zone

Afterwards, the model is run and parameters are adapted (calibration in a testing phase) based on the feedback of the predicted traffic state by the practitioners of the The Hague municipality. Section 4 describes which parameters can be adapted, and which effect they have. Section 5 discusses the results in light with the requirements stated above. Section 6 shows the quality of the model for different parameters, which can be seen as face validation or sensitivity analysis. The paper ends by the conclusions in section 7.

2 LARGE SCALE TRAFFIC DESCRIPTION

Already in the 1960's, traffic engineers envisaged that for traffic in an area there would be a relationship between the number of cars in an area and the speeds (6). The relationship between number of vehicles and speed was shown using simulation (7). The idea of an area-based relationship gained momentum when Daganzo showed the actual arrival rate could decrease for too many vehicles (2). A major step then was paper by Geroliminis and Daganzo (3), showing that this relationship holds in practice.

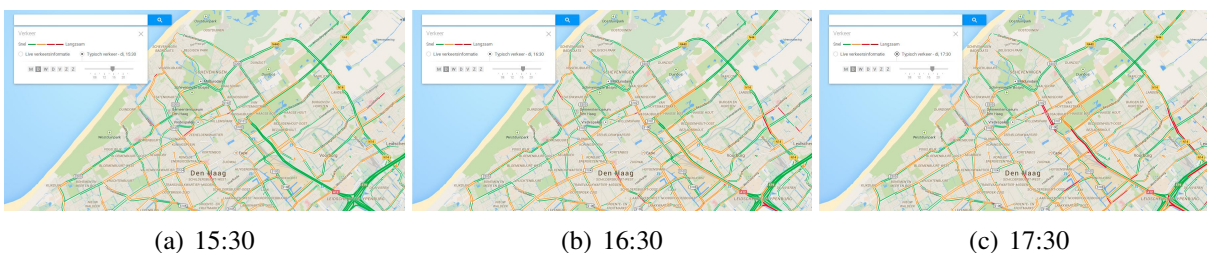


FIGURE 3 The typical traffic state in Google Maps

This relationship is called the macroscopic fundamental diagram (MFD), or network fundamental diagram, which exists in several, slightly different versions, relating slightly different variables. Fig. 2 shows the relationships between the various variables. The base variables are the accumulation and the production. Accumulation is determined by a generalisation of Edie's definition (8), being the vehicle hours travelled divided by the aggregation time. Likewise the production is determined by the vehicle miles travelled divided by the aggregation time. The more common equivalents of accumulation and production are density and flow. These are obtained by dividing the accumulation and the total lane length in a zone. Performance, or outflow rate, is obtained by dividing the production by the average trip length.

Several works have been published in the past decade, using the MFD as basis for control (e.g., (9, 10, 11, 12)). Some of the works use a simplified model of traffic at an aggregated level (e.g., (13)). More models have been developed, for instance one presented in (14). In this paper, we use the Network Transmission Model, as presented in (1).

In short, this model works as follows. An urban area is split into different zones. In each of the zones an MFD is assumed to hold. Traffic is modelled destination specific, all with a route from the zone to the destination. Demand and supply functions are established, showing the demand of vehicles out of the cell and the supply of vehicles in the receiving cell. This gives the amount of vehicles going from one cell to the other. The demand function is equal to the MFD (in accumulation-performance form) of the sending cell. The supply function is equal to decreasing part of the MFD of the receiving cell and for accumulations lower than the critical accumulation it is equal to the capacity. Moreover, the demand over a edge between two cells is limited to the (road) capacity which crosses that edge; for this moment, this is a parameter in the model, for which later we will find a value based on the road capacities. In case the demand to a cell is larger than the supply, supply will be allocated proportional to demand (over different sending cells, as well as traffic with a certain destination). For the full description of the model, we refer to (1).

The model has been proposed based on theoretical ideas and the empirical relations between performance and accumulation. The dynamics of the model were shown to make sense for a hypothetical grid network, but the model has never been tested for a real life network. Therefore, in this paper the question is studied: does the NTM describe urban traffic realistically?

The outcome of the study should show the strong and weak points of the model, as well as the ease of calibration of the model.

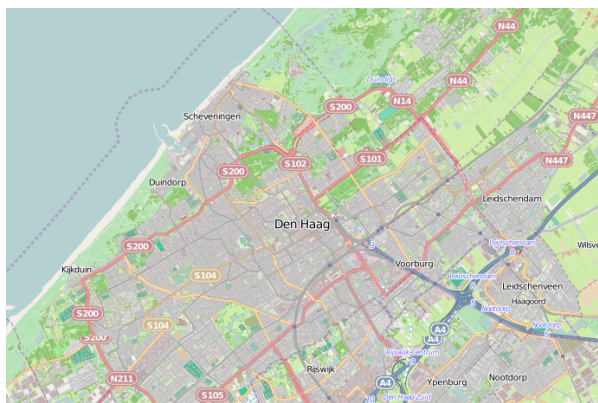


FIGURE 4 The Hague. Blue roads denote freeways. Area size approximately 20x10 km.

3 SET-UP OF THE MODEL FOR THE HAGUE

In this study we first run the model with an initial setting of parameters and zones. For the NTM to work, the following elements are required:

1. a network defined as zones
2. a dynamic OD matrix
3. capacities of the edges
4. an MFD per zone, indicating the exit rate as function of the accumulation
5. a routing strategy

This section describes how the first two are obtained. These two do not change in the calibration phase. In the calibration or testing phase (described in section 4), the right values for third to fifth elements are found.

To test the quality of the model we use the test case of the city of The Hague, see fig. 4. This city has over 500,000 inhabitants, an area of approximately 10x5 km. It is noteworthy that the city has no freeway ring road. There is a ring road (S200/N14/A4/N211), but at places the speed limit is 50 km/h. At one side it lies at the sea, which influences the origin-destination (OD) pattern, as well as the network. At the east side, a freeway passes north-south direction. Another freeway goes into the city center (A12).

3.1 Zones

The process followed is as follows. The first element used to build the model is the static model of the The Hague municipality. In this model the network is divided into zones, and for an afternoon peak hour the total traffic demand is given for each OD pair (zones). Origins or destinations outside the modelled zone are aggregated in boundary zones at the side of their true origin and destination. The division in zones is shown in fig. 5a (the thin blue lines are the roads and the bold black lines are the zone separations). The zones are too small for a good Macroscopic Fundamental Diagram (MFD): no homogeneous conditions can be found if just several roads (with possibly some queues)



(a) All zones. The dark lines are the zone boundaries, (b) Aggregated zones. The black arrow in the left hand side indicates the movement C80-C16-C96

FIGURE 5 Zones in the traffic models

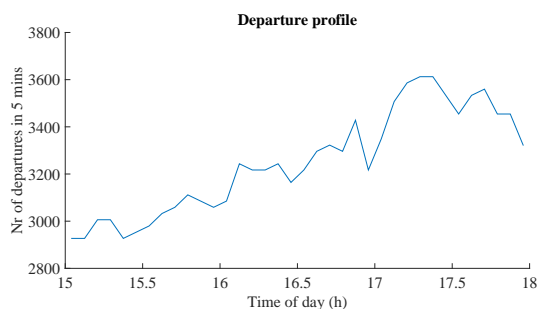


FIGURE 6 The profile of all departures as function of time.

are in the network. Moreover, internal congestion within the zones is unlikely, hence an MFD will not hold.

New zones are constructed, by which neighboring zones with similar characteristics are combined into larger zones. This was done based on expert opinion of the authors that are familiar with the city. They tried to combined them into zones with similar size and to separate residential zones from working zones or shopping zones. The areas have similar size, but separation of type was not possible for all zones. The resulting 29 zones are shown in fig. 5b. The OD matrix is adapted to the new zoning by aggregating the trips with origin and destination in the small zones into the larger zones. For simplicity Dedicated algorithms are developed to provide the most homogeneous areas both statically (15) as well as dynamically (16). However, these need link specific data which are not available for most of the roads. Moreover, since an OD demand is required, it is desirable to link the zones to the zones in the static model, which is not guaranteed in both .

3.2 Origin Destination matrix

The simulated time for the NTM is from 15.00 to 18.00, which is 3 hours, of which the first 30 minutes are considered a warm up period. This time is being based on the longest trip in the network. The static OD matrix has 78 thousand trips in 2 hours, which needs to be changed into a time dependent, dynamic matrix for 3 hours. For the transition to a three hour period, we multiplied the original OD matrix by 1.5 (3 hours/2 hours), to get a representative for the total number of trips. Within this period, we require a peak, which is derived from counts on a non-congested part of the network. The total number of trips is now scaled based on that profile. Fig. 6 shows the total number of trips departing in 5 minutes. The same scaling has been done for each OD pair.

4 TUNABLE PARAMETERS

The dynamics of the network transmission model are governed by the model equations and the parameters. The tunable parameters are:

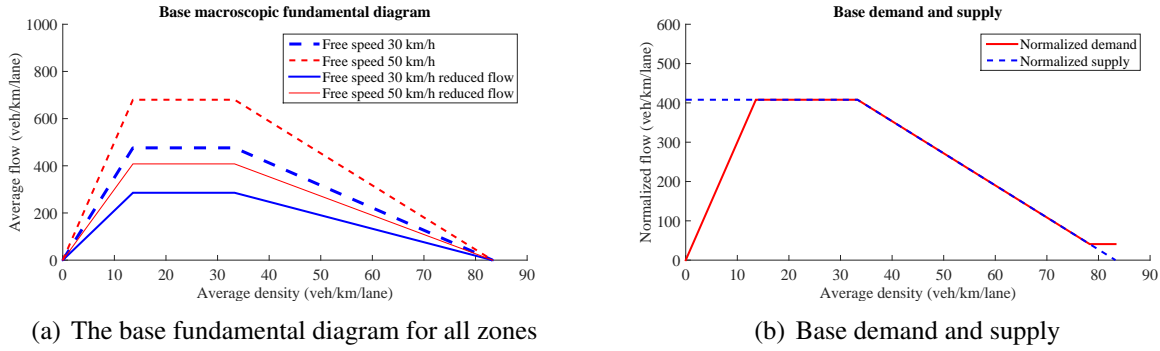
- the total capacity between two neighboring zones
- the total traffic production of a traffic zone
- route choice of traffic through the network

The succeeding subsections discuss these items and shows how we quantify the relevant equations and parameters. For these parameters a initial choice is made based on reasoning. Afterwards, the model is run. The dynamic traffic states predicted by the model are assessed by practitioners from the The Hague municipality, which know the traffic states occurring in real life. Based on the comparison of model and real life, the parameters are adapted. The subsections consist of the meaning of the parameter, as well as the way they influence the traffic dynamics.

4.1 Capacities of the edges

The model is implemented in the OpenTraffic simulation platform (17). To find the neighboring zones, the platform first detects which zones have a common edge. Subsequently, for all these pairs of touching zones, the roads that cross their common edge are identified. If one or more of these roads have a junction in both zones, we assume that these zones are connected by this link and thus are neighbors in the sense that there are traffic flows possible between the links. The capacity between the neighboring zones is calculated by the sum of the capacities of the roads that connect these zones. These total capacities are stored for every pair of neighbors. In cases of incidents this capacity can be lowered to represent the loss of road capacity. Alternatively, in case of events or evacuations specific measures could be taken to increase capacity, in which case the parameter value would increase to values above one.

For the case at hand, this base estimation did provide reasonable results for most zones. At the edge where the traffic has to merge into the motorway, notorious problems are known with the traffic lights and internal spillbacks on the junction, limiting the inflow into the motorway. For this reason, the capacity for the edge from the city zone to the zone with the motorway has been further reduced, to a value where the congestion matched the real life value.



(a) The base fundamental diagram for all zones

(b) Base demand and supply

FIGURE 7 Characteristics of the zones. Note that the units have to be scaled by the lane length in the zone and the trip length to get the outflow demand Q

4.2 Characteristics of the MFD per zone

Based on threshold values (1200 veh/h/lane) the number of lanes (p) for each of the roads l in the static model is found ($p_l = \text{floor}(\frac{C_l}{1200}) + 1$). Multiplying this by the length the link (S) and summing over all links in the zone (\mathcal{L}) gives the total amount of lane length in the zone ($L = \sum_{l \in \mathcal{L}} p_l S_l$). Also, the speed limit for each of the roads is known, which leads to a free flow speed, calculated by an average of speeds weighted by the capacity of the links:

$$\left(\frac{dP}{dN}\right)_{N=0} = \frac{\sum_{l \in \mathcal{L}} u_{\text{free}, l} S_l p_l}{L} \quad (1)$$

The NTM requires a diagram which relates the performance (outflow in veh/h) as function of the accumulation. This is based on the characteristics of the roads as well as theoretical considerations; a full theoretical approach can be found in Laval (18). In this paper, we chose a more practical approach. For each zone, we use a base MFD as shown in fig. 7a. The figure uses fixed values for k_1 , k_2 and k_{jam} as we will initially use (see sequel of this section). Equation 1 is used for the slope in undercritical conditions. This assumption means that the capacity varies with the free flow speed. Indeed, this seems reasonable since also at a road level lower speeds (in urban areas) lead to lower capacity; moreover, for the MFD a low speed could indicate high interference with traffic lights, which also decrease capacity.

The slope of the production (equation 1) and the critical density would yield a capacity. However, that capacity would only hold in case of an unrestricted flow for all roads, including no restrictions at any intersection, which is not the case. Therefore, a multiplicative factor is applied to the capacity. This factor should account for intersections. One can think of the ratio of green time over the cycle time for an intersection (which should be on average 0.5). A better interpretation is the weighted average green time, i.e. the average green time weighted for the capacity of the incoming links. On intersections the main road is likely to get a larger share of green time, and has a higher capacity. Therefore, average availability of capacity exceeds 0.5; in our case 0.6 was chosen.

From this MFD, the demand and supply can be derived. Compared to the original NTM formulation (1), a change is made in the demand function to avoid complete and insolvable gridlocks. In fact, the demand in the congested branch does not return to zero for jam density, but remains at 10% of the capacity, see fig. 7b.

Note that for the base MFD in fig. 7a, the horizontal axis shows the vehicles per km lane-length, and is basically an average flow - average density diagram for the zone (right column of fig. 2). To come to the MFD we multiply by the total length of all lanes in the zone (from the map and the number of lanes), and the relationship between production and accumulation is known. Finally, a constant trip length of 1 km is assumed (all zones are similar in size). We divided the production by this trip length, which gives a relationship between exit rate and the accumulation. We are aware the the trip length can have an effect (see also (19)); in this first-order estimate we assume a constant trip length.

Varying the values for the different densities sorted various effects. The most important value was the density from which the production would decrease (k_2). Lowering that value causes outflow to decrease and the thereby the accumulation to increase, causing an even lower outflow. This is the most critical value for a zone. The density at which the speed first starts to reduce (k_1) is relevant for getting the right speeds in slight congestion. However, it will not influence the propagation of congested patterns through the network, hence its influence is more local. The jam density (k_{jam}) indicates how much extra storage capacity there is in overcritical conditions. Combined with the capacity and the value of the start of the decreasing branch (k_2) k_{jam} indicates the speed at which congestion spills backwards. By experimenting with different values for the densities the following values were found to give speed patterns over time which matched the experience of the practitioners at the Traffic Management Division.

Using experience from earlier research (e.g., Laval and Castrillon, Knoop and Hoogendoorn (18, 20)) and trying some values (equal for all zones), we fixed k_1 to 14 veh/km/lane, the k_2 to 33 veh/km/lane, and k_{jam} to 83 veh/km/lane. These values are low, because a homogeneous state with all roads and all lanes in jam density (which would result in a k_{jam} of 125 veh/km or higher) cannot be reached. In fact, traffic will stop in an inhomogeneous network at lower densities (21).

The MFD is tuned for normal circumstances. In case of a serious accident, the performance of an area might decrease significantly. This can be quantified by tuning the area-specific MFD diagrams, for instance by decreasing the average critical density and maximum capacity by a certain factor.

In the calibration process with the traffic operators especially the accumulation where the production decreases (k_2) has received attention, since this turned out to be the critical parameter. Lowering this parameter would have the most serious impact on traffic flow, since it starts congestion, which due to the increasing accumulation then worsens.

4.3 Routing strategy

For routing we follow the description in (1). For each zone the routing is to a destination is coded as a split fraction: which part of the traffic to destination D goes to which neighbor n . This is indicated by $\Psi_{i,D}$, which is a vector of which the length is the number of neighbors of zone i . This is updated every time interval of length τ . At that moment in time, the fastest routes from a zone towards a destination is determined, given the speeds in all the zones. Travel times are derived from the speeds and they are disturbed using an error with a normal distribution (mean 0, 10% st. dev). This is repeated several times, leading to different routes. For these routes, it is considered which part goes to neighboring zone n . This gives a routing vector for the routes at that time step: $\psi_{i,D}$. The new routing vector now is an weighted average of the old routing vector Ψ and the new

one ψ :

$$\Psi_{i,D}^{\text{new}} = (1 - w)\Psi_{i,D}^{\text{old}} + w\psi_{i,D} \quad (2)$$

The weight w indicates which fraction “reconsiders its route” during the time interval τ between two route updates. Note that this is an interpretation: for instance, not the same travellers are updating their route all time intervals, and moreover, no routes are assigned, but rather fractions are updated. Due to this scheme of creating routes which also start differing from the next zone, the number of draws on travel time does not need to be very high. Also considering computational load, we choose 6 routes for each probit round

In the testing phase, the route update times τ as well as the fraction of drivers changing their route is changed. If the update frequency was low (less than once per 10 minutes), congestion had time to grow (due to the fact that no equilibrium assignment was used) and then with a new route update it would suddenly reduce and another congestion area would grow. This was not in line with the experience of the practitioners of the Traffic Management Division. A fast update with a large share would lead to traffic homogeneously spread over the network, which was also not according to their experience.

Based on the traffic patterns and the experience from the traffic management center the route choice was set to a re-routing fraction of 5% every 5 minutes (w in eq. 2 equals 0.05) – similar to a method of successive averages. With a longer time, the traffic states were too much fluctuating. A shorter re-routing time kept the traffic states stable. The amount of re-routing relatively low, suggesting indeed that most people do not adapt their route based on the changing situation en route. This was according to the traffic management center the most realistic situation.

5 RESULTS

This section describes the results of the simulations. First the base results for a recurrent peak, and the adjustment by practitioners of the Traffic Management Division are presented.

Fig. 8 shows the simulation results graphically. When using only the base MFDs as explained above, the road network experiences some congestion (see fig. 8a and 8b), just like in reality. The first 10 iterations of adaptation were used to find the abovementioned overall parameters (MFD parameters and routing update parameters). Now we focus on adapting the parameters of the individual zones and MFD boundaries. In this paper we only present time snapshots of the traffic states, but in during calibration, movies for the whole peak period have been used, showing the dynamics of the congestion patterns.

With the initial parameters not all congestion as represented as in reality. As explained in section 4.1, the local traffic operators explained that several traffic lights upstream of the entrance to the freeway A12 cause congestion. The calibration step taken is to reduce the edge capacity for the flow from the east towards the city center.

By consequence the traffic is more congested, and spilling back in the way the traffic operators expect, and is seen in real life (see fig. 3 for a typical situation of the evening peak). The congestion starts in the right area and spills – at approximately the right pace – back to the more upstream areas.

The amount of congestion is adapted by adjusting the capacity at the edge: less capacity will mean more congestion. The adaptation was done together with the traffic operators, which

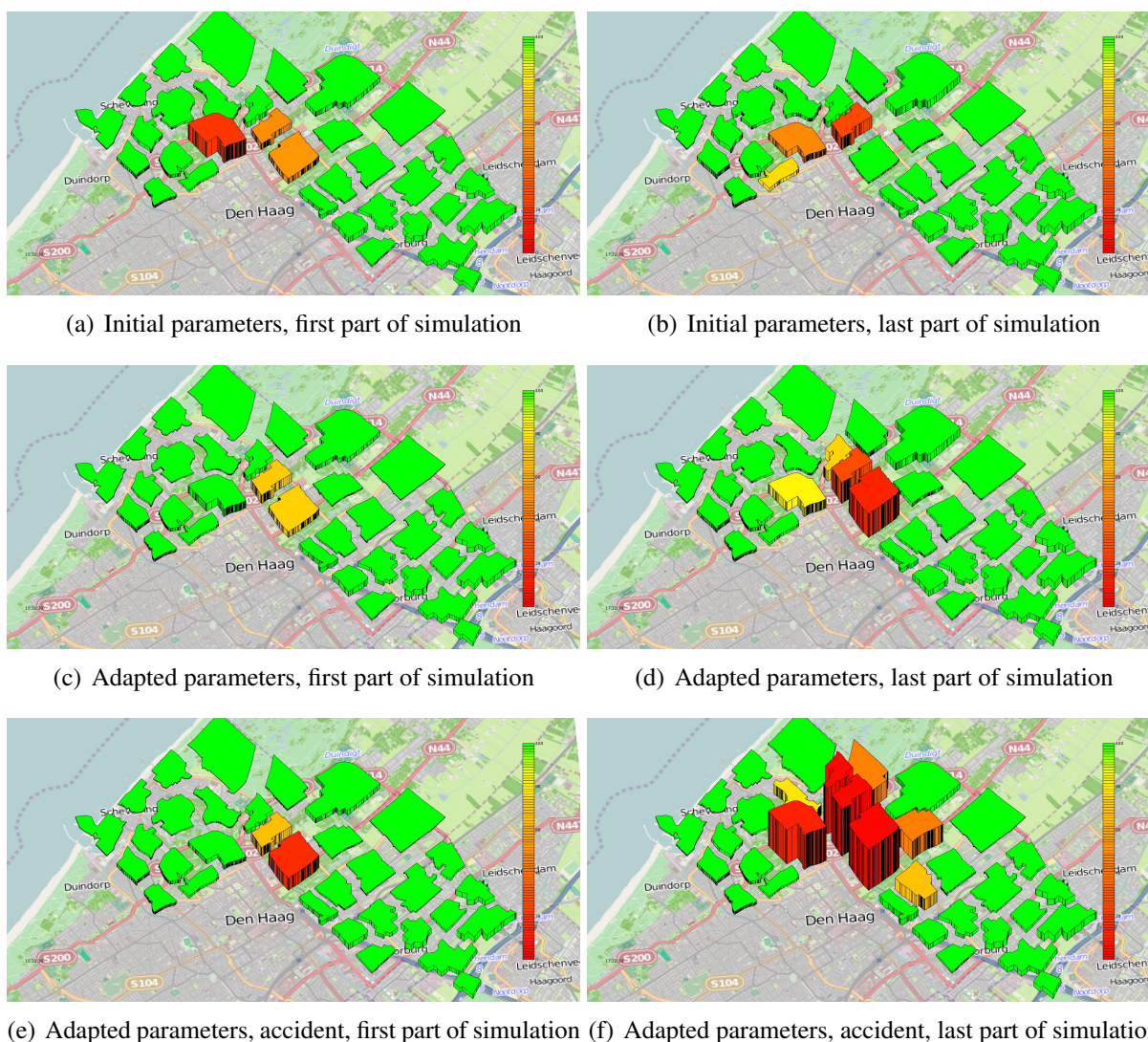


FIGURE 8 Screen shots of the simulation. The color indicates the speed relative to the free flow speed, and the height the accumulation

shows the quality of the model in the second requirement, i.e. “The tuning of the model should be intuitive by operators of the traffic management center”.

The tuning parameters turned out to work as described in section 4. After finding the overall parameters in 10 iterations (section 4), 14 more iterations were needed to get a satisfactory result – a few hours work. Adaptations carried out were changing some boundary capacities, changing k_1 for two zones (one with a change of speed, the other with a change of capacity), and change of k_1 and k_{jam} for one zone. k_{jam} was increased in order to avoid further spillback of the traffic jam.

After the capacity at the edges was adapted, congestion occurred and propagated further upstream. The model works with zones which can get congested (for traffic to all directions), whereas in the ideas of an “evening peak” the traffic engineers were only concerned with traffic leaving the city. The model showed situations that in case of high congestion inbound traffic was also hindered, but the congestion mainly spread to the upstream locations for the main traffic

direction, i.e. the outbound direction. The resulting combination of congestion propagation was well in line with the experience of the Traffic Management Division. Therefore, the most important conclusion is that after the calibration the model was well able to predict congestion at the right location at the right time.

The model is very fast: simulating a 3 hour period on a (one core of a) laptop (Dell Latitude, Intel core i7-2530M CPU 2.8 GHz, RAM 4 GB) costs 15 seconds. The code is not optimized for computation time, and the programmers expect that optimization of the code can result in approximately 10 times faster computation times. If even further reduction in computation times for many scenarios is required, improvement of the hardware is possible, as well as making the computations for the different scenarios on different CPUs.

The model showed also undesirable outcomes. First, after congestion starts occurring, drivers chose a route around congestion via an infeasible path. The path C80-C16 (see the black arrow fig. 5b) is possible with a high capacity. Also the connection C16-C96 is possible. However, the sequence C80-C16-C96 is not possible due to a restriction in turning: the main traffic stream taking that route needs to continue straight (no right turns). In a future version, the routes can be coded using directional graphs, rather than via the destination-specific split fractions in the network, by which this problem can be overcome.

Secondly, traffic is assumed to have reached its destination once it arrives in the zone of arrival, which is not necessarily the case in reality. In fact, parkings can be full, leading to queues waiting at the entrance blocking other traffic, or traffic can keep circling to find an on-street parking spot. These outcomes should be included in a future version of the model; some ideas how to represent parking on a network level have already been developed (22)

6 FACE VALIDATION

The previous section showed the results of the model where the model parameters were tuned to match the recurrent traffic patterns. The model has many variables (4 per zone for the MFD, one per neighboring pair for the capacity, 2 for routing). There is a risk that the model is tuned to represent the reality, but the parameters are not correct – for instance due to overfitting. To test whether the model might be tuned towards the outcomes and does not have the processes modelled, we do face validation. In fact, two test cases which differ from the regular (calibrated) morning peak are run by the model, for which only the input parameters are differed. The model has not been calibrated further. The considered test cases are: (1) an excess demand due to visitors to the beach, and (2) an accident partially blocking the freeway A12 outbound. Both scenarios occur frequently, so the traffic engineers from the traffic management center know the outcome. The situations are calculated, changing the demand for one origin (case 1), or the capacity of one edge (case 2).

The traffic state for case 2 is depicted in fig. 8e and 8e. In both cases the network becomes more congested at the locations which were expected by the practitioners. In case of the excess demand caused by visitors of the beach and leaving in the evening peak shows that congestion starts at the same locations as the average evening peak. However, due to the increased amount of people leaving the city, the level of congestion is higher and causes a spreading of congestion to upstream areas. While we did not quantitatively test the level of congestion with observed data, the phenomena that appeared seem to be face valid, as was confirmed by the The Hague Traffic

Management Division.

7 DISCUSSION AND CONCLUSIONS

The first finding is that the model works reasonably well with a set of default parameters for all zones. This is surprising given the fact that the impact of loading patterns, traffic light settings and inhomogeneity are discussed extensively in literature. Apparently, a generic approach works reasonably well. With the adapted parameters, the traffic congestion is found at the right place, and the traffic dynamics are presented in a correct way. The working of the model parameters was considered intuitive by the practitioners of the Traffic Management Division: they were able to quickly adapt the parameters of the model to get a realistic outcome. Finally, the model worked very fast, well under the requirements set by the Traffic Management Division.

Shortcomings which came up in the model were that traffic in reality does not leave the network the moment it reaches a destination and that sometimes turning could be restricted. For both issues solutions will be tested. For the first, a limited reservoir in each zones could represent the parking capacity. In case of busy hours, this is full and vehicles have to circulate until there is space (22). The modelling of these reservoirs could be similar to zones, with a supply function. For the routing explicit routes can be determined on beforehand, and during the route choice update the travel times on the predetermined routes are updated. That would avoid infeasible routes to be chosen.

The aim is to apply the model also for a larger area than one city, for instance the region including more towns. However, not all that areas are urban areas, hence the MFD will not hold in all areas. In particular, there will be no internal congestion and spillbacks. This problem is already partially present in the current area, with freeways being sometimes in another state than the underlying road network. This can be solved with further developments, which entail a combination of the NTM and the Cell Transmission Model (CTM). Zhang et al. (23) give for instance a combination how a reservoir can be combined with a CTM. This should be adapted to a multi-reservoir system to integrate it into the NTM.

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