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Coordination of Ramp Metering Control in Motorway Networks

Yufei Yuan

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Information: Henk Taale
E-mail: henk.taale@rws.nl

Written by: Yufei Yuan

Graduation committee:
Prof. Dr.Ir. S.P. Hoogendoorn (Thesis supervisor, TU Delft)
Prof. Dr.Ir. B. De Schutter (TU Delft, 3ME)
Dr.Ir. A. Hegyi (TU Delft, T&P)
Dr.Ir. W. Daamen (Daily supervisor, TU Delft, T&P)
Ir. H. Taale (RWS)
Ing. C. Cappendijk (RWS)
Ir. P. Wiggenraad (TU Delft, T&P)

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Summary

The considerable expansion of car-ownership has led to the daily appearance of congestion on urban and interurban motorways, especially during peak hours. The steadily increasing number and length of traffic jams on motorways inconvenience road users, increase total travel time, economic losses and environmental pollution, and reduce traffic safety. As a result, the total social welfare decreases. This is a matter of control problems. What is urgently needed is to restore and maintain the full utilization of the motorways' capacity, instead of simply increasing capacity by expansion of infrastructure. Ramp metering has proven to be one of the most efficient means to solve this problem, as one of several dynamic traffic management (DTM) measures. Meanwhile, it is noticed that contemporary DTM tends to focus on the integrated and coordinated deployment of measures. Hence, an integrated control strategy on a network-wide level is needed.

This graduation project studies a new traffic control algorithm. Ramp metering has been introduced on the Amsterdam A10 beltway several years ago. In the near future, the remaining main on-ramps along the beltway A10 will be equipped with ramp metering as well. In addition, a new algorithm (HERO) for coordination control of the whole ramp metering system will be initiated. The effects and consequences of this implementation, however, are unclear to the Dutch government. Hence, the main objective of the project is to perform an ex-ante study using a microscopic simulation model assessing the new control algorithm by comparing coordinated ramp metering to individual control. Possible improvements of the HERO algorithm are investigated within the project as well.

Many macroscopic simulation studies related to coordinated ramp metering in the Amsterdam network have been reported before. However, few previous studies have concentrated on the “HERO” coordination algorithm in a microscopic simulation environment. In this case, microscopic simulation is performed, as it could provide more precise description of traffic behaviour and thus more reliable results without interfering with reality. The microscopic simulation tool VISSIM is used to predict the traffic conditions. The study area is the traffic network of the A10-west, where the existing four ramp metering controllers are located. Several evaluation criteria have been defined in order to assess the corresponding effects of different alternatives (no control case, local and coordinated control). For the optimization of the parameters of the HERO algorithm, the related robustness study has been performed.

Based on the results of simulation, it is concluded that the HERO coordinated control outperforms the non-coordinated local ramp metering control. The improvement on average travel time on the main study area in the HERO network is 2.00% compared to non-coordinated control case, and 25.67% compared to no-control case. It is able to postpone congestion on the motorway at the expense of inducing more unfair local delay with a 2.59% increment on total delay time compared to non-coordinated control network. Nevertheless, HERO improves the equity requirement for each on-ramp because of early activating upstream ramp metering controllers.

This new control strategy turns out to provide less congestion, higher mean speed and lower travel time spent in the network, and thus poses potential positive effects over the targeted application area. Hence, it is in accordance with the objective set up for the Amsterdam network under the framework of “Improvement of the flow on the ring-road A10”.

Meanwhile, based on the given traffic information, optimal parameter settings are found for real implementation with respect to the specific traffic network of the A10 west. The activation/deactivation thresholds for the HERO algorithm, speed switch and flow switch of local controller are 50/25%, 70/80 km/h and 1800/1650 veh./h, respectively.

Key words: Coordinated ramp metering, HERO algorithm, Amsterdam A10, Microscopic simulation

Preface

This report is the final product of my M.S-c thesis, and it is also regarded as a milestone of my two-year master study in Delft.

This graduation work is executed on behalf of Rijkswaterstaat (RWS). The research output will be used as a reference for real application of the project for ramp metering control. I have to say it is my great experience to do my thesis work at ITS Edulab. This precious opportunity enables me to find a way to integrate theory with practical aspects and learn many things besides the technical skills which cannot be obtained from textbook.

I would like to extend my heartfelt thanks to my daily supervisor, Winnie Daamen, for giving me sufficient guidance and patient monitoring. Her critical comments and suggestions enable me to make this thesis better than I could have done by myself.

I would also like to express my gratitude to all my other committee members, Prof. Serge Hoogendoorn, Prof. Bart De Schutter, Andreas Hegyi, Henk Taale, Cyril Cappendijk and Paul Wiggenraad, for their supervision and their help in making my project possible.

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Delft
22 June 2008

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Chapter 1 Introduction

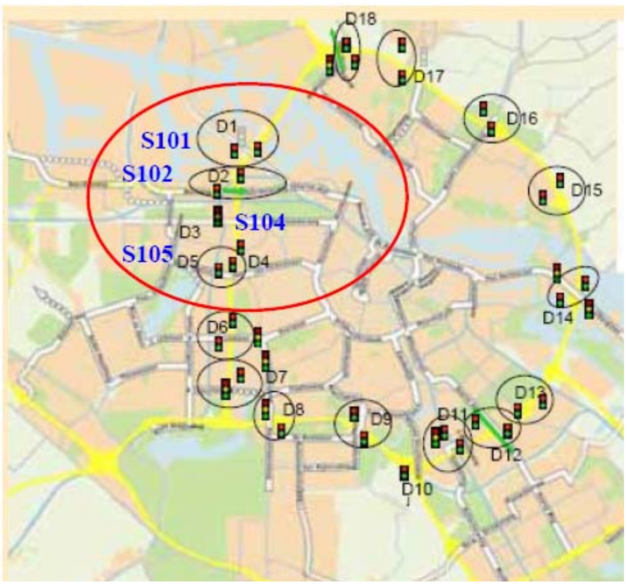
Urban and interurban motorways have originally been conceived to provide unlimited mobility to road users. The considerable expansion of car-ownership has led to the daily appearance of congestion, especially during peak hours. The steadily increasing number and length of traffic jams on motorways inconvenience road users, increase total travel time, economic losses and environmental pollution, and reduce traffic safety. As a result, the total social welfare decreases. This is a matter of control problems. What is urgently needed is to restore and maintain the full utilization of the motorways' capacity, instead of simply increasing capacity by expansion of infrastructure. Ramp metering has proven to be one of the most efficient means to solve this problem, as one of several dynamic traffic management (DTM) measures, whereby short delays at on-ramps and freeway-to-freeway intersections is the relatively low price to pay for capacity flow on the freeway itself (Papageorgiou and Kotsialos, 2002). More precisely, this measure is to control the inflow of the on-ramp and to keep the motorway from capacity drop. Meanwhile, it is noticed that contemporary dynamic traffic management tends to focus on the integrated and coordinated deployment of measures. More and more researchers recognise that the effects of the measures on the network level have many advantages compared to local control. Hence, an integrated control strategy on a network-wide level is needed.

The enhanced use of existing infrastructure is one of the key instruments in the Dutch traffic and transport policy (Taale, 2003). Many intelligent transport systems have been introduced to the road-side infrastructure, such as ramp metering, variable speed limits, dynamic route guidance, opening shoulder lanes and dynamic route information panels. As known, the beltway A10 around the city of Amsterdam is one of the busiest urban motorways in the Netherlands. Several on-ramps have been equipped with ramp metering controllers. This control measure is helpful to ameliorate traffic problems to a certain extent. Moreover, coordinated ramp metering control, which is able to combine individual ramp metering controllers, has been developed, A simulation study (Kotsialos et al., 2005) has reported a predicted decrease of 15.9% and 42.9% of the total time spent (TTS) by all vehicles after installing optimal coordinated ramp metering on the Amsterdam ring road A10 using hierarchical control strategy, compared to solitary ramp metering and no-control case respectively. While this simulation is based on a complete model predictive approach in an iterative way, which is not operable in practice, the outcome may be overestimated, due to the unrealistically large drop in the capacity when congestion occurs in the model used. For the long run, the government would like to apply coordination control concepts for further improvement of traffic situation. Based on this sophisticated control strategy, a new and operable algorithm of coordination control of ramp metering has been developed by Kotsialos and the Dutch Ministry of Transport, Public Works and Water Management (RWS), which is called HEroistic Rampmetering Optimalisation (HERO) (Rijkswaterstaat DVS, 2007a). This measure has not been implemented yet. The purpose of this thesis project is to perform an ex-ante study to investigate the effects and feasibility of the implementation of coordinated ramp metering control using the HERO algorithm in A10 ring road. If possible, it aims to improve the HERO algorithm within the study, including calibration of parameter settings.

1.1 Main objective and research questions

This graduation project studies the new traffic control algorithm "HERO". Ramp metering, has been introduced on the Amsterdam A10 beltway as a traffic control strategy several years ago. As shown in Figure 1.1 below, there are four ramp metering systems (Toeritdoseerinstallaties: TDI) on the western part of the A10 at present (red circle). In the near future, the remaining main on-ramps along the beltway A10 will be equipped with ramp metering as well (Rijkswaterstaat Noord-Holland, 2007a-b). In addition, a new algorithm (HERO) for coordination control of the whole ramp metering system will be initiated. The effects and consequences of this implementation of coordination, however, are unclear to the government. Hence, the main objective of the project is to perform an impact analysis using a simulation model assessing the coordination control algorithm as a support measure in control scenarios by comparing coordinated control to individual ramp metering. More specifically, the aim is to investigate the traffic conditions (flow, speed, route choice) resulting from implementing the HERO control algorithm on part of the A10 ring-road. Possible improvements of the HERO algorithm will be investigated within the project, including choosing optimal parameter settings.

Figure 1.1: Current and future situation for ramp metering (Rijkswaterstaat Noord-Holland, 2007a)



Note that S101, S102, S104 and S105 (see Figure 1.1) originally denote four urban roads which intersect with A10 beltway. Here, these codes stand for freeway-to-freeway intersections where the related ramp metering is located.

The study area will be the traffic network of A10-west (North direction), where the current four ramp metering controllers are located. What is worth mentioning here is that the main research stretch will be restricted to the motorway road from S105 to Coentunnel. This part of motorway is considered as the critical spot by the government where recurrent heavy motorway congestion occurs. Certain evaluation criteria will be defined in order to assess the corresponding effects of different alternatives (no control case, local and coordinated control).

According to the framework described in "Improvement of the flow on the ring-road A10" (Rijkswaterstaat DVS, 2007a), the objective of Dynamic Traffic Management (DTM) measures set up for the A10 is to keep the ring-road running. Of course, it is expected that this new coordination control scheme would yield less congestion, higher mean speed on the motorway and lower total time spent in the whole network (both motorway and underlying networks).

The main research questions in this project are the following:

1. What is the predicted impact of coordinated ramp metering on the A10 beltway?
   - How does it compare against non-coordinated ramp metering and no-control case?
   - Does the implementation of coordination control meet the objectives of DTM set up for the network around Amsterdam?

2. What are the optimal parameter settings within the HERO algorithm for real application?
   How robust is the performance with respect to these settings against changing traffic conditions?

1.2 Research method

In order to predict the effects of a new control measure, a simulation study is needed. Many simulation studies related to coordinated ramp metering in the Amsterdam network have been reported (Papageorgiou and Kotsialos, 2002; Kotsialos and Papageorgiou, 2004; Kotsialos et al., 2005). These studies have been performed using the macroscopic deterministic simulation model METANET. Overestimated results have been generated with the model because of the unrealistic capacity drop in the model. In this case, microscopic simulation is needed, as it could provide more precise description of traffic behaviour and thus more reliable results without interfering with reality.

For microscopic simulation, several models could be chosen, such as FOSIM (Freeway Optimisation Simulation), AIMSUN, PARAMICS and

VISSIM. FOSIM cannot be associated with external traffic control. In TU Delft and Edulab, VISSIM is the most prevalent simulation tool compared with AIMSUM and PARAMICS. Hence, VISSIM will be used here. VISSIM is a microscopic, time step and behaviour based simulation model. VISSIM can analyse traffic operations under constraints such as lane configuration, traffic composition and traffic signal control, thus making it a useful tool for the evaluation of various alternatives based on transportation engineering and planning measures of effectiveness.

Although VISSIM is widely used for motorway modelling for its capabilities of emulating various traffic operations, it can not cope with ramp metering issues using its internal modules. For this graduation project, the ramp metering and its coordinated control will be realised in VISSIM via the external control interface. The control interface has been developed by the traffic company "VIALIS". The interface reads the "real-life" data in VISSIM and it transfers these to the controllers. Then, each controller realises the control application based on the given information and sends the control information back into VISSIM.

During the simulation study, different scenarios (such as no control case, local and coordinated control and scenarios for optimization) will be proposed in line with the research aims and questions and be simulated in VISSIM. The simulation output (raw data) will be analysed using Matlab with respect to certain assessment criteria. The final conclusions will be presented based on the simulation results.

1.3 Outline of the thesis

In this section an outline is given of the chapters in this thesis.

In chapter 2, an overview is given on the state of the art in ramp metering control. Based on the increased insights into the problem, the problem is redefined at the end of this chapter.

In chapter 3, the methodology to assess the HERO algorithm is described. In this section, the research methods, the simulation model and the control tools are introduced.

In chapter 4, a detailed case study on the Amsterdam network is addressed.

The modelling and the general calibration based on empirical data of the simulation model are showed in chapter 5.

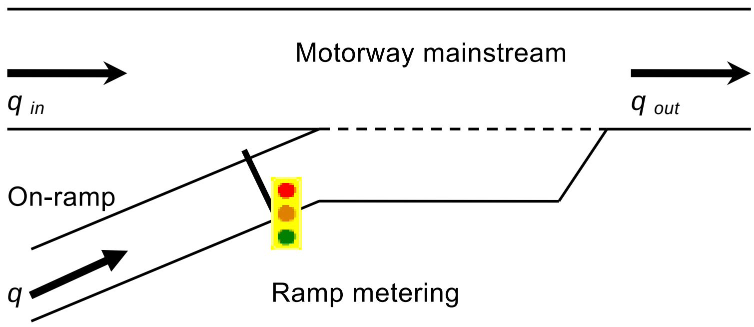
Chapter 6 and chapter 7 describe the effects of the HERO algorithm and the improvement of this algorithm respectively.

Chapter 8 summarizes the conclusions and recommends some points for further research and improvement.

Chapter 2 Literature survey on coordinated ramp metering control

Ramp metering is implemented via installation of traffic lights at motorway on-ramps that control the amount of traffic flow allowed onto the motorway, as shown in Figure 2.1. The traffic lights are operated in dependence of the currently prevailing traffic conditions on both the motorway mainstream and the ramps. The corresponding traffic-responsive control strategy (or control algorithm or control logic) is the connecting element between the measured traffic conditions and the operated traffic light settings. The pertinence of the employed control strategy is crucial for the full exploitation of the potential benefits offered by ramp metering; therefore, the employed ramp metering strategy should be designed and configured with proper understanding of the potential benefits achievable (Papageorgiou and Papamichail, 2007).

Figure 2.1: Illustration of ramp metering control



Potential improvements achievable via ramp metering measures include (Papageorgiou and Papamichail, 2007):

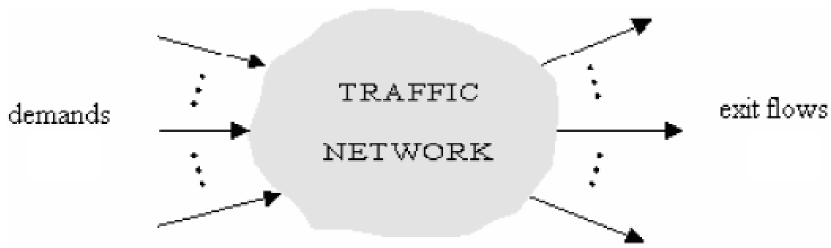
1. Reduction of motorway congestion in space and time (or even elimination of congestion under certain conditions).
2. Increase of motorway throughput.
3. Reduced (or avoidance of) congestion spillback to the adjacent urban traffic network or to other merging motorways.
4. Significant improvement of traffic safety on the motorway due to reduced congestion duration, less congestion spillback and an improved merging process at on-ramps.
5. Improved and orderly utilization of the overall traffic network in accordance with specific policies.

An overview of different control strategies related to ramp metering will be provided in the next sections. Firstly, the individual control strategies will be discussed. Then, the coordination control is followed. Subsequently, the introduction to the HERO algorithm is described. Finally, the conclusions of the literature review are addressed, including a restatement of the problem definition.

2.1 Local ramp-metering control

In order to understand the effect of ramp metering, some basic concepts will be introduced here. Consider any traffic network as shown in Figure 2.2 with demand appearing at several locations (e.g. at the on-ramps, in case of a motorway network) and exit flows at several destinations (e.g. at the motorway off-ramps). Clearly, the accumulated demand over, say, a day will be equal to the accumulated exit flows, because no vehicles disappear or are generated in the network. This is regarded as the principle of vehicle conservation. Let us assume that the demand level and its spatial and temporal distribution are independent of any control measures taken in the network. Then, we are interested to know how much accumulated time will be needed by all drivers to reach their respective destinations at the network exits (network efficiency!). It is quite evident that this total time spent by all drivers in the traffic network will be longer if, for any reason (e.g. due to lack of suitable control measures), the exit flows are temporarily lower, i.e. if vehicles are delayed within the network on their way to their destinations. The delays may be caused by lacking of capacity, which lead after congestion to lower outflows. As a consequence, any control measure or control strategy that can manage to increase the early exit flows of the network, will lead to a corresponding decrease of the total time spent. In other words, the earlier the vehicles are able to exit the network (by appropriate use of the available control measures) the less time they will have spent in the network. These statements may be formalized by simple mathematics (Papageorgiou, 1983; Papageorgiou et al., 1998).

Figure 2.2: A general traffic network (Papageorgiou and Papamichail, 2007)



Meanwhile, capacity drop phenomenon exists in motorway networks. A traffic stream with increasing density reaches a higher capacity value (free flow capacity) than a traffic stream starting from a congested state that ends in the so called “queue discharge capacity”. The discontinuity in capacity of motorway leads to low efficiency of the network performance (Hoogendoorn, 2007).

According to the basic property of the traffic/motorway network mentioned above, it turns out that there are several advantages of solitary ramp metering control. To make it simple, firstly, it could prevent the motorway capacity from dropping; as a result, the vehicles are able to exit the network earlier and thus they will have spent less time in the network. Meanwhile, it could avoid the secondary blocking of an upstream off-ramp. Last but not least, it could affect the route choice behaviour of certain O-D pairs related to motorway network; so as to reduce rat-running phenomena and concentration of traffic on the motorway and to increase or decrease underutilized or overloaded utilization, respectively. More detailed explanation about the advantages of individual ramp metering can be referred to (Papageorgiou and Kotsialos, 2002) and (Papageorgiou and Papamichail, 2007).

In order to realize ramp metering control, several control strategies could be used, such as fixed time strategies and reactive ramp metering strategies (Papageorgiou and Kotsialos, 2002; Papageorgiou and Papamichail, 2007). Fixed-time strategies are derived off-line for particular time-of-day, based on constant historical demands, without use of real-time measurements. They are based on simple static models. These strategies are blind to the prevailing traffic conditions and may therefore either under-load or overload the motorway.

In this report, we focus on local reactive control strategies. This kind of control strategies are local control. They make use of real-time traffic measurements in the vicinity of a ramp to calculate suitable ramp metering values, i.e. in the aim of keeping the motorway traffic conditions close to pre-specified set values. The strategies are activated at each control time interval T, whose value is typically selected from the range 20s…60s. More specifically, at the end of each running period T, time-averaged measurements of traffic volume (flow) or occupancy from the ending period are used to calculate (via the corresponding strategy) the ramp flow to be implemented in the next period. The most popular local ramp metering strategies are the demand capacity strategy, ALINEA and their variations. These strategies are described in further detail in the following.

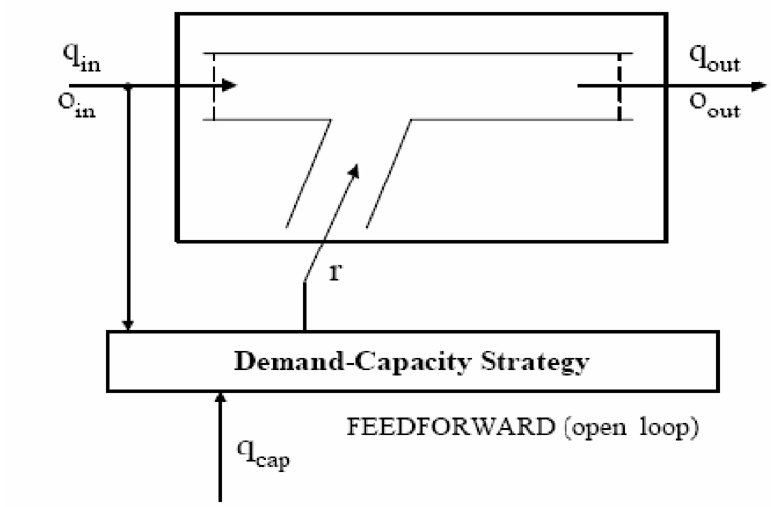
2.1.1 Demand-capacity strategy

The demand capacity (DC) strategy is employed at a tactical level, based on the motorway capacity and the traffic demand on the motorway. The metering rate *r(k)* is calculated by a pre-specified capacity value and the incoming flow (Masher et al., 1975):

$$r(k) = \begin{cases} q_{cap} - q_{in}(k-1), & if \quad o_{in}(k) \le o_{cr} \\ r_{\min}, & else \end{cases}$$

where (shown in Figure 2.3) k=1,2,… is the discrete time index; $r(k)$ is the ramp flow (in veh./h) to be applied during the new period k; $q_{in}(k-1)$ is the measured upstream motorway flow (in veh/h) over all lanes during the previous time period; $o_{in}(k-1)$ is the measured upstream motorway occupancy (in %) (averaged over all lanes) during the previous time period; q_{cap} is the downstream motorway (pre-specified) capacity; r_{min} is a minimum admissible ramp flow; o_{cr} is the critical occupancy. The DC strategy attempts to add to the last measured upstream flow $q_{in}(k-1)$ as much ramp flow $r(k)$ as necessary to reach the known downstream motorway capacity. If, however, for some reason the last upstream measured occupancy $o_{in}(k-1)$ becomes overcritical (i.e. a congestion may have formed), the ramp flow $r(k)$ is reduced to the minimum flow r_{min} in order to dissolve the apparent congestion. Finally, in order to avoid ramp closure, the ramp flow $r(k)$ resulting from this strategy is truncated, if it is smaller than r_{min}.

Figure 2.3: Demand-capacity local ramp metering strategy (Papageorgiou and Papamichail, 2007)



Clearly, the DC strategy does not really represent a closed-loop strategy but an open-loop disturbance-rejection scheme. It is a feed-forward control instead of a feedback control, which is blind with regard to the control outcome and generally known to be quite sensitive to various non-measurable disturbances. In addition, a pre-specified flow capacity value is targeted in the strategy. In fact, the mainstream flow capacity is uncertain on different days, even under similar environmental (e.g. weather, lighting) conditions (Keen et al., 1986); in contrast, the critical occupancy o_{cr} being more stable from day to day even with different environmental conditions (Cassidy and Radjanakanoknad, 2005), it may provide a more robust and efficient target for ramp metering operation. So if a fixed capacity value is used, this may be either too high on some days or too low on other days. It is an internal flaw of this control concept.

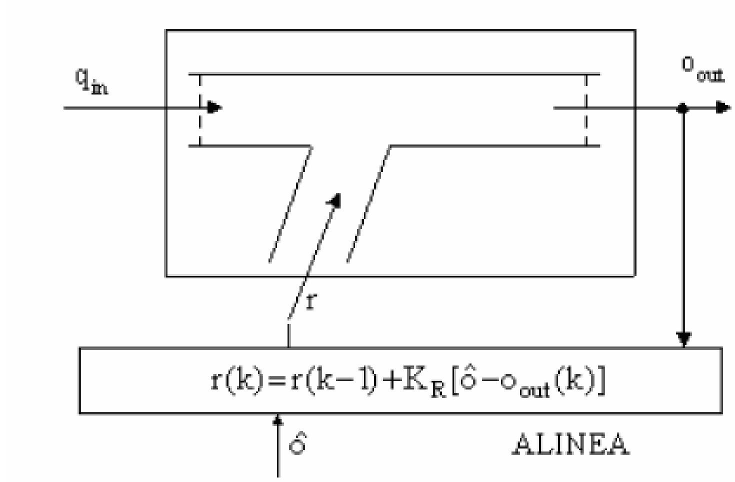
2.1.2 ALINEA

ALINEA (Asservissement LInéaire d'Entré Autoroutière) control is a feedback ramp metering strategy (Papageorgiou et al., 1991). It let the inflow be determined as proportional to the difference between the ideal occupancy and the observed occupancy.

$$r(k) = r(k-1) + K_R[\hat{o} - o_{out}(k-1)]$$

where K_R>0 is a regulator parameter and $\hat{o}$ is a targeted set (desired) value for the downstream occupancy. Typically, but not necessarily, $\hat{o} = o_{cr}$ may be selected, in which case the downstream motorway flow becomes close to q_{cap} (see Figure 2.4). The same value of K_R has been used in all known simulation or field applications of ALINEA without any need for fine-tuning. If occupancy o is measured in the range [0,100]%, then KR=70 veh./h/% is recommended.

Figure 2.4: ALINEA local strategy (Papageorgiou and Papamichail, 2007)



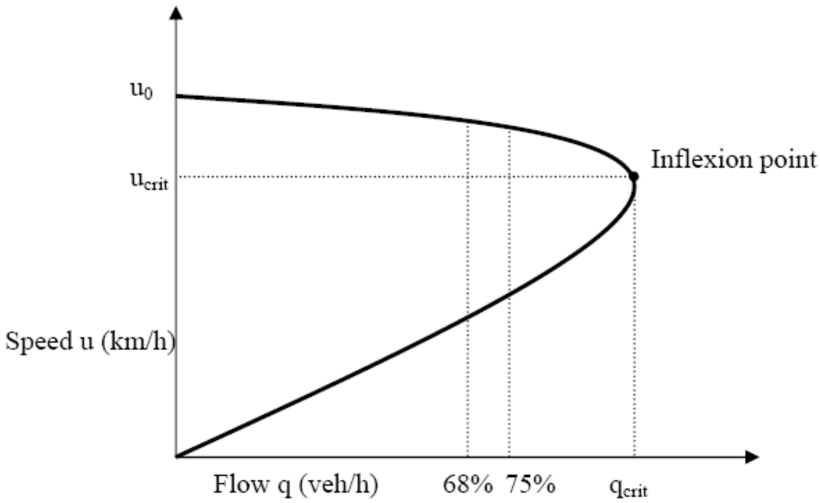
The above equation is called an I-type (integral) regulator in the classical Automatic Control Theory. It is well-known that this regulator leads automatically to $o_{out} = \hat{o}$ under stationary average conditions, i.e. when traffic conditions from time-period to time-period are not changing substantially, This is a particularly attractive feature of ALINEA as it automatically rejects any changing values of q_{in} as well as other possible disturbances. ALINEA reacts smoothly even to slight errors $\hat{o} - o_{out}(k-1)$, thus stabilizing the traffic flow around the set value. Meanwhile, as ALINEA targets the relatively stable critical occupancy $\hat{o} = o_{cr}$ for maximum motorway throughput, it does not suffer from the degraded efficiency caused by uncertain flow capacity values.

2.1.3 RWS strategy

In this project, the ramp metering controllers used for research have the same configuration as the roadside controllers on the A10 beltway. These controllers developed by the Dutch ministry of transport are based on the RWS strategy which is actually derived from DC strategy. In the following, an overview of the Dutch control strategy for ramp meters (TDI) will be given. More detailed information about the Dutch TDI system may be found in (Middelham and Taale, 2006) and (Rijkswaterstaat DVS, 2007b-d).

The RWS strategy is based on the flows on the motorway and on the on-ramp and the speed of the traffic on the motorway. The traffic data is measured with induction loops. At the roadside, the detectors not only read the flow data, but also average speed instead of occupancy rate. This control principle is based on the speed vs. flow fundamental diagram as shown in the figure below. The essence is to prevent the traffic state from reaching the inflexion point.

Figure 2.5: Fundamental diagram: speed vs. flow



- **Switch on/off control**

The flow and average speed measured are compared with the threshold values (e.g. flow: 75% of capacity, speed: 70 km/h). If these thresholds are exceeded, the metering system is activated. The metering system is switched off based on the measured flows and speeds, again compared to certain thresholds (e.g. flow: 68% of capacity, speed: 80 km/h).

- **Control Scheme**

The strategy aims at a good use of the available capacity. The number of vehicles allowed to enter the motorway is calculated with:

$$r_k = C - I_{k-1}$$

Where r_k (in veh/h) is the number of vehicles allowed to enter the motorway in time interval k, C is the pre-specified capacity of the motorway downstream the on-ramp and the variable I_{k-1} is the measured and smoothed flow upstream the on-ramp in the previous time interval.

- **Cycle time**

The cycle time of the metering system is then calculated with:

$$t = \frac{n * 3600}{r_k}$$

Where t is the cycle time in seconds and n is the number of lanes on the on-ramp. This calculated cycle time is compared with a minimum and maximum value and if necessary, these values are used instead of the calculated one. Usually, the maximum cycle time is 15~20 seconds (Rijkswaterstaat DVS, 2007f). During the green time, only one vehicle per lane is allowed to enter the motorway in most cases, known as a one-car-per-green realization in the Netherlands (somewhere: two-car-per-green). An important point is that the green time is dynamic. It depends upon the reaction time of the driver and its acceleration and is in a range of tenths of seconds. Typically, the green time is 2.0 seconds. The amber time is dynamic and depends upon the speed behind the stop line. Typically, the amber time is 0.5 seconds. The length of the red time varies, depending on the actual situation on the motorway and taking the queuing on the on-ramp into account. It is the rest of the cycle time minus the green time minus the amber time. The minimum red time is 2.0 seconds. Given these figures the minimum cycle time is typically 2.0+0.5+2.0=4.5 seconds. That means, in control status, the maximum metering flow is 800veh/h (3600/4.5) per lane.

For each ramp metering, when speed drops on the motorway either upstream or downstream, the access from the on-ramp is limited to a minimum. When a queue develops on the on-ramp, the access from the on-ramp may be set to a maximum. Moreover, when the length of a queue on the on-ramp reaches to congestion detector (filedetector) located at the beginning of on-ramp where the congestion status is detected, there are three options for the control schemes. Firstly, the cycle time is set to zero (a minimum value) in order to decrease the queue (Rijkswaterstaat DVS, 2007b). Or the cycle time is set to a maximum (usually not used). In some practical cases, ramp metering is released (switch off manually from traffic control centre) so as to let the complete demand enter the motorway. The last option is actually used at Amsterdam A10-west in reality.

The Dutch control strategy (RWS) is straightforward compared to ALINEA occupancy strategy. The basic measured parameters are flow and speed instead of occupancy rate, so the control application is simpler and better operable in reality. However, it is also noticed that the RWS strategy is derived from demand-capacity (DC) strategy, which is feed-forward disturbance-rejection policy and generally known to be sensitive to various further non-measurable disturbances (e.g. a slow vehicle, a short shock wave, merging difficulties, etc.) and thus low accuracy. Finally, a pre-specified flow capacity C is used in strategy which may lead to further efficiency degradation due to the inherent uncertainty of the motorway capacity (the control strategy may be too permissive on some days and too restrictive on other days).

In order to improve the existing ramp metering system in the Netherlands, Stanescu (2008) has investigated whether a value of capacity C based on current conditions would improve the impact of the RWS algorithm. Furthermore, the ALINEA occupancy strategy could be introduced as it targets a more stable set value $\hat{o}$. And it was reported that the ALINEA algorithm produced comparable or better results than the RWS algorithm (Middelham and Taale, 2006). However, occupancy as a set parameter is not understood very easily. Due to operational reasons such as comprehensibility by traffic operators and traffic managers, it has been decided to stay with the RWS strategy. This also because tuning and validating ramp controllers from time to time is inevitable and a difficult and time-consuming task. Hence, the coordination strategy of several individual ramp metering controllers should be introduced. In this report, the focus is on the coordination control.

2.2 Coordinated ramp metering

Other than the drawback of the local ramp metering system presented above, the system by its nature, does not address the strategic problem of optimal utilization of the overall infrastructure, nor does it guarantee a fair and orderly capacity allocation among the ramps.

Hence, the main reasons for coordinated ramp metering are the limited ramp storage space, which calls for co-operation of multiple ramps to avoid congestion, and equity consideration which can hardly be observed if local ramp meters act independently of each other.

Several coordinated ramp metering strategies have been proposed in the technical literature, but field installations are rather sparse (mainly in the USA). These strategies may be further subdivided into optimal control strategies, hierarchical control strategies and rule-based strategies. The following passages will provide a brief overview of these strategies, which are described in further detail in (Papageorgiou and Papamichail, 2007).

Optimal control application to coordinated ramp metering on motorways has a long history (Papageorgiou and Kotsialos, 2002). Recently developed tools include AMOC (Advanced Motorway Optimal Control) and OASIS (Optimal Advanced System for Integrated Strategy). Optimal-control based ramp metering strategies employ a macroscopic traffic flow model (e.g. METANET) that is run several times in an iterative way so as to produce optimal ramp metering flows over an optimization time-horizon. The main advantage of optimal control strategies is that they produce pro-actively the best achievable results to be used as a reference case for the assessment of the sub-optimality level. The solution provided by optimal control strategies is of an open-loop nature. As a consequence, its direct application may lead to traffic states different from the calculated optimal ones due to errors associated with the initial state estimate, the prediction of the future demands and the model parameters used.

A receding-horizon (model predictive) approach can be employed to address any mismatch between the predicted and the actual system behaviour. This approach is extended to the hierarchical control system which consists of three layers: the estimation/prediction layer, the optimization layer and the direct control layer. The estimation/prediction layer receives historical data and information as input. This information is processed in order to provide the current state estimate and predictions of the future demands to the next layer.

The optimization layer (e.g. using the generic motorway network optimal control tool: AMOC) would generate the optimal control trajectory and the corresponding optimal state trajectory with the given demand predictions. The direct control layer consists of independent regulators, one for each metered ramp, that use the optimal (AMOC) results as set values for their operation. It is shown that this control scheme is efficient, fair and real-time feasible in (Kotsialos et al., 2005).

The rule-based coordinated ramp metering strategies make their real-time decisions by checking appropriate heuristic rules and activating specific regulators or actions at individual on-ramps. Since no common general method is used, rule-based strategies may be quite different in approach, complexity, required calibration effort, and, most importantly, efficiency. A few rule-based strategies have been reported. A list of these strategies is given below:

Table 2.1: List of different rule-based strategies

No.	Name	Description
1	**ACCEZZ algorithm**	The method is based on fuzzy logic. The rule base, defined as the set of rules in the fuzzy logic algorithm, incorporates human expertise.
2	**Zone algorithm**	The motorway network is divided into zones which end at a bottleneck. The algorithm aims at balancing the entering and exiting traffic volumes of each zone.
3	**Helper algorithm**	It performs a form of hierarchical coordinated control where decisions with respect to local ramp metering are taken on a higher level.
4	**Bottleneck algorithm**	Demand-capacity strategy is used at local level. At a network-wide level, the formation of congestion at various bottleneck locations is identified and a decision is made with respect to the required volume reduction.
5	**Fuzzy logic algorithm**	The fuzzy logic approach requires the use of a number of inference rules, which provide the guidelines for the system's behaviour.
6	**Linked-ramp metering system**	The coordination aspect of this system rests on a heuristic logic, similar with that of the Helper Algorithm.
7	**Sperry ramp metering algorithm**	The strategy operates at two distinct modes, the restrictive and the non-restrictive with respect to a predefined threshold.
8	**SWARM strategy**	It uses a linear regression and Kalman filter applied to detector data for the forecast of the future traffic demands.
9	**HERO algorithm**	HERO (HEuristic Ramp metering coOdination) incorporates local ALINEA regulators. When the queue of an on-ramp becomes larger than a predetermined threshold, then the burden of decreasing this queue is assigned to upstream on-ramps.

An advantage of these methods is that they were actually implemented and operated, although the level of achieved efficiency is not easy to assess and comparative evaluations are very few. Some disadvantages that are partly shared by several approaches are the usage of pre-fixed flow capacity values for the motorway mainstream and the feed-forward approaches used at either the local or the global level of both.

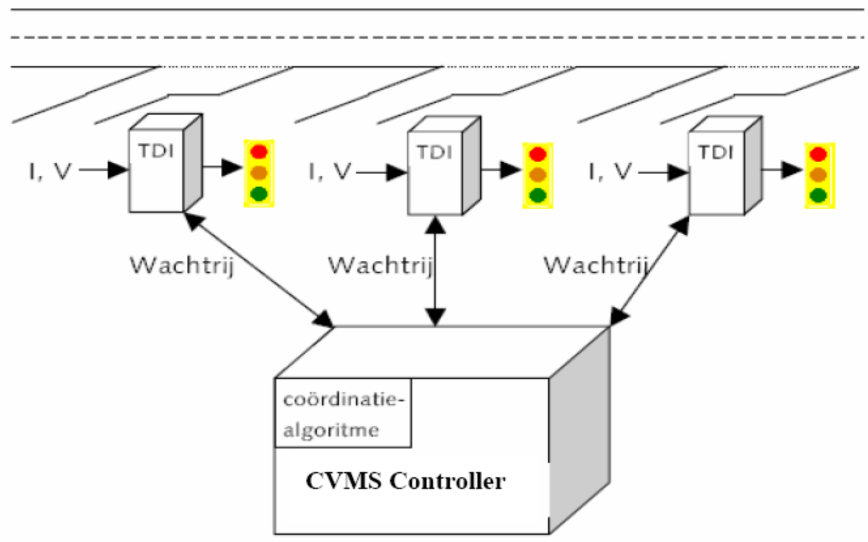
Nevertheless, the proposed HERO algorithm (in cooperation with employed local ALINEA regulators), by its nature, can circumvent the disadvantages mentioned above. In fact, the new strategy is shown to reach the efficiency of sophisticated optimal control schemes (Papageorgiou and Papamichail, 2007; Papamichail and Papageorgiou, 2007a-b). A version of HERO was field-implemented and successfully tested in EURAMP's Paris site (motorway A6 north). HERO is currently considered for field application in a couple of further sites in Europe and beyond and it is regarded as the most recent and promising approach for large-scale field application of coordinated ramp metering.

2.3 Introduction to HERO algorithm

Kotsialos et al. (2005) have reported positive simulation results on the ring-road A10 by implementation of coordinated ramp metering using a macroscopic simulation tool "AMOC". However, to implement the control strategy in AMOC into field areas is very complex and not operational. So, Rijkswaterstaat together with the author of the initiative developed a simple coordination strategy (HERO-algorithm) for the Amsterdam beltway network. Note that the algorithm used in this project, which incorporates local RWS controllers, is a variant version of the "real" HERO algorithm, which uses ALINEA regulators for the local level as described in (Papageorgiou and Papamichail, 2007; Papamichail and Papageorgiou, 2007a-b). Nevertheless, the basic concepts of these two algorithms are similar, namely rule-based control strategy.

In the following, the basic description of the HERO algorithm will be presented.

Figure 2.6: Basic control concept of the coordinated ramp metering (Rijkswaterstaat DVS, 2007a)



The current HERO algorithm belongs to rule-based strategies, which make their real-time decisions by checking appropriate heuristic rules and activating specific regulators or actions at individual on-ramps.

The control scheme is simple and reactive, based on readily available real-time measurements without any need for real-time model calculation or external disturbance prediction.

In the figure above, it is shown that each Ramp-metering (TDI) in the coordinated network is an agent-based control system, which in principle works autonomously at a local level. Each TDI gets up-to-date information from the roadside in order to control the traffic on the on-ramp road, aiming at realizing the local optimization. The information, for instance, consists of speed and flow on the motorway, and queue length on the on-ramp. Each controller is based on the RWS control strategy which has been described in section 2.1.3. The local control measure does not take the upstream/downstream situation of the on-ramp into account.

In the HERO algorithm, all the individual ramp metering systems are taken into consideration. Each TDI processes locally. When the queue length on a certain on-ramp is large than a predefined threshold, then the burden of decreasing this queue is assigned to upstream on-ramps, and HERO starts gradually recruiting upstream located metered ramps as “slaves” to activate metering. The reason for recruiting “slave” ramps is in order to factually enlarge the exploitable storage space that would otherwise be limited to the storage space available at the “master” ramp only. More specific, it aims at preventing the queue on “master” ramp from reaching the location of the congestion detectors.

For control application, a CVMS (Centraal Verkeerregelinstallaties Management Systeem: Central Traffic Signal Control Management System) controller for algorithm calculation is used to communicate and coordinate with each local controller. This coordination controller reads the data from each ramp metering controller, including control status, traffic situation of each TDI, current queue length on the on-ramp and maximum admissible queue length of each TDI. When a certain TDI starts to control and its queue exceeds a certain threshold, it is regarded as “master” controller in the algorithm. Then the coordination controller will tell the successive controllers (defined as “slave” controllers) when to start/stop metering control and the minimal desired queue length on-site.

The working principle of the HERO algorithm is detailed as follows:

Some variables and parameters are explained in advance, as shown in the following table:

Table 2.2: List of variables and parameters in the HERO algorithm

Variable/Parameter	Description
i	the concerning TDI
j	the concerning coordination route
k	the following upstream located TDI
n	the number of TDI in a certain coordination route
master[i]	the related TDI as a master controller
slave[k]	the related TDI as a slave controller
wachtrij_actueel[i]	current queue length on on-ramp
wachtrij_max[i]	maximum admissible queue length of each TDI
som_wachtrij[i]	summation of the current queue length of each TDI within the coordination control string (start with master[i])
som_wachtrij_max[i]	summation of the maximum admissible ramp queue of each TDI within the coordination control string (start with master[i])
kritische_drempel_inschakelen[j]	activation threshold of the concerning coordination route
kritische_drempel_uitschakelen[j]	deactivation threshold of the concerning coordination route

More detailed explanation related to these variables and parameters can be found in (Rijkswaterstaat DVS, 2007a).

1. Local RWS-C controllers (TDI) are operated at each metered ramp for maximum local motorway mainstream throughput.

2. During every control interval T_c, the current ramp queue lengths and control status are received from the local controls; based on these data, possible coordination actions are decided.

3. When a ramp relative queue (wachtrij_actueel[i]/wachtrij_max[i], $i \in [1, n-1]$) exceeds a certain activation threshold value (kritische_drempel_inschakelen[j]), it becomes a “master” (master[i], $i \in [1, n-1]$), and the HERO control strategy is activated. HERO starts gradually recruiting upstream located metered ramps as “slaves” (slave[k], $k \in [i+1, n]$) based on certain criteria, up to a pre-specified maximum number of slaves (usually 4~6).

4. Slave ramps receive from HERO minimum desired ramp queue lengths to maintain, so as to virtually increase the available storage space needed at the master ramp to face the forming of congestion. The minimum desired queue length is given by:

$$wachtrij\_\min[k] = \frac{wachtrij\_\max[k] \times som\_wachtrij[i]}{som\_wachtrij\_\max[i]}$$

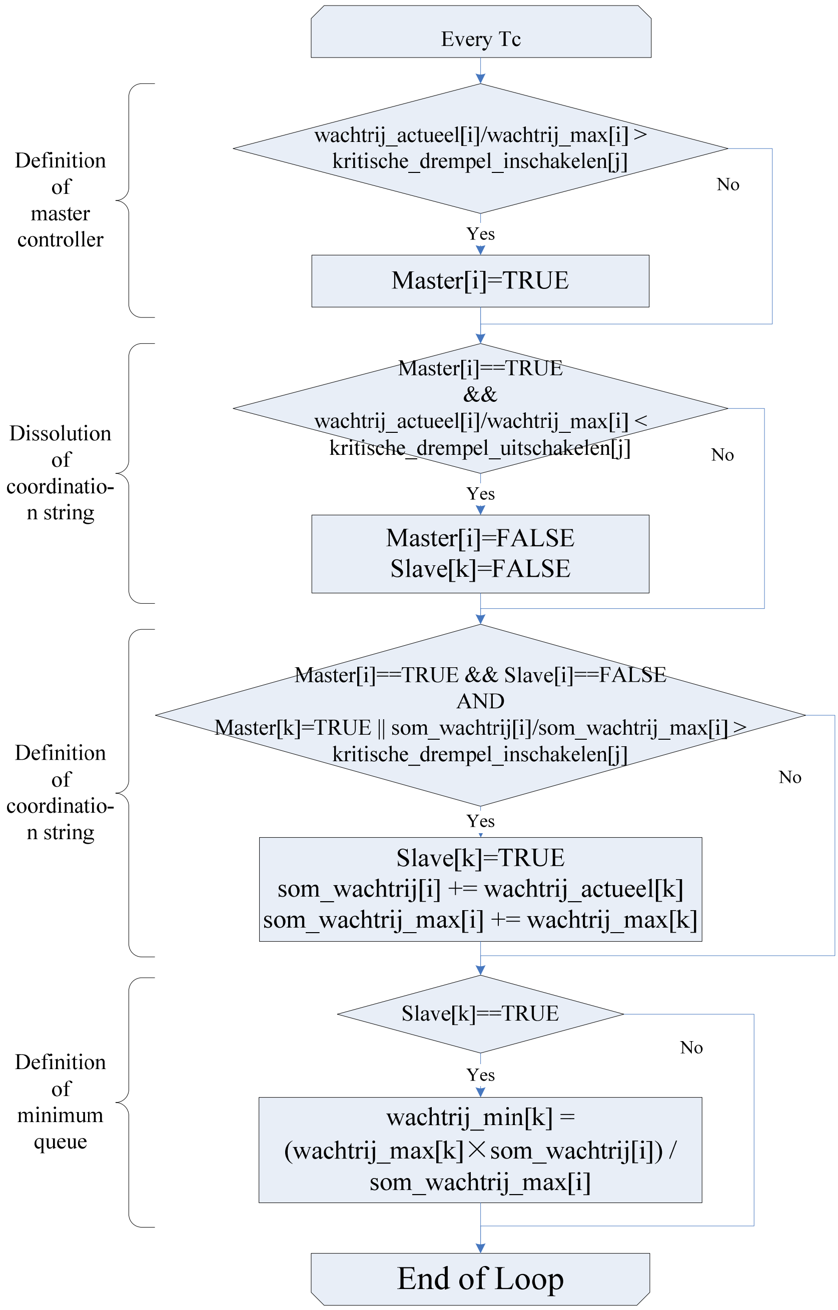
As the demand increases, the queue of the master ramp may continue to increase; therefore, the HERO algorithm is updating the minimum queue length of each slave ramp each T_c such that the relative queues at each ramp are maintained close to each other.

5. The created cluster(s), each consisting of one master and several slave ramps, are dissolved if the relative queue of the master ramp falls below a deactivation threshold (kritische_drempel_uitschakelen[j]).

The schematic control strategy is shown as follows. There are four main steps in the following flowchart. The first step is the definition of the master controller related to the working principle 3. Secondly, it is the definition of dissolution of the coordination string related to principle 5. The third step provides the definition of coordination string and its related slave controllers corresponding to principle 3. The last step determines the minimum desired queue length for each slave controller corresponding to principle 4.

Note that the flowchart just presents the control concept, which is simple version of the specific programming/computing procedure. That means the loop statement of each step is neglected here. The sequence of the steps is in accordance with that in the source code.

Figure 2.7 Schematic of the HERO algorithm



As each TDI controls locally, the control scheme is also determined at local level. The decision of control-application and the cycle time would be decided based on the local traffic situation as well as the message sent from HERO (CVMS). If upstream located TDI must coordinate, which means the Help-Function "H_coordinatie" is "on", then the related TDI will start metering and it calculates the cycle time. The current queue length on the on-ramp and the minimum queue length determined in HERO algorithm for this slave ramp metering controller will be taken into account in the cycle time calculation.

If the current queue length of a "slave" is smaller than the minimum desired queue length (imposed by coordination algorithm), the cycle time is established higher. The movement on the on-ramp is stopped so that the queue length is created. If the current queue length is larger than the maximum admissible queue length, then the cycle time is lower. More movement is let through as a result of which the queue length becomes smaller.

The cycle time for each TDI application will be stipulated in a hierarchical level (Rijkswaterstaat DVS, 2007a). The first level is on the basis of the rest of capacity, given by the following formula:

$$Cycletime_{rest\_capacity} = \frac{n_{lane} \times n_{veh} \times 3600}{Capacity_{highway} - I_{agh\_}RW_{so}}$$

Where, n_{lane} = number of lane on the on-ramp

n_{veh} = number of vehicle per green per lane

(Dutch: one-car-per-green in most cases, n_{veh} =1; somewhere: n_{veh} =2)

$I_{agh\_}RW_{so}$ = incoming flow on the motorway upstream the on-ramp

If the cycle time calculated with respect to the minimal queue length is larger than that defined in the first level, then the second cycle time will be used. It is calculated as follows:

$$Cycletime_{\min\_queue} = \frac{n_{lane} \times n_{veh} \times 3600}{(Queue_{current} - Queue_{\min.desired}) \times \dfrac{3600}{Control\_Interval}},$$

If *current queue < minimum desired queue,*

Then, $Cycletime = \max[Cycletime_{rest\_capacity}, Cycletime_{\min\_queue}]$.

Thirdly, the cycle time is on basis of the maximum admissible queue if *Cycletime* $_{max\_queue}$ is less than *Cycletime* $_{rest\_capacity}$. The definition is given by:

$$Cycletime_{\max\_queue} = \frac{n_{lane} \times n_{veh} \times 3600}{(Queue_{current} - Queue_{\max.admissible}) \times \frac{3600}{Control\_Interval} + I_{gh}\_TR_{so}}$$

If *current queue > maximum adimissible queue,*

Then, $Cycletime = \min[Cycletime_{rest\_capacity}, Cycletime_{\max\_queue}]$.

Where, $I_{gh}\_TR_{so}$ = incoming flow on the on-ramp

Finally, the definition of cycle time is based on remaining conditions, such as traffic congestion on-ramp, restriction of cycle time, etc. A precise description of above calculations and a description of the remaining conditions could be found in (Rijkswaterstaat DVS, 2007b).

The essence of the algorithm is to postpone the occurrence of congestion on the motorway on basis of more ramp storage space of the successive on-ramps, leading to higher outflow and lower total travel time.

2.4 Conclusions and problem restatement

In this chapter an overview has been given of current approaches to individual and coordinated ramp metering control. In the following table, a list of main related control strategies is presented.

Table 2.3: List of related control strategies

Control strategies	Control property	Coordination
RWS (Demand-Capacity)	feed-forward (pre-fixed capacity)	no
ALINEA	feedback	no
HERO (ALINEA)	feedback	yes
HERO (RWS)	feed-forward (pre-fixed capacity)	yes

The coordination control scheme, HERO, is regarded as currently the most promising approach for large-scale field application by Papageorgiou and Papamichail (2007). The features of this control concept are simple, real-time operable and highly efficient. And it is very attractive to the Dutch government for real application. A simplified HERO (RWS) algorithm is developed based on the current Dutch ramp metering systems and will be finally applied to the whole Amsterdam A10 network in the coming future. As HERO incorporates local RWS controllers, the drawback of the local control strategy is embedded in the coordination scheme. It will be interesting to see whether the coordination control could compensate this drawback. So, correctly identifying and analyzing the effect and consequence of the proposed HERO algorithm is crucial to developing an implemental coordination control scheme to enhance the whole performance in the Amsterdam network.

Currently, although some macroscopic simulation (AMOC) studies show the positive improvement on the traffic situation in A10 network based on the optimal ramp metering control or the hierarchical control strategy, the analysis about coordination control on A10 based on the rule-based control algorithm (HERO) is never reported. Meanwhile, it is noticed that the previous coordination studies mainly operate in a macroscopic simulation environment. It is proposed to use a microscopic simulator which is supposed to give more precise and reliable results.

Therefore, the new proposed HERO algorithm will be tested in a microscopic simulation environment. The effect of the new algorithm will be compared against non-coordination and no control cases. The optimal parameter settings for the algorithm will be studied within the project as well. The details of the proposed methodology and the related case study are described in the next chapters.

Chapter 3 Methodology for evaluation of HERO algorithm

In this chapter, the methodology to evaluate the HERO algorithm is discussed. First of all, the introduction to the microscopic tool VISSIM is given. Next the traffic assignment method in VISSIM is described. Subsequently, the realization of ramp metering and its coordinated control is addressed. Then, assessment criteria are defined. Finally, the methods for impact analysis, parameter optimization and its robustness study are presented.

3.1 VISSIM model and traffic assignment process

As discussed in Chapter 1, the macroscopic model used before for impact analysis of the coordination algorithm by its nature has a drawback of the unrealistic capacity drop, which may be the direct reason for overestimated results. Thus the microscopic simulation model VISSIM will be used to predict the effects of the new control strategy HERO.

VISSIM is a microscopic, time step and behaviour based simulation model developed to model urban/motorway traffic and public transit operations. The program can analyze traffic and transit operations under constraints such as lane configuration, traffic composition, traffic signals, transit stops, etc., thus making it a useful tool for the evaluation of various alternatives based on transportation engineering and planning measures of effectiveness. (PTV, 2007)

The traffic demand is placed in the origins of the zones as defined in O-D matrix. The flows from all the origins need to find some reasonable routes to reach their destinations. Then traffic assignment is necessary. The standard assignment procedure in transportation planning is the so called Static Assignment. Static here means that the travel demand (how many vehicles want to make trips in the network) as well as the road network itself is constant over time. However, in reality travel demand changes significantly during the day, and even the road network may have time-dependent characteristics, e.g. signal control may vary during the day (traffic control system). The available traffic demand is given in an O-D matrix pattern with no specific route choice. To consider these time dependencies and the condition of the exiting model, Dynamic Assignment procedures are required. Furthermore, the dynamic assignment could help to model the route choice behaviour of drivers (e.g. rat-running phenomena), especially when different control strategies are applied. In this case, dynamic traffic assignment will be used for simulation.

In dynamic assignment (PTV, 2007), the criteria for the route search are generally determined by costs with the real travel times measured in the current simulation. The following expression is used to calculate the general cost:

General cost = α * travel time + β * travel distance + γ * financial cost + Σ supplement

The general cost is computed as a weighted sum in VISSIM. The coefficients α, β and γ can be defined by the user. In VISSIM the weights are specific to vehicle types and allow the modelling of driver groups with different route choice behaviours. The travel distances are determined by the geometry of the links (sum of link lengths). The financial costs of an edge (the connector link between two zones) are the sum of the costs of all links that are contained in that edge. The individual cost of a link is computed by multiplying the travelled distance on that link by the cost specified as the link attribute plus adding the supplements.

To calculate the general cost in VISSIM, α, β and γ are chosen as 5.0, 0.0 and 1.0 respectively. Usually, the financial cost of each link is set as zero in the network. That means the travel distance and financial cost are neglected in the expression, and the travel time information is the most important parameter in general cost.

The dynamic assignment module uses O-D demands to assign vehicles to the transportation network. The link traffic volumes are determined by an iterative process where each simulation run is considered as an iteration. Each iteration records link travel time information, thus determining the fastest routes between all origins and destinations. Vehicles with the same O-D pair will be assigned to suitable routes according to Kirchhoff's law with respect to general cost:

$$p(R_j) = \frac{U_j^k}{\sum_i U_i^k} = \frac{e^{k \cdot \log U_j}}{\sum_i e^{k \cdot \log U_i}} = \frac{e^{-k \cdot \log C_j}}{\sum_i e^{-k \cdot \log C_i}}$$

Where, $p(R_j)$ = probability of route j to be chosen;
U_j = utility of route j;
C_j = general cost of route j;
k = sensitivity of the model (default 3.50).

This route assignment approach implies that paths have to be generated in advance. After this ‘pre-trip’ convergence the model can be applied for network analysis. Note that during a simulation routes are not changed.

The assignment process requires that traffic volumes and travel times on the links converge after a number of iterations depending on the size of the network and the traffic demands. However, for a network with many OD-relations, this is really a delicate and time-consuming work! For example, in the network with 112 zones, the number of inter-zonal relations is 12432 (112×112-112), so the route set of the network is quite large.

The sequence of simulations is shown below. A preparation stage is needed to get paths in a network, the specific principle of dynamic assignment can be found in Appendix E. Then, multiple simulations are required to deal with the stochastic traffic processes.

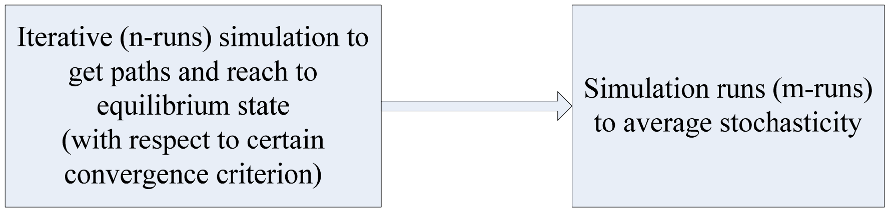


Figure 3.1: Sequence of simulation

3.2 Implementation of HERO control

In VISSIM, the ramp metering cannot be realized by using its internal modules. In order to assess the HERO algorithm, the related control should be functioned in the model.

The HERO control application has been realized in another macroscopic simulation environment: Flexsyt as a demo. Ramp metering relies on a control interface, called “flash”, to realize control in this macroscopic model. However, this compiler is incompatible with VISSIM. Then, much work has been done to translate this demo version into VISSIM simulation environment.

The ramp metering (Standard Ramp Metering Application) and its coordinated control will be realised via the external control interface in VISSIM. The control interface (Promit-E application (VRIVissim.exe)) is developed by the traffic company “Vialis” (the distributor of VISSIM in the Netherlands), which is actually on basis of Dynamic Data Exchange (DDE) communication technique. The interface reads the “real-life” data in VISSIM and transfers these into each controller. Then each controller would apply the related control scheme into VISSIM based on the information collected.

3.3 Assessment criteria definition

In order to assess different research scenarios, the performance criteria need to be decided.

The total travel time spent (TTS) by all vehicles is an important index to reflect the overview performance of the whole network; it is very common in most projects as a control criterion (Papageorgiou and

Kotsialos, 2002; Taale, 2003; Kotsialos et al., 2005; Kotsialos and Papageorgiou, 2004; Hegyi et al., 2001; Papamichail and Papageorgiou, 2007a-b; Zhang et al., 2008). Less TTS in the network means higher outflow, less delay and thus better traffic situation. However, all traffic demand defined in the input O-D matrices is not equal to the number of vehicles really entered in the model, some vehicles are “stacked” outside the network because of insufficient space to let all vehicles enter from origins. The difference of number of vehicles in the network may change from scenario to scenario. Hence, it is necessary to compare average travel time of individual vehicle existed in the network. Meanwhile, it is necessary to know the total distance travelled in the network. This index can also be used to reflect the related amount of traffic that travel in the network.

As discussed in Chapter 1, the main studied area of the Amsterdam network is the motorway section from S105 to S101. The bottleneck, on-ramp S101, is very important here. It is reasonable to know the traffic condition (outflow, driving speed, travel time) information on this area. Average travel times, total throughput, mean speeds and related speed contour plot of the motorway section can be used to reflect the improvement on traffic condition with respect to the new control measures. Moreover, the speed contour plot will be also used for the comparison with the plot derived from MONICA data collected from the reality, for calibration of the model, see the Section 5.3.

An additional requirement of ramp metering installations is equity (or fairness). The delays experienced by road users at different metered ramps should not be excessively different from each other. Average delay time of each on-ramp is of great necessity here. Meanwhile, queue length of each on-ramp over time will also be used to reflect the fairness requirement. Furthermore, these two criteria can be used to assess the equity of different traffic groups (the motorway traffic and the traffic on the underlying network).

Another effect of ramp metering control is on the route choice. Road users choose their routes towards their destinations to minimize their individual travel times. When a control measure is introduced that may change the delay experienced in particular network links (e.g. on specific on-ramps), a portion of the drivers will accordingly change their usual route in order to benefit from the new network conditions. The throughput of the on-ramp road (usage of on-ramp) can be used to reflect the influence on route choice by different control measures.

Based on the above analyses, the evaluation criteria could be determined. These criteria are, the total time spent, average travel time and total distance travelled in the whole network; the average travel time, total throughput, mean speeds and the related speed contour plots for the main study area; the average delay time, queue length and throughput on each on-ramp. More detailed description of the assessment criteria for the case study will be presented in the next chapter.

3.4 Method for impact analysis

For impact analysis, the coordinated ramp metering control will be compared against non-coordinated control and no-control cases. Then, three scenarios are needed. The null scenario is used as a reference. In this case, no control strategy is implemented. Secondly, the solitary ramp metering control strategy is tested to see the improvement of the DTM measure. Finally, the new HERO algorithm is simulated to see the benefit of coordinated control.

First of all, for each scenario, a preparation stage is needed to get the traffic model convergence. Based on the convergence network, further analysis on the outputs can be performed. As discussed in Section 3.1, multiple simulation runs are required to get an average result in order to deal with the stochastic processes in VISSIM. On basis of statistics, the more simulation runs are performed, the higher accuracy in the resulting values will be gained. The desired size of a simulation, which is able to estimate a particular parameter with a sufficient accuracy, depends on three factors, namely the variation in the phenomenon that is being measured (σ), the accuracy on the statement one wants to make (*d*) and the reliability on the statement (*Z*) (Verhaeghe, 2007). The following relationship holds:

$$n \geq \frac{Z^2}{d^2}\sigma^2$$

Since there are many parameters with regard to the assessment criteria as defined before, to calculate the required size of simulation for estimating the average travel time on the main area is taken as an example here. It is assumed that the standard deviation (σ) of this parameter is 30 (sec.). If this estimated parameter is with an accuracy of plus/minus 10 sec. (*d* =10) and with a reliability of 95% (*Z* = 1.96), the sample size (*n*) is equal to 35 (34.6). If the parameter is estimated with an accuracy of plus/minus 20 sec. and with the same reliability, then the sample size is reduced to 9 (8.6).

However, in this specific Amsterdam network, it is either difficult to measure the variation of certain parameters with respect to the assessment criteria or to determine the required accuracy. Meanwhile, simulation is a time-consuming work. In term of the consumption of simulation time and system memory, ten simulation runs are performed for each scenario, with different random seeds (Nr. 1 to Nr. 10). It is assumed that 10 runs are sufficient to get representative results.

3.5 Methods for parameter optimization and robustness study

Another aim of this graduation project is to improve the HERO algorithm for real implementation. The optimal parameter settings for the HERO algorithm should be found.

There are lots of parameters in each decentralized (agent-based) controller as well as in the HERO algorithm itself. Since the HERO algorithm mainly checks the queue length of each on-ramp with respect to the threshold values to decide when and where to start ramp metering, the optimization study will be restricted within the parameters related to queue length and local traffic conditions (speed and flow) to start ramp-metering control. These are, e.g., the activation and deactivation thresholds, the critical values of speed and flow for local control. So some local control parameters of each TDI controller, such as maximum amber time (5.0 s), fixed amber time (1.5 s), maximum cycle time (15.0 s), minimum red time (2.0 s), and so forth, will be remained as default.

To fully investigate the robustness and applicability of the proposed parameter settings, simulation tests will be conducted under various traffic demands. Based on the reference network with proper traffic demand, a less-congested network and an over-congested network should be determined for robustness study.

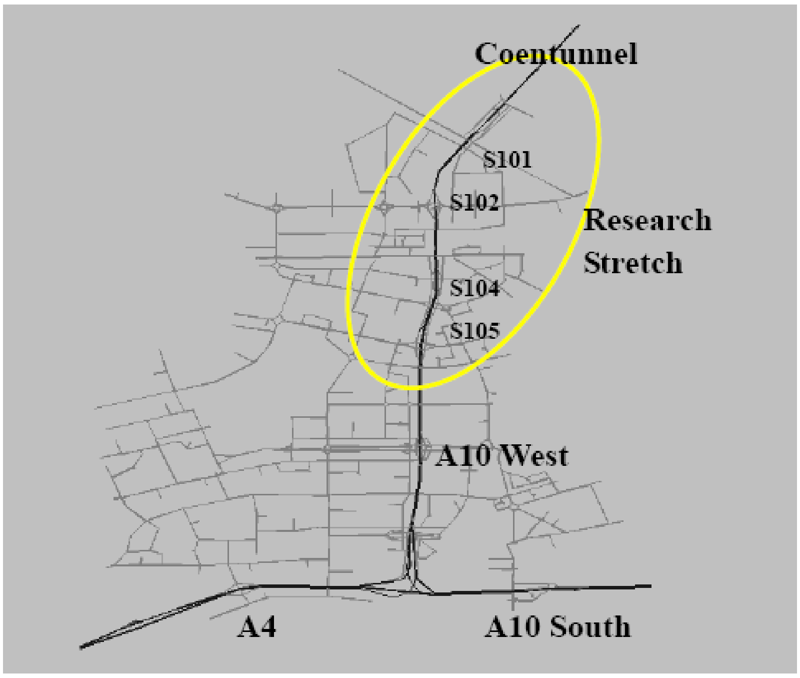
So far, the basic research methods for this simulation project are presented. The detailed case study will be discussed in the next chapter. After that, model modification and calibration are further needed before the “real” simulation test.

Chapter 4 Case Study: Amsterdam A10-West

In this chapter, the case study on the Amsterdam A10-west network will be discussed. Firstly, the introduction to the existing Amsterdam VISSIM model is given. Secondly, some assumptions for this model are addressed. Then, basic information about the infrastructure and the related controllers is described. Finally, the detailed criteria for assessment and the scenarios for parameter optimization are presented. On the basis of this information, the impact analysis and parameter optimization can be further investigated in the following chapters.

4.1 Introduction to the studied network

Figure 4.1: Existing VISSIM model for A10 west



The study area, parts of A10-west, A10-south and A4, has already been modelled in VISSIM, as shown above. What is worth mentioning here is that the main research stretch will be restricted to the motorway section from S105 to Coentunnel (yellow cycle). The traffic-related data, such as traffic demand and O-D matrix (collected in 2000) (Li, 2005; Taale et al., 2004), are included in this model. In the network, the area is subdivided into 112 zones as shown below. Each zone has a unique origin and destination as well as the related generation and attraction. Note that zones 109, 110 and 112 are regarded as the main origins and destinations of the motorway network, which are located at the ends of A10-west, A10-south and A4 in this model respectively.

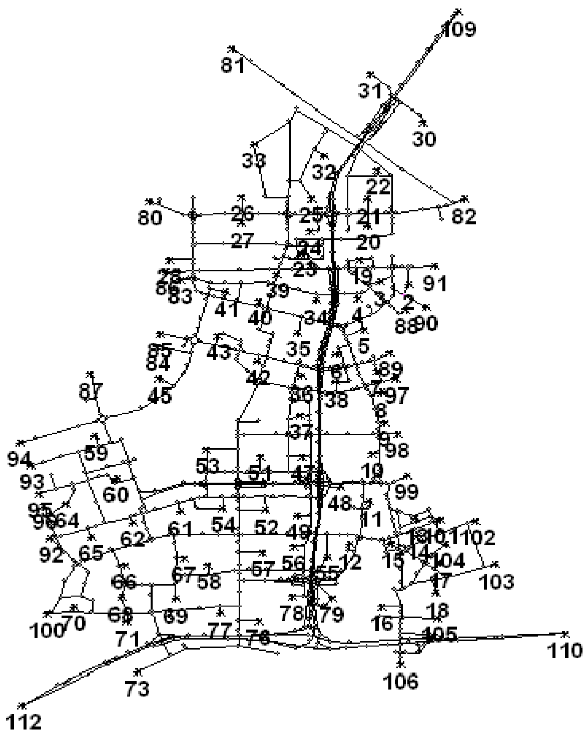


Figure 4.2: Zoning of the VISSIM model (Li, 2005)

4.2 Assumptions for the model

There are some assumptions related to the study model presented below:

4.2.1 Traffic demand information

The demand O-D matrix files are derived from the Amsterdam static model, from 15:30 to 18:00 in the afternoon peak in the year of 2000 (average demand data of the year) (Li, 2005; Taale et al., 2004). Firstly, the given O-D matrix is assumed to be reliable for our research, even though road works on the A10 west have been done after 2001 and different traffic control strategies (e.g. speed limit) have been implemented after that, thus the current O-D demand may be quite different from the given one. The total simulation period is two and a half hours. Since a warming-up period for simulation study is needed, the first half hour is preserved as this preparation period. Hence, the measurement will start from the first half an hour to two and a half hours. The cooling-down period will not be taken into account.

The bus type is excluded in the traffic demand input, as the demand data is only available for passenger cars. As a result, the bus lanes and the related bus routing will not be included in VISSIM. However, the truck (HGV) type should be taken into account in the traffic demand. Based on the measurement of flow for A10 west, it is decided that the truck flow accounts for about 10% of the total traffic flow.

It is noticed that the traffic demand used in VISSIM is different from the real situation at present. From the point of view of impact analysis, a network with a reasonable traffic demand is eligible for the investigation. While for parameter optimization, the control parameters will be used for real application in the end, so the optimal parameters generated from this model may not be suitable for real situation perfectly (to be tested).

4.2.2 Traffic control

The traffic-actuated control scheme is used in part of the urban traffic intersections within the study area in real life (Van Katwijk, 2008). However, in VISSIM, all the traffic controllers in urban area are fixed time control. Obviously, fixed time control can be simply reached in VISSIM so as to save system resource and simplify the network. Although it is assumed that this different urban traffic control strategy will not affect the performance of traffic flow on the motorway too much, the result related to the performance of the whole network may still be different.

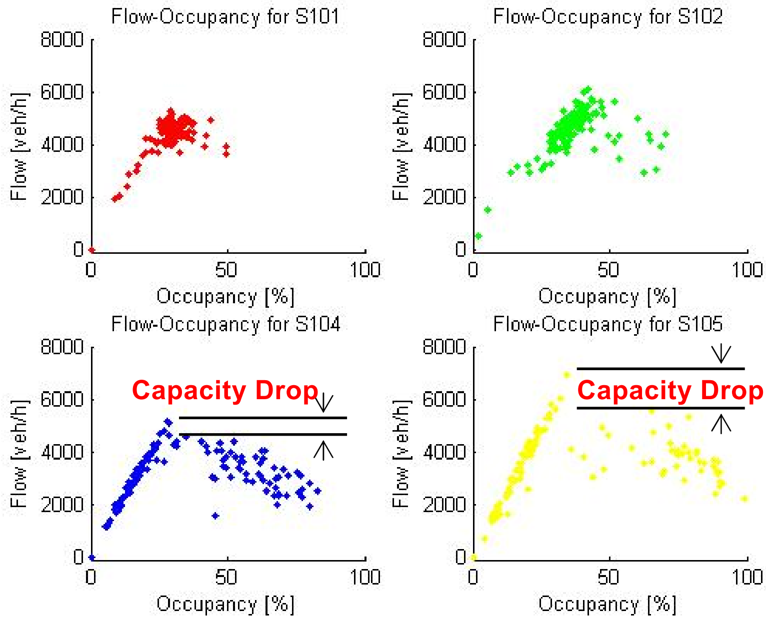
Meanwhile, the speed limit control strategy (limit of 80km/h) is implemented on A10-west in reality starting from October of 2005. In this study, this control measure will not be modelled in VISSIM. The main focus is on the ramp metering control. Otherwise, the effects of the two measures will be coupled. Some comments about the speed limit can be found in Section 5.3.1.

4.2.3 Capacity of the motorway

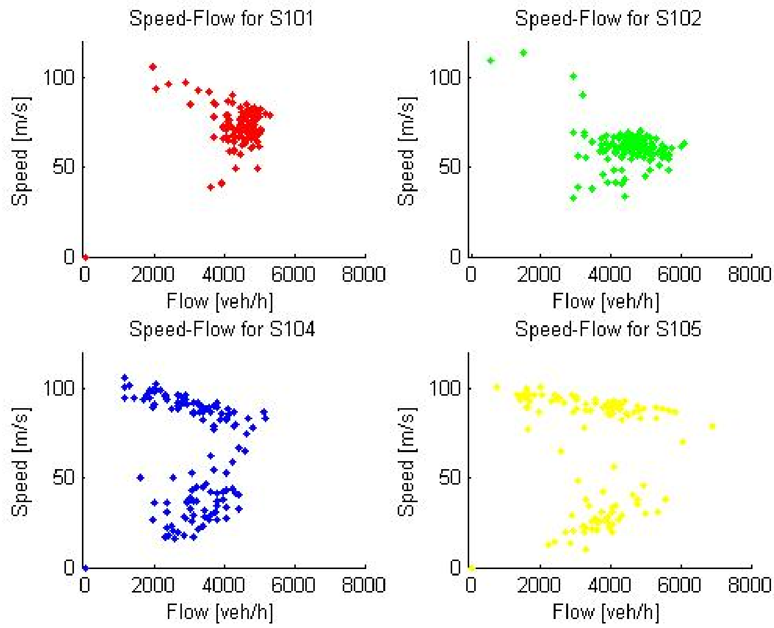
As known, the mainstream flow capacity is an uncertain value when designing traffic-responsive ramp metering strategies. Similarly, the road capacity in VISSIM is based on the car-following model (driving behaviour) instead of providing an exact value. However, as the external TDI controllers will be used in VISSIM model, the pre-specified value of motorway capacity q_{cap} needs to be decided for each controller in advance. So it is assumed that the motorway capacity is a fixed value used here. Note that the variation of capacity will not be taken into account in VISSIM. That means the parameter (desired time headway: CC1), which is used to affect the value of capacity in VISSIM, is set as default value (0.9).

Usually, the normal value of capacity on motorway ranges from 2100 to 2400 veh./h/lane (Hoogendoorn, 2007). In this simulation study, the capacity value will be determined on basis of the fundamental diagrams derived from the model. At the downstream section (bottle-neck section) of each on-ramp surveyed in this model, the detection is set so as to detect the flow, speed and occupancy rate (density) information. Based on the simulation information, the following figures are drawn to show the performance of the motorway sections in simulation.

Figure 4.3: Fundamental diagrams for the four on-ramp sections



(a) Flow-Occupancy diagrams



(b) Speed-Flow diagrams

Based on the above figures, the maximum observed flow value can be regarded as the free flow capacity of motorway for VISSIM simulation. From the fundamental diagrams, it is found that the maximum flows at different data collection locations are 5280 veh./h (S101, 2-lane), 6120 veh./h (S102, 3-lane) and 6900 veh./h (S105, 3-lane), respectively. Considering some measuring errors, the average value, about 2300 veh./h per lane is regarded as the initial capacity value of motorway.

Considering more robustness and the reaction buffer time of the external ramp-metering controllers, about 5% reduction in capacity will be introduced (safety factor: 95%), the value will be set as 2200 veh./h per lane on motorway as the road capacity.

Meanwhile, it is noticed that the capacity drop phenomenon is partly illustrated in the above figures. From the flow-occupancy diagrams for S104 and S105 (Figure (a)), the discontinuity around the capacity point is shown. At first, traffic flow increases and reaches to a maximum value, when traffic stream arrives at a congested state, then the traffic flow drops to a lower flow value. Actually, the capacity drop offers a substantial possible benefit of ramp metering. In conclusion, this microscopic model is able to generate "capacity drop" and thus the potential benefit of ramp metering could be expressed in simulation.

4.3 Basic information for infrastructure and related controllers

In this section, the basic information related to the four on-ramps will be given. Then, the default parameter settings for ramp metering control will be given.

4.3.1 Information for the four on-ramps

The basic infrastructure information of the surveyed on-ramp roads is shown below. Figure 4.4 gives the direct impression of the four on-ramps.

Figure 4.4: Four ramp meters at A10-west

(a) S101

(b) S102

(c) S104

(d) S105

From the above pictures, it is shown that there is one bus lane located on S101 and S102 respectively. On-ramps S101, S104 and S105 have one on-ramp lane, whereas S102 has two. Table 4.1 lists the basic information of these on-ramps.

Table 4.1: Controlled on-ramp information

Number of lane	Motorway Lane	On-ramp Lane	Bus Lane*
S101	2	1	1
S102	2	2	1
S104	3	1	0
S105	3	1	0

***Here, bus lane is not taken into account in the model.**

4.3.2 Default parameter settings for control

The default parameter settings of each individual ramp metering controller and the HERO algorithm are described in the following passage.

The RWS-C ramp metering controller meters the queue at local level. Although at the traffic control centre, the control parameters, such as capacity, threshold control values, might be changed based on real traffic situation, the pre-specific values of each TDI still need to be decided for simulation in advance. As mentioned in Section 4.2.3, the lane capacity of a motorway is 2200 veh./h. The critical flow values for each TDI to start or stop metering are about 75% and 68% with respect to the road capacity, thus 1650 veh./h/lane and 1500 veh./h/lane respectively. The critical speeds as the switch of each TDI both for downstream and upstream are 70 km/h and 80km/h respectively. (Rijkswaterstaat DVS, 2007b, f)

The maximum admissible queue length (in number of vehicle) of each TDI used for coordination should be decided individually based on the length of on-ramp. At local control level, it is known that when the queue reaches to the congestion detector, then the ramp metering is released. Therefore, the maximum admissible queue should not exceed the location of this detector. According to the typical layout of detectors of one lane ramp meter (Middelham and Taale, 2006), the distance between the beginning of on-ramp and the congestion detector is 20 meters. So the effective length for maximum admissible queue is calculated by the length of on-ramp minus 20 meters. Here, it is assumed that each vehicle needs 6 m on average in space, as the length of input passenger car type is range from 4.11m to 4.77m (truck type: 10.21m) and the standstill distance in VISSIM is set as 1.5m. The maximum admissible queue is calculated by the effective length obtained from VISSIM divided by 6 (m). The related control parameters of each TDI are presented in the following table:

Table 4.2: Control parameters of each TDI controller

Parameters	S101	S102	S104	S105
Capacity[veh/h]	4400	4400	6600	6600
Flow(on)[veh/h]	3300	3300	4950	4950
Flow(off)[veh/h]	3000	3000	4500	4500
Speed(on)[km/h]	70	70	70	70
Speed(off)[km/h]	80	80	80	80
Max.Queue[veh](m)	36(240-20)	32(120-20)	18(130-20)	18(130-20)

The most important parameters in the HERO algorithm are the activation and deactivation thresholds. The default values of these two pre-defined parameters are 30% and 15% respectively (Rijkswaterstaat DVS, 2007a). When a relative ramp queue exceeds 30%, it becomes a "master", and HERO starts to recruit upstream located metered ramps as "slaves". The created cluster is dissolved if the master ramp relative queue falls below 15%.

4.4 Detailed assessment criteria for Amsterdam model

Based on the criteria definition in Chapter 3, the following criteria are used for the Amsterdam A10-west model. These criteria are presented as value or figure corresponding to the performance of each scenario on traffic situation and route choice.

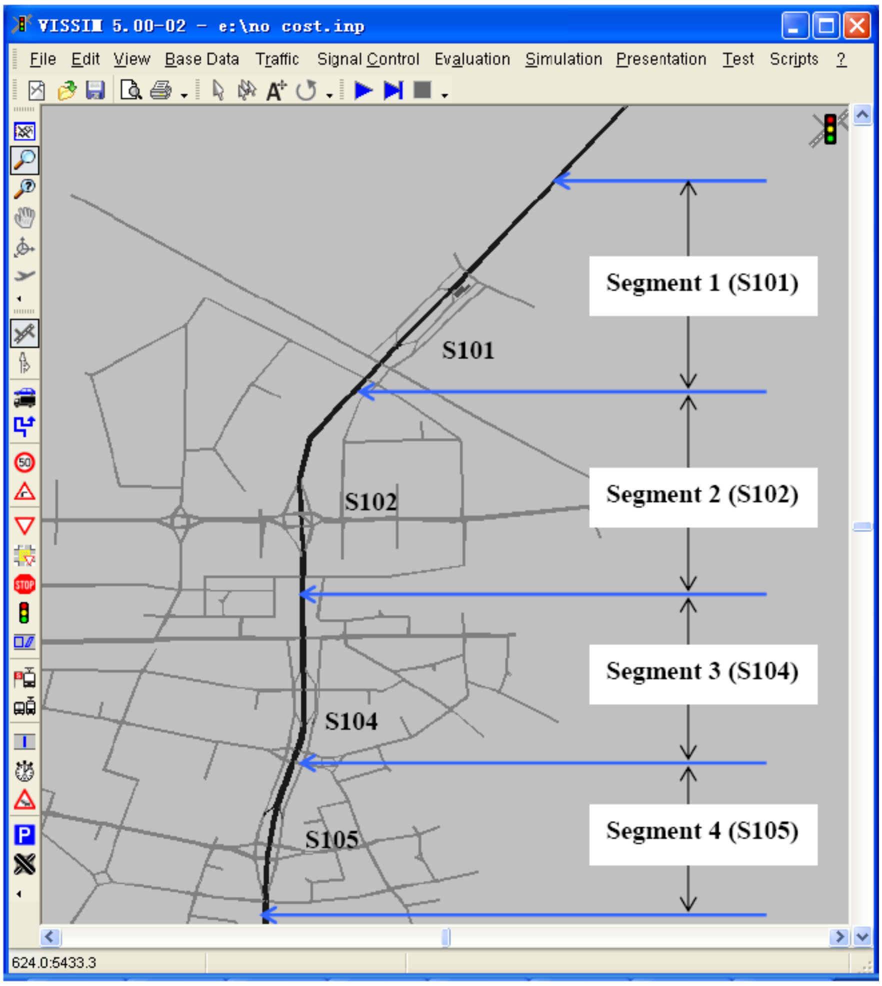
- Total time spent (TTS) by all vehicles in the Amsterdam A10-west network (motorway & urban road)
- Average travel time for each vehicle in this network
- Total distance travelled in this network

- Average travel time on the main surveyed motorway stretch (from S105 to S101)
- Total throughput of the main surveyed motorway stretch
- Mean speeds of the four segments* on the main surveyed stretch
- Speed contour plot of the related motorway stretch

- Average delay time on each on-ramp
- Queue length on each on-ramp over time
- Usage (throughput) of each on-ramp

*Note that the main study area from S105 to S101 is subdivided into four small segments as show in the following figure. Each segment contains one ramp metering controller.

Figure 4.5: A stretching overview of the main study area



Based on the description of the assessment criteria, the related raw data will be obtained from simulation and be analyzed by Matlab. Total time spent, average travel time of each individual vehicle and total distance travelled can be derived from the "path evaluation file" for dynamic assignment module. Average travel time on main study area and average delay on on-ramps can be calculated by "travel time sections". Queue length of each on-ramp over time can be collected by "queue counters". The other criteria can be obtained from the "data collection points" defined in VISSIM. Note that, in reality, these kinds of data collection points (detectors) are located every 500 meters along the motorway. In order to acquire high accuracy, the data collection points (detection) are set up along the motorway A10 west (eastern part: from the beginning to the Coentunnel) in every 200 meters.

4.5 Scenario description

Based on the project objective and research questions, the studied scenarios are described as follows:

4.5.1 Scenarios for impact analysis

As the coordinated ramp metering control will be compared against non-coordinated control and no-control cases, three scenarios are chosen.

Null scenario: No ramp-metering control implemented in the A10-west model—no control case
Scenario 1: Model with four existing individual ramp metering control application—current situation
Scenario 2: Coordinated ramp metering (HERO) implemented in the network—future situation

4.5.2 Scenarios for parameter optimization

Another aim of this graduation project is to improve the HERO algorithm for real implementation. It is decided in the last chapter that the studied parameter groups in the whole control process are the activation and deactivation thresholds in HERO and the critical speed and flow values for local control, because they are most related to the control principle of this algorithm. The default values of these studied parameters are already described in Section 4.3.2.

These default values are obtained from the setting in the standard ramp metering application or estimated on literature or experience. Hence, the thresholds should be optimized for real application in this specific traffic network of the A10 west.

In order to search for the optimal parameters, first of all, the list of different studied parameters needs to be decided. In the following, different combinations of the chosen parameters, namely activation and deactivation thresholds in HERO, the critical speed and flow values for local control, are presented in the tables.

Table 4.3: List of parameters in HERO

(%)	1	2	Default	3	4	5
Activation Threshold	10	20	30	40	50	60
Deactivation Threshold	5	10	15	20	25	30

Table 4.4: List of parameters in local controller

	Speed (km/h)			Flow (veh./h/lane)				
	1	**Default**	**2**	**1**	**2**	**Default**	**3**	**4**
Activation Threshold	65	70	75	1350	1500	1650	1800	1950
Deactivation Threshold	75	80	80*	1200	1350	1500	1650	1800

***Here, "85" is not used because in reality there is 80 km/h speed limit implemented on roadside.**

The optimal parameter settings for HERO application should be determined. Then, the related robustness study on the performance with respect to these settings will be performed with an increasing traffic demand in VISSIM.

Based on the Amsterdam model, the given evening peak-hour traffic demands from 15:30-18:00 serve as the master data, of which 65% is used as current traffic demand for impact analysis which is discussed in detail in the Section 5.3, and then traffic volumes change in 5% increments from the 60% to 70% of the master data (60%, 65%, 70%). Because traffic congestion of main study area in the network with the traffic demand less than 60% will be negligible, and traffic condition in the network with more that 70% traffic demand will be too congested, as demonstrated in the Figure 5.10 of the Section 5.3. So the 60% demand network can be referred as less congested case, whereas the 70% demand network can be regarded as the over congested case. Such test conditions provide a reliable platform to demonstrate the effectiveness of the parameters chosen and quantify the HERO system performance.

In order to search for optimal parameters for real application of the new algorithm, several scenarios with respect to studied parameters presented in Table 4.3 and Table 4.4, are listed in the following table. The first scenario is considered as a reference. Note that each scenario in parameter optimization will be tested with regard to three different traffic demand (60%, 65% and 70%).

Table 4.5: List of scenarios for optimization

Scenario	Activation/Deactivation Value		
	HERO Switch (%)	**Speed Switch (km/h)**	**Flow Switch (veh./h/lane)**
1	Default (30/15)	Default (70/80)	Default (1650/1500)
2	10/5	-	-
3	20/10	-	-
4	40/20	-	-
5	50/25	-	-
6	60/30	-	-
7	-	65/75	-
8	-	75/80	-
9	-	-	1350/1200
10	-	-	1500/1350
11	-	-	1800/1650
12	-	-	1950/1800

Before the further investigation on the impact analysis and optimal parameter settings, the network modelling and general calibration of the current VISSIM model are presented in the next chapter.

Chapter 5 Modelling and general calibration of Amsterdam A10 model

In this chapter, basic configuration and the modification of the existing Amsterdam VISSIM model are presented, followed by the general calibration of the current network with regard to the empirical data.

5.1 Basic configuration in VISSIM

5.1.1 Simulation parameters

As the total simulation period is two and a half hours, the period in VISSIM is 9000 simulation seconds. The simulation resolution is the number of times that the vehicle's position will be calculated within one simulated second (range 1 to 10). The higher the value is, the more smoothly the vehicles will move during simulation, and the lower the simulation speed will be. Note that the VISSIM model can only handle detectors from adaptive signalized controls (external controllers) when using the "0.1 s" setting. Thus, the resolution 10 will be chosen during the simulation. Simulation speed is chosen as "maximum" so as to let simulation run as fast as possible and save the running time, although the actual achieved simulation speed depends on the computer performance and network size. The interface for simulation parameter settings is presented in Appendix A (A2).

5.1.2 Dynamic assignment simulation

When doing the dynamic assignment, some settings have been subject to change (refer to Appendix A(A3)).

The evaluation interval should be smaller than the interval in which the demand changes (15 minutes) and should have at least the double temporal resolution of the demand changes. On the other hand, an evaluation interval below five minutes does not make sense because the fluctuation of the values will increase with smaller intervals. So this interval for dynamic assignment will be changed from 60 sec to 300 sec (5 minutes).

In order to model a growing experience of travel times, the times not only from the immediately preceding iteration should be considered but from all preceding iterations. The expected travel times for the next iteration are stored in the VISSIM cost file after an iteration of the simulation in order to provide a base for the route choice in the next iteration. MSA (method of successive averages) for calculating the expected travel times is used here, in which the older measurements have more influence to the current iteration. It is regarded to be able to speed up the convergence. The user-defined value is set according to the order of each iteration.

For route searching, limited number of the routes per O-D pair is set as "3" (9 originally). Condition for rejecting paths is set as "when its costs are larger than the cost of the best path by 50%". These settings aim to limit the route in route set so as to make the iterative simulation be able to converge faster.

The process of iterated simulation runs to compute the result of the Dynamic Assignment can be stopped if eventually a stable traffic situation is reached. This is the case when travel times and volumes do not change significantly from one iteration to the next. The convergence condition for dynamic assignment is chosen as the change of "travel time on paths" is less than "30%". This condition is considered not too tight; otherwise the convergence is never reached, especially for this large scale network.

Usually, under certain convergence conditions, for a simple network (two nodes and two links) 25 iterations (simulation runs) are needed to get close to an equilibrium state. So for large networks it can be hypothesized that many more runs are needed to create acceptable paths. In this Amsterdam network, 112 nodes are included and it is found that each iteration took about 3 hours real time with respect to 10 resolution, even though the simulation period is 2 and a half hours. It could be imagined that quite long time is needed for network route searching and convergence.

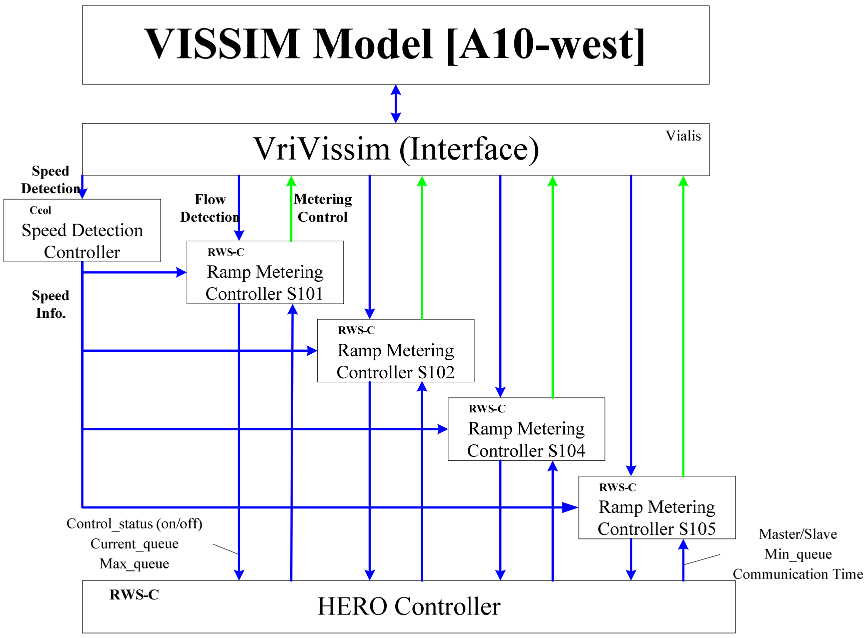
In the model, the nodes 109, 110 and 112 (as shown in Figure 4.2) are regarded as the most important zones which also have large traffic generation (demand input). It is reasonable to make sure these O-D relations which contain the main nodes as origins or destinations to reach an equilibrium state with respect to the convergence condition after a certain amount of simulation runs. While, for some O-D relations related to underlying network with a lower demand, it is difficult for them to get close to an equilibrium state. Here, it is assumed that these O-D relations would not affect the whole situation too much. When the main O-D pairs get convergence, it is defined that the whole network would reach to a convergence situation, which is also considered as a standard for each scenario.

5.1.3 Configuration for external controllers

In the VISSIM model, for ramp metering and HERO coordination (CVMS) control, RWS-C controllers are used for control application. However, RWS-C controllers cannot read the speed data from VISSIM. For local ramp metering control, speed information is an important index for the control algorithm. Therefore, the CCol controller will be used for speed detection in VISSIM. The data communication between CCol and RWS-C controller as well as that within the same (RWS-C) type controllers (HERO and Individual Ramp Metering) is realized via the so-called linking cables provided by the control interface.

The following figure presents the functioning of the external traffic control process in this VISSIM model. Based on the interface (VRIVissim) connecting VISSIM with external control program, the flow data is transferred to local ramp metering controller directly. The speed data is transmitted to local controllers via the CCol speed detection controller. Given the flow and speed information, the local controller will calculate its own control scheme and realize the metering control autonomously. If the HERO coordination controller is activated, the information of each local agent, such as control status of local controller (on/off), current queue length on on-ramp and maximum admissible queue, is read by the HERO controller. This information is used in the HERO algorithm to generate coordination control command, for instance, activation/deactivation command of certain controllers, minimum desired queue and communication time (actually the communication time is only effective in practice and it is not used in simulation).

Figure 5.1: Functioning of external control

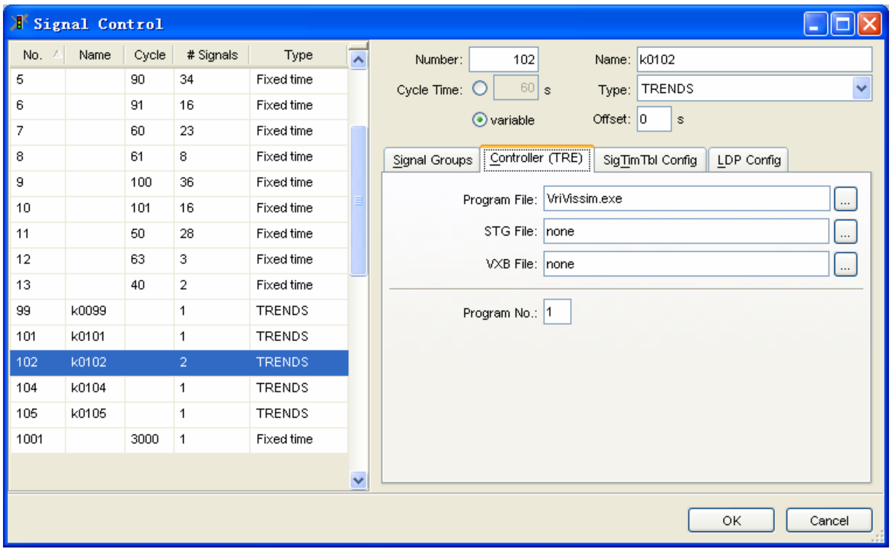


The simulation interface with all the external controllers is shown in Appendix A (A1).

A brief description of the basic configuration of each ramp metering controller in VISSIM is given in the following. More detailed and technical explanation could be found in the Manual in Appendix C and the specification (Kaal, 2007).

The number of each controller should be the same as the controller identified code which is set from external C-code (e.g.102). In the interface for “Edit controllers” as shown in the figure below, “cycle time” is set as “variable”, Type is chosen as “Trends”.

Figure 5.2: Configuration of controller in VISSIM



Then the controller is able to create the signal heads and related detectors on the roadside. The number and name of the signal heads and detectors of each controller defined in VISSIM should be also identified by external program. The location of signal heads and loop-detectors and length of each detector are configured based on (Middelham and Taale, 2006), (Rijkswaterstaat Noord-Holland, 2007c) and Google Earth Map.

5.2 Model modification

The existing VISSIM model for the Amsterdam ring-road has been built many years ago and designed for another study purpose. In order to ensure this simulation model performs as well as needed, some testing and modification need to be done with respect to the real situation as shown in the following.

5.2.1 Infrastructure

The infrastructure network comes from the previous simulation study. It has been found that some important urban links are missing in the existing network (Li, 2005), as shown in the figure below. These links in the urban area of the network are regarded as the important corridor connecting the south and the north (red cycle). So the new links (VISSIM links 251 & VISSIM nodes 1262) will be added in VISSIM based on the real road infrastructure, as shown in the figure below.

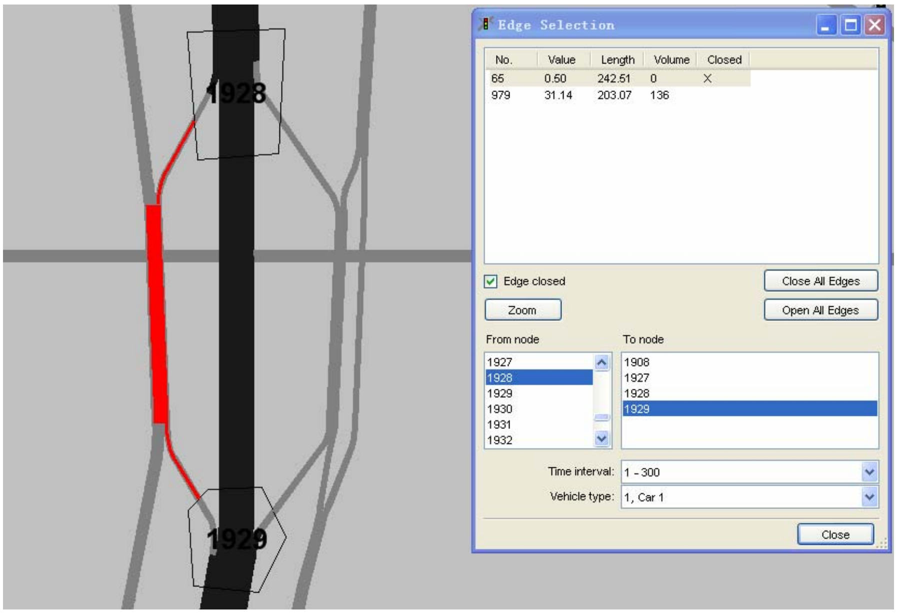
Figure 5.3: Infrastructure updating

5.2.2 Route choice behaviour

According to (TP department, 2006] and my experience accumulated before, it is known that there are some limitations in the VISSIM model itself. For instance, the assignment procedure does not seem to be correctly implemented into the model: the model does not give theoretically expected results (e.g. route choices) in many cases. In order to make the existing model more reliable, the following efforts have been done.

Some illogical routes need to be avoided during the assignment procedure. In VISSIM, some edges* between certain nodes are closed in order to prevent traffic flow from travelling along illogical routes. For example, in reality the flow does not use the off-ramp and on-ramp at the same freeway-to-freeway intersection as an alternative of going through this motorway section directly. In dynamic assignment, the route with the edge containing off-ramp and on-ramp of the same section is still searched and assigned to some part of flow. The route search control will be done to close certain unrealistic routes. Following is an example to show the edge closure of certain part of the motorway, as shown in Figure 5.4. During simulation, there may be two routes found for vehicles travelling from node 1928 to node 1929; one is a motorway section, while the other is an off-ramp to on-ramp section. The later one will be removed from the route set. Note that the closure edge is in red. All the edge-closure relations are listed in Appendix B (B1).

Figure 5.4: Example of edge-closure



*From the information given by the user's definition of nodes, VISSIM builds an abstract network graph as soon as the Dynamic Assignment is started. The graph consists of what we will call "edges" to distinguish them from the "links" the basic VISSIM network is built from. The edges are the basic building blocks of the routes in route search, i.e. a route is a sequence of edges. For all the edges travel times and costs are computed from the simulation providing the information needed for the route choice model. (PTV, 2007)

In addition, certain routes (a sequence of links and connectors) will be closed as well to avoid the illogical route searching during simulation; this is also considered as another option to limit simulation run time: manually select links which are not to be used as alternative path for a certain OD-relation. During the iterative route searching process, there are 2 route closure decisions made in VISSIM, and 2 routes closed in total. A list of the route closure in VISSIM can be found in Appendix B (B2).

Meanwhile, "surcharge" will be used for assignment control. This method is to affect the behaviour that some parts of the road network attract more or less traffic than expected. In the network, all the off-ramps along the motorway are assigned some surcharge values. By doing this, the routes for the flows coming from the main OD pairs (relations between 109, 110 and 112) are restricted to the motorway network instead of choosing some unrealistic underlying network. The other OD relations are not affected by this change too much. A list of links assigned with surcharge values is given in Appendix B (B3).

By doing these, the traffic assignment procedure could provide more reasonable routes and the whole iterative simulation process could be shortened.

5.2.3 Lane change behaviour

The turning movement (lane change) behaviour at certain locations (e.g. merging sections and sections before split points) needs to be rectified.

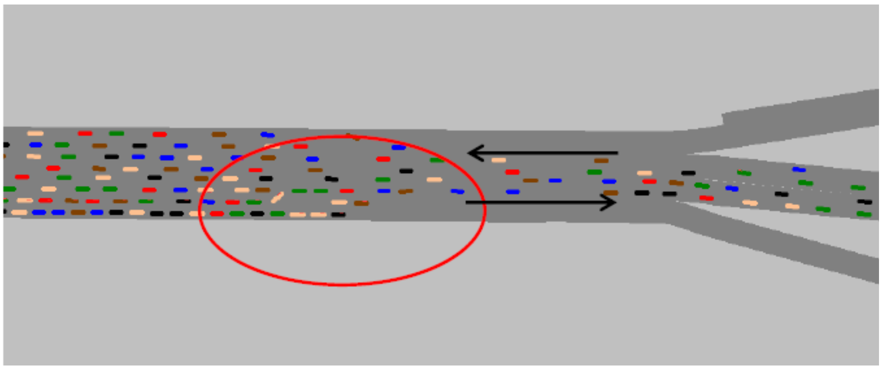
In reality, there is certain buffer distance preserved on the motorway for vehicles changing lane. For instance, the motorway sections from A4 to A10-west and from A10-south to A10-west related to plots (a) and (b) as shown below. In this buffer distance, straight-forward and right-turning vehicles are separated into two streams. While in the existing VISSIM model, it is noticed that some straight-forward/right-turning vehicles keep trying to change lane till they reach the division points as no available gap size was found before. They are waiting in the front of the queue for an available gap size for lane changing as defined in VISSIM, which occupies the right-turning/straight lanes, as shown in Figure 5.5 (a) and (b) (red circle). This blocking hinders the flow which turns right/goes straight, lowers the overall throughput, and thus makes the traffic situation worse as capacity is much lower than in reality. Due to the specific cases presented below, the traffic demand from the origins 110 and 112 cannot reach the study area A10-west completely.

Moreover, some merging sections for on-ramp traffic merging to the main motorway, the vehicles are just waiting at the acceleration lane for an acceptable gap for lane changing as shown in plot (c) (yellow circle). This seems unrealistic too, since in reality drivers will not come to a stop and the successive drivers will find a way to pass the blocking vehicle, or to reach their next link.

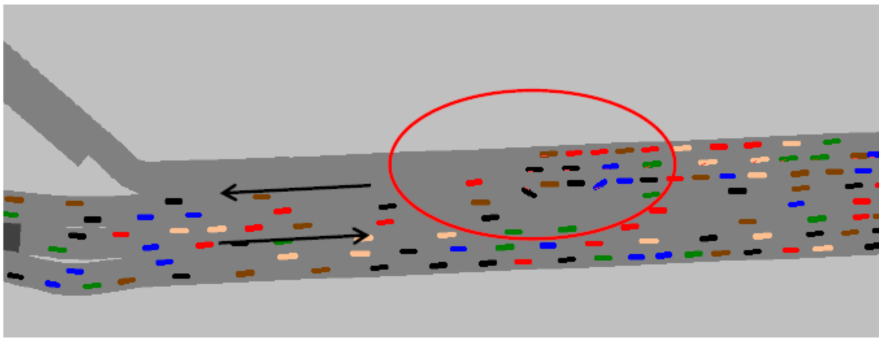
Furthermore, similar problems exist at certain on-ramps (e.g. S101, S104 and S105) where there are two lanes, one for traffic entering the motorway, the other for underlying network. Some vehicles keep trying to make lane change till the stop line of ramp metering and thus block the straight-forward flow as shown in plot (d) (blue circle).

Figure 5.5: Some lane change problem spots

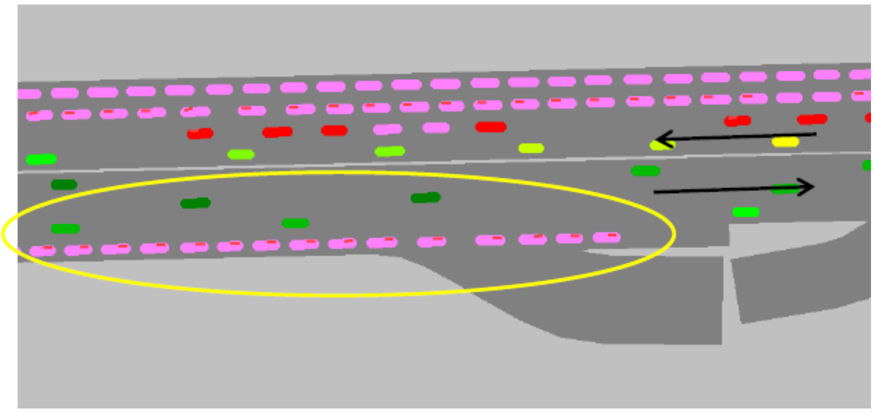
(The vehicle with red dot denotes lane-changer)



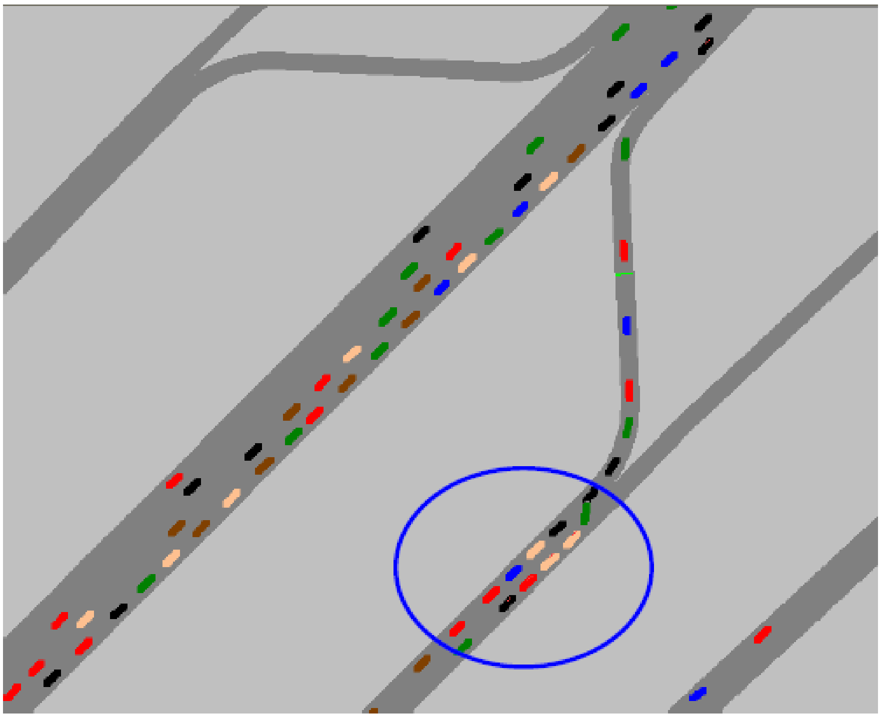
(a) Motorway section from A4 to A10-west [Blocking of motorway]



(b) Motorway section from A10-south to A10-west [Blocking of motorway]



(c) Merging section for on-ramp traffic [Blocking of on-ramp traffic]



(d) On-ramp section (S101) [Blocking of straight-forward flow]

Given these cases, a possible solution is that the lane change decision distances at certain locations are set long enough before the merging/division points (the connectors) to provide sufficient distance for lane-changing. That means the vehicles will start lane changing earlier before the connector downstream to increase the chance to find a proper gap. Meanwhile, the emergency stop distance, a property of connectors, which defines the last possible position for a vehicle to change lanes, will be moved backwards at certain places based on reality (Google Earth). The links (connectors) of which the properties are changed are listed in Appendix B (B4).

Finally, some motorway links (merging section or splitting section) will be given a new set of parameters for the lane change model. These new parameters for lane changing are tested in a small motorway model. The main modification is to lower the safety reduction factor. As a result, small gaps are accepted for lane changing. So, the new model is considered to be able to generate more acceptable lane change behaviour. The specific configuration of these parameters and the list of the links using this setting are presented in Appendix B (B5&B6).

After this modification, the lane changing situation at the previously mentioned critical spots and the related on-ramps is better than before. However, when high demand is loaded on certain links, the model still cannot provide acceptable results. In my opinion, the lane change model in VISSIM does not describe the real traffic behaviour properly. It is an internal drawback in VISSIM and thus it is difficult to be improved.

So far, the Amsterdam A10-west network has been modified. Certain parameters have been updated and illogical routes have been avoided. After a certain amount of simulation runs, the existing VISSIM network will reach a convergence state based on the current input information. Before it can be used as a null alternative for further research, the general calibration with the reality needs to be done first. This is described in the following section.

5.3 General calibration with empirical data

Generally speaking, for a simulation study, calibration and validation of the model are required. It should be made sure that the model is able to resemble the real traffic situation as close as possible. As not all the real-life data is available for the whole Amsterdam network (urban-road and motorway), calibration is limited to the A10-west. The traffic data (Monica data) collected by loop detectors are available in Rijkswaterstaat, which provide general information about the real traffic situation on the motorway. A software package, MONIGRAPH, can read the Monica data collected and translate these into useful information, for example, time-dependent flow and speed data. By comparing the traffic performance on the main study area from the reality and from the simulation, the "general calibration" of the existing VISSIM network (without any ITS traffic control on the motorway) is performed.

5.3.1 Empirical Data

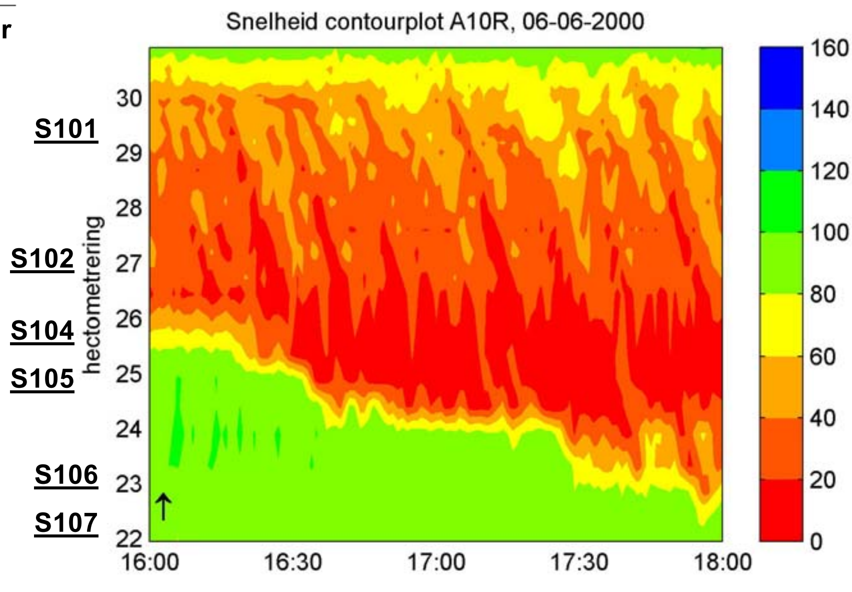
As the traffic demand data (demand matrix) for this model is derived from the average of the statistics of the year of 2000, the real-time data of the corresponding period is needed for comparison. Based on the Monica data provided by RWS, the basic analysis on real traffic situation is also given below.

Here, the Monica data are available for the main study area in June of 2000 (non-holiday period) from Rijkswaterstaat. The speed contour plot generated from a weekday (6^{th} of June, 2000) is used here, as shown in the Figure 5.6 (a), because this contour plot is able to represent most of the cases during this month. As exception, some contour plots, will not be used for general calibration, as shown in Figure 5.6 (b) & (c). Because on those days, the traffic demand are either higher or lower than the average demand level, as a result, the traffic condition are either too congested or less congested.

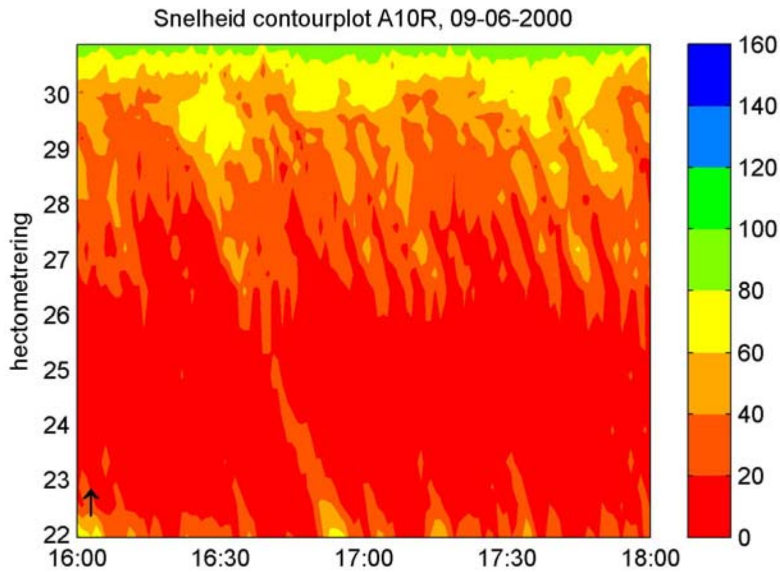
The location and related information of each Monica set could be found on the website (www. dataportal.nl). The configuration of MONIGRAPH is presented in Appendix D.

In the following figures, the space (y) axis denotes the corresponding location (in kilometres) on the A10-west from the intersection (A4-A10s-A10w) to the Coentunnel. For instance, kilometre "29" is related to the location of S101, kilometre "25" is related to the motorway section S105, etc. The time (x) axis denotes the evening peak from 16:00 to 18:00.

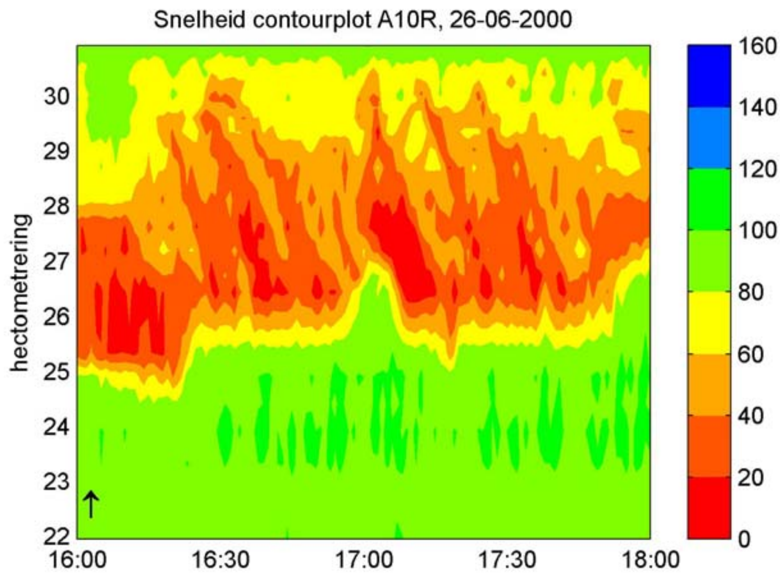
Figure 5.6: Speed contour plots of certain days in 2000



(a) Speed contour plot used for general calibration



(b) Traffic condition is too congested because of high demand

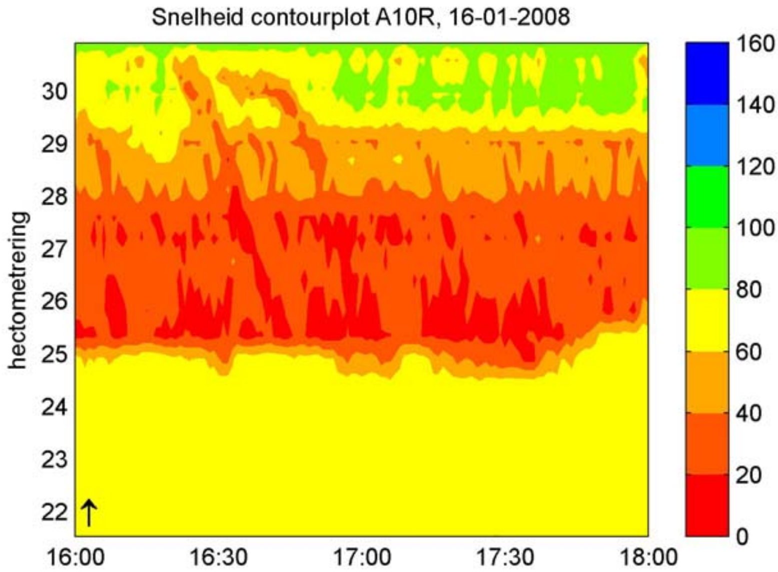


(c) Traffic condition is less congested than average due to lower demand

From the plots above, it is found that the congestion section on the eastern part of the A10 west in 2000 is mainly located from S106 to S101. During the evening peak hours, the congestion queue grows upstream from S104 up to S106.

Actually, this situation is slightly different from what happened currently on the A10 west. The following speed contour plot taken in 2008 demonstrates the point. The main difference between the plots taken from the two different years is the driving speed and the location of congestion. It is noticed that the speed in the non-congested area of the contour plot in 2000 is higher than 80 km/h (green area) because no speed limit is used there, while in 2008 the driving speed is limited around 80 km/h. As known, speed limit control was implemented in October of 2005, which means that the speed on this part of motorway should not be higher than 80 km/h. Meanwhile, the traffic congestion queue is restricted within the area from S105 to S101, which means the congestion is alleviated to a certain extent. This is regarded as another contribution to the improvement of the traffic condition by the speed limit strategy. In order to avoid this coupled effect, the speed limit strategy is not modelled in VISSIM as also discussed in Section 4.2.2.

Figure 5.7: Speed contour plot taken in 2008

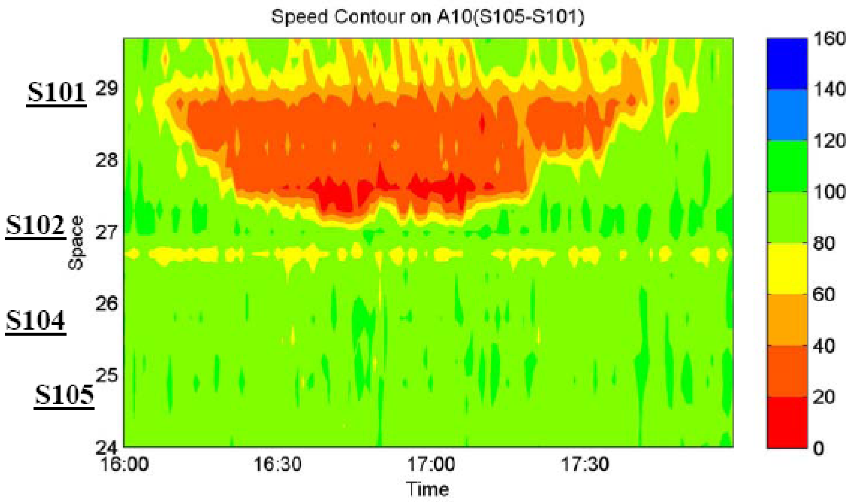


What is worth mentioning is that in reality, either in 2000 or 2008, the ramp metering is already functioning at roadside. In the sense of calibration, the network with individual ramp metering control should be used in simulation for the comparison with the real life data. However, the simulation with external controllers usually takes long time to get convergence. Although it is technically possible, the existing no-control network (null scenario) is used for general calibration here. The explanation is given as follows. For simplified reason, it is easier and faster in null-network to get convergence for general calibration, compared to control-network. Meanwhile, the main goal for the general calibration is to search for a reasonable traffic demand for the current VISSIM model that is able to reproduce similar congestion on the main area compared to the real situation. If the related demand value, which is found based on the null-network, can also be used in the networks with different control strategies to generate similar congestion patterns, then this method for general calibration is feasible. This point has been proven in the next chapter (Section 6.2.2).

5.3.2 Adjustment of traffic demand of certain OD relations

For impact analysis, it should be made sure that a proper model is found. As the main study area is the motorway section from S105 to S101, this area should have enough traffic demand to reproduce congestion. Although the effort on the lane changing problem improves the traffic throughput on the motorway section of A4 and A10 south, the traffic demand is still not enough for the main study area, since the expected congestion does not occur. As shown in the figure below, the congestion only occurs in short period within a small region (from s102 to s101).

Figure 5.8: Speed contour plot derived from simulation



According to the error files generated by VISSIM after each simulation run, a large amount of traffic from the origins 110 and 112 is stacked out of the network. One explanation is the limitation of the capacity of the motorway connecting these two origins. For example, the motorway connecting origin 112 (A4 part) is a four-lane road. It is assumed that its maximum inflow is 17600 (2200*4*2) vehicles within 2 hours (although the real amount of traffic from this origin that enters the network is around 13000 vehicles based on the output file from VISSIM). However, the traffic production of origin 112 defined in the OD matrix is about 33091 (31818*1.04) vehicles in 2-hour period, far more than the capacity. This situation applies to origin 110 similarly.

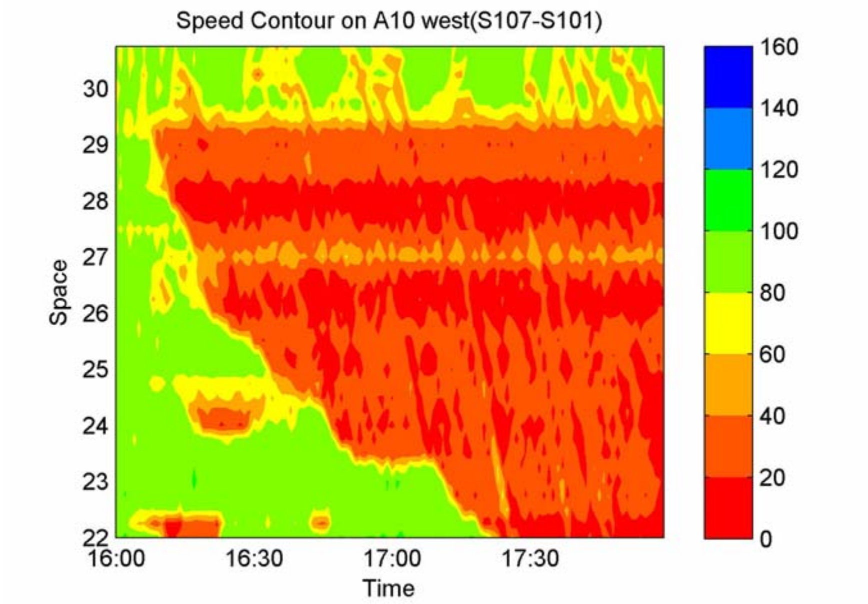
Meanwhile, it is noticed that the O-D pairs 110→112 and 112→110 account for most of the traffic demand (about 17652 and 19718 respectively). This part of generation from the respective origins is even larger than the real traffic input from the same origin to the VISSIM network. As a result, the demand from zones 110 and 112 to zone 109 (through the main study area) will be affected by the flow between zone 110 and zone 112: it cannot enter the network and thus it can not reach the main study area.

Based on the study purpose of this project, the OD matrix will be changed. The demand between O-D pair 110 and 112 is decreased to 20 % of the original. The purpose of this modification is to lower the demand between the OD pair 110 and 112 to let the traffic production from these two origins to other zones (especially zone 109) be able to enter the model. After this adjustment, based on the output file of simulation, it is found that almost all the attraction of zone 109 from origins 110 and 112 defined in the OD matrix could enter the network.

5.3.3 Adjustment of total traffic demand

Given the demand adjustment mentioned above, the main study area is able to get enough traffic demand from the A4 and A10 south. However, this leads to another problem. From the result of simulation, it turns out that the whole eastern part of the A10 west is congested severely. The waiting queues are generated upstream, from S101 up to the A10 south and A4. As shown in Figure 5.9, the speed contour plot is derived from the simulation related to main study area when the total demand is used. It is shown that the congestion queue is not restricted within the surveyed section, but it keeps increasing upstream. This performance is not comparable to reality. In this case, it can be concluded that this part of motorway section is overloaded. So, a reasonable input demand needs to be decided to make the model performing well as well as to preserve some space left over capacity for robustness study.

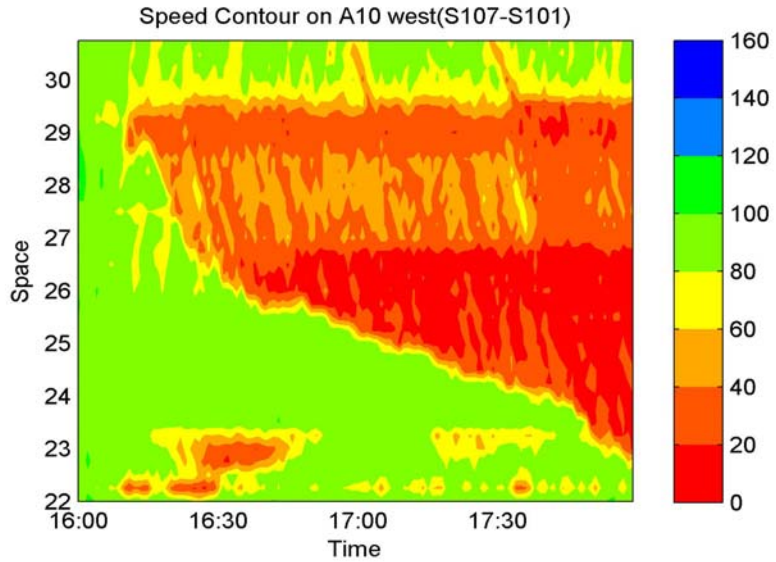
Figure 5.9: Speed contour plot (no control case with 100% demand)



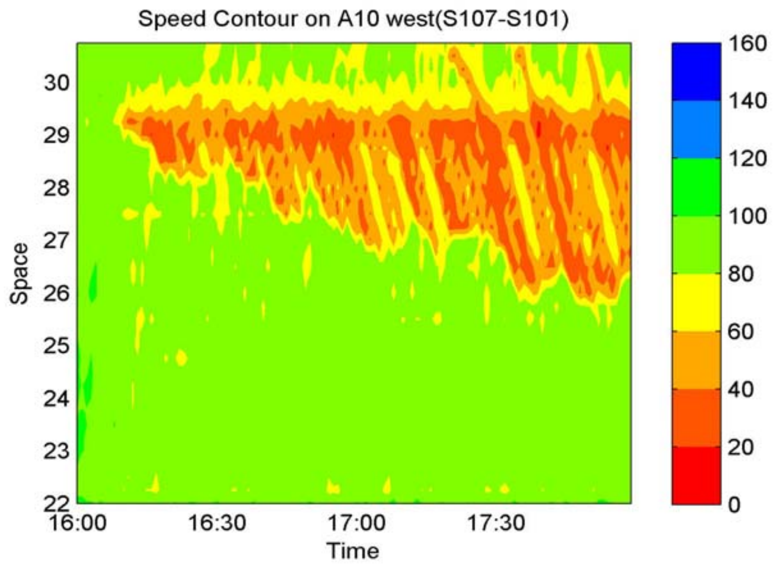
From the point of the view of “general calibration”, the location of the start and the end of the congestion in the simulation network should be more or less the same as in the real situation. Some test simulation runs are conducted in order to find a suitable traffic demand to make sure that the main study area does not congest too much or it does not have insufficient demand. As there is no further information on scaling of individual flows, the test runs are based on scaling the complete OD matrix.

It is found that the traffic situation in the model is most similar to the real situation when **65%** of the total demand is used. The following speed contour plots are derived from the simulation model, in which 65%, 60% and 70% of the total demand are used respectively.

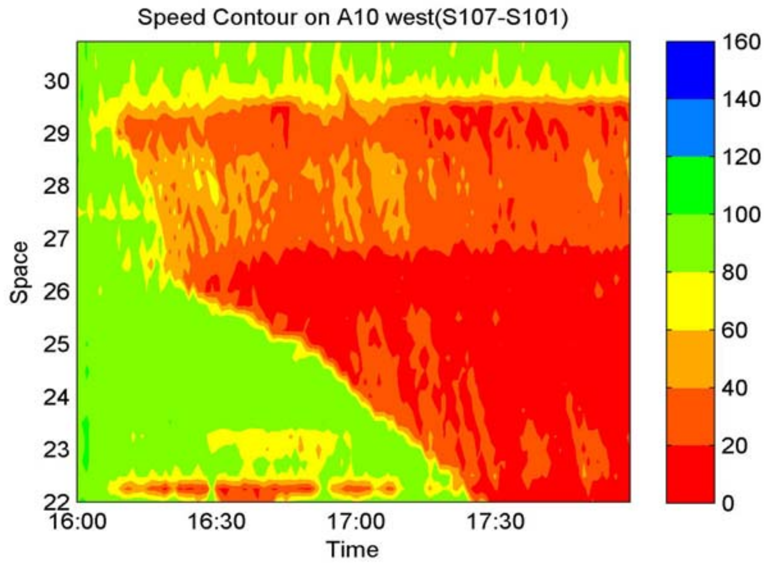
Figure 5.10: Speed contour plots (no control case with 65%, 60% and 70% demand)



(a) 65%demand



(b) 60% demand



(c) 70% demand

From the figures above, it is shown that the traffic situation of the main study area in the network with 60% demand (plot (b)) is not congested enough and unrealistic as a result of less traffic input. The traffic situation in the 70% demand network is however too congested. Hence, the 65% demand network is the most appropriate case for impact analysis, compared to the other two situations. The comparison between this network and the real situation in 2000 is given in the next passages.

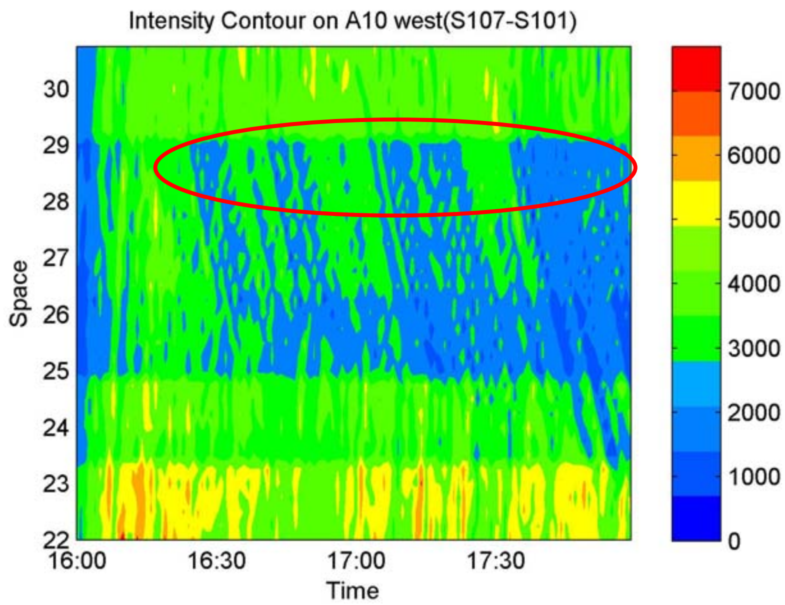
The location of the start and the end of the congestion during the afternoon peak hours in the simulation network with 65% demand (Figure 5.10 (a)) is from S101 up to S106, which is similar to the situation in Figure 5.6 (a). In both cases, the speed in the downstream part of the congested area (indicated in warm colours) is much higher than that in the upstream part. And the upstream part of the queue is completely congested.

However, it is also noticed that the congestion period between simulation and reality is different. In simulation, the congestion starts at the location of S101 at around 16:15 hr. Then, the congestion queue increases upstream. In reality, the congestion occurs much earlier. At 16:00 hr., the queue already reaches to the location of S104 (26 km). As shown in the related speed contour plots (Figure 5.6 and 5.10), the speed for queue increasing (shock wave speed) in VISSIM is faster than that in reality. Actually, the queue increasing is much more moderate in real life. The congestion in VISSIM occurs later than that in real life. One reason is that the warming up period (starting from 15:30hr) in VISSIM is not able to generate enough traffic to cause congestion. Nevertheless, it is good and necessary for impact analysis. Because during the simulation period, the model contains traffic situation with both the non-congestion stage and the congestion stage, the activation of the control application is included in this period.

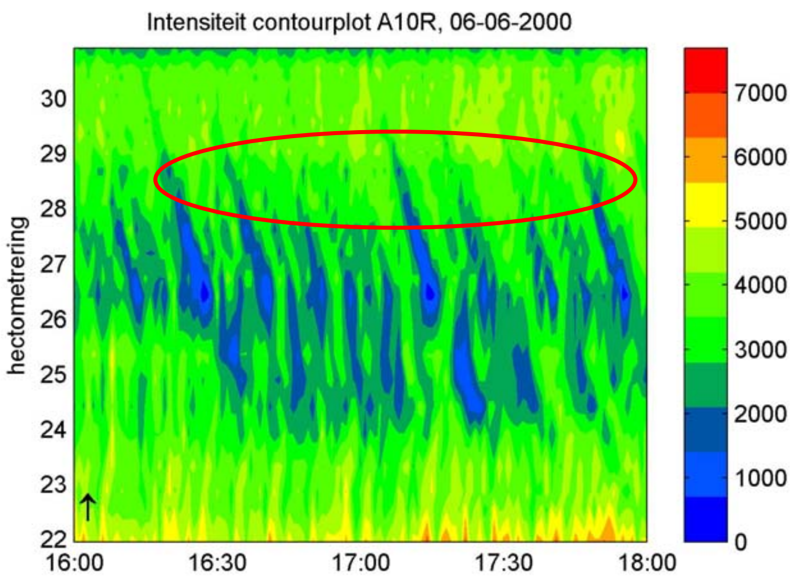
Meanwhile, at location "30 km" in the speed contour plot, which is corresponding to the Coentunnel section in reality, it is found that there is not much congestion. However, this section is congested in real life which is demonstrated in Figure 5.6 (a). In the tunnel, driving behaviour tends to be more conservative. As a result the road capacity is much lower. But in VISSIM, the tunnel environment is not modeled.

The above discussion mainly focuses on the speed information on the main study area. In the following, the general comparison is based on the flow contour plots, which are derived from the 65%-demand network and the empirical data collected at roadside.

Figure 5.11: Flow (Intensity) contour plots from simulation and reality



(a) Simulation result



(b) Monica flow data

The low volume area (blue area) in these two plots is generally located from “25 km” (S105) to “29 km” (S101). However, the low volume area in reality is longer than that in simulation, as it reaches to the location “24 km” (place between S106 and S105). Meanwhile, the flow in the front of the low value area is higher in reality than in simulation (illustrated in red circles). After all, the flow in reality is smoother as shown in the latter plot, whereas the flow contour is rough from simulation. In summary, the basic pattern of the emulated flow contour plot is similar to that in Monica contour plot. The chosen demand value for network input appears to be reasonable.

5.4 Conclusion

Based on the above analyses, the main surveyed area in this model could reflect the reality in the sense of congestion patterns and basic traffic performance (speed and flow conditions). It is thus concluded that the current adapted VISSIM model with 65% demand could be used as a null-alternative for impact analysis. The detailed analysis and comparison are presented in the following chapters.

Chapter 6 Impact analysis of HERO algorithm

In this chapter, the simulation results of the three studied scenarios (no-control, non-coordinated and coordinated control) are presented. After a certain amount of simulation runs, the null scenario with 65% demand has reached an equilibrium state. Based on this null network, the same iterative process has been applied to the other scenarios. Individual ramp metering (scenario 1) and coordinated ramp metering (scenario 2) control will be tested.

With regard to the criteria defined in Chapter 4, the resulting comparison is shown in the following paragraphs. The overall performance is discussed in Section 6.1. The traffic conditions related to the main study area are described in Section 6.2. The route choice behaviour and equity requirement are addressed in Section 6.3. Section 6.4 summarizes the statements found in this chapter.

6.1 The overall performance of the network

As VISSIM is a stochastic model, we need to perform multiple runs to get an average result. For this reason, several simulation runs is needed. As discussed in Chapter 4, ten simulation runs are performed for each scenario, with different random seeds (Nr. 1 to Nr. 10).

In Table 6.1, total travel time (TTS) (in veh*h), average travel time (Ave.TT) (in sec.) and total distance travelled (TDist) (in veh*km) of the whole network for different scenarios are presented, which are used for comparison.

Here, the null scenario without any control is considered as a reference. In scenario 1, the resulting TTS and Ave.TT are reduced to 9781.24 veh*h and 594.86 sec. respectively, which lead to negligible 0.54% and 0.78% improvement compared to the no-control case. The resulting TTS and Ave.TT of scenario 2 are equal to 9803.59 veh*h and 588.13 sec. respectively, which are 0.32% and 1.90% improvement compared with the null scenario. Although the improvement related to these two criteria of scenario 1 and scenario 2 is slight, in this large traffic network, less TTS still means higher outflow, less delay and thus better traffic conditions. The main difference between null scenario and the new 2 scenarios is the control application. Hence, the effects derived from the limited area on the whole traffic network are limited. However, the improvement of traffic conditions on the main study area is manifest, as explained in the next section.

Table 6.1: Integrated simulation results from 10 simulation runs

No.	Null Scenario					
	TTS[a](Dist[b])	Imprv[e]	Ave.TT[c]	Imprv[e]	TDist[d]	Imprv[e]
1	10075.80 (59248)		612.22		5307.303	
2	10141.22 (58962)		619.19		5298.613	
3	9730.52 (58894)		594.80		5288.057	
4	9920.52 (59394)		601.30		5335.113	
5	9807.24 (59430)		594.08		5338.445	
6	9794.68 (58754)		600.14		5276.328	
7	9758.87 (58829)		597.19		5284.704	
8	9713.89 (58845)		594.27		5283.995	
9	9656.54 (58919)		590.02		5291.807	
10	9748.90 (59273)		592.11		5322.293	
Average	9834.82	0%	599.53	0%	5302.666	0%
	Scenario 1					
1	9820.14 (59753)		591.64		5365.074	
2	9855.90 (59579)		595.53		5349.344	
3	9751.51 (58676)		598.29		5276.809	
4	9735.43 (58422)		599.90		5253.930	
5	9754.25 (59234)		592.82		5321.892	
6	9801.59 (59494)		593.10		5343.931	
7	9706.69 (58921)		593.07		5293.471	
8	9820.78 (59501)		594.19		5339.780	
9	9702.45 (58612)		595.93		5268.196	
10	9863.64 (59770)		594.10		5363.141	
Average	9781.24	-0.54%	594.86	-0.78%	5317.557	0.28%
	Scenario 2					
1	9762.28 (59896)		586.75		5381.028	
2	9888.49 (60377)		589.60		5419.795	
3	9797.36 (60061)		587.24		5392.329	
4	9776.51 (59857)		587.99		5377.242	
5	9795.82 (59959)		588.15		5384.836	
6	9809.68 (60023)		588.36		5389.721	
7	9854.77 (60077)		590.53		5395.831	
8	9800.21 (59991)		588.10		5384.059	
9	9840.60 (60208)		588.40		5404.135	
10	9710.20 (59639)		586.14		5359.092	
Average	9803.59	-0.32%	588.13	-1.90%	5388.807	1.62%

[a] total travel time spent in the network (in 2 hours), [b] traffic demand, [c] average travel time in the network, [d] total distance travelled, [e] improvement

Note that the default results for travel time values measured in VISSIM accurate to 2 decimal places. In order not to lose precision, all values related to travel (delay) times are with accuracy of 2 decimal points.

It can be noticed that the TTS derived from scenario 2 is higher than that from scenario 1. Nevertheless, in scenario 2, the number of vehicles that really entered and travelled in the network is generally much larger than that in scenario 1, refer to the brackets in the above table. As a result, the calculated Average Travel Time is less than that for the same scenario, with a 1.9% improvement compared to the no-control case. Meanwhile, due to the improvement in the traffic situation in scenario 2, the total traffic demand increases, and the resulting total distance travelled in the network becomes to 5388.807 veh.*km, which is a 1.62% improvement compared with the null scenario and a negligible 1.01% improvement with respect to the scenario 1.

Although the overall performance in the coordinated control network is the best one among the three scenarios, these results are not statistically significant. Because only ten simulation runs are performed, the accuracy in the results is not high enough and the margin of the average results is not small enough. From the current simulation results, it can only be roughly reported that the effects and consequences derived from the new HERO control strategy are positive on the whole traffic network. More detailed explanations are given in the following section.

6.2 Traffic conditions of the main study area

The main study area is restricted to the motorway section from S105 to the Coentunnel. This part of the motorway is important to the government as most of the congestion occurs in this area. Hence it is necessary to quantitatively analyze the traffic conditions in this area.

6.2.1 Basic performance

In the following table, the simulation results are already averaged based on 10 simulation runs. The standard deviation for each value based on the ten results is presented. These standard deviations are small; the change in each criterion value is statistically significant.

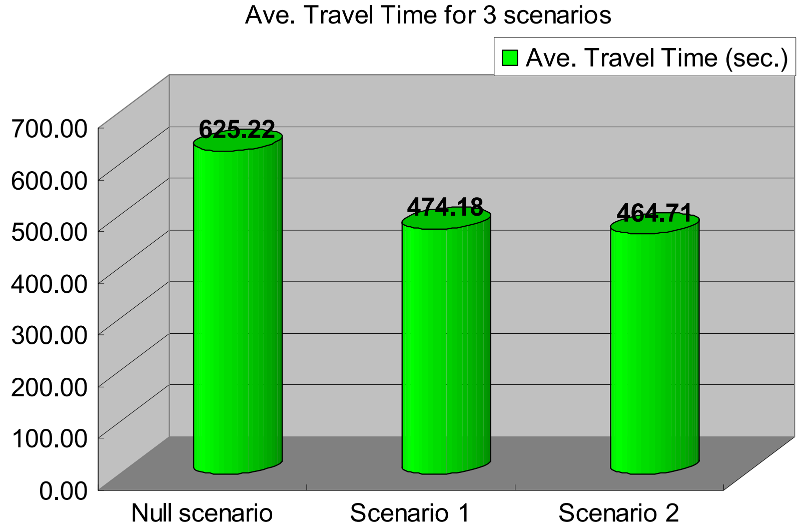
Table 6.2: Performance on main study area during 2 hours

		Null Scenario	Scenario 1		Scenario 2	
		Value(σ *)	Value(σ *)	Improvement	Value(σ *)	Improvement
Ave.Travel Time(sec)		625.22(30.78)	474.18(18.36)	- 24.15%	464.71(14.90)	-25.67%
Total Throughput(veh)		8383(123.38)	8843(38.74)	5.49%	8859(36.94)	5.69%
Mean Speed (km/h)	Segment 1	34.45(1.33)	50.38(0.75)	46.24%	52.14(1.50)	51.35%
	Segment 2	48.16(1.10)	61.78(0.93)	28.28%	62.97(1.39)	30.75%
	Segment 3	37.91(2.99)	35.47(2.41)	- 6.44%	36.29(2.34)	- 4.27%
	Segment 4	56.96(6.65)	58.23(4.43)	2.23%	56.92(5.98)	- 0.07%

***σ: Standard deviation**

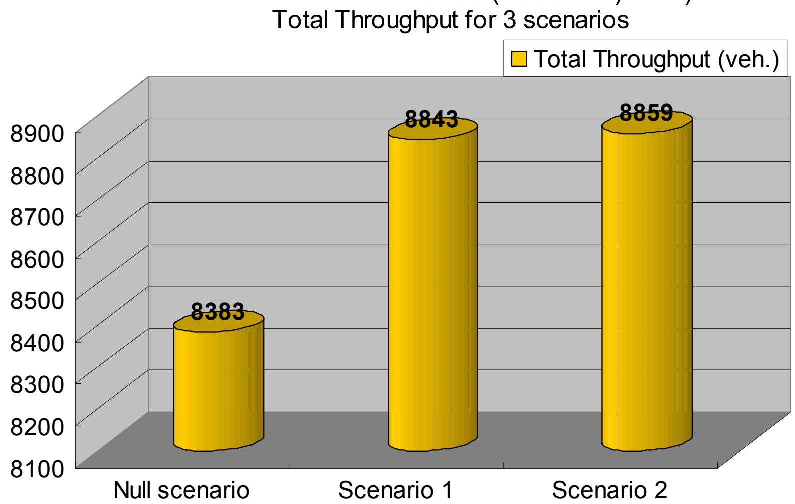
On the main study area, the average travel time from S105 to the end of Coentunnel is equal to 625.22 seconds in no-control case. In scenario 1 and scenario 2, the related values decrease to 474.18 sec. and 464.71 sec., respectively, as shown in Figure 6.1. The corresponding improvement on average travel time in the two control cases are 24.15% and 25.67%. The average travel time in scenario 2 is less than that in scenario 1 by 10 seconds, which is a 2.00% improvement. The improvement in traffic conditions in the main study area is obvious. As discussed in the last section, the new control strategies are the main reason to account for this positive effect, both on the main area and on the whole traffic network.

Figure 6.1: Bar chart for average travel time on main study area



Due to the amelioration of traffic conditions in this area, the total throughput in the two control cases increase from 8383 to 8843 and 8859, respectively, with 5.49% and 5.69% improvement compared with the null scenario, as shown in Figure 6.2. That means the outflow of the main area increases. However, the difference between scenario 1 and scenario 2 is small and not significant. The limit of throughput has been reached. It should be kept in mind that the further improvement of this value is subject to the restriction of the road capacity (The capacity of two-lane road in two hours is about 9200 (2300*2*2) veh.).

Figure 6.2: Bar chart for total throughput on main study area



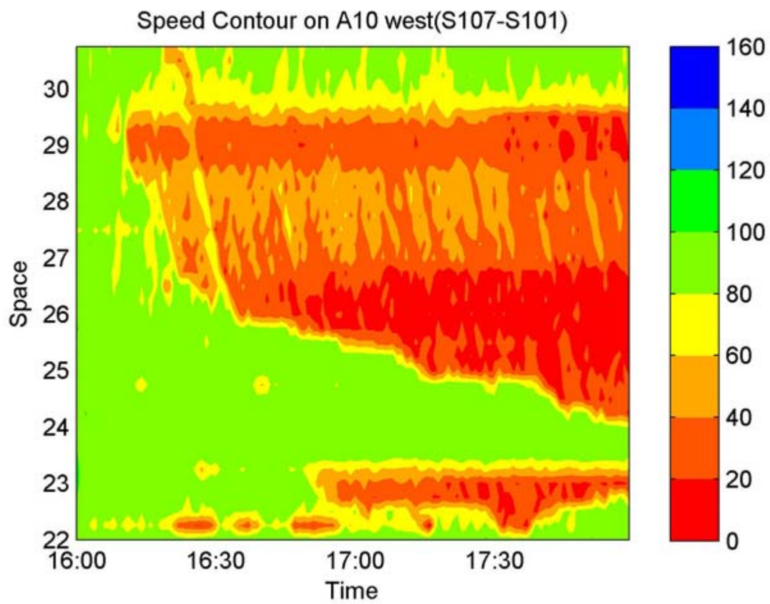
Moreover, the mean travel speeds on the first two segments of the main area are improved. This is considered as the main contribution to the decreasing travel time. In scenario 2, the improvement of the mean speed on segment 1 is even higher than 50% compared to no-control case. This improvement is because the inflows are metered at on-ramps to limit mainstream flow. In these three scenarios, the speed profiles of the last two segments are very close to each other. That is because in the upstream part of the congested area, the traffic is completely congested. It is worth mentioning here is that the improvement on mean speeds in the downstream part of the congested area in individual control network compared to no-control network is similar to what has been observed in real situation after the implementation of individual ramp metering controller.

From the above analyses of the numerical results, it can be concluded that the network with ramp metering control strategies outperforms the no-control network. The new HERO control shows its potential effect over the individual ramp metering control, as almost all indicators in scenario 2 are better than those in scenario 1. In the following, more discussion is presented on the speed contour plots, showing the traffic performance on the main study area graphically.

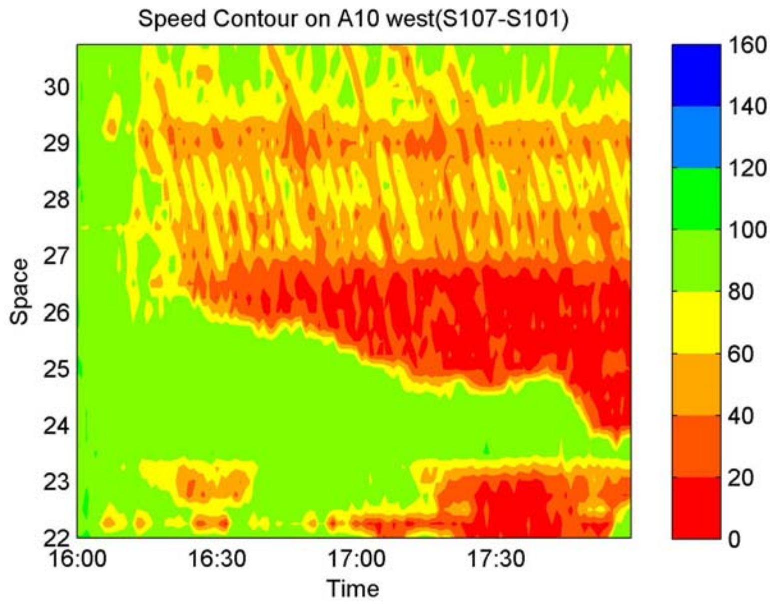
6.2.2 Speed contour plot

For the comparison of the speed contour plots, the typical plots from the multiple (10) runs of each scenario will be used here. Note that each speed contour plot within the ten simulation runs does not vary much from each other.

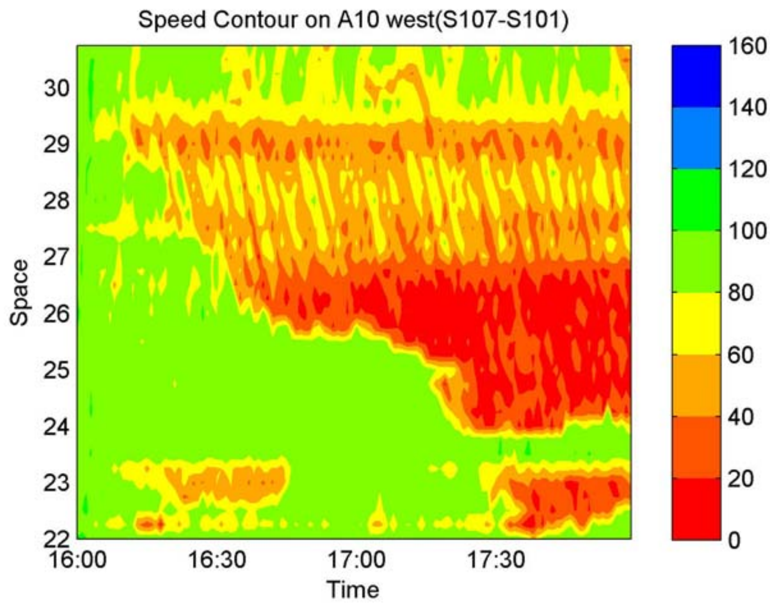
Figure 6.3: Speed contour plots for the three scenarios



(a) Null Scenario



(b) Scenario 1



(c) Scenario 2

The basic patterns of these plots are very similar to each other. The motorway merge congestion starts at the bottleneck location S101. Then, congestion queue increases towards upstream.

Compared with the speed contour plot of the null scenario, the speed values for the congested part (indicated in warm colours) are much higher, in the second and the third plots. In plots (b) and (c), the speeds in the downstream part of the congested area mostly range from 40 km/h to 60 km/h, whereas the related speed value in the null scenario mainly ranges from 20 km/h to 40 km/h. This phenomenon can be used to illustrate the improvement on mean speeds of segment 1 and segment 2, as shown in Table 6.2. In the upstream part of the congested area, the traffic speed is mostly below 20 km/h for the three cases, as indicated in red colour. That means the traffic is completely congested at the end of the queue. That is why the mean speeds for segment 3 and segment 4 are very close to each other in the three cases as shown in the table,

What is worth mentioning here is that the congestion occurred in scenario 2 much later than that in the null scenario and scenario 1. As shown in plot (c), during the first half an hour from 16:00 to 16:30, the queue increasing speed (shockwave speed) is much slower than in the previous two cases. In the congestion area, the overall speed indicated in plot (c) is much higher than that in plot (b). This is another evidence to prove the benefit of the HERO coordinated control. In scenario 2, the upstream located ramps are called as “slave” controllers to start control early in the coordination control string. By doing this, the storage space for inflow is enlarged and the congestion is postponed.

From the above three plots, it is noticed that congestion occurs on the location S106 (23 km). This phenomenon is unrealistic. Even in the convergence states, this congestion still exists. The main cause for that is too much motorway traffic uses the off-ramp at S106, which forms the upstream queue. One explanation is that the two main motorway origins (110 & 112) generate too much demand towards to the underlying network. Similar to what has been discussed in the Section 5.3.2, the traffic demand for this kind of OD relations is subject to be changed for further improvement.

6.3 Performance of local traffic around the main area

The performance on the four on-ramps in each scenario is shown below. Note that the results are the mean values over ten simulation runs.

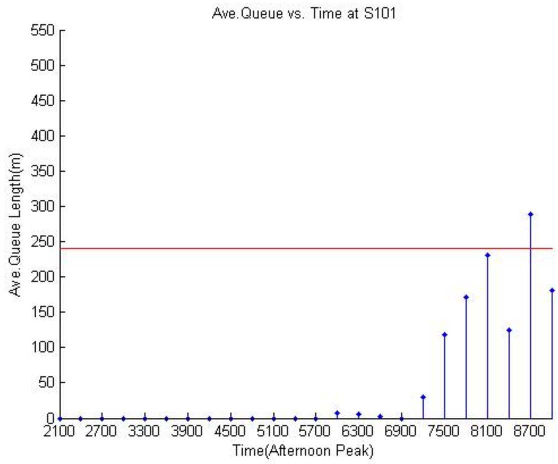
Table 6.3: Simulation results related to on-ramps during 2 hours

	Null Scenario		Scenario 1		Scenario 2	
	ADT [a]	**Throughput** [b]	**ADT**	**Throughput**	**ADT**	**Throughput**
S101	7.64	2800	102.36	1271	105.50	1382
S102	0.26	200	27.40	581	27.49	405
S104	7.92	1044	31.64	1299	31.60	1291
S105	22.20	175	15.61	726	8.91	661
Total		4219		3877		3739

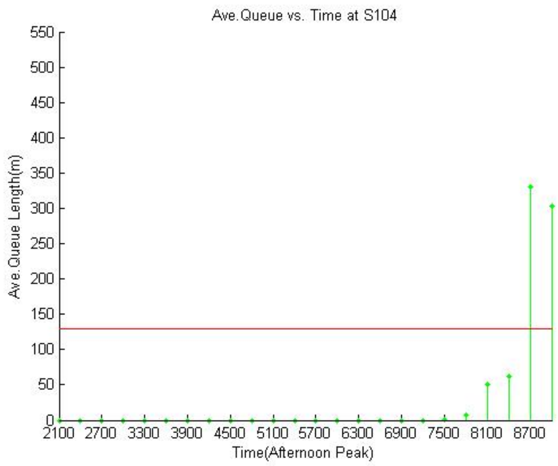
[a] average delay time per car (in seconds), [b] total throughput of on-ramp (in number of vehicles)

In the above table, it is found that in the null scenario the traffic delay mainly occurs on the on-ramp S101, S104 and S105. Nevertheless, the extent of the delay is negligible compared with the other two scenarios. In the null scenario, no control is implemented on the related on-ramps, thus the main cause for the delay is the queue formed on the motorway in the latter period of the simulation. From the plots of queue length over time, taken S101 and S104 as examples, it is also shown that there is a certain queue length formed on the related on-ramps in the latter phase of simulation period. That is because the mainstream is overloaded in this period so that the flow from on-ramps cannot enter the motorway.

Figure 6.4: Queue length over time plots derived from the Null Scenario (Horizontal red line denotes the length of each on-ramp)



(a) S101



(b) S104

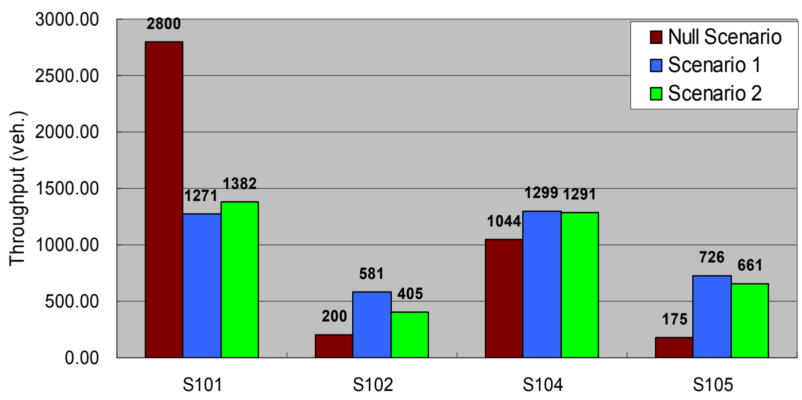
In the no-control network, many upstream ramps may contribute to the increase of mainstream flow; merge congestion eventually appears at the downstream ramp. Meanwhile, most road users, whose destination is towards to the Coentunnel (zone 109), use the on-ramp S101(2800 vehicles), which is the main reason to account for the formation of the bottleneck at S101 and the bad traffic situation on the main area. This phenomenon is similar to the situation happened before the year of 1989, when the first ramp metering application was installed.

6.3.1 Route choice

In scenario 1, it is manifest that the average delay times on the on-ramps are larger than those in no-control case, as shown in Table 6.3. That is reasonable. Because of the implementation of local ramp control, the incoming traffic flows from on-ramps are metered to enter the mainstream. Then, more travel times for on-ramp flow are needed. It also reflects the comprehensive impacts of an individual ITS application. The benefit for motorway traffic is at the cost of local delay on each on-ramp.

The following bar chart illustrates the throughput of each on-ramp in the three scenarios, which can be used for route choice analysis.

Figure 6.5: Throughput of each on-ramp for the three scenarios



As the local ramp metering is implemented at on-ramps, the road users will interact with the new control scheme. The local traffic is redistributed over these on-ramps. At S101, the users experience higher travel times than before, then part of drivers will choose to use the upstream on-ramps to reach their destination instead of the on-ramp S101. The throughputs of the on-ramps S102, S104 and S105 all increase compared with the null scenario, whereas the throughput at S101 decreases from 2800 vehicles to 1271 vehicles. It is also noticed that the total throughput of the four on-ramps in scenario 1 decreases to 3877 veh. from 4219 veh.. The explanation is that part of flow uses upstream no-control on-ramps to reach the destination. This phenomenon based on the route choice model in VISSIM can reflect the real situation in the roadside traffic network.

In scenario 2, the HERO control is used. Ramp metering S101 is assigned as the “master” controller. The successive ramp metering will be called by the master controller to start metering control early, even when no congestion happens on the related motorway section. The following table shows the starting control time of each upstream “slave” controller, which is derived from two representative simulation runs.

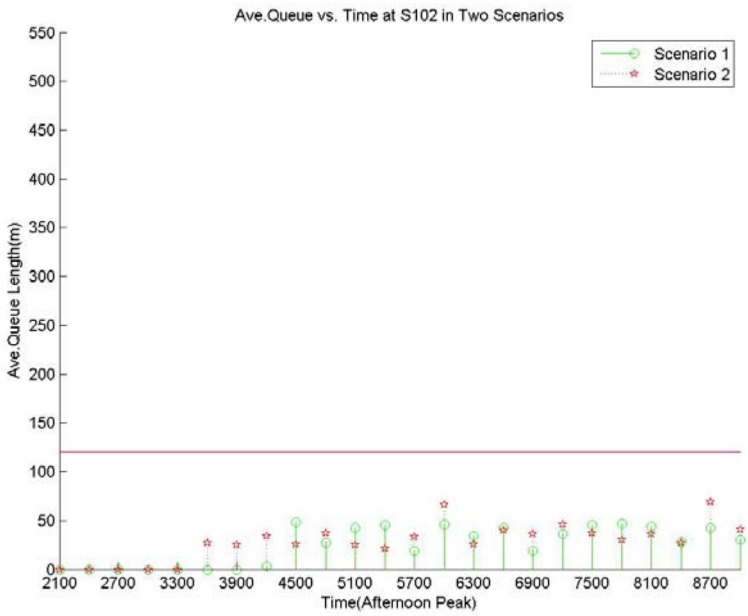
Table 6.4: Starting control time of each “slave” controller

Starting control time(min.)	Scenario 1	Scenario 2
S102	43	21
S104	38	21
S105	75	21

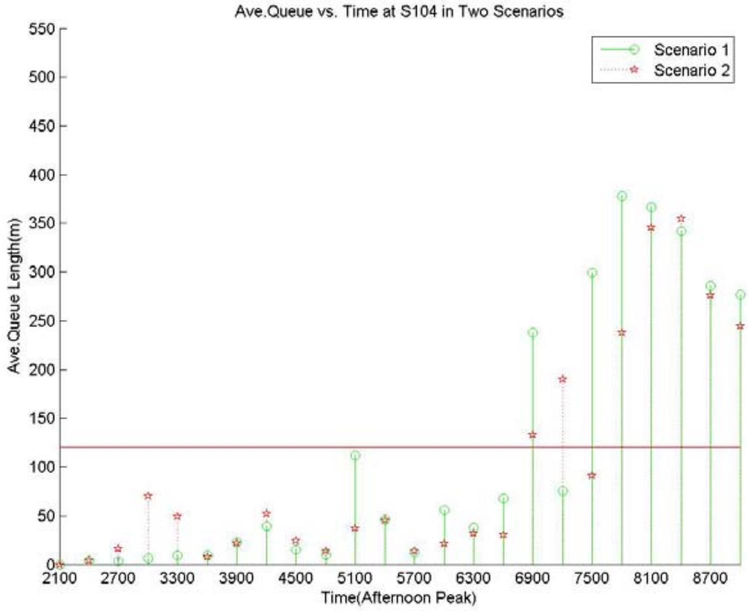
Note that the starting time of simulation is 15:30 hr. in the afternoon peak.

It is shown from the above table that the starting control time for S102 and S104 is about 20 minutes earlier in HERO network. The starting control time on S105 is even 50 minutes earlier compared to scenario 1. Due to the early control of on-ramps, the queue formed at the upstream on-ramps will occur earlier than that in the non-coordinated control case. As shown in the following figures, the queue length over time plots for the on-ramps S102 and S104, the queue is formed about 15 min earlier on S102 and 20 min earlier on S104 respectively in scenario 2 than in scenario 1, whereas the states of the queue length in the later stage are similar in both cases.

Figure 6.6: Queue length over time plots derived from Scenario 1 and Scenario 2 (Horizontal red line denotes the length of each on-ramp)



(a) S102



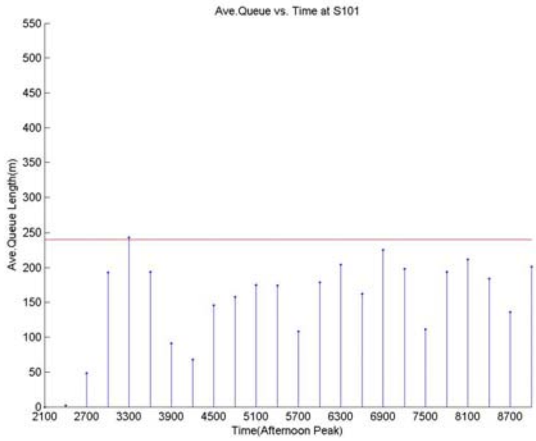
(b) S104

In this simulation model, the new control scheme also takes some effect on the route choice behaviour, as indicated in the Figure 6.5. Here, S102 is taken as a starting point. As the ramp metering on S102 starts control earlier than non-coordinated control case, it is expected that the average delay time would increase a bit. However, the resulting average delay times are virtually close to each other. The explanation is that, as the ramp metering will start earlier, the on-ramp S102 is no longer attractive for some drivers, which are originally travelling on S101 in null scenario. The new control strategy drives this part of road users back to the original routes and the throughput of S102 decreases from 581 vehicles to 405 vehicles. As a result, the demand for S102 decreases. This is the main reason for the non-increasing average delay time on S102.

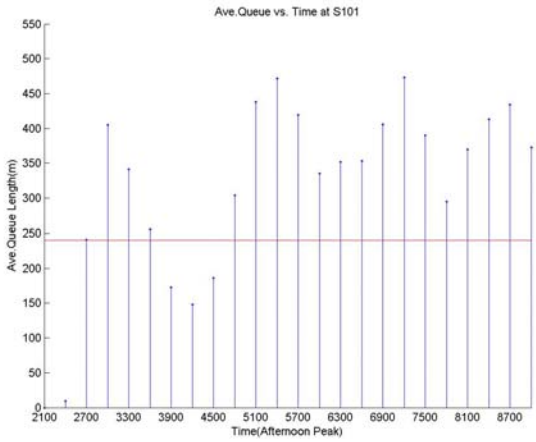
Similar theory applies to the other on-ramps. The demand on S105 is also changed from 726 vehicles to 661 vehicles, the rerouted road users will either use the on-ramps located downstream or the on-ramps located upstream which are beyond this coordination control string. This change results in the lower average delay time on S105, which decreases from 15.61 sec. to 8.91sec.. Meanwhile, the rerouting flow towards upstream no-control on-ramps could account for the reduction on the total throughput of the four on-ramps (3739 veh.).

For the on-ramp S101, the control status in both control cases is similar. The main change is the increasing incoming flow on the on-ramp, and the throughput increases from 1271 vehicles to 1382 vehicles, as a result of route choice behaviour. Then, the average delay time increases from 102.36 sec. to 105.50 sec., and the queue length on the on-ramp also increases. As shown in Figure 6.7, in scenario 2, the queue lengths at S101 in most intervals are larger than the length of the on-ramp. In this case, the on-ramp traffic will spill back to the urban intersection and affect the urban traffic network.

Figure 6.7: Queue length over time plots for on-ramp S101 (Horizontal red line denotes the length of each on-ramp)



(a) S101-Scenario 1



(b) S101-Scenario 2

The situation shown in scenario 2 should be avoided in reality, because the overloaded on-ramp queue would cause secondary blockage in the urban traffic network. When the HERO control is implemented in real life, and if the generated effect on route choice is true, some additional enforcement measure (e.g. Variable Message Signs) should be added to restrict the upstream on-ramp flow from rerouting towards to the on-ramp S101.

However, it should be kept in mind that this traffic assignment result is based on the route choice model defined in VISSIM, which is actually based on travel time measured (the utility value) in the simulation to make route choice. Although in simulation much urban traffic flow tends to use the first on-ramp road (S101) within the studied coordination string to reach the motorway, in reality urban traffic flow from further upstream location of the S101 may still use the original on-ramps. That means the traffic demand for the on-ramp S101 may less load than VISSIM predicts. The reason can be various. In real life, the route choice behaviour depends on many factors, such as personal preference, personal experience, comfort, and not just on the experienced travel time. For example, the upstream drivers may know that a large waiting queue already exists on the on-ramp S101 so as not to use that on-ramp. The route choice model used in VISSIM cannot capture all these factors. Meanwhile, the traffic assignment is a multi-dimension behaviour. Besides the route choice, the departure time choice should also be taken into account. For instance, if the control starts early on S102, some drivers will choose to leave even earlier in order to save travel time instead of just simply changing their routes towards to S101. This topic is beyond the boundary of this thesis. Hence, further research on the effect of the HERO algorithm on the traffic assignment is still needed for the real implementation.

6.3.2 Equity

In the following two paragraphs, the discussion will be based on the point of view of equity. The term of "equity" used here has two folds of meanings.

First of all, the focus is on the fairness between the motorway traffic and the underlying traffic. Since the DTM (or ITS) measures have a big impact on the whole transport system and do more than just solve local problems, it is absolutely necessary to have a policy with well-defined goals for the application area of ITS. The objective of DTM measures set up for the A10 is to keep the ring-road running. That means that the control scheme should give priority to the motorway traffic. The individual ramp metering has been proven to benefit the motorway traffic at the expense of the local delay of incoming on-ramp flow. This control strategy turns out to be unfair to the local travellers in terms of fairness. The HERO control strategy activates the upstream located controllers in order to postpone and reduce the congestion on the motorway. As the ramp metering starts control earlier than non-coordinated control case, it can be imagined that the total delay time for the local traffic will increase, which can also be estimated on the data in the Table 5.3 as well as on the assumption that the traffic demand for each on-ramp would not change too much. If the calculation is based on the simulation results, the total delay time for the traffic using the four on-ramps in scenario 2 increases to 203569.68 veh.*sec from 198428.88 veh.*sec in scenario 1, which is a 2.59% increment. Although it is more unfair for local travellers, the new control scheme meets the authorities' objective by inducing more local delay and reducing delay on motorway.

Secondly, the equity is needed for the drivers using the on-ramp roads. In the non-coordinated control case, huge delay imposes at S101. For the users using the on-ramp S101, it is unfair. The HERO algorithm aims at distribution of the delay in a more balanced way. In its coordination control string at the A10 west, although it is shown in simulation that the delay at S101 does not decease, the strategy activates the control at the upstream ramp metering. As a result, more delay will be generated at the upstream entrances of the motorway. If the route choice behaviour presented in this simulation is neglected, the total delay for the upstream located on-ramps will certainly increase. From this point of view, it is more equitable for drivers travelling through the first on-ramp. It can be concluded that HERO improves the equity requirement for each on-ramp within the coordination control string.

6.4 Conclusions

From the above analysis, conclusions can be drawn as follows.

1. In the no-control network, many upstream on-ramps may contribute to the increase of mainstream flow and merge congestion will appear at one downstream on-ramp (S101) eventually.

2. Local ramp metering control has proven to be a valuable and efficient control measure to improve the traffic conditions in the congested area as well as to benefit the whole traffic network, albeit at the cost of unfair local delay on on-ramps.

3. The traffic network with the new HERO control outperforms the non-coordinated control network. The improvement on average travel time on the main study area in the HERO network is 2.00% compared to non-coordinated control case. The new HERO coordination control shows its potential effect over the individual ramp metering control strategy. The congestion on the motorway can be postponed effectively.

4. The HERO coordination control, as one of the DTM measures, is in accordance with the objective set up for the Amsterdam network under the framework of “Improvement of the flow on the ring-road A10”. Although it may induce more unfair local delay (2.59% increment on total delay time for the traffic using the four on-ramps) compared with the individual ramp metering control case, it turns out to provide less congestion, higher mean speed and lower travel time spent in the targeted network.

5. The HERO algorithm improves the “equity” requirement for each on-ramp within the coordination control string and distributes the delay in a more balanced way

6. The route choice model in VISSIM partly resembles the route choice behaviour in real life. In the network with local ramp metering control scheme, the reaction on route choice by road users is realistic from simulation. Whereas for the coordinated control case, the route choice behaviour affected by the new control strategy is still needed to be further studied.

In this chapter, the HERO algorithm is proven to pose positive effect over the current control network in Amsterdam. In order to implement this control strategy in real life, the optimal parameter settings within the control algorithm should be found. The next chapter will present the optimization study on this new algorithm.

Chapter 7 Optimization of parameter settings of HERO algorithm

Another aim of this graduation project is to improve the HERO algorithm for real implementation if possible. The optimal parameter settings for the HERO algorithm should be found. Then, the related robustness study on the performance with respect to these settings will be done with an increasing traffic demand in VISSM.

In this section, the results of twelve proposed scenarios with respect to the changing demand will be presented. Note that each scenario in parameter optimization is tested with three different traffic demands (60%, 65% and 70%).

7.1 Optimal parameter study and robustness

In order to search for the optimal parameters within the whole control algorithm, first of all, it is decided that the studied parameter group is restricted to three series of parameters, namely the activation and deactivation thresholds in HERO and the critical speed and flow values for local control, because they are most related to the control principle of this algorithm.

The most important parameters in the HERO algorithm are the activation and deactivation thresholds. The default values of these two pre-defined parameters are 30% and 15% respectively according to the specification (Rijkswaterstaat DVS, 2007a). When a relative ramp queue exceeds 30% of the maximum admissible queue length, it becomes a “master”, and HERO starts to recruit upstream located metered ramps as “slaves”. The created cluster is dissolved if the master ramp relative queue falls below 15%. Meanwhile, the activation threshold is not only used to decide which ramp metering controller is the “masters” or not in the internal process of the HERO algorithm, but it also affects the decision for how many upstream “slaves” should be recruited and how long each minimum desired queue length should be.

The critical flow values for each TDI to start or stop metering are about 75% and 68% with respect to the road capacity (2200 veh./h/lane), thus 1650 veh./h/lane and 1500 veh./h/lane respectively. The critical speeds as the switch of each TDI both for downstream and upstream are 70 km/h and 80km/h respectively.

These default values are obtained from the setting in the standard ramp metering application or estimated on literature or experience. Hence, the thresholds should be optimized for real application in this specific traffic network of the A10 west.

Note that the specific surveyed parameters for the twelve scenarios are already shown in Section 4.5.2. Here, the scenario list is repeated as Table 7.1. The first scenario with default parameter values (30%/15%; 70/80 km/h; 1650/1500 veh./h) is regarded as a reference.

Table 7.1: List of scenarios for optimization

Scenario	Activation/Deactivation Value		
	HERO Switch (%)	**Speed Switch (km/h)**	**Flow Switch (veh./h/lane)**
1	Default (30/15)	Default (70/80)	Default (1650/1500)
2	10/5	-	-
3	20/10	-	-
4	40/20	-	-
5	50/25	-	-
6	60/30	-	-
7	-	65/75	-
8	-	75/80	-
9	-	-	1350/1200
10	-	-	1500/1350
11	-	-	1800/1650
12	-	-	1950/1800

For the assessment of different scenarios in this chapter, the criteria are restricted to traffic performance of the whole network as well as the main study area. The discussion on equity and route choice will be neglected here. That is because that for parameter study, the improvement in traffic conditions is mainly reflected by the indicators related to whole network and main study area. In Table 7.2, the integrated simulation results with regard to the chosen criteria for optimal parameter study are presented.

Table 7.2: Integrated simulation results for parameter optimization

Scenario	Demand	TTS[a]	Ave.TTN[b]	TDist[c]	Ave.TTM[d]	Throughput[e]
1	60%	7788.63	500.92	5018.112	251.73	8715
	65%	9888.49	589.60	5419.795	490.03	8816
	70%	10871.36	625.72	5643.837	523.85	8908
2	60%	7809.43	502.03	5020.962	256.40	8699
	65%	9888.49	589.60	5419.795	490.03	8816
	70%	10871.36	625.72	5643.837	523.85	8908
3	60%	7788.63	500.92	5018.112	251.73	8715
	65%	9888.49	589.60	5419.795	490.03	8816
	70%	10871.36	625.72	5643.837	523.85	8908
4	60%	7802.14	501.69	5019.321	236.10	8687
	65%	9802.38	586.82	5399.395	489.57	8746
	70%	10871.36	625.72	5643.837	523.85	8908
5	60%	7793.60	501.15	5019.215	222.10	8770
	65%	9849.16	587.66	5415.908	475.90	8869
	70%	10771.75	626.46	5589.641	536.65	8867
6	60%	7802.20	501.87	5017.143	250.98	8737
	65%	9789.26	586.34	5396.758	488.30	8794
	70%	10716.25	624.96	5567.937	526.39	8877
7	60%	7793.21	501.12	5019.321	256.19	8726
	65%	9852.85	588.54	5411.260	487.89	8768
	70%	10804.93	625.86	5608.155	529.68	8901
8	60%	7823.17	502.64	5024.136	260.60	8713
	65%	9916.79	590.69	5424.965	492.44	8767
	70%	10664.44	623.54	5555.722	497.14	9036
9	60%	7782.40	500.53	5018.013	229.24	8763
	65%	9888.49	589.60	5419.795	490.03	8816
	70%	10753.00	624.99	5585.585	511.52	8941
10	60%	7782.40	500.53	5018.013	229.24	8763
	65%	9888.49	589.60	5419.795	490.03	8816
	70%	10753.00	624.99	5585.585	511.52	8941
11	60%	7782.18	500.52	5017.901	215.90	8781
	65%	9888.49	589.6	5419.795	490.03	8816
	70%	10753.00	624.99	5585.585	511.52	8941
12	60%	7797.25	501.37	5019.431	222.45	8757
	65%	9880.24	589.38	5418.555	490.90	8778
	70%	10927.66	627.07	5658.689	517.24	8923

[a] total time spent (TTS) in the network (in 2 hours) (in veh.*hr.), [b] average travel time in the network (in sec.), [c] total distance travelled (in veh.*km), [d] average travel time on main study area (in sec.), [e] total throughput of the main study area (in number of vehicles)

From the above results, it is noticed that the indicators related to the whole network performance, namely TTS, Ave.TTN and TDist, are not sensitive to the changing parameters. For instance, the change in the average travel time in the network with respect to different parameters is less than 0.5% of the reference case (scenario 1 in parameter optimization). As the main objective of this control algorithm is to improve the motorway traffic, the assessment for each parameter can be based on the criteria related to the studied motorway area, namely the average travel time and total throughput on the main study area.

Meanwhile, it is found that in some scenarios, the resulting indicators are exactly the same as the reference case. That means that the control performance actuated by the given traffic input with respect to different "HERO" control parameters is the same as the reference situation. Theoretically speaking, this phenomenon should not occur, because the control in the model will vary with the changed control parameters. The reason can be various. Firstly, before the local controller is activated, the queue already fills in the related on-ramp. Then, the starting time for activation of the upstream controllers is the same. Secondly, there is some error in measuring the queue length on on-ramps by the ramp metering detectors. Thirdly, there is some error in communicating the control information by linking cables. The last two reasons are considered as the critical technical problems. Nevertheless, the analysis can still proceed with regard of the reasonable scenarios.

Firstly, the discussion focuses on the activation/deactivation thresholds in HERO. Referring to the scenarios 1 to 6, it is found that the 50%/25% combination in scenario 5 outperforms the other parameters under the less congested traffic network (60% demand) and the normal network (65% demand), as presented in Figure 7.1. The resulting average travel times on the motorway section are reduced from 251.73 sec. and 490.03 sec. to 222.10 sec. and 475.90 sec. respectively, which are 11.77% and 2.88% improvement compared to the reference, whereas the throughput values also increase. From the following speed contour plots for the main study area, it can also be illustrated that the traffic performance is improved by using the new parameter settings.

Figure 7.1: Bar chart for average travel time on main study area for scenarios 1-6

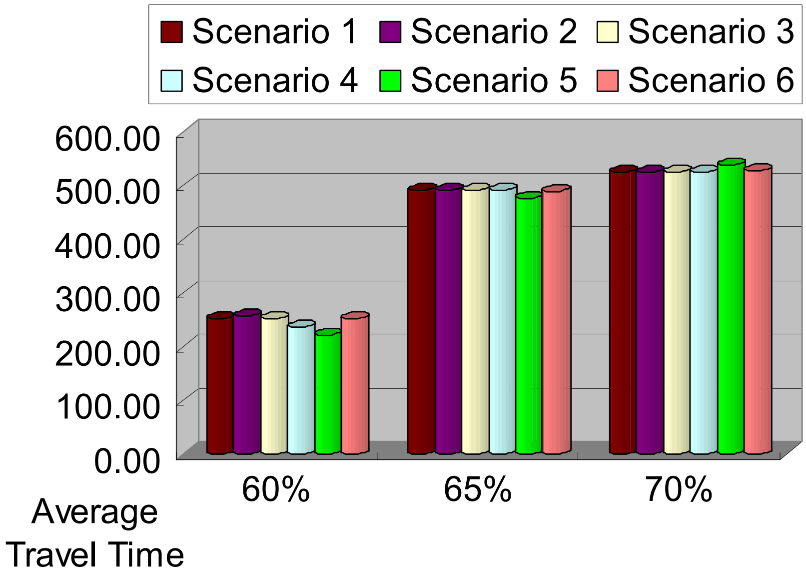
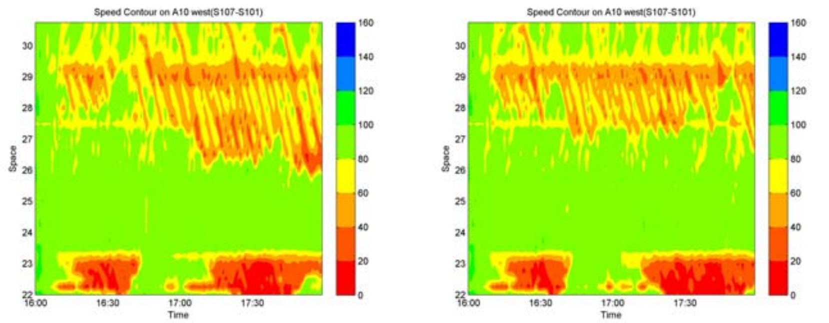
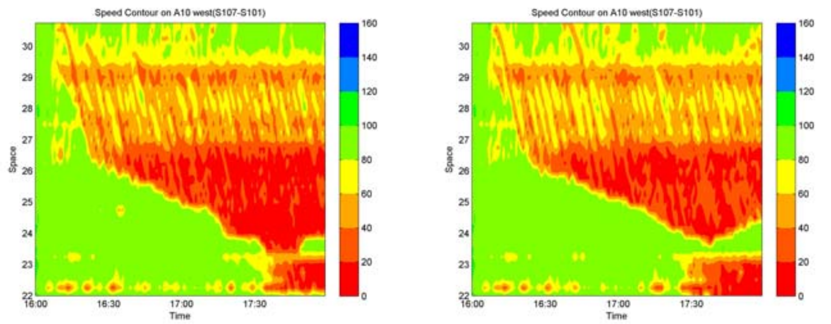


Figure 7.2: Speed contour plots for parameter optimization of HERO (Scenario 1 and Scenario 5)



(a) 60% demand network ➔



(b) 65% demand network ➔

Obviously, lower threshold values result in earlier control activation of the upstream "slave" controllers, and vice versa. Although the new combination (50%/25%) is higher than the default value, it is able to make efficient use of the upstream storage space by ordering higher minimum desired queue at "slave" on ramps while it does not activate the "slave" controllers too late. In the normal network and less congested network, the 50%/25% threshold combination is the optimal one.

However, as the demand increased in the traffic network (70% demand), the performance based on this parameter setting is not as good as expected. The traffic condition is worse than that in scenario 1. The average travel time on the main study area in scenario 5 increases to 536.65 sec. from 523.85 sec., as shown in Figure 7.1. That means the system with this parameter is not able to cope with the variation of traffic demand. From this point of view, the 50%/25% setting is not robust.

In scenario 7 and scenario 8, the speed switch values are studies. However, the performance on the main study area does not seem to be sensitive to these parameters. As shown in Figure 7.3, it is only noticed that under the over-congested network (70% demand), the system with 75/80 km/h setting in scenario 8 outperforms the reference. The resulting average travel time becomes to 497.14 sec. from 523.85 sec., which is a 5.10% improvement compared with the reference, and the related throughput also increases. The speed contour plots also illustrate the improvement as follows.

Figure 7.3: Bar chart for average travel time on main study area for scenarios 1, 7 and 8

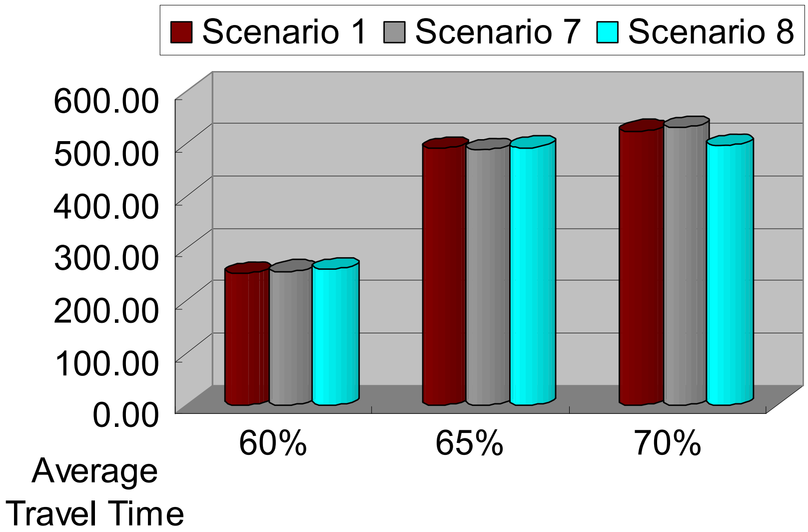
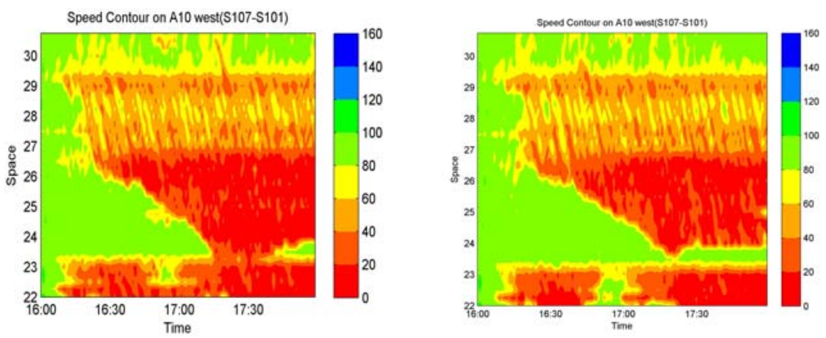


Figure 7.4: Speed contour plots in 70% demand network for parameter optimization (Speed threshold)

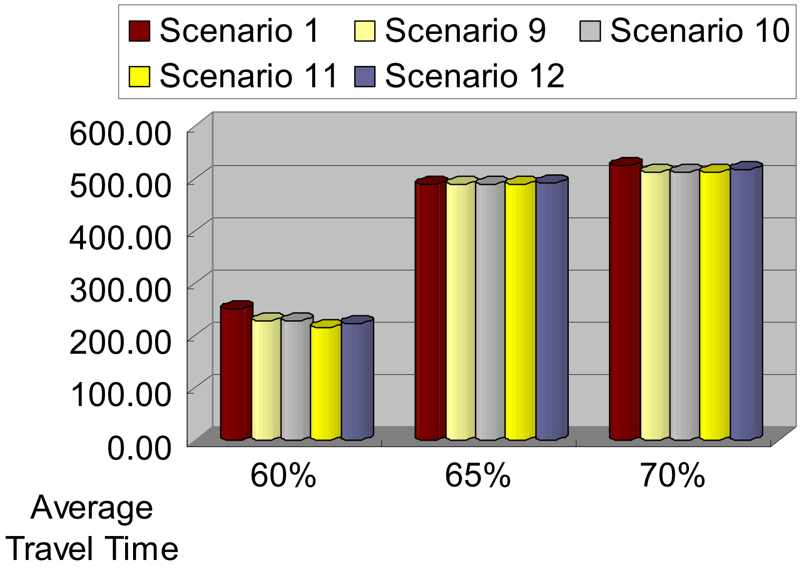


(a) 70/80 km/h ➔ **(b) 75/80 km/h**

Similar to the property of thresholds for HERO, higher speed thresholds result in much earlier control activation as well as later control deactivation, and vice versa. In the over-congested network, the earlier activation of the local control by setting a higher speed activation value (75 km/h) is beneficial to the motorway traffic network, while in the normal network, the default speed thresholds is ok.

The last four scenarios study the flow thresholds for local control. Among the five corresponding scenarios, it is found that the system with the 1800/1650 veh./h setting performs best, as illustrated in Figure 7.5. The related indicators make a progress compared with the reference scenario. Even in the over-congested network, the system with this flow threshold is still robust. So it can be concluded that the 1800/1650 veh./h setting is the optimal and also robust choice for the existing research traffic network.

Figure 7.5: Bar chart for average travel time on main study area for scenarios 1, 9-12



7.2 Conclusions

In summary, based on the results presented in this section, the optimal and/or robust parameters within the HERO algorithm for the current traffic control network are found. The 50%/25% threshold value has proven to be the optimal setting for HERO used in normal traffic network, whereas it is not robust with respect to the increasing demand. The default speed thresholds can be still used in the normal traffic network, whereas a much higher activation value (75 km/h) can be considered to use in over-congested case. And the 1800/1650 veh/h/lane value is the optimal and robust flow threshold.

For real implementation, not only the threshold parameters for control algorithm but also the parameters for specific on-ramps should be determined. As presented in the Section 4.3.2, the maximum admissible queue lengths (in number of vehicles) for each on ramp in this specific traffic network are also found based on the real geometric size.

The list of the parameters, which might be used for real implementation, is shown in the following table.

Table 7.3: Optimal parameter settings within the control algorithm for the Amsterdam motorway network

		Activation	Deactivation	Value
Threshold in HERO (%)		50	25	
Speed threshold (km/h)		70(75)	80	
Flow threshold (veh./h/lane)		1800	1650	
Max. admissible queue(veh.)	**S101**			36
	S102			32
	S104			18
	S105			18

Chapter 8 Conclusions and recommendations

The main objective of this project is to investigate the effects and the consequences of the HERO algorithm. Meanwhile, the study on optimal parameter settings and a related robustness study within the algorithm are conducted. In this section, the conclusions related to the research aims and questions will be presented, and recommendations for further research and development are given

8.1 Summary of research process

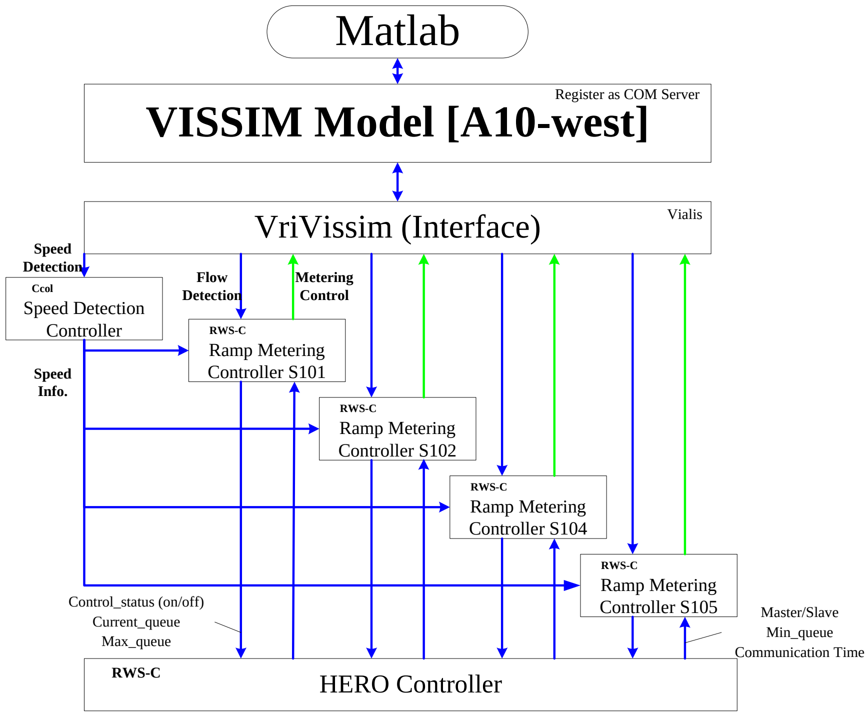
First of all, a brief summary of the work has been done for this thesis is given.

In the VISSIM microscopic simulation model, the previous Amsterdam traffic network has been updated. Appropriate assumptions, configurations and modifications make sure that the existing model performs as well as needed. These assumptions are mainly related to traffic demand, traffic control and motorway capacity. The traffic demand collected in 2000 for passenger cars is used for simulation study with 10% truck flow in the total demand. Urban traffic control at intersections is fixed-time control strategy. The speed limit control strategy is not modelled in the A10-west network to avoid coupled effect. The capacity for motorway is estimated as 2200 veh./h/lane.

Field study and literature survey on the ramp metering control area have been performed to collect correct and reliable information for the infrastructure and the controllers as the model input. Meanwhile, appropriate parameters in VISSIM have been chosen to make the simulation environment functioning well.

The control application of the HERO algorithm has been realized via the external control interface (Promit-E: VriVissim.exe). The control interface enables VISSIM to connect the related external controllers. The data communication is relied on the Dynamic Data Exchange (DDE) technique by using computer’s RAM memory. However, when doing multi-runs for the scenarios with ramp metering control, the program fails to reopen the external controllers after the first simulation run because of shortage of system memory. Solution has been found by using Matlab to control VISSIM to realize the multi-run function. In this case, VISSIM has to be registered as a COM (Component Object Model) server. Moreover, Matlab is also used for processing the raw-data derived from simulation. The whole simulation environment with controllers is further illustrated in the following figure.

Figure 8.1: VISSIM simulation environment



About modification of the Amsterdam model, firstly, the infrastructure network in VISSIM has been updated by adding some missing links. Then, main efforts focused on the route choice and lane change behaviour have been made. Illogical routes have been avoided in traffic assignment process by using edge/route closure function and "surcharge" function. Certain parameters related to lane changing have been updated to provide more acceptable behaviour.

Furthermore, the general calibration of the current network has been given so as to provide more reliable and reasonable results. The main goal for the general calibration is to search for a reasonable traffic demand for the current VISSIM model that is able to reproduce similar congestion on the main area compared to the real situation. By comparison of the empirical data with the simulation results, it is concluded that the current adapted VISSIM model with 65% demand could be used as a basic model for impact analysis.

In this project, ten criteria have been drawn to assess different scenarios. Three scenarios have been proposed to test the effects and consequences of the new coordination algorithm. The null scenario is used as a reference. In this case, no control strategy is implemented. Secondly, the solitary ramp metering control strategy is tested to see the improvement of the DTM measure. Finally, the new HERO algorithm is simulated to see the benefit of coordinated control. Moreover, there are twelve scenarios with regard to different parameters used for optimization study.

8.2 Conclusions

Based on the analyses in the Chapter 6 and Chapter 7, two main research questions, which were posed in the beginning of this report, will be answered. The following conclusions are addressed:

1. What is the predicted impact of coordinated ramp metering on the A10 beltway?
- How does it compare against non-coordinated ramp metering and no-control case?
- Does the implementation of coordination control meet the objectives of DTM set up for the network around Amsterdam?

In the no-control network, many upstream on-ramps may contribute to the increase of mainstream flow and merge congestion will appear at one downstream on-ramp eventually. Local ramp metering control has proven to be a valuable and efficient control measure to improve the traffic condition in the congested area and to benefit the whole traffic network, albeit at the cost of unfair local delay. The improvement on average travel time on the main study area is 24.15%.

The new HERO coordination control shows its potential effect over the individual ramp metering control strategy. The traffic network with the new HERO control outperforms the non-coordinated control network. The improvement on average travel time on the main study area in the HERO network is 2.00% compared to non-coordinated control case, and 25.67% compared to no-control case. The congestion on the motorway can be postponed effectively.

Meanwhile, the HERO coordination control, as one of the DTM measures, is in accordance with the objective set up for the Amsterdam network under the framework of “Improvement of the flow on the ring-road A10”. Although it may induce more unfair local delay (2.59% increment on total delay time for the traffic using the four on-ramps) compared with the individual ramp metering control case, it turns out to provide less congestion, higher mean speed and lower travel time spent in the targeted network. Furthermore, the HERO algorithm improves the equity requirement for each on-ramp within the coordination control string and distributes the delay in a more balanced way.

2. What are the optimal parameter settings within the HERO algorithm for real application?
How robust is the performance with respect to these settings against changing traffic conditions?

Based on the given traffic information, optimal parameter settings within the HERO control scheme are found with respect to the specific traffic network of the A10 west. The 50%/25% threshold value has proven to be the optimal setting for HERO used in normal traffic network, whereas it is not robust with respect to the increasing demand. The default speed thresholds can be still used in the normal traffic network, whereas a much higher activation value (75 km/h) can be considered to use in over-congested case. And the 1800/1650 veh./h/lane value is the optimal and robust flow threshold. For real application, this set of parameters is still subject to be tuned and validated.

8.3 Recommendations for further development

In this section, the recommendations for further improvement of this ex-ante study for the HERO algorithm on the A10 beltway will be presented.

Impact analysis
The impact analysis of the new coordinated control strategy is conducted in a vertical way by comparing coordinated control to solitary control and no-control cases. Actually, the analysis could proceed laterally by comparing HERO (RWS) algorithm with other rule-based algorithms (e.g. HERO (ALENEA) algorithm), as well as the optimal control strategy of coordinated ramp metering. It would also be interesting to test whether the new algorithm could reach the efficiency of the optimal control scheme in the microscopic simulation environment.

Moreover, the effect of the HERO algorithm on the route choice behaviour as well as the departure time choice should be further studied for the real application of this control strategy. It would be helpful for road management authorities to make some additional DTM measures.

Traffic network data
According to the ambition of the government, besides the current four existing ramp metered on-ramps, the remaining main on-ramps of A10 will be equipped with ramp metering as well. Then, the HERO algorithm will be implemented along the whole ring-road. However, the Amsterdam network studied in this project only contains part of A10 ring-road where the existing ramp metering controllers are located. In order to study on the potential benefits of this coordination algorithm on the whole ring-road network, it is better to investigate the traffic condition derived from a complete A10 network with all possible TDI

controllers. In that case, the potential effects of the HERO algorithm can be further exploited. Since more local delay is imposed at on-ramps, the traffic conditions on the motorway will be better.

As known, the traffic demand input is based on the statistic data with respect to the passenger cars in the year of 2000. It is difficult to testify the correctness of the data. Compared with the current traffic situation, the O-D demand data is changed already. Meanwhile, certain modifications and recommendations have been made with respect to the given demand information. In order to obtain more reliable and realistic results from simulation, firstly it should be make sure that the traffic input information is close to the real situation as much as possible. It is also important for choosing optimal parameters (such as activation/deactivation thresholds) used for real application. Hence, it is suggested that new traffic demand data should be derived from the current traffic network for further research.

Parameter study

For parameter optimization, only three series of the parameters are chosen. They are activation and deactivation thresholds in the HERO algorithm, the critical speed and flow values for local control. As in the related robustness study, the number of step for changing demand values is also three, from 60%, 65% to 70%. The range is limited. In the future, the study ranges both for parameter and input demand variations could be extended. Meanwhile, to fully understand the effect of each parameter on the obtained control output, more detailed sensitivity analysis should be required.

Simulation program

Another problem in this project is that the simulation time for each scenario is quite long. As the convergence condition is difficult to reach, many simulation runs are needed for each scenario. For large scale networks, the dynamic assignment function in VISSIM is really required to be improved. Or it is optional to search for some other microscopic simulation packages for network study.

In the model modification, it is found that the lane change model in VISSIM does not describe the real traffic behaviour properly. It is an internal drawback in VISSIM and thus it is difficult to be improved.

The route choice model in VISSIM can be further improved by capturing more factors in real life, such as personal preference, personal experience and comfort factor. By doing this, more exact results can be provided on route choice behaviour affected by the new algorithm. To get more information for route choice, it is necessary to do more study and survey based on the road users in the application area.

Discussion on the prioritization of certain on-ramps

In the ring-road network, certain on-ramps would get priority over the other on-ramps with respect to the authorities' preference. In my opinion, it is possible to realize the prioritization of certain on-ramps within the HERO algorithm. Priority of certain on-ramps means that these on-ramps are treated as "master" controllers in the HERO coordination control. This can be realized in two ways. Firstly, a pre-condition for a "master" controller is that this controller has to start metering. In a coordination control string, a prioritized on-ramp can be always set as activation state. However, according to the control algorithm, each control string can only contain one "master" controller. In a coordination control string, if a downstream located ramp meter starts control, then the prioritized ramp meter will be forced to be a "slave" controller of that downstream ramp meter. Some special statement can be made in the internal control algorithm to keep this prioritized ramp meter as "master", whereas the downstream located ramp meter will function locally.

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Appendices

Appendix A: VISSIM Interfaces

Appendix B: VISSIM model modifications

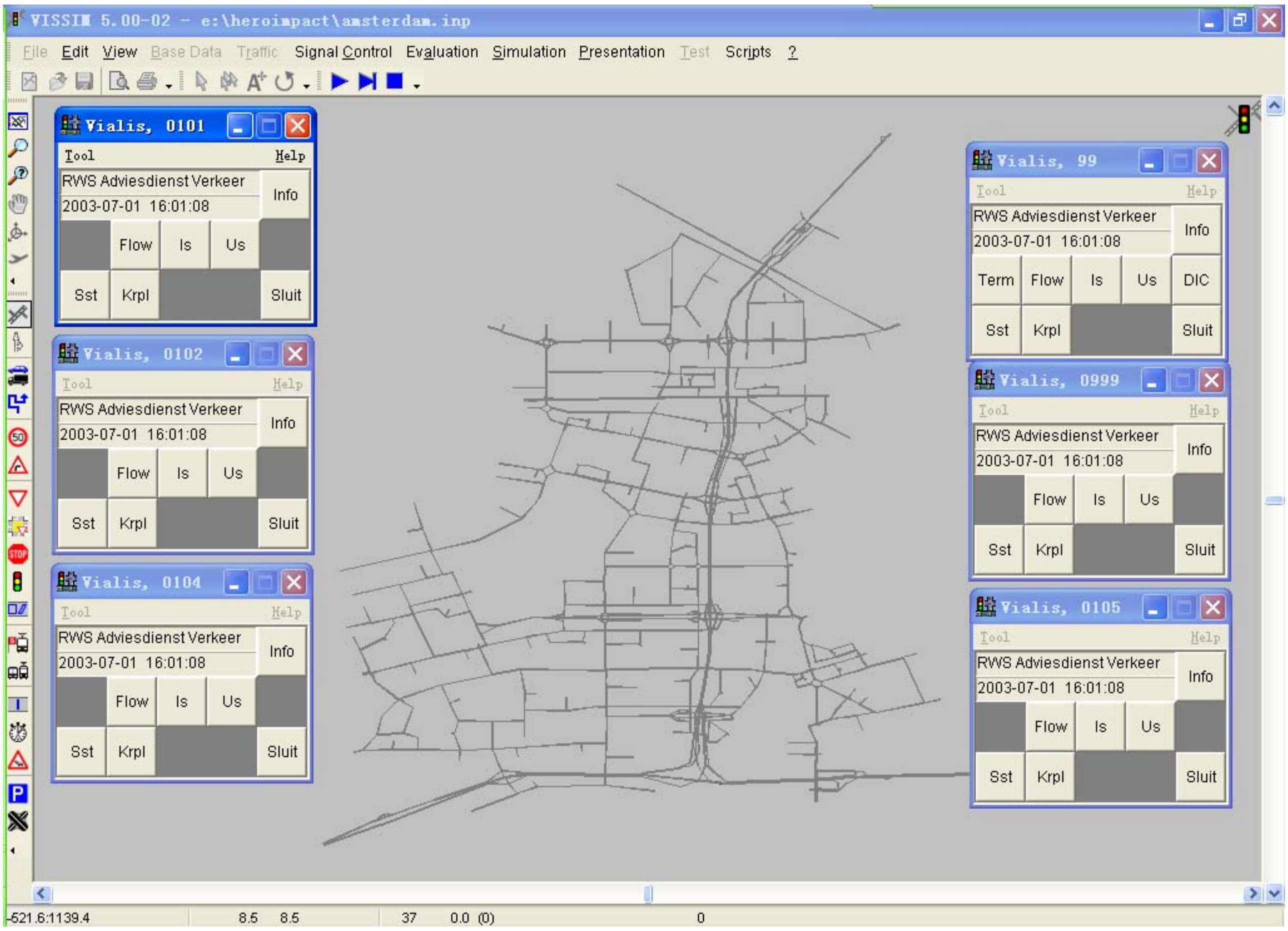
Appendix C: Manual for configuration of external controller

Appendix D: Configuration of Monigraph

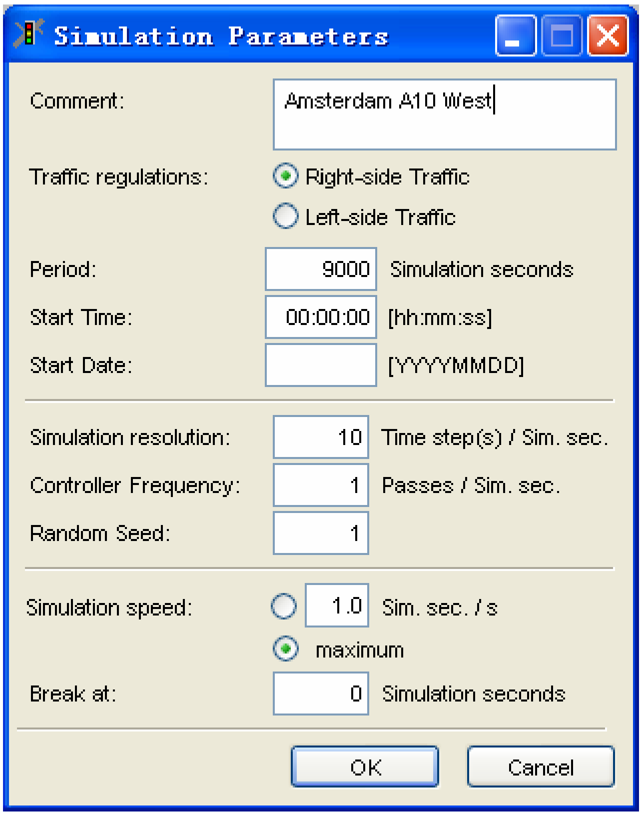
Appendix E: Dynamic Assignment

Appendix A: VISSIM Interfaces

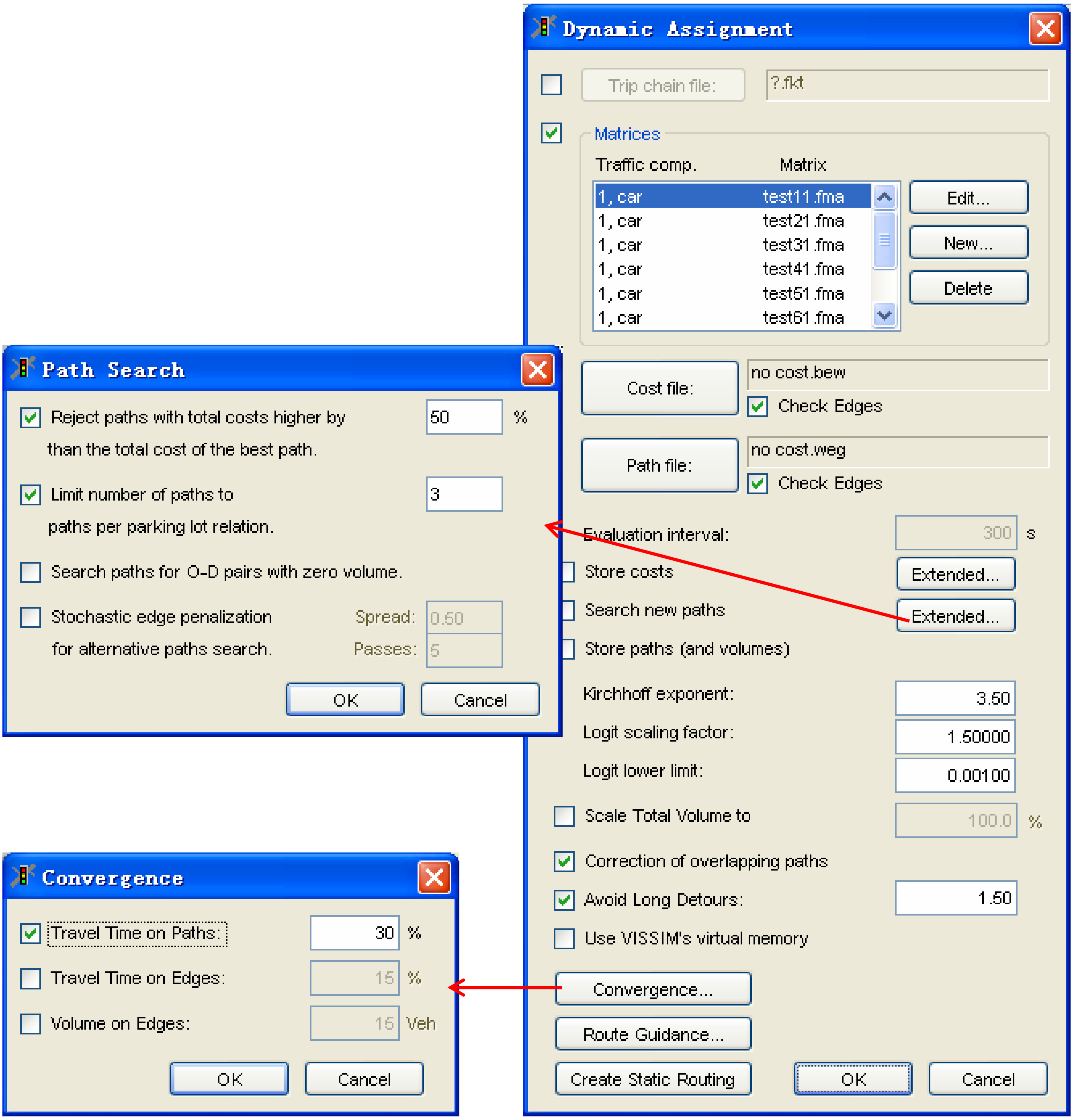
A1. VISSIM simulation interface with external controllers



A2. Configuration of simulation parameters



A3. Configuration of dynamic assignment

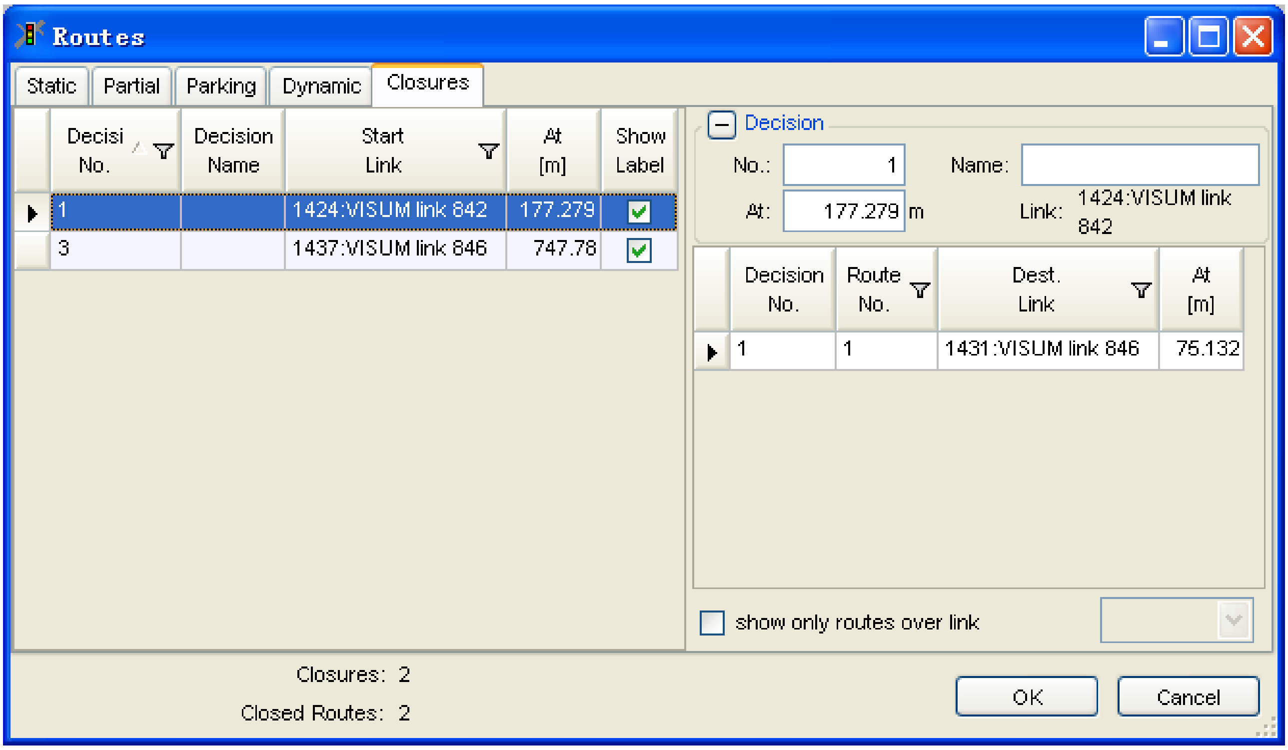


Appendix B: VISSIM model modifications

B1. Table: Edge closures

EdgeClosure	From (Node No.)	To (Node No.)
1 (S101)	1924	1925
2 (S101)	1925	1924
3 (S104)	1928	1929
4 (S104)	1929	1928
5 (S105)	1930	19301
6 (S105)	19301	1930
7 (S106)	1931	1932
8 (S106)	1932	1931

B2. Route closure decision



B3. Table: List of surcharged links

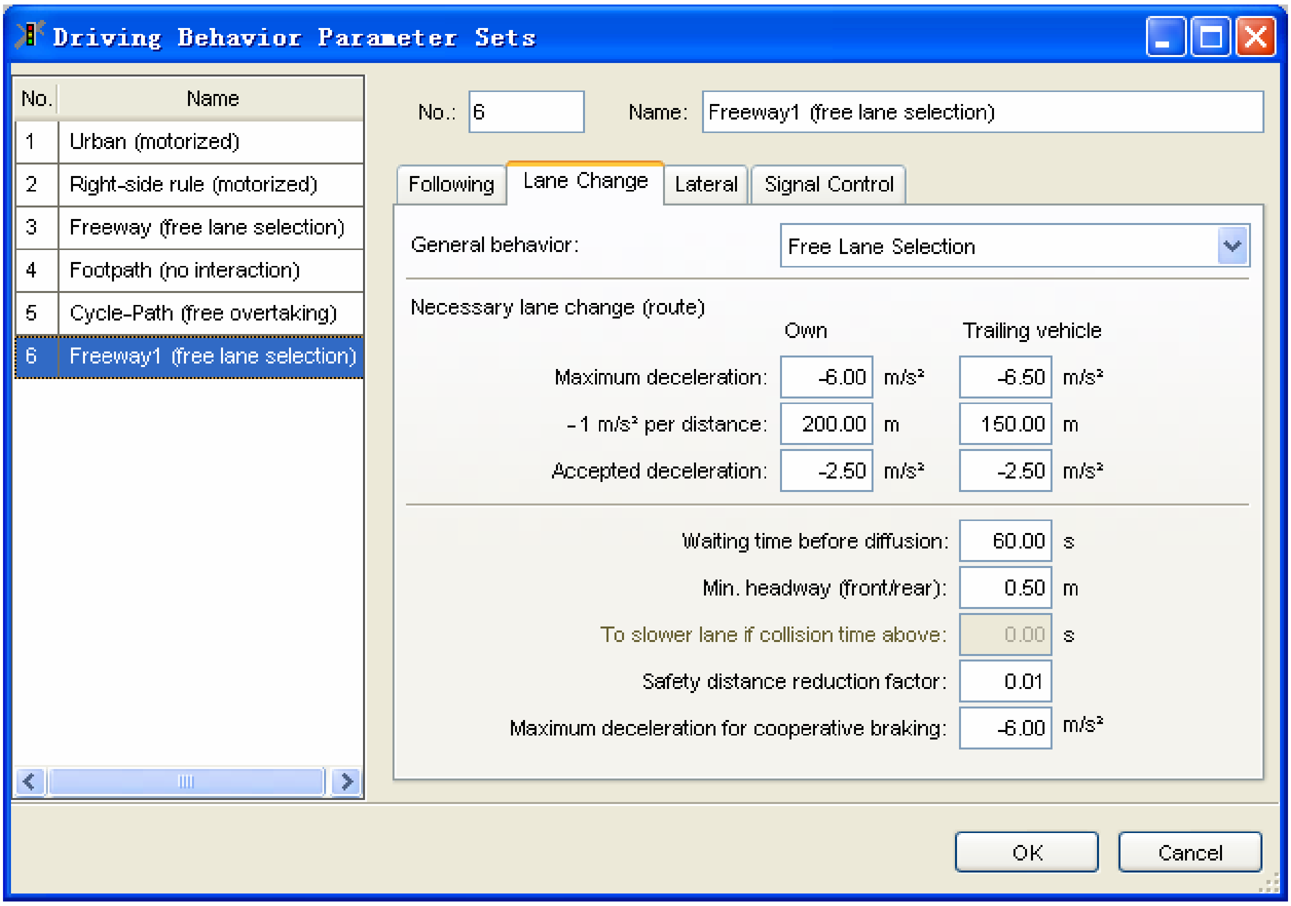
Area	Link Nr.	Surcharge Value($)
A10 West	463	2000
A10 West	839	2000
A10 West	1324	2000
A10 West	1343	2000
A10 West	890	2000
A10 West	884	5000
A10 West	1335	2000
A10 West	475	2000
A10 West	833	2000
A10 South	1007	2000
A10 South	429	2500
A4	285	2000
A4	287	2000

B4. Table: Variation of link lane change parameters

Area	Link Nr.	Previous		Present		Remark
		L.C.D.*(m)	E.S.**(m)	L.C.D.*(m)	E.S.**(m)	
A10 West	3105	200	50	1000	50	
	3246	400	250	1000	50	
	10090	200	5	1000	5	
	10094	200	5	1000	5	
	10086	200	5	1000	5	
	10087	200	5	1000	5	
	5865	200	5	1050	50	
	4596	1000	50	1050	150	
	3078	1000	50	1050	50	
	10101	200	5	500	5	***
	5830	200	5	300	5	***
	5841	200	5	300	5	***
	3145	200	5	250	220	S101 On-ramp
	3966	200	5	100	5	S102 On-ramp
	4365	200	5	200	130	S104 On-ramp
	10099	200	5	200	120	S105 On-ramp
A4	1765	1000	50	1050	200	
	1768	1000	50	2000	900	
	1769	1000	50	1500	50	
	3355	200	5	800	5	
	3032	200	5	500	5	***
A10 South	10091	300	50	2000	700	
	10093	1000	50	1500	50	
	1754	300	15	1050	50	
	1753	300	15	1000	15	
	5878	200	50	1050	400	
	10437	200	5	1000	5	
	5874	200	5	400	5	***

* L.C.D.: Lane change distance
** E.S.: Emergency stop distance
*** At merging section, the *Lane Change distance* for the connector downstream from the merge link (weaving section) must be larger than the length of the merge link itself.

B5. New lane change model



B6. Table : Links using the new lane change model

Area	Link Nr.
A10 South	15
	16
	1160
	5072
	438
	5874
	1439
A4	20
	583
A10 West	466
	467
	471
	1001
	1003
	482
	489
	537
	538
	1423
	1424
	1428
	1431
	1437

Appendix C: Manual for configuration of external controller

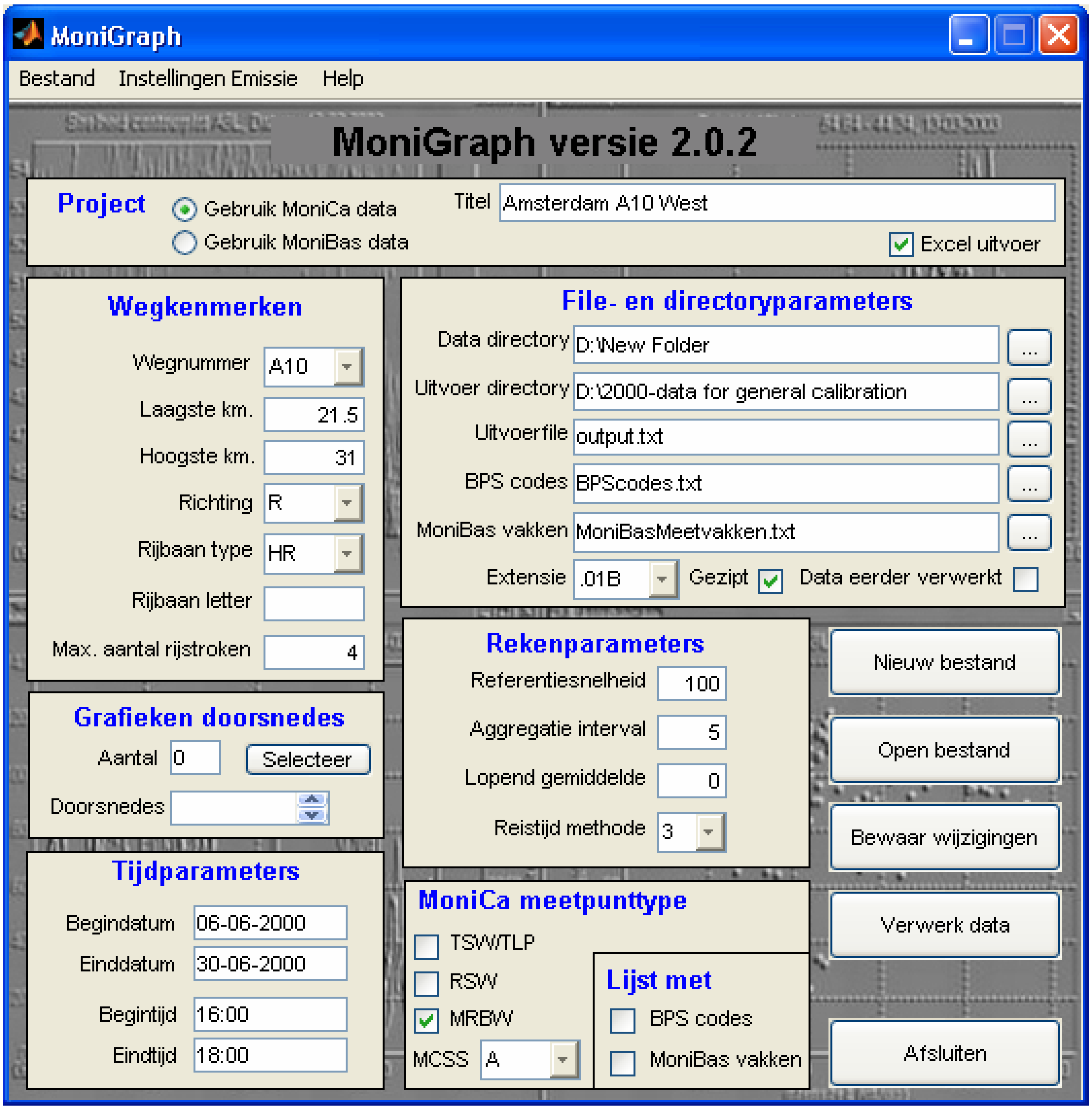
<1> All VISSIM files (***.inp and related input file), compiler (StartShell.exe and StartShell.ini), external control interface (VriVissim.exe, vrivissim.wtt, TrafficSim.ini and “None”) and all controller files (controller codes contained in the folder “dat”) should be put in the same directory.

<2> First to make sure all the codes of the controllers correct. Then click StartShell.exe to compile each controller. This compiler could find and compile the code of controller in the path “dat” file. In the upper left side of the window, type the name of controller in the blank (Here, controller S102 is taken as an example, type in “k0102”), then the compiler will identify the type (Cc Fr34, Cc Fr90, Cc Ccol and Cc Rwsc) of each controller (k0102: Cc Rwsc), and the tab of the corresponding type in the lower left side would be activated. Click it to compile the controller. Then the related controller program (k0102.exe) will be generated in the folder (k0102) under “dat”.

<3> Open VISSIM model. Click signal control to choose “edit controllers”. Right click to add new controller.
The number of each controller should be the same as the controller identified code which can be found in “dat” (e.g. 102). Cycle time: “variable”. Type: “Trends”.
Click tab “signal groups” to add new signal group (10201 and 10202) with the type of “normal”.
Click tab “Controller (TRE)” to define the external interface. Program file: “VriVissim.exe”. STG file : “none”. VXB file: “none”.
Then it is able to create the signal heads and related detectors on the roadside.
More detail information about configuration of controller and adding signal heads and detectors could be found in the Manual about VRIVISSIM (Koppeling VRI met Vissim]

<4> After all signal heads and detectors are placed in the network. The control could be realized.
Note that VISSIM can only handle detectors from adaptive signalized controls when using the 0.1 s setting. That means the simulation resolution is set as 10 time steps per simulation second.
Start simulation, the interface window for each control will pop up. In the corresponding “US/IS” (outgoing/incoming) windows, communication could be defined by “shift+click” the coordinated variable using a unique linking cable (the number of the link cables ranges from 1 to 255).

Appendix D: Configuration of Monigraph



Appendix E: Dynamic Assignment

Principle of dynamic assignment (PTV, 2007)