

Optimization Traffic Control

Using

Route Information



Jun Li
Transport Planning
Civil Engineering
Delft University of Technology

Committee members:
Prof. Dr. H. J. van Zuylen (T&P) (chairman)
Ir. T. H. J. Muller (T&P)
Ir. W. van der Hoeven (DHV)
Ir. P. B. L. Wiggenraad (T&P)
Ir. Monique van der Berg (3mE)



Abstract

Optimizing traffic control for a multiple-junction road network is a difficult but important task in traffic system design. A properly designed control strategy with various control measures is effective in handling traffic flows in diverse traffic conditions. Regarding the limits and low performance of existing control system, this paper presents a novel route information traffic control strategy (RICS), which integrates the route demands into traffic control strategy design.

RICS aims to optimize network traffic performance and facilitate the movements on some specific routes with maximizing the capacity of infrastructure and maximizing the utility of certain route. It is potential to relieve movements blocked problem in saturated condition or improve the movements of big traffic demand route in some special traffic conditions. The measures of RICS are in a wide variety, which include adjustments in the signal timings and roadside geometric. They can be designed corresponding to the route demands in the network. RICS enjoyed big advantage in generating higher flexibility in signal control setting and adaptability to various traffic conditions. RICS potentially provides special control for preferential routes.

The application system of RICS involves input system which provides traffic condition and route demands and output system such as traffic signal control and traffic management. RICS can be pre-designed or it can react or adapt to the real time traffic condition.

This report presents a general concept of RICS including its design, application and evaluation. Finally, the case study of delft proves that the proposed RICS is promising and well-performed to improve the traffic performance of preferential routes.

Key words: route information, OD matrix, traffic control strategy, network optimization

Preface

This report performs as the final contribution to my master education.

It is executed in TU Delft with support from DHV, one of the most famous engineering consultancies in Netherlands. This study tries to contribute to the theory of optimization of traffic control strategy, which is regarded as a cost-effective and efficient way in relieving traffic congestion nowadays.

After more than half year efforts, this report is finally achieved with the supports from a lot of people. First, I would like to thank my committee members for their guidance, suggestion and criticism. The frequent meetings and discussions enable me to keep on making progresses. All these are helpful for me to improve theoretical knowledge and personal abilities during the thesis study period. Then, I would like to thank the colleagues in DHV, who are very experienced, friendly and patient. They provided me a lot of practical support during the project and created a nice environment for me to finish the project. I really appreciate that.

Finally, I would thank my family and friends in both china and Netherlands. It is very nice to spend the past two years with you. The precious experience and feelings will always be in my mind. You deserve to share the happiness and success of this moment.

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1. Introduction

1.1 Introduction of traffic control strategy

Traffic jams are usually caused by the traffic demand exceeding the motorway capacity due to either an increase in the demand, or a decrease in the capacity. Congestion is deemed recurrent when the demand exceeds the capacity regularly, e.g., during the peak hour. Non-recurrent congestion can be caused by a temporary and non-regular increase of the demand or decrease of the capacity, for example as a result of a concert (demand) or bad weather conditions (capacity).

Increasing the motorway capacity or reducing the traffic demand can reduce congestion. However, increasing capacity by expanding the infrastructure is costly and time-consuming, and it might eventually lead to an increasing traffic demand as the improved infrastructure attracts more travelers. On the other hand, plans to reduce the traffic demand by raising the cost of travel are continuously delayed, which are always faced with public and political resistance as it decreases the utility of road users.

Traffic control strategy is regarded as a cost-efficient way to deal with traffic problem, which can be defined as the common basis of all activities of the participating organizations with respect to traffic management in a regional network. In view of the imminent traffic congestion and lack of possibilities for infrastructure expansion in urban road networks in the current situation, the importance of efficient signal control strategies can hardly be overemphasized. Traffic control strategy affects both the demand side and supply side of traffic system to improve the traffic performance.

A good control strategy can be formulated as an optimization problem of maximizing the capacity of existing infrastructure and minimizing the system delay time. It determines signal control variables and various traffic management measures with subject to the control constraints,

The goal of traffic control strategy need to unite the separate targets which the participating organizations (mainly road authorities and road users) want to achieve in that region. In this respect, it should balance the needs from all stakeholders. Here lists the expectations of some major stakeholders:

From travelers' aspects

The travelers are individually optimizing their profit during their trips. Everyone seeks for the shortest travel time from their own aspects and they do not want to be hampered by other travelers. They would seek for the goals of:

- Avoiding the negative effects from other vehicles as much as possible;
- Minimizing the delay in the traveling;
- Ensuring the safety during traveling;

- Saving fuel consumption.

From road authority's aspects

The government is also the main stakeholder of traffic control strategy, who wants to increase the total national benefits. Therefore the government has declared in the "Nota Mobiliteit" [1] that they want to decrease the negative effects of people hindering each other while traveling. Also some other disadvantages of traveling, like the unreliability of the system, the unsafe and negative consequences for the environment are stated to be of importance. Some general targets are mentioned to decrease these disadvantages of traveling:

- The increasing need for mobility should be facilitated. Although people like to travel more, the disadvantage of doing so should not increase.
- The reliability of traveling should be improved, the more reliable the system is the less the disutility becomes.
- Traveling should become safer.
- The negative consequences of traveling for the environment should somehow be reduced.

Providing in these requests is one of the main tasks of Rijkswaterstaat. In general they use constructing, pricing and utilization as their main pillars to for their policy. Some possible measurements that they can use to achieve improvements are:

- Adding extra capacity to the existing transport network;
- Try to manage all the travelers in such a way that they don't hinder each other so much;
- Try to improve the travelers behavior;
- Create limitations, for instance to limit the amount of air pollution.

With balancing the needs of those stakeholders, the objective of traffic control strategy can be set, for example, a safe trip with an acceptable and reliable travel time, given certain (financial and environmental) restrictions.

1.2 Problem definition

It is a difficult task to fulfill the requirements of different stakeholders as they are not always match to each other. The conflicts might occur in the following aspects:

Travelers vs. network

As a new trend of traffic control development, the traffic control measures are changed from a technique-oriented to a result-oriented. In the other word, there is a growing emphasis on the quality of traveling experienced by road users in traffic control strategy design. From traveler aspects, route traveling performance is the direct criterion for road users to evaluate their travel quality. From the network, the goal is set to reach the system optimal. The conflict is always existing in the two objectives. The compromise of the benefits of travelers and network is always a critical task in traffic control strategy design. In some cases, the measures could be designed to decrease the delays on certain routes even though it might increase delays for the rest network.

Vehicles vs. infrastructure

The capacity of existing infrastructure is aimed to be maximized in traffic control

strategy. Route information, which indicates the traffic pattern of the network, is helpful in diverse ITS applications such as providing traffic condition in advanced information system and reroute management. Dynamic route guidance system is expected to balance the distribution of vehicles to reach a more efficient use of existing infrastructure. This also brings two problems. In one aspect, the traffic situation changes a lot meanwhile so that traveler will never encounter the traffic situation given at the moment of his choice, especially when longer distances are traveled. The other problem is that the improved situation will attract more travelers so that the pressure on the infrastructure is still not solved.

Short term vs. long term

The current traffic control strategy mainly is based on the approaching link flow. The predicted traffic arrival is very short term so that the optimizing objectives of traffic control is only designed within a short period, while route information indicates the vehicle flow trend with the time and the space, which might help to allocate the infrastructure capacity in time and space in a longer period and in a more efficient way.

Summarizing, the problem definition is formulated as follows:

A suitable control strategy should be designed to compromise the needs of travelers and networks, vehicles and infrastructure, short term and long term. It is unclear what effects route information can bring on traffic control strategy to allocate the existing infrastructure capacity on the supply side.

The problem formulation leads to the objective of this thesis:

Investigate how route information influences traffic control strategy and propose a new control strategy using route information (RICS). The study will cover its design, application, and implementation in a theoretical system, while explore the impacts and evaluate the results by practical real-case experiment.

This gives rise to the following research questions which cover the design, application, implement and evaluation of the RICS. They are expected to be explored during the process:

- Which effects are to be expected by route information?
- How can route information effect traffic control strategy design?
- What situation RICS could be applied?
- How can be RICS applied?
- What kind of management system is needed?
- How can RICS be properly evaluated?
- What advantages and disadvantages might RICS result in?

1.3 Research questions

As the goals stated above, the general research questions can be described more in detail according to the traffic management process.

The Handbook of Sustainable Traffic Management (Rijkswaterstraat, 2003) subdivides the process into nine steps. Figure 1-1 graphically shows the process steps. The process performs successfully in the Netherlands as an approach to set up integrated

traffic management plans on a regional level and it enabled different road authorities (state, province and municipalities) to work together effectively. The study will analyze the problem following the main steps.

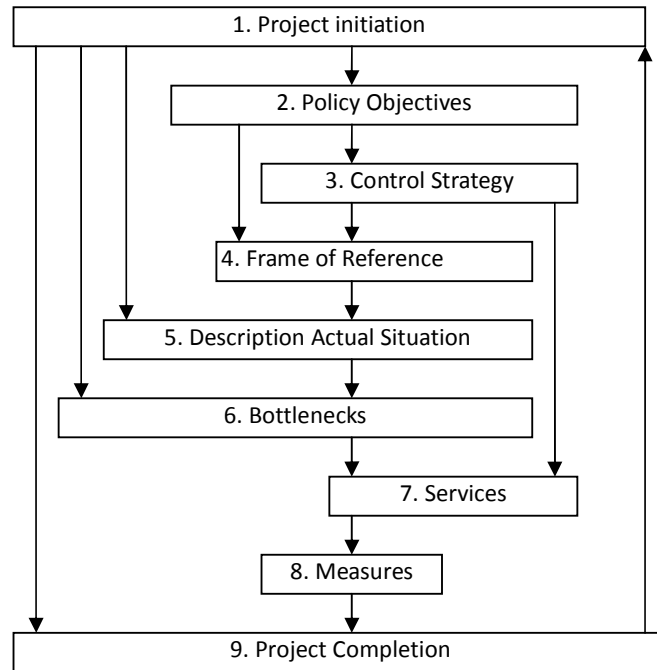


Figure 1-1 Traffic control management Process

Determining the effects

In this formulation, there is a very wide range of possible consequences that will be investigated. Therefore it needs to investigate what are the effects that are of interest and of importance and how they are to be measured.

First of all, it should be clear what is likely to occur when combining the route information and traffic control. Of course, the combination of these two is not commonly reached on and it could bring some new ideas. The research questions could be:

- Which effects are to be expected with route information?
- How can these effects be applied in traffic control?

Setting the measurable criteria

This step contains several tasks. On the one hand, it focuses of the impact of route information on traffic control system. On the other hand, it analyzes the route information control strategy itself, which states that it is of importance how such a system works. The research questions can be:

- What is the influence of RICS?
- What can be stated about the quality of the control?
- How can it be properly evaluated?

For travelers

Eventually, the travelers are experiencing the effects mentioned above, in which all travelers are mentioned together in the goal. This group however needs to be split up as different groups of traveler who can have different demands.

In generally, two groups of users of RICS are logical to distinguish: on one hand there is the group of users within RICS system. On the other hand, there is the group out of RICS network, facing the consequences of the action of RICS.

- Which different user classes need to be distinguished?
- How are different road user groups influenced by RICS?

For road authority

The consequences of the RICS can be drawn for all different stakeholders. The interests of road authority, the main stakeholder of traffic management should be also investigated. For example:

- How does it work in over-saturated situation?
- What negative effects could it bring?

Purposing the measures

After the proper measures are selected, the next step is to apply and implement it in a practical way.

- How can it be applied in a wide network?
- What kind of management system is needed?

1.4 General approach

In this section, the general approach of this study will be described. The approach aims to reach the thesis objective by answering the research questions one by one. The approach consists of two parts: a literature review and an experiment.

Literature study

The literature review is split into three parts. The first part focuses on existing traffic control system to provide insight into shortcomings of current traffic control strategy. The second part identifies and analyses the potential effects which route information can bring. The third part is going on the detailed design ,application and evaluation.

Experiment simulation

As stated, the effects of RICS on travelers somehow should be determined. In order to observe these, various traffic performance measurements have to be obtained. Such measurements could be done from an experiment in real life, but as the limits of time and available money, it is chosen to simulate the impact of route control strategy in a simulation environment. The considerations as which network is needed, which criteria are necessary and how to evaluate the performance and some other choices have to specifically be made during the case study.

The various data indicating the network performance are available and well-organized in database after simulation, so that it is easy to make comparison of different scenarios and select the optimal alternative. It is much faster and easier to investigate various scenarios (e.g., different O-D demand levels, different control plans) in a simulation environment rather than a real-life experiment.

1.5 Thesis outline

The contents of this report will follow the structure of research approach described above in order to generate a clear picture of the route information control strategy (RICS). The study will present a step by step overview of its design, application and implementation, followed by a case study in Delft to demonstrate its impacts on the network.

This study aims to take an initial step into the route traffic control concept and to present as a helpful reference for further studies in this direction. It is composed of three primary parts. Figure 1.2 graphically summarizes the report structure.

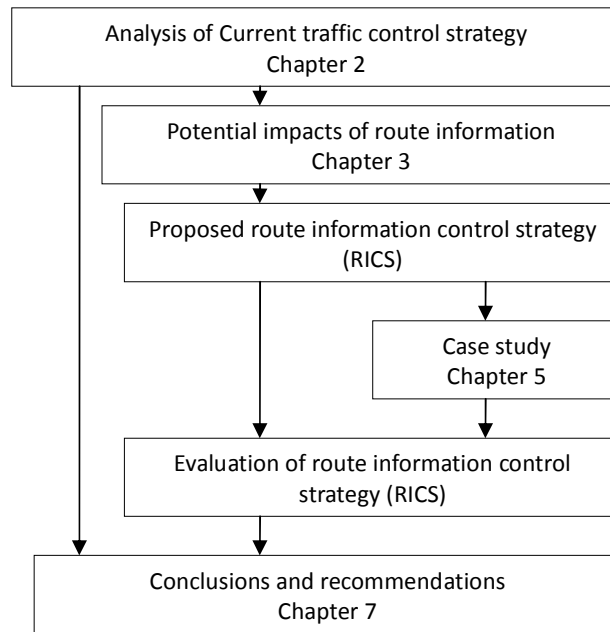


Figure 1-2 Report structure

The first part is to overview the existing traffic control strategies and analyze their inefficient performance in certain situations.

The second part describes an innovative concept of traffic control strategy using route information (RICS) and looks further into its potential design, planning, evaluation and implement. To start with, the study introduces the concept with an easy network of two origins and two destinations. The advantages of the RICS could exist in various control measures such as separating signal group, readjusting the signal timing, coordination along routes and separating lane for different routes in order to achieve a good allocation of time and space according to route demand. Further, the application of RICS on network is also explored.

The following part is a case example to provide results of RICS application in real network. RICS is recognized to be effective in this case network as the results show positive impacts of increasing road efficiency and reducing the congestion problem in

the network. After the theory study and experiment investigate, a comprehensive evaluation of RICS will be presented in SWOTs analysis and then the conclusions are drawn.

Due to the limited contents of this study and practical constraints in the case application, more comprehensive researches are recommended to study further on RICS.

2. Overview the current traffic control strategy

From long-term practice and experience, the proper design and operation of control strategy can definitely improve traffic performance and safety of road users as well as relieve the pressure on roadside infrastructures. There are many researches on how to design effective control measures and strategies in the recent years. This chapter provides an overview of various current traffic control strategies.

2.1 Introduction of traffic control measures

There are various control measures available in the current advanced control strategy design in aim of combating congestions and reducing the pressure of transport infrastructure either in demand side or the supply side. Generally, it includes traffic signal control, link control, advanced traveler information management, ramp metering control and re-routing strategy. Those measures will be explained in this section.

On the demand side, the measures can aim to shift in mode, time, route or destination of vehicle trips. It could be realized by implementing by diverse measures e.g. financial incentives, physical restriction (enclosure of a street), delay-based restrictions (like signal control for metering traffic input rates), reroute the traffic to decrease the demand on certain roads

Ramp metering control

At motorway entries, ramp metering can be introduced to reduce the number of vehicles that enter already nearly saturated or even oversaturated parts of the motorway network. It provide a regular flow of traffic and lower entering volumes at busy entrance ramps, the meters allow the freeway main lanes to carry more volume and at higher speeds.

Ramp metering has two direct effects [2]. The first is the reduction of the flow entering the motorway, which aims to prevent or at least postpone the excessive flow of the downstream of the on-ramp. The second is the spreading of dense groups of vehicles, or platoons, on the on-ramp. These platoons are usually formed by traffic lights at the intersection upstream of the on-ramp. Platoons merging onto the motorway can seriously disrupt the traffic flow on the motorway, causing a temporary reduction of the motorway capacity. This might even lead to a traffic jam at a relatively low traffic flow. Both direct effects result in a reduction in congestion.

Re-route [3]

Re-routing control strategy is to promote route shifts between roadways by en-route traveler information devices which advise motorists of congestion ahead, direct them to adjacent freeways or arterials. While lane control and ramp metering are only applicable to motorways, re-routing is an important strategy for both motorway and urban networks.

Re-routing is applied based on the combined corporation of Automatic Incident Detection,

congestion prediction, information of obstructions in the network, general actual traffic volumes in the network, and on-line O/D information. The first three of these would initiate re-routing procedures, whilst traffic volumes and the O/D information are the data basis for the optimization process. If the O/D matrix for a network is known, the diversion can be focused on particular traffic streams in order to re-route a desired number of vehicles rather than to take all-or-nothing decisions.

Re-routing strategy highlights the needs for a prediction-based information system. With recent advances in information technology, the technical issues have largely been overcome. Currently, there are two such systems developed: DYNAMIT and DYNASMART-X. Based upon travelers' responses to the information, these systems predict traffic flow and provide information, which is consistent with experienced travel time. In practice, an effective implement of re-route control needs a network with additional alternative routes and reliable real-time route information.

It can encourage travel and land use patterns in order to make the system in less congestion producing ways (travel demand management, non-automotive travel modes, and land use management). These measures include putting more people into fewer vehicles, shifting the time of travel, and eliminating the need of travel altogether. The major obstacle to the satisfaction of those measures is that they require adjustments in the lifestyles of travelers and the requirements of employers, which is rather complex and different to obtain in a short term.

On the supply side, measures could be designed to increase the physical capacity of the road system, e.g. building additional facilities or physically altering existing facilities to provide additional capacity. Adding more lanes to exiting highways and building new ones have been the traditional response to congestion. In some metropolitan areas, it is becoming increasing difficult to implement major highway expansions due to funding constraints on increased right-of-way and construction costs, and opposition from local and national groups.

They also can be designed to maximize the use and operational capacity of existing facilities. Various traffic management techniques aim to minimize capacity-reducing factors or to maximize the use of existing road networks. Dynamically retiming traffic signals and monitoring transit vehicles in real-time can effectively work on that.

Advanced Traveler Information system

This system provides travelers with real-time information on roadway conditions such as where congestion has formed, how bad it is, which route can be alternative. Recently, this system evolves into a wide operations tool that collects processes and broadcasts traffic information. Data is collected through a communication infrastructure, a closed-circuit television system, and sensor detection system. The information is then used to make real-time traffic management decisions and provide motorist with information through dynamic message signs, radio travel advisories, and a telephone advisory system. Travelers may also get access functional classes to obtain average speed, traffic conditions, and lane closures due to weather or construction activities from an interactive online GIS mapping service for higher. In addition, travelers can view selected road conditions through on-line video links.

Traffic signal control

Traffic signals are used to separate the conflicting traffic streams in time. It is one of the most powerful tools for urban traffic control available to city authorities. This measure will be comprehensively studied in Chapter 2.

Lane control

There are other effective strategies that do not rely on advanced technology, such as geometric improvements on roads and intersections or converting streets to one-way operations. At a smallest scale, for motorway and other highway networks, those measures, which generally only affect the traffic flow between two junctions, are referred to here as lane control.

They are normally initiated by detected incidents or predicted congestion. In the case of incident detection, lane control serves mainly as a safety measure to prevent secondary accidents. In the case of congestion prediction, lane control is aimed at smoothing the traffic flow and thereby preventing heavily capacity reducing or accident risks increasing from a traffic breakdown.

It may include one or a combination of the following actions: variable speed limitation, changeable message signs with indications for “keep lane”, or congestion warning, or environmental warning (e.g. information about the pavement state), lane control, incident warning, reversible flow lanes (tidal flow) or closing one or more lanes of traffic to make traffic movements quicker, safer, and more effective (e.g., when avalanche conditions have been detected or after one has occurred).

These control strategy measures, when properly integrated in a system, may effectively generate the improvement in travel time reliability and congestion decline as well as reduction of other negative effects on safety, environment. Table 2-1 summarizes the various traffic control measures working on demand side and supply side.

Table 2-1 Traffic control measures

DEMAND	Ramp metering Lane enclosure Rerouting vehicles
SUPPLY	Traffic signal control Advanced traffic information Lane control

The study will put emphasis on traffic signal control measure as it is usually regarded as one of the most cost-efficient way to deal with the traffic congestion. The traffic control designers should think and find creative ways to incorporate new traffic control designs with other alternative measures to accommodate the concerns of diverse groups and a variety of system users.

2.2 Traffic signal control

Traffic signal controls are the main control measures in control strategy. There is no doubt that time separation of conflicting traffic streams by using traffic signals is one of the most powerful tools for urban traffic control available to city authorities.

They are implemented for the purpose of reducing or eliminating conflicts at intersections.

Control can be exercised by determining: [4]

- Number and constitution of stages at intersections during which a set of traffic streams have the green light duration for each stage;
- Time taken for a complete cycle of signals to take place at an intersection (cycle time);
- Offset between cycles at successive intersections;
- And other traffic management measures.

At the local level, traffic signals are designed to manage vehicle conflicts at intersections, allocating time among the conflicting traffic streams which must share the use of the intersection. They are designed in order to:

- Disable concurrent traffic flows to enter at the same time in the same intersection;
- Decrease congestion and overall delay in the certain intersection;
- Harmonize transport modes.

At a higher network level, traffic signals can be part of a broader control strategy. In this case, signal controllers are used as tools for managing traffic flow, either along a corridor or throughout a network, to provide a more efficient use of the urban street network. In this respect, it aims to balance the needs from all road users and to improve the ultimate quality of the trip experienced, such as a safe trip with an acceptable and reliable travel time. The performance of the network is measured through suitable parameters such as the total time spent by all the vehicles in the network or the total delay time over a time horizon.

Figure 2-1 presents the basic structure of traffic signal control system. In the following contents of this chapter, various urban road traffic signal control types will be distinguished, and four examples of wide-applied control systems will be explained.

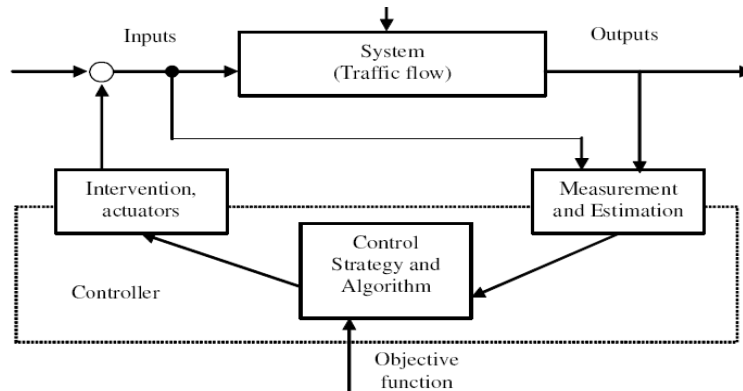


Figure 2-1 General Structure of traffic control system [5]

2.2.1 Traffic Control types

There is wide range of ways by which traffic control strategies can be categorized. The first is differed by the scope of control strategy, which consists of isolated intersection control and network control. The second is the type of control logic, which indicates how the controller responds to local traffic conditions. This logic can be pre-timed, actuated, or adaptive (FHWA, 1996). Table 2-1 presents the general traffic control categories by

control scope and control logic.

Table 2-2 Traffic control category

Traffic control category	
Control scope	Control logic
Isolated intersection control	Pre-timed
Network control	Actuated
	Adaptive

2.2.2 Control scope category

Isolated intersection control

Isolated signalized intersection controls traffic without considering adjacent signalized intersections. The signal timing decisions are based solely on the traffic demands in the approaches to the intersection. The well accepted criteria for optimal cycle length and split at a signal controlled intersection is minimization of delay of the intersection, maximization of outflow capacity and minimization of the length of queues.

A traffic signal controller allocates right-of-way at an intersection through a sequence of green signals. Each approach or separate movements is allocated to a phase or signal group. Inter-green times are specified between conflicting groups. Each traffic stream is controlled separately and its green phase has tactic driven green sub-phases. A complete structure of all green phase is called a cycle. The signal control parameters in isolated intersection control will include:

Intersection cycle time: Most of signal timing software use the Webster-Cobbe signal optimization method for design isolated intersection pre-timed cycle time. The method determines the green split and cycle length of individual intersections by analyzing the arrival and departure flows on each intersection approach. In actuated control system, the minimum cycle time needs to be calculated.

Optimal signal cycle is calculated by formula:

$$T = \frac{1.5t_{LT} + 5}{1 - Y} \quad (\text{Pre-timed control})$$

$$T_{\min} = \frac{t_{LT}}{1 - Y} \quad (\text{Actuated control})$$

Where,

T: optimal signal cycle length,

t_{LT}: lost time,

$Y = \sum Y_i$, Y_i is volume-saturation ratio of the lane group.

$Y_i = \frac{q_i}{S_i}$, S_i is saturation flow of lane i

Split: portion the total available green time between the various phases serving traffic at the intersection being considered in proportion to the flow ratio y of each phase and the optimal cycle length.

Split is calculated by formula:

$$\sum_j g_j = C_{opt} - \sum_j I_j$$

$$g_j = \left(\sum_{j=1}^n g_j \right) \cdot \frac{y_j}{Y}$$

Where g_j is the duration of the green interval for phase j (seconds) and I_j is the length of the inter-green period following phase j (seconds).

Area-wide system control

Network control treat all or a major portion of signals in a city (or metropolitan area) as a total system, in which the signal timing design not only takes into consideration of the approaching vehicles in the local intersection but also the traffic signals settings of other adjacent intersections connected in order to facilitate passing vehicles in the signalized system. In contrast with isolated intersections, the area control signals must operate as a system, which provides progressive traffic flow along the arterial. It can be realized by good offset design.

Offset is defined as the time difference between the start of the signal's green interval and a system reference time. Setting the offset between adjacent intersections equal to the travel time between those intersections will establish progression. It can be recognized that a signal releases platoons traveling to the next signal.

If adjacent signalized intersections are coordinated in such a way that they operate with the same cycle time and with constant split and offset, it is possible to set these signal timing parameters on a one-way street in such a way that the platoon from the upstream intersection will arrive at the downstream stop-line when this signal is green.

In order to maintain the flow of these platoons, the system must coordinate timing of adjacent intersections. The system accomplishes this by establishing a time relationship between the beginning of arterial green at one intersection and the beginning of arterial green at the next intersection. By doing this, static queues receive a green indication on their approach in advance of arriving platoons.

When a platoon of vehicles is released from a traffic signal, the degree to which this platoon has dispersed at the next signal (difference from profile at releasing signal) in part determines whether significant benefits can be achieved from signal coordination. This permits continuous traffic flow along an arterial street and reduces delay. Figure 2-2 and Figure 2-3 individually shows the signal coordination situation of one direction and bi-direction.

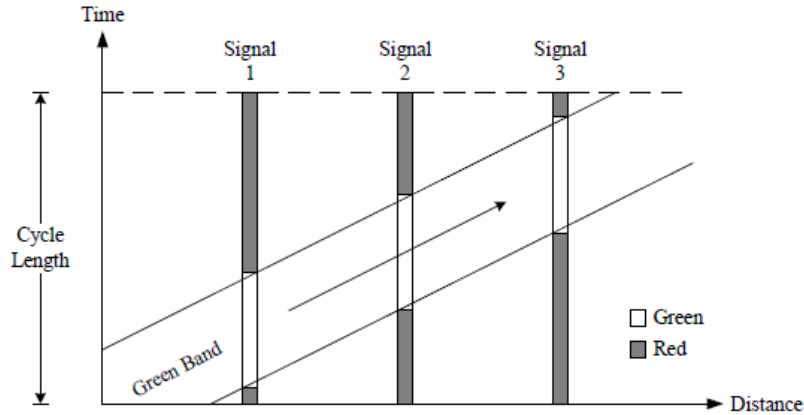


Figure 2-2 Progressive traffic flow under signal coordination

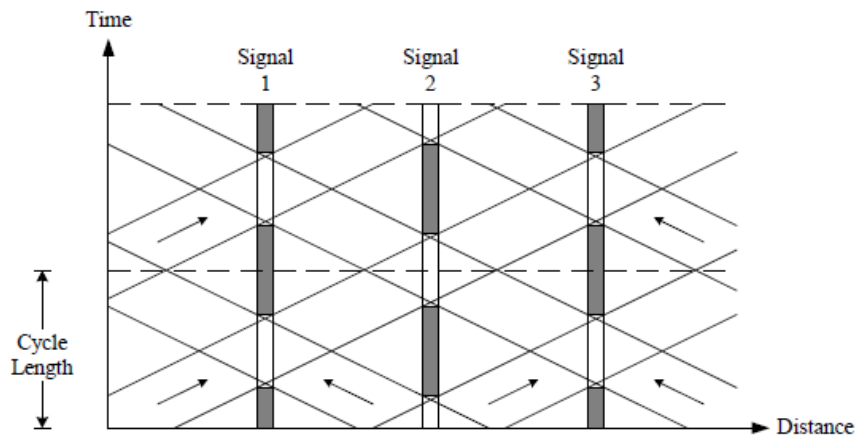


Figure 2-3 Bi-directional progressive traffic flows [6]

While coordination of adjacent signals often provides benefits, the traffic systems engineers should always be careful to decide whether better performance will be achieved by coordinated or isolated operation as the traffic conditions in the real life greatly varies from case to case.

2.2.3 Control logic category

Pre-timed control

Pre-timed control, which is often used in fixed time control or time-of-day control, is the most basic type of signal control. The control parameters such as cycle time, split and offset are designed offline by historical data to set up strategies for specific time-of-day control. They are set at fixed values in the real world application but different plans according to different demand like peak hours and off peak hours can be defined. It operates without regarding fluctuation in the traffic demand.

Pre-timed control signal timing is calculated to minimize overall intersection delay for the traffic demand during the study period. Compared with the actuated control introduced below, it is less time consuming, easily implemented and with less infrastructure cost. It is suitable for the situation where the traffic demand is relatively stable or all the streams have high traffic volumes. However, if the traffic demands are less balanced, application of fixed control will lose much spare capacity for the vehicles on the busy streams as the green time length can not be shortened if there are no vehicle demands on conflicting streams. Nowadays, it has been largely replaced by actuated control and adaptive control.

Actuated control

Traffic-responsive strategies make use of real-time measurements collected by sensors and inductive loop detectors to adjust the split of each stream in the intersection. The most common feature of actuated control is the ability to extend the length of green interval for a particular phase in order to allow vehicles to pass the intersection without stops when there is no conflict stream. Another common feature of actuated control is the ability to skip a phase if no demand for that phase is present.

It is pointed out that traffic-responsive strategies, when suitably designed, are potentially more efficient than pre-timed control strategy, especially in unsaturated conditions. If there are no vehicles waiting for any movements of a certain phase (indicated by the detectors at the stop lines), the actuated controller can skip that phase and move directly to the next phase in the sequence.

Examples of real-time strategies include the SCOOT system, a traffic-responsive version of TRANSYT that has been used in over 150 cities. A study of several more recently developed coordinated traffic-responsive strategies describes the basic problem they all face: application of solution algorithms is exponentially complex [7].

Adaptive control

Adaptive control, which is like actuated control to some extent, responds to traffic demand in real time, while there are more control parameters that can be changed according to the real-time demand. The most common adjustments are on the cycle time and to the phase splits, which determine the allocation of the cycle time to the various phases. These strategies rely on traffic data collected from each approach of the intersection, and this data is used by the controller to estimate conditions at the intersections and to respond to them in real-time. This logic is often optimization-based, to maximize vehicle throughput or to minimize vehicle delays or stops.

Adaptive logic can also be predictive, projecting future conditions based on detector inputs or historical trends and then adjusting signal settings accordingly. Adaptive traffic control systems are becoming more widespread, both in application and in development. Applications of systems such as OPAC and UTOPIA are becoming more prevalent

2.2.4 Summary

There is a trend of development of traffic control strategy from pre-timed control to actuated or adaptive control and from local isolated control to high-level network control. Table 2-2 summarizes the signal timing parameters. Those are the main components of traffic signal control design.

Table 2-3 Definitions of the fundamental signal timing variables

Signal timing variable	Definition
Cycle Length	The time required for one complete sequence of signal intervals (phases).
Phase	The portion of a signal cycle allocated to any single combination of one or more traffic movements simultaneously receiving the right-of-way during one or more intervals.
Interval	A discrete portion of the signal cycle during which the signal indications (pedestrian or vehicle) remain unchanged.
Split	The percentage of a cycle length allocated to each of the various phases in a signal cycle.
Offset	The time relationship, expressed in seconds or percent of cycle length, determined by the difference between a defined point in the coordinated green and a system reference point.

The experiments of different traffic control strategies show the advanced control really improve the traffic performance with network optimization and real-time detection. They are relatively low-capital-intensive in comparison to other traffic improvement measures. The experiment results also show that the extent of improvement might vary from case to case due to the traffic conditions and roadside configuration.

2.3 Existing control systems

There have been diverse models developed to design advanced traffic control strategy in the past a few years, in which four typical traffic design models are explained here, i.e. TRANSYT, TOPTRAC, SCOOT and UTOPIA. They individually display the special features of different traffic control type. Their methodology, design features and application performance will be presented below.

2.3.1 TRANSYT Model [8]

The Traffic Network Study Tool (TRANSYT) has become one of the most widely used models in the United States and Europe for pre-timed signal network timing. The TRANSYT system computes the signal timing plans given the geometry of the traffic network and the average traffic influx at each approach.

This system is based on a macroscopic model of the traffic network and uses a weighted average of the delay, stops, fuel consumption and public transport priority level as the performance index, which is kept at a minimum when designing the cycle and split.

The model represents the dispersion of a vehicle platoon departing from a signalized intersection. Figure2-4 also shows percentage saturation (a measure of volume) as a function of time at three points along the roadway when no downstream queue is present.

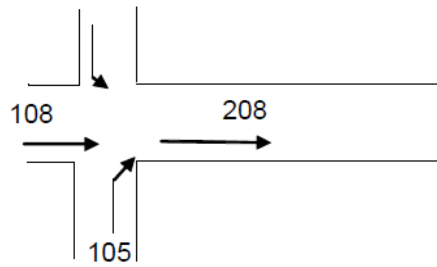


Figure 2-4 Feeding links in TRANSYT

TRANSYT assumes that the average flow demand at an approach remains constant, i.e., the flow patterns for each cycle repeat. The actual traffic flow fluctuations are not taken into consideration in TRANSYT.

Vehicles leaving the link can disappear from the network or they are distributed over consecutive links. The fraction in which this distribution takes place has to be defined as input to the program. TRANSYT calculates the input pattern of the next links by adding up the fraction of the output patterns of all feeding links. At the end of the link, the arrival pattern is determined by the input pattern, shifted in time over the travel time and smoothened according to the algorithm:

$$O(i) = \alpha O(i-1) + (1 - \alpha) A(i - T)$$

Where:

$O(i)$ is the output pattern of the link,

$A(i)$ is the arrival pattern at the entry of the link,

T is the travel time (in time steps) and

α is the smoothening parameter, dependent on the length of the link.

The departure pattern of a link is determined by the traffic lights controlling the stop line, and possible remaining conflicts. During the red phase, the arriving vehicles are stored in a queue. During the green phase, the queue is discharged, where the departure pattern is determined by the saturation flow. Figure 2-5 illustrates the example of predicting arrival pattern in the neighboring intersections. If there are conflicts, e.g. a left turning flow that has to wait for conflicting vehicles, TRANSYT looks for gaps in the conflicting flow and calculates the average possible departures rates in these gaps.

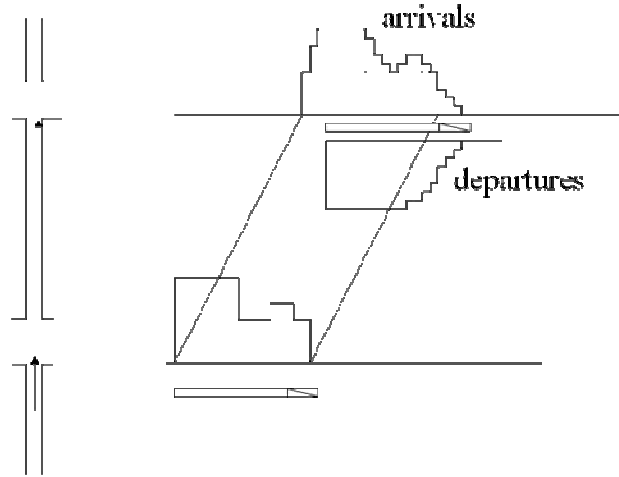


Figure 2-5 Arrival patterns in TRANSYT

In a one-way street including a set of traffic signals, it is usual to provide coordination so that traffic passing through these signals can meet subsequent signals at green. Under relatively free flow conditions, the offset between the start of green for the principal route at successive junctions can be determined by the average speed of traffic. In that way, the signal plan facilitates a smooth forward progression of vehicle platoons along arterial routes. Figure 2-6 presents the analysis of coordination impacts.

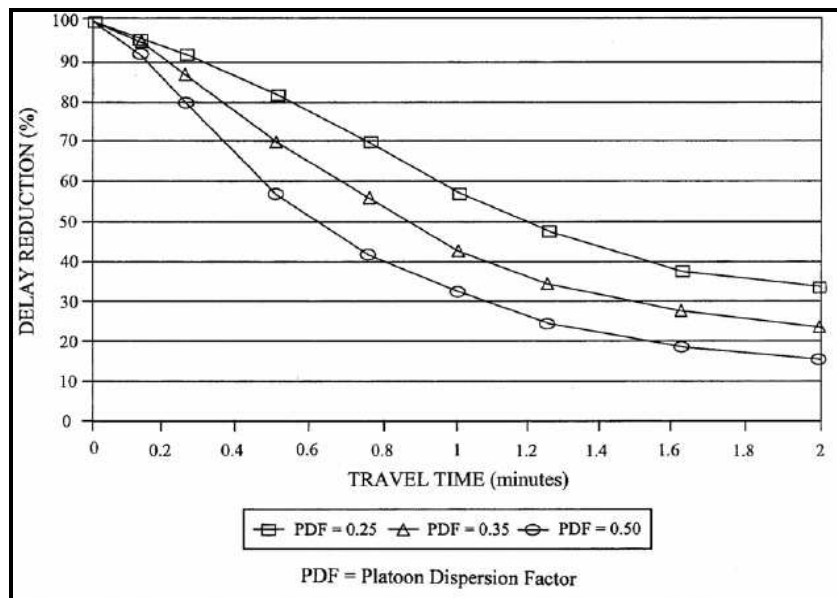


Figure 2-6 Benefits of signal coordination [9]

(The PDF presented in this graph is the same as the smoothing parameter alpha in the formula 1)

The big advantage of this kind of off-line methods is the relatively low cost of computation. As the traffic demands are given, the performance measures can be calculated in a short period of time. A reasonably good solution can be obtained quickly. However, the performance of these solutions under the randomly fluctuating traffic volume levels may deteriorate significantly, which indicates that regular retiming of traffic signals is inevitable due to the growth and decline of traffic demands (Sunkari 2004).

As congestion increases and junctions become saturated, queues begin to disrupt the movements at upstream junctions. If over-saturation persists, then the saturated fixed-time plans have to be found to exacerbate the problems caused by the spillback of queues into upstream junctions. This makes conventional procedures for optimizing fixed-time signal control, such as TRANSYT, deteriorate rapidly when severe congestion or bottle persists.

2.3.2 TOPTRAC (Ad Wilson) [10]

TOPTRAC is a traffic-respond network control system, which is purposed to minimize the objective function defined in real-time TRANSYT.

These functions are performed with detectors just before the stop line. Additional loops may be added as more information is required on exit rates or queue lengths. The detected information is periodically sent to the central system, and thus the densities and exit rates for each lane can be predicts. TRANSYT optimizes real-time network system based on the predicted inflow. The optimized signal parameters include the cycle time, green division per intersection and the offset between the intersections. As many other network control program, TOPTRAC can not optimize the phase sequence.

After the network system is optimized, the start and end times of green information are assigned to the local intersections of the network and activated as quickly as possible.

It performs in optimization of two levels:

- At the network level: Traffic-driven network optimization (real-time) using TRANSYT on the basis of current intensities.
- At the intersection level: Vehicle actuated control.

TOPTRAC is expected to lead to better traffic movements, less congestion and fewer vehicle stops in changing conditions and it is widely used in traffic control design in Netherlands.

2.3.3 SCOOT (Split, Cycle and Offset Optimization Technique)

The Transport and Road Research Laboratory (TRRL) in Great Britain developed SCOOT in 1973, and by 1979 it had been implemented on a full-scale trial in Glasgow. The traffic network under SCOOT is divided into regions and each region is controlled by regional controller. SCOOT is an actuated traffic control model so that it can respond to the fluctuation of the real-life traffic. Based on detector measurements from upstream approaches of the intersection, the SCOOT traffic model computes the cyclic flow profile for every traffic link every four seconds. It projects these profiles to the downstream intersection using the TRANSYT dispersion model.

SCOOT has three key principles [11]

- Cycle flow profile (CFP): This aspect is similar to the one used in TRANSYT, but in this case they are updated every a few seconds. In the case of TRANSYT, the accuracy depends on the data about the average flows, saturation flows, cruise time and some other variables, while, in SCOOT, this process is automatic and carried out in real-time.
- Updated online model and queue estimation: The queue estimation is also carried out in the same way as in TRANSYT. The calculation of the queue is done every a few seconds while the data of the real-time traffic from the sensors is collected. The detectors are placed upstream and downstream of the intersection. Figure 2-7 illustrates the detector locations in SCOOT.

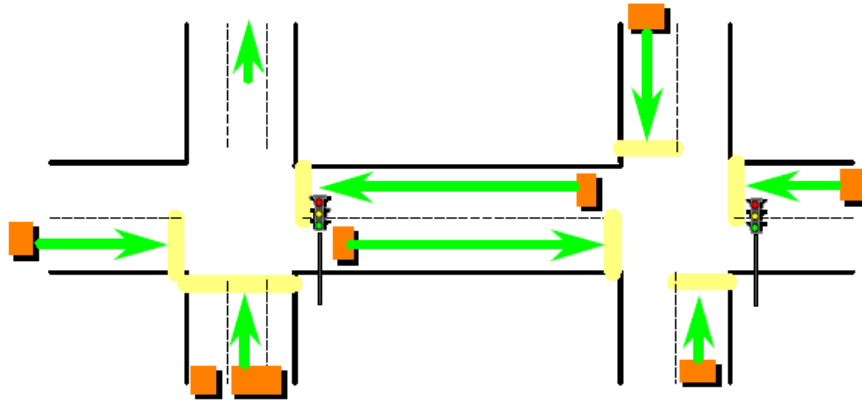


Figure 2-7 SCOOT detector loops positions [12]

- Incremental optimization: SCOOT uses an elastic coordination that stretches or shrinks the coordination plans to match them to the detected CFP. This process is carried out to evaluate the effects of modifying up or down the length of the cycle in a series of frequent but small increments. For some intersections the decisions are not suitable but it can be compensated with the positive effects of the large majority of intersections. Figure 2-8 shows the general principle of SCOOT.

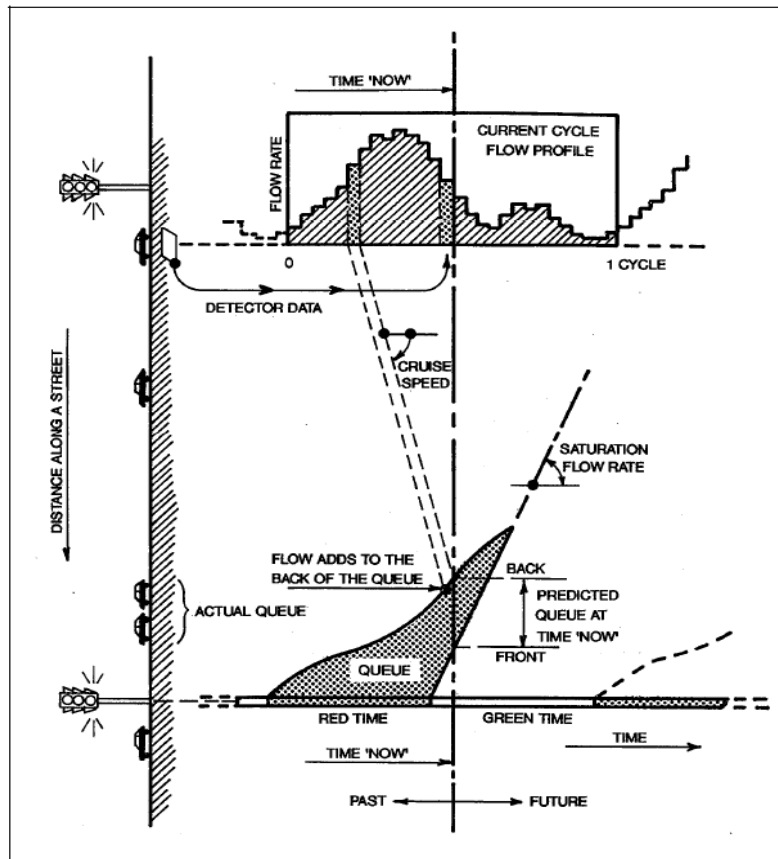


Figure 2-8 Principle of SCOOT traffic model [13]

The SCOOT system has been used in over 150 cities. Many studies with the experiment results show SCOOT is able to improve the condition in some cases but performance may deteriorate in saturated traffic conditions. [14]

2.3.4 UTOPIA

In recent years, there is a great advance in informatics and telecommunications, which led to a new generation of coordinated and self-optimizing systems. UTOPIA (urban Traffic Optimization by integrated Automation) is a specific concept designed to improve urban travel conditions by the application of fully automated control principles. The control strategies aim to reduce significantly the total time lost by private vehicles during their trips within the controlled area.

General concept of UTOPIA

UTOPIA control serves in a bi-level system control, including local level and area level. The area control module has the tasks of calculating optimal control of the network at area level and of providing the local controllers with the coordination parameters needed to implement the control (i.e. reference plan, weights).

It receives the current status of the network (flows, turning percentages, saturation flows)

from the observer module. This information has been updated from the data received from the peripherals. At the same time it receives information from the integrated control module on particular events present on the network (closure of or obstructions on the arcs) and the current network control strategy (target O/D matrix, target speeds). On the basis of this information, the optimal steady state control of the network can be calculated.

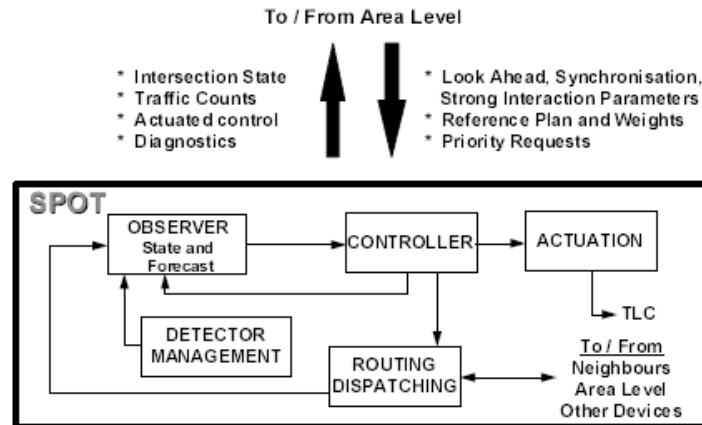


Figure 2-9 Bi-level self optimizing system control [15]

In order to guarantee stability and robustness at the network level, interactions are provided with a higher control level, where an area optimal control problem is defined on the basis of the area traffic macroscopic model. The communication network of the whole system is developed according to the hierarchical-distributed system architecture. The central system that operates at the area level and the intersection control units are nodes of a network where each node can transmit messages to all the others. If a node needs to send a message to another node that is not directly connected to it, it passes its message via other node(s). This allows a physical communication scheme where links exist for connecting local control units to the adjacent one(s) and for connecting some of them to the area level.

For the incoming links, the following inputs are required for rolling horizon optimization:

- Traffic counts;
- Traffic forecasts provided by the neighboring controllers (forecasts correspond to vehicles leaving the upstream intersections; an approximation is made assuming that the outgoing flows are uniform at intervals);
- Forecasts of arrivals of public transport vehicles assigned with priority;

For the outgoing links, the following input is required for rolling horizon optimization:

- The control strategies defined by the downstream controllers.

For the neighboring intersections, there are several requirement of information therefore identified:

- Implementation of the strong interaction principle requires knowledge of the traffic light control foreseen for the downstream intersections;
- Implementation of the look-ahead principle requires knowledge of the traffic light

control foreseen for the upstream intersections and the availability of traffic information for the incoming links of the upstream intersections themselves.

SPOT-UTOPIA system enables faster changes of signal timing as the optimal steady state is not calculated for the entire network, but for separate sub areas of the network that contain intersections with the same traffic characteristics, so that traffic light cycles are achieved with the same duration on all the intersections within a sub area. Once the steady state optimum is calculated, the local optimization weights are calculated to bring the local responsive control closer to the target area control. However, because of its decentralized mode of optimization, UTOPIA-SPOT does not guarantee that optimal traffic performance is obtained on a sub-area or network basis.

Saturation control in Utopia

UTOPIA introduces saturation control into the control strategy design. Each controller receives from its neighbors their traffic lights plan and some other information about downstream links such as queues, storage capacity, forecasts of releases, estimated saturation flow and a reference cycle from the Area Level Control.

Using this information the controller is able to evaluate how its stages planning will affect downstream intersections and how neighbors' cycles will influence its released vehicles. To coordinate cycles of neighboring intersections the percentage of released vehicles that will be blocked at downstream intersections is monitored. This, together with the reference cycle, allows the evaluation of the optimum offset between cycles and in low traffic conditions to obtain a green wave in the main direction.

During the branch-and-bound optimization process, the controller also evaluates downstream queues according to expected releases of the control strategy and penalizes exceeding of the storage capacity. This allows the reduction of the green percentage of the cycle when downstream links are near to saturation conditions.

Modifying and calibrating weighting factors make it possible to obtain a control law that balances the requirement of capacity maximization for low traffic conditions with the requirement of a gating action under saturation or over-saturated conditions.

To avoid saturation and congestion of an upstream intersection, it should be realized that the effect on the upstream releases does not change from the time when the queue starts to clear until when the starting wave reaches the last stopped vehicle on the downstream link. For a correct evaluation of the effects that released vehicles from upstream intersections have on downstream jams, the upstream controller should not consider the number of vehicles in queue, but rather the position of the last vehicle stopping on the downstream link, the so-called horizontal queue.

2.4 Weakness of the current signal control system

The current control strategies mentioned above have the following weaknesses in real-life practice. This section gives a summary of these weaknesses, followed by explanation:

- Weak in adaptability and flexibility to the traffic fluctuation
- Complexity in computation
- Ineffectiveness in combined levels control of traffic system

Weak in adaptability and flexibility to the traffic fluctuation

It is true that the actuated control can respond to real-time traffic flow fluctuation with adjustments in green length and adaptive control can further adjust the sequence of signal phase to adapt to the existing traffic condition. However, the coordinated intersections usually need to apply the same cycle length or the double cycle length over the network and even adaptive traffic lights in modern control schemes are usually restricted to a variation of cycle-based control. There is still little space for creating various alternative of signal setting in the current traffic signal design system as the traffic condition really greatly differs in every case.

The weakness becomes more and more apparent in oversaturated situation or high fluctuation in traffic flow due to special events. Normally, traffic control strategy is designed based on unsaturated traffic volume of the intersection. This designed control strategy works well as long as traffic flow through the intersection is not too high. Once volume rises beyond the capacity or there is suddenly a large group of vehicles entering the network, programmed control strategy can not respond to the changed situation and clear traffic off critical roads fast enough, which would cause secondary congestion and delay in the network as well as increase the risks of accidents.

When traffic demand exceeds capacity in a portion of the corridor, the better objective of the traffic control strategy will be to manage the spread of congestion rather than to respond to the traffic demand. The goal is to minimize the adverse effect that the congestion has on overall system performance by controlling the location of queues. Although there are already queue models existing in SCOOT and UTOPIA model, sometimes the results are not so satisfactory.

Complexity in algorithm computation

Generally, the advanced self-optimizing control will over perform the conventional fixed control and actuated control, but it is pointed out that it might face a computation problem as the more objectives a system should achieve, the more difficult it is to design control of signals. Besides, the extension of the network will also increase the complexity in computation. The larger the number of nodes, or lights, in a system, the huger amount of data is necessary to handle with, which will give traffic control designers a great challenge to develop an effective and robust algorithm.

In the U.S, the performances of several experimental adaptive control systems were not satisfactory based on the evaluation results which partly deteriorate its popularity. Traffic engineers were not convinced of their practical superiority despite the theoretical strengths of these methods. Several deficiencies were identified by a recent research (Shelby 2004) and it was concluded that at least a 250-fold increase in computational burden would be incurred to overcome these deficiencies in this study.[16]

Ineffectiveness in combined levels control of traffic system

The majority of the currently used strategies optimize the coordination of a sub network of traffic signals, or the metering rates at a series of freeway on- ramps in a corridor network, without accounting for their interaction. However, as both the spatial and temporal extent of recurrent or non-recurrent traffic congestion increases, the assumption that each sub network operates in virtual or real isolation clearly becomes

invalid.

The cooperation of bi-level network becomes even more urgent if one realizes that a major part of the delay experienced by road user is suffered on the rural and urban roads and not on the motorway network. For the Netherlands, it was estimated for 1996 that the delays on the rural and urban roads are 2.5 times higher than on the highway network (Wilson, 1998). The control strategy design of the different level of traffic should be cooperated in one system.

The factors above indicate the necessity of the implementation of control techniques in traffic and the introduction of innovations in the transportation area. Design and operation of effective, safe and environmentally friendly intersections require a high level of knowledge about the relationships between intersection design, traffic flow, environment, and impacts on traffic performance, safety and emissions (Bang, 1997).

2.5 Opportunities of new traffic control strategy

Opportunities for the new traffic control strategy can be exploited to make good use of current advanced control system and reduce the existing weakness. In this section the opportunities of new control strategy are described to achieve the common objective of system optimum as well as travelers' satisfaction. The aim of new control strategy is defined as:

A new control strategy should be developed to aim at more flexibility in traffic signal setting design, more adaptability to different traffic situation and simplicity in application in real life. Special attention should be put on bi-level network including highway and urban street intersections and oversaturated situations.

There is a trend of designing traffic control strategy to achieve multi-objectives rather than uni-objective of improving traffic flow in regular conditions. The multi-objectives can be set by the following aspects:

Diversification of stakeholders

Various road authorities (and other relevant stakeholders) should work together on the basis of equality to design integral and sustainable traffic management solutions. Reducing emissions or increasing traffic safety is now commonly regarded as objectives of traffic control strategy in that there is an increasing need for socio-economic evaluation, which allows "better" choices to be made for future allocations of public resources.

Diversification of road users

There are some forms of trade-off needed to be made in traffic control strategy as it will bring diverse impacts on traffic flow, air quality and travel time. Some of these impacts will affect the road users experiencing the traffic control strategy (direct impacts); while others will impact the road users out of the scope of traffic control strategy (indirect impacts). A comprehensive objective which makes trade-offs between the impacts and the impact groups are necessarily to be set.

Diversification of traffic conditions

The traditional optimal goal of regular condition is far from enough. Traffic control strategy should also be applied to ensure traffic safety and optimize traffic flows in

non-regular conditions, such as road works, events or accidents and peak hour periods.

3. Potential impacts of route information

The previous chapter identified the weaknesses of the current traffic control strategy. Furthermore, it was shown that the objectives of development of new traffic control. In this chapter, an answer will be given to the first research question:

“What effects are expected from route information on traffic control strategy?”

The general introduction of route information in traffic design is presented in section 3.1. Then the potential impacts of route information on traffic control strategy will be studied by reviewing the methods and performance of various traffic control measures which take advantage of route information. These provide diverse expectations of proposing route information control strategy using (RICS) in Chapter 4.

3.1 Introduction of route information

The route information discussed in this study is mainly about the demands of traffic flows on routes in the network. The route flow generally can be obtained from traffic assignment generated by OD matrices and route choices.

3.1.1 OD matrices

Trip Origin-Destination (O-D) demand of network is one of the most important components for transportation planning and traffic operation. An O-D matrix estimate is essential to determine travel patterns on a zonal network at a given time period.

When an O-D matrix is assigned onto the network, a flow pattern will be generated. It shows the network traffic characteristics, represents the travel behavior and indicates the infrastructure performance. In macroscopic transport planning design, OD matrix is the key element in obtaining the network traffic condition, identifying the problems and devising some kind of plans. Therefore, it plays a very important role in various transport planning studies and transport management schemes.

There are many different ways to obtain the OD matrices. Direct methods to obtain an OD matrix are from e.g. household survey and road interview. It is time-consuming and costly. It can also be estimated by indirect data like traffic counts. There have been several different methods have been developed for the OD estimation but the basic steps are generally the same.

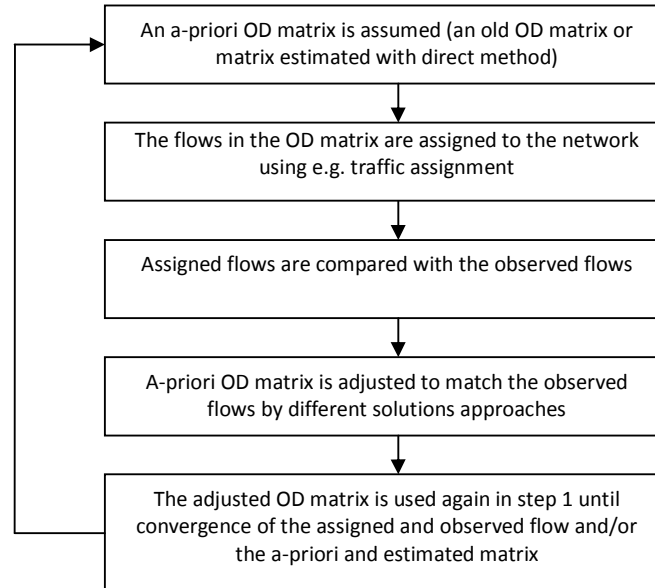


Figure 3-1 General steps of estimating OD matrices

3.1.2 Route choice

An OD matrix has information about how many vehicles are traveling between the zones in the network, but it does not include the information about the route choice of these vehicles.

If there is only one route between the OD pair, then the route demand can easily get for OD matrix. If there are more than one route between the origin and destination, the route demands are distinguished by the distribution of the trips in the OD matrix over the available routes for each OD pair. The route flows can be obtained by traffic assignment. Figure 3-2 illustrates the algorithm of route assignment.

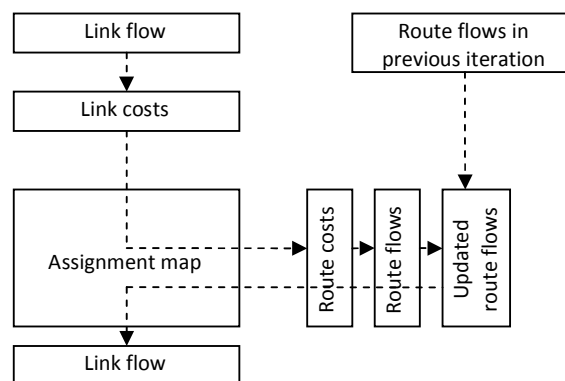


Figure 3-2 Route assignment algorithm

3.2 Potential impacts of route information

In the section, the potential impacts of route information on traffic control strategy are explored by studying the current research.

Traffic control designs, which make use of the vehicle route information, are already partly studied, especially in the projects of dealing with special traffic conditions by advanced control strategy. They include:

- Queue management
- Separated lane for special vehicle type
- Priority treatment of public transport and trucks
- Different signal treatment for different routes
- Integrating signal control with route choices

Queue management

As congestion increases and junctions become saturated, queues begin to disrupt the traffic movements at upstream junctions. Pignataro et al. (1978) described a queue management strategy which they term “equity offsets”. This strategy, based on the principle of reverse progression, seeks to provide equitable treatment of competing flows at a junction situated on upstream of an oversaturated link. There are several principles presented out, in which separated signal and special turning lanes are introduced to solve the spilled back queues.[17]

The principles involve:

- If the turns are indeed significant, and storage and capacity exists, establishment of turn lanes with separate signalization should be considered. In this way, the through movement could be continued;
- If necessary, turn prohibitions should be considered so that the cross stream through movement is not severely impacted by queued turning vehicles.

Separated lane for special vehicle type

There are a lot of studies which introduce separate lane for public transport. The separated lanes are designed along public transport to facilitate their movements as the vehicles with high-occupation rate are supposed to be able to leave the network as soon as possible to improve the network efficiency and it also increases the reliability and punctuality of the public transport. The separated lanes can also be assigned for trucks regarding the environment and safety issues. [18]

The separate lane measure aims to keep goods and passenger movements smoothly, improve overall mobility along the freeway and improve traffic safety and air quality. The concept is already implemented in some projects. The evaluation of the results shows the impacts of the separate lane differ from region to region, as they greatly rely on the existing traffic condition and roadside layout. It is necessary to have a careful analysis of its benefits and costs before real-life implementation.

Priority treatment of public transport and trucks

As the similar function of the above separate lane application, the transit priority is also designed for public transport or trucks to promote their movements, while this approach focus mainly on local control rather than network control as the priority request is sending when the vehicle is approaching the intersection. Different priority weights can

be used to control the green phase for these special vehicles. There are mainly four actions to realize the priority control strategy, which consist of green extension, shortening of current phase, insertion of extra phase and green restarting.

Multiple-realization is a related strategy in which the green phase for the transit corridor occurs twice within the same cycle. The cycle length can remain unchanged if each of the two green phases is half the length of the original phase. When the cycle length is reduced, lost time is relatively increased, but the increase will be smaller in this case because only one additional phase transition is added per cycle. This strategy benefits transit vehicle by reducing the amount of time between green phases, thus reducing the waiting time for vehicles encountering a red signal.

Signal coordination is another strategy that can be used to benefit some vehicles. Arterial progression, for example, can be designed to favor public transport vehicles by timing the green band at the average public transport vehicle speed instead of the average automobile speed, which is typically faster.

Different signal treatment for different routes

The concept of providing different signal treatments to different route exists in some traffic control programs to realize special control, such as the shared stop line function in TRANSYT.[19]

Different streams can be simulated separately by the option of shared stop line in TRANSYT to achieve the network optimal. A shared stop line means that different flows can arrive at the same stop line (similar as shown in Figure2-3, but the identity of these flows remains: the flows are not simple merged, but the different flows can be distinguished in the input patterns, queue pattern and departure pattern.

The shared stop line concept makes it possible to trace certain flows in the network, to give these flows a special treatment, e.g. to give them a high priority in the optimization of traffic control. This can be used for buses, vehicles of the fire brigade, cyclists or for certain OD-flows.

Integrating signal control with route choices

Traffic signals have a significant effect on the choice of routes by motorists in urban areas. They are of primary importance in the development of advanced traffic management strategies that involve dynamic rerouting of traffic flows through signal-controlled street networks.

A combined network model that simultaneously accounts for both the route choices made by motorists and the desired signal controls to match these choices is presented in this study by Nathan H. Gartner and Mohammed Al-Malik. Given OD information, the model generates signal controls to optimize network performance and calculates the resulting traffic volumes in the network. This optimization model inherently reflects the mutual consistency between traffic flows and signal controls. Figure 3-1 presents the system of integrating traffic signal control and route choice behaviors.

This is particularly important in the development of advanced traffic control strategies that involve rerouting traffic for the purpose of reducing congestion and avoiding

bottlenecks. The model is applicable to both fixed-time and demand-responsive signals. Such controllers are likely to form the backbone of advanced traffic management systems of intelligent transportation systems. [20]

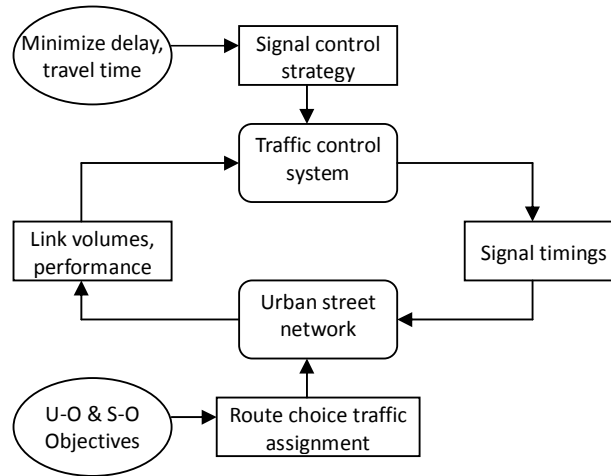


Figure 3-3 Interdependency of traffic signal control and route choice behavior

The potential effects of route information are presented and these studies indicate that the control design taking route information into consideration will be beneficial to manage the queue length, make maximum use of existing facilities, and facilitate the traffic movements in some circumstances. Figure 3-4 illustrates how route information can have impacts on traffic control strategy.

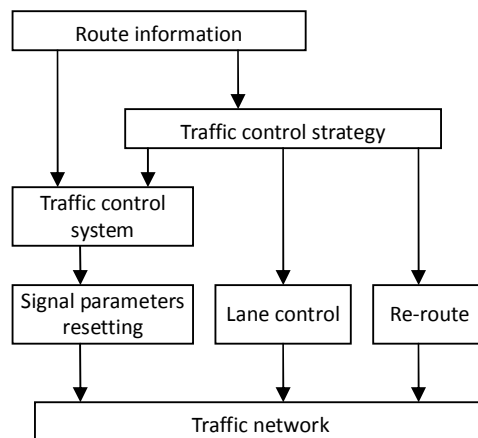


Figure 3-4 the system of route information impacts

In summary, integrating the route information has potential to bring many innovative functions in the traffic control. In the following chapters, the idea of integration of OD information with traffic control will be explored in details. Its potential designs and impacts on the local traffic and network traffic performance will be analyzed. Road

improvements are expected on target key congestion or hot spots due to various control measures to increase junction capacity and reduce the route travel time.

4. Proposed route information control strategy (RICS)

In the previous chapter, using route demand information was described as a promising direction to improve control strategy. In this chapter, a route information control strategy (RICS) will be proposed.

4.1 RICS introduction

RICS is the proposed control strategy using route demands. RICS takes consideration of the route information (historical data or real time information) into local intersection signal control design. It can also be composed of various control measures which aim to improve traffic movements using route information. Those measures such as lane control and rerouting are integrated in RICS to achieve improved performance in the network.

In this chapter, a series of research questions are going to be answered to present the features of RICS. They are listed as following:

‘Which effects are to be expected by RICS?’

In order to answer this question, RICS will be compared with current link control strategy. RICS gets rid of the constraints of link flows in current control strategy design. It can be made use of with separating signal group and separating lanes. The detailed difference of route control and link control will be described in section 4.2. It will be illustrated with two parts, signal setting design and layout design.

‘How RICS can be applied in the network?’

The RICS system will be studied in section 4.3. The subsystems and their functions will be explained. In the following section 4.4, more application issues of RICS are studied. The control logic is presented as passive, active and adaptive control. The integrated RICS system can provide possibility to design a special control treatment along a certain route. Then it follows by the two questions:

‘Which route should be treated special with preferential control strategy?’

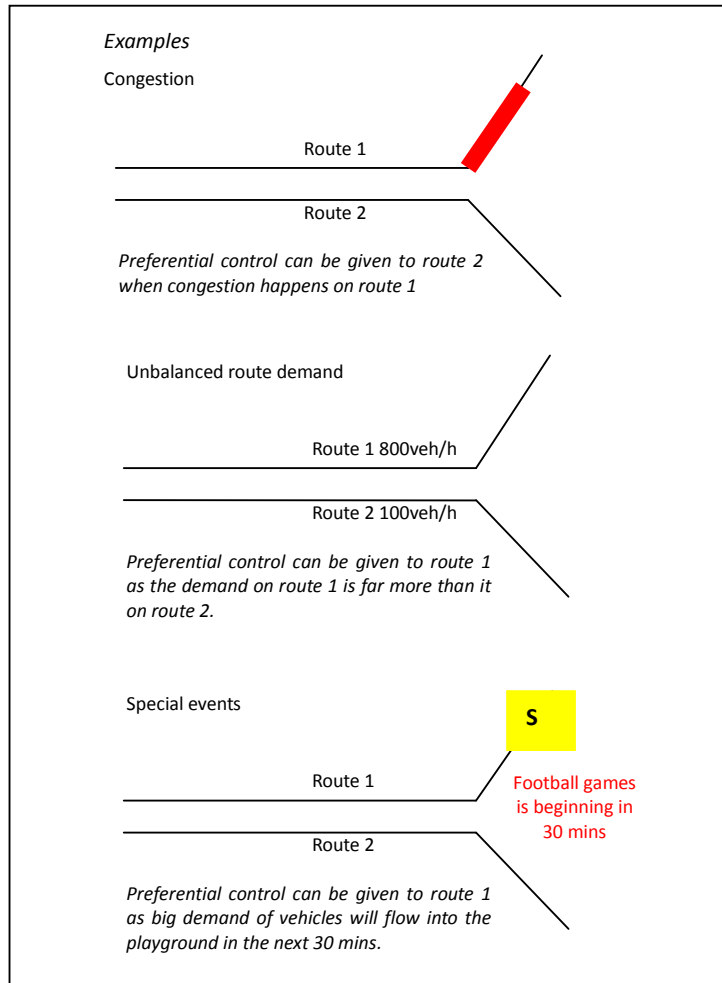
Route preferential index is introduced which indicates the importance of the special control for this route (the higher of the preferential index, the stronger request of special control). Here shows the example situation where certain route is expected to be special controlled.

‘When RICS can be applied?’

After the analysis of RICS effects, control logic, and system, this question tries to summarize the suitable situations for RICS, mainly which includes:

- Congestion occurring in the downstream intersection;
- Unbalanced route demands in the network;
- Non-recurrent incidents;
- Peak hours.

The detailed explanations of those above traffic conditions can be found in section 4.4. There are some examples showing when and how RICS can work on the network.



The last question: 'How can it be properly evaluated?'

The performance of RICS can be described with a set of criterions which behalf of the different stakeholders, mainly of travelers and road authorities. This part will be described in section 4.5

4.2 RICS description

RICS vs. Link concept control

In this section, we will look into the differences between traffic control using link information and route information, which indicate the core concept of RICS. We start to look into a simple network where there are two origins and two destinations. We will discuss only a single direction here for reasons of simplification. Figure 4-1 and Figure 4-2 respectively show the network in link concept and in route concept.

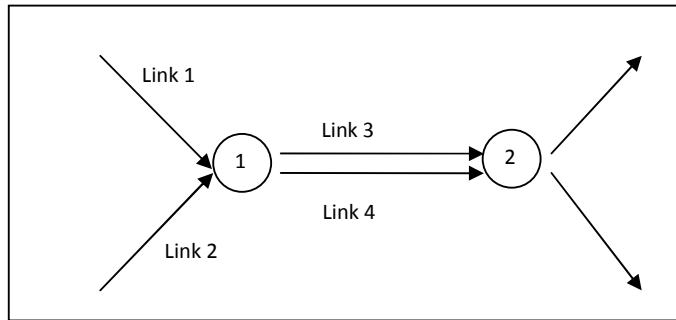


Figure 4-1 Link concept network

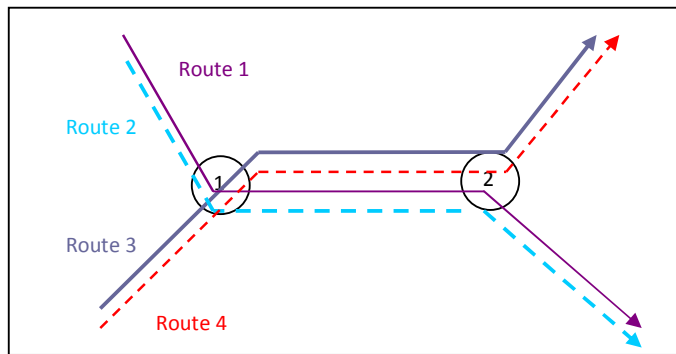


Figure 4-2 Route concept network

There are two intersections in the network and each intersection has only two streams. In link control, the input data is the flows on the approaches of the intersection, which means intersection 1 will consider the **two** approaching counts on link 1 and on link 2, intersection 2 will consider the flows on link 3 and on link 4. Based on the link flow data, all control parameters like cycle length, split and offset can be designed.

In route control network, the input data is the route demand of the network. There are four routes existing in the example network. In route control concept, every intersection is expected to take the **four** route volumes into its signal design.

The major difference between the route concept and the link concept is the previous one can distinguish the signal group with its destinations as well as its origins. The intersection signal will not be designed only based on upstream link flows but also the route of the passing vehicles. It brings the change in signal setting design and layout design.

4.2.1 Signal setting designs

RICS can contribute to control strategy design in the following signal setting elements including signal composition, phase scheme, control structure and offset.

Separated signal groups

The primary idea of RICS is to separate the signal group according to different routes

which means the signal is not dedicated to stream movements in the intersection but to the traveling routes in the network.

For example, figure 4-3 illustrates the separated signal groups in RICS. There are two signal groups which individually controlled the traffic streams on two approaches of the intersection, but if there are two different destinations of each stream in the downstream intersection, each signal group can be split into two signal groups controlled by four signals. Each signal head controls one route (shown as the example network in Figure 4-1). Each route will have a special control signal at the intersection. The concept enables the flexibility to follow the actual route demand instead of stream demand in actuated control system.

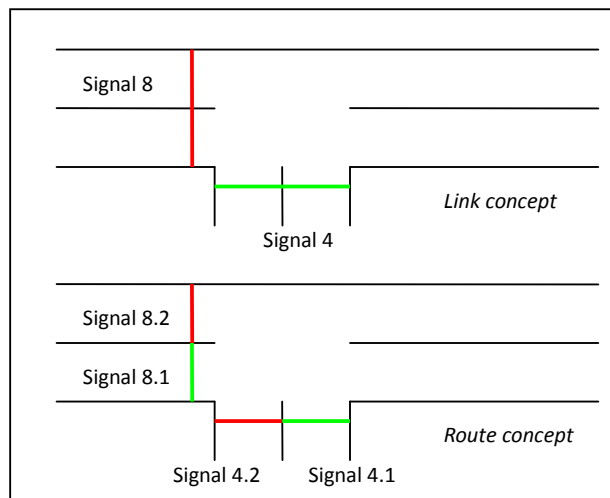


Figure 4-3 Signal group design in RICS

Along with the signal separated, the conflict group differs from the previous situation. The number of potential conflict group at an intersection depends on:

- The number of approaches to the intersection;
- The number of lanes on each approach;
- The type of signal control;
- The extent of channelization;
- The movements permitted.

The new design of signal will have a great influence on traffic signal setting parameters including cycle time, phase scheme, green length and offset design. The RICS makes use of its advantage in split-phasing and signal synchronization design to practically improve signal timing especially in this heavy volume intersections or heavy turning movements.

Phase schemes design

Along with the separated signal group, phase scheme in route control is different from the traditional one. Taking the example network above, Figure 4-4 shows the phase schemes design in link control concept. The intersection 1 has two in which phase 1 for signal 8 and phase 2 for signal 4.

In the route concept, it is obvious that there are more different phases available in phase schemes design, i.e. signal 8.1, signal 8.2, signal 4.1, signal 4.2, signal 8.1 and 8.2, signal 4.1 and 4.2 as shown in figure 4-5. Then the sequence of phases to compose a signal cycle can be generated with more flexible and various options.

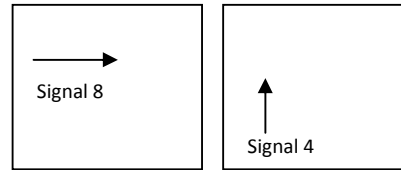
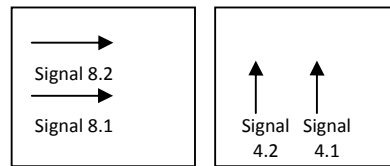
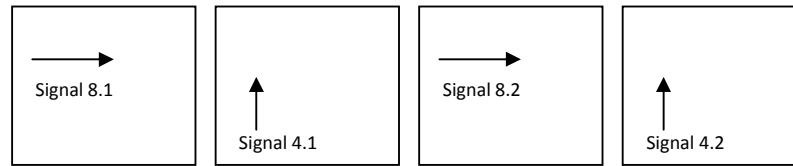


Figure 4-4 Phase scheme in link concept



Basic phase



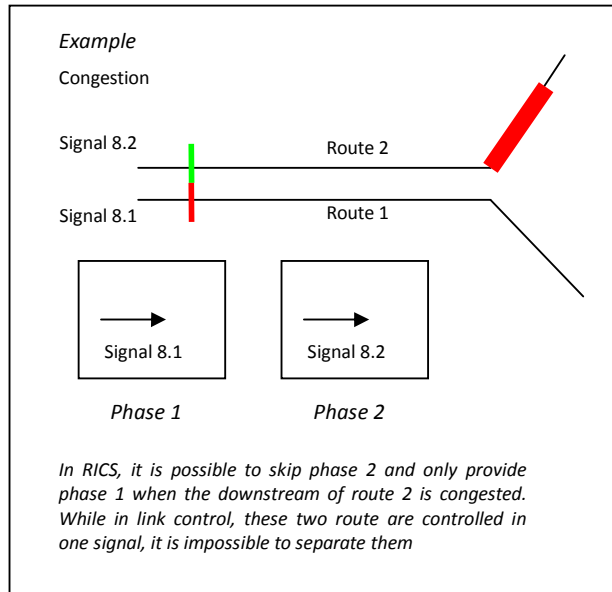
Extra alternative phase

Figure 4-5 phases scheme in RICS

Figure 4-5 shows the phase scheme design in RICS. The basic phase scheme is as same as link control but extra phase can be alternatively selected to meet special need of the network. In actuated control, each route vehicles can be assigned different extension green time in signal design according to its own vehicle demand.

Introducing more phases into the signal control intersection is not proper in regular traffic condition as more phases commonly mean more amber and all red, which may reduce the throughput of the intersection and increase vehicle delays in under saturated junctions due to longer waiting times during the red phase.

While the increasing number of available phases could benefit the situation where there is one downstream route congested. The signal control of other routes can still allow traffic going through the intersection by providing green phase at the same time block the congested route and control the queues on the downstream lane. As a result, unnecessary delays of vehicles on some routes can be avoided and the whole network performance might be improved. This is impossible to be realized in link control as one green phase will allow different route vehicles inflowing to the downstream section. The movements of different route can not be separated.



Green split design

Green split design aims to minimize the risks of over saturation and queue spillback. This control objective is approached through the appropriate manipulation of the green splits at signalized junctions for a given cycle times and offsets. A new split control can be designed to well correspond to the route demand.

In RICS, the splits could be adjusted to provide longer or shorter green phase according to the route demand.

Offset design

RICS can provide us a new environment of offset design in which coordination is not limited only to apply on the main stream: it can be extended to more streams.

In link control, green waves are always introduced only on the main stream of linear corridors to increase the smooth progression of bigger traffic flow. As shown in Figure 4-6, the coordination can be generated between signal 8 in the first intersection and signal 8 in the first intersection and signal 9 or signal 7 in the second intersection.

In RICS, coordination can be generated separately according to the routes. Signal 8.1 in the 1st intersection can be coordinated with Signal 7 to control route 1, while coordination can also be designed between Signal 8.2 in the first intersection and Signal 9 in the second intersection to control route 2.

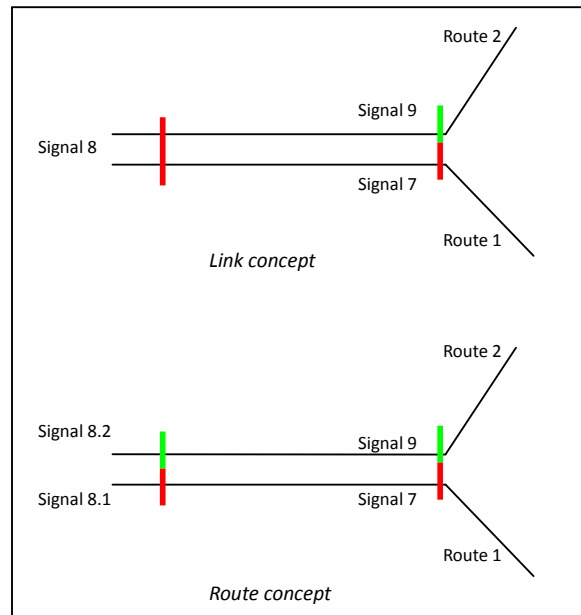


Figure 4-6 Offset design of RICS

4.2.2 Layout design in RICS

The roadside geometric design of network should correspond with RICS. It is necessary to study whether or not the geometric design can make the control strategy feasible, effective and cost-efficient in the current situation. There are the detailed geometric design alternative shown below.

The geometric roadside design should aim to achieve those objectives:

- Good cooperation with the new route control design;
- Good cooperation with the existing roadside geometric;
- Low investment cost including initial construction cost and long-term maintenance cost;
- Easy construction and maintenance;
- Road safety and friendly environment.

Managed lanes facilities are very important in RICS. They are aimed to provide correct and real-time information to drivers of unfamiliar access, geometric layout, and operating rules. Conveying information concerning these features requires effective usage of standard and novel traffic control devices. As managed lanes techniques continue to evolve, new operational strategies and geometric designs may require new traffic control devices.

Generally, the road side layout adjustments according to RICS include right-of-lane design, and extra equipment design such as barrier and signs.

Right-of-way lane design

Another idea that is introduced in RICS is to apply right-of way lane on the roadside.

Right-of-way means providing exclusive lane for certain vehicles. Normally it is used to distinguish the movements of different vehicle type or different speed vehicle to ensure traffic safety. In route control strategy, it can be introduced to provide exclusive way for certain route vehicles.

If the road geometry is available, the vehicles on preferential route can be guided to their right-of-way lane. Rather than the function of separating vehicles with different speed, right-of-lane here is expected to avoid the disturbance from congestion on one route to vehicle movements on other routes.

This measure can prevent side effects of oversaturated bottleneck and it is helpful to make green wave coordination design between two signals. Besides, it can also reduce the negative lane changing effects.

Figure 4-7 shows the roadside layout of right-of-way application in RICS. As the vehicles will have two destinations on the second intersection, the link connecting the two intersections separates two lanes to provide each route vehicle own right-of-way lane. Therefore, the lane changing behavior on this link can be prevented by this geometric layout.

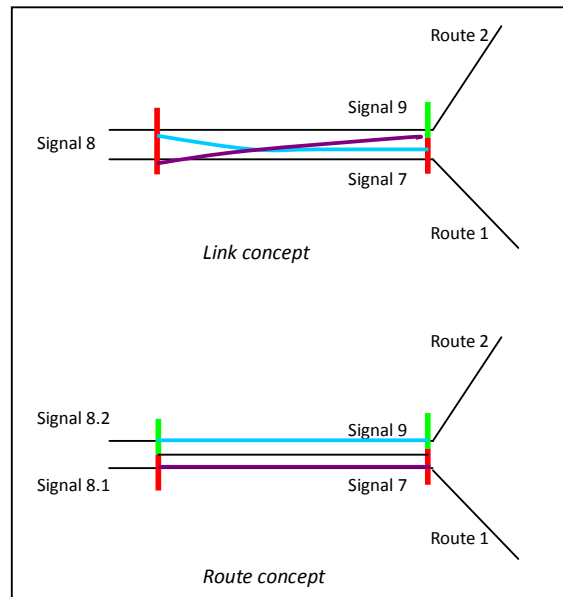


Figure 4-7 Right-of-way layouts

The design of right-of-way lane can be taken advantage in the closely intersections roadside design. If the distance between the neighboring intersections is short, the lane changing behavior will have great influence on the traffic movements due to the constrained space. There will be a great probability that other route outflow capacity is reduced by the spilled back queues as the storage of queue of short section is low.

In technical way, the right-of-way lane can be realized by installation of barriers or curbs (long-term or temporary) between two lanes. It also can be realized by changing the

geometric layout by introducing side ramp and diamond interchange on the highway. The width of the lane, speed of passing vehicles and existing geometric layout all should be taken care in consideration when designing the right-of-way lane. Simple and clear signs and marks are very important to guide the travelers to follow the right way and ensure the movements safety.

Extra equipment design

Compared to link control, extra equipment might be needed in RICS to support the new control strategy (extra signal heads and lane separation barriers) and to ensure the safety of road users (signs and marks).

Great attention should be paid on the design of those extra equipments as the proper design will greatly enhance the safety and operation at conflict points in a road system. The following content will introduce the general concept of barrier design and pavements & signs design, which can be applied in RICS.

Barrier design

Road barriers are usually categorized as flexible, semi rigid or rigid, depending on their deflection characteristics on impacts. Flexible barriers, such as cable barriers, generally impose lower impact forces upon vehicles than the other categories since more of the impact energy is dissipated by the deflection of the barrier (ASHTO 1996).

The most common used barrier on the highway is cable barrier, W-beam barriers and concrete barrier [21]. Table 4-1 presents the characteristics of those barrier types.

Table 4-1 Comparison of barrier types

Cable barrier	Concrete barrier	W-beam barrier
-Low initial cost -Easy installation and removal -removable in emergency situations -Frequent maintenance after accidents -Higher risk of accidents	-Twice as expensive to install -Lower life cycle costs -Long-term safety performance -Prevent dangerous motorway accidents	-Retain efficiency after minor impacts -Bend the beams to make smooth radius along curves -Reduce visibility through the barrier -High risk for snow accumulation

The selection of road barrier type should be based on the following criterion:

- Performance requirements:
Containment level, impact severity, level of deflection, possibility to modify the deflection level, possibilities for connection of the barrier types and to the barrier end terminals;
- Other safety requirements:
Visibility of the surrounding areas;
- Maintenance cost:
Easy to repair, available spare parts and possible to reuse the foundation without need for straightening measures
In snow-rich regions, snow drifts have to be taken into account as well.

For a short period, cable barrier is very popular as its low installation cost and flexibility to the traffic condition. It can be selected when RICS is taken as a temporary control strategy

or when RICS needs to be adjusted with changeable traffic conditions.

For a long time period, concrete barriers enjoy big advantage due to its long-term safety performance and reduced life cycle costs.

Pavement Marks and signs design

Additional signal heads and separated lanes increase the complexity of the road layout In RICS. Drivers might be confused by the road design and take the wrong side. The wrong way driving can be reduced with good geometric design, proper signing, roadway marking and other managed lanes facilities. Measures are designed to prevent confusing traffic situations as much as possible.

There should be simple and understandable signs installed to indicate the route destination before the separating location such as work zones. Traffic signs including regulatory signs, warning signs, and guide signs are very important for informing travelers about interrupted traffic conditions. Benekohal et al (1995) indicated that half of the surveyed truck drivers wanted to see warning signs 3-5 miles in advance. Additionally the marks on the roads will guide the turning movement of vehicles at the intersection. Figure 4-8 gives some examples of pavement marks and signs.

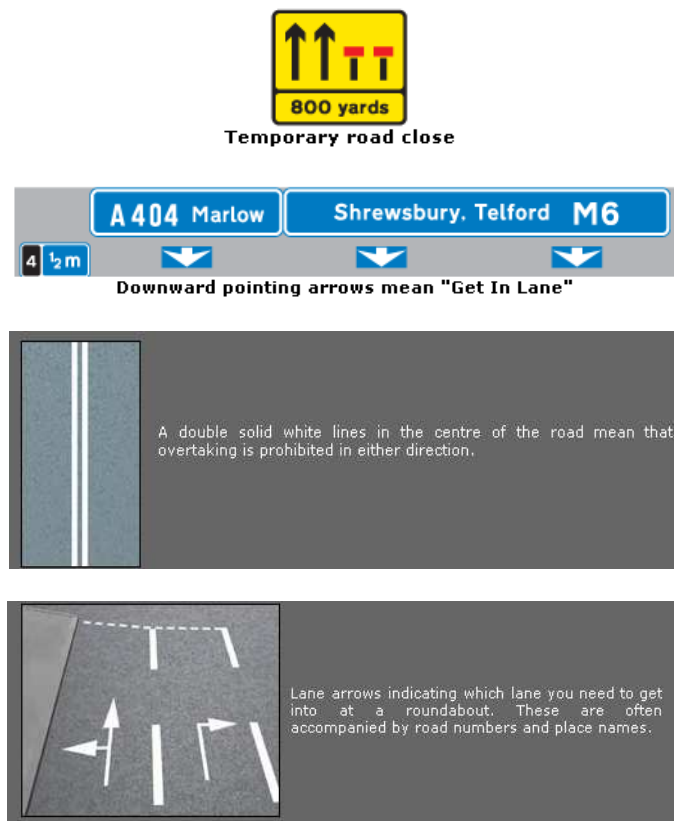


Figure 4-8 Examples of signs and marks

4.3 RICS system

There are some main elements supposed to be coordinated in RICS. The basic elements of RICS are route information (OD matrices), traffic signal control and traffic condition on the network. RICS makes use of route information and traffic condition as input to design the control strategy in which traffic signal control is one of the outputs. Figure 4-9 shows basic RICS system.

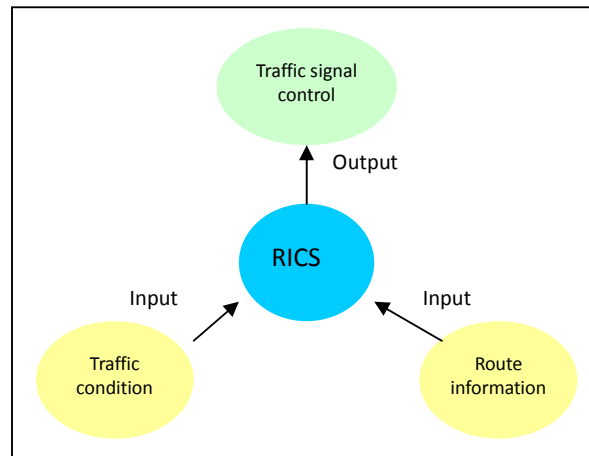


Figure 4-9 Basic RICS system

When RICS is applied with real-time information, it needs a more advanced management system. The RICS system is expanded to deal with the on-line route information and traffic condition. There are five main subsystems involved:

- Vehicle detection system;
- Traffic condition checking system;
- Communication system;
- Traffic signal control system;
- Traffic management system.

Vehicle Detection Request system

The vehicle detection request system is responsible for collecting link flow data for dynamic OD matrices estimation. The detectors are located at the links to collect data from every passing vehicle and then they will send the information to the communication center to estimate the OD matrices. Based on the new OD matrices, RICS can be redesigned and updated.

Traffic condition checking system

The system is composed of sensors of road side infrastructures. They will continuously check the current traffic conditions in the network including saturation ratio, queue lengths, incidents and maintenance events. They will also provide the information, like which route will be greatly delayed or blocked according to the traffic condition, to the communication center.

Traffic signal control system

The traffic signal control system is responsible for acting on RICS request and making any

applicable changes to the signal indications via the local traffic signal controller. A centralized traffic signal control system will direct the local controller to take applicable action.

Traffic management system

Various traffic management measures have great potential in well-implementing RICS, which might include advanced traffic information system, dynamic lane control and rerouting measures.

Communication system

The communication system for RICS includes the provision of vehicles information detection, traffic condition data and traffic management centers.

Figure 4-10 shows the diagram of advanced RICS.

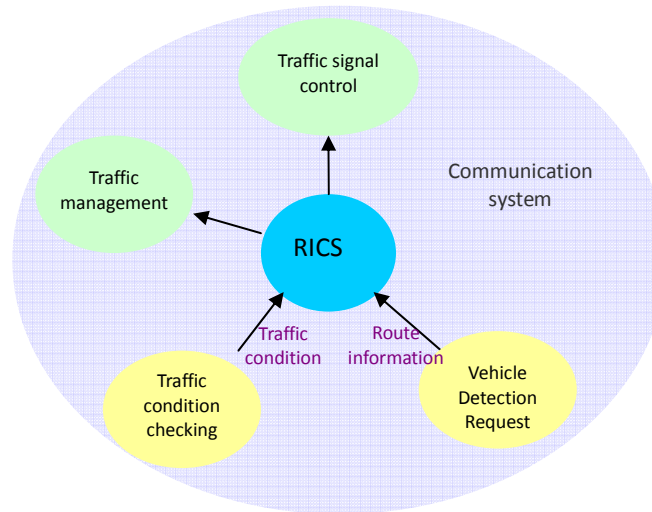


Figure 4-10 Advanced RICS system

4.4 RICS application

RICS is initiated with a simple network where there are two intersections with only two origins and two destinations network. In this section, the study will go on the investigation of its application in a network.

Application RICS to provide each route with its special control seems to be impossible regarding the constraints of signal heads and limited road space. There are probably two approaches to apply route control strategy in a large network:

4.4.1 Special route control in network

If RICS is applied in a large network, it might work effectively by creating a special signal control along a certain route. RICS can be an operational strategy that facilitates the

movement of a certain route through traffic signals along intersections in a wide network.

This route could be separately controlled from other vehicles so as to reduce its delay time, number of stops and travel time. The selection of the special route is an important task. It can be realized by introducing the route preferential index which indicates the importance of the special control for this route (the higher of the preferential index, the stronger request of special control).

Route preferential index

It is calculated as:

$$C_{j,k} = \beta_j P_{j,k}$$

$P_{j,k}$, number of vehicles taking route j during k

β_j , priority weight for vehicles on route j

K is the time interval for route preferential index calculation

One of the most difficult tasks is to determine the parameter β_j , which indicates the priority weight of the route. It should differ from route to route and it might also differ with the time period. Basically, it could be determined by road authority in the respects of the role of this route on the whole network. A series of questions could be asked to determine its value.

- Is this route crucial for the whole network?
- Is this route passing the main shopping center or commercial offices areas?
- Is this route the important link connecting two centers?
- Does the congestion on this route have great negative impacts on the other routes?

There is also a standard preferential index of the current network C_F which means maintain the current control strategy without any route preferential. Each of the calculated route preferential indexes will compare with standard index and choose the maximum.

This approach is best suitable to centrally controlled system, where a central control plan over the whole network directs all the actions of the local intersections.

4.4.2 Neighboring intersection control

The other idea is to apply RICS in decentralized system, in which the big network is divided into a group of sub-networks, each with two neighboring intersections. Every small sub-network regards the approaches of the first intersection as origins and the exits of the second intersection as destinations. Considering one direction from intersection 1 to intersection 2, the vehicles will start from the different approaches in the first intersection and disperse into three destinations in the second intersection, which will form nine different routes totally. The network of neighboring intersections is shown in Figure 4-11.

According to the measures of RICS introduced above, it is possible to create separated

signal control for different routes trace the vehicle stream from the origins at first intersection to its destinations at the next intersection. Figure 4-11 presents the two intersections in distributed network. This approach is intersection-based so that it can be categorized as distributed network control. The computing time is less than centralized network control and the design network is easier.

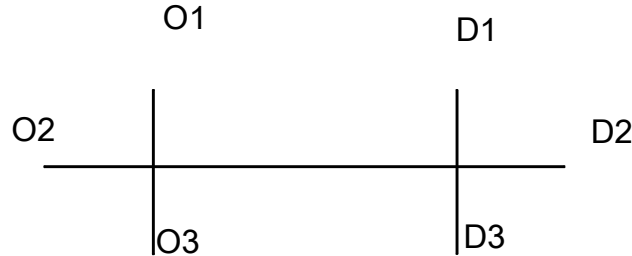


Figure 4-11 Distributed network

4.4.3 Control logic of RICS

The control logic of RICS can be categorized as passive, active and adaptive. The comparison of them is shown in Table 4-2. The following presents the detailed explanations:

Table 4-2 RICS control logic

Control logic	Passive	Active	Adaptive
OD matrices	Static	Dynamic	Dynamic
Traffic condition	Pre-defined	Real-time detected	Real-time detected
RICS	Pre-designed; Initiated by time	Pre-designed plan; Real time initiated	Fully Real-time

Passive RICS

Passive RICS operates according to plan regardless of whether the change of traffic condition and OD matrices and does not require a vehicle detection system and traffic condition checking system. In general, the OD matrix can be available from historical data and the traffic condition for peak hour or special events can be predictable. When the level of the route preferential is really high, RICS can be predesigned and initiated by time schedule.

Compared with the following active and adaptive control, passive RICS is easy to apply as the system is rather simple. The disadvantage is also very clear that it is less adaptive to the fluctuated traffic condition and lack of retiming signal control. Passive control can be applied to deal with daily recurrent congestion (e.g. peak hour flow) or special event traffic condition when the general OD matrix and route information can be available from past experience or simulation experiments.

Active RICS

The difference between active control and passive control is that the previous one triggers RICS by real detecting of the network rather than pre-setting. Active route control strategy provides special treatment to a specific route travelers following detection. When the requirements of special control for certain route is met (indicated by detectors), the current control strategy begins to switch to RICS.

Implementation of active requires the detection of the vehicle information and real-time road condition in order to switch strategy change action. It needs a vehicle-infrastructure information system in which the route information of individual vehicle can be sent to the detection system. It also could be realized by real time route choice estimation which is available by dynamic macroscopic model like DYNASMART. When the high flow on certain route or special traffic condition is detected, RICS can be triggered by management center and when the demand has gone back to normal or the traffic problems has been solved, RICS can be switched back to the regular control.

In the case that RICS covers the whole network including several intersections, it is also possible that the local signal control can change following the vehicle movements. As soon as the target vehicles pass the one intersection, the control plan of that intersection changes back but the other downstream intersections still perform in RICS.

Adaptive RICS

The difference of adaptive route control and active route control is that adaptive RICS continuously monitors traffic conditions and adjusts control strategies. There are a set of RICS for different routes can be designed and to be selected simultaneously. The management center selects the preferred route of the current phase, at the same time it will prepare for the next phase by simultaneously cumulating route preferential index of all entrance link of the network in the current phase and those to be activated in the next phase. The OD matrices, traffic condition and implemented RICS are all updated with real time information.

After the minimum duration of the current phase expires, the algorithm compares the preferential index of different routes again. If the new preferred route is selected, then the control switch to the new RICS, otherwise, the current control is extended until the next extension check time. The control parameters like cycle time, split offset are variably designed according to the route demand and other dynamic control management also can contribute to the preferred route travelers. Figure 4-12 illustrates adaptive route control framework.

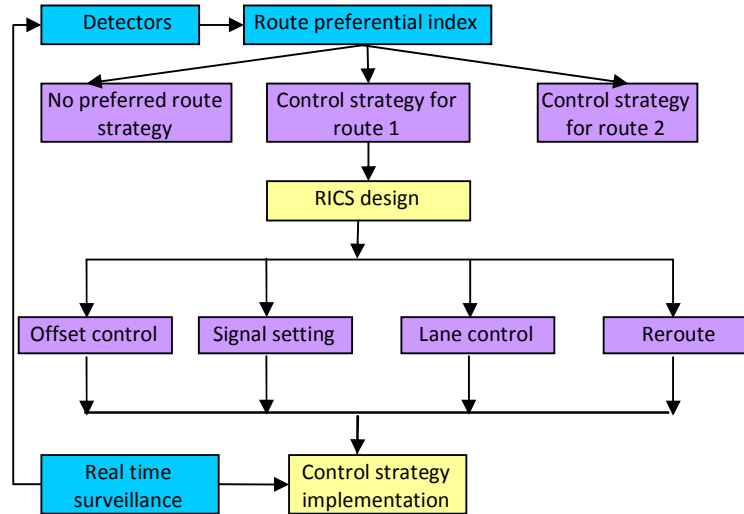


Figure 4-12 Adaptive route control framework

4.4.4 Suitable application situations of RICS

In this part, the analysis focuses on the traffic condition prerequisites of RICS application. After obtaining the knowledge of RICS, we would like to explore the question of when to apply this concept. Those traffic conditions provide suitable environment of RICS application, in which RICS can be competitive to the current control strategy. They are summarized as followed:

Congestion occurring in downstream intersection

Congestion usually happens when the demands of flow exceed the supply of road capacity, which will cause the bottleneck in the network and queues will begin to disrupt movements at upstream junctions. In this situation, it is better to apply RICS in the upstream intersection of the bottlenecks to limit the inflow vehicles to the bottleneck and manage the queue length in the section; while the inflow vehicles to other direction can be kept as smoothly as possible to take best advantage of the capacity of existing road infrastructure.

There are various causes of congestion in real traffic conditions: [22]

- Physical Bottlenecks (“Capacity”)

Capacity is the maximum amount of traffic capable of being handled by a given highway section. Capacity is determined by a number of factors: the number and width of lanes and shoulders; merge areas at interchanges; and roadway alignment (grades and curves);

- Special Events

A special case of demand fluctuations of traffic flow in the vicinity of the event will be radically different from “typical” patterns. Special events occasionally cause “surges” in traffic demand that overwhelm the system;

- Fluctuations in Normal Traffic

Day-to-day variability in demand leads to some days with higher traffic volumes than others. Varying demand volumes superimposed on a system with fixed capacity also results in variable (i.e., unreliable) travel times;

- **Traffic Incidents**

Incidents disrupt the normal flow of traffic, usually by physical impedance in the travel lanes. Events such as vehicular crashes, breakdowns, and debris in travel lanes are the most common form of incidents. In addition to blocking travel lanes physically, events that occur on the shoulder or roadside can also influence traffic flow by distracting drivers, leading to changes in driver behavior and ultimately degrading the quality of traffic flow. Even incidents off of the roadway (a fire in a building next to a highway) can be considered traffic incidents if they affect travel in the travel lanes;

- **Work Zones**

Construction activities on the roadway result in physical changes to the highway environment. These changes may include a reduction in the number or width of travel lanes, lane “shifts,” lane diversions, reduction, or elimination of shoulders, and even temporary roadway closures. Delays caused by work zones have been cited by travelers as one of the most frustrating conditions they encounter on trips.

Unbalanced route demands in the network

The route control strategy can be designed for unbalanced route demand network, where the huge demand route can be provided with longer green time extension or priority signal in order to generate better traffic performance of the network. While it is meaningless to be applied on a balanced route diversion network, the route control strategy will have less impact on it.

Closely Spaced Intersections

In the case of closely spaced intersections, a careful coordination design is necessary as the shortage of vehicle storage. In this case, it is more possibility that queues spill back from one intersection to the upstream intersection. As the congested condition mentioned above, it can seriously disrupt operation of vehicles with other destination. RICS with good coordination can be well-functional in these cases.

When signals are spaced too far apart, there is enough room for the storage of waiting vehicles and the variety of traffic arrival pattern of the downstream intersection increases. Traffic may not form these platoons thereby undermining the effectiveness of signal coordination.

Non-recurrent incidents

RICS is used to deal with traffic flow in some special events. When there is a football game or large evacuating situation, a great number of vehicles will flow on the same route over a very short period. The traffic demand is often far excessive to the road capacity and has a negative influence on travelers on the other routes. In this case, the special control plan could be implemented to guide the vehicles on the busiest route in the network. This control strategy is supposed to last for a period until the excessive numbers of vehicles have left the network.

Under above circumstances, traffic control should be designed considering specific route

travelers.

Peak hours

Peak hours seem to be the most important time period for RICS application. During peak hours, networks and arterials are operating under constrained conditions with the greatest volume of traffic of a day, when congestion will probably occur and the incident risk is higher.

However, it might happen that a certain RICS in some network is effective in peak hour but it worsens the traffic performance in off-peak period. In that case, the RICS could be implemented temporally. The signal settings should be able to change during the time and the adjustments on roadsides layout should be removable or flexible to different control strategies.

The major effect of RICS is to provide special control treatment for a certain route of vehicles. It might be not so effective in the regular traffic situation when the traffic flows are low or the route demands of the network are balanced but it has positive effects on controlling the spill back queue length in the congested network and making good use of the spare capacity so as to promote the movements of certain routes.

4.5 RICS performance evaluation

4.5.1 Evaluation introduction

Once potential operations strategies have been identified, an evaluation of those strategies is very important as it can ensure the most appropriate strategies to be selected. The evaluation process and criteria should reflect the goals and objectives that were established earlier and can vary from simplicity to complexity.

Strategies that require multiple stakeholders are more complex because of competition of diverse expectations. Therefore, it is necessary to have a flexible evaluation approach to selecting potential strategies and understanding that all parties must be willing to support the strategies to be implemented. In this chapter, a comprehensive evaluation methodology of RICS is performed.

4.5.2 Socio-economic evaluation

A socio-economic evaluation is carried out here to provide information on the use and allocation of public resources or the efficiency of RICS. A socio-economic evaluation is essential to show the chosen traffic management measures were superior over available alternatives and expenditures were thus justified. [23]

Socio-economic evaluation is strongly related to impact evaluation. It uses impacts and evidence of causal attribution of impact evaluation as input. On the other hand, socio-economic needs to define which impacts should be measured in impact evaluation. Figure 4-13 shows this relationship.

A socio-economic evaluation is required to show to what extent impacts generated by route control strategy compensate for invested public resources.

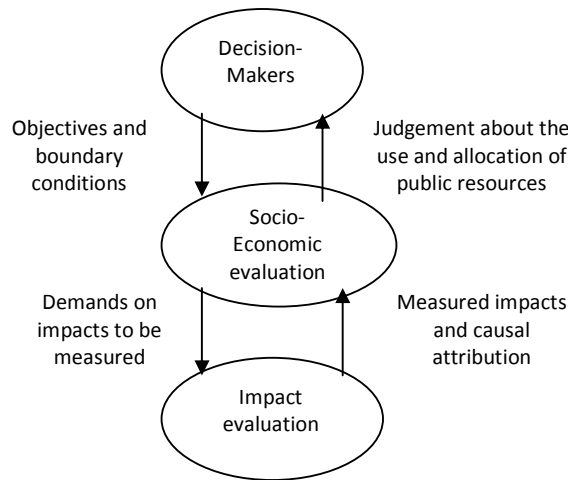


Figure 4-13 Relationship of socio-economic evaluation system

4.5.3 Impact evaluation of RICS

In socio-economic evaluation, all impacts of RICS need to be determined. The impacts generally can be categorized as direct, indirect and external impacts.

Direct impacts

Direct impacts of RICS are for example an improvement of traffic flow and reduction of travel time on a certain route.

Generally speaking, the main measurements of traffic performance are delay, travel time and the average number of stop. They are defined and explained as following:

- Delay

It is defined as the amount of additional time spent by the vehicles on a section of road due to congestion. It is the difference between the travel time at a non-congestion speed and the current speed. It is also important to review the delay trends, which indicate the development of congestion and pro-active intervention.

- Travel time

It is the most direct measure for mobility, indicating the time needed for traveling from a given origin to a destination. It is useful to understand the impacts of congestion on traveler and it also represents the satisfactory level of mobility. Meanwhile, it is crucial to realize small reductions in overall average travel times often relates to significant reductions in delay.

- The average number of stops

It is also a very important criterion as it is strongly related to the fuel consumption of each vehicle, especially when there is a world-wide trend of increasing emphasis on environmental issues. The less number of stops means less fuel consumption and less air pollution from emissions.

Besides, in congested or oversaturated network, the queue lengths and actual capacity of infrastructure should also be important criterion.

Indirect impacts

The direct impacts also lead to indirect impacts, since road users adapt to new situation. The impacts of RICS can be divided to the effects on the preferential route users and not preferential route users. They should be evaluated separately as a short delay on a certain route might cause the delay on the other routes.

These indirect impacts could also consist of changes of destination, route, departure time and mode choices of road users. A new equilibrium is formed. On the long run this new situation may even affect spatial-economic development.

External impacts

External influences probably include economic trends, environment impacts and traffic safety. These are growing to be a big concern of road authorities and they can not be ignored in RICS evaluation.

4.6 Summary

Generally speaking, RICS brings new features in signal settings design and road layout design. A series of signal adjustments can be made with the additional route information, such as redesigning the signal group, resetting the green time split and coordination or separated lanes.

RICS is supposed to be effective in handling special traffic conditions such as congestion, special events and unbalanced network demand. It aims to reduce the travel time of certain route vehicles, balance the network demand and lead the increased quality of control service and network efficiency. Potential negative impacts could consist primarily of delays to side street traffic.

A Socio-economic evaluation methodology is proposed to access the functions and impacts of RICS and provide information on the use and allocation of public resources or the efficiency of route control strategy.

As a summary, the process of RICS design can follow the below steps:

Check the current conditions

The current condition consists of the traffic condition on the network and route information (OD matrices). Analyze the current situation carefully and take it as the baseline of the further design of RICS, the following aspects should be analyzed:

- Congestion condition in the network;
- OD matrices of the network;
- Traffic performance of vehicles on specific routes.

Check the existing roadside infrastructure

Observe the geometrical layout of the roadside to see if they can well serve the RICS design.

- If there is enough space at this intersection to separate signals (the number of lanes per

stream, the lane width);

- If it is possible to apply right-of-way lane to different routes (The length between the two intersections, the lane width).

Design RICS for a specific network

- Design the control scheme for a series of intersections (cycle time, phase sequence and split);
- Design the proper coordination between intersections;
- Design the new roadside geometric layout;
- Design the suitable road installments to support RICS;
- Combine the various measures in a well-organized framework.

5. Delft Case study

This chapter presents a case study of Delft Kruithuisweg corridor, which is located between the A4 and the A13.

The study site is selected to be the Kruithuisweg corridor which experiences severe congestion during the peak hours. The vehicles traveling on this corridor at speeds of less than 10 kilometers per hour during the peak periods, which is recognized as a big problem in this area.

In recent years, the accessibility between Den Haag and Rotterdam is growing which increasingly attracts more passengers and freight vehicles to this region. The pressure on the highways in the region is very extensive, which lies in the central region: the A13. The A13 is one of the largest congested bottlenecks in the Netherlands. There are more than 160,000 vehicles using this highway daily and also daily traffic jams existing on corridor Kruithuisweg, which performs as a main connection to convey the vehicles to the A13 highway.

The Kruithuisweg in Delft is a very important corridor which leads from freeway the A4 and to the roundabout Kruithuisplein of the A13. Figure 5-1 shows the study site location. It plays a significant role in commuting and freight transportation of Delft. The traffic flows are relatively high, especially during the peak hours. The movements of vehicles on this corridor mainly depend on the traffic condition of the A13. As the A13 can hardly handle the traffic demand due to its structural shortage of road capacity, the congestion will have great negative impacts on the traffic on Kruithuisweg which will result in decreasing accessibility in Delft and adjacent area. This case study will try to find ways to manage the traffic flows on Kruithuisweg in a more proper way without adding extra traffic pressures on the A13.

Building an additional link between the A4 and Rotterdam is an alternative solution for this case, but the investment cost is rather high and construction duration is quite long compared to control strategy implementation. In this case, RICS might be a competitive alternative. Therefore, this case is chosen to study the impacts of RICS in real network.

The objective of RICS is to control the spill back and take advantage of the spare capacity for going-through vehicles at the downstream intersection to facilitate their movements. The OD matrix and the route information will be considered and detailed design of the control strategy of the critical intersections will be presented in the following contents.

The goals of RICS can be defined as:

- Improving the efficiency of a certain route groups;
- Balancing demands across the network to efficiently utilize the available capacity;
- Reducing the negative side effects of queues spilling back, such as blocking the movements of other routes

5.1 Experiment set up

Network selection

The site has potential to implement RICS as there is an oversaturated situation due to the ramp metering on the A13 and there is a great diversion of route demands in this area.



Figure 5-1 Study area map

Simulation environment

Overall traffic simulation models can be divided into macro-, meso- and micro-simulation. Mesocosimulation model like DYNASMART can do the traffic assignment and obtain dynamic OD matrices, but it can not perform traffic actuated control. The case study is modeled via the AIMSUN, a microscopic modeling and simulation tool. The software implementing the real time actuated control strategy. It is achieved by 'external control'. AIMSUN can use the extension provided by the simulator for CAI interface that allows AIMSUN to feed traffic control at each simulation step with the necessary loop occupancy measurements and public transport priority requests. (see details in Appendix B)

Methodology descriptions

It was planned to use micro-simulation to make "controlled experiments" with new route control strategy. The following steps were included in the research methodology:

- Collect data on the OD matrix and traffic conditions of current situation;
- Investigate the network problem and design RICS ;
- Set up simulation in AIMSUN and get the simulation results;
- Evaluate RICS by simulation results;
- Conclusions and suggestions

Performance indicator

There are various performance indicators used in this case study to evaluate the performance of RICS, which include the performance of network and the performance of selected routes. The general performance indicators include:

- Average delay per vehicle: A vehicle comes to a stop at an intersection if the signal light

for its direction is red and hence waits at the intersection until it changes green.

This waiting time at the intersection together with deceleration and acceleration delay is the total delay experienced by the vehicle and should be minimized. The average delay per vehicle is the total delays of the vehicles in the traffic network divided by the total number of vehicles which had been generated in the system. This value of the average delay is the waiting time which a vehicle will experience in the traffic network.

$$\text{average delay} = \frac{\sum \text{delay for each vehicle}}{\text{total number of vehicle}}$$

- Mean number of stops: This parameter can account for the average number stops a vehicle has to experience while traveling through the road network which is under control by the traffic control system being simulated.

Explanation

A stop is defined with the setting of queuing up speed queue leaving speed in AIMSUN.

Queuing up speed: vehicles whose speed decrease below this threshold value (in m/s) Vehicles whose speed decreases below this threshold value (in m/s) are considered to be stopped and consequently, to join a queue. This parameter affects statistical data gathering for stops and queues.

Queue Leaving Speed: Vehicles that are stopped in a queue whose speed increases above this threshold value (in m/s) are considered to have left the queue and no longer to be at a standstill. This parameter affects statistical data gathering for stops and queues.

In this case study, the queuing up speed is defined as 1m/s and queue leaving speed is 4m/s in AIMSUN.[24]

$$\text{mean number of stops} = \frac{\sum \text{number of stops for each vehicle}}{\text{total number of vehicle}}$$

- Average travel time: this parameter indicates the time for a vehicle from its origin to its destination.

$$\text{average travel time} = \frac{\sum \text{travel time for each vehicle}}{\text{total number of vehicle}}$$

5.2 Study area description

The network of the case study will take the whole corridor from the A4 Delft-Zuid to the A13. There are a number of main intersections along the corridors. Figure 5-2 shows the location of main junctions on Kruithuisweg:

Intersection 1. Abtsrechtseweg;

Intersection 2. Laan der verenigde Naties;

Intersection 3. Buitenhofdreef;
Intersection 4. Provincialeweg;
Intersection 5. Voorhofdreef-Tanthofdreef;
Intersection 6. Schieweg;
Intersection 7. Schoemakerstraat;
Intersection 8. Kruithuisplein roundabout;

Between intersection 7 and 8, there is very important signal control(9) for the merging traffic.

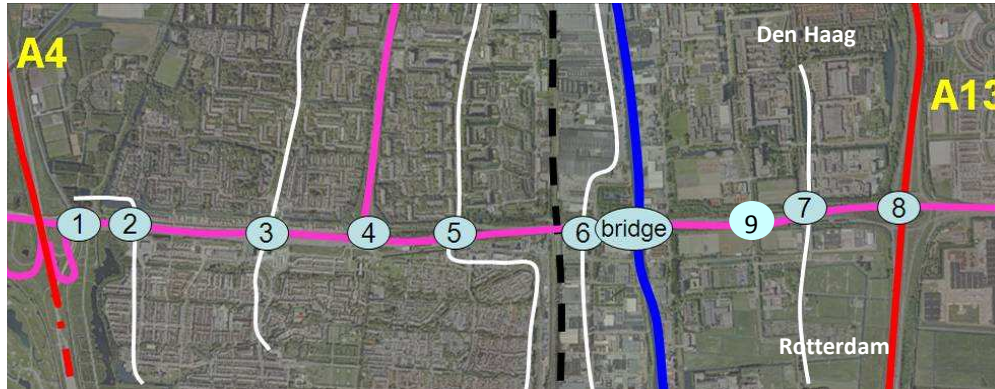


Figure 5-2 Main junctions on Kruithuisweg

N470 Kruithuisweg corridor between the A4 and the A13 in Delft is serious congested during peak periods. The main bottleneck is located at the on-ramp from Kruithuisplein to the A13 where a ramp metering control system limits the inflow to the southbound main stream.

As Figure 5-3 shows, the vehicle flowing into this section come from two origins, in which one is the Schoemakerstraat on-ramp, the other is the mainstream of Kruithuisweg (the colourful lines indicate the traffic movements and the black lines indicate the signal locations). The vehicles entering the network are first controlled by the signals in the merge intersection, then enter the same section and split at the Kruithuisplein intersection by their own destination, Den Haag (north) and Rotterdam (south).

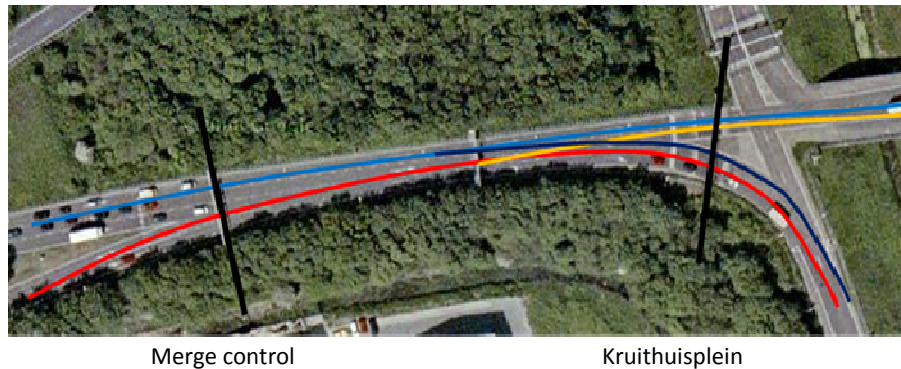


Figure 5-3 Route diversion in the section

When the demand of the vehicles exceeds the capacity of the ramp-metering on the A13 to Rotterdam, the queue spills back will continuously block the upstream intersections. Of course it will also block the stream going on the A13 to Den Haag, which usually has more capacity on downstream intersections. The problem is worse in the afternoon peak. The queue will block the upstream link of Kruithuisplein, and further block the whole Kruithuisweg corridor. Therefore, the study will focus on the afternoon peak period.

In this case study, we design RICS based on static OD matrices. The OD matrices of this network are available from historical data in the morning peak hours. It is estimated by the link counts collected by real-time detection. In order to simulate the traffic condition in the afternoon peak hour, the morning OD matrix is transversed to get the afternoon matrix.

According to the OD matrix, the demand flow on each approach of the merging control intersection can be estimated. There are two origins of the flow, in which one is from on-ramp from Schoemakerstraat, and the other is from the main stream of Kruithuisweg. The inflow of the on-ramp is not big in the afternoon peak hour, which is about 275veh/h. Most of the vehicles will go further to the South of Kruithuisplein. While on the main stream of Kruithuisweg, the total flow is about 1750veh/h, 60% of which will turn right and go to ramp metering on the A13, and the others will go through the Kruithuisplein. There is a great potential to improve the going through traffic movements without being disturbed by the queues spilling back from the ramp metering.

5.3 AIMSUN simulation set up

5.3.1 Network layout

The simulation area of this case study covers the whole Kruithuisweg corridor from the A4 to the A13, where there are nine junctions in total. There is no route choice taken into account in this study as there is only one route available between one origin and one destination in this network. During the simulation, the lane configurations were kept the same for the all designs except for the adjustment proposed in RICS.

5.3.2 Traffic demand

The traffic demand of the simulation is average afternoon peak hour demand.

Figure 5-4 gives the centroids layout of this case network. Table 5-1 shows the afternoon peak hour traffic demand in OD matrices.

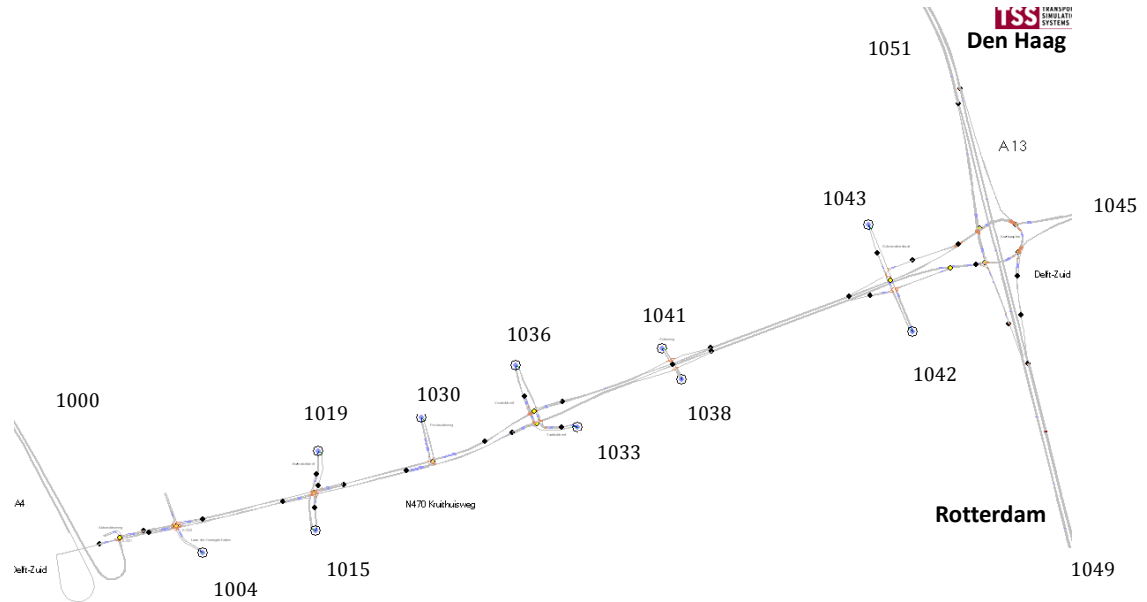


Figure 5-4 Network Centroids layout

Table 5-1 Traffic demand of afternoon peak hour (veh/h)

OD	1000	1004	1015	1019	1030	1033	1036	1038	1041	1042	1043	1045	1049	1051	Totals
1000		123	91	246	0	105	80	63	1	41	65	10	57	1	883
1004	271		6	65	70	11	15	11	1	5	19	5	30	1	510
1015	269	4		127	185	22	44	21	0	12	51	14	71	41	861
1019	371	50	115		55	30	0	21	0	20	26	0	105	18	811
1030	0	65	111	0		106	5	61	1	24	0	0	181	0	554
1033	115	10	17	12	72		210	34	7	25	83	17	128	219	949
1036	87	15	37	0	0	258		97	0	42	78	8	378	192	1192
1038	55	5	12	36	29	21	73		28	13	79	14	71	164	600
1041	0	0	0	0	0	1	0	30		1	0	0	27	6	65
1042	0	0	0	0	0	1	0	2	0		0	0	22	13	38
1043	12	6	12	0	0	46	7	70	2	47		2	189	46	439
1045	0	4	8	0	0	17	4	21	2	2	5		183	39	285
1049	34	18	36	100	62	84	224	63	27	100	198	97		4000	5043
1051	1	1	3	0	0	258	55	242	12	257	129	73	4000		5031
Totals	1215	301	448	586	473	960	717	736	81	589	733	240	5442	4740	17261

5.3.3 Control Plan

Each intersection was controlled by actuated signal designed based on average flow per hour in this case study. The minimum cycle time, signal sequences and minimum green time of each signal are designed based on the average flow during the afternoon peak hour. The outflow of ramp-metering on the A13 is controlled as 900 veh/h, which is estimated from historical data.

5.3.4 Detectors setup

In order to accomplish the actuated control in the AIMSUN simulation, there are two detectors (short loop detector and long loop detector) located on each approaching lane of signal control intersection.

5.3.5 Simulation period

The simulation period was from 16:00 to 18:00 with afternoon peak hour demand.

5.3.6 Simulation Scenarios

There are three scenarios to be simulated in AIMSUN, which are:

Scenario 0: Current control strategy (basic line)

Scenario 1: Proposed RICS

Scenario 2: Rerouting strategy

5.4 RICS design

The steps of RICS design in this case study follow the design process explained in section 4.6.

Check the current conditions

The bottleneck of this network is located at the ramp metering of the A13 (on Link 5) which is presented in Figure 5-5. The merging control (intersection 9) and downstream intersection (intersection 8) are selected to apply RICS design.

This structure of the two intersections is quite simple and it also meets the requirement of RICS. First, the stream of the first intersection will have a huge route diversion in the second intersection. Second, there will be oversaturated condition on certain route on the second intersection and have negative impacts on the vehicles going to the other direction.

In this case, the vehicles going through Kruithuisplein are hampered by the spill back queue of turning right vehicles. This area can be regarded as the bottleneck of the network and it will be tested in RICS.

Check the existing roadside infrastructure

The length between the two intersections is quite short, only 150 meters. Figure 5-5 shows the layout of this network and the number of lanes on each link. The design will base on the concept explained in the previous chapter. Figure 5-5 and Figure 5-6 show the difference of the bottleneck network in link control concept and route control concept.

Table 5-2 presents the traffic demand on different routes in this network.

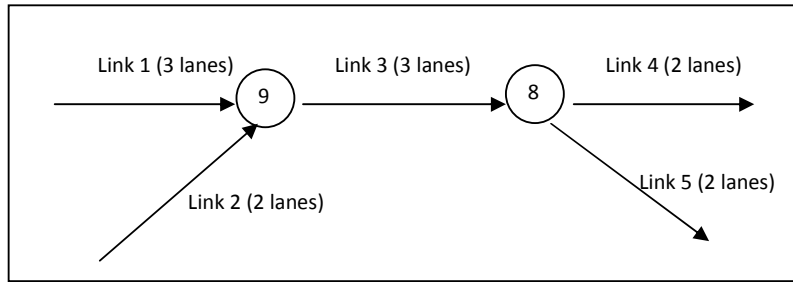


Figure 5-5 Bottleneck of the network

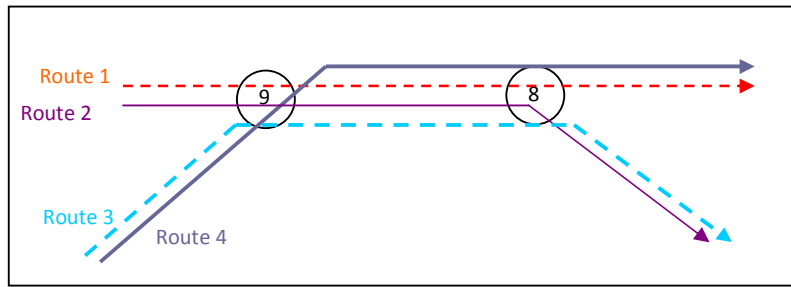


Figure 5-6 Route description

Table 5-2 Route demands

Route	Demand (veh/h)
Route 1	710
Route 2	1048
Route 3	61
Route 4	211

Propose the RICS design for this network

A series of control measures of RICS can be applied in this case, e.g. signal timing adjustment, layout design and other control measures. They will be detailed explained in the following contents.

5.4.1 Signal timing adjustments

Signal parameters consist of cycle length, green splits and offset design variables, which were adjusted in RICS as follows:

Separate the signal on the main stream of Kruithuisweg

The route diversion of the vehicle on main stream of Kruithuisweg is about 2/5 for going through and 3/5 for right-turning in the downstream Kruithuisplein roundabout in which the right-turning movements will be constrained by ramp metering. Separating the signal of this stream is aimed to smooth the go-through traffic with the least disturbance by the oversaturated right-turning vehicles.

In the existing road geometry, there are three lanes connecting the two intersections. The left lane can be reserved for the route to Den Haag with non-signalized control as it has no conflicts with any other traffic stream.

Separate the signal of on-ramp stream of Schoemakerstraat.

In the current situation, the vehicles from the on-ramp will suffer huge delays due to right-turning queues. The vehicles from the main stream always fill in the section so that there is hardly any space for the on-ramp vehicles. One of the most important tasks of the new control strategy is to improve their traffic performance.

Separating signals of on-ramp vehicles can promote the movement of the go-through vehicle on Kruithuisplein with minimized delay time caused by huge right-turning flow.

No Separated signal at downstream intersection Kruithuisplein.

The further discussion is if it is necessary to also introduce separated signal on the next following intersection Kruithuisplein. Figure 5-7 describes the route pattern of Kruithuisplein intersection (west part). Analyzing the network with three controlled signals (Kruithuisplein control of west part, ramp metering control on A13, downstream signal of Kruithuisplein), it can be divided into two sub networks with two intersections, as shown in Figure 5-8.

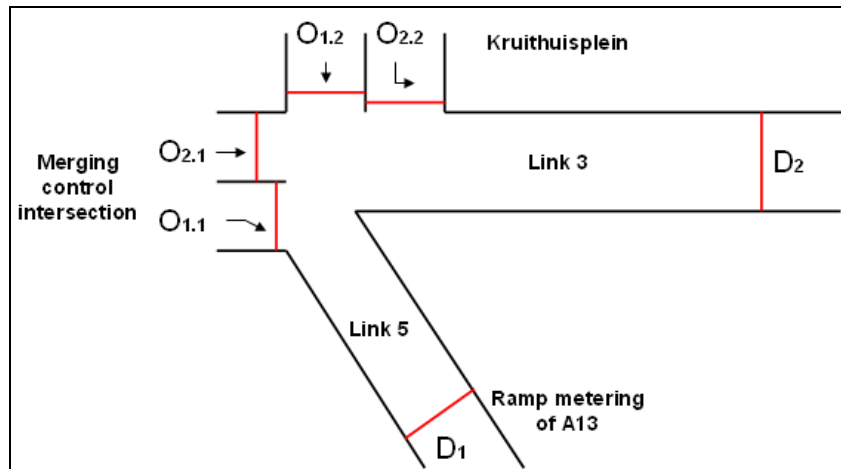


Figure 5-7 Route pattern of Kruithuisplein

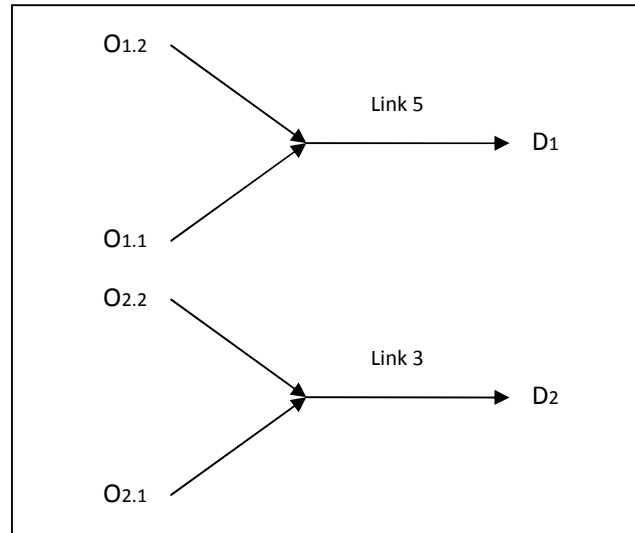


Figure 5-8 Two sub network layouts

The vehicle using link 5 are from $O_{1.1}$ and $O_{1.2}$ but they will all go to the ramp metering on the A13. In this case the two routes are already separately controlled by two signals. The route control measures such as separated signal or separated lane are not needed as there is no difference between link control and route control in this network.

The route pattern is similar in the network with link 3 and corresponding intersections. All the vehicles on link 3 starting from either north Kruithuisplein or Kruithuisweg will go through Kruithuisplein. Two signals separately control the vehicles on two routes and there is enough capacity for the going through vehicle in the network.

As explained above, we would like to keep the signal control of this intersection remaining the same as in the current situation.

Signal parameters resetting

Along with the adjustments of separated signal and separated lane, the signal parameters setting of this intersection will change. The design of actuated control in this case study is made by software VRIGEN (detailed in Appendix B)

The signal parameters setting in current control and RICS of merging intersection are shown in Figure 5-10. In current situation, Signal 8 controls the vehicle stream on Kruithuisweg and Signal 4 controls the on-ramp vehicles. The current control is with two phase, signal 8 and signal 4. The minimum cycle time is designed as 26 seconds (clearance time is four seconds and yellow time is two seconds). The signal setting variables in the current control are shown in Table 5-3.

In RICS, Signal 8.1, Signal 4.2 and Signal 4.1 separately control the vehicles of different routes (the details can be seen in Figure 5-10). With the adjustments of signal group and roadside layout, the corresponding new signal setting of RICS is shown in Table 5-4. It performs still as two-phase control (one for signal 8.1, the other for signal 4.2 and 4.1), but the minimum cycle time is 42 seconds.

Table 5-3 Signal settings in current control

Signal	8	4
Saturation flow (veh/h)	5400	3600
Traffic demand (veh/h)	1758	272
Minimum green(s)	8	6
Extending green(s)	82.9	14.9

Table 5-4 Signal settings in route control

Signal	8.1	4.2	4.1
Saturation flow (veh/h)	1800	1800	1800
Traffic demand (veh/h)	1048	211	71
Minimum green(s)	24	6	6
Extending green(s)	82.8	15.3	0.1

5.4.2 Layout design

Right-of-way lane design according to vehicle routes

In order to cooperate with the separated signal of the merging section, the Right-of-way lane is designed for every route stream. Figure 5-9 presents the new geometric layout and Table 5-5 summarizes the link adjustments in this case study.

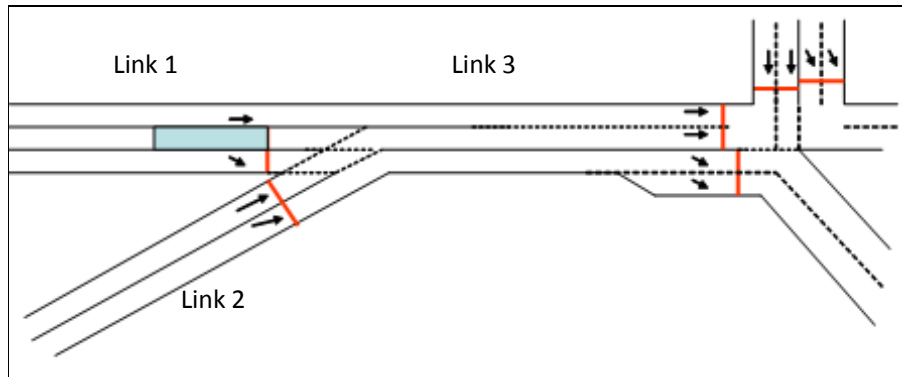


Figure 5-9 New geometric design

Link 1 is a three-lane link. In the layout of RICS, the left lane is for going through vehicles and the right one for right turning vehicles and the middle one can be blocked as it is hardly contributive to RICS.

Link 2 is separated according to different routes of on-ramp Schomkerstraat vehicles, which will be controlled by different signal heads.

Link3 connecting the two intersections also is a three-lane link. The over saturation from the ramp-metering is unavoidable due to capacity constraints and the lanes for right turning vehicles will only perform as queue storage. Therefore, it is not wise to allocate a big space for them. Only the right lane is reserved to the right-turning traffic. It is separated with the other two lanes by installing barriers. The barriers will start from merging control intersection to the Kruithuisplein roundabout so that the right-turning vehicles are totally prohibited to take the reserved lane for going through vehicles. The

left lane is reserved for the vehicles passing through Signal 8.1, and the middle lane can be made use of by the on-ramp vehicles from signal 4.2 (going-through roundabout), so that the movements of vehicles going through Kruithuisplein and from on-ramp Schoemakerstraat can be effectively facilitated.

Table 5-5 Summary of the link layout adjustments

Link	Adjustments
Link 1 (upstream link of merging point)	Block the middle lane and separate the two stream vehicles
Link 2 (on-ramp from Schomakerstraat)	Separate the south going and north going vehicle
Link 3 (section between merging point and roundabout)	Separate the right turning vehicles in one lane and going through vehicles in two lane

Barrier design

The middle lane of link 1 will be blocked by a barrier as it does not make big effects when the inflow to the downstream is constrained. The on-ramp section of Schomakerstraat is also needed to be separated by barriers, which should be long enough to prevent spilled back queue on the right lane interfering the movements on the left. From the simulation results, the maximum queue on the right turning lane is about 8 vehicles. Considering the length of normal vehicle and the gap length between them, 60 meter-long barrier is suitable in this case. It is recommended to apply concrete barrier as the big concern of safety. In spite of limited space in the existing roads, the concrete barrier is expected to have higher performance in reducing driver confusion of the layout and prevent severe accidents.

This roadside geometric design is aimed to well adhere to RICS, make good use of existing road geometry and minimize the cost of extra construction but without at expense of safety.

RICS adds more signals and separated lane regulation in the network, which means there are more risks of accidents in this area. Therefore, the proper design of the signal setting and roadside geometry is very important, which should be carefully studied in order to correspond to the existing network and meet road safety requirements.

The necessary extra investment will include installation of barrier, additional signal head, proper sign and marks. The roadside detectors already exist in the current network, so they do not need extra installments.

Figure 5-10 shows the detailed layout of merging intersection. With considering all above aspects of road design, this layout presented here is regarded to be proper and practicable in real world situation.

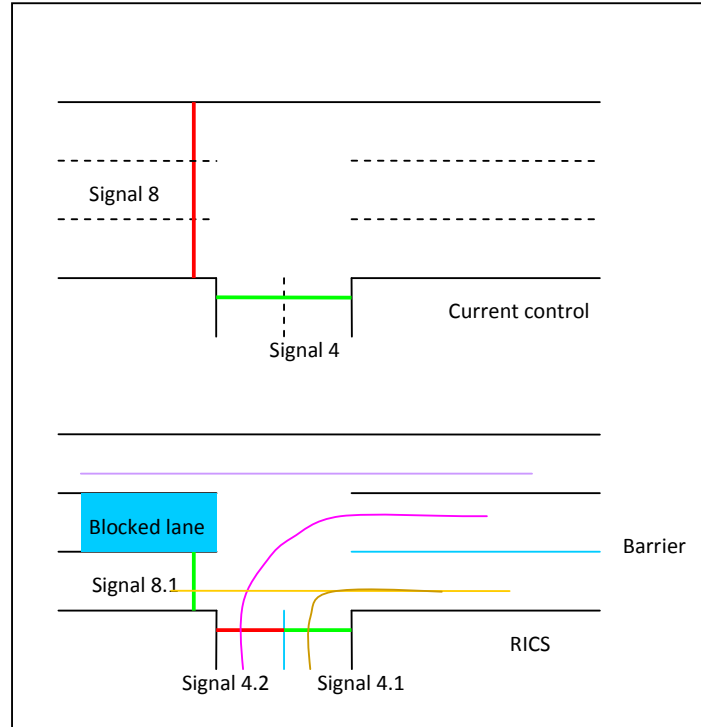


Figure 5-10 Merging intersection layout design

5.4.3 Other adjustments

Queue length control

In order to prevent the spilled back queue blocking the intersection, there is a queue detector located on the end of the right lane on link 3.

Queue detectors are used in special circumstances to detect stationary vehicles for queue detection and strategic purpose. In this case, when the queue already occupies this lane, then the control strategy will stop the green phase of signal 8.1 and signal 4.1 but the green for signal 4.2 can still be provided responding to the vehicle demand.

The detection zone of queue detectors must be long enough so that it can span the distance between standing vehicles. Concomitantly, it must be shorter than the shortest gap in moving traffic so that the break between motion vehicles will cause the delay timer to reset.

Figure 5-11 shows the location of queue detector. The length of the detector is 9 meters in the simulation.

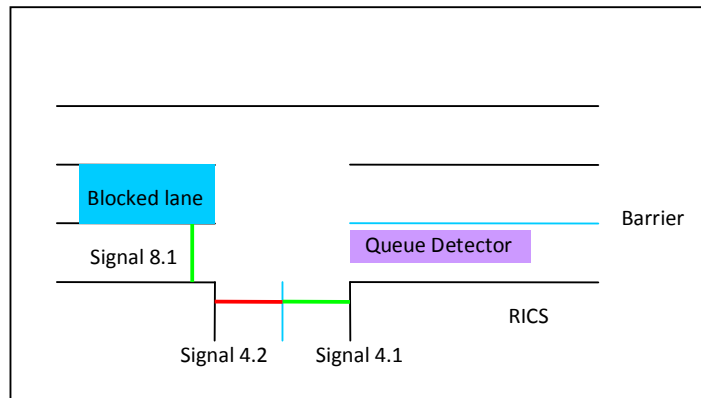


Figure 5-11 Queue detector location

New signal control intersection

In the current situation, the intersection Schoemakerstraat is in non-signalized control. The traffic demand of this junction is not big in the regular time but it grows a lot during the peak hours. When the congestion of the kruithuisweg occurs, the waiting vehicles will probably spill back from on-ramp to this intersection. The non-signalized control adds the risk of collision.

Considering safety and demand in peak hours, an actuated signal control is strongly recommended to replace the non-signalized control in Schoemakerstraat junction. The control parameter settings are designed based on the afternoon peak traffic demand. Figure 5-12 shows the layout of signalized Schoemakerstraat.

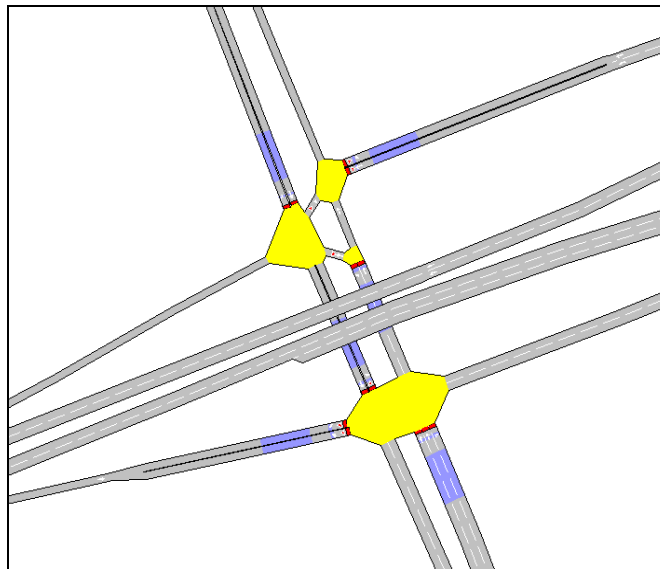


Figure 5-12 Schoemakerstraat intersection

5.4.4 Design summary

Summarizing the above contents, the proposed RICS includes the following adjustments:

- New actuated control signals at junction Schoemakerstraat;
- Split the signal group according to vehicle routes at merging control intersection;
- Right-of-way lane according to vehicle route in the section between merging control and Kruithuisplein roundabout;
- Queue detectors on the downstream of the merging control intersection to keep the merge intersection always clear.

RICS is expected to have following positive impacts:

- Increase the outflow capacity for go-through Kruithuisplein traffic;
- Smooth the go-through Kruithuisplein traffic which can pass main road Kruithuisweg with no signal control;
- Facilitate the go-through traffic from Shoemakerstraat on-ramp by separated signal control;
- Prevent the spilled back queue blocking the merging intersection;
- Prevent lane changing behavior so as to increase the safety between the closely neighboring intersections (merging intersection and Kruithuisplein).

5.5 Micro-simulation results evaluation

Here is the analysis from simulation results in AIMSUN. The traffic performance in the current control strategy is taken as the baseline for comparison with new route control strategy. The comparison of the results of the Delft case will lead to several conclusions. There will be a network performance evaluation and more detailed information of specific route travelers.

In order to get enough and reliable results for evaluation, the sample size should be decided before the simulation. The reliability of the sample results depends on the accepted deviation, the sample standard deviation and the sample size. The required reliability of the sample results should be determined before taking the sample. A 90% or 95% probability that the sample result does not differ more from the reality than the accepted deviation is common used.

The reliability depends on the sample size. Too few samples can not present a reliable result and too many samples will cause extra time and efforts in analysis and calculation.

In this case study, six replications were simulated first and taken as sample data. With calculating the sample standard deviation of average travel time, the sample size for reliable results is calculated as 34 replications (with probability 90% and accepted deviation 1s/veh in calculation).

5.5.1 Network performance

The network performance is shown by comparing total flow, average number of stops, average travel time and average delay. Table 5-6 summarizes the network performance of the current control strategy and RICS.

Table 5-6 Network performance

Network performance	Current situation	RICS
Total flow (veh/h)	14841	15003
Average number of stops	1.05	1.14
Average travel time	100	101
Average delay (seconds/km)	62	63

There is no obvious difference between the two strategies as the average travel time and delay are almost the same. The total flow is a little increasing by 1.2% in the route control strategy while there is also a slightly increase in the number of stop, which might be carried out by increasing signal phase design and forbiddance the movements when upstream queue is detected.

Explanation of the results

In order to simulate in a complete network, we still keep the traffic demand on freeway A13 (from centroid 1051 to 1049 and the opposite direction). The flow is 4000veh/h/direction, which is very big traffic demand compared with the flows on Kruithuisweg. Those vehicles performances will contribute a big part to the network performance, however they are not controlled by any signal and their performance will not differ with the control strategy changing. This makes it difficult to see the performance difference in the whole network range.

There are still some improvements in RICS shown in the density figure of the network. Figure 5-13 shows the traffic network condition in current control strategy and Figure 5-14 shows the traffic conditions in RICS. The color from green to red indicates the increasing density of the network (the red parts indicate the area with density more than 90veh/km and the green parts indicate the density less than 12veh/km). Under the current control strategy, the whole Kruithuisweg corridor from West to East is severely congested and it is also partly congested on the opposite direction.

Comparing the two figures, it is obvious that the red area is less in RICS, which indicates the congestion is a bit relieving. However, as the traffic demand of the network dose not change, the traffic pressure in the area is still at such a high level that the majority of Kruithuisweg from west to east is still in congestion.

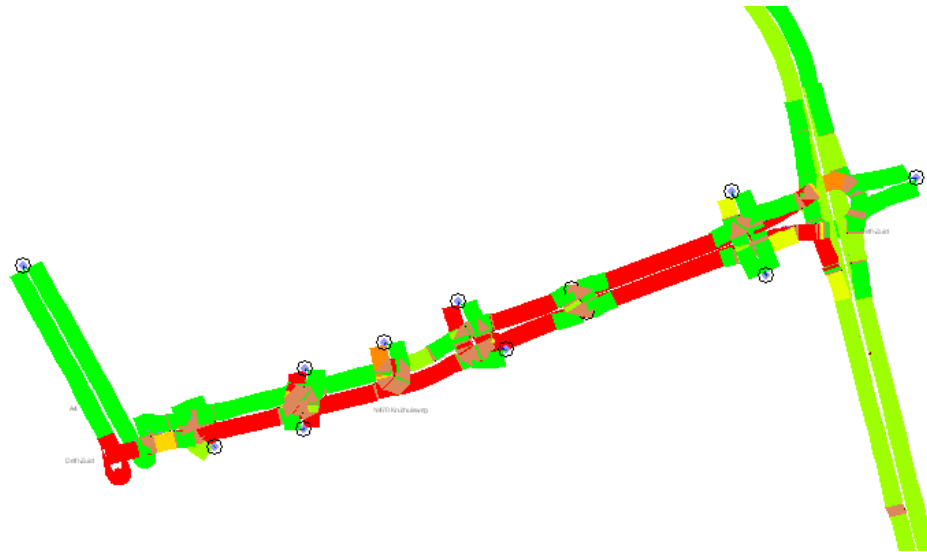


Figure 5-13 Current Congested area in afternoon peak hour

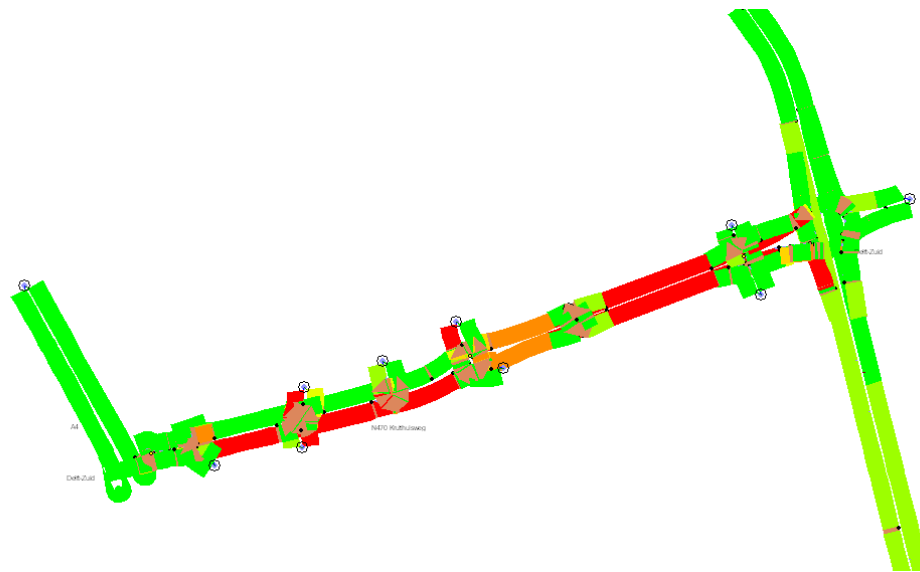


Figure 5-14 Congested area in route control strategy

5.5.2 Performances of selected road users

Besides of the network performances, the evaluation should focus on more specific part as the goal of RICS is to minimize the negative effects generated by spilled back queue and maximize the capacity of existing infrastructure. There are several other criterions of specific area chosen to evaluate the results.

Average travel time on selected routes

Travel time is one of the major criteria for assessing the mobility performance roads, for both freeways and arterials. It is also one of the most important forms of traveler information that is currently provided to the driving public by various means.

There are seven crucial routes selected to evaluate RICS in the case network (the routes with big traffic demands are chosen). The comparison differs by preferential routes and non-preferential routes. The routes going to destination Den Haag are the preferential groups in RICS, whose traffic performance will show if RICS can effectively reduce their delay time which is generated by the constraints of spill-back queues. The other three routes to Rotterdam are non-preferential groups of RICS whose performance indicate how RICS influence movements on the congested routes.

Table 5-7 Average travel time comparison

destination	Route\travel time(s)	current setting	RICS	change %
Rotterdam	1043-1049	739	579	-21,7
	1036-1049	1604	1619	+ 0,9
	1030-1049	1675	1658	-1,0
Den Haag	1043-1051	340	169	-50,3
	1038-1051	1034	849	-17,9
	1033-1051	1263	1170	-7,4
	1036-1051	1252	1195	-4,6

Table 5-7 lists the change on travel time of selected routes in current situation and RICS. The results indicate that RICS leads to a significant reduction in average travel time of almost all selected routes (only a slightly negative impact on one route from 1030 to 1049). The percentage of reduction in travel time varies from 1.0% to 50.3% and the greatest improvements are enjoyed by the vehicles from on-ramp Schoemakerstraat to Den Haag whose travel time reduces from 340 seconds to 169 seconds.

The traffic performance on the four routes to Den Haag shows that the reduction percentage in travel time is 50.3%, 17.9%, 7.4% and 4.6% respectively. Although the route control strategy is not targeted for the vehicles going to ramp metering bottleneck as the excessive inflow to this part is unavoidable, there is still an obvious performance improvement for these routes, which might benefit from fewer disturbances by lane changing behavior and queue length control.

The results indicate that RICS performs effective in limiting the negative effects of growing congestion in the network.

The throughout flow of stream going through Kruithuisplein- outflow counts on link 3

A lot of studies suggest that the objective function of signal plans should be maximizing capacity instead of minimizing delay or some closely related in oversaturated conditions. This criterion can be the measurement to judge if RICS increases the throughout of the targeted stream. The vehicles going through Kruithuisplein are the targeted vehicle group which is given priority in RICS.

Table 5-8 shows the average flow of going through traffic and Figure 5-15 further

illustrates its trend. It is clear that RICS is contributive to increasing the outflow of the bottleneck section, as the average flow of going through Kruithuisplein increases from 520veh/h to 538veh/h.

It is notable that the capacity for through going vehicles increases during free-flow and slightly congestion traffic condition (from 16:00 to 16:40). When the queue grows and gradually spills back to the upstream link of the merging control intersection, the outflow of going through vehicles are probably constrained again. There is no obvious advantage of RICS in the severe congested network as the outflow is similar to the current situation but overall the outflow capacity is still improving.

Table 5-8 Go-through roundabout vehicle flow comparison

Control strategy	current setting	RICS
Average go through flow (veh/h)	520	538

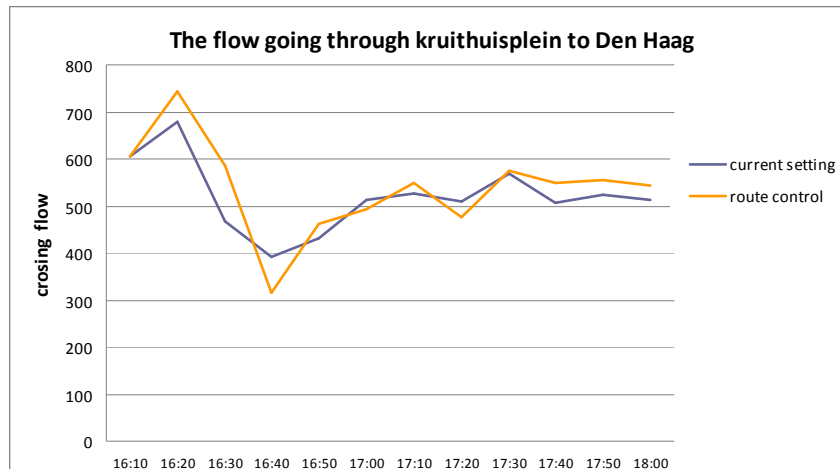


Figure 5-15 Going-through flow trend

Travel time trend of selected route

Understanding the travel time trends is also an important part in evaluation. The route demand from Tanthofdreef to A13 Den Haag is a very important vehicle group going through the targeted network. The demand of this route is about 219 veh/h (the biggest flow in the all routes going to Den Haag). The vehicles will turn right at Tanthofdreef intersection, and then go to Kruithuisweg where they might be disturbed by growing queues from ramp metering on the A13. The average travel time trend on this route indicates how RICS performs on the target group of vehicles with the simulation period. The time interval is chosen to be 10 minutes. (Detail data seen in Appendix C)

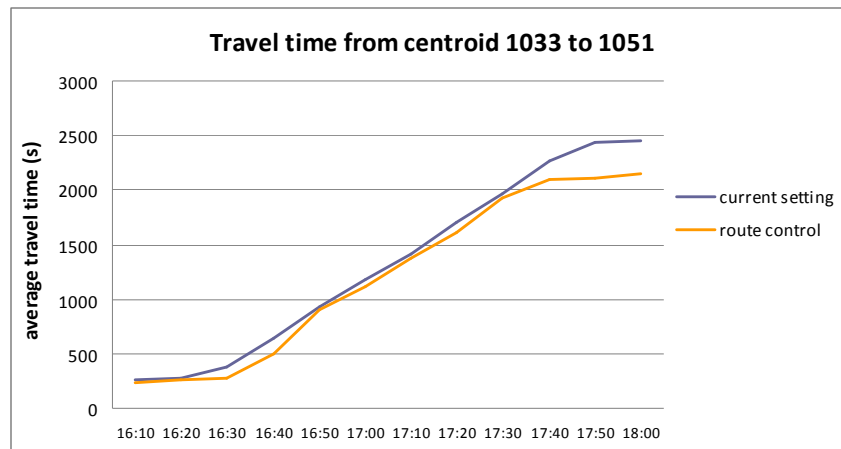


Figure 5-16 Travel time trend of selected routes

Figure 5-16 shows the growing trend of route travel time from Tanthofdreef to A13 Den Haag. The curve of travel time on this route shows a growing trend during the afternoon peak hours, which indicates the increasing congestion from the ramp metering will cause great delay on the vehicles of this route. Comparing the two lines shown in Figure 5-15, we can see RICS leads to an obvious improvement on this route as the average travel time lower than that in the current situation. During the whole simulation period, the advantage of RICS is more obvious during 17:40 to 18:00, when the network is severely congested. The results further prove the effectiveness of RICS in this network.

5.6 Additional tests of rerouting strategy

Reroute strategy is usually considered as an effective way to reduce the traffic pressure on the existing network. In the delft case, the alternative strategy could be rerouting all the going through vehicles of Kruithuisplein to the urban network and keeping the capacity of the links only for right turning vehicles. Under the constraints of available network of study, we simply deleted the going through vehicles from traffic demand and did the test simulation to see if rerouting will have some benefits for right turning vehicles. Right turning movements are still greatly limited by ramp metering on the A13 so the great positive effects are not expected.

Table 5-9 Reroute strategy performance

Destination	Route\ travel time(s)	current setting	RICS	change %	reroute	change %
Rotterdam	1043-1049	739	579	-21,7	720	-2,6
	1036-1049	1604	1619	+ 0,9	1554	-3,1
	1030-1049	1675	1658	-1,0	1615	-3.6

The simulation results shown in Table 5-9 indicates the rerouting strategy barely had further improvements on right turning vehicles by comparison of travel time on three main routes designating to Rotterdam. As the reroute strategy does not give special treatment for the vehicles from on-ramp, the travel time of this route only experience 2.6% decrease while the reduction of travel time is 21.7% in RICS. The other routes

respectively gain 3.1% and 3.6% reduction in travel time, which only show a slightly improvement compared with RICS.

The results indicated the performance of right turning stream had little potential to improve even providing more road capacity for them, while rerouting vehicles to urban network will often cause the congestion problem on the other roads. The reroute strategy is not so satisfactory in this case.

5.7 Conclusions from case study

The traffic conditions and roadside geometric layout in this case are providing an ideal environment for application of RICS in a simply and effective way. The performance of RICS can be clearly viewed from evaluation of the simulation. Here a number of conclusions from this case are drawn.

5.7.1 Results analysis

RICS is an innovative idea in dealing with traffic flow in special traffic situation, which is not expected to adapt all traffic conditions. The traffic condition and roadside geometry of this case study can well meet the requirement of its application, which is prerequisite to explore the potential effectiveness of the new concept. From the above analysis of the simulation results, RICS, which was proposed in this case study, presented a very positive improvement of traffic performance in the Delft network.

Congestion problem of the whole network still existed but almost all the vehicles passing the merging intersection reduced their travel time in RICS, especially the vehicles from the on ramp from Schoemakerstraat. It proved to provide relatively high-level efficiency in relieving the negative effects of over saturation, facilitating traffic flow on certain routes and promoting the vehicle movements of the on-ramp. The measures of RICS were quite effective, which included proper design of separated signal, separated lane and other traffic control measures. It also enabled the existing roads to handle more traffic without additional pressure on the outside of the network.

5.7.2 Limitations of the case study

The case study is an initial test for RICS. There are still a number of limitations in this case as a lot of impacts of RICS are not clear or not be well represented in this case study. Here list some limits and their explanation. They might be further studied in other application cases.

- Small network with RICS application
- Static OD matrices
- No offset optimization design
- Unclear impacts of other potential control measures
- No route choice diversion
- No enough robustness evaluation

Small network with RICS application

The crucial part of the network is defined including only two intersections and the link between them. As the main problem is generated from this short link, RICS mainly focus

on the local intersection design rather than network route design. In this case, one intersection is applied separated signals and redesigned signal settings; the other intersection still remains as the current setting.

Static OD matrices

As the limitation of the software, it is not possible to connect dynamic OD matrices with actuated signal control in AIMSUN. This case applies the passive RICS (explained in Chapter 4). The active and adaptive RICS are not enough studied.

No offset optimization design

Offset design is a very important part in RICS but it is not applied in this case as the downstream bottleneck existing and layout constraints. It can be potential in other cases as related junctions will have to make compromises in their configuration in order to achieve an optimal setting for the network. Nevertheless, the case gave some sort of indication as to how well the route control strategy has performed.

Unclear impacts of other potential control measures

There are various control measures of RICS but they are not all applied in this case study as its special circumstance such as the coordination between intersections. The control measures should always be selected to well adapt to the existing network, so that the measures which are not applied in this case can be selected in other suitable network.

No route choice diversion

There is no big urban network included in this case, where only one route exists between one origin and destination. Therefore, it can not present the impacts of RICS on driver route choice reactions. When faced with a long queue at an on-ramp, some drivers divert to another on-ramp while some others avoid the freeway entirely. As mentioned before, reroute might be a good solution to relieve the traffic flow pressure in the bottleneck, but it is not applied in this case study.

No enough robustness evaluation

The robustness has not received sufficient attention in this case study as the simulation only based on the flow in the afternoon peak. RICS might not be effective in various demand scenarios, which was not investigated enough in this case.

6. Evaluation of route information control strategy (RICS)

6.1 Introduction

In Chapter 2, the objectives of the new control strategy are defined as:

“A new control strategy should be developed to aim at more flexibility in traffic signal setting design, more adaptability to different traffic situation and simplicity in application in real life. Special attention should be put on bi-level network including highway and urban street intersections especially in oversaturated situations.”

The following chapter will present a comprehensive analysis of the proposed route control strategy to judge if it meets the pre-setting objectives. It is based on the above theoretical study (Chapter 2, Chapter 3 and Chapter 4) and experiment results (Chapter 5). This results in an analysis covering the strengths, weaknesses, opportunities and threats of RICS (SWOT analysis).

6.2 Strengths of RICS

Increasing flexibility and adaptability in the signal setting

The main improvement comes with the RICS is that it provides more different alternatives in signal settings. The input information to the signal control in RICS is more than that in link control concept. The traffic signal can be split according to different routes and correspondingly there are more available alternatives of signal structure. The flexibility in signal setting and adaptability to actual real-life environment is increasing. Therefore, RICS provides more opportunity to find the optimal control strategy for a specific network considering its own route pattern.

Good coordination between the neighboring intersections

Second, good coordination between the neighboring intersections can be realized with route control design. It is potential to trace a certain route of vehicles and provide green-wave coordination along its movement. When the route is crucial in the network, it is potential to improve traffic performance not only on this route but also has positive side effects on vehicles of other route in the network, especially in oversaturated and special events situations.

Easy algorithm

RICS does not introduce the complexity in algorithm calculation. It can well adapt to the existing traffic control system like SCOOT, Utopia. It is also feasible in wide network application as the technological and informatics support for it is available.

6.3 Weaknesses of RICS

Many prerequisites of traffic condition

As mentioned above, there are a lot of requirements of traffic condition in selecting the

network RICS. Otherwise, it is difficult to get a desired improvement. Every network has its specific problems and requires specific treatment which can not be simply fulfilled by a uniform regulation. The pre-study of projects should be comprehensive and realistic, which needs a lot of real-time data to support. While the real-life traffic differs from time to time as a lot of uncertainty exists, it is a very complicated and time consuming process to make preparation for RICS.

Increasing the complexity in control strategy design

The introduction of RICS greatly increases the complexity of the signal control design. The road users will not only be separated by their movements on this intersection but also further be separated by their routes in the network. More signal groups should be defined, which will increase the difficulty of the control strategy design.

Difficulty in selecting the optimal control strategy among a great number of alternatives

As mentioned above, there will be a huge number of alternative control structures in RICS. Then it is very complicated to compare and evaluate their effects and to choose the most suitable control strategy for the existing network. A lot of impacts should be included in evaluation, such as network delay, travel time, speed, queue length, construction cost, safety and environmental issues. Its impacts really vary from case to case so they should be carefully studied before application in real-life.

Difficulty in application in wide area network

The study starts RICS with the simplest network with only two origins and two destinations, and then there is a key question remaining on how the approach handles a larger number of junctions. Although RICS could be applied in wide network with advanced system as mentioned in section 4.4, the amount of data considering and various possibilities in the design of phase sequences design will be explosive and the uncertainty is growing with the extension of the network. It will further increase the difficulty in network selection. It might be too time-consuming or too complex to apply RICS in a wide area network

6.4 Opportunities of RICS

Improving the traffic performances of target routes

Expected benefits of RICS include reducing the travel time of target route, balancing the network demand, leading an increasing quality of control service, improving safety of movements and increasing network efficiency. From the case study results presented in Chapter 5, the traffic improvements on the target route are very apparent, which showed that RICS performed effectively in the practice.

Potential in providing special treatment for certain route

With the increasing flexibility and adaptability in the signal setting, it is potential in providing special treatment for certain route. It is promising in some special situation as mentioned, such as where there are unbalanced vehicle flows on different routes, severe queue problem existing or unexpected extra demand on a certain route.

6.5 Threats of RICS

Limitation by roadway geometry

Traffic control strategy design need to be supported by roadway geometry. Roadway

geometry is impacted by the type and level of surrounding land development. Surrounding development, among other factors, impacts the location and number of intersections, generates traffic in the area and dictates transit stop locations.

AS roadway geometry directly dictates to transportation system capacity and types of possible operations, it is usually a limiting factor in new control strategy implementation and is one of the most important factors for the operation of any transportation system.

It is necessary to make adjustment on the roadway geometry to cooperate RICS. Design elements of road geometry include lane layout and other installment such as median, signs and marks, other traffic lights and new detectors.

Uncertain effects for the other parts of the network

The initial design of RICS is only introduced in a rather small network, in which the goal is to relieve the negative impacts of the congestion and facilitate the traffic movement of a certain route. The impacts of RICS are wide spread so that there is great uncertainty on how it can influence the other part of network other than the small bottleneck network.

In the short term, RICS probably has influence on the traffic performance of adjacent minor road. It can cause primarily of delays to side street traffic, but these delays could be reduced if the control strategy is properly designed, which is proven by the delft case study in chapter 5.

In the long term, it might change route choices of travelers in that more travelers can be attracted by the improved traffic conditions. It is very difficult to estimate the impacts of RICS on the other routes which are outside the small adjusted network in short period or in long period. In order to handle this problem, a proper and comprehensive evaluation including the performance on non-adjusted part of network is very important to balance the traffic demand of whole network. Besides, a micro-simulation tool now also provides nice environment to explore further effects of RICS.

Extra roadside equipment cost

Additional roadside construction cost is always a big concern of road authority. The extra installments on the roadside such as barriers, marks and signals are necessary for RICS application. It needs the extra initial investment and long-term maintenance costs.

6.6 Summary

The evaluation analysis presented in this chapter was performed by using literature study, theory of methodology and case study. It gave overview judgments of RICS, which was helpful for us to look on the further development of it. Table 6-1 summarizes SWOTs analysis of RICS.

Table 6-1 SWOT analysis of RICS

• Increasing flexibility and adaptability in the signal setting • Good coordination between the neighboring intersections	• Many prerequisites of traffic condition • Increasing the complexity in control strategy design • Difficulty in selecting the optimal control strategy among a great number of alternatives • Difficulty in application in wide area network
• Improving the traffic performances of target routes • Potential in providing special treatment for certain route	• Limitation by roadway geometry • Uncertain effects for the other parts of the network • Extra roadside equipment cost

7. Conclusions and recommendations

7.1 Introduction

In this Chapter the conclusions and recommendations of the study will be presented.

In section 7.2 of this final chapter will present a summary of answers to the research questions stated in Chapter 1. Using this summary of answers, the final conclusion of the report will be drawn in Section 7.3 by answering the core research question of the report.

What effects can route information bring to traffic control strategy to allocate the existing infrastructure on the supply side?

And how to design a proper control strategy to compromise the needs of travelers and networks, vehicles and infrastructure, short term and long term?

Based on the conclusions of section 7.3, recommendations will be made in section 7.4.

7.2 Main research findings

In this section the findings of this research are summarized by answering each of the research questions:

What effects can be expected by route information?

Route information is potential applied in order to perform the following functions:

- Control the length of queue in queue management;
- Smooth the movement of special type vehicles by separated lane;
- Smooth the movements of public transport or trucks by priority signal treatment;
- Provide different signal treatment for different route;
- Integrate signal control with route choice.

These functions represent the opportunities of RICS:

- Potential in providing special treatment for certain route;
- Potential in improving the traffic performances of target routes.

How route information can have impacts on traffic control strategy?

Generally, route information can be made used in signal parameters adjustments, roadside layout adjustment and other control measures design.

The impacts on signal setting consist of:

- Separating signal group according to route diversion;
- Increasing alternatives in phase scheme design to prevent the disturbance from

congestion;

- Good coordination of signal control to trace the movements along a route.

The layout adjustment mainly is realized by right-of-way lane to decrease the change lane effects and route information also can be used in lane control and rerouting control measures.

When to apply and how to apply the traffic control strategy using route information (RICS)?

Regarding the variety of impacts of route information on traffic control, RICS is competitive in handling traffic in the following situations:

- When there is congestion on one route and it blocks the movements of other routes;
- When there are great distinguish existing in the route demand, high demand route can be treated separately from the low demand route.

The congestion and unbalanced traffic demands will probably occur due to extra demand in peak hours or non-recurrent incidents. The disturbing effects from congestion are more obvious in the closely-spaced intersections due to the limited space for queue storage.

RICS can be pre-designed with historical route demands and traffic conditions (passive control) or it can be implemented actively or adaptively with dynamic OD matrix and real-time detected traffic condition. The whole advanced system consists of vehicle detection request system, traffic condition checking system, communication system, traffic signal control system and traffic management system.

How does RICS perform?

The performance of RICS should to be evaluated to for diverse stakeholders. A socio-economic analysis can take consideration of the concerns of road authorities (like traffic safety, environment and investment cost) and the utility of travelers (like travel time, delay, and queue length). The traffic network performance is not enough in RICS evaluation as this control strategy does not treat all road users equally. There are preferential route users who are given the priority control in RICS and the others are non preferential groups. They should be evaluated separately to see if the possible negative impacts of non preferential groups can be offset by the positive effects of preferential groups.

The delft case showed a quite promising result that RICS worked effectively in preventing negative impacts of congestion for preferential road users and only bringing minor effects on non-preferential groups.

7.3 Conclusions

With the summary of the answers of research questions in section 7.2, an overall conclusion of this study will be drawn.

The objective of the study is defined in Chapter 1 as:

“Find and investigate how route information influences traffic control strategy by studying

its design, application, and implementation in a theoretical system, while explore the impacts and evaluate the results by practical real-case experiment.”

The literature review and theoretical analysis showed route information (route flows) can be made use of in traffic control strategy. There are various innovations coming with additional route information in traffic control design. The signal setting is not directly designed by the approach volumes while the route demands become the main input of the signal control variables design. RICS will increase the flexibility and variety of signal designs so that it can well correspond to the vehicle demand in real situations. The roadside layout and other control measures can also be incorporated. RICS is expected to reduce the negative impacts of bottlenecks or congestions on other routes of vehicles in the network. It is promising to deal with unbalance route network especially during the peak hours. It can also be applied in incident management to evacuate large traffic flow on one route.

The results from the case study proved the feasibility and effectiveness of RICS. RICS was quite helpful to facilitate the movements of targeted routes with minimizing delay caused by spilled back queues. However, it might cause the additional delay on non-preferential routes in the network. The simulation results also showed these negative impacts can be minimized by proper design of roadside layout.

This study also pointed out that there were various expected problems in RICS. For example, there are a huge increasing in the number of alternatives of RICS design along with increased flexibility, which also could be a drawback of its application due to increased complexity and uncertainty. The roadside geometric design is an important part of RICS, which might need long-time construction for adjustments. RICS should be designed under the constraints of the road layout. Finally, the evaluation is also a difficult task as there are a lot of uncertainties with respect to the performances of RICS remaining in various traffic demands and roadside geometry layout. The performance evaluation should consider the diversification of stakeholders and diversification of road users to provide a comprehensive view of its impacts.

7.4 Recommendations

In the following section, some suggestions are made for further research and development based on the limitation of this study.

Application in a wide network

In this study, the theory of how to apply RICS in wide network is reviewed but the case study is only limited in a small network application. It will be challenging for other research to explore RICS application of large network in practical way, such as tracing one special route along several intersections. It might be a little time-consuming as the complexity in roadside layout design. The computing time for selecting the optimal signal setting will also increase in active or adaptive RICS system.

Active or adaptive RICS

The RICS of delft case is pre-designed by static OD matrix and observed traffic condition instead of real-time detection. In this situation, RICS can easily adapt to existing traffic control systems like SCOOT and Utopia as the adjusted signal group and layout change can directly be regarded as new inputs. RICS can be better taken advantage when connecting

to an advanced information system, which can provide dynamic route flow and design the RICS according the real-time traffic condition. The further research can study the application of active and adaptive RICS using dynamic OD matrices and triggered by detected traffic condition.

Interaction between route choice and traffic control strategy

This report only studies the impacts of route demand of traffic control strategy on supply side of the network. RICS does not include the impacts on the traffic demand side though the change of traffic control strategy will further influence the route choice of travelers both in short term or in long term. As the interrelationship between route choice and traffic control strategy can integrate the supply and demand of traffic, the route choice could be further added as a part of route information.

Simulation environment

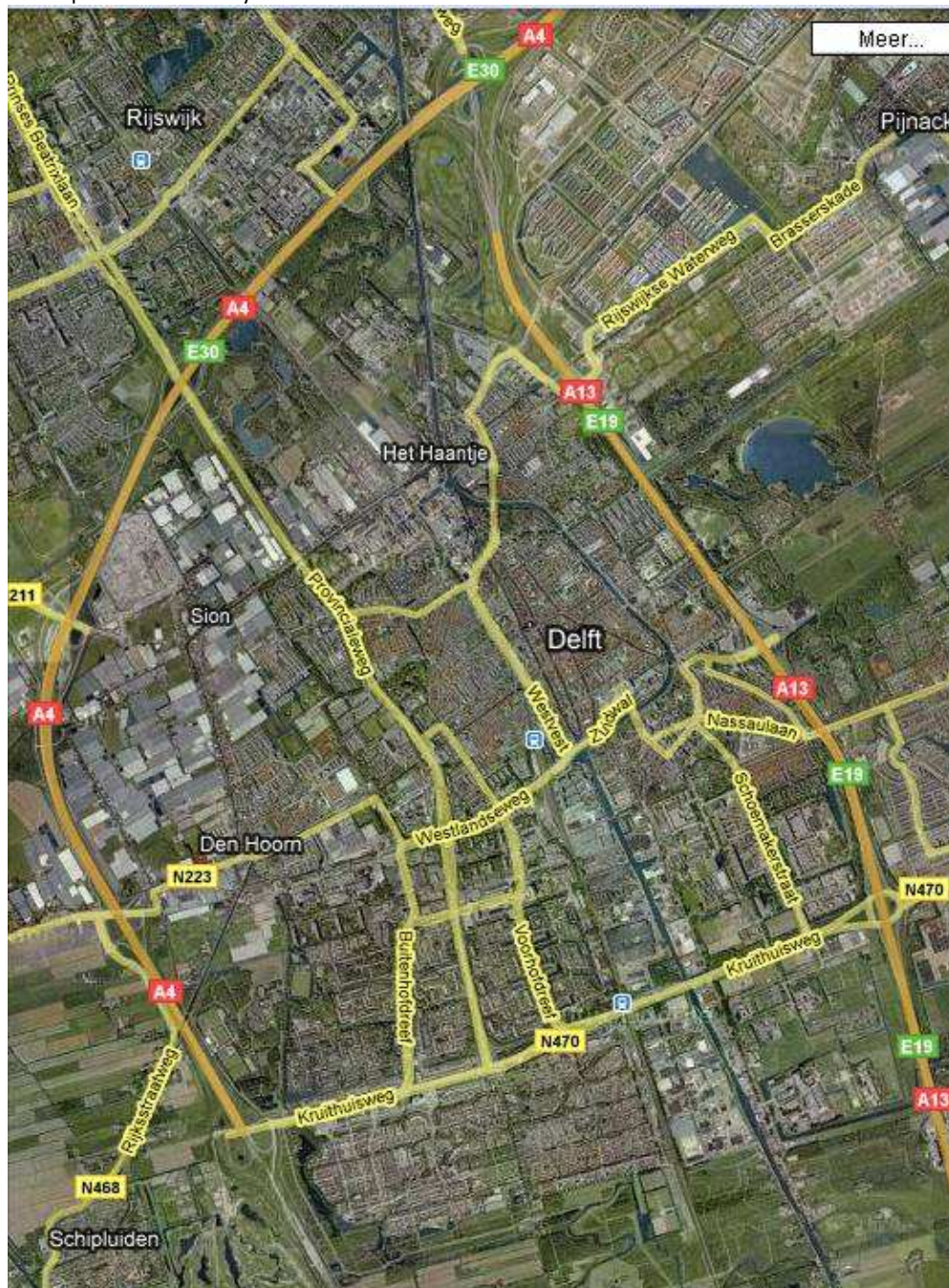
This study is simulated in AIMSUN with external signal controller. It is possible to get dynamic OD matrices in macro-simulation tools like DYNASTMART but it can not be the input of traffic control design and self-optimization traffic control system like UTOPIA can change the signal setting according to the real-time traffic demand. If there are two interfaces (one between DYNASTMART and AIMSUN, the other between AIMSUN and UTOPIA), then dynamic route demand control can be realized. There is already an interface between UTOPIA and AIMSUN developed by PEEK TRAFFIC. Further researches can study the performance of integrating macro-simulation, micro-simulation and traffic controller.

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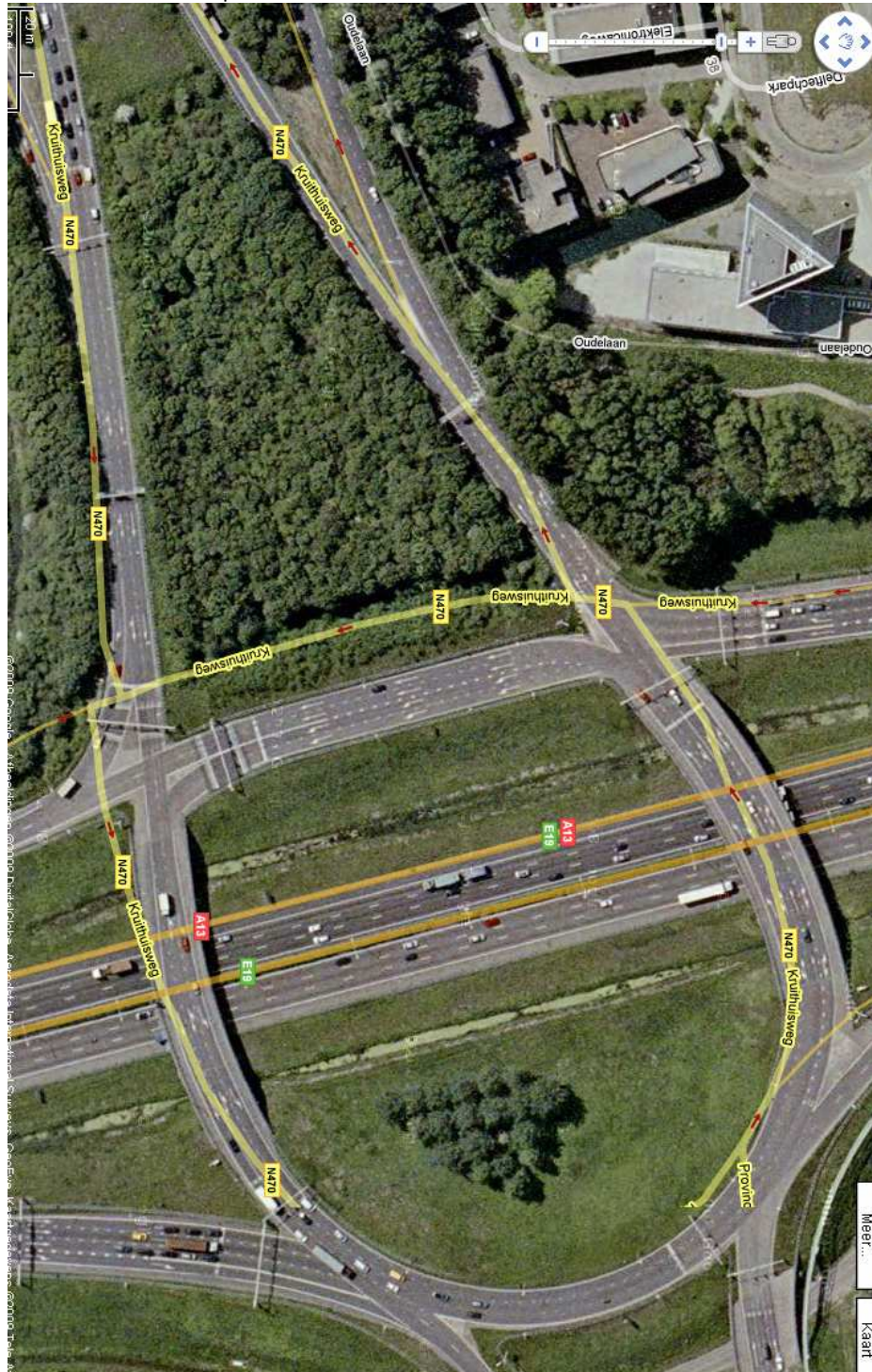
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Appendix A. Case study site

A1 Map location of study area

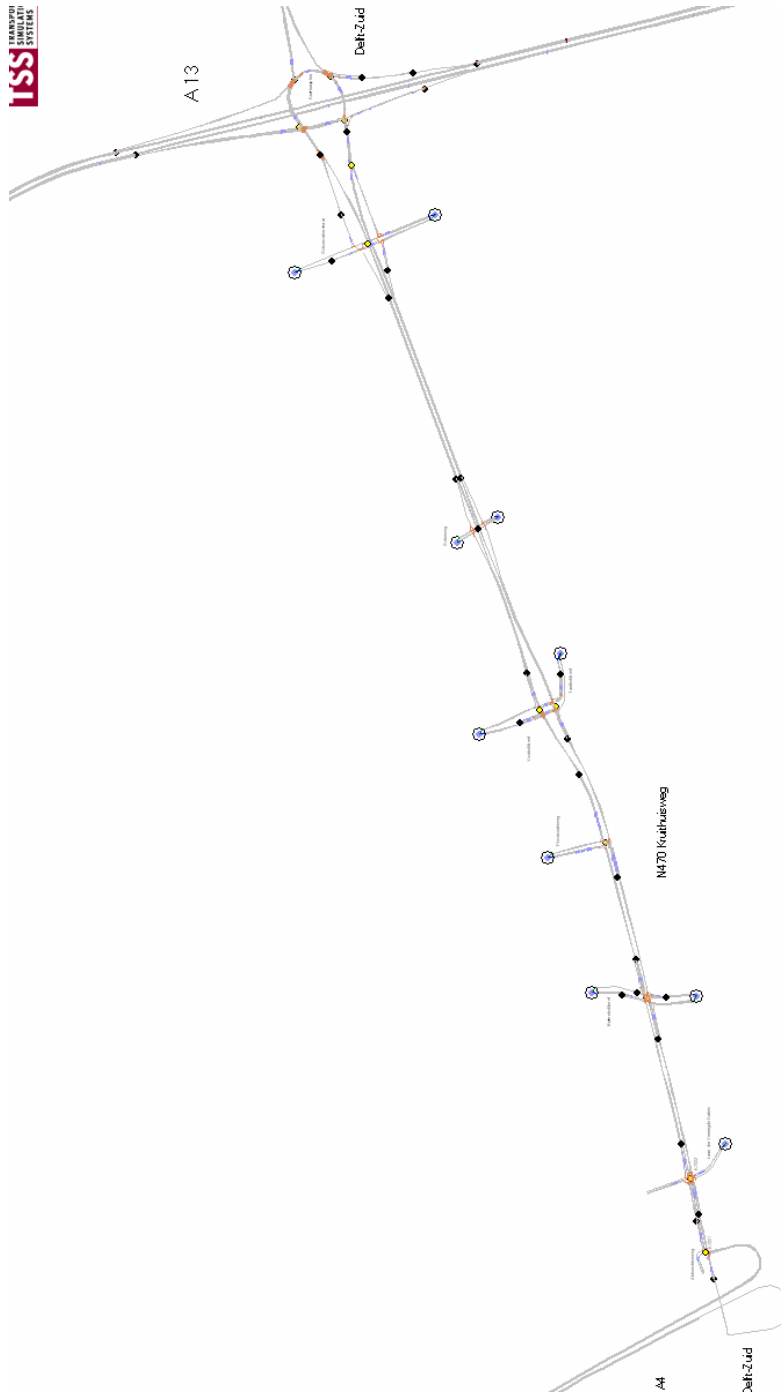


A2 Picture of Kruithuisplein roundabout



Appendix B. Case study in AIMSUN

B1. AIMSUN network



B2. Control design programme VRIGEN

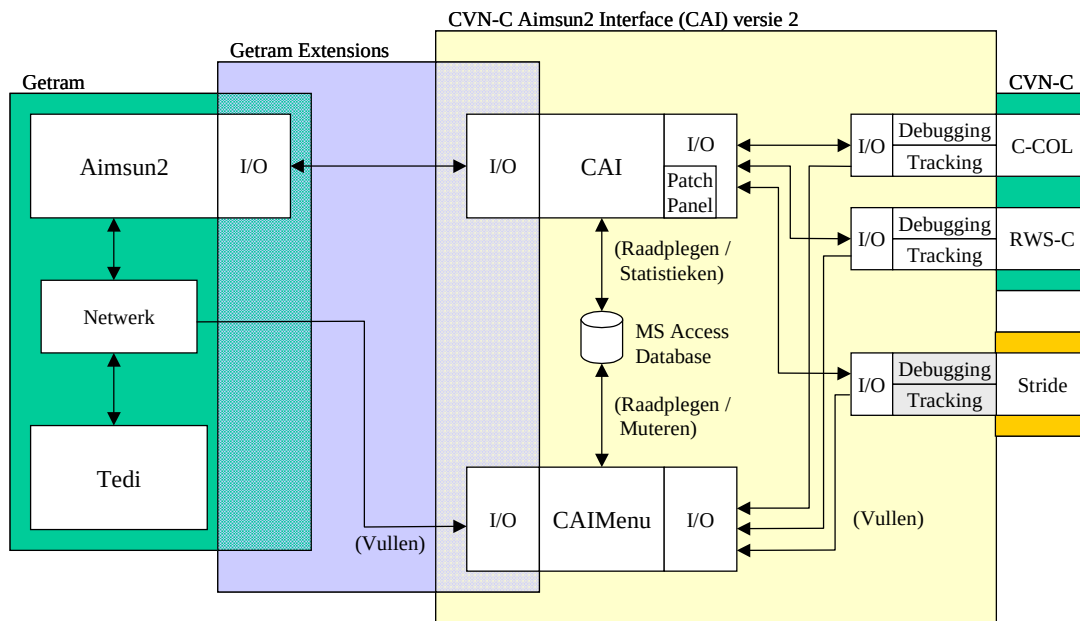
VRIGEN offers the possibility of designing an intersection with traffic controls, for which the programme gives an optimized structure and associated green times. The programme generates all possible structures and gives the minimum cycle time and maximum flexibility. After the choice of the structure it is possible to modify the tactics

VRIGEN contains a method that supports the designer in choosing an appropriate control structure. Application of this method helps designers to gain insight in the design process of traffic control. The method has also proved beneficial in traffic control design.

For education and research purposes the design aid program VRIGEN includes a program generator. It can generate a file with the traffic control program, which can be connected with controller simulator CCOL, which can operational connect to AIMSUN as external traffic signal controllers.

B3. CAI-AIMSUN Interface

Diagram of CAI-AIMSUN interface



CAI setting window in AIMSUN

CVN-C Aimsun Interface 2.0 (NG Versie)

Koppelsignalen	Overige ingangssignalen	Overige uitgangssignalen	Vecom signalen	Statistieken
Algemeen	C-Regelaars	Regelingen koppelen	Detectoren koppelen	Signaalgroepen koppelen

CRegelaar	Omschrijving
K31	Kruithuisweg-Voor...
K43	Kruithuisweg-Buite...
K7001	A4 en N470 Delft...
K7002	N407 CNIS Nr 2
K7003	Kruithuisweg/Provi...
K7005	Kruithuisplein A13 ...
K777	Schoenmakerstraat
K799	nieuw kruispunt
TD01	TDI01 A13 westba...

CRegelaar kenmerken

ID

GUID

Type

Registratie naam

Omschrijving

Brondirectory

SYS-bestand Bestand...

REG-bestand Bestand...

Record(s)

Ready NUM

Appendix C. Simulation results in Delft case

C1. Table travel time trend from centroid 1033 to 1051

Travel time trend from centroid 1033 to 1051 (s)		
Time	current setting	route control
16:10	256	242
16:20	278	258
16:30	377	281
16:40	646	499
16:50	936	902
17:00	1173	1113
17:10	1412	1373
17:20	1703	1605
17:30	1971	1924
17:40	2265	2092
17:50	2433	2108
18:00	2445	2142
average	1263	1170

C2 Table outflow traffic of going-through Kruithuisplein

Outflow of going-through Kruithuisplein (veh/h)		
Time	current setting	route control
16:10	605	605
16:20	679	744
16:30	469	586
16:40	391	316
16:50	432	463
17:00	512	494
17:10	527	548
17:20	510	476
17:30	568	574
17:40	508	549
17:50	525	555
18:00	512	543
average	520	538

C3. Graph of route travel time comparison on selected routes

Route travel time comparison on selected routes (s)

