Smartest

Simulation Modelling Applied to Road Transport European Scheme Tests
http://www.its.leeds.ac.uk/smartest

APPENDIX A

DETAILED MODEL UPDATE SPECIFICATIONS

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1. PUBLIC TRANSPORT SERVICES

1.1 Introduction

Public transport services do not behave in quite the same way as other traffic; therefore their behaviour needs to be modelled differently.

Public Transport Vehicles

Four types of public transport vehicle will be considered here, namely:

- Buses
- Guided buses
- Trolley buses
- Trams or Light Rapid Transit (LRT)

Bus. Buses provide the most common form of public transport in urban areas. They come in many different sizes and shapes. Typical parameters for some types of bus are given below.

Single deck bus

Double deck bus

Minibus

Articulated bus

	Length (m)	*Width (m)*	*Capacity (People)*	*Acceleration rate (m/s/s)*	*Deceleration rate (m/s/s)*
Articulated	18.5	3.0	120		
Double deck	10.0	4.2	80		
Single deck	8.5	3.4	55	1.0	1.2
Minibus	7.0	2.4	25		

Figure 1: Typical parameters for four different types of buses (Source: US DOT, 1992)

Taxi operations are outside the scope of this specification.

Public transport can move large numbers of people while occupying relatively little road-space, thus offering a highly efficient use of resources.

Guided bus. A recent development to protect buses from the effects of congestion has been to segregate them on sections of carriageway along which they can be guided. Such guided busways provide more effective and reliable priority than ordinary bus lanes. The main advantages that a guided busway has over a bus lane are:

- priority benefits to the buses are not diminished by violations by other vehicles as the physical design of the guideway ensures that only wide bodied vehicles, such as buses, equipped with a guidewheel can use the guideway,
- the guideways have a narrower width than bus lanes, which is useful as road space is always at a premium,
- buses can travel faster down the guideway as their drivers can be confident that no other vehicles will cut in front of them.
- Guided busways are generally less expensive to implement than LRT schemes. Some proponents of guided bus have argued that LRT is marked by higher capital costs than guided bus by up to 400%. The flexibility offered by guided bus is a further attraction. An LRT scheme requires a continuous length of track for the trams to follow. This is not a necessary requirement for a guided bus scheme as buses can use the normal roadway in places where there is no guideway. This has advantages both in terms of phasing construction and targeting locations where guidance would provide a distinct advantage and leaving those areas where guidance is not required, not feasible or difficult to implement. Buses can have a guidewheel added during construction at little additional cost, and existing vehicles within a fleet can have a guidewheel fitted at a cost of about 4000 ECU.

Figure 2: A guided busway in Leeds

Trolley bus. A trolley bus is an electric, manually steered, rubber-tyred bus, propelled by a motor drawing current through overhead wires from a central power source not on board the vehicle. Trolley buses also usually have an alternative means of propulsion for off-wire operation. As they produce no air pollution and little noise pollution, they can be seen as being to an environmentally friendly solution for urban mass transit.

Figure 3: A trolley bus

Figure 4: A tram in Brussels

Trams or LRT. Trams or LRT are perceived by the public as being a modern, high quality, and environmentally acceptable mode of transport. They require a fixed track, which can reduce network-wide accessibility. Trams / LRT can face the same on-street operating problems as buses. To overcome these problems tram / LRT systems are often implemented with a high degree of segregation from other road traffic and use of various priority measures. Trams typically come in either single or double/articulated units. Some typical basic parameters are given below.

	Length (m)	*Width (m)*	*Capacity (People)*	*Acceleration rate (m/s/s)*	*Deceleration rate (m/s/s)*
Single unit	15.0	2.6	110	1.5	1.6
Articulated	22.0	2.7	200	1.3	1.6

(Source: US DOT, 1992)

Public transport lanes

A bus lane is an area of carriageway reserved for the use of buses, and occasionally other permitted

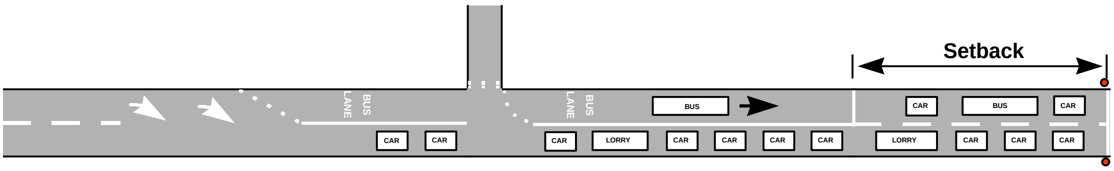


Figure 5: Bus lane layout (driving on the left in a two lane one way street)

vehicles, for all or part of the day. They allow buses to bypass traffic queues, usually on approaches to signalised junctions or roundabouts. The location of the start and finish of bus lanes within a link are crucial.

The lane should start upstream of the end of the predicted traffic queue and a safe distance should be provided to allow non-priority vehicles to merge. Most bus lanes are terminated, i.e. setback, from the stopline of the junction they approach. The setback ensures that the full width of the stopline is available for all vehicles and thus the capacity of the junction is maintained. The length of the setback should be such that buses entering from the bus lane can clear the traffic signal stopline on the first available green. This distance, in metres, can be approximated by twice the green time, in seconds.

Times of operation. The times of operation of bus lanes can be specified. Bus lanes can operate all day or on weekdays only or they may only operate during certain time periods, usually at times when there is most traffic congestion. However, it is usually the case that the times of operation of the bus lanes within an urban area are standardised to avoid confusion to road users.

Pre-signals. A bus-advance area is sometimes used to allow buses to advance into an area of road, clear of other traffic, before a signal controlled junction (Figure 6). Pre-signals, in advance of the junction, always control traffic entry to the advance area, with a bus lane provided up to the pre-signal. The objective of the pre-signal and the advance area is to re-order vehicles, so that the buses may be given priority to reach the junction first. At the pre-signals, general traffic is controlled by one set of signals, while the bus lane is controlled by another set. General traffic can thus be held back while the bus is allowed to enter the bus advance area. Some implementations of bus advance areas include a bus detection system to allow the general traffic to be held back only when a bus approaches the pre-signal in the bus lane.

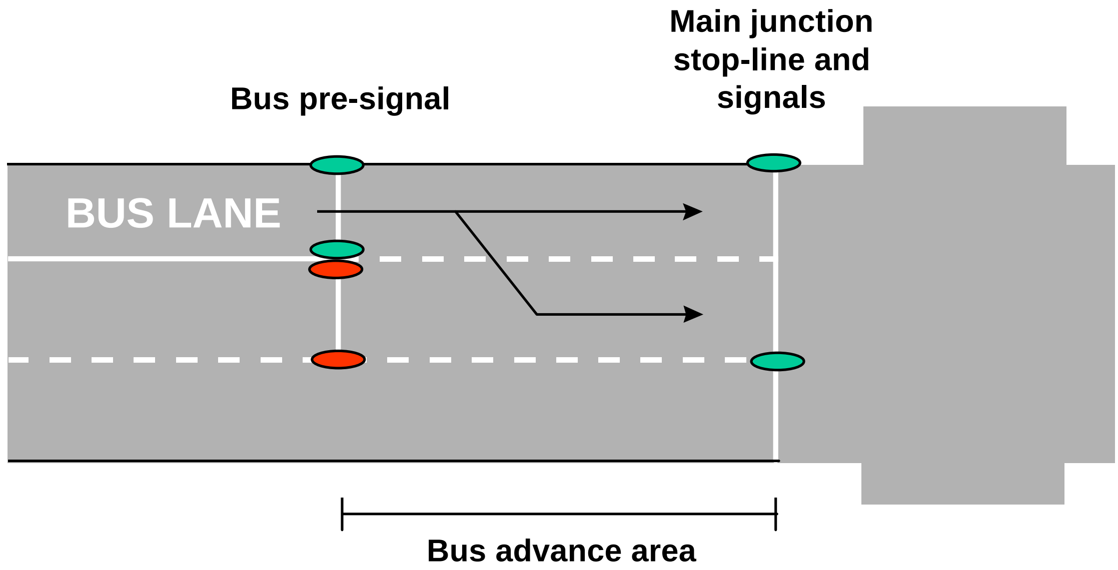


Figure 6: Bus advance area (UK driving conditions)

Use by other vehicles. Pedal cyclists are usually permitted to use bus lanes. Taxis are also sometimes permitted to use bus lanes, provided they do not set-down or pick-up passengers whilst in the bus lane. Very rarely motor cycles are also permitted to use bus lanes.

Public transport routes and schedules

A major difference between public transport vehicles and other road traffic is that they follow fixed routes. They also usually try to adhere to a pre-defined timetable.

Routes. Public transport routes are a fixed series of links from an origin to a destination. All public transport vehicles which follow a particular route are usually identified by a route number and a destination. The destination serves a dual purpose. It identifies the direction that the vehicle is travelling along the route. It is also possible that some vehicles will not travel all the way to the route’s end, but will terminate at an earlier stop, so the destination identifies where the vehicle will terminate.

Timetables. The passage of public transport vehicles along a route is usually governed by a timetable. The bus starts at its origin at a given time and is expected to arrive at stops along the route at predicted times. This allows passengers along the route to know when they should arrive at the stop in order to catch the vehicle they require, e.g. a 93 bus going to Leeds will arrive at 10:32. If the frequency of vehicles is high then sometimes a timetable is not used. Instead a typical wait time for vehicles on each route is given at the stop, e.g. a 93 bus going to Leeds arrives every ten minutes.

Public Transport Stops

Public Transport stops are common within road networks and can significantly influence the behaviour of traffic in their vicinity. A critical element in the efficiency of public transport operations is also the behaviour of passengers boarding and alighting at stops. It is therefore essential that micro-simulation models should be able to model the various types of public transport stop found in road networks throughout Europe.

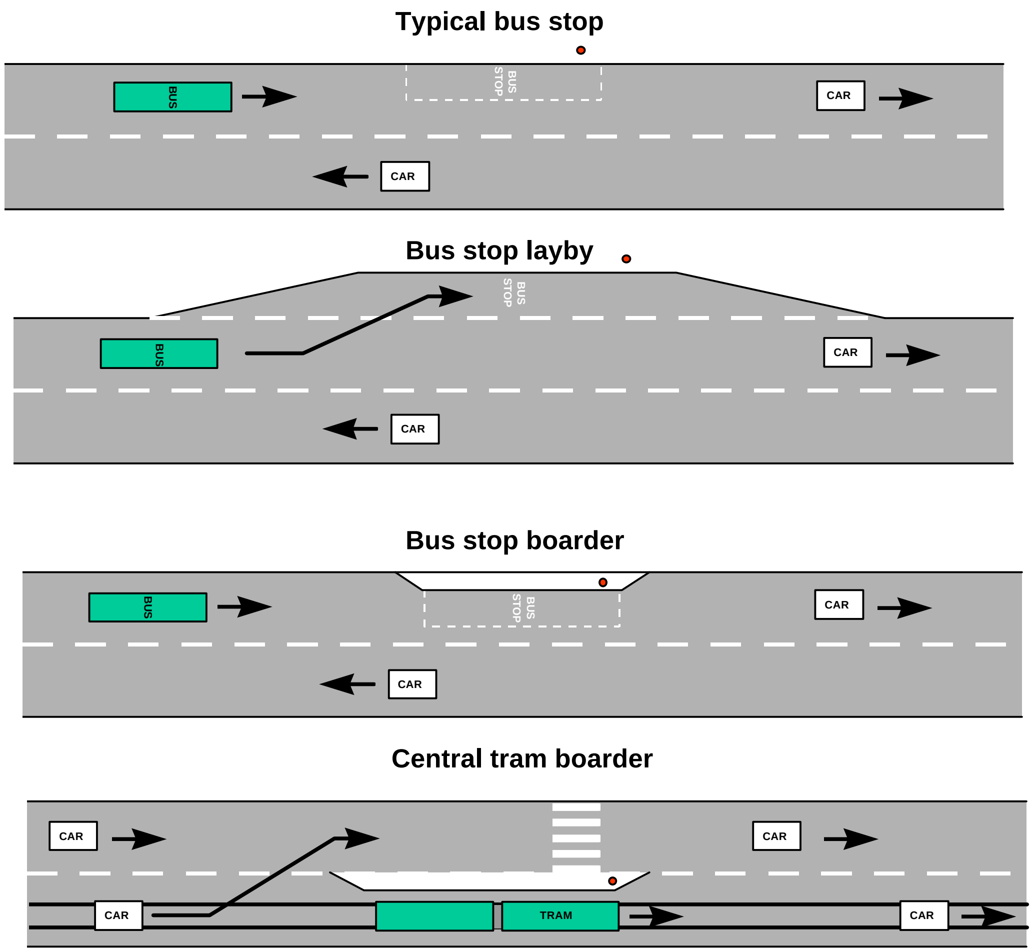


Figure 7: The four different types of public transport stop driving on the left

There are four main types of public transport stop (see Figure 7). The simplest is just indicated by a sign on the roadside and the public transport vehicle stops alongside it to pick up or put down passengers. Two other types of stop are bus laybys and bus boarders. A bus layby provides a space for a bus to pull into at the stop and thus allows following traffic to pass the bus after it stops. A bus boarder is the opposite of a bus layby. Here the footway is extended out into the road. Bus boarders are used in areas where there are usually lots of parked vehicles. The boarder deters kerbside parking at the bus stop and allows passengers to have easier access to the bus. The fourth type of stop is a central border which is used when the public transport vehicles (usually trams) use a lane in the centre of the carriageway. Access to the boarder is usually via a pedestrian crossing. When a tram is stationary at the stop the following vehicles switch to the inside lane to overtake the tram. All types of stop often have the road space adjacent to them marked to protect them from parked vehicles.

Public transport stops are usually associated with vehicles on given routes. At some stops, any public transport vehicle that uses the adjacent road can stop if required. Other stops might only be designated for use by public transport vehicles of a certain route. Some stops are also only for use by passengers alighting from the public transport vehicle, whilst others might only be used for passengers getting on to the public transport vehicle.

There are also rules which determine whether a public transport vehicle will stop at a given stop. If there is a passenger on the vehicle who wants to alight or a passenger at the stop wanting to get on the vehicle then the vehicle will stop. However there are sometimes stops where the vehicle will always stop whether there is demand or not. Sometimes public transport vehicles will also have to wait at a stop until the scheduled departure time before they can move off, to ensure that they conform to a timetable (such a stop is called a timing point).

1.2 Data flows and content

Public transport vehicle data

- Vehicle identifier
- Type of vehicle (bus, guided bus, trolley bus, tram/LRT)
- Location of vehicle
- Length and width of vehicle
- Movement parameters
  - acceleration / deceleration rates
  - maximum cruising speed
  - vehicle following and lane changing parameters
- Vehicle route identifier
- Number of passengers on the vehicle
- Which stops passengers are travelling to
- Capacity of the vehicle (maximum number of passengers)
- Boarding rate per passenger (mean and standard deviation)
- Setting down rate per passenger (mean and standard deviation)
- Dead time for opening or closing the doors

Public transport route data

- Route identifier
- The chain of links which define the route

Public transport lane data

- Lane identifier
- Type of lane
  - permitted vehicles
  - maximum speed
  - times of operation
  - whether a guideway
- Lane length
- Lane width
- Lane location in the link
- Entrance node

- Exit node

Public transport schedule data

- Schedule identifier
- Associated route
- Type of schedule
  - Fixed times
    - Departure time (include a small random deviation term)
    - Expected arrival time at stops on the route
  - Frequency
    - Frequency of departure (mean and standard deviation)

Public transport stop data

- Stop identifier
- Location on the link
  - Distance along the link
  - layby, border or adjacent
  - width of layby or boarder
  - length of layby or boarder
- Priority rule for exiting layby
- Bus routes that use the stop for
  - alighting
  - setting down
  - both
- Number of passengers waiting for each destination
- Stop is a timing point
- Rule to use if another public transport vehicle is already at the stop
  - pull in as well
  - pull in only if a different route
  - do not stop

1.3 Interface description

The above data needs to be supplied to the model. This can be done either via text input using an editor or by using a graphical network builder. Outputs will either be additions to the current text outputs or additions to the animated graphical displays or both.

Text inputs. The user will be allowed to enter the public transport data by using a standard text editor.

Graphical inputs. If a graphical network builder is available to create the network files then the data might be entered as follows.

The public transport vehicle data will be entered using an extension of the current graphical method used to enter data for each vehicle type.

- The location of the public transport stop is specified by clicking on a link at the required location. Only links which have public transport routes going along them can be selected. The extent of the stop is specified by dragging the edges of the stop with the mouse.

- Other stop data is then specified via a pop-up box which appears when the stop is double clicked.

Text outputs. The user will have the option of asking the model to produce the following text outputs.

When each public transport vehicle is generated an option should be available to produce:

- the time at which it was generated
- the place it was generated
- the vehicle parameters

A step-by-step output of any public transport vehicle's

- position (link, lane, position on the link)
- speed
- whether at a stop (with the stop identifier)

Summary data for public transport vehicles giving for output time intervals for every link:

- exit flows on each link
- entrance flows on each link
- for all vehicles which have left the link in the time interval
    - average journey time
    - average number of stops made
    - total distance travelled
    - average fuel consumed
    - average pollutants emitted

Summary data for each public transport route:

- number of vehicles which started the route
- number of vehicles which completed the route
- for all vehicles which have completed the route in the time interval
    - average journey time
    - average number of stops made
    - total distance travelled
    - average fuel consumed
    - average pollutants emitted

For each departure from a public transport stop

- Public transport vehicle identifier
- Time vehicle arrived
- Time vehicle departed
- Number of passengers picked up, along with their destinations
- Number of passengers set down
- Number of passengers on the bus on departure
- Number of passengers remaining at the stop

The passenger flows and average travel times between each passenger origin-destination pair during a given time interval.

Graphical outputs. If an animated graphical display is used to show the simulation progressing then it should be possible to have an option to display the following information:

On the public transport vehicles

- a route identifier on each public transport vehicle
- a destination on each public transport vehicle
- the number of passengers it is carrying

At the public transport stops

- symbol to identify the stop
- the number of passengers waiting and their destination
- the public transport timetable for the stop

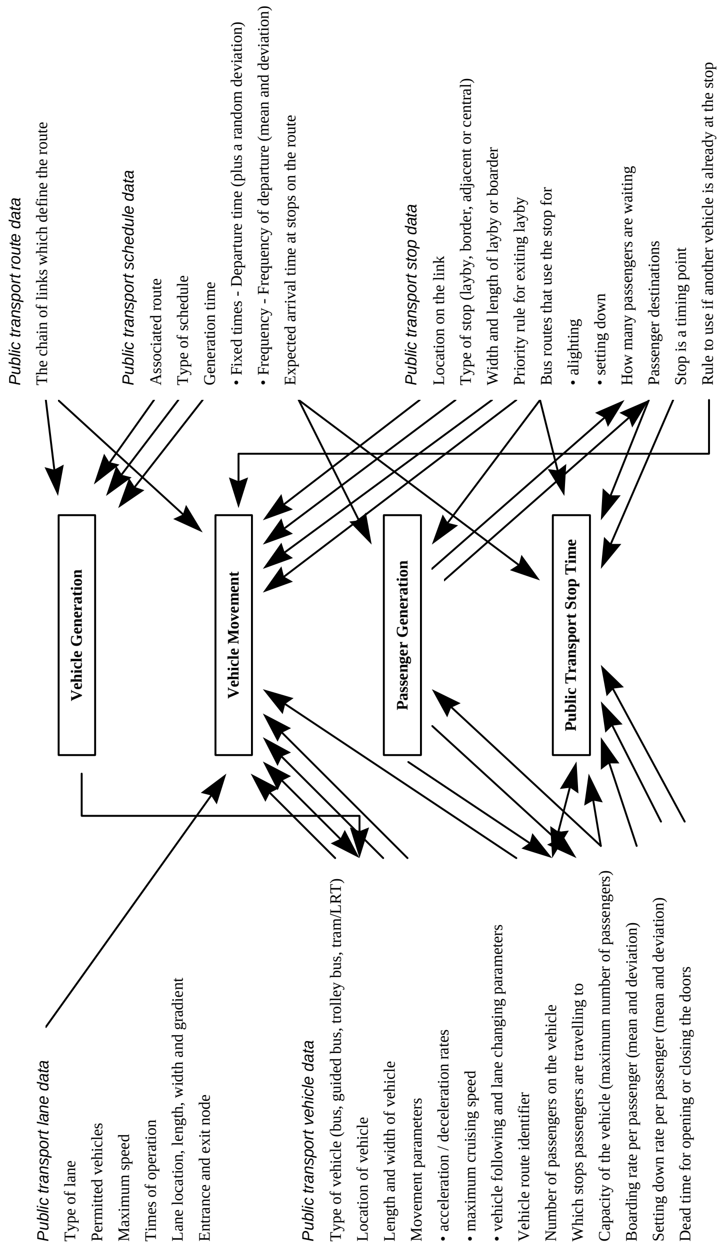


Figure 8: Public Transport stop data flow diagram

1.4 Functional description

The above data will be used by four sub models within a typical micro-simulation model, namely:

- Vehicle generation
- Vehicle movement
- Passenger generation
- Public transport stop time

A passenger generation model is only required if the user wishes to either a) model the waiting time of public transport vehicles at stops as accurately as possible or b) is interested in comparing complete journey times for private and public transport. If neither of these options is required then it is possible that a passenger generation module is not required at all and that a simpler module can be developed to ensure that public transport vehicles stop for a suitable length of time at each stop.

Vehicle generation model

Public transport vehicles need to be generated at appropriate times and places in the network. Vehicles should be generated at times according to the Public Transport Schedule, at nodes that define the start of their route and with a destination given by their route.

Vehicle movement model

Public Transport vehicles follow a fixed route through the network.

Movement along the route depends on the vehicle's movement parameters (acceleration / deceleration rates, car following rule etc.). Trams, trolley buses and guided buses travelling on guideways are restricted to following their tracks. Other buses can change lanes like other vehicle types. Care should be taken to ensure that long vehicles, especially articulated buses and trams, make realistic movements when negotiating corners.

Certain lanes in a network can be designated for use only by public transport vehicles (violations by other vehicles are quite frequent in the real world, so the modeller might want to consider a level of non-conformance). When such a lane is available it will be used by the public transport vehicles.

Public transport vehicles stop at fixed points along the route to pick up and set down passengers. The amount of time spent at the stop is determined by the *Public Transport Stop Time* model. The movement of the public transport vehicle in the vicinity of the stop needs to be modelled. The vehicle movement model should:

- ensure that public transport vehicles move into the lane to access the stop at a suitable time,
- public transports pull into a layby or move alongside a boarder or a roadside stop if required to stop at the public transport stop,
- other vehicles move around a vehicle stopped at a stop if there is sufficient space,
- the public transport vehicle is able to exit from a layby either by waiting for a suitable gap in the traffic or if a priority rule is in operation the other traffic is to give way to let the vehicle exit.

Passenger generation model

The passenger generation model is to:

- generate passengers at public transport stops that allow passengers to board
- generate passengers on vehicles when the vehicle is generated.
- each passenger is to have:
  - a destination which is either another public transport stop or an exit node serviced by one of the public transport vehicle routes using the stop,
- the rate of generation is to be based on a user supplied O-D matrix between public transport stops and entrance nodes and other stops and exit nodes. It might also be based on the arrival timetable for that stop, with passenger arrivals clustering around the time just before a public transport vehicle is due to arrive.

Public transport stop time model

The public transport stop model which is developed must be able to realistically represent traffic behaviour, of both buses and other vehicles, in the vicinity of stops. This will interact with the *Vehicle Movement* model and the *Passenger Generation* model.

The stop time model is to:

- determine whether a public transport vehicle is to make a stop at a public transport vehicle stop this is to depend upon,
  - whether a stop is mandatory for the public transport vehicle approaching the public transport vehicle stop,
  - whether there are passengers on the public transport vehicle who wish to get off the public transport vehicle at the stop,
  - whether there are passengers waiting for the public transport vehicle at the stop, with a destination that can be reached by the current public transport vehicle and the current public transport vehicle has the capacity to take more passengers,
- determine how long the public transport vehicle waits at the stop, this is to depend upon:
  - the number of passengers boarding the public transport vehicle,
  - the number of passengers leaving the public transport vehicle,
  - the time required for opening and closing the public transport vehicle doors,
  - the boarding rate per passenger,
  - the setting down rate per passenger,
  - whether the public transport vehicle has to wait until a given time before it can leave the stop.

If no passenger generation model is required, the Public Transport Stop model will only use statistical data describing the stop times, per time of day, bus stop and bus route.

1.5 Restrictions and limitations

There are no major restrictions or limitations.

1.6 Performance requirements

The standard performance requirements of the SMARTEST modifications are to apply

1.7 Verification tests

To check that the model is working as specified, scenarios are to be generated which allow the following checks to be made:

That public transport vehicles:

- contain the correct number of passengers as they enter the network
- only travel along their given route
- accelerate and decelerate at appropriate rates
- trams, trolley buses and guided buses only move along tracks
- long vehicles successfully negotiate corners
- use reserved lanes where appropriate and at the correct times of operation
- move into the correct lane to access public transport stops if necessary
- stop for an appropriate length of time at the stop

If a passenger generation model is used public transport vehicles should

- stop at public transport vehicle stops if there are passengers wanting to get off
- stop at public transport vehicle stops if there are passengers waiting to get on and there is room on the public transport vehicle
- do not stop at public transport vehicle stops if there are no passengers waiting to get off but there are passengers waiting at the stop and there is no room on the public transport vehicle

1.8 Validation criteria

The model can be validated using the following data sets:

- Average vehicle travel times from stop to stop
- Standard deviations of vehicle travel times from stop to stop
- The average of other vehicle travel times down links containing public transport stops
- Standard deviations of other vehicle travel times down links containing public transport stops

1.9 References

Department of Transport (1991) *Keeping Buses Moving: A Guide to Traffic Management to Assist Buses in Urban Areas*, Local Transport Note 1/91, HMSO, ISBN 0-11-551075-3.

Department of Transport (1995) *The Highway Code*, HMSO, ISBN 0-11-550962-3.

Institution of Highways & Transportation (1997) *Transport in the Urban Environment*, Institution of Highways & Transportation, London, ISBN 0 902933 21 3.

US Department of Transportation (1992) Characteristics of Urban Transportation Systems. (Available on-line at: http://www.fta.dot.gov/fta/library/reference/CUTS/)

2. ROUNDABOUT

2.1 Introduction

A roundabout junction operates as a one-way circulatory system around a central island where entry is controlled either by give-way markings and priority must be given to traffic on the roundabout (the UK practice), or by signals.

Roundabouts are commonly used in a road network when either:
- traffic flows on major and minor traffic arms of a junction are at medium levels or there is a large farside turning flow,
- or where the road changes in character from a fast flowing inter-urban road to a more congested urban situation,
- or a U-turn facility is required.

The layouts of roundabout junctions are usually more complicated than other types of junctions such as signalised or priority junctions. Drivers' driving behaviour is also more complex due to the higher level of driver/vehicle interactions on the junctions. It is therefore a challenge for a micro-simulation model to represent roundabouts, especially the complex behaviour exhibited on it realistically.

There are various types of roundabout layout; the common ones are: 'conventional' roundabouts which have a kerbed central island with diameter greater than or equal to 4 metres; and 'mini' roundabouts where a flush circular marking less than four metres in diameter is used with or without flared approaches. Other types of roundabouts include double, grade separated, ring, signalised and gyratory system. Illustrations and descriptions of the different types of roundabout have been extracted from *Transport in the Urban Environment* (IHT 1997) and are given in Table 1, Figure 9 and Figure 10.

Type	Description	Typical Use/ Location
Conventional	• Kerbed central island with diameter greater than or equal to 4m • Flared approaches to allow multiple entry lanes • See Figure 9	• New developments and construction • Junctions within or at end of dual carriageways • To change direction of a new road at a junction
Mini	• Flush or slightly raised central island less than 4m in diameter • Road markings indicate pattern of movement • No street furniture on central island in order to allow long vehicles to overrun • See Figure 9	• To improve the performance of existing junctions where space is severely constrained • Mainly as conversions from other roundabout and junction types • At sites subject to a 30 miles/h speed-limit

Type	Description	Typical Use/ Location
Double	• Two conventional or mini roundabouts are placed within the same junction connected by a short link road • Figure 9	• For controlling unusual or asymmetric approaches. • At approaches with heavy opposing right-turning movements, staggered approaches and at sites with more than four arms.
Grade-separated	• At least one traffic movement passes through the junction without interruption, while the remainder are brought to one or more roundabouts at a different level • Compact designs are favoured • For pedestrians and cyclists the roundabout is elevated, to allow easy gradients for pedestrian and cycle network below • See Figure 10	• On urban motorways and dual carriageways • On high capacity roads and those with high approach speeds of traffic • On new construction where there are high forecast vehicle and pedestrian flows
Ring junctions	• A large two-way circulatory system where each approach is provided either with 3-arm roundabouts (normally minis) or with traffic signals • See Figure 10	• At some special sites to solve particular local problems • For conversion from very large roundabouts which have entry problems • Not recommended for a new facility
Signal controlled	• Traffic entering the roundabout from one or more arms is signal-controlled for all or part of the day • See Figure 10	• To increase capacity under certain operating conditions
Gyratory systems	• Small one-way systems where normal–land use activities can be maintained on the central island	• In urban areas, especially town centres • Safe access to the island must be ensured for pedestrians, cyclists and possible maintenance vehicles

Table 1: The different types of roundabout and their main characteristics

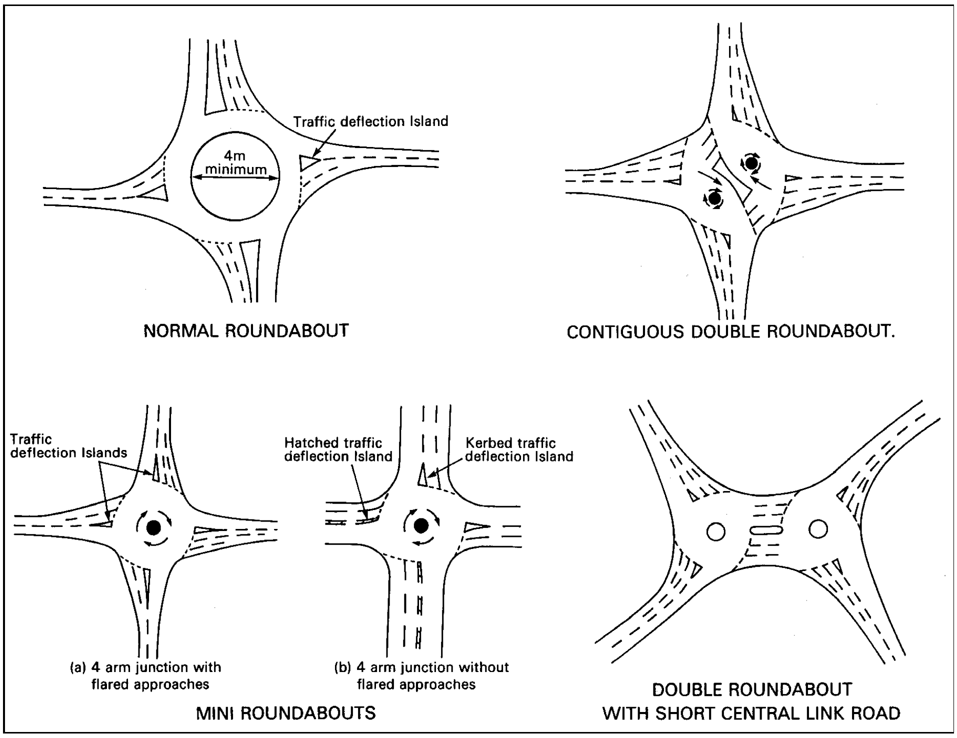


Figure 9: Different types of roundabout (Conventional, Contiguous double, Mini and Double) (left-hand driving practice)

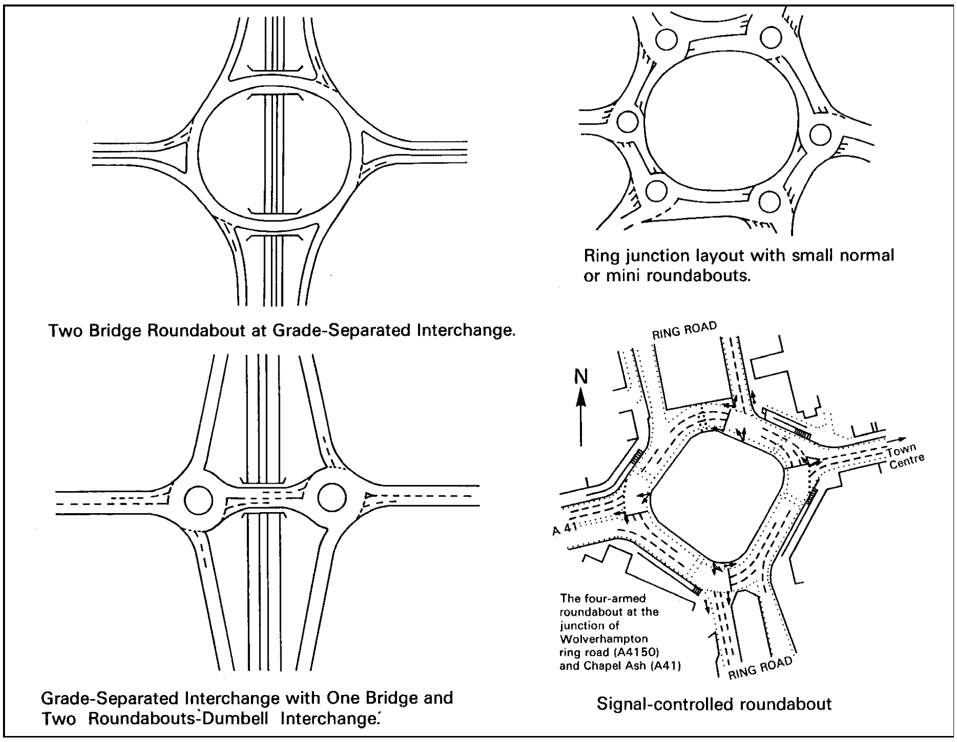


Figure 10: Different types of roundabout (Two bridge, Grade Separated, Ring and Signal Controlled) (left-hand driving practice)

The entrance to a roundabout is sometimes 'flared' to provide extra lanes. This can have a significant impact on the entry capacity of a roundabout. There may also be segregated lanes for nearside-turning traffic if there is large proportion of the traffic entering the junction which leaves at the first exit.

According to The Highway Code (DOT 1993), regulations for traffic approaching and moving on a roundabout are as follows:

- get into the correct lane according to desired exit
- reduce speed
- give way to traffic on the roundabout unless road markings indicate otherwise
- watch out for traffic already on the roundabout, especially cyclists and motorcyclists
- when making nearside turning, approach in the nearside lane and keep to the nearside on the roundabout
- when going straight ahead, approach in the nearside or centre lane on a three lane road, or in the farside lane if the nearside lane is blocked on a two-lane road
- when making farside turning or going full circle, keep to the farside on the roundabout
- when there are more than three lanes at the entrance, use the most appropriate lane on approach and through the roundabout
- watch out for traffic crossing in front on the roundabout, especially vehicles intending to leave by the next exit
- give long vehicles plenty of room as they may have to take a different course, especially on a mini-roundabout where they may have to cross the centre.

2.2 Data flows and content

A roundabout model should have the following data inputs (please refer to Figure 11 for particulars):

- roundabout identifier
- location
- type (conventional, multiple)
- physical layout, e.g.:
  - junction diameter (D)
  - width (W) or number of lanes of circulating carriage way etc.
- connections:
  - number of entry and exit arms
  - for each entry arm:
    - entry width or number of entry lanes
    - number and length (l) of flared lanes
    - number of segregated nearside-turning lanes
    - entry angle (ϕ)
    - entry radius (r)
    - lane turning restriction marking
- traffic regulation:
  - rules for entering, moving on and exiting the roundabout
  - where applicable, signal timings.

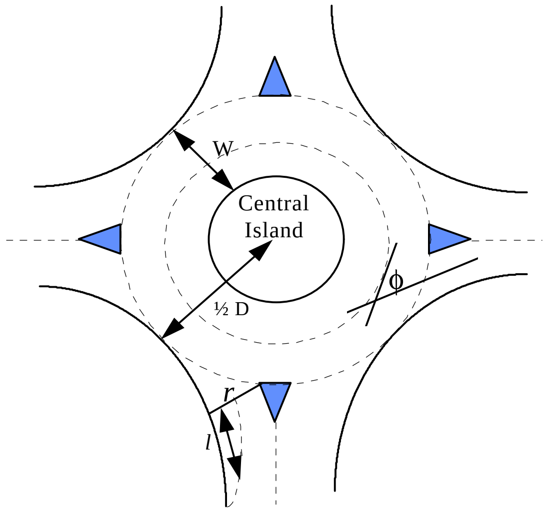


Figure 11: A normal roundabout in left-hand driving practice.

2.3 Interface description

The input data can be supplied to the model either via text input using an editor or by using a graphical network builder if available. In the later case, the graphical network builder should enable users to supply the inputs relating to the physical layout of a roundabout by simple drawing at the required location and to the required size, and be able to mark the lane turning restrictions by clicking on the relevant lane. The traffic regulation is supplied via pop-up box which appears when the roundabout or an connection arm is doubly clicked.

For the text outputs from the model, the user should have the option to ask the model to produce the following information at user-specified output time interval:

For each roundabout:

- roundabout identifier and type
- number of trips which arrive at the roundabout
- number of trips which leave the roundabout
- average speed on the roundabout
- for each entry arm:
    - average and variance of gaps accepted by vehicles entering from this arm
    - average and variance of entry headway
    - average and variance of queuing delay
- for each entry-exit pair:
    - number of trips exit
    - geometric delay due to traffic having to slow down while circulating the roundabout
    - average and variance of travel time

The graphical display should be possible to display the detailed junction layout, animation of vehicles movement with an indicator showing the exit the vehicle intends to use leave the roundabout.

2.4 Functional description

A roundabout model should realistically represent traffic behaviour, especially with regard to vehicle lane choice and gap acceptance behaviour. This will require the development of three sub-models: a roundabout car-following model, lane choice model and gap acceptance model.

The car-following is to mimic traffic movement in a single lane. It should represent realistically the response of a vehicle following the vehicle(s) in front. This depends on driving behaviour and vehicle mechanics, as well as the road condition.

The lane choice model is to determine for each vehicle the lane to take on an entry arm when approaching a roundabout, on the roundabout, and when leaving the roundabout into an exit arm. This depends on the desired movement of each trip, the lane markings and the traffic regulations. In the presence of flared lanes or segregated lanes, the model should realistically represent the lane capacity.

The gap acceptance model is to look for gaps in the traffic stream that the vehicle wants to join and to decide if it is acceptable for the individual driver concerned. This depends on the traffic condition on the driver's target lane(s) and the driver's acceptable gaps. The later may vary with driver's patience and especially the time a driver has been waiting or looking for gaps. The model should also represent gap-creation behaviour where priority traffic deliberately create gaps for a vehicle to join in the traffic stream or for a vehicle wanting to leave the roundabout.

2.5 Restriction and limitation

There are no major restrictions or limitations.

2.6 Performance requirement

The standard performance requirements of the SMARTEST modifications are to apply.

2.7 Verification tests

To check that the model is working as specified, scenarios are to be generated which allow the following checks to be made:

that vehicles:

- get into the correct lane at the entry arm of a roundabout
- take appropriate gaps to enter the roundabout
- do not change lanes unnecessarily on the roundabout
- exit from the roundabout into the desired arm

2.8 Validation criteria

The model can be validated using the following data:

- roundabout entry capacity
- average travel time between entry-exit pairs
- average speed on roundabouts

2.9 References

DOT 1995, The Highway Code, Department of Transport, HMSO, ISBN 0-11-550962-3.

IHT 1997, Transport in the Urban Environment, Institution of Highways & Transportation, London, ISBN 0 902933 21 3.

3. TRAFFIC CALMING

3.1 Introduction

Traffic calming is primarily a traffic management measure for controlling speed in built up areas. Effective traffic calming schemes are made up of a combination of measures. It is essential that traffic calming is set within a coherent policy framework, taking into account a range of transport and lane use policies.

There are a large number of traffic calming techniques which can generally be classified into the following areas:

- Reallocation of carriageway space to non-traffic by redesigning and enhancing the street environment, such as widening footways, redefining road space to provide parking, using street furniture, etc.
- Road narrowing, such as use of buildouts, chicanes, pinch points, gateways.
- Speed interruption, measures such as road humps, bar-marking, speed cushions, central islands and small corner radii.
- Flow interruption, which includes measures to break-up a road into shorter sections to slow traffic, such as false roundabouts, mini roundabouts, junction priority changes, and the use one-way streets to make indirect routes.

Traffic calming measures can be further classified into two categories: *traffic management measures* and *network supply side measures*. The traffic management measures include the use of one-way streets and changes of junction priority, the aim of which is to manage the traffic flow without having to alter the road structure. In terms of network modelling, the first category can be covered within general traffic management modelling, hence will not be specified further in this document.

Most traffic calming measures, however, involve changes in the road surface either vertically or laterally to some degree. Some of them are unique to traffic calming schemes which are not normally represented in network models, such as road humps, speed cushions, and pinch points. A traffic calming model needs to be able to represent a road with variable width and gradients, and to represent drivers' behaviour in the presence of these measures.

3.2 Data flows and content

Junction Data

- Junction identifier
- Junction type
- Number of links connected to the junction
- Size of roundabout, if appropriate
- Corner radii
- Traffic regulations

Link data

- Link identifier
- Number of lanes on the link
- Width and length of the link
- Number of traffic calming measures on the link

- For each measure:
  - location on the link
  - length
  - width
  - gradient
  - resulting link width

3.3 Interface description

The input data are best supplied to the model using a graphical network builder since it helps to locate the traffic calming measures on the network. For measures which involve a lateral shift of carriageway, the user should be able to simply draw the road narrowing on screen. For a vertical shift of carriageway, for example a road hump, the height of the ramp is supplied via pop-up box which appears when a ramp is doubly clicked.

The input data can always be supplied with the use of text editor when a graphical network builder is not available.

For the text outputs from the model, the user should have the option to ask the model to produce the following information for before and after a traffic calming measure is applied:

For each junction:
- junction identifier
- number of turning movements at the junction
- for each turning movement:
  - turning movement identifier
  - average flow making the turning
  - average speed

For each link:
- link identifier
- number of traffic calming measures
- average travel speed
- average delay
- pollutant emission

The graphical display should be able to display the detailed junction and link layout with traffic calming measures marked specifically and animation of vehicles movement.

3.4 Functional description

A traffic calming model should represent realistically the traffic behaviour in the presence of specific traffic calming measures, especially with regard to vehicles' acceleration and deceleration behaviour. This will require the development of a car-following model which takes into account the effect of lane width and of road gradient.

3.5 Restriction and limitation

There are no major restrictions or limitations.

3.6 Performance requirement

The standard performance requirements of the SMARTEST modifications are to apply.

3.7 Verification tests

To check that the model is working as specified, scenarios are to be generated which allow the following checks to be made:

that drivers:

- react to the presence of traffic calming measures
- reduce speed before the measure in order to pass over safely
- accelerate after passing the measure

3.8 Validation criteria

The model can be validated using the following data:

- drivers reaction time to the presence of traffic calming measures
- deceleration and acceleration rates
- average speed drivers travel over the measure

4. ADAPTIVE TRAFFIC SIGNALS

4.1 Introduction

For a long time the test and evaluation of Urban Traffic Control Systems (UTCS) has been one of the main application fields of microscopic traffic simulations. Due to the great variety of existing traffic control strategies, as well as those under development or to be developed, it is clear that the simplest way to integrate them in the simulation process is to consider each of them as a *separate* software module, able to communicate with the simulation tool.

This of course implies that all the basic components addressed by such strategies (traffic lights, loop detectors, ...) are correctly modelled in the microscopic simulation tool, and that a communication protocol is available for data exchange between the strategies and the simulation tool.

These specifications propose a unique framework, which is able to take into account fixed time traffic signal plans as well as sophisticated adaptive signal strategies like PRODYN or SCOOT and also include simple plan changing strategies. Simple plan changing strategies are also considered here as external strategies, because firstly they can use detector data, and secondly several plan changing methods exist, which can produce more or less smooth transitions between plans.

As detector specifications are covered elsewhere in this document, we concentrate here on traffic signals and data exchange specifications related to adaptive strategies.

For a given intersection, traffic signals are assigned to specific lanes of its controlled links, as shown in Figure 12:

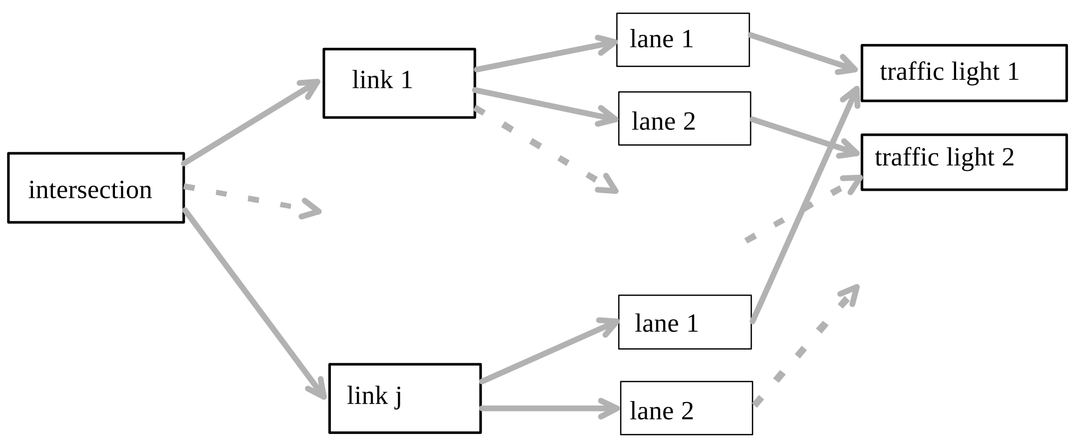


Figure 12: relations between traffic lights and network geometry

The state of each traffic light is then represented by a « generalised colour », which can be a simple colour (red, amber, green), a special colour (arrow, blinking amber), or even a combination of colours (red+amber, red+arrow for example, in some countries). As indicated in Figure 13, a given driving behaviour can be associated with each « colour », which can be a « simple » behaviour (to stop at red, to pass on green), or a more complex one, including appropriate give-way rules.

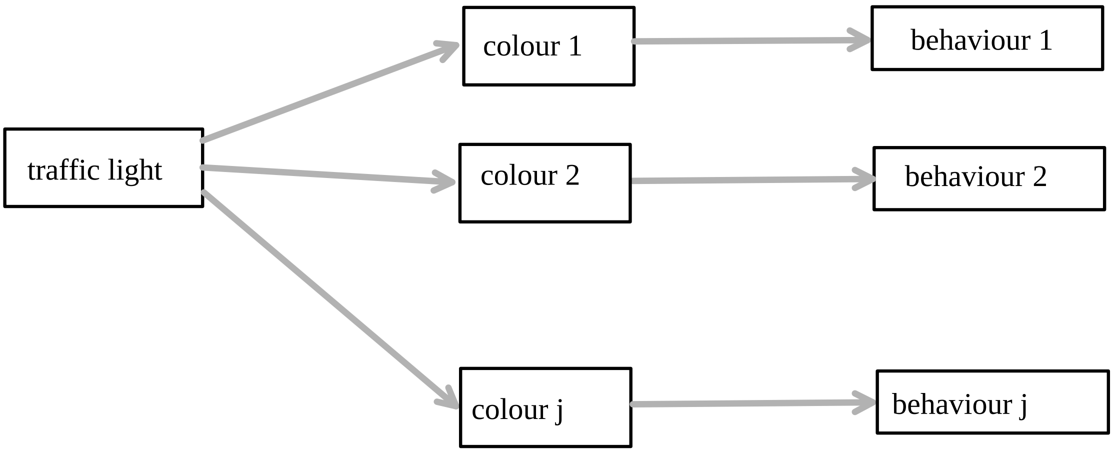


Figure 13: relations between traffic lights and driving behaviour

There are several ways of representing colour distributions over time per traffic light linked to a given intersection; some originate from fixed time plan descriptions, and therefore too restrictive to enable adaptive signal management.

The type of representation proposed is the following one, illustrated by Figure 14:

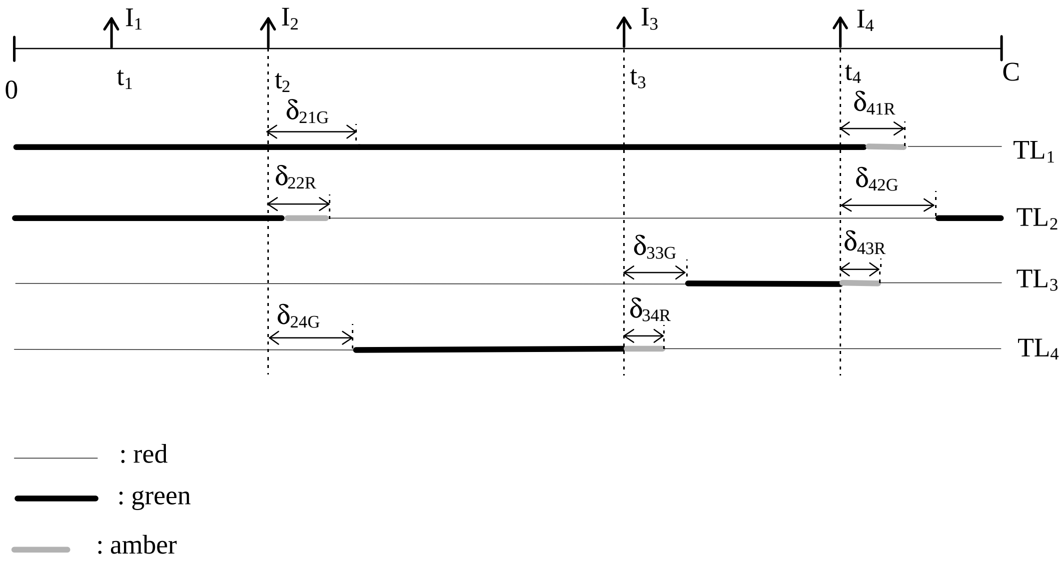


Figure 14: traffic lights sequencing description

This representation, which is similar to the stage-based approach, but offers more flexibility in order to cover adaptive signals, uses the following notation:

- C: cycle length, in seconds
- I_j : stage impulse number j
- t_j : time of stage impulse number j
- TL_i : traffic light number i
- δ_{jiG} : time-lag between stage impulse number j and effective green colour on traffic light i

Independently from the « generalised colour » definition given previously, we also introduce « stable » colours (most of the generalised colours are stable) and « transient » colours, an example of which is given on Figure 14 with amber. A « transient » colour is a colour that can occur at the transition between two « stable » colours (from green to red in this example). A given « transient » colour duration can be associated with an intersection or a traffic light. In order to cope with particular sequencing situations, a supplementary « stable » colour identifier has to be considered: the « no change » colour, which means - keep the present colour.

Finally, to achieve a complete description of sequencing, we associate with each couple (TL_i , I_j) two parameters: the next stable colour to be indicated, and the corresponding time-lag. In the case of traffic light #1 in Figure 14, we would obtain:

(TL_1 , I_1) → red, δ_{11R}

(TL_1 , I_2) → green, δ_{21G}

(TL_1 , I_3) → green, δ_{31G}

(TL_1 , I_4) → red, δ_{41R}

Although δ_{11R} and δ_{31G} do not appear in Figure 14, they should be given. For the case of an adaptive signal strategy, if impulse#2 is omitted between impulse#1 and impulse#3, the colour of traffic light#1 must be changed to green when impulse#3 occurs, after time-lag δ_{31G}.

Colour distributions and sequencing of traffic lights must comply with a set of constraints that include *amber duration*, *conflict clearance times*, *minimum* and *maximum green* times, which are usually enforced by the intersection controller. For example, the time-lag parameters appearing in Figure 14 must satisfy:

$$\delta_{22R} \geq \text{amber duration}$$

$$\delta_{21G} - \delta_{22R} \geq \text{conflict clearance time}$$

The external strategy has anyway to produce traffic signal settings that satisfy the above mentioned constraints, and therefore must know them. We will therefore assume that, except for amber duration, the other constraints are embedded within the external UTC strategy.
Two main classes of UTC (Urban Traffic Control) strategies can be considered for the implementation of adaptive signals:

- local strategies, which operate at isolated intersections: they can choose the active stage, extend or shorten its green time. These decisions are based on real time inductive loop measurements, and therefore they can occur at any time, assuming that the safety constraints are verified. Simple traffic-actuated control strategies, based on vehicle interval detection, Miller's algorithm, or more sophisticated strategies such as PRODYN belong to this category

- strategies that operate at an arterial or network level, thus implying signal co-ordination: they include simple fixed time plan changing strategies (based on time of day or on traffic pattern recognition through detectors measurements), and more sophisticated ones like SCOOT. They are characterised by a common cycle time shared by a group of contiguous intersections, and a less important data flow exchange, as far as the controls are concerned.

In order to be able to cope with the widest set of UTC strategies, a high degree of flexibility has to be offered by the data exchange architecture and interfacing system. This could mean that a strategy would be able to control each traffic signal at the lowest level. In order to avoid, when it is possible, unnecessary and high density data flows, it seems better to introduce the traffic controller entity on the traffic simulation side, which will be able to store and execute a given sequence of predefined stages through the impulse sequence defined above.

Figure 15 summarises the resulting data flow exchange between the microscopic traffic simulation and the UTC strategy, for both detector data and control settings.

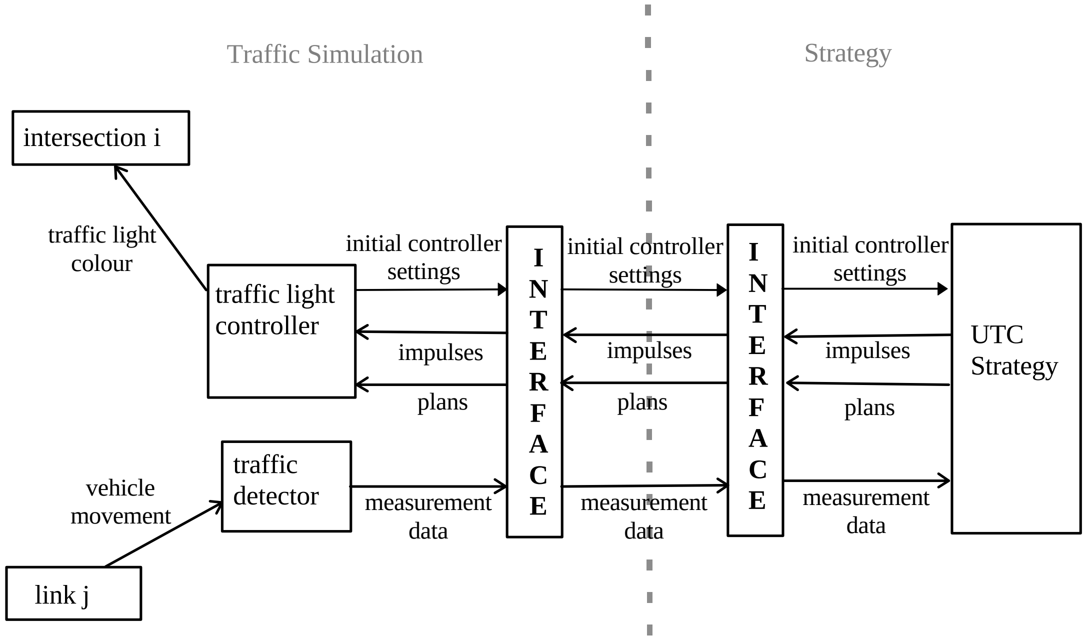


Figure 15: general data exchange layout

Initial controller settings, which are sent to the strategy at the beginning of the simulation run, concern controllers associated to the intersections controlled by the external UTC strategy. The other data flows may occur at each simulation step.

4.2 Data flows and content

Traffic light data

- traffic light identifier
- intersection identifier
- list of lane identifiers (which are controlled by this light)
- list of « stable » colours supported by the light ; for each of them :
  - associated behaviour identifier
- list of « transient » colours supported by the light; for each of them:
  - associated behaviour identifier
  - duration
  - preceding and following colour identifiers

Traffic controller data

- controller identifier
- intersection identifier
- type of strategy (internal : fixed time plan), or external
- cycle time
- list of stage impulses ; for each of them :
  - impulse time
- list of traffic lights ; for each of them :
  - for each impulse : next « stable » colour identifier (including the « no change » colour), and associated time-lag (does not apply for the « no change » colour)

4.3 Exchange data description

Initial controller settings

- list of controller identifiers to be controlled by the external strategy; for each of them :
  - cycle time
  - list of stage impulses ; for each of them :
    - impulse time
  - list of traffic lights ; for each of them :
    - list of « stable » colours supported by the light
    - list of « transient » colours supported by the light ; for each of them :
      - duration
      - preceding and following colour identifiers
    - for each impulse : next « stable » colour identifier (including the « no change » colour), and associated time-lag (does not apply for the « no change » colour)
    - initial colour

Impulses

- message identifier
- controller identifier
- impulse number
- impulse time (time when the impulse should occur : this means that this message should reach the traffic simulation at a time less than or equal to the impulse time)

Plans

- message identifier
- new cycle time
- synchronisation times : new value of cycle reference time and corresponding absolute time value
- list of controllers identifiers ; for each of them :
  - list of stage impulses ; for each of them :
    - impulse time

Measurement data

see Vehicle detectors

4.4 Data communication process

It seems difficult to choose or impose a given communication process for the data exchange between the microscopic traffic simulation and the external UTC strategy. Various protocols are used by model developers, from a simple process using synchronisation and data files to a standard process like CORBA (Common Object Request Broker Architecture), based on an interface definition language (IDL) and a protocol for communication between ORBs (Object Request Brokers). This last approach seems promising, insofar as it appears to be well suited to allow interoperation between pieces of software developed by different suppliers, which means being independent of programming languages, operating systems and database tools.

The maximum data exchange rate is given by the time step of the microscopic simulation. It is a fixed rate (synchronous) for traffic detectors data, and can be asynchronous for the impulse transmission.

4.5 Interface description

The need of a graphical editor does not seem to be crucial in order to supply the above data to the model. Outputs will either be additions to the current text outputs or additions to the animated graphical displays or both.

Text inputs. Traffic light data and traffic controller data will be allowed to be entered by using a standard text editor.

Text outputs. The user will have the option of asking the model to produce the following text outputs:

- for each traffic light controlled by the external strategy
  - the mean, minimum and maximum cycle time values observed per time slice and over the simulation period
  - the mean, minimum and maximum green time values observed per time slice and over the simulation period
- for each intersection related to the above mentioned controllers
  - the total time spent by the vehicles on the input links of the intersection per time slice and over the simulation period
  - for each input link of the intersection
    - the mean speed observed on the link per time slice and over the simulation period
    - the maximum queue length value observed on the link per time slice and over the simulation period
- for all the intersections controlled by the external strategy
  - total time spent by the vehicles on the input links of this set of intersections and total throughput per time slice and over the simulation period
- for the whole simulated network
  - total time spent by the vehicles in the network per time slice and over the simulation period

Graphical outputs. The graphical display should be able to display an indicator (icon for example) indicating which traffic lights are controlled by an external strategy .

4.6 Functional description

The adaptive signal specifications given above allow to run any default fixed time plan on the traffic light intersections : the controllers associated to each intersection simply execute its current stage settings, which is in fact the initial process.

When a traffic controller receives an impulse type message, this means that an adaptive strategy is now running on this controller, so that it should no longer execute its predefined stage settings, but wait for the next impulse message.

In case of an adaptive strategy based on a series of fixed time plans, and in order to minimise the data exchange rate, the « plan » type message has been introduced. The receipt of such a message means that the controller now has to take control of the intersection by executing the new stage settings, until reception of a new « impulse » type message, which will in this case announce a new plan change. As indicated in the introduction, taking into account the various existing plan changing strategies available, it seems preferable to leave this transient period management under the external strategy control.

Initial traffic lights settings computation

In order to start the simulation run with the signals displaying the correct colours, all the traffic controllers will simulate a cycle time, without running the microscopic simulation model. This will enable the run to start with the correct initial signal colours, after transmission of the controller initial settings to the external strategy.

4.7 Restrictions and limitations

Those specifications should allow the implementation of a very large variety of adaptive signal strategies. However strategies with variable amber duration such as LHOVRA are not considered. Another limitation concerns the safety tests which can be found on certain traffic controllers. They are not supported here, which means that it is assumed that the external strategies deliver the correct, safe, control settings.

4.8 Performance requirements

The standard performance requirements of the SMARTEST modifications are to apply.

4.9 Verification tests

To check that the adaptive signals model is working as specified, scenarios are to be generated which allow the following checks to be made (we do not consider here tests related to the external strategy itself or to the chosen communication process):

that traffic controllers
- execute the stage sequence accordingly to their specified default settings
- receive and react correctly to the impulse and plan type messages sent by the external strategy

4.10 Validation criteria

- Validation does not really apply here. It would rather concern the adaptive strategy themselves, which is not the responsibility of the simulation model developer. The above mentioned verification tests are sufficient.

5. PT PRIORITY

5.1 Introduction

The idea of developing priority systems for Public Transportation comes from the basic objective of giving priority to *person movement* as opposed to *vehicle movement*, that is to say to ease the movement of vehicles having a higher occupancy rate.

The strategies aiming at giving priority to Public Transport vehicles usually combine two kinds of techniques: the first one uses the network layout, e.g. reserved lanes, and the second one deals with the development of specific traffic signal control algorithms, using information given by detectors able to detect and in some cases to communicate with PT vehicles (usually buses). This means that we will concentrate on *adaptive* strategies, without considering here strategies using fixed time plans like those produced by the TRANSYT program.

The software implied by those strategies can be distributed over three main locations: on-board, in the PT Control Centre, and in the Traffic Control Centre.

Figure 16 gives an overview of several detection and control elements involved in PT priority strategies. A given strategy will not use all of them, and three main « families » can be defined, depending on the set of selected components:

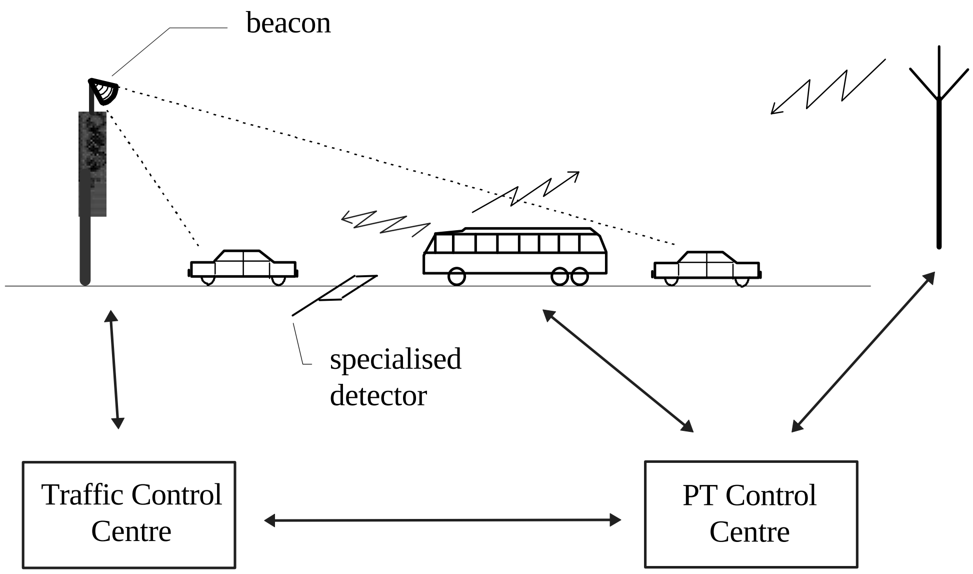


Figure 16: general framework of PT priority systems

- point detection systems: buses are equipped with « electronic registration plates », which send a message including the bus identification to a specialised loop detector able to read this message when the bus crosses it; in this case, we get a precise location at a given time.

- area detection systems: an infrared, radar or radio frequency emitter is mounted on the bus, and the messages are received by a beacon when the vehicle occupies the area covered by this beacon; messages can include complementary information such as bus stop departure time, ahead/behind of schedule signal and turning signal; reception quality may depend upon meteorological conditions.

- integrated priority systems: in this case, PT management is entrusted to an Automated Vehicle Monitoring (AVM) system, which collects all bus positions and communicates with the Traffic Control Centre in order to manage the priority actions. These systems also use Automatic Vehicle Localisation (AVL) systems, with different possible localisation techniques. Usually buses either use on-board positioning systems (odometry, GPS), which enable them to send their position either in a quasi continuous way (e.g. every 20 seconds) to the PT Control Centre, or only when they pass predetermined locations. Localisation beacons placed along the route enable the drift of odometry based localisation systems to be cancelled.

From a functional point of view, we can distinguish two main categories of priority strategies:

- unconditional strategies, which simply give priority to all detected buses approaching the intersection
- conditional ones, which use rules or criteria to decide whether to activate this priority or not. An example of rule is the use of a schedule adherence algorithm, and PRODYN-BUS (Henry, 1994) can be considered as an example of a strategy using an optimisation criterion.

From the simulation point of view, the same arguments as the ones put forward in the *Adaptive Traffic Signals* chapter still hold: the strategy producing or altering the traffic signal settings should be considered as an external strategy, interfaced to the microscopic traffic simulation and exchanging measurement data and new signal settings with it. The only difference with this preceding approach (*Adaptive Traffic Signals*) is that this external strategy can group together two different functional entities: the first one devoted to traffic signal control, and the second one dealing with bus management. This last one needs for example to know the schedules in order to derive the behind/ahead of schedule parameters.

Among the whole set of parameters and functionality that are necessary to deal with PT priority, some are proper to the simulation, others to the external strategy and a third category should be shared by the two agents. The bus schedules can be considered as an example of this last category, as it is first needed by the traffic simulation (for bus departure times) and secondly by the external strategy if an AVM strategy is to be modelled. Some of this data can be found in the *Public Transport Services* section.

Finally, the functional decomposition and data flow exchange looks greatly like the one proposed for *Adaptive Traffic Signals*, which only has to be extended on both sides by adding supplementary detectors and associated exchanged messages. Figure 17 gives an overview of this layout. Compared to the corresponding layout proposed for *Adaptive Traffic Signals*, we therefore keep with the same traffic light management principles, as the PT priority strategy should use or include a UTC strategy to produce modified signal settings.

If buses are not equipped with an AVL system, they send a bus identification or more complete message to the bus detector (depending on the nature of this detector). This message is then transmitted to the PT priority strategy through the interface. For the other case, with an Automatic Vehicle Localisation system, this system has to be modelled in the microscopic traffic simulator. The « positioning » box is devoted to this task, and enables localisation errors to be taken into account. These can be reset at given points by localisation beacons (case of odometry based systems). The bus message, which now includes localisation information, is either sent only at given points of the network (communication points, which are modelled by a specific type of detector), or at regular time intervals.

The content of the messages exchanged between the buses and the PT priority detectors will be considered as a field of the detector model. When the bus crosses the detector or enters the beacon coverage area, a request is sent by the detector to the vehicle, with the list of parameters asked for.

The *PT description data* box represents data that should be shared by the traffic simulation and the strategy. Initialisation data enable the strategy to send general configuration parameters to the traffic simulation, including for example the bus timetables.

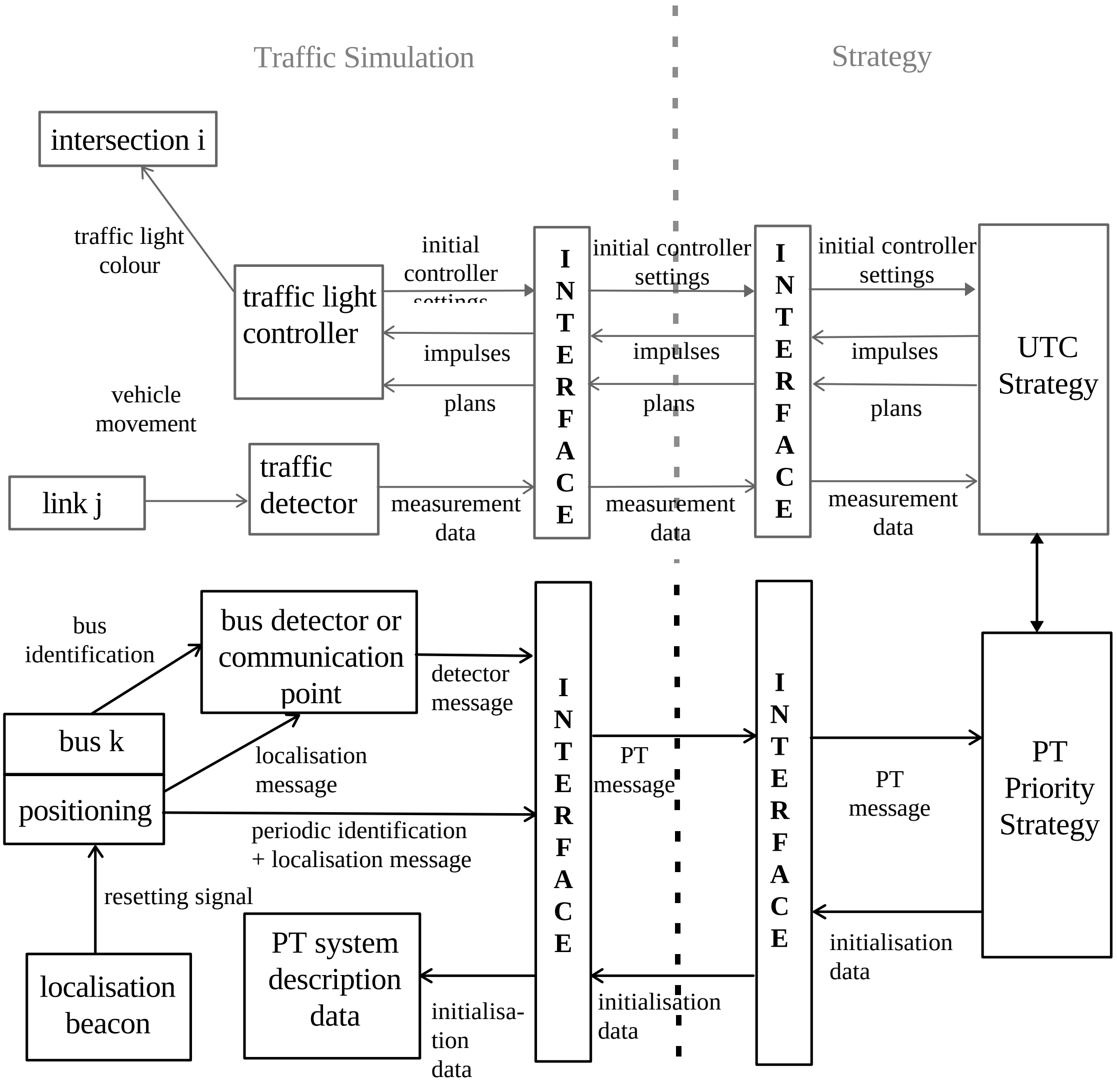


Figure 17: general data exchange layout for combined adaptive signals and PT priority modelling

5.2 Microscopic simulation data content

PT vehicle data

We do not consider here data related to the basic PT system management, that is to say the PT route description and the timetable, which are supposed to exist already, as far as those vehicles are modelled by the traffic simulation.

- vehicle identifier
- type of positioning system (Relative, Absolute or None) ; depending of the type :
  - relative (odometry) : statistic localisation error parameters : mean and standard deviation values for the localisation drift, in metres per kilometre.
  - absolute (GPS) : mean and standard deviation of the absolute positioning error, in metres.
- communication process : through detectors, or at a given rate (seconds)

PT detector data

PT priority detectors should be considered as active detectors, which start up a dialogue with detected vehicles belonging to a specified category. The following field should be added to the ones defined in the *Detectors* update specifications :

- detected vehicle type

5.3 Exchange data description

PT message

The content of these messages will depend upon the type of strategy to be tested, and consequently upon the nature of the detectors. The following items can thus be included (for the case of buses):

- bus identification
- detector identification
- detection time
- bus stop departure time
- turning signal
- bus localisation
- ahead or behind time schedule

initialisation data

- PT schedule description

5.4 Data communication process

The same recommendations as those given for *Adaptive Traffic Signals* hold. As far as data exchange rates are concerned, PT messages will be generated at a lower rate than the one associated with ordinary traffic detector messages.

These recommendations should especially guarantee that the traffic simulation and the external strategies involved share a common PT system description database.

5.5 Interface description

As in the case of *Adaptive Traffic Signals*, the use of a graphical editor does not seem to be crucial to supply the above data to the model. If available, it will be nevertheless helpful to enter the detector data (especially location). Outputs will either be additions to the current text outputs or additions to the animated graphical displays or both.

Text inputs. Buses and PT detectors data will be allowed to be entered by using a standard text editor.

Text outputs. The user will have the option of asking the model to produce the following text outputs (similar to those of the *Adaptive Traffic Signals* update specifications, adding separate and complementary results for buses) :

- for each traffic light controlled by the external strategy
  - the mean, minimum and maximum cycle time values observed per time slice and over the simulation period
  - the mean, minimum and maximum green time values observed per time slice and over the simulation period
- for each intersection related to the above mentioned controllers
  - the total time spent by the vehicles on the input links of the intersection per time slice and over the simulation period, per vehicle category (buses and others)
- for each input link of the intersection
  - the mean speed observed on the link per time slice and over the simulation period
  - the maximum queue length value observed on the link per time slice and over the simulation period
- for all the intersections controlled by the external strategy
  - total time spent by the vehicles on the input links of this set of intersections, per vehicle category, and total throughput per time slice and over the simulation period
- for the whole simulated network
  - total time spent by the vehicles in the network per time slice and over the simulation period, per vehicle category
- for buses only
  - travel times between bus stops and from terminus to terminus per time slice
  - regularity indicators (mean and standard deviation of ahead/behind of schedule times)

Graphical outputs. The animated display should be able to display an indicator (icon for example) showing which traffic lights are controlled by an external strategy. When a detailed timetable is available, the display could also indicate the status of the bus relative to its predefined schedule (behind or ahead), using for example a change of colour. Bus detectors should also be differentiated from other detectors.

An interesting graphical (but not animated) output is the time/space representation of bus trajectories belonging to a given route. The superposition of the simulated graph and the theoretical one given by the timetable can constitute a relevant qualitative performance indicator for the simulated strategy.

5.6 Functional description

A PT priority strategy being a special kind of adaptive strategy, it should use the same protocol as the one described in the *Adaptive Traffic Signals* update specifications to control traffic lights in the microscopic traffic simulation. In the same way, bus priority detectors have to comply with the general framework described in the *Detectors* specifications.

The PT priority model which is developed must be able to represent different kinds of data exchange schemes with an external strategy using specific detectors. The bus model has to be completed with localisation process modelling (odometry, GPS). The external PT priority strategy must be able to comply with the signal settings specifications previously defined, or to communicate with the an external UTC strategy in order to apply the new settings on the network.

5.7 Restrictions and limitations

These specifications should allow the implementation of a very large variety of PT priority systems, including different bus positioning systems modelling (absolute or relative). The only limitations come from the fact that the external PT strategy should comply with the *Adaptive Traffic Signals* specifications for traffic light control.

5.8 Performance requirements

The standard performance requirements of the SMARTEST modifications are to apply.

5.9 Verification tests

To check that the PT priority model is working as specified, scenarios are to be generated which allow a set of checks to be made. This set includes of course those already mentioned for *Adaptive Traffic Signals* and *Detectors*, but also the following complementary ones :

that the bus positioning system (if relevant)

- delivers position estimates in conformity with the specified statistical parameters
- sends the localisation messages to the associated detectors or at the predetermined rate

that the bus detectors

- collect the predetermined set of parameters from the bus
- deliver the correct messages to the external strategy

5.10 Validation criteria

If available, data from real life operation of bus positioning systems can be used for the validation of the modelled system. Concerning the specific detectors used for PT priority, the same validation process as the one presented in the *Detectors* chapter applies. As for *Adaptive Traffic Signals*, we do not consider here tests related to the external strategy itself or to the chosen communication process.

5.11 References

Henry J.J. and Farges J.L., PT priority and PRODYN, Proceedings of the 1st world Congress on Application of Transport Telematics and Intelligent Vehicle Highway Systems, vol 6, ERTICO (Ed.), pp 3086-3093, 1994

6. PARKING MANAGEMENT

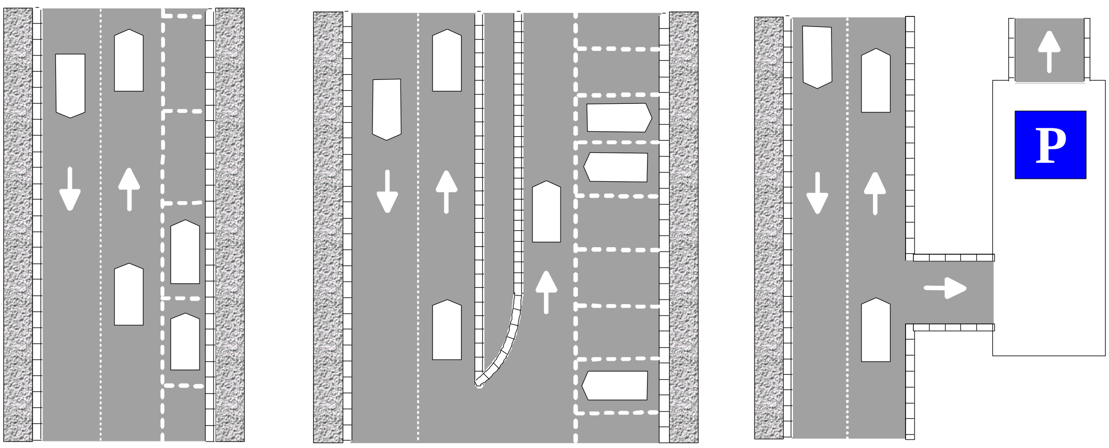
6.1 Introduction

Despite the fact that car parks have existed for many years and that parked is the most common vehicle position, parking management has received low attention in micro-simulation models. Indeed searching for a parking space and getting in or out of a parking space influences traffic conditions.

There are three main types of car park (see Figure 18):

- The first is located along the roadside and drivers usually arrive at reduced speed looking for a parking space. Getting in or out of this type of parking space usually requires a manoeuvre that can influence the behaviour of traffic in the vicinity of the car park.
- In the second type of car parks, parking is organised along a parallel road that is connected to the main road by an entry point and an exit point. Queue spill back in the car park can influence traffic behaviour in the main lane near the entry point. Priority signs or traffic lights exist at the exit point to control vehicle insertion from the car park to the main lane. Note that drivers can enter this type of car park and get out of it a short time later if no parking space is available.
- The third type of car park is connected to the road by an entry lane and an exit lane. They can be for example underground or multi-storey car parks. Queue spill back on the entry lane can influence traffic behaviour. The exit lane is generally controlled by a priority sign or a traffic light. Note that the entry lane and the exit lane may not be connected to the same lane and that many entry lanes and exit lanes can exist.

Car park types



Along the roadside (a) **With parallel lane (b)** **With entry and exit lanes (c)**

Figure 18: car park types

Other car park features are interesting to consider:

- public car parks, that can be accessed by all types of drivers
- private car parks, where access is restricted to some types of drivers

These two types of car parks influence driver behaviour in search of a parking space. A driver who can access a private car park does not look for a parking space since this driver goes directly to the car park and uses a reserved parking space. A driver who uses public car parks is never sure of finding a parking space in the car park he/she intends to enter. This driver is really looking for a parking space and can spend some time in the same area driving around the network trying to find one. Note that some public car parks offer subscription systems or reserved parking spaces that make drivers who use them the same as private car park users.

Parking style is another car park feature that influences traffic behaviour near parking spaces. It concerns access to the parking space. Three parking styles can be identified (see Figure 19).

- perpendicular to the pavement: for this type of car park, vehicles can park forward in and then reverse out. The other possibility is to reverse in and then go out forwards. The reverse in and reverse out manoeuvres can be supposed to take from 4 to 10 seconds while the forward in and forward out manoeuvres only require from 2 to 5 seconds.
- along the pavement: in this case, vehicles generally reverse into the parking space and go forward out of it. If the available place is sufficiently wide (e.g. if two adjacent parking spaces are free) vehicles can sometimes park by going into the space forwards. It can be supposed that a vehicle never reverses out from this type of parking space. The reverse in manoeuvre can be supposed to take from 4 to 10 seconds while the forward in and forward out ones require from 2 to 4 seconds.
- at an angle to the pavement: in this case vehicles go forward into the parking space and then reverse out. The reverse out manoeuvre can be supposed to take from 4 to 10 seconds while the forward in manoeuvre requires from 2 to 4 seconds.

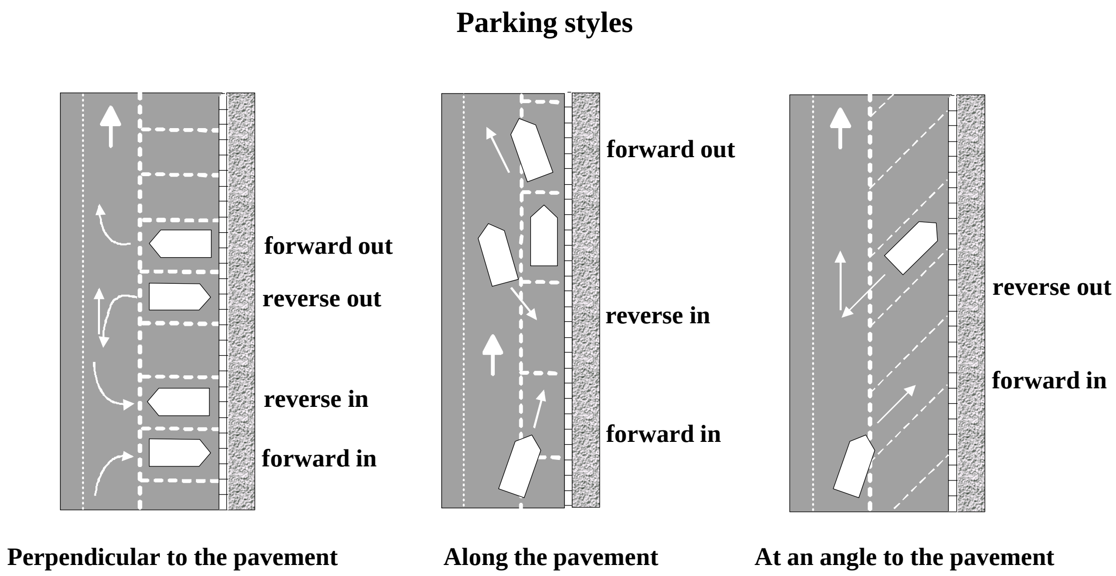


Figure 19: parking styles

The parking management model supposes that the micro-simulation model will provide appropriate vehicle assignment. The definition of vehicle destinations, typically output nodes of the network, need to be extended to cover the different behaviour of drivers whose destination will result in them parking. Before arrival at this output node the vehicle can spend some time within car parks, that can be considered as intermediate destinations, and need to be included in the vehicle assignment model. Note that this destination may be a car park but can also be a series of links where access to many car parking spaces is possible (in fact it is an area that a driver thinks is an acceptable area to park in). New assignment may also have to be computed during the micro-simulation run. This is the case if driver does not find any available parking spaces where he/she planned to park or if information provided by Variable Message Signs (not necessarily related to car parks) make parking impossible in the planned area (or in the planned car park). To prevent difficult situations that inappropriate assignment may produce, it may be necessary to generate fewer vehicles in search of a parking space than available spaces in the network or to provide an artificial mechanism to solve such problems if they occur. Anyway, vehicle assignment is not the purpose of the parking management model. The intention was to emphasise the importance of this point.

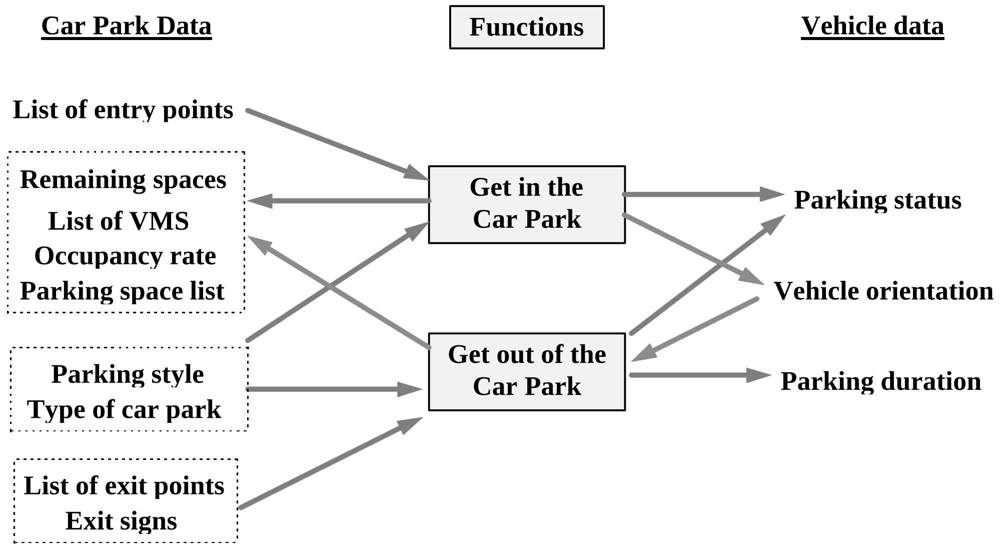
6.2 Data flows and content

The parking management model requires two types of data: car park data that describe car park features and vehicle data that give vehicle information related to parking.

Car park data

- Size of the car park: total number of parking spaces
- **Type of car park**: along the roadside, with a parallel lane or with entry and exit lanes
- **Parking style**: perpendicular to the pavement, along the pavement or at an angle to the pavement; not applicable to car park with entry and an exit lanes.
- Vehicle type authorised to park
- **Parking space list**
- Initial available number of parking spaces: available parking spaces at the beginning of the simulation
- **List of Variable Message Signs** that give real-time information about the car park
- **Occupancy rate** data: parked vehicle count over total available parking spaces
- Authorised maximum parking duration, if any
- Type of **exit signs**: priority sign, stop sign or traffic light, if any
- Public or private car park: a car park is considered to be private if access to all parking spaces is restricted. If not, it is considered as public and the following data need to be provided:
  - number of parking spaces with a reserved access or submitted to subscription
  - number of **remaining parking spaces** that are currently available (real time information)
  - number of remaining free of charge parking spaces
  - number of remaining charged parking spaces
- cost of parking
- **List of entry points**; for each of them:
  - entry point identifier
  - for each lane from which access to the car park is possible:
    - lane identifier
    - location from the beginning of the lane
    - side of the lane where the entry point is located (left or right)
- **List of exit points**; for each of them:
  - exit point identifier
  - lane identifier
  - location from the beginning of the lane

Note that a car park along the roadside can be considered to have one entry point given by the location of its first parking space and one exit point given by the location of its last parking space. Given the car park size (number of spaces) the entry point and exit point locations, an entry point and exit point location can be computed for each parking space.



Vehicle data

- **Parking status**: currently in a parking space or not
- Parked **vehicle orientation** (not applicable to car park with entry and exit lanes)
- Final destination: typically an output node of the network
- Intermediate destinations: for each destination
  - List of car parks and of areas that driver wants to access
    - Parking identifier if the vehicle has a subscription or a reserved parking space
    - Destination area if not: list of link identifiers
  - Trip purpose: the objective of the trip (work, home, shopping...) gives an indication on the expected parking duration
  - Planned parking duration: parking duration computed from trip purpose at the parking entry applying a random variation. It is the time that vehicle will stay in car park. It is used to determine car park exit time.
  - Effective **parking duration**: time spent parking

6.3 Interface description

The above data need to be supplied to the model. This can be done either via text inputs using an editor or by using a graphical network builder. Outputs will either be additions to the current text outputs or additions to the animated graphical displays or both.

Text inputs. The user will be allowed to enter the car park and vehicle data by using a standard text editor.

Graphical inputs. If a graphical network builder is available to create the network files then the car park data might be entered as follows:

- the location of the car park entry point is specified by clicking on a link at the required location
- the user then selects other entry point locations by clicking on links
- the same procedure is repeated for exit point location
- the location of variable message signs related to the car park, if any, is specified by clicking on links at the required location
- other car park data is then specified via a pop-up box which appears when the car park is double clicked

Text outputs. The user will have the option of asking the model to produce the following text outputs:

- for each car park
  - the occupancy rate over the simulation period
- for each vehicle that searched for a parking space (several searches may exist)
  - total time spent parking
  - total time spent looking for parking space (0 for each private search)
  - list of car parks where vehicles parked, time spent parking in each of them and time spent searching for each parking space
  - number and identifiers of public car parks unsuccessfully explored
- for the overall simulation (all vehicles and all searches)
  - total time spent parking
  - total time spent searching for a public parking space

Graphical outputs. If an animated graphical display is used to show the simulation progressing then it should be possible to have the following information included in the displays:

- for each car park
  - symbol to identify the car park
  - current number of available parking spaces (displayed near the car park symbol and near related VMS symbols)
  - an option to display the occupancy data over time via a graphical representation
- an option to display with a different colour vehicles in search of a parking space
  - vehicles that intend to park in a selected car park
  - all vehicles that intend to park in a selected area

6.4 Functional description

The parking management model which is developed must be able to represent traffic behaviour near car park entry points and exit points. This requires the development of two models: the get in a car park model and the get out of a car park model.

The get in a car park model

This model describes how the entry of drivers in car park influences traffic.

Car park of type a: along the roadside
The driver in search for a parking space slows down before the beginning of the car park and then drives slowly through the car park. Manoeuvring into the parking space then depends on the parking style as previously described and on the final vehicle orientation. During the manoeuvre, other vehicles can overtake.[1]

Car park of type b: with parallel lane
In this type of car park, the driver gets in the parallel lane at the entry point. He/she drives slowly in this lane looking for an available space. If no place is available, the driver gets out of the car park a short moment later. If a parking space is available, manoeuvring depends on the parking style and on the vehicle final orientation. This manoeuvre influences other drivers in the lane who have to stop and to wait for the vehicle to park. Note that queue spill back may occur on the main lane due to vehicle manoeuvring in the parallel lane.

[1] This suppose the existence in the vehicle movement model of an overtaking model possibly using adjacent lanes.

Car park of type c: with entry and exit lanes
Drivers get into car parks of type *c* using the entry lane. When the car park is full no entrance is possible. This is indicated by a sign near the entry point that makes the driver stay in the initial lane and to continue the search. When entrance is possible, driver slows down, has to stop in the car park lane to register if parking is not free of charge and enters in the car park itself. Several vehicles can wait for entrance and a small queue can form in the entry lane and possibly spill back on the main lane.

The get out of a car park model

This model describes how the exit of drivers from car park influences traffic.

Car park of type a: along the roadside
The driver who leaves a parking space of type *a* has to wait for a sufficient gap to appear in the traffic stream. This gap has to be computed depending on the parking style and on the vehicle orientation in the parking space.

Car park of type b (with parallel lane) and car park of type c (with entry and exit lanes)
Exit lanes of car parks of types *b* and *c* have a sign that can be a yield sign, a stop sign or a traffic light. Driver behaviour at these signs is generally considered in micro-simulation models and is not described here.

6.5 Restrictions and limitations

The parking management model is not intended to describe driver behaviour inside a car park or on a parking space. Phenomena such as vehicles parked on two parking spaces, parked on pavements or parked for longer than the authorised parking duration cannot be considered (illicit double-parking may be modelled by incidents).

Another limitation concerns driver behaviour near car parks. In the model, a parking space is considered available as soon as a vehicle completely leaves it. In fact, a driver can wait on the road for a space to become available, whether someone is leaving a space or not. This behaviour is not considered here.

In real traffic conditions, drivers may sometimes pass through an opposite lane to park in a parking space located on the other side of the road. In the same way, drivers who get out from a parking space may pass through a lane to move into the opposite one. These types of manoeuvre are not authorised in the parking management model.

The search for a parking space model is to be applied to drivers who have a good network knowledge. If this is not the case, drivers are supposed to be occasional car park users and would probably follow information given by car park related Variable Message Signs or by other roadside signs. This type of driver has not been taken into account for the parking management model.

6.6 Performance requirements

The standard performance requirements of the SMARTEST modifications are to apply.

6.7 Verification tests

To check that the parking management model is working as specified, scenarios are to be generated which allow the following checks to be made:

that vehicles

- get in car park if parking space is available
- do not get in car park if no space is available or if it is not authorised to (vehicle type not admitted, expected parking duration too long)
- get out of car park
- can get in car park along the roadside and get out of it a short moment later if no space is available
- stop or slow down if another vehicle is manoeuvring in front of it to get in or out of a parking space
- can possibly pass a manoeuvring vehicle

and that

- the current number of available parking spaces decreases (respectively increases) when vehicles get in (respectively get out) car park
- occupancy rate data changes reflect the current car park status

6.8 Validation criteria

The model can be validated using the following data sets:

- car park occupancy rate data
- average travel time of vehicles in search of parking space
- average of other vehicle travel times down links containing car park entry points

6.9 References

Bernd Reich and Friedrich Hanish, *"Joining forces. Integrating parking guidance and traffic management"*, Traffic Technology International 97, UK & International Press, pp 36-37.

Eamonn Griffith, *"Demand parking management system in Dublin"*, Traffic Technology International 95, UK & International Press, pp 122-124.

W. Young, *"Planning and design for parking"*, Traffic Engineering Practice, 4th edition, Department of Civil Engineering, Monash University, 1989, pp 229-250.

M.A.P. Taylor and W. Young, *"Traffic and parking surveys"*, Traffic Engineering Practice, 4th edition, Department of Civil Engineering, Monash University, 1989, pp 412-432.

7. DETECTORS

7.1 Introduction

These variables are useful for network knowledge, traffic management, user information, toll gate management and violation suppression. In micro-simulation models, many of these variables are provided as simulation results and modelling vehicle detectors could appear to be of little use. Nevertheless one of the objectives of micro-simulation models is to test control and information strategies that are based on variable measurements. These strategies could benefit from realistic modelling of vehicle detectors.

In this context it is interesting to define the passive or the active nature of detectors. Passive detectors take variable measurements and do not exchange data with vehicles. Active detectors take variable measurements or receive information from vehicles and can also send information to vehicles. They exchange data in a bilateral way and can be used for example in dynamic route guidance.

There is a broad range of variables for which it is possible to obtain measurements via detectors. It covers various types of strategies that can be implemented in micro-simulation models. Passive detectors can provide measurements of **real variables** such as:

- traffic volumes, flows and concentrations
- occupancy
- vehicle speed
- gap times and headways
- vehicle length, width, height and weight
- lane changes
- vehicle turns
- queue length
- travel time (between measurement sites)

or can provide measurements of **traffic events** such as:

- stationary traffic
- incident detection, inverse direction
- vehicle presence
- bicycle detection
- vehicle classification (car, bus, truck, ...)
- violations such as exceeding the speed limit or jumping red lights
- on street parked vehicle

Active detectors can exchange data such as[2]:

- travel time
- origins and destinations
- information on accidents or congestion
- guidance information

[2] See the Dynamic Route Guidance specification section to obtain more details about the kind of information that can be exchanged between vehicles, vehicle detectors and control centres.

Currently available detectors that can measure these data include induction loops, Doppler effect radar, ultra-sonic sound detectors, cameras and image processing systems, etc. Obviously, vehicle detector modelling cannot be limited to this detector type list. In order to obtain general detector modelling possibilities it is interesting to consider a vehicle detector as a device that provides measurements of variables that have to be selected by the user. In this case the detector technology does not matter and the interest for micro-simulation models lies in the data that can be measured and exchanged.

7.2 Data flows and content

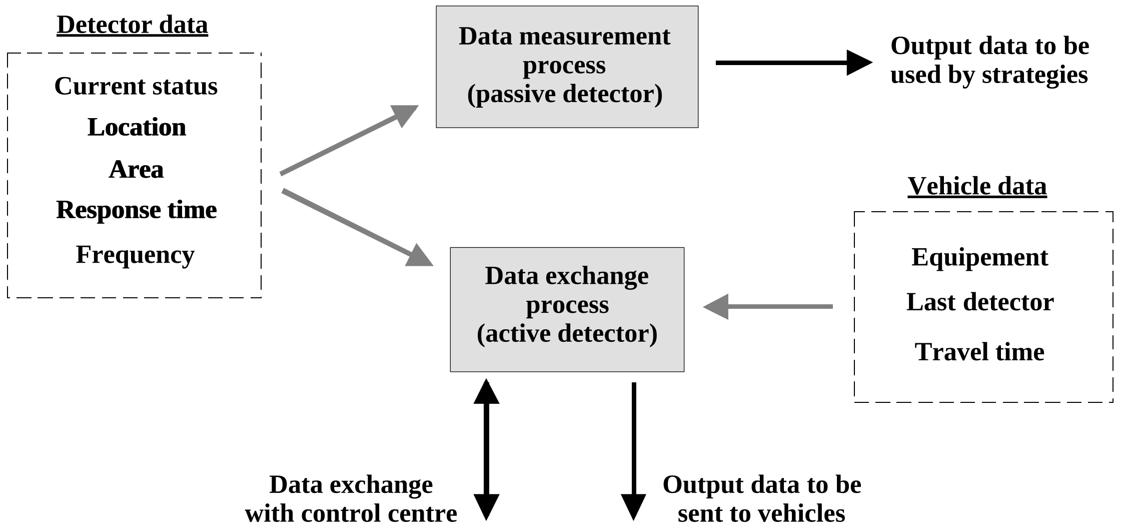
Detector data

- Detector identifier
- **Control centre** identifier: active detectors may be grouped together so that they all can exchange some centralised information like accidents, congestion or travel times. This information can be communicated to vehicles.
- Detector **type**: active or passive
- **Current status**: operational or broken down
- **Location**
  - link identifier
  - location from the beginning of the link
  - length of the measurement or the exchange **area**
  - list of lanes of the link from which data can be collected (links may have several lanes and detectors may not measure data on all of them).
- Data collection **frequency**: not applicable to active detectors
- **Response time** (can be used for traffic event detection since such detection sometimes requires further data processing)
- For each measured or exchanged variable
  - Variable name (see the previous description)
  - Error rate

Vehicle data

- Type of on-board **equipment**
- **Last detector** encountered
- **travel time** since last encountered detector

Note: vehicle detectors are supposed to measure data during the whole simulation time span, except if a breakdown is simulated. It should be possible to simulate these breakdowns while the simulation is running.



7.3 Interface description

The above data needs to be supplied to the model. This can be done either via text inputs using an editor or by using a graphical network builder. Outputs will either be additions to the current text outputs or additions to the animated graphical displays or both.

Text inputs. The user will be allowed to enter the detector data by using a standard text editor.

Graphical inputs. If a graphical network builder is available to create the network files then the detector data might be entered as follows:

- the location of the detector is specified by clicking on a link at the required location
- the user selects the detector type and the associated control centre if any
- the user selects variables that can be measured or exchanged with the detector
- other detector data are then specified via a pop-up box which appears when the detector is double clicked
- a pop-up dialogue box has to be provided before and during the simulation to enter detector breakdown data

Text outputs. The user will have the option of asking the model to produce the text outputs specified in the section "introduction" for each detector following the data collection frequency. They are:

- real variable measurements
- traffic event detection
- information exchanged by active detectors

Graphical outputs. If an animated graphical display is used to show the simulation progressing then it should be possible to have the following information included in the displays:

- for each detector
  - symbol to identify the detector: all detectors of the same type have the same graphical representation
  - symbol to indicate the detector current status: operational or broken down

7.4 Functional description

The vehicle detector model which is developed must be able to represent the data measurement process and the data exchange process during simulation.

The data measurement process

The data measurement process concerns passive detectors. It consists in computing measurement values and in writing them in output files that can be used by control or information strategies. This process can be described by the following for each passive detector and for each simulation step:

- check the detector status to see if measurement operation is possible (no breakdown)
- determine which variables have to be measured and
  - for **real variables**: increment variable counts according to the measurement area
  - for **traffic events**: determine if the event to measure occurred in the measurement area and in that case store its occurrence date
- check if it is time to write measurement values according to the detector frequency and in that case
  - for **real variables**:
    - compute average values and apply a random variation according to the error rate
    - write **real variable** measurements
  - for **traffic events**:
    - apply to event occurrence a false alarm probability given by the error rate
    - write **traffic events** according to detector response time

The data exchange process

The data exchange process concerns active detectors. It defines the information exchange between detectors and vehicles but also between detectors and the control centre to which detectors are connected. This process can be described as follows for each active detector and for each simulation step:

- check the detector status to see if measurement operation is possible (no breakdown)
- for any equipped vehicle into the exchange area and that has not already exchanged data with the detector
  - get vehicle information (origin, destination, route, travel time since the last encountered detector...)
  - send information to the vehicle
- exchange data with the control centre to:
  - update information on traffic events, travel times, ...
  - send information on the encountered vehicles (routes, travel times, ...)

7.5 Restrictions and limitations

The vehicle detector model is not a detailed representation of detector performance. The interest for micro-simulation models is to have a variable measurement model on which to test control and information strategies. Interesting detector features to model in this context are breakdown probability and measurement error rate.

7.6 Performance requirements

The standard performance requirements of the SMARTEST modifications are to apply.

7.7 Verification tests

To check that the vehicle detector model is working as specified, scenarios are to be generated which allow the following checks to be made:

that

- **real variable** measurements are performed as specified
- **traffic event** detection occurs according to detector response time and data collection frequency
- during detector breakdown, no data measurements or exchanges are performed
- error rate is correctly applied to **real variable** measurements and to **traffic event** detection compared to the values "without error" given by simulation

7.8 Validation criteria

Output data provided by the vehicle detector model are directly related to simulation result. The output data validation part of the detector model validation is then similar to the simulation model validation and is not considered here. The other validation part of the detector model concerns error rate and breakdown occurrence. The following data sets can be used for validation:

- technical performances of each detector type
  - detection rate
  - false alarm rate
  - false alarm frequency
  - detection time
  - breakdown probability
- data issued from traffic control centre
  - breakdown history for each detector type
  - currently number of broken down detectors
  - actually installed detectors

7.9 References

Traffic Technology International 97, *"Section 2, Field equipment, integration and control"*, UK & International Press, pp 91-206.

Traffic Technology International 96, *"Section 2, Surveillance, Incident detection and Roadside Technology"*, UK & International Press, pp 105-266.

Yves David, Laurent Bréheret, *"Exploitation des transports de surface. Etat de l'art"*, Rapport SODIT, April 1997, unpublished document.

8. VARIABLE MESSAGE SIGNS

8.1 Introduction

The main objective of the use of Variable Message Signs for traffic guidance is to support drivers by dynamic and collective information about suitable directions to reach their destinations.

Within the extensive concept of Collective Traffic Information, the purpose of variable message signs is to provide drivers with information of general interest concerning current and foreseen problems in the network - such as roadworks and limitations to traffic circulation. This information does not necessarily include suggestions about the route to follow.

Focusing on Collective Traffic Guidance applications, a significant influence on traffic behaviour is achieved by placing the signs at strategic points of the road network, in such a way as to intercept main traffic flows, and then by providing additional information on the *causes of the diversions* when the directions suggested differ from those "normally" chosen by traffic on the basis of the network knowledge, or from those suggested by static signs.

Strategies for urban (and sub-urban) Collective Traffic Guidance based on the use of VMS are being developed, verified and demonstrated in several European "city laboratories". The interest in collective guidance strategies comes primarily from their potential capability to contribute to the prevention and reduction of congestion in urban areas, by means of specific actions such as:

- diverting traffic flows from critical zones
- suggesting preferential routes and reducing driver uncertainty when choosing between alternatives
- directing vehicles towards parking areas where parking spaces are available
- by providing additional information about the underlying reasons behind the suggestions and recommendations.

Collective traffic guidance strategies are also interesting because they can be suited to co-operate with other traffic control strategies, such as in-vehicle information systems and traffic signal control systems, with the purpose of achieving common traffic management objectives. The implementation of such an IRTE - Integrated Road Transport Environment - has been taken up as a challenge in a number of urban areas throughout the world.

Micro-simulation models are well suited for performing the "verification" (operational tests and impact analyses) of guidance strategies. This practice normally requires the preparation of suitable simulation environments where the strategy (autonomous or integrated with other strategies) is implemented as a module apart from the micro-simulation traffic model, takes dynamic traffic data from this model and provides as a dynamic feedback the information to be communicated to traffic. Implications for the simulation environment are described in the subsequent section.

In the following sections some more details are provided concerning VMS characteristics.

The Variable Message Signs

In the field of Traffic Information and Control, Variable Message Signs are normally intended as roadside equipment, such as panels and displays, which are able to provide drivers with dynamic information and recommendations established by higher level strategies.

VMS' features (size, layout, technology) may differ significantly according to the environment (urban, extra-urban), the installation constraints and the application purposes (traffic information, traffic regulation, traffic guidance), but the information they communicate belongs to three general categories:

- information concerning current and forecast network conditions (provided by text messages and/or pictograms)
- suggestions about the direction to be followed to achieve specific destinations (expressed by text messages or by a combination of fixed and dynamic symbols and text)
- speed and traffic limitations (provided typically by pictograms).

In Figure 20 and Figure 21 the layout of a text based information panel is shown. In Figure 20 the panel shows a future date when an area should be avoided. In Figure 21 information is shown about a current event. These kinds of panel are planned for example in London and Gothenburg.

MON 9 NOV

10AM - 1PM

WHITEHALL

AVOID AREA

Figure 20: Variable Message Sign planned in London - Calendar information

STAMFORD HILL

CLOSED

LONG DELAYS

Figure 21: Variable Message Sign planned in London - On event information

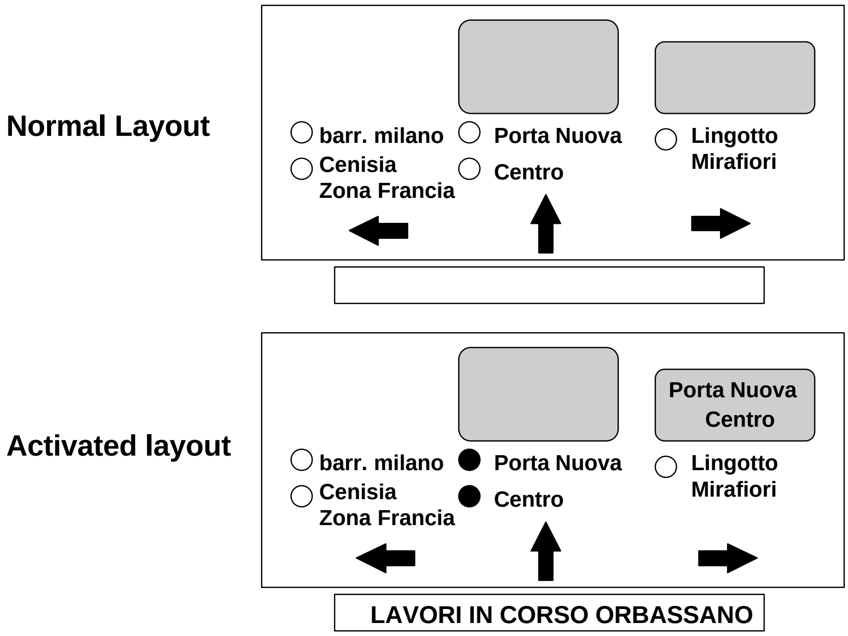


Figure 22: Variable Direction Sign panel adopted in Turin for collective traffic guidance.

The panel represented in Figure 22 is based on rotating prism technology for the main board and also features an additional one line display. Destinations for which diversion is suggested are presented dynamically on the yellow rotating prisms. Warnings are also provided by amber lamps blinking alongside the default directions. The LED display can present a message giving the reason for the suggested diversions.

Figure 23: Variable Direction Sign panel adopted in Turin for Parking Guidance

The panel shown in Figure 23 is designed to guide traffic towards controlled parking areas. This kind of panel is used in Torino.

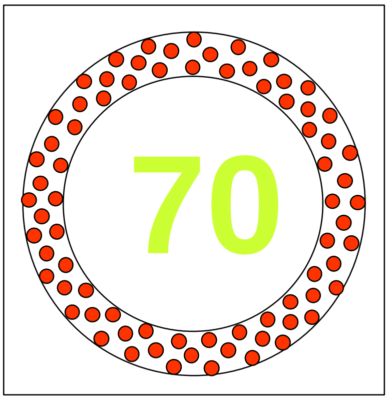


Figure 24: Variable Message Sign panel adopted in Turin for Traffic Calming strategies

The panel shown in Figure 24 is designed to provide recommendations such as speed limitations. This kind of panel has been used in Torino for traffic calming measures.

The VMS which are relevant for the actuation of collective traffic guidance strategies correspond to those represented in Figure 22 and Figure 23. They are also said to be VDS - Variable Direction Signs - given that they provide information that can help drivers select a route for their destination directly.

The Simulation Environment

Collective traffic guidance modelling involves four different aspects:

- the development of the module which performs the collective traffic guidance strategy
- the representation of the infrastructures (VMS) which are located in the network
- the extension of the driver behaviour model to include the interaction with VMS
- the development of the interface between the network/traffic model and the guidance strategy module.

A general architecture of the simulation environment is represented in the following scheme.

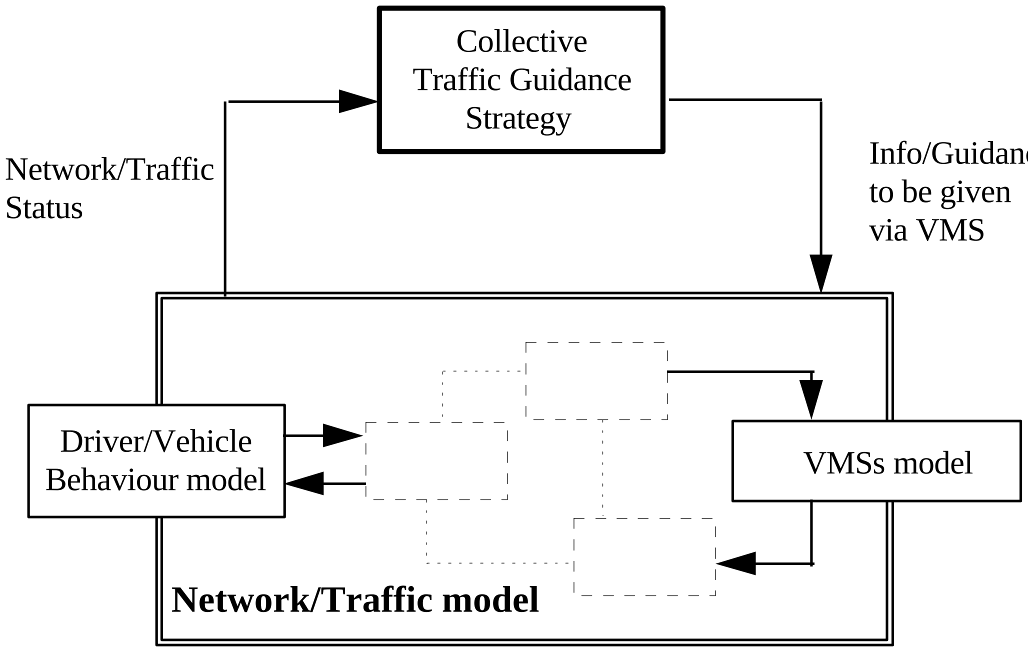


Figure 25: General organisation of the Simulation Environment

In this scheme only the functions that are relevant for the discussion are outlined. The Guidance Strategy is considered as a function outside the network/traffic model to which the Strategy is assumed to be connected through a suitable interface.

VMS and driver interaction models are assumed to be integrated within the network/traffic model because of their direct links respectively with the network and the vehicle behavioural models that are already important components in any micro-simulation model.

In any case these hypotheses do not affect the generality of the specifications.

In order to specify the data flows and provide functional descriptions, some additional basic concepts must be described concerning traffic guidance modelling.

Location of VMSs and influence on traffic

In real applications VMS are located and positioned in such a way to be read only by traffic running along a well defined link and according to a defined direction.

Therefore, in the network model the position of the VMS is identified by the oriented arc (in the following simply said "link") where the VMS is located and by its position within this arc.

Each VMS can address one or more pre-coded destinations. Obviously the VMS can influence only those drivers who are interested in the destinations addressed by the VMS. These drivers start adapting their behaviour according to the information observed on by the VMS after meeting the VMS itself. Normally this results in vehicles performing suitable turns along (for possible parking) or downstream from the link where they saw the VMS.

The driver/VMS interaction modelling requires the definition of:

- the VMS status, intended as the internal code representing the information being communicated to traffic
- the driver's "compliance" parameter, representing the level of compliance assigned to the single driver

Furthermore the drivers' behaviour modelling requires the implementation of a dynamic assignment of vehicle routes.

Possible solutions are outlined in the subsequent "functional description" section.

Micro-destination and Macro destination concepts

The destinations addressed by VMS are selected in such a way to meet the interest of main traffic flows crossing the sites where the signs are placed. Normally the destinations correspond to well-known zones of the city, car parks, sites of general interest, other cities.

Sometimes destinations correspond to the name of elements of the road network such as intersections and squares, but also in these cases they are used to identify larger zones in the same vicinity.

Therefore VMS control strategies must be able to model and elaborate traffic diversions towards destinations that in general correspond to groups of elements of the road network and that can be defined as "*macro-destinations*". Input of the control strategies are traffic data related in any case to elementary elements of the network (nodes and arcs).

On the other hand, the destination of the driver corresponds to a particular point (or limited zone) of the network. Normally, for micro-simulation purposes this destination is modelled in terms of nodes. Consequently, driver destinations can be defined as "*micro-destinations*".

So, a correspondence between macro and micro destinations must be defined both to implement the model of the interaction between drivers and VMS (the driver needs to identify the possible macro-destination which corresponds or includes his micro-destination) and to fix the area addressable by the guidance strategy by means of each VMS.

Defined:

- $\mathbf{d_i}$ the generic micro-destination
- $\mathbf{D_j}$ the generic macro-destination

The following table provides a correspondence suitable for a given VMS_1.

	d_1	d_2	d_3	d_4	d_5	$\mathbf{D_1}$
	d_6	d_7	d_8	d_9	d_{10}	
$\mathbf{D_2}$	d_{11}	d_{12}	d_{13}	d_{14}	d_{15}	
	d_{16}	d_{17}	d_{18}	d_{19}	d_{20}	
	d_{21}	d_{22}	d_{23}	d_{24}	d_{25}	

Macro-destination D_1 = aggregation of micro-destinations (d_4 , d_5 , d_9 , d_{10} , d_{14})
Macro-destination D_2 = aggregation of micro-destinations (d_{11} , d_{12} , d_{13} , d_{16} , d_{17} , d_{18})

The same macro destination can be addressed by different VMS, but due to the different VMS positions the common macro-destination could correspond to a different aggregation of micro-destinations. The following table presents a possible correspondence for VMS_2 :

				$\mathbf{D_1}$		
	d_1	d_2	d_3	d_4	d_5	
	d_6	d_7	d_8	d_9	d_{10}	
$\mathbf{D_2}$	d_{11}	d_{12}	d_{13}	d_{14}	d_{15}	
	d_{16}	d_{17}	d_{18}	d_{19}	d_{20}	
	d_{21}	d_{22}	d_{23}	d_{24}	d_{25}	

Macro-destination D_1 = aggregation of micro-destinations (d_9 , d_{10} , d_{14})
Macro-destination D_2 = aggregation of micro-destinations (d_{11} , d_{12} , d_{13} , d_{16} , d_{17} , d_{18})

Generalities on the Collective Guidance Strategy

In order to determine the network conditions and perform adaptive traffic guidance, the strategy needs

- to receive timely information on traffic status
- to run periodically and consequently update guidance recommendations.

Even if the detailed definition of the data required to represent the traffic status depends on the control strategy formulation, in general the information that can be considered relevant for any strategy can correspond to

- measures normally modelled by micro-simulation models, such as traffic counts, queues, travel times
- specific estimates introduced for the application, such traffic density, level of congestion and others

Information is normally required at the elementary level (network link) and on the basis of time periods depending on the strategy iteration time.

Furthermore, both current and forecast traffic data can be of interest. In the case where forecast data is needed, the prediction function can be included in the guidance strategy environment itself or demanded from the modules that normally collect data and perform statistics in the micro-simulation model context.

The guidance strategy module iteration time depends on two main factors:

- the module execution time
- the requirement to perform adaptive control in concert with the typical traffic variations of the network.

For application in an urban context, an iteration time ranging from 5 to 15 minutes is considered suitable.

8.2 Data Flows and Contents

With reference to the scheme of the simulation environment architecture, the relevant data flows are as follows.

Collective Traffic Guidance Strategy

- Input
  - Network description:
    links (code, capacity, physical characteristics)
    nodes (code, feasible turns)
    micro-origins, micro-destinations (code, type)
    park areas (code, entrance and exit locations, capacity)
  - Traffic demand (if required by the strategy)
    O/D matrix
    Nominal turning percentages per micro-destination
    Nominal flows on the links
  - Current & Historical Traffic Data
    Traffic counts, Travel Times, Density, Congestion levels
    and any other traffic parameter required by the strategy

for each link and time interval
- VMS description
  VMS identification (code, type, location)
  Addressable macro-destinations (code, alternative directions)
  Correspondence macro-destinations/micro-destinations
  Default status
  Current status

- Output
  - VMS status to be represented

Variable Message Sign

- Input
  - VMS description
    VMS identification (code, type, location)
    Addressable macro-destinations (code, alternative directions)
    Correspondence macro-destinations/micro-destinations
    Default status
    Current status
    Status to be represented

Driver/Vehicle Behaviour

- Input
  - VMS codes and locations
  - Correspondence between macro-destinations and micro-destinations for every VMS
  - Compliance rate (%, possibly defined per driver/vehicle class)
- Output
  Action undertaken (turn at the downstream node, entrance into the parking area, new route to the destination)

8.3 Interface Description

Most of the above input data need to be supplied to the model. This can be done either via text input using an editor or by using a graphical network builder. Outputs will either be additions to the current text outputs or additions to the animated graphical screen or both.

Text inputs. The user will be allowed to enter the VMS specific configuration data and the users compliance rates by using a standard text editor.

Graphical inputs. If a graphical network builder is available to create network files then the VMS characteristics might be entered as follows:

- The location of the VMS is specified by clicking on a link at the required location. As a consequence a pop-up a dialog window is activated to define VMS typology, code and position.
- VMS layout description can be done selecting a suitable panel from a panels database (a graphical editor has to be available to allow for new VMS definition if there is no suitable type already defined in the database).
- Addressable macro-destinations could be easy defined through an exhaustive combination of destination windows, colour windows and messages section status. Similarly possible directions

for each macro-destinations could be easily defined. Manual insert/modify/delete functions should be available to allow possible status set modifications.

- Default VMS status (if any) is then specified via a pop-up box which is activated when the VMS is selected.
- Macro-destinations/micro-destinations correspondence could be easily defined through an exhaustive combination of destination windows or by simply clicking on a graphical representation of the network on the screen.

Driver compliance rates could be entered/modified via a loading procedure activated as menu item.

Text outputs. For the "collective traffic guidance strategy" evaluation users need the following text output:

- global data:
  - global travel time
  - average speed on whole network
  - total distance travelled
  - total delay
- link / carriageway data:
  - travel time (mean value and standard deviation)
  - average speed
  - number of vehicle entered during the simulation
  - number of vehicle exited during the simulation
  - number of stopped vehicles
  - average delay
  - average occupancy (average number of vehicles / carriageway capacity)
- VMS link data:
  - number of vehicles which crossed the link
  - number of vehicles which received VMS suggestions (suggestions concern vehicle destinations)
  - number of vehicles which followed the recommendations (according to driver behaviour model)
  - number of vehicles that modified their route according to VMS suggestions

Graphical outputs. If an animated graphical display is used to show the simulation progress, it should be possible to have the following information included in the displays:

- On the VMS panel
  - VMS identificator
  - VMS status (if required on-line)
  - addressable macro-destinations (if required on-line)
- On the traffic
  - number of vehicles receiving VMS suggestion
  - number of re-routed vehicles

8.4 Functional Description

Collective Traffic Guidance Strategy

See the paragraph "Generalities on the Collective Guidance Strategy" of section *The Simulation Environment.*

Variable Message Sign

For the purposes of the Traffic Guidance strategy, the information provided by the VMS is relevant when it suggests diversions from the normal routes, that is from the routes that vehicles follow on the basis of the "knowledge of the network" they normally exploit to move towards their destinations, or from the routes suggested by static signals.

Given that the "default status" corresponds to the condition "no diversions to recommend", when the VMS is in this condition it has to be considered as if it was "not operational" or "not activated", that is vehicles should not care about it.

Two main types of VMS are considered:

- the generic Variable Direction Sign, which suggests the directions to follow in order to reach the destinations it can address
- the Variable Direction Sign specific for Parking Guidance, which suggests the direction to follow to reach a parking area under control and normally provides also information on the availability of parking spaces

For the former, the VMS status is defined only by the macro-destination addressed and by the directions suggested.

For the latter, the status contains also an information that can help the driver better decide how to proceed. This kind of VMS is meaningful only if the driver model features the management of the vehicle parking actions and if the simulation model supports parking area management.

A combination of these two types of VMS is possible and does not need further discussion.

A further type of VMS of possible interest for simulation, allows for the simulation of a message stressing the importance or the reason of the diversions suggested. In this case the VMS status definition requires only the addition of a condition flag (diversion with message "on" or "off") for each addressable destination. This kind of VMS can be useful for evaluating the impacts of several levels of driver compliance depending on the quality of the collective information provided.

Driver/Vehicle Behaviour

Some more details are provided in the following in addition to the considerations presented in paragraph "Location of VMS and influence on traffic" of section "*The Simulation Environment*".

In the field of the micro-simulation models two main methods are adopted to generate the route of the origin/destination vehicles:

- assignment of a route at the time of vehicle generation: the route is defined according to the origin and the destination selected for the vehicle and according to criteria which try to generate the nominal traffic conditions in the network
- random definition of the turn to perform at the downstream node every time the vehicle enters a new link. The turn is selected randomly on the basis of turning percentages defined by a suitable traffic assignment model run before simulation started. Turning percentages depend on the link and on the vehicle destination.

If the second method is adopted, the influence of the diversions recommended by the VMS is easy modelled by adapting the turning percentages related to the node downstream from the link where the VMS is located for the vehicles that are interested by the macro-destinations for which the diversions are suggested.

If the first method is adopted a recalculation is required of the route to be assigned to the vehicle interested in the diversion, starting from the link where the VMS is located.

In both cases:

- the compliance rate (static or dynamic) should be taken into account at first to define if the vehicle is interested or not in the VMS recommendations
- in case of VMS for parking guidance the driver interest depends also on the possible information on the availability of spaces in the desired parking area.

The driver behaviour model could be further improved by making the driver compliance depend on the distance (or foreseen travel time) between the VMS and the destination. The principle is: the longer the distance to travel higher the compliance rate. That is: in case the VMS informs the driver about a congestion along his route, if the distance remaining to travel is considerable the driver probably feels it would be dangerous to move towards the congestion. If the driver is close to his destination he probably feels only a small advantage would be gained by accepting the suggestion and probably he will ignore it.

8.5 Restrictions and Limitations

There are no major restrictions or limitations.

8.6 Performance Requirements

The standard performance requirements of the SMARTEST modifications are to apply.

8.7 Verification Tests

The model has to be checked against the following scenarios:

- Basic scenario (without control actions):
  - general traffic data (congestion detection)
- Basic scenario with Collective Route Guidance System ON:
  - compliance rate = 100%
  - compliance rate = 50%
  - compliance rate depending on drivers distance from destination.
- Incident Management:
  - compliance rate = 100%
  - compliance rate = 50%
  - compliance rate depending on drivers distance from destination.

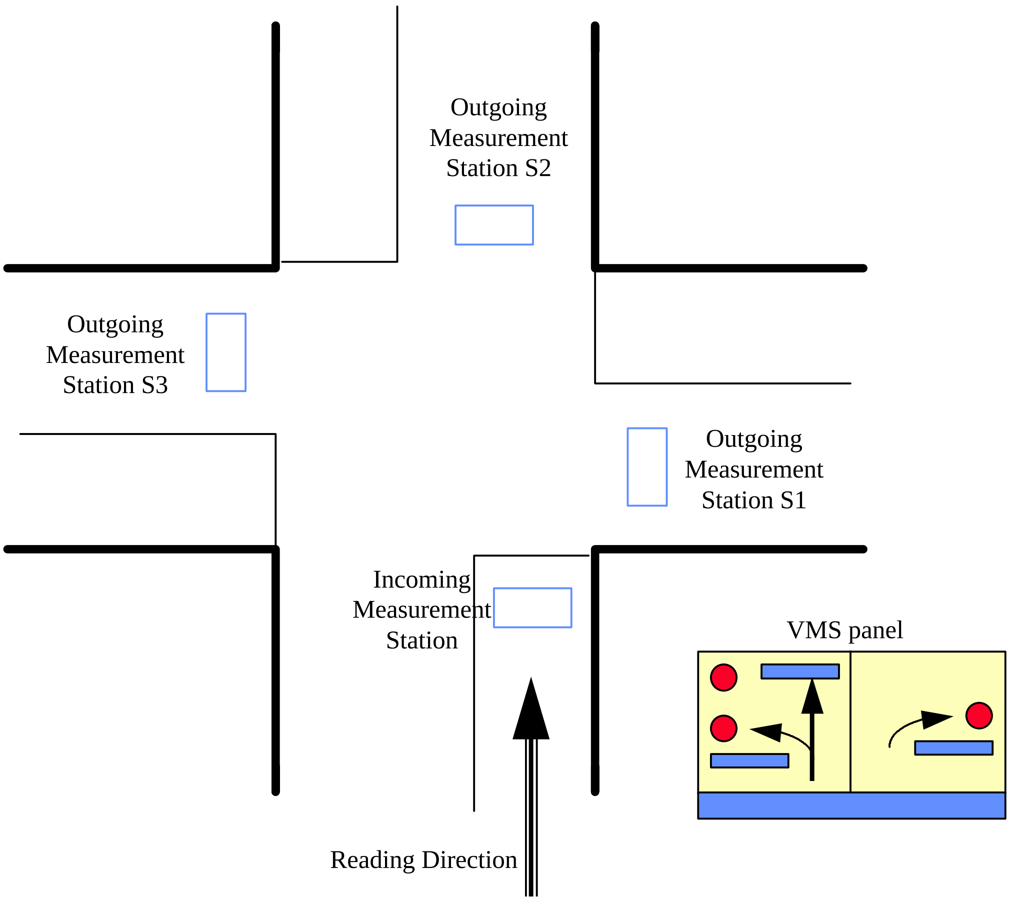
For each scenario, the following must be verified:

- actuated control strategy
- panel status
- number of vehicles which crossed the equipped links
- number of vehicles receiving VMS suggestion (suggestion concerned with their destinations)
- number of vehicles that complied with the suggestion (according to driver behaviour model)
- number of vehicles that modified their turning movement according to VMS suggestions

8.8 Validation Criteria

For Collective Traffic Guidance Strategies, user compliance is very important. Compliance rates can be validated by field trials and on the basis of two different methods:

- indirect method:
  compliance rates are computed on the basis of re-routed traffic flows.
  An ON/OFF approach can be used to gather traffic data in the two different operative conditions: system in operation (ON) and system not in operation (OFF).
  During OFF measurements, VMS must be non visible.
  Carriageways downstream to the link where the VMS is located must be equipped with traffic detector in order to gather traffic counts in both On and OFF conditions (see the following scheme). These values will be used to compute turning percentages.
- direct method:
  compliance rates are computed by direct interview of drivers downstream of the VMS.



9. DYNAMIC ROUTE GUIDANCE

9.1 Introduction

Collective and Individual Traffic Guidance are both recognised as kernel functions of Traffic Management, but while the former aims at supporting as much traffic as possible by supplying guidance information via collective information media (such as VMS/VDS panels), the latter operates on an individual basis, guiding a specific subset of vehicles - the vehicles equipped with suitable on-board devices - towards their destinations.

Individual guidance information is provided to the driver by means of acoustic, optical or combined technologies. The best solution has not been fixed yet and depends both on the type of information to be communicated and on safety issues. Currently most of the systems provide guidance indications superimposed on background map representations, and LCD displays seem to be the preferred solution adopted.

Individual guidance is provided according to static route definitions or dynamic route calculation. The dynamic solution is performed basing on current and foreseen traffic conditions and is more related to Traffic Management concepts.

Individual Route Guidance systems (in the following simply referred to as IRG) can be classified in several ways:

- according to the characteristics of the information used for route calculation:
  - <u>static</u>
  - <u>dynamic</u>

  Information includes essentially the network map and the representation of traffic conditions. Travel time, traffic density and congestion are the parameters normally adopted to represent traffic conditions in the network links and are the items typically subject to dynamic updating in the context of the dynamic IRG systems.

- according to the location of the "route calculation" function:
  - <u>autonomous</u>: the route choice is performed on-board the vehicle.

  Decisions are taken according to the current vehicle position referred to the digitised territorial map, following pre-defined routes or taking into account possible dynamic traffic information (congestion, incidents, flows or travel times according to the system) provided by broadcasting systems

  - <u>infrastructured</u>: the system operates based on two-way communication between on-board equipment and roadside infrastructure (such as infrared beacons) connected to a centre.

  The ultimate "route choice" is performed on-board the vehicle according to the driver destination, while the "route calculation" is preferably performed at the central level where dynamic traffic data are processed to update the network status estimate and to consequently optimise the routes for the possible O/D pairs. Decentralised solutions are also implemented which give the responsibility to the roadside infrastructure to tune route suggestions according to traffic conditions observed locally.

  When the vehicle enters the area influenced by the roadside equipment it receives the complete set of recommended routes to reach the possible destinations, and in the other direction it transmits data on the route taken (such as link travel times and queuing times). On-board equipment selects the route to be shown to the driver according to the destination declared. The vehicle receives further and possibly updated recommendations when it crosses the area of a new roadside equipment.

•dual-mode: it is a combination of autonomous and infrastructured systems.

The vehicle is able to perform the route choice on-board, based on the local data base and on the traffic information transmitted by the broadcasting systems. When it crosses the area of the road side equipment it exchanges data and performs as in the case of the infrastructured solution.

•according to the technical solution adopted for system-vehicle communication (dynamic guidance only):

•Short Range Communication based systems: communication performed by means of Infrared or Radio Beacons.

An example is the EUROSCOUT system. The first prototype was the Aliscout system operated in Berlin in the context of the LISB Project. Euroscout was then tested in Stuttgart in the context of the QUARTET Project. A decentralised solution is currently in operation in Turin.

Beacons are located about every 2km at some intersections. An equipped vehicle that arrives in a beacon range action (accuracy of 20 m) transmits a telegram including travel times and stop times of travelled links, and receives a local map that includes a set of routes calculated in the control centre (and possibly tuned locally). The route shown to the driver is selected according to his preferences and destination. The driver receives both audio and graphic information.

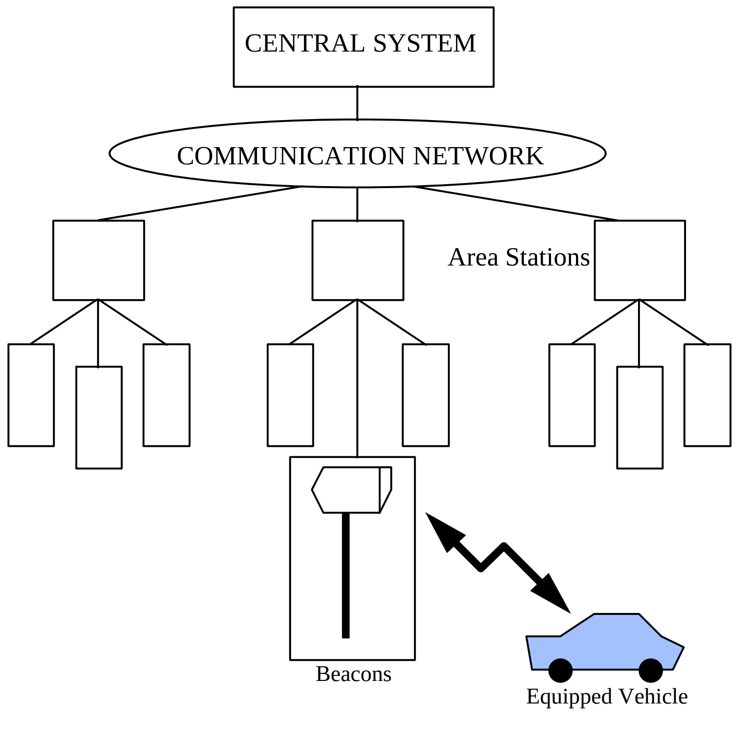


Figure 26: Infrastructured Route Guidance general architecture

The global map is located at the infrastructure level. Small streets are not modelled. Positioning is performed on-board using autonomous equipment (dead reckoning and map matching functions), and dynamically via beacons. Traffic data (from vehicles and other sources) are centralised and refreshed with a sample period of few minutes. They are used together with historical data to compute the optimal routes.

Mono-routing and multi-routing criteria are used to define routes. In the mono-routing concept only one route is suggested to the flow of equipped vehicles going to the same destination. In the multi-routing concept the flow is split on several paths according to possible (significant) alternatives.

•<u>GSM - based systems</u>: communication performed via cellular radio.

An example of a cellular radio system is SOCRATES, which communicates with on-board navigation systems CARIN. Experiments were conducted in Hessen (RHAPIT project), in London (APPLE project) and Gothenburg (TANGO project).

The central computer receives traffic data from traffic control systems (e.g. SCOOT in London APPLE project) and transmits data to vehicles equipped with a suited navigation system. Each time a vehicle leaves a link it sends its travel time and stop time on this link to the centre.

The GSM network, consisting of a base station at the centre of the cells and switching centres, insures the bi-directional transmission. GSM is not adapted to the transmission of routes. Indeed at the opposite of the SRC-based systems, the origin of the route is not given by the beacon position. Thus it would be necessary in a radio cell to send all routes beginning at all possible origins in that cell.

The system relies on the on-board navigation system. The map information is stored on a compact disk (CD) and supports possible parking guidance schemes. The route is computed on-board on the basis of the travel times received from the centre. The driver may receive audio, text information and graphics.

•<u>RDS - based systems</u>: communication performed via RDS/TMC channels.

Examples of existing systems are: CARMINAT, with experiments in Paris (CITIES project), DYNAGUIDE, with experiments in Gothenburg and Stockholm (CLEOPATRA project, and others, with experiments in Stuttgart (STORM project), Munich (COMFORT project) and Turin (QUARTET and QUARTET PLUS projects).

The infrastructure consists of VHF/FM transmitter stations connected to a central control room. The communication protocol between stations is well defined: information is coded in RDS/TMC standard ALERT C+ protocol. No communication is provided from vehicles to infrastructure.

Navigation is performed on-board. The on-board map can be simple or very precise, depending on the informatic support (CD, RAM, ...). Updating is performed via RDS or by purchasing a new CD. The driver may have to enter the current location of the vehicle or to be assisted by dead-reckoning, map-matching and/or even a global positioning system GPS.

Traffic data are collected by the centre from other traffic control and monitoring systems, filtered and updated frequently (some minute basis). They are then degraded by some levels because of the low capacity of RDS. The route is computed on-board using the updated data according to individual criteria.

The driver is informed of the turn to perform at the next junction both by graphic display and voice communication.

Project constraints

The interest in Individual Route Guidance systems simulation is due to the general opinion that this kind of system will soon become an important instrument for Traffic Management.

Interest is both in the possible impact of different systems features, architecture and penetration rates, and in the feasibility of integration of schemes involving IRG, UTC, VMS and other traffic and transport control systems.

It must be underlined that in this field results are expected only from the Dynamic IRG solutions, that is those normally referred to as DRG.

In the following we will focus on these kind of systems.

Some functions can be outlined that are relevant for the micro-simulation of IRG systems:

- Vehicle location:

This function is directly connected to the vehicle simulation task. It could be of some interest to simulate the effects of vehicle positioning errors.

- Route computation:

This is the fundamental function. It can be performed on-board or at a central level according to the system architecture. In any case it works on the basis of the traffic and network data set made available by the data filtering function

- Route choice:

  This function assigns the route to the vehicle choosing between alternatives (if any). It is performed on-board or at the infrastructure level.

- Data filtering:

  Data available by network and traffic micro-simulation must be managed and possibly aggregated according to the IRG models and features. Possible forecast functions can be included.

- Vehicle/Infrastructure communication:

  This function regulates the timing of the events related to communication processes. Simulation of delays in transmission links can be performed at this level.

- Equipped vehicle generation:

  An O/D matrix could be defined which differs from the O/D related to normal traffic. Furthermore, the penetration rate of the IRG system (ratio between the equipped and the normal vehicles) has to be modelled. Thus, a specific function is required to handle the generation of IRG vehicles.

- Driver compliance:

  This function represents the driver acceptance of the information provided by the system. Even if equipped vehicles are expected to perform according to the system for which they are introduced, the driver compliance simulation can help to better represent the driver behaviour.

The Simulation Environment

Individual route guidance modelling involves the following aspects:

- the development of the module which performs the strategy for route calculation according to the optimal criteria adopted
- the development of the module which performs the route choice for the single vehicle
- the representation of the communication infrastructures (if any) which are located in the network
- the extension of the driver behaviour model to include the interaction with the on-board equipment
- the development of the data filtering module that acts as the interface between the network/traffic model and the guidance strategy module.
- the development of the scheduler which defines the timings of exchange of information (if any) between vehicles and infrastructure
- the extension of the traffic model to include the new typology of equipped-vehicles, the related generation procedure and the connection with route choice activities.

A general architecture of the simulation environment is represented in the following scheme considering an infrastructure DRG system model.

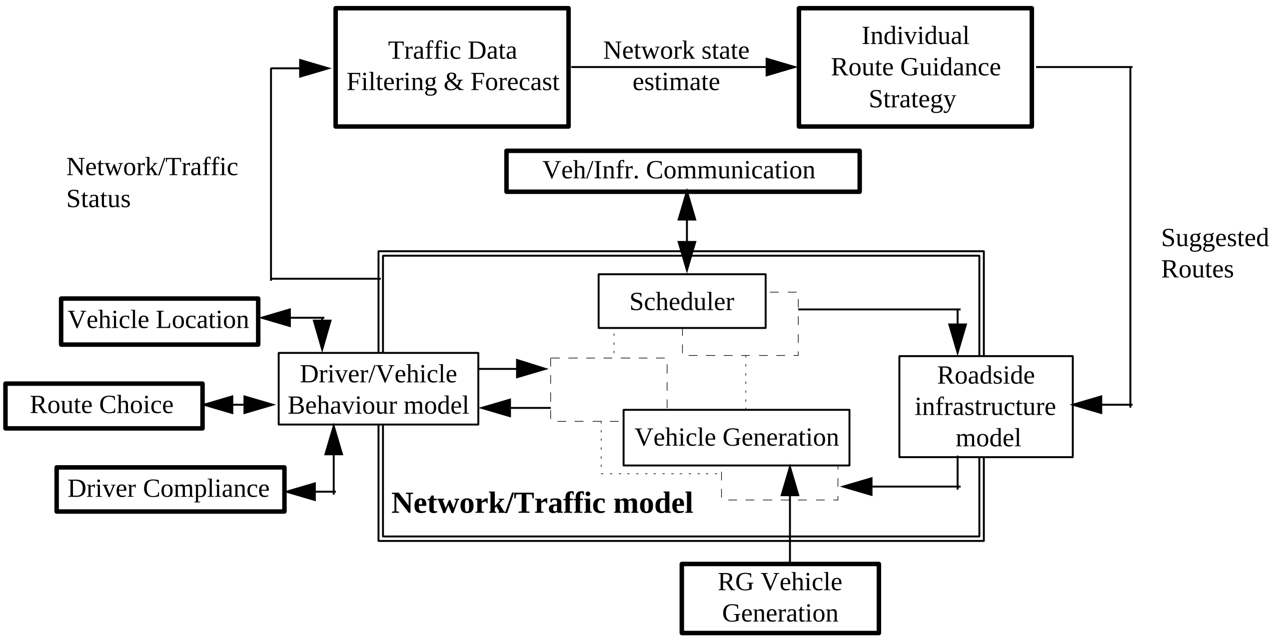


Figure 27: General organisation of the Simulation Environment for Infrastructured DRG

In this scheme only the functions that are relevant for the discussion are outlined. Individual RG Strategy and Data Filtering are considered as functions outside the network/traffic model to which they are supposed to be connected through a suitable interface.

Roadside Infrastructure Model, Driver/Vehicle model, RG Vehicle generation and the management of the RG data flows are supposed instead to be integrated within the network/traffic model due to their direct correspondence with models that are already important components in the micro-simulation model.

In the case of an Autonomous RG system the IRG strategy should be connected directly to the Driver/Vehicle block model, but it should be in any case considered as a function outside the micro-simulation model.

In any case these hypotheses do not affect the generality of the specifications.

In order to specify data flows and provide functional descriptions, some more basic concepts must be described concerning route guidance modelling.

Location of the Roadside Infrastructures (if any) and influence on traffic

In real applications roadside infrastructures are located at nodes and can influence equipped vehicles within a fixed size area around that node.

So, in the network model the position of the infrastructure is identified by the node and the area of influence is defined through a parameter.

The vehicle/infrastructure interaction modelling requires the definition of:

- the data flow details from the infrastructure to the vehicle and vice versa
- the driver's "compliance" parameter, representing the level of compliance assigned to the single driver

Furthermore the drivers' behaviour modelling requires the implementation of a dynamic assignment of vehicle routes & route choice.

Modelling of Radio Cells and influence on traffic

In real applications radio cells depend on the location of the related station. From the point of view of the IRG simulation this is not relevant. It could be supposed that a radio system is available covering the whole area.

Otherwise a mapping based on suitable matrices can be easily defined providing the required correspondence.

Modelling of RDS/TMC channel

This does not require any infrastructure to be modelled. It is a part of the central strategy that has to decide which information to send, the related network element and to operate according to the correct timing.

Correspondence between RG network model and road network model

The network model adopted by the IRG could differ from the model used by the micro-simulator. Normally the latter is more detailed than the former and a solution can be found:

- defining the nodes of the RG network as a subset of nodes of the road network model
- defining the links of the RG network as aggregations of the links of the road network.

So the RG destinations and turns are covered by corresponding elements of the road network and data mapping in the reverse direction is also feasible.

Generalities on the Individual Route Guidance Strategy

In order to determine the network conditions and perform adaptive traffic guidance, the strategy needs

- to receive timely information on traffic status
- to run periodically and consequently update guidance recommendations.

Even if the detailed definition of the data required to represent the traffic status depends on the guidance strategy formulation, in general the information that can be considered relevant for any strategy can correspond to

- measures normally modelled by micro-simulation models, such as traffic counts, queues, travel times
- specific estimates introduced for the application, such traffic density, level of congestion, incidents and others

In general, information is obtained by aggregation of data that are normally available at the elementary level (road network links and nodes). Possible information provided by equipped vehicles are available after certain events (vehicle leaving a link or crossing an infrastructured node). Traffic data from the network are required on the basis of time periods depending on the strategy iteration time and other possible constraints actuated by the scheduler module.

Furthermore, both current and forecast traffic data can be of interest. In the case where forecast data is needed the prediction function can be included in the data filtering function.

9.2 Data Flows and Contents

With reference to the simulation environment architecture, the relevant data flows are as follows. Data flows are described by considering most of the data required by all possible IRG systems.

Traffic Data Filtering & Forecast

- Input
    - Road Network description:
      links (code, capacity, physical characteristics)
      nodes (code, feasible turns)
      origins, destinations (code, type)
    - Route Guidance Network description:
      RG links (code, capacity, physical characteristics)
      RG nodes (code, feasible turns)
      RG origins, RG-destinations (code, type)
    - Current Traffic Data
      for any link and time interval
        Travel Times (link code)
        Queuing Times (link code)
        Density (link code)
        Traffic Counts (link code)
        Congestion level and incidents (link code)
        others required by the IRG strategy

- Traffic Data Historical Profiles
  for any link and time interval
  Travel Times (link code)
  Queuing Times (link code)
  Density (link code)
  Traffic Counts (link code)
  others required by the IRG strategy

- Output

  - RG Network Current Status Estimate
    for any RG link
    Travel Times (RG link code)
    Density (RG link code)
    Traffic Flows (RG link code)
    Congestion level and incidents(RG link code)
    others required by the IRG strategy

  - RG Network Status Forecast on the next (pre-fixed) horizon
    for any RG link
    Travel Times (RG link code)
    Density (RG link code)
    Traffic Flows (RG link code)
    Congestion level (RG link code)
    others required by the IRG strategy

Individual Route Guidance Strategy

- Input

  - Network description:
    links (code, capacity, physical characteristics)
    nodes (code, feasible turns)
    origins, destinations (code, type)

  - Route Guidance Network description:
    RG links (code, capacity, physical characteristics)
    RG nodes (code, feasible turns)
    RG origins, RG-destinations (code, type)

  - RG Network Current Status Estimate
    for any RG link
    Travel Times (RG link code)
    Density (RG link code)
    Traffic Flows (RG link code)
    Congestion level and incidents(RG link code)
    others required by the IRG strategy

  - RG Network Status Forecast on the next (pre-fixed) horizon
    for any RG link
    Travel Times (RG link code)
    Density (RG link code)
    Traffic Flows (RG link code)

Congestion level (RG link code)
others required by the IRG strategy

- Traffic demand (if required by the strategy)
  O/D matrix
  Nominal turning percentages per destination
  Nominal flows on the links
- Roadside Infrastructure description
  Roadside Infrastructure identification (code, type, location)
  Size of the influence area (radius in metres)

- Output
  - O/D suggested Routes (and alternatives when meaningful)
    to be sent to the roadside infrastructures (infrastructured system)
    or to be displayed to the driver identification (autonomous system)

Roadside Infrastructure Model

- Input
  - Roadside Infrastructure description
    Roadside Infrastructure identification (code, type, location)
    Size of the influence area (radius in metres)
  - O/D Suggested Routes (and alternatives when meaningful)
- Output
  - Suggested Routes (and alternatives when meaningful) per destination

Driver/Vehicle Behaviour

- Input
  - Roadside Infrastructure identification (code, type, location)
  - Size of the influence area (radius in metres)
  - Destination declared by the driver
  - Compliance rate (%, possibly defined per driver/vehicle class)
  - Location error variance
  - Suggested route
- Output
  - Action undertaken (turn at the downstream node, entrance into the aside parking area, new route to the destination)

RG Vehicle Generation

- Input
  - RG Vehicle O/D matrix
  - Penetration rate
- Output

- Vehicle generation according to the O/D matrix and the penetration rate.

RG Vehicle/Infrastructure Communication

- Input
  - Iteration periods for scheduling the following RG processes:
    Data collection from network
    Data filtering and Forecast
    IRG strategy
  - Variance of iteration times
- Output
  - Processes scheduling.

9.3 Interface Description

Most of the above input data need to be supplied to the model. This can be done either via text input using an editor or by using a graphical network builder. Outputs will either be additions to the current text outputs or addition to the animated graphical screen or both.

Text input. The user will be allowed to enter the Roadside Infrastructure data, the drivers compliance rates and RG process time schedules and variance by using a standard text editor.

Graphical inputs. If a graphical network builder is available to create network files then the Roadside Infrastructure characteristics might be entered as follows:

- The location of the Roadside Infrastructure is specified by clicking on a node at the required location. As a consequence a pop-up dialog window is activated to define Roadside Infrastructure type and code.

Driver compliance rate could be entered/modified via loading procedure activated as menu item.

As for the Road network creation, the network builder will be used to create the RG network model by dedicated windows allowing for the definition of the correspondence between the road network and RG network elements.

Text outputs. For the "individual route guidance strategy" evaluation users need the following text output:

- global data:
  - global travel time
  - average speed on whole network
  - total distance travelled
  - total delay
- global data for RG vehicles (as above but referring RG vehicles only)
- link / carriageway data:
  - travel time (mean value and standard deviation)
  - average speed
  - number of vehicle entered during the simulation
  - number of vehicle exited during the simulation

    - number of stopped vehicles
    - average delay
    - average occupancy (average number of vehicles / carriageway capacity)

- link / carriageway data for RG vehicles (as above but referring RG vehicles only)

- Roadside Infrastructure data:
    - number of equipped vehicles crossing the node
    - number of vehicles which received route suggestions
    - number of vehicles which followed the suggestions (according to driver behaviour model)
    - number of vehicles that modified their route according to the suggestions

Graphical outputs. If an animated graphical display is used to show the simulation progress, it should be possible to have the following information included in the displays:

- On the Roadside Infrastructure
    - Infrastructure identificator
    - Infrastructure status (if required on-line)
    - addressable destinations (if required on-line)

- On the traffic
    - number of vehicles receiving route suggestion
    - number of re-routed vehicles

9.4 Functional Description

Individual Traffic Guidance Strategy

Functions and characteristics to be modelled are described under section *The Simulation Environment.*

9.5 Restrictions and Limitations

There are no major restrictions or limitations.

9.6 Performance Requirements

The standard performance requirements of the SMARTEST modifications are to apply.

9.7 Verification Tests

The model has to be checked against the following scenarios:

- Basic scenario (without control actions):
    - general traffic data (congestion detection)

- Basic scenario with Individual Route Guidance System ON:
    - equipped vehicles = 100%
    - equipped vehicles = 50%
    - equipped vehicles = 10%
    - compliance rate = 100%
    - compliance rate = 90%

- Incident Management:
    - equipped vehicles = 100%

- equipped vehicles = 50%
- equipped vehicles = 10%
- compliance rate = 100%
- compliance rate = 90%

For each scenario, the following must be verified:

- effectiveness of the actuated guidance strategy
- roadside infrastructure status (re-routing percentage for each destination)
- number of vehicles which crossed the equipped nodes
- number of vehicles receiving route suggestion
- number of vehicles that complied with the suggestion
- number of vehicles that modified their turning movement according to route suggestions

9.8 Validation Criteria

In order to validate an Individual Route Guidance Strategy, either historical system performance indicators or system users interviews could be used.

10. INCIDENT MANAGEMENT

10.1 Introduction

A well-accepted definition of an incident[1] defines it as *any non-recurrent event that causes reduction of roadway capacity or abnormal increase in demand.*

Fast and reliable *motorway incident detection* is instrumental in reducing traffic delay and increasing safety. In particular, with the information from incident detection, traffic management strategies guide the traffic flow towards smooth operation by preventing additional vehicles from entering upstream of the incident and by communicating traffic information to the travellers. In addition, incident detection constitutes the cornerstone for prompt incident management and safety improvement near the incident location.

Automatic incident detection (AID) involves two major elements: A *traffic detection system* that provides the traffic information necessary for the detection and an *incident detection algorithm* that interprets the information and ascertains the absence or presence of an incident. Local presence detectors embedded in the motorway pavement are used extensively to obtain traffic data, primarily on occupancy and volume. Wide-area machine-vision detectors and other detector types can also be used for data collection. Incident detection algorithms can detect capacity reducing incidents, and safety reducing incidents. Traffic information for incident detection is typically collected from loop detectors and includes occupancy and volume averaged at specified time intervals, usually across all lanes. Detector spacing along the motorway is critical for the efficiency of the detection. Certain systems also use paired detectors to collect speed data.

Different, often locally developed, algorithms are employed depending on traffic conditions. However, to date, quite often, high false alarm rates have prevented implementation of fully automated incident detection. This is a result of the difficulty that some of the existing incident detection algorithms have in distinguishing between recurring and non-recurring congestion.

Fast and accurate detection of incidents can, therefore, substantially reduce the impact of incident congestion on motorway traffic. In particular, when an incident alarm is promptly signalled, traffic management plans can be adjusted in real time to produce the best control and guidance actions in motorway corridors.

Traffic Data

Traffic volume, occupancy, and space mean speed are the most common data collected by the traffic sensors. The detection process can be either based on the direct observations or on more complete information from treated data, e.g., first and second order statistics of the data. Traffic data may include travel time and routing information, e.g., turning movements or tracking of vehicle paths through the test site. Data are sampled at regular intervals. Traffic data are statistically treated and processed. Examples of processing include comparison with historical data and/or with results from a simulation model.

Incident Detection (ID) Algorithms

Detection algorithms on which incident detection practice is or could be based include two-station and single-station algorithms. Two-station algorithms are based on measurements from two stations on the roadway and are inherently more accurate than single-station ones. They include comparative, time series, probabilistic, dynamic modelling, neural networks, and filtering algorithms. Single-station algorithms can be less hardware-intensive than two-station algorithms and include algorithms that are based on the fundamental traffic diagram, and algorithms based on wide-area detection by machine vision.

In the two-station family, comparative, time series, and probabilistic algorithms are characterised by a large number of false alarms. Dynamic modelling and neural network algorithms are promising but the former have strong data requirements and the latter require a long training period. Filtering algorithms have indicated increased potential for transferability, and have been shown to reduce the number of false alarms.

In the single-station family, algorithms based on the fundamental diagram have the potential for reduced false alarms but are not based on a robust calibration procedure. Machine-vision based algorithms have demonstrated promising performance.

Incident detection algorithms provide the logic for evaluating and processing the information obtained from electronic surveillance. Detection of traffic incidents has typically been based on models that determine the expected Traffic State under normal traffic conditions and during incidents. The following classes of algorithms can be identified:

- Comparative - or pattern recognition - algorithms such as California, Algorithm 7,8 (Payne, et al., 1976; Collins, et al., 1979; Persaud, et al., 1990; Masters, et al., 1991)[2] establish predetermined incident patterns in traffic measurements and attempt to identify these patterns by comparing detector output against pre selected thresholds.
- Time series algorithms (Dudek, et al., 1974; Cook, et al., 1974; Ahmed, et al., 1982)[3] employ simple statistical indicators or time series models to describe normal traffic conditions and detect incidents when measurements deviate significantly from model outputs.
- A third class includes algorithms that involve traffic flow modelling to describe the flow dynamics, and compare actual traffic patterns with ones produced by the models (Willsky, et al., 1980; Cremer, 1981)[4]. The diversity of incident patterns requires development of a large number of pattern-specific models and this has limited the potential of these algorithms for practical applications.

Existing algorithms, even when including models that determine traffic trends, do not pre-process current traffic observations prior to applying the detection test. However, actual traffic measurements reveal that short-duration random fluctuations exist in traffic even if no external factor (e.g., incident) generates a disturbance. These fluctuations may significantly hamper the performance of a detection algorithm, since alarms from such sources are classified as false.

Algorithm evaluation

The evaluation of incident-detection algorithm performance has used primarily four major indicators: Detection rate, false alarm rate, modified false alarm rate and mean time to detect.

Detection rate is the ratio of incidents detected out of all incidents that occur during a specified time period.

False alarm rate is the ratio of false alarms out of all decisions (incident and non-incident) made by the system during a specific time period.

Relative false alarm rate is the percent of false decisions out of all incident decisions during a certain period of time.

Mean time to detect is the average time required by the system to make a detection.

The preceding measures of effectiveness are related because, at least in the single-test algorithms, increasing the detection rate causes the false alarm rate to increase. No standards have yet been adopted for determining the best combination of detection and false alarm rates.

The evaluation results are generally non-transferable and this is due to the varying traffic conditions, weather and driver characteristics across application sites. Differences across sets of incident data are an additional reason for the lack of transferability. Several of these differences result from varying assumptions on whether incidents with very limited impact, or no impact, on traffic should be included. Therefore, unbiased comparative evaluation of algorithms requires concurrent evaluation of these algorithms on a common data set.

Incident Management

The incident detection module communicates to the traffic management and incident response systems the occurrence of the incident and its location. The specific management and response actions, like motorist information using variable message panels, access control using ramp metering policies, speed control on the main road sections, lane reservation for incident response units, etc., are decided by the Traffic Management System and implemented.

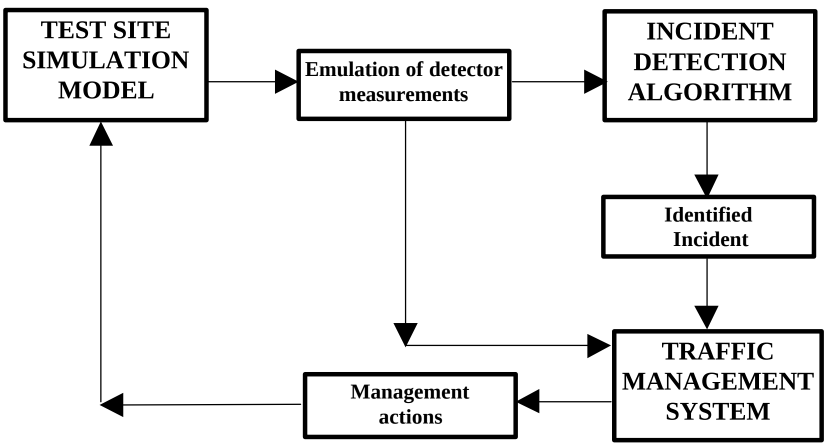


Figure 28: Data flows between the simulator and the detection module

10.2 Data flows and content

Incident Data

- Incident location
- Time at which incident takes place
- Incident severity
  - Lanes blocked by the incident
  - Length of incident
  - Duration of Incident

Traffic Data

Detection Data

- Detector Identifier
- Location of detector

- Lanes detected
- Detector measurements
  - Traffic Volume
  - Space mean speed
  - Occupancy

Other Traffic Data

- Travel times
- Routing Information
  - Turning movements
  - Vehicle paths
- Weather Conditions

Management Actions Data

- Motorist information, for Variable Message Signs. There can be different types of messages:
  - Warning messages
  - Recommendation of alternative routes
  - Obligatory diversion
  - For each message
    - Degree of compliance
    - Routing Information
- Access control, using ramp metering policies
  - Ramp identifier
  - Ramp control parameters
- Speed control on the main road sections
  - Section identifiers
  - Speed limit
- Lane reservation, for incident response units
  - Section identifiers
  - Reserved lane

10.3 Interface description

The above data needs to be supplied to the model. This can be done either via text input using an editor or by using a graphical network builder, although the use of a graphical editor is advisable.

An incident could be generated anywhere on the simulated road network, either in a deterministic way or stochastically. Deterministic incidents may be defined by the user, dialoguing with the simulation model through an Incident Generation window. The user may, through the graphical interface, select the section, the lane in the section, the position on the lane, the lane length blocked by the incident, the time at which the incident will occur, and the incident duration. Depending on the severity of the incident the user may decide whether one lane or more than one lane are going to be blocked by the incident.

The user may define as many deterministic incidents as desired, either at the beginning of the simulation or at any time during a simulation run. A set of incidents for a given model may be stored in a Log File, which can be re-used in future simulation experiments. This feature allows using the same set of pre-established traffic incidents for different simulation experiments, in order to evaluate how different alternatives of incident management would behave with the same traffic conditions. The Incidents Log File can be either directly edited as text file or input through the graphical interface.

Stochastic incidents are those that are created on each road section according to a corresponding probability model for that section. That requires adding new sections attributes. The additional items will be those describing the incident probability model attached to the section and its parameters:

- Code that identifies the probability distribution: i.e. Poisson/negative binomial, multi-proportional Poisson, etc.
- Values of the parameters of the probability distribution.
- Parameters describing the severity of the incident, which will be associated to the number of lanes, length and duration of the incident.

Graphical outputs. If an animated graphical display is used to show the simulation progressing then it should be possible to view the following aspects related to the incident in the display:

- Incident or lane blockage
- Effect of the incident in the traffic behaviour
- Management actions decided by traffic management system
- Effect of the management actions in the traffic behaviour

10.4 Functional description

The incident detection and management model should be able to reproduce the appearance of the incident, the behaviour of traffic at the vicinity of the incident, the on-road equipment installed to detect incidents (i.e. traffic detectors), the management and control actions implemented to alleviate the impact of the incident.

Modelling the Incident

The model should be capable of generating incidents everywhere on the simulated road network and then reproduce the dynamics of the queue and congestion building processes. If an incident prediction or incident warning system is taken into account, then incidents should be created on each road section according to the corresponding probability model for that section.

The simulation process should deal with the probabilistic incident generation as a scheduled event for the sections, that means that at the beginning of each simulation step, at the same time that the simulator control module updates the other scheduled events, like those related to the traffic control light changes, will also check whether incidents will occur at the sections according to the corresponding probability distribution.

Therefore, Traffic Incident Generation will follow an Event Scheduling simulation approach. At the beginning of simulation, the first Incident Event will be generated for every section in the network, according to the specified probability distribution. The following fields compose an Incident Event:

- Time at which incident will take place
- Duration of Incident
- Number of lanes blocked by the incident
- Length of incident

Incidents can be sorted in the simulation Event List by time of occurrence. At every simulation step, the Event List is checked to see whether or not a traffic incident is due to occur in the current simulation step. If so, the incident is generated and the corresponding event is removed from the Event List. Then, next incident event is scheduled for that section, according to the incident generation parameters defined.

The incident may be implemented in the simulation by the generation of a dummy vehicle, which is located at the incident position, and will be stopped there during the duration of the incident. Therefore, other vehicles will be affected by the incident by following normal vehicle behaviour models (car following and lane changing). Checking whether an incident has finished is done when updating a vehicle. If it is an incident dummy vehicle and the incident duration time has expired, the dummy vehicle may be removed from the network, so the blockage may be finished.

Emulation of Detector Measurements

Detection output data has to be produced by the simulator periodically, provided that there are some detectors defined in the network. The data produced depends on the measuring capabilities of the detectors. It may be Count (number of vehicles per interval), Occupancy (percentage of time the detector is pressed) and Speed (mean speed for vehicles crossing the detector). These data may be stored in files or sent directly to an external application, e.g. through TCP/IP sockets. This external application could be a Traffic Control System, a Traffic Management System, an Incident Detection Algorithm, etc.

Modelling of Management Actions

The type of management actions that need to be modelled include modifications of the speed limits, recommendations of alternative routes or just information about the presence of an incident. As impacts for these messages, the modeller can define the following actions:

- Modifications of the speed limit of any section. This is used to model both, the variable speed limit signs and the warnings for incidents or congestion ahead.
- Input flow modifications, which is only applicable to the input sections. The modeller can specify an increment or decrement (in percentage) in the flow rate.
- Turning proportions modifications for any section in the network. It is also specified as a percentage of the current proportion. This is used to model the recommendations for alternative routes to drivers, when simulation is based on flows and turning percentages.
- Set next turning movement for drivers in certain section going to specific destinations. This is also used to model the re-routing actions, when simulation is based on OD matrices and paths between origin and destinations.

10.5 Restriction and limitation

There are no major restrictions or limitations.

10.6 Performance requirement

The standard performance requirements of the SMARTEST modifications are to apply.

10.7 Verification tests

To check that the incidents model is working as specified, scenarios are to be generated which allow the following checks to be made:

that incidents

- are generated at the correct place and time
- last for the expected time period

that drivers:

- behave properly in the presence of the incident
- react to the management actions

10.8 Validation criteria

The model can be validated using the following data:

- reduction of capacity due to the incident
- queue length produced by incident
- drivers reaction time to the management actions
- new distribution of flows in the incident surroundings

10.9 References

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11. RAMP METERING

11.1 Introduction

The primary objective of ramp metering is to improve the safety and efficiency of freeway operations, or at least the reduction, of the factors contributing to congestion. Ramp metering control is a method of improving overall freeway operations by limiting, regulating and timing the entrance of vehicles from one or more ramps into the main line, so that the demand on the freeway will not exceed its capacity. Maximum flow rates will thus be achieved by ensuring that the freeway traffic moves at or near optimum speeds.

Ramp metering has consequences in that some of the traffic wishing to use the freeway has to wait on the entrance ramp before being allowed to enter. In locations where freeway entrance ramps have adequate storage capacity or where the surrounding street network can accommodate additional traffic, ramp control systems can provide substantial operational improvements under certain combinations of traffic demand and freeway capacity.

Ramp metering control is advisable when: a) the expected reduction in delay to freeway traffic is greater than the expected delay to ramp users, b) there is adequate storage space for vehicles delayed at the ramp, c) there are suitable alternative routes available having capacity for traffic diverted from the ramp.

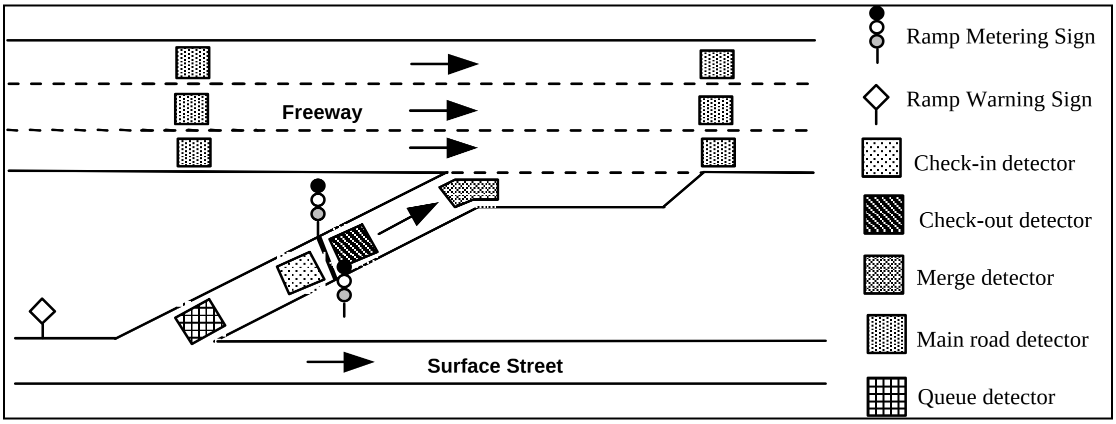

Figure 29: General layout of traffic-responsive entrance ramp metering system

Control Modes

Pre-timed-Control Mode
Control is not influenced by traffic in the main lane. In some cases, both demand and passage detectors are used to actuate and terminate each metering cycle. Metering rates used with pre-timed control are only a function of past traffic observations. Metering operations depend solely on the time of day, the day of the week or on special events. No interconnection with other ramps is used.

Local-Actuated-Control Mode
Ramp metering is directly influenced by the mainline traffic conditions during the metering period. The control is based primarily on real-time, locally measured traffic conditions based on mainline detectors in the immediate vicinity of the ramp. No interconnections with other ramps is used.

System-Control Mode
Real-time information on total freeway traffic conditions is used to control the entrance-ramp system. Interconnection, which is a feature of this class of metering, permits conditions at one location to affect the metering rate imposed at one or more other locations. The components of

these type of systems are the controller, signal heads, detectors, a communication medium and a control computer.

Control Strategies

Pre-timed-Control Strategies
Based on matching uniform demands with control measures that reduce freeway congestion. A preliminary control plan is developed which limits access by the desired amount, based on current traffic data. While the system is operating traffic data of the freeway under control are collected. These data are then used as feedback to revise the metering rates for continuing control. Integrated demand-capacity procedure is often used for calculating metering rates for pre-timed control. Calculation is made from upstream to downstream. If traffic is congested within the freeway, then the on ramp volume upstream of the bottleneck section is set so that the section volume is equal to or less than the bottleneck section capacity. Variable origin-destination matrices are usually used to determine the exit demands as a function of the upstream input volumes. Linear programming techniques are also used in the formulation of pre-timed ramp metering strategies.

Local-Actuated-Control Strategies
Freeway speed, volume, density or occupancy can be used as a measure of the quality of flow. A typical local-actuated strategy limits the on-ramp volume to a desired value by correlation with the occupancy level of the adjacent mainline traffic, which is determined by measuring the percentage of time that vehicles are over a point of detection.

System-Control Strategies
Assume a control system where any given entrance ramp is to have an across-all-lanes detector counting station both upstream and downstream of the ramp, together with speed detectors at critical downstream bottleneck locations. The strategy would compare these three parameters (upstream and downstream volumes, and downstream bottleneck speed)

11.2 Data flows and content

Metering data

- Metering Identifier
- Link or section controlled
- Ramp metering sign location

Control data

- Control Mode (fixed or adaptive)
- Cycle length time (fixed or minimum and maximum values)
- Offset time
- Green time (fixed or minimum and maximum values)
- Entrance flow (fixed or minimum and maximum values)
- Platoon length
- Priority vehicles

Detector data

- Queue detector
- Check-in/demand detector
- Check-out/passage detector
- Merge detector

- Main-line detectors
- For each detector
  - Location of detector
  - Lanes detected
  - Length of detector
  - Measuring capabilities of detector

11.3 Interface description

The above data needs to be supplied to the model. This can be done either via text input using an editor or by using a graphical network builder. Given that there are different objects that need to be located for the correct layout definition of the ramp metering it is encouraged to use a graphical editor.

Text Inputs. The user will be allowed to enter the ramp metering data by using a standard editor

Graphical Inputs. If a graphical network builder is available to create the model, the ramp metering data might be entered as follows:

- The location of the ramp metering is specified by clicking on a section at the required position.
- Other ramp metering data is then entered trough a dialog window which appears when the ramp metering is selected
- The detectors related to the metering may be specified also by clicking on the section at the desired position and then, the width and length of detectors may be specified by dragging the edges of the detectors area.

Text Output. The user will have the option of asking the model to produce the following text outputs:

- For each ramp metering
  - ramp identifier
  - number of vehicles arriving to the metering
  - number of vehicles crossing the metering
  - queue length produced by the metering (mean and maximum)
  - waiting time per vehicle (mean and maximum)
- For each detector related to the metering
  - measures detected

Graphical Outputs. If an animated graphical display is used to show the simulation progressing then it should be possible to have the following information included in the displays:

- icon to represent the ramp metering
- symbol to represent the current status of ramp metering: (open, closed, disconnected)
- icons representing the detectors associated to the ramp metering

11.4 Functional description

The ramp metering model should be able to reproduce the metering control process, the behaviour of traffic at the presence of the ramp metering, and the vehicle detectors related (vehicle detection model is described apart).

Three types of ramp metering may be considered, which depend on the implementation and the parameters that characterise it

Green Time Metering
Parameters are green time and cycle time. The ramp metering is modelled as a traffic signal that turns red and green on a cyclic basis. If it is a fixed traffic control, only a constant green time is used. In case of simulating together with some external Adaptive Traffic Control System, there would be a minimum and maximum values for the acceptable range of green time variation. The rest of the cycle time, the traffic signal will be red. Vehicles will stop at red light and cross at green light.

Flow Metering
Parameters are platoon length and flow (veh/h). The meter is automatically regulated in order to permit the entrance of certain maximum number of vehicles per hour. In this case the ramp-metering objective is to let certain amount of vehicles per hour to cross the metering. Each time the meter is opened to release vehicles, it is done in a way that platoons of a certain length parameter, can pass. This can be done in two ways, either by counting the vehicles crossing the meter or by allocating a green time as a function of the platoon length. At the average, a certain number of vehicles per hour will be released. In case of simulating together with some external Adaptive Traffic Control System, there would be minimum and maximum values for the acceptable range of flow variation.

In any case, the vehicle stop at ramp metering line may be achieved by putting a dummy vehicle at the stop line which will be stopped while the ramp metering is closed and will be removed when it is opened.

There would be the possibility of using the same Ramp metering model to emulate other types of access control in which the stopping time may be a certain random distribution:

Delay Metering
Parameters are the mean delay time and the standard deviation. This type of metering may be used to model the stop of vehicles due to some control facility, such as tolls, customs, checkpoints or any other type of individual control. It is assumed that every vehicle will have to stop at the control point (i.e. the ramp metering stop line) during certain amount of time. This time is a random variable distributed according certain probability distribution, e.g. a normal distribution with certain mean and standard deviation.

11.5 Restriction and limitation

There are no major restrictions or limitations.

11.6 Performance requirement

The standard performance requirements of the SMARTEST modifications are to apply.

11.7 Verification tests

To check that the ramp metering model is working as specified, scenarios are to be generated which allow the following checks to be made:

that ramp meter
- allows the entrance of the expected mean flow

- produces the correct platoon lengths
- is opened and closed in a cyclic way with the expected durations

that drivers:
- behave properly in the presence of the ramp metering
- reduce speed and stop when ramp meter is closed
- accelerate and cross the meter when it is opened

11.8 Validation criteria

The model can be validated using the following data:

- capacity of the ramp metering according to the control policy and the traffic demand
- queue length produced by ramp metering
- average waiting time at ramp metering