5. SPECIFICATION FOR MODIFICATIONS TO THE EXISTING MICRO-SIMULATION PACKAGES

In this section general specifications are provided that should be considered when modelling or improving the set of features (traffic phenomena, telematics applications, infrastructures) highlighted in Chapter 2 as priority features for micro-simulation models:

- Public Transport Services
- Roundabout
- Traffic Calming
- Adaptive Traffic Signal
- Public Transport Priority
- Parking Management
- Detectors
- Variable Message Signs
- Individual Route Guidance
- Incident management
- Ramp Metering

In the following the general concepts only are reported. Detailed descriptions are collected in Appendix A.

5.1 PUBLIC TRANSPORT SERVICES

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)

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	1.0	1.2
Double deck	10.0	4.2	80		
Single deck	8.5	3.4	55		
Minibus	7.0	2.4	25		

Table 13: Typical parameters for four different types of buses (Source: US DOT, 1992)

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 above.

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:

Figure 15: A guided busway in Leeds

- 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.

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 16: A trolley bus

Figure 17: 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 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.

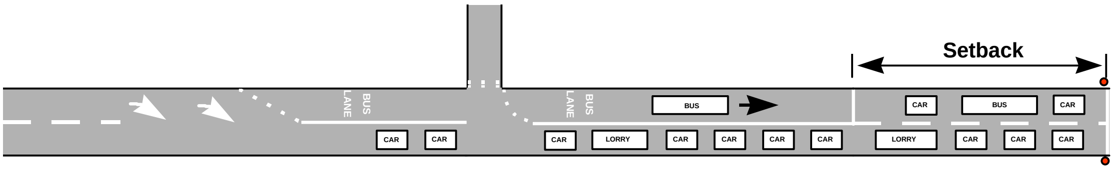


Figure 18: Bus lane layout (driving on the left in a two lane one way street)

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, often 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 19). 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.

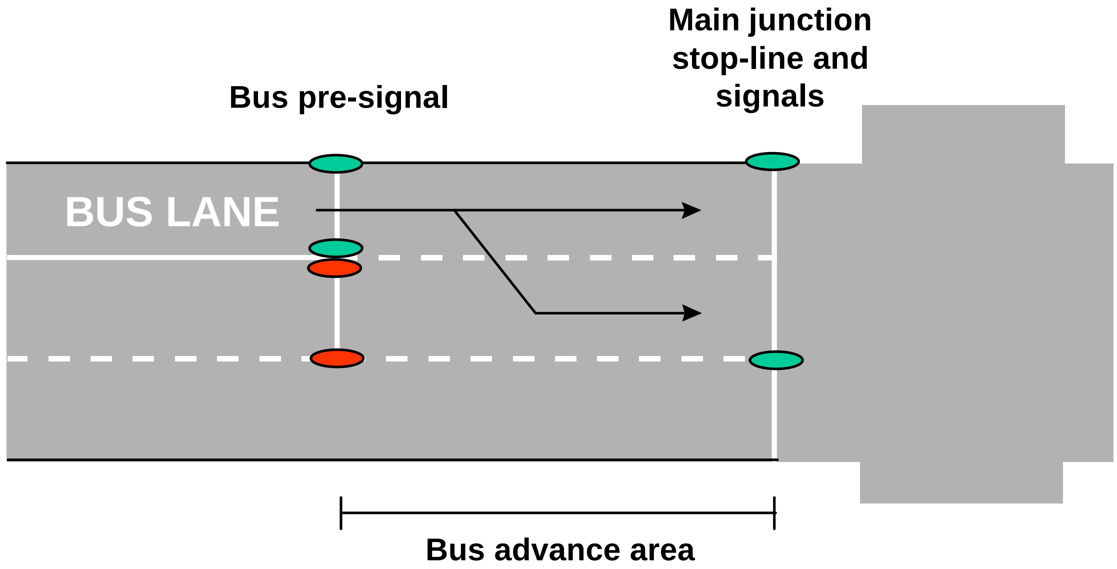


Figure 19: Bus advance area (UK driving conditions)

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 that 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.

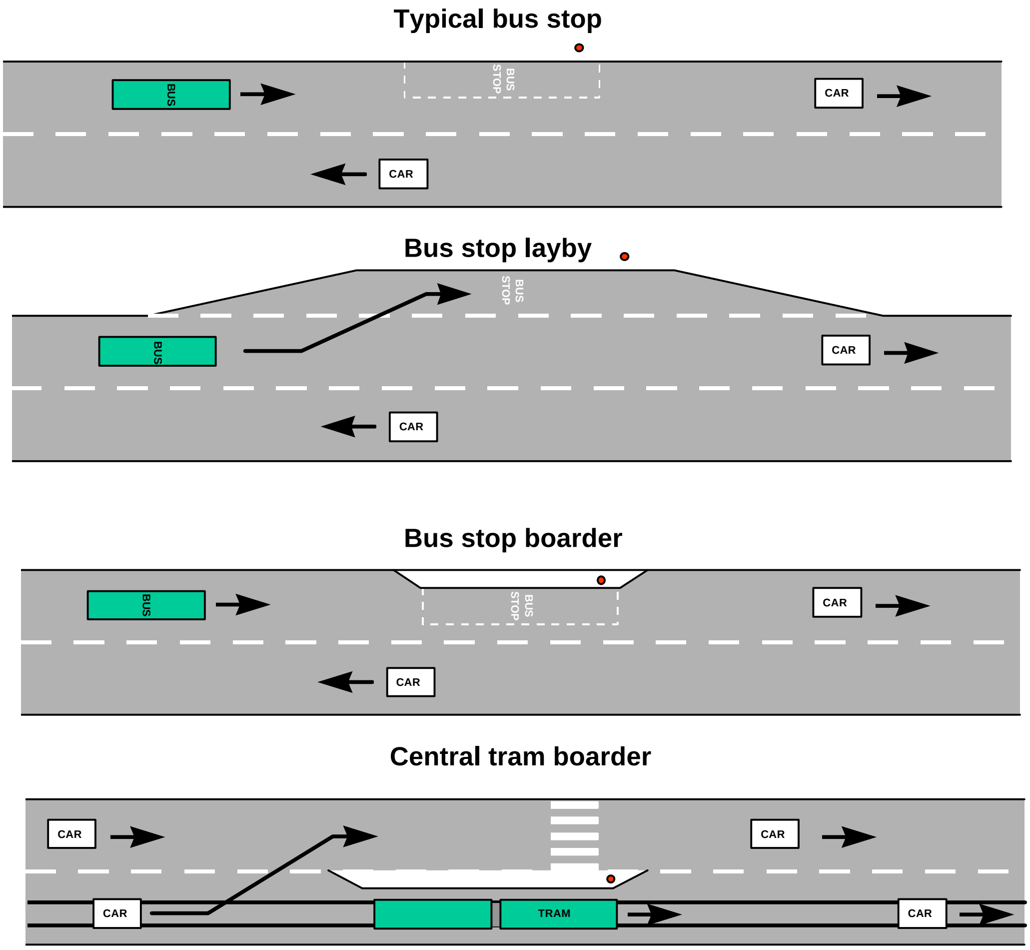


Figure 20: The four different types of public transport stop (UK conditions)

There are four main types of public transport stop (see Figure 20). 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 that 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 that 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).

5.2 ROUNDABOUT

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 that 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 Table14, Figure 21 and Figure 22.

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 21	• New developments and construction • Junctions within or at end of dual carriageways • To change direction of a new road at a junction

Type	Description	Typical Use/ Location
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 21	• 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
Double	• Two conventional or mini roundabouts are placed within the same junction connected by a short link road • See Figure 21	• 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 22	• 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 22	• 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 22	• 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 14: The different types of roundabout and their main characteristics

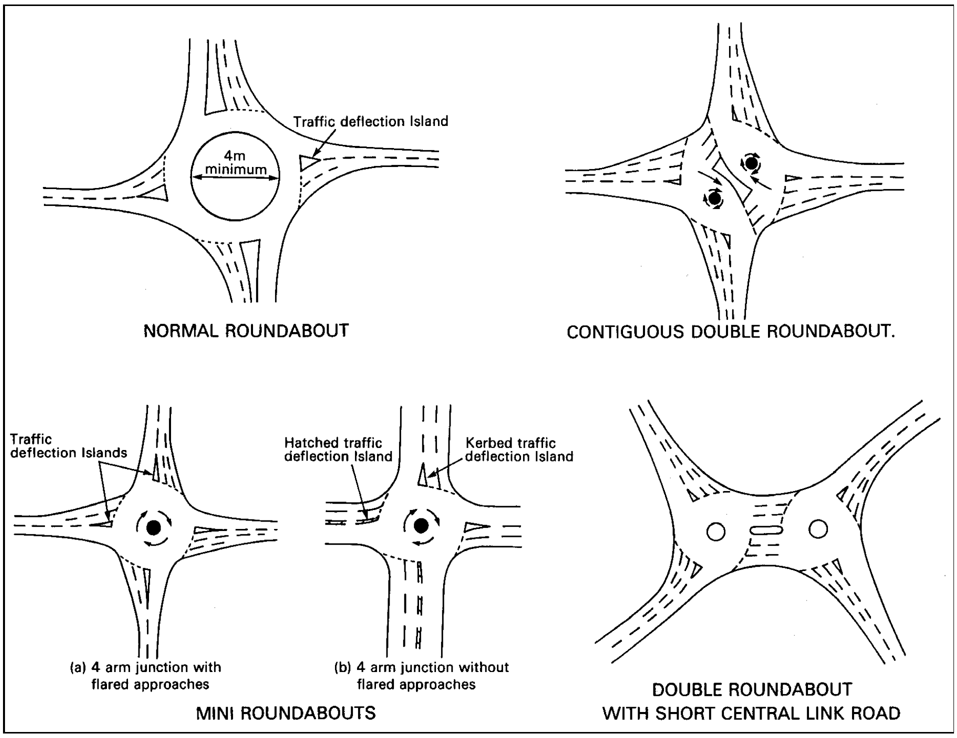


Figure 21: Different types of roundabout (Conventional, Contiguous double, Mini and Double) (left-hand driving practice)

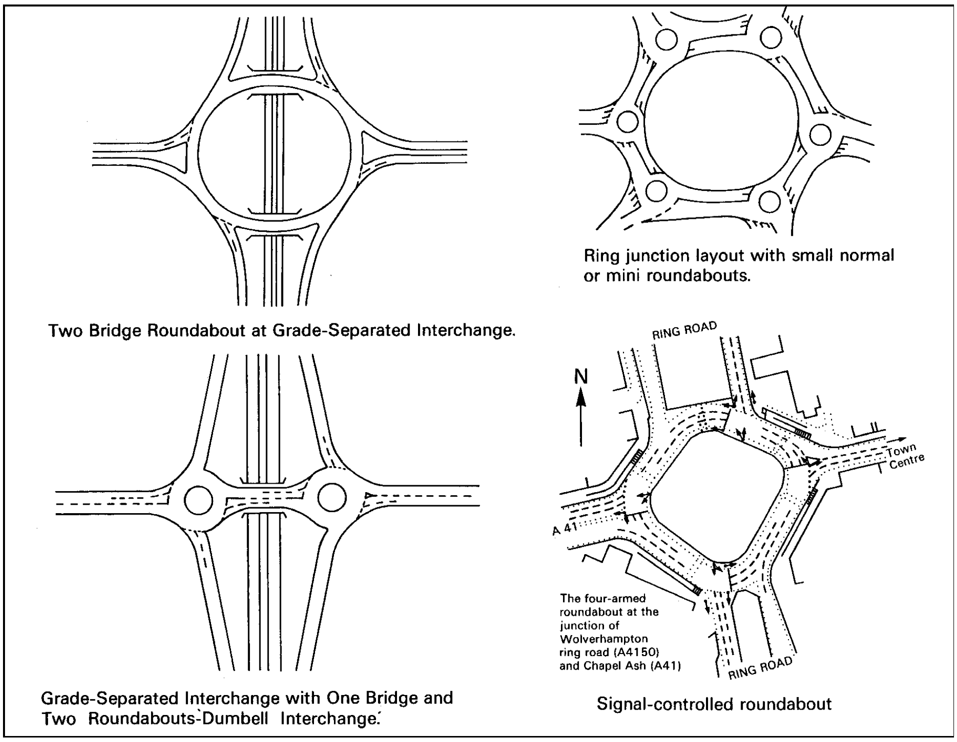


Figure 22: Different types of roundabout (Two bridge, Grade Separated, Ring and Signal Controlled) (left-hand driving practice)

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 that 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.

5.3 TRAFFIC CALMING

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 that 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 that 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.

5.4 ADAPTIVE TRAFFIC SIGNALS

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 23:

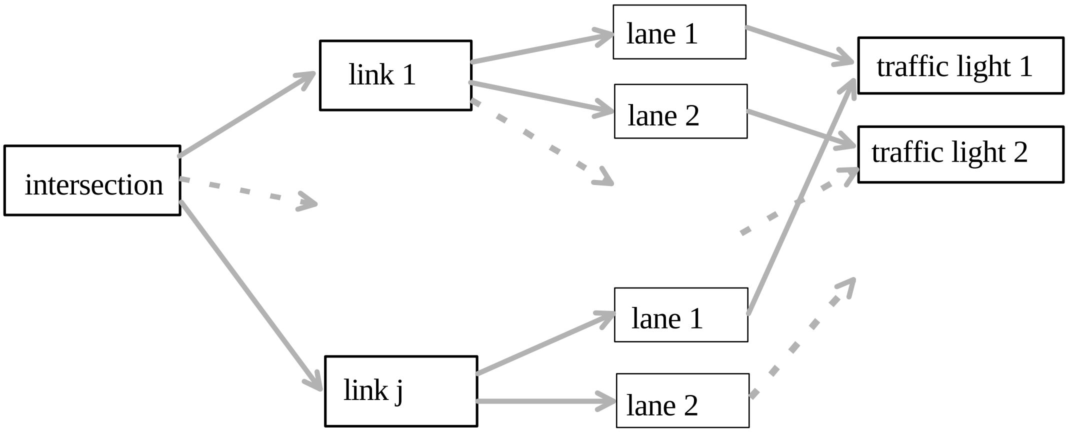


Figure 23: relations between traffic lights and network geometry

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 24, 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.

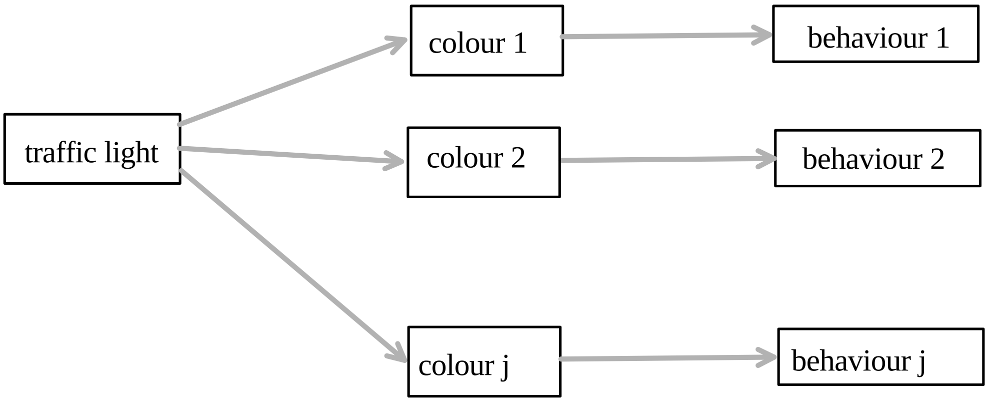


Figure 24: relations between traffic lights and driving behaviour

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 25:

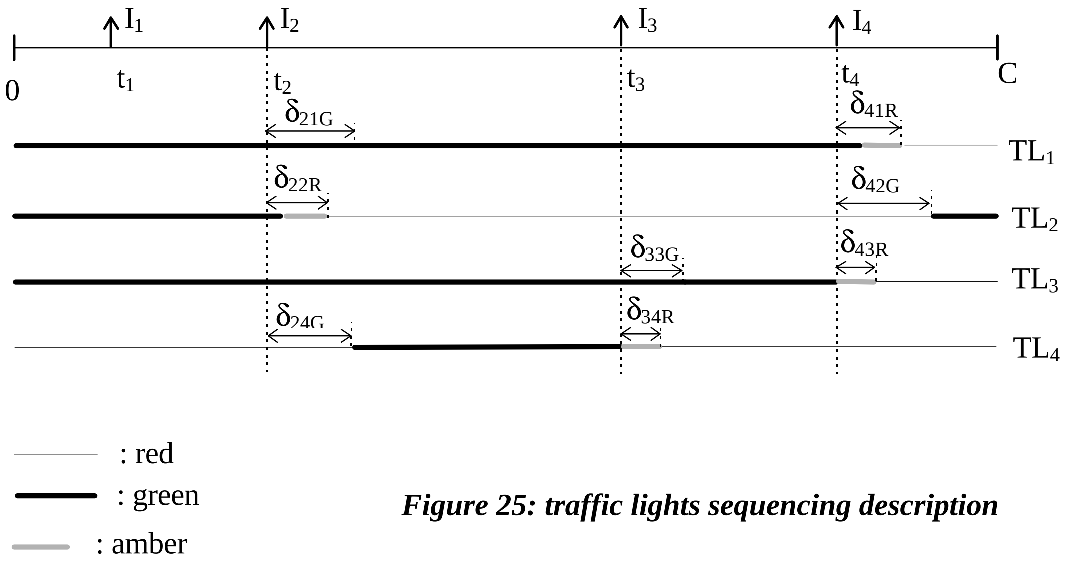


Figure 25: traffic lights sequencing description

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 25 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 25, 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 25, 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 25 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 26 summarises the resulting data flow exchange between the microscopic traffic simulation and the UTC strategy, for both detector data and control settings.

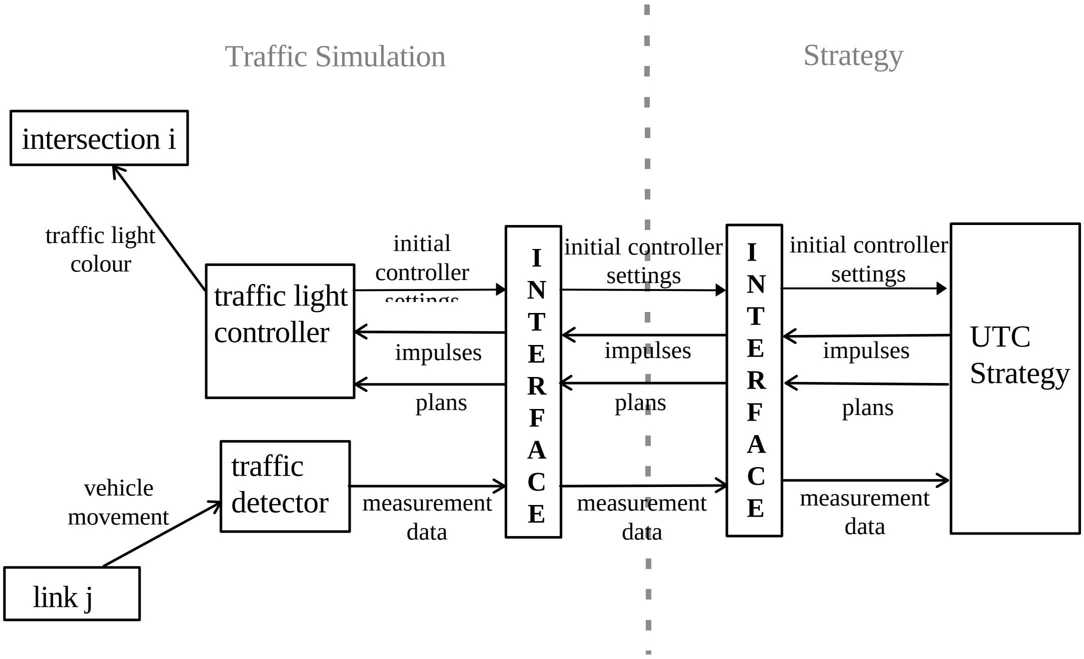


Figure 26: general data exchange layout

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.

5.5 PT PRIORITY

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 27 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:

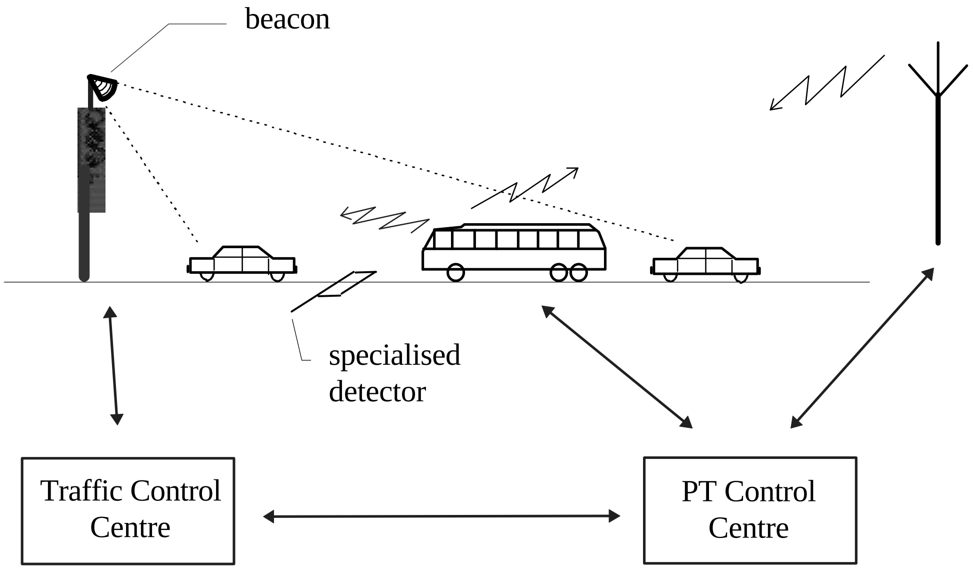


Figure 27: general framework of PT priority systems

- point detection systems: buses are equipped with « electronic registration plates », which sends 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 28 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.

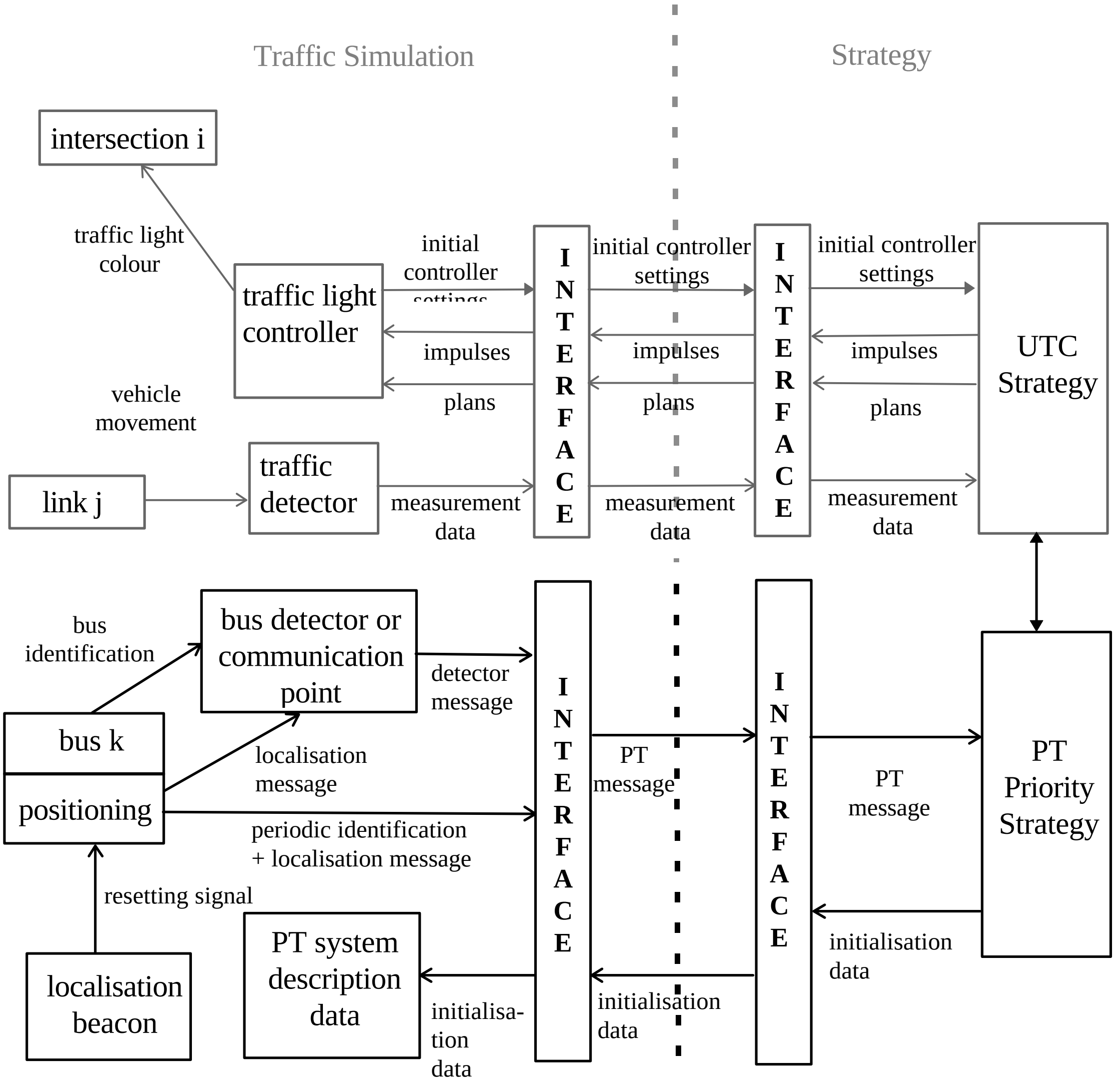


Figure 28: general data exchange layout for combined adaptive signals and PT priority modelling

5.6 PARKING MANAGEMENT

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.

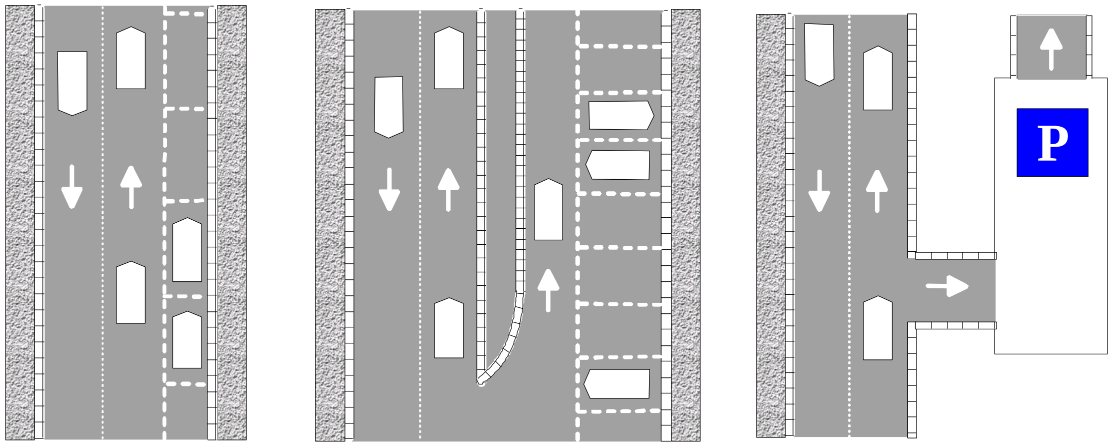
There are three main types of car park (see Figure 29):

- 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 29: 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.

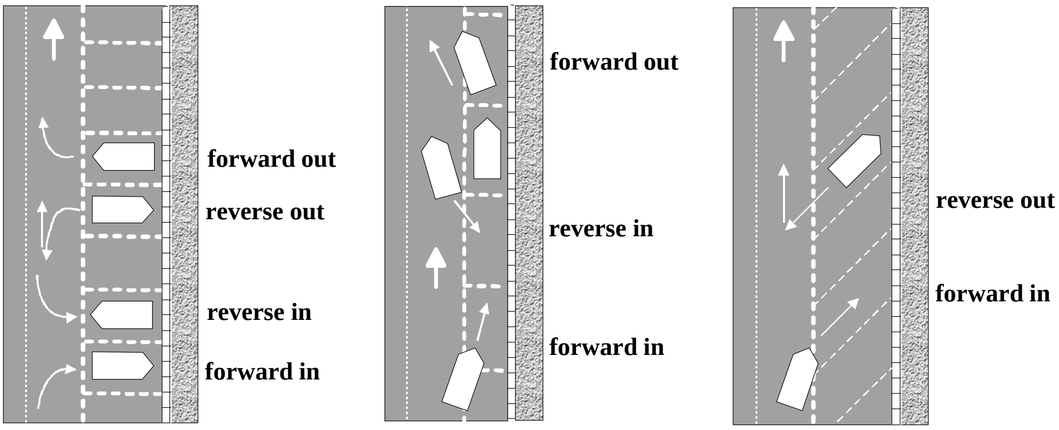
Parking style is another car park feature that influences traffic behaviour near parking spaces. It concerns access to the parking space. Three parking styles can be identified (see Figure 30).

- 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.

Parking styles



Perpendicular to the pavement **Along the pavement** **At an angle to the pavement**

Figure 30: 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.

5.7 DETECTORS

Traffic related variables that can be measured include:

- general traffic variables
- events that influence traffic
- vehicle features
- weather conditions
- violations
- environment variables
- other data

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[1]:

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

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

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[1] 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.

does not matter and the interest for micro-simulation models lies in the data that can be measured and exchanged.

5.8 VARIABLE MESSAGE SIGNS

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 Figures 31, and 32 the layout of a text based information panel is shown. In Figure 31 the panel shows a future date when an area should be avoided. In Figure 32 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 31 - Variable Message Sign planned in London - Calendar information

STAMFORD HILL

CLOSED

LONG DELAYS

Figure 32 - Variable Message Sign planned in London - On event information

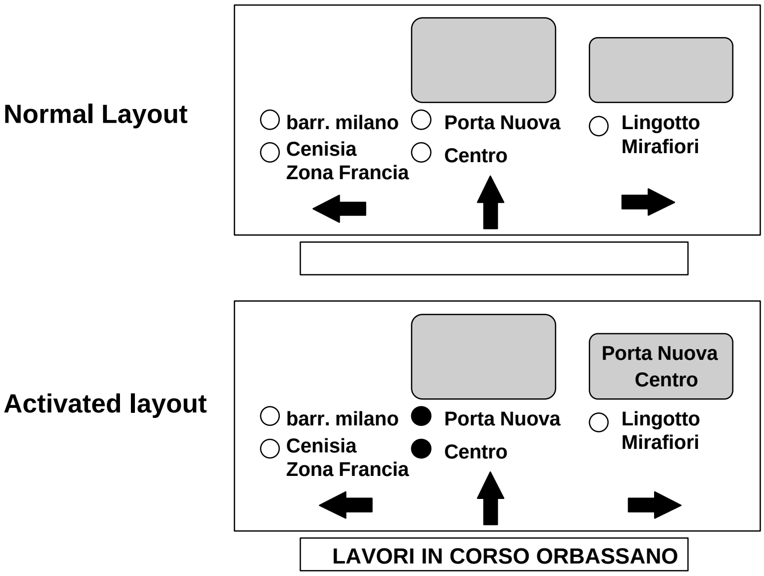


Figure 33 - Variable Direction Sign panel adopted in Turin for collective traffic guidance.

The panel represented in Figure 33 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 34 - Variable Direction Sign panel adopted in Turin for Parking Guidance

The panel shown in Figure 34 is designed to guide traffic towards controlled parking areas. This kind of panel is used in Torino.

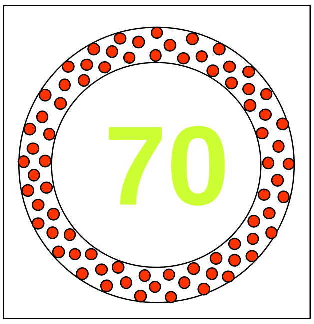


Figure 35 - Variable Message Sign panel adopted in Turin for Traffic Calming strategies

The panel shown in Figure 35 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 Figures 33 and 34. 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.

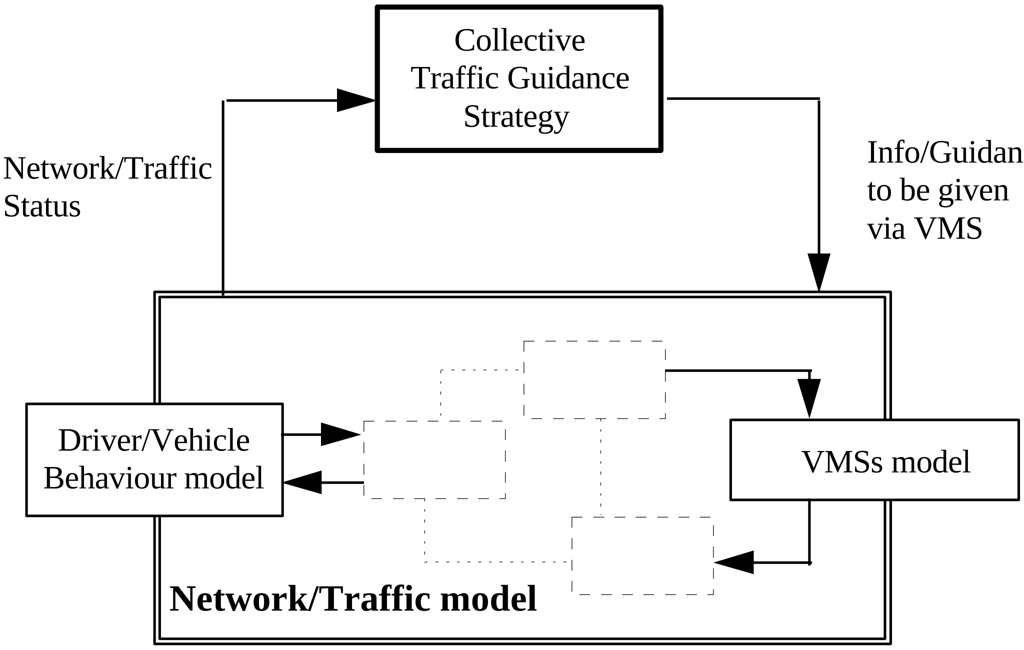


Figure 36- General organisation of the Simulation Environment

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 VMS 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).

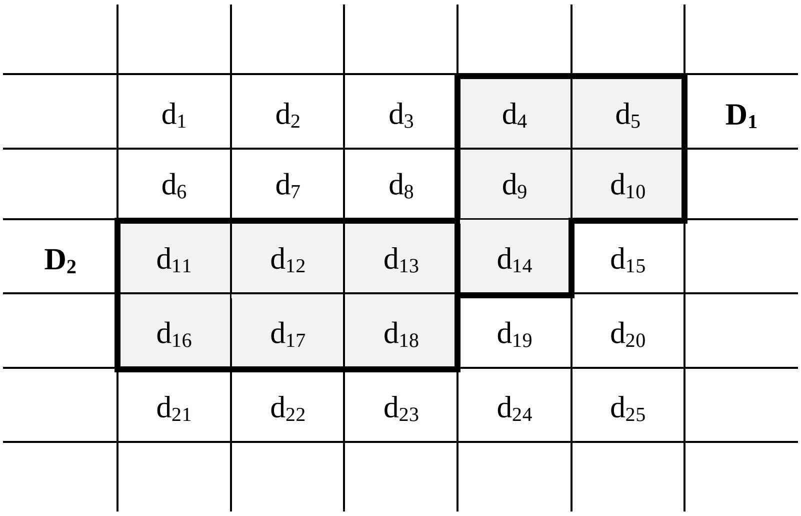
On the other hand, the destination of the driver corresponds to a particular point (or limited zone) of the network. Normally, for micro-simulation purposes this destination is modelled in terms of nodes. Consequently, driver destinations can be defined as "*micro-destinations*".

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 :

				D_1		
	d_1	d_2	d_3	d_4	d_5	
	d_6	d_7	d_8	d_9	d_{10}	
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.

5.9 DYNAMIC ROUTE GUIDANCE

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:
    - static
    - dynamic

    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:
    - autonomous: 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

    - infrastructured: 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.

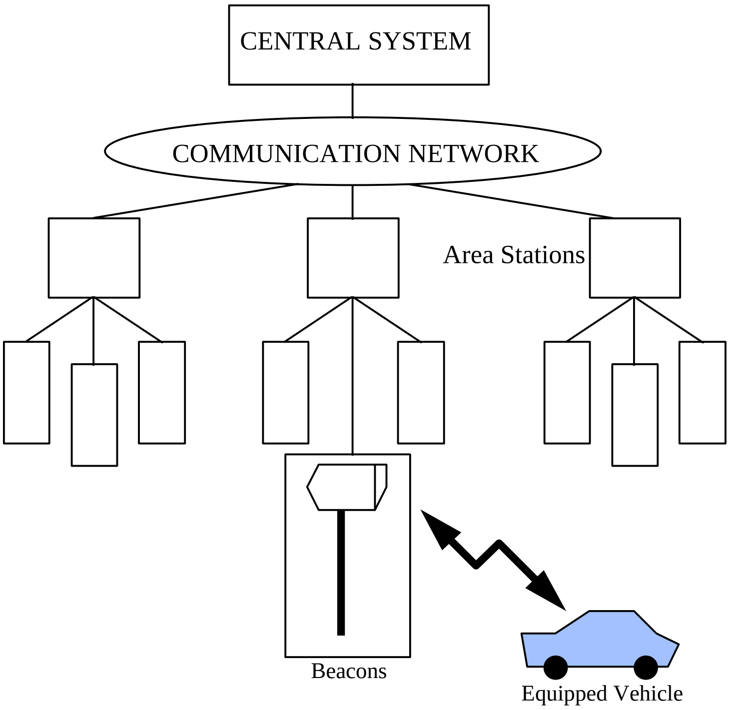


Figure 37 - Infrastructured Route Guidance general architecture

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.

•GSM - based systems: 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.

•RDS - based systems: 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.

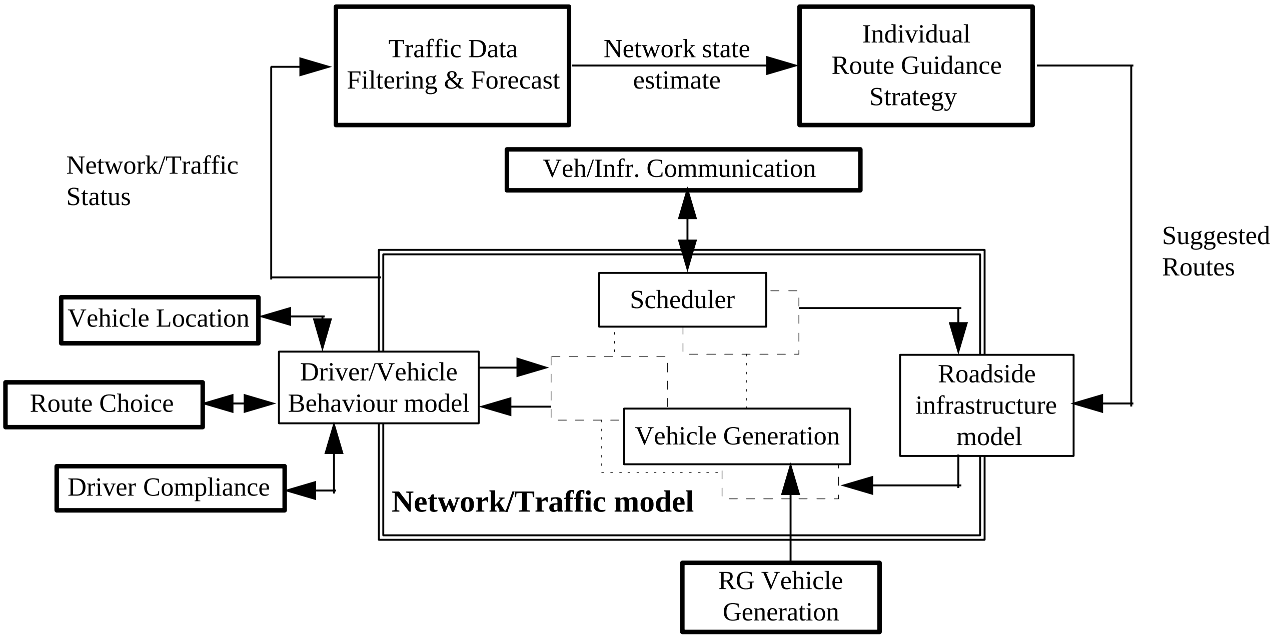


Figure 38 - General organisation of the Simulation Environment for Infrastructured DRG

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.

5.10 INCIDENT MANAGEMENT

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.

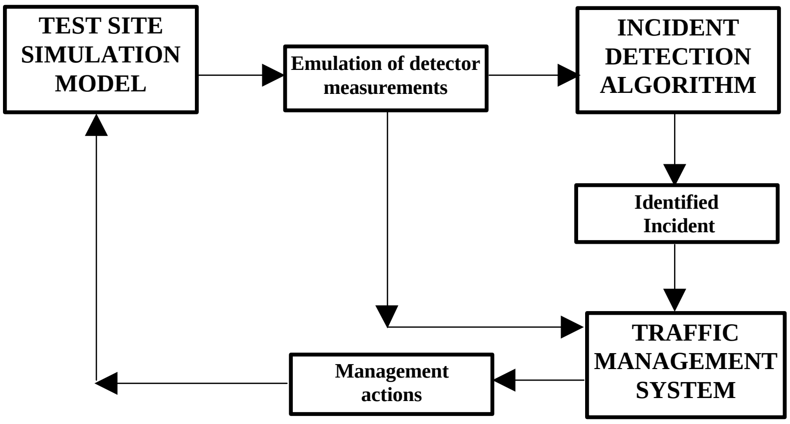


Figure 39: Data flows between the simulator and the detection module

5.11 RAMP METERING

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.

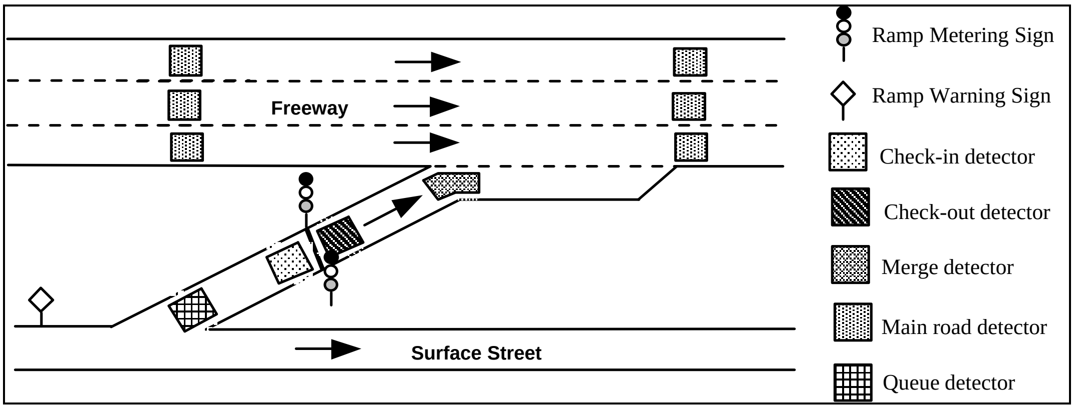


Figure 40: General layout of traffic-responsive entrance ramp metering system

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)

6. CONCLUSIONS

The activities performed in the context of WP03 - Model Update Specification, led to a clear definition of the enhancements that are being introduced in the SMARTEST micro-simulation tools in order to fill the gaps identified in WP02.

In Section 2 ("Prioritisation of gaps") a detailed list of models and features to be improved or to be added is provided for each SMARTEST tool. The following table provides an overview of the items that are going to be addressed:

traffic phenomena modelling	Public Transport
	Roundabout
	Traffic Calming
	Parking Management

Transport Telematic Functions	Adaptive Traffic Signals
	Public Transport Priority
	Vehicle Detectors
	Variable Message Signs
	Dynamic Route Guidance
	Incident Management
	Ramp Metering

user friendly (graphical) interface	Results Analysis
	Network Builder

Better Validation

The partners in the project decided to concentrate their efforts on these items based on two main principles:

- to take the state-of-the-art forward by a significant amount, taking into account the main issues emerging from the deep user requirement analyses performed in WP02, and of the current features of their models
- to look for important improvements and validations feasible within the lifetime of the project.

In order to ensure a standard approach at least at the project level, general specifications were worked out for modelling the features that constitute the main gaps identified in the tools. These specifications are reported in Chapter 5 and Appendix A, and also constitute a useful reference for development of models outside the scope of the SMARTEST project.

Scenarios were identified in the sites of Torino, Toulouse, Stockholm, Barcelona and Genova for testing, evaluating and cross-validating the enhanced models. Details are provided in Chapter 3.

Finally specific data requirements were provided in Chapter 4 to make feasible significant calibration and validation in the several project test sites.

As a general conclusion we can state that the activities performed in the context of WP03 provide the guidelines and the framework for a significant enhancement of the SMARTEST tools, towards the expectations identified through the deep user requirements analysis. The field was then prepared for congruent model evaluation and validation.