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A REVIEW OF MODELS OF URBAN TRAFFIC NETWORKS (WITH PARTICULAR REFERENCE TO THE REQUIREMENTS FOR MODELLING DYNAMIC ROUTE GUIDANCE SYSTEMS)

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A Review Of Models Of Urban Traffic Networks (With Particular Reference To The Requirements For Modelling Dynamic Route Guidance Systems)

David Watling (University of Leeds)

Abstract

This paper reviews a number of existing models of urban traffic networks developed in Europe and North America. The primary intention is to evaluate the various models with regard to their suitability to simulate traffic conditions and driver behaviour when a dynamic route guidance system is in operation.

1. INTRODUCTION

With the great interest currently in the use of information technology and telecommunications to influence the behaviour of drivers in urban situations, there has been more focus than ever on the use of simulation models to predict the effects of proposed measures. Because the level of investment required is likely to be many times higher than, say, conventional traffic management schemes, mistakes will be very costly.

This paper is concerned with the simulation of a particular technological development - that of a dynamic route guidance (DRG) system. Such a system may take a number of guises, but typically it is envisaged that it will take the form of a two-way communication system. On the one hand, a central control system will recommend routes to drivers (through in-vehicle devices) based on estimates of current or expected (or, most likely, a combination of current and expected) travel times, and according to some user- or system-based objective (eg shortest time route for the user). On the other hand, the in-vehicle devices communicate their position to roadside detectors, with the data relayed back to the central control system in order to produce estimates of prevailing journey times and traffic conditions. The routes recommended for each movement provide the 'dynamic' element, perhaps being updated every five minutes or so, and changing on the basis of expected daily variations in traffic conditions as well as unexpected conditions predicted from the on-line data.

A discussion of the modelling issues raised by dynamic route guidance systems was given in an earlier paper (1). This focused on identifying the maximum possible number of effects such a model could seek to simulate; it is unrealistic, however, to expect a model to be developed which incorporates all of the features identified. The paper presented here, on the other hand approaches the problem from a different angle by considering existing models of network performance, and investigating to what extent they are able to simulate the most important effects (or at least are amenable to modification in order to represent those effects). The paper also discusses recent research developments in the area of network modelling which are relevant to dynamic route guidance simulation.

It is intended that this paper will achieve two major objectives. Firstly, with the imminent implementation of real-life route guidance systems, it is necessary to have a model which at present gives the best possible indication of the likely effects (even if it is not an ideal model). Secondly, the findings will lead if necessary to the specification for a new form of network model which is able properly to evaluate DRG.

2. EVALUATION CRITERIA

The (existing) models will be introduced below and evaluated with respect to a number of criteria which are - it is proposed - key factors in attempting to simulate DRG. (They are taken from a more comprehensive list discussed in reference 1).

Firstly, general details of the model are given, including its purpose and where it was developed. The review then considers:

(a) **Route choice.** At the heart of any route guidance system is the potential for influencing route choice. There is a need, then, to consider how each model handles assignment, if at all.

(b) **Stochastic effects.** This concerns primarily the modelling of variability and uncertainty. For example, network conditions and travel demand vary from day to day and between the same day in different weeks. 'Incidents' such as accidents or parked cars can severely reduce capacity, and provide one of the main instances where DRG systems will be at their most effective; the ability to model incidents is therefore an important issue. There is also variability in the way in which different drivers react to conditions encountered and the behaviour of other vehicles. Uncertainty is present whenever a driver makes a choice decision; routing information from a DRG system is not even perfect, due to (for example) sampling variability in the data from which journey time predictions are made.

(c) **Dynamic effects.** This concerns variations in time over the very short term - for example, within a peak period. Since a DRG system is expected to react to variations in traffic conditions over a short time span (of, say, a few minutes), there is a need to cope with time-varying demand as well as the way in which route decisions vary with time and may be adapted en route. There is also the need to predict downstream interactions between competing or conflicting traffic streams.

(d) **Driver behaviour.** The general laws of driver behaviour underpinning the model.

(e) **Level of detail.** This is related firstly to the level at which traffic is modelled; for example, whether treated it is treated as a fluid (macroscopic level), whether individual vehicles are represented (microscopic), or whether there is some form of intermediate, mesoscopic representation. Secondly, there is the issue of diversity of driver behaviour; in a DRG situation, there will be quite different responses apparent in equipped drivers than in unequipped ones. Furthermore, the reaction and usefulness of the advice given - and therefore the behaviour - may vary according to trip purpose, familiarity with the network and route choice criterion.

The model descriptions will therefore refer to the above aspects as far as possible, subject to the amount of information readily available on the model. When the principles upon which the model is based are well-known and documented (eg car-following theory, equilibrium assignment), the descriptions will tend to be more brief; the more novel approaches generally receive rather more attention. On the whole, the review is concerned only in currently supported models; for a history of the development of such models, the reader is referred to reference 2. The final proviso is that the review is limited to European and North American models - the author was unable to obtain information on models from elsewhere, but would appreciate any contacts which could be suggested.

3. REVIEW OF EXISTING MODELS

3.1 CONTRAM

CONTRAM - CONtinuous TRaffic Assignment Model - was developed at the UK Transport and Road Research Laboratory (3-5). It is basically a traffic assignment model for simulating the growth and decay of congestion through time. The aim is to achieve a form of dynamic equilibrium, with drivers following minimum journey time routes taking into account the junction delays encountered at the times vehicles arrive at each junction (Although, as Alfa (6) points out, 'CONTRAM does not explicitly take into account those flows which, although entering the network after a given traffic, would affect its progress').

This equilibrium is achieved by a mesoscopic representation of traffic, in the form of groups or 'packets' of vehicles. Vehicles are loaded onto the network iteratively and incrementally - on a particular iteration, a packet is assigned to the minimum journey time route based on the current travel time estimates. Whilst there is no guarantee that this process will converge, Leonard et al. (3) reported that in tests 'all the runs of the latest version of CONTRAM have converged within satisfactory limits, given a sufficient number of iterations'.

Link journey times are assumed to be made up of two components: cruise time along a link (free run time for vehicles travelling at the average speed on the link) and delay at the downstream stop-line (time taken to discharge the queue, based on time dependent, stochastic queuing theory).

The demand for travel, in the form of origin-destination flows, is assumed to be inelastic but time varying; the modelled period is divided into time slices, with the demand assumed to be constant within each time slice. (The aim of the model, then is to produce an equilibrium-like distribution of flow for each time slice). Capacities and saturation flows too may vary between time slices.

Some diversity of driver behaviour and attributes is permitted, by the definition of different 'classes' of user. These classes may differ according to cruise time (up to a link independent constant), network restrictions (eg banned turns, links), time-varying origin-destination flows and generalised cost definition, but not according to the delay at the stop-line.

3.2 ROGUS

ROGUS (ROute GUidance Simulator) is an extended version of CONTRAM designed specifically for modelling dynamic route guidance (7,8). It is currently under development by the Transport and Road Research Laboratory; the following discussion concerns the features which are available in the initial version of the program.

ROGUS consists of two parts. Firstly, there is a modified version of CONTRAM to model unguided drivers; the only modification is that drivers are routed on randomly perturbed (rather than actual) minimum cost routes according to some specified probability distribution, in the spirit of conventional stochastic user equilibrium models (9). Secondly, a submodel known as ROGUS/Ada is used to simulate guided drivers and the operation of the roadside communication 'beacons' of the route guidance system. This works by assigning vehicles to routes via an event-based simulation, but using the (standard) CONTRAM delay and queue calculations. The link 'costs' upon which the routing is based are formed from a combination of historical data and real-time information (with appropriate communication delays represented). The historical journey time data are obtained from a previous run of modified CONTRAM or of the complete ROGUS model.

The approach is amenable to the simulation of 'incidents', by the introduction of temporary reductions in capacity.

3.3 TRAFFICQ

TRAFFICQ was originally written at the London borough of Wandsworth, but is now the property of the Department of Transport (10,11). It was designed for studying a detailed section of road network, with a practical maximum of typically around 60 links. It is basically a simulation model of queuing and platooning behaviour, specifically for congested networks where there is extensive queuing and the need to monitor the effect of interactions between junctions (eg blocking back).

Traffic is modelled at the microscopic level, tracking the progression of individual vehicles through the network as the traffic lights change, and queues and vehicles block the way ahead. Vehicles are moved in discrete time intervals (of the order of five seconds); the modelling is divided into a series of 'activities' which are scanned sequentially and instructions performed only if certain conditions are met.

Monte Carlo simulation is used, with - for example - demand flows assumed to follow a Poisson distribution, and vehicle running times described by Pacey's distribution (in order to model platooning).

Turning flows and routes are user-defined and fixed (ie do not vary with time and no re-assignment).

3.4 NEMIS

The NEMIS model has been developed by a university team of IENGF and by MIZAR Automazione, both of Turin (12,13). It was designed to evaluate different signal control policies (vehicle actuated, network wide, local intersection, closed loop) and to test network modifications.

It represents traffic at the microscopic level; it is an incremental model, tracking the movement of every vehicle every second.

NEMIS compromises three main procedures: VIAS, BASSOT and DIGIT. VIAS acts as a database, taking care of the network definition and signal settings. BASSOT performs an assignment, with the (time independent) origin-destination flows as input. DIGIT then performs a simulation, using the origin-destination matrix and the turning percentages at each junction from BASSOT (using them as <u>mean</u> values).

Looking at the assignment and simulation in more detail. BASSOT aims to determine the average turning percentages for all links to any destination, as well as average link travel times and flows. A stochastic assignment model is used, being achieved by an iterative process:

(i) Given the journey time mean and standard deviation for all links, perform a stochastic load by choosing 'random' samples of journey times, and for each determining the minimum delay origin-destination path.

(ii) Update 'journey time' parameters based on these flows (as well as on the network topology and signal settings).

This assignment procedure can be applied in a static framework, by basing the initial journey time distribution (prior to the first application of step (i)) on the network topology and signal settings. Alternatively, it can be applied in a dynamic framework, by basing the initial distributions on the journey times produced by NEMIS in the previous simulation step.

The simulation, performed by DIGIT, takes account of the rules of the road, signal settings and other vehicles, allowing for overtaking and lane-changing, by use of a car-following model.

Specified lanes can be blocked within the model in order to simulate an incident. Also, vehicles can be divided according to physical characteristics (eg small car, large fast car, large slow car, HGV) by specifying parameters which, for example affect the distance between adjacent vehicles and vehicle speeds.

3.5 PHEDRE

PHEDRE (Programme Heuristique d'Evaluation Dynamique d'un REseau) is a model developed by INRETS in France for studying traffic assignment and its effects on traffic conditions in periods of saturation (14,15). It is a dynamic simulator, representing traffic at the macroscopic level.

In its most complete form, it consists of three modules: Assignment, Control and Simulation (although it is possible for the user to pre-define the assignment and/or the control). In detail, these modules work as follows:

The assignment is used to produce an average distribution of flows over the network. Journey times are assumed to be made up of the time on the link (described by a user-specified speed-flow relationship) and the delay at junctions (from queuing considerations, giving rise to a formula similar to Webster's). The assignment model is a static, equilibrium-like one, obtained by iteratively determining minimum cost routes.

The control module iterates with the assignment, its purpose being to determine optimal signal settings. It takes into account the amount of traffic at the upstream end of the link, the traffic assignment, platoon dispersion and conflicting movements.

The simulation is a quite original procedure, and so needs to be described at some greater length. The simulation takes the turning percentages from the assignment model as input, these being assumed to represent the constant average demand flows through the simulation period. It then performs a macroscopic simulation of the evolution of the traffic flow in time and space, with the traffic flow being treated as a fluid. The links are processed in (variable) time steps of length p, where p is the journey time on that link without a queue. At time t, having studied the other links, the traffic volume arriving at the upstream end of the link in the period [t-2p,t-p] is known, and this volume will appear in the queue at the downstream end in the period [t-p,t]. From this arriving traffic and the queue already present, the queue length at time t may be deduced, and by means of a 'balance relationship' (which relates the average queue length to the outgoing volume), the traffic volume which can leave the downstream end of the link is calculated. The turning percentages obtained from the assignment are then applied to this volume to obtain the flow entering each of the downstream links.

Basically, then, the simulation has three constituent parts: (i) the journey time on the link (excluding queuing), calculated using a speed-flow law; (ii) the vertical queue - link specific 'balance relationships', recalculated after each assignment, describe the effect of the average queue length on the outgoing volume; and (iii) the junction crossing time, which is user-specified.

3.6 SATURN

SATURN (Simulation and Assignment of Traffic to Urban Road Networks) was developed at the University of Leeds, for evaluating the effect of traffic management schemes (16-18). Traffic is represented at the mesoscopic level.

Within SATURN, the network is defined at two levels of detail: the outer ('buffer') network, where links represent roads; and the inner ('simulation') network, where links represent turning movements as well as the roads connecting adjacent junctions.

SATURN has two modelling stages: an assignment and a simulation. The two stages are iteratively repeated until convergence (that is, until the flows from successive assignment stages are sufficiently close).

For given link flow-delay relationships, the assignment program performs a (static) Wardrop equilibrium assignment (via the Frank-Wolfe algorithm) for the whole network, with 'links' as defined above. [Alternatively other assignment procedures such as generalised cost, stochastic user equilibrium or multiple user classes may be selected].

On the other hand, for a given route choice and set of demand flows from the assignment, the simulation program performs a detailed simulation of junction interactions within the (inner) simulation network. The simulation considers traffic at the mesoscopic level, in terms of TRANSYT-style cyclic flow profiles; the assumption is that traffic will exhibit a cyclical behaviour, imposed by the traffic signal settings. The simulation takes account of processes such as gap acceptance for opposed movements, signal settings, platoon dispersion, conflicts at roundabouts and merges, blocking back, queuing and lane choice. Like the assignment program, the simulation has internal iterations, allowing for interactions within and between junctions.

The basic principle behind SATURN is that the assignment determines the average demand flows over the modelled period; the simulation is used to estimate the amount of this demand which can be served in the network. The output from the simulation is used to recalculate the parameters of the flow-delay curves assumed for each turning movement in the simulation network, and these relationships are fed into the assignment model to recalculate the demand flows.

A dynamic element may be introduced by modelling successive time periods with different characteristics, to simulate the effect of a time dependent level of demand or changes in the network (supply) conditions over different periods. In this case, the queues left on the network at the end of the previous time period are pre-loaded onto the network for the subsequent period. Facilities are also available for the simulation of random (day-to-day) fluctuations in travel demand or network conditions, and the study of the effect on network performance.

Multiple user classes of vehicle may be defined: these may differ in their demand origin-destination flows; fixed (flow independent) attributes such as free flow travel time; generalised cost weightings; available road network; permitted turning movements; or perception error variance (if routed based on stochastic user equilibrium).

3.7 SIMNET

SIMNET (SIMulation model for evaluation of integrated traffic control in urban NETworks) was developed at the Technical University of Berlin (19,20). Its representation of traffic has been termed mesoscopic, since it combines a microscopic model of individual vehicles, with a macroscopic method for moving vehicles along a link. It was designed for evaluating traffic control strategies including traffic responsive signal control, bus priority measures, tidal flow systems, parking guidance and route guidance.

Average entry flows are pre-specified for each link: vehicles are modelled as arriving as a random process. Each vehicle is either assigned a destination and route or is moved without destination, randomly choosing a turning direction at each junction according to the given turning proportions. Shortest path origin-destination assignment is also possible as a means for determining routes. The model allows time dependent (down to a one minute resolution) flows and routes.

The simulation has two parts. The first, mesoscopic part requires the input of travel distance and cruising speed, and models flows, travel times and queues. The aim is to determine a vehicles's cruise time for the link ahead, given its desired speed, and thus to determine the earliest time it could reach the downstream end of the link. Whatever control measure is employed (to be evaluated), its influence on saturation flow and gap acceptance affects the time at which the vehicle may leave the link. The second, microscopic part again requires the input of travel distance and cruising speed, but in this case lane-changing, acceleration/deceleration, speed, flow, queues and stops are modelled.

Time dependent changes in the network conditions are possible within the tidal flow system, but not elsewhere. Different vehicle types may also be defined.

Route guidance is one of the specific control measures available - the route (and destination, in the case of parking guidance) of a vehicle can be redefined en route. It is also possible to achieve multi-routing, by randomly assigning one of a number of alternative routes to a vehicle, according to given probabilities. Drivers may accept or reject the recommendations; different acceptance rates may be specified according to the driver and the route recommendations.

3.8 SITRA-B

SITRA-B was developed by ONERA/CERT in France (7, 21-23). It was devised in the first instance to evaluate signal control policies, and more recently to evaluate dynamic route guidance. Traffic is represented at the microscopic level. It uses a discrete, quasi continuous time simulation, with a one second increment. Its basis is a car-following and a lane-changing model.

It is able to take account of any complex network structure, and can model inductive loops and roadside communication beacons. The demand for travel is given in terms of a multi-modal, time-sliced origin-destination matrix.

The model also has an internal routing algorithm, which is based on an extended form of the Dial algorithm (24). In this extended technique, vehicles are assumed to follow the route given by the Dial method when the vehicles are first generated. However, they may occasionally choose a new route if and when they meet an 'obstacle' (in order to simulate the response to unexpected incidents), ie if a link is congested and depending on the driver's knowledge of the network. Alternatively, the driver may be given a new route if the microscopic network structure does not allow the original route.

In order to evaluate dynamic route guidance, the demand for travel from guided drivers is given as a proportion of each origin-destination-mode-time slice flow. Unguided drivers are assumed to follow routes according to the modified Dial algorithm described above (where drivers divert from their initially chosen routes reasonably rarely). Guided drivers also follow routes initially according to this algorithm; however, when a guided vehicle reaches a beacon, a new route can be recommended by some on-line guidance algorithm (external - not provided in SITRA-B). Depending on the driver's level of adherence, he may accept or reject the recommendation.

3.9 PACSIM

PACSIM is an approach to behaviourally driven route choice and assignment, developed at FUNDP (Faculties Universitaires ND de la Pais) in Namur, Belgium (25,26). It was purpose built for modelling so-called Road Transport Informatics (RTI) systems. It represents traffic at the mesoscopic level, being a dynamic model split into time slices of varying size. It assumes that all modelled quantities (traffic, congestion, information, etc.) are constant within a given time slice (which suggests small time slices will be necessary for simulating a peak hour).

PACSIM differs from other models in that the level of detail of traffic representation is driven by behavioural considerations. Traffic is moved in 'packets', where a packet is a group of vehicles moving with 'coherent behaviour'. With the model in its current form, this means that vehicles in a packet must have in common their destination, mode, trip purpose and their capability to access driver information systems and to assimilate the information provided. Since this is likely to mean that there will be a great number of packets required, a computational procedure is used which - while packets are still some distance from their destination - will aggregate all destinations within the same district (say) into a single 'abstracted destination'.

The network definition is also behaviourally motivated. It is used to represent the fact that drivers tend to perceive the network at a more disaggregate level when they are close to a given location, whilst distant locations are perceived in a more aggregated form (for example, only the main districts and major roads). PACSIM has three levels of aggregation - the main, strategic and detailed networks. This has a great influence on the structure of the model - for example, the computational procedure described in the previous paragraph and the definition of the users' knowledge of the network (described later).

The basic modelling part of PACSIM is a behavioural mechanism, split into two stages:

(i) definition of the 'perceived network' - the network as perceived by a particular packet of users.

(ii) a routing decision for that packet within the framework of (i).

Part (i) above is done in two stages. Firstly, a position-dependent, multi-level detail of network is built, using the three levels of aggregation described above. Secondly, behavioural rules are used to modify this network to obtain a packet-dependent version, according to the packet's characteristics and the information it has accumulated in past time slices. (This latter is modelled by use of a 'background network' which builds up long-term dynamic experience of the network, and is at present common to all drivers). This modification could, for example, remove links outside a packet's knowledge, represent differences in cost definition or take account of broadcast information on congestion.

Part (ii) above then assigns a user optimized (shortest) path to the packet, given the network in (i). Alternatively, the costs may be first randomly perturbed (in a similar vein to stochastic user equilibrium models) in order to represent within packet variability.

Finally, with RTI systems such as route guidance in mind, a fourth level of network (the information network) is defined, in order to model the two-way flow of information between network and user. In this part of the model, it is possible to take account of: detectors, with different sensitivities, reliabilities and reaction delays; traffic information centres (which collect and distribute data); information outlets, such as roadside communication beacons, which may vary according to the amount of information they can store and the frequency of the information update; and traffic control centres, which maintain and distribute sets of recommended routes for DRG. These are all linked by communication lines, whose reliability and delay can be modelled. Also, the configuration of the information network can be dynamically updated.

3.10 MICSIM / ITM

Both ITM (Interactive Traffic Modeller) and MICSIM were developed by SIAS of Edinburgh, UK (27-29).

ITM represents traffic at the microscopic level, being governed primarily by driver perception of gap acceptance and car-following rules. Movements of vehicles are determined by network geometry, kinematics and the rules of the road. It is an incremental model, in which during each interval the simulation cycles around each junction in the network and then around each input link to the junctions. It makes use of simple heuristics in order to make the computational task more manageable, with the size of inter-vehicle gap (a function of relative speed) determining the car-following procedure to use at each simulation cycle.

ITM was designed as a tool for assessing traffic management schemes over a whole network, but more recently has been incorporated in a new model MICSIM, which aims to simulate the effect on driver behaviour of various RTI systems.

MICSIM has been designed with the purpose of being a microscopic sub-model of the mesoscopic model PACSIM (described in section 3.9). MICSIM performs a microsimulation of a portion of the network (the perceived network) about a given junction, the junction having been chosen by the model user during a PACSIM simulation. PACSIM defines the perceived network and transmits this information to MICSIM, together with the positions of all packets of vehicles in this subnetwork. MICSIM then disaggregates these packets.

MICSIM has three subsystems. Firstly, there is the local network manager, which transmits details of the network and vehicle/packet positions between MICSIM and PACSIM. Secondly, there is a local RTI manager, which receives details of 'traffic events' (over the whole network) from PACSIM. A rule-based behavioural theory (29) is then used to determine new routes for vehicles affected by these events. The third component is the vehicle manager, which carries out a simulation using ITM. The vehicle manager also detects "congestion" (long queues) and informs PACSIM of this.

Once the network has been set up by the local network manager, iterations take place between the local RTI manager, which computes routes given the traffic events, and the vehicle manager, which carries out the simulation. The behavioural theory and the choice of 'perceived network' uses the same concepts as those described earlier for PACSIM.

3.11 PREDICT

PREDICT (Pollution REDuction by Information and Control Techniques) is a model developed by the European Community's DRIVE 'PREDICT' consortium (Castle Rock Consultants, Costas Abacoumkin Associates; Epsilon International; Intracom SA; and Organisation for the Environmental Protection of Athens) (30). It was designed as a tool to predict the pollution effects of different traffic management measures and control strategies. It is both a descriptive (estimating pollution concentration at the link level) and a predictive model (using link-based environmental penalties).

PREDICT has four elements, working at different levels of detail (macroscopic, mesoscopic and microscopic): an assignment, traffic, emissions and dispersion model.

At the macroscopic representation level, the assignment is based on Dial's stochastic method (24). The network is defined at two levels: the 'external network', where a link is a road, and the 'control network', where each link represents a turning movement. In the context of the use of variable message signs, it models unguided and (fully compliant) guided drivers by an incremental technique. The origin-destination matrix is partitioned, with the guided drivers first assigned to the minimum cost route for each movement, and then the unguided drivers assigned according to Dial.

At the mesoscopic level, the traffic model used is TRANSYT (31,32). The turning volumes and flows predicted by the assignment model are fed into TRANSYT, which acts both as a traffic model (based on cyclic flow profiles) and a signal optimizer.

The emissions model (PREMIT) works at the microscopic level, taking the output from the traffic model to calculate quantities of various pollutants emitted. It achieves this by taking account of the time spent by vehicles in various driving modes, namely cruise, acceleration, deceleration and idling (working on the basis that these modes are due to stopping and starting at intersections).

Finally, there is the dispersion model (PREDCO) which estimates the atmospheric dispersion of pollutants.

3.12 METANET

METANET is a freeway network model (33), developed at the university of Munich, which makes use of a formulation of dynamic assignment due to Papageorgiou and Messmer (34). METANET uses special purpose link flow models within this framework; however, since the general approach of Papageorgiou and Messmer is more relevant to this review, we shall concentrate on that rather than the specific capabilities of METANET.

The framework is a control theoretic one, under the assumption of inelastic but time-varying demand. Traffic is represented at the macroscopic level. The approach is applicable to multi-origin, multi-destination networks (although there is no guarantee of a unique solution to the problem).

The modelling takes place in three interacting stages:

(i) link flow model
(ii) traffic composition model
(iii) dynamic assignment model

(i) and (ii) describe the time-dependent movement of flow on a single link, for a given route choice; (iii) ensures that, for the given models of time dependent link flow, routes are chosen so as to satisfy dynamic user optimum conditions. (NB For a <u>static</u> equilibrium, then, models (i) and (ii) would be redundant, and in this special case the formulation would lead to the model of Dafermos and Sparrow (35)).

Considering these three stages in more detail. Parts (i) and (ii) are concerned with flow on a given link - the link flow is characterised by a number of variables, which may be classified either as 'global' (they do not distinguish between subflows with different destinations), with which (i) is concerned, or as 'destination-oriented' (they take account of the composition of the flow with respect to the different subflows), to which (ii) relates.

Stages (i) and (ii) are concerned with transforming respectively the total flow and composition rates (both time dependent) at the upstream end of a link to their equivalents at the downstream end; the composition rates at the beginning/end of a link for destination j is defined as the proportion of flow at the beginning/end of the link which is destined for j.

The authors suggest some possible forms for the models in (i) and (ii). For example, the 'conservation of traffic density' equations used by Merchant and Nemhauser (36) and by Wie (37) (where the difference in traffic density between times k and k+1 is the density of traffic entering the link in period k which does not leave the link in time period k) are specific forms of (i). A possible form for (ii) is gained by setting the output composition rate (for each destination and link) at time k+1 equal to a weighted average of input and output composition rates at time k, where the weights are constant or (for example) the weight given to the input rate could be inversely proportional to the travel time along the link.

Part (iii) of the model controls the dynamic route choice. This gives the opportunity to model the natural behaviour of drivers via a 'predictive user optimum', where the cost of travel on a link at time k is the predicted travel time and depends upon future conditions. On the other hand, there is the option to model control through the use of variable message signs or dynamic route guidance, via a 'reactive user optimum', where the cost is the travel time under the current conditions. That is to say, a driver would normally choose the route which (according to his experience, which is assumed to have been extensive and ignores factors such as day-to-day variability) gives the shortest expected travel time. With real-time information, on the other hand, the driver would choose the route which currently appears the shortest.

3.13 AIMSUN

AIMSUN (Advanced Interactive Microscopic Simulator for Urban Networks) was developed at the Polytechnic University of Catalunya, Barcelona, Spain (38,39). It was originally designed to assess traffic control and management schemes in urban networks where all junctions are signal controlled. It can now also handle priority junctions, roundabouts and motorways.

AIMSUN represents traffic at the microscopic level, with the behaviour of individual vehicles 'continuously' modelled throughout the simulation time. Vehicle behaviour is determined according to car-following, lane changing, queue discharge and gap acceptance models. AIMSUN simulates on a discrete, time-scanning basis - that is, time is split into fixed, short intervals (with the length of the interval equal to the reaction time of drivers) called the simulation cycle, with all elements composing the system (vehicles, traffic lights, etc.) updated every cycle.

Vehicles are generated at the input links of the network via Monte Carlo simulation, with inter-arrival times modelled by a shifted exponential distribution, which depends on the mean flow rate and minimum headway (both user-specified). Arrivals are generated on a lane by lane basis, with the link flow distributed across the lanes. At the generation of each vehicle, Monte Carlo simulation is used to draw: its arrival time; the driver's desired speed; the maximum acceleration the vehicle can achieve; and the maximum deceleration the driver accepts as safe.

AIMSUM has no route choice model; the user must specify the mean flow per hour at the input links and the turning proportions at each simulated junction.

It is possible for the user to manually introduce some additional dynamics/variability (that is, they are not modelled in any way, but can be externally specified), since the approach is condusive to generating 'incidents' (position and duration specified) or dynamically varying the input parameters (namely the flows at the input links, the turning proportions and the signal settings). Both of these may be achieved by the user interrupting the simulation, specifying appropriate values and then re-starting the simulation from its last position.

3.14 CORQ

CORQ is a model which was developed at the university of Waterloo, Ontario (40). Its aim is to model the operation of a corridor; that is, a network with a dominant direction, whose flows are of interest. The documentation is written with reference to a particular type of corridor - that is, a freeway and its parallel surface streets. It was designed to assess the system-wide effects of traffic control strategies, in particular aiming to estimate the effect of queuing and ramp metering on the freeway and to study the impact on the parallel surface streets of freeway control policies.

CORQ represents traffic at the macroscopic level. It is basically a deterministic, queuing-based, capacity restrained, dynamic assignment model, which treats major intersections/interchanges in greater detail than the rest of the network. At these latter locations, CORQ models queue evolution and dissipation using deterministic queuing, as well as representing the 'conflicts' which are special to freeway corridor networks, such as merging and weaving operations.

The demand for travel is specified in the form of a time-varying step function, with demand constant over approximately fifteen minute periods. CORQ then calculates a (dynamic) equilibrium traffic assignment over one period at a time; any queued vehicles remaining on the network at the end of one time period complete their journey in the subsequent period. Drivers aim to follow minimum cost routes, where cost is a function of link flow and queuing delay. They are assumed to know the costs exactly for the present time slice, but not for future time slices. If the route chosen leads to a queue, then the remainder of the driver's route will be chosen based on costs at the time when he is ready to leave the queue (that is, drivers experiencing queues may change from their initially chosen route during the journey).

It is also possible for the user to vary capacities between different time periods.

3.15 TRAFLO

The TRAFLO model was conceived by the Federal Highway Administration of USA (41,42). It was developed for testing transportation management strategies. Traffic is represented at the macroscopic level of detail.

TRAFLO consists of five submodels which interface with one another, and are described below.

Firstly, there is a traffic assignment model, which is a conventional, static, Wardrop equilibrium; this is achieved by the application of the model TRAFFIC (43,44).

The remaining submodels form a suite of macroscopic simulation procedures, three of them representing different macroscopic levels of detail and the fourth being specifically for freeways.

The first of these simulations, known as 'Urban Level I', is the most detailed (42). It is an event-based, stochastic (monte carlo) simulation, which takes account of queuing, headways and a car-following law. Although it is macroscopic in terms of its treatment of the traffic stream, it can distinguish individual vehicles in the stream with possibly different characteristics.

The second simulation procedure, 'Urban Level II', is less detailed, being based on TRANSYT-style cyclic flow profiles. It takes account of the dynamics of flows, assuming a cyclical behaviour which is imposed by the traffic signals, and allowing for platoon dispersion, service rates and queues.

The third simulation submodel, 'Urban Level III', is even less detailed. It uses an extension of Webster's relationships between delay and traffic volume, signal settings and saturation flow, in order to simulate time-dependent link flows and turning delays as a function of the volume making the turn, as well as of opposing flows.

The final and least detailed simulation is the freeway model, a deterministic macrosimulator known as FREFLO (45). By treating the flow of traffic as a fluid, FREFLO represents traffic on sections of the freeway in terms of flow rate, density and mean speed, making use of equilibrium speed-density relationships. (FREFLO is a development of the MACK model; it has since been further developed, to be known as FRECON (46)).

The idea behind the whole TRAFLO model is that the network is divided into subnetworks with different levels of detail for the simulation. The interface between the assignment and the simulation submodels is in terms of the turning proportions fed from the assignment to the simulation.

3.16 MICRO-ASSIGNMENT

Micro-Assignment is a very simple model developed for the Bureau of Public Roads, USA. (47). It was designed specifically for traffic studies in small areas, such as the study of detailed traffic movements within a central business district. Traffic is represented at the macroscopic level.

The most novel (at the time it was developed) feature of the model is its network definition, with links used to represent turning movements. Turning movements at different junctions are joined mid-block.

The model is basically an assignment of some description. Delays on the turning movements are assumed to be a function of the turning volume. The procedure used is to load all the trips from a given origin (or, possibly, set of origins) onto the minimum cost route for each movement to the destinations; after loading that origin, the costs are updated using the delay relationships, and the next origin is considered. The model is thus some form of capacity-restrained, all-or-nothing assignment.

3.17 JAM/QJASN

JAM (Junction Assignment Model) is a traffic assignment model developed by Wootton Jeffreys Consultants, UK (48). It was designed for use in most urban traffic studies, such as the design and evaluation of traffic management schemes or the assessment of the effect of new developments. It uses a macroscopic traffic representation.

JAM requires the specification of a time-sliced origin-destination matrix, with demand assumed to be constant over fifteen minute periods. It attempts to achieve an equilibrium assignment in each period by the use of incremental loading and an iterative capacity restraint process. The periods can be linked by passing the queues remaining at the end of one period as the initial input to the subsequent period.

The network can be coded with different levels of detail:

(i) 'JAM modes', where detailed geometric and operational data - typical of specialist roundabout, traffic signal, etc. programs - is provided;
(ii) peripheral network, where conventional link-based flow-delay relationships are specified;
(iii) external network (eg up to 20-50 miles from the central study area), which is coded with (flow independent) fixed delays.

At JAM nodes, turning delays are a function of the demand flows and the turning proportions (thus, capacities are also essentially updated at each iteration of the assignment algorithm, by the recalculation of delays in this way). A 'randomness parameter' is also included, which allows for variability in the arrival and service patterns.

Delays and queues at roundabouts, priorities and merges are calculated using time dependent queuing theory. There is the option to randomise link costs, using a uniform error structure.

The QJASN model (49,50) is a similar approach, which has been designed as an alternative to JAM for junction-based assignments. The main advantage QJASN has over JAM is its ability to use theoretically convergent equilibrium assignment algorithms, such as the Frank-Wolfe method and the method of successive averages. QJASN achieves this, however, at the expense of cruder delay assumptions (in particular, they do not vary over the study period as in JAM).

3.18 ASTERIX

ASTERIX is a consortium within the European Community DRIVE programme, led by the Polytechnic University of Catalunya in Barcelona (7). The main objective of the consortium was to develop a general purpose simulation environment for Road Transport Informatics systems. It was designed to use improved versions of already existing traffic simulation systems, but is able easily to integrate future simulators with new modelling capabilities.

The system shell acts as an interface between different models working at different levels of detail, depending on the level at which the RTI system is working:

(i) regional level (macroscopic model)
(ii) intermediate size networks (mesoscopic model)
(iii) local level (microscopic model)

The models chosen to perform the tasks (i), (ii) and (iii) were respectively: the assignment submodel of SATURN, CONTRAM, and SITRA-B. (These are described in this paper in sections 3.1, 3.2, 3.6 and 3.8).

3.19 IMAURO

Like ASTERIX, IMAURO is also a consortium (led by FUNDP of Namur in Belgium) within the EC DRIVE programme; they too are aiming to produce a simulation package consisting of three submodels, each capable of simulating urban traffic networks but at different levels of detail (28).

Given the demand origin-destination matrix, the three submodels are:

(i) TOPSORT (51), which determines the initial costs and flows for all links of the network, and supplies these to submodel (ii).

(ii) PACSIM (described in section 3.9), where traffic is split into packets to produce a mesoscopic model.

(iii) MICSIM (described in section 3.10, as is the interaction between PACSIM and MICSIM), which performs a microsimulation within one small area of the whole network.

3.20 INTEGRATION

INTEGRATION is a model which was developed in Canada, at the University of Waterloo and Queen's University, Ontario (52,53). It was designed to evaluate the operation of integrated freeway/traffic signal networks in recurring and non-recurring congestion.

INTEGRATION represents traffic at the microscopic level. Individual vehicles are moved through the network, using routing which attempts to reproduce a (microscopic) continuous, dynamic equilibrium, by use of an incremental assignment technique.

The demand for travel is specified in the form of a time-sliced origin-destination matrix. At a vehicle's scheduled departure time (which may be generated 'randomly' from some distribution), it leaves its origin, starting out on what currently is the minimum cost route to its destination. (NB routing is based on the current state of the network, rather than expected future conditions; this also implies there is no need for iteration). The costs are based purely on link travel times, which are estimated considering the free flow travel time, capacity, signal settings, traffic volumes and queues. (The costs may also be randomly perturbed, à la stochastic user equilibrium). The route initially chosen by the driver may be changed at any intersection (eg to avoid incidents), given the fact that the costs are periodically recalculated during the simulation, to reflect changes in link travel times (Van Aerde and Yagar suggest that updating every six seconds seems to provide a reasonable compromise between computational efficiency and accuracy).

Considering specifically the dynamics of queuing in the model: A vehicle takes the current link travel time to travel from the upstream to the downstream end of the link. The vehicle may be held (in a First-In-first-Out stack) at the downstream end of the link, due to - for example - capacity, traffic signals or blocking back considerations. The simulation works by checking each link's stack every time increment (of a tenth of a second duration), to determine the first vehicle eligible for departure. Once a vehicle departs from a link stack, there is a specified minimum headway before the next vehicle in the stack may depart.

The FIFO stack means on the one hand, that the simulation is very efficient within each increment - as only the first vehicle in the stack on each link need be considered. On the other hand, it means that the model does not permit overtaking on a link.

INTEGRATION is also able to model incidents, by the user specifying a duration and severity (effective reduction in the number of lanes).

3.21 DYNEMO

DYNEMO was developed at the university of Karsruhe, Germany (54), for assessing traffic management schemes on freeway networks, such as ramp metering and speed limits.

DYNEMO is a mixed microscopic and macroscopic model. It goes further than traditional macrosimulators, which use speedflow relationships to move vehicles through the network and use a division of the system into homogeneous parts to represent geometry and speed limits. DYNEMO combines this general approach with knowledge about desired speeds, to calculate the actual vehicle speeds.

A time dependent origin-destination matrix is supplied to the model, with vehicle routes calculated via a shortest path algorithm.

3.22 SIGNET

SIGNET was developed in the USA, at Wilbur Smith Associates (New York) and the University of Tennessee (55). It was designed to represent traffic flow on a signalised street network.

It is a microscopic (time incremental), car-following - like simulator. Vehicle departures are generated pseudo-randomly from a shifted exponential distribution. At generation, each vehicle is 'randomly' assigned a target velocity, a minimum desired acceleration and deceleration, and a type (car/HGV). From the user-specified (average) route choice - given in terms of turning proportions - the turning movement at the next intersection is randomly sampled.

Stopping - whether behind another vehicle or at a stop-line - is represented by a constant deceleration model. The turning movement model requires that vehicles do not exceed a given maximum speed during the turn.

3.23 TRAF-NETSIM

NETSIM (formerly known as UTCS-1) was developed for the USA Federal Highway Administration, and was later integrated in the TRAF simulation system (56-58). It simulates driver response to, for example, traffic control devices, transit operations, pedestrian activity and lane closures.

Traffic is represented at the microscopic level. NETSIM uses a fixed time, discrete event, stochastic simulation technique, tracking the performance of every vehicle every second.

Vehicles are divided by category (car, HGV, etc), type within each category (according to operational and performance characteristics) and driver behavioural characteristics (passive, normal, aggressive). All of these characteristics are randomly assigned to vehicles at generation, according to specified probability distributions.

Vehicles enter the network at a uniform rate (according to the specified input volume) and are moved according to car-following logic (which, loosely speaking, allows vehicles to accelerate to their desired speed, subject to maintaining a safe distance from the preceding vehicle).

Turning movements are randomly assigned to vehicles, according to the user-input turning percentages. It is also possible to specify some kind of additional route-like information: link-specific conditional turning percentages. These define the turn probabilities conditional on the turning movement undertaken by the vehicle when entering the current link.

'Events' (eg parked vehicle) can be modelled within NETSIM. These result in a lane closure, and vehicles react by looking for lane change possibilities, but are subject to the same constraints (eg on available gap). Short-term events (less than a minute) have a user-specified frequency, duration and link. Long-term events have a specified start time, duration, lane and link. The exact location of the event on the link is randomly determined.

3.24 TMODEL

TMODEL is a traffic and transport package developed at the Centro Studi sui Sistemi di Transporto (CSST) in Turin, Italy (59,60). It is a package incorporating traffic assignment, transit assignment and origin-destination matrix estimation, and was developed for transport planning and research purposes.

The traffic assignment model is known as TROAD; this represents traffic at the macroscopic level. It uses a 'conventional' representation of the network, with nodes corresponding to junctions. The model is a static equilibrium one (using the Frank-Wolfe algorithm), with the option of user equilibrium, system optimum or multiple user class equilibrium. The link parameters (eg capacity) can be randomised to represent day-to-day variability.

3.25 Mahmassani & Jayakrishan

These authors have developed a model at the University of Texas (Austin), especially to model in-vehicle information strategies (61,62). It was adapted from a macroscopic simulation model which was developed to study commuter dynamics in congested traffic corridors. In the adapted model, however, traffic is represented at the microscopic level.

The overall model has four main components which are sequentially applied: a macrosimulator, a queuing model, a route processor and a user decision model. These will now be described in more detail.

The macrosimulator is known as MPSM (MacroParticle Simulation Model), and describes the dynamics of traffic flow on a link (65). The logic of the simulation is derived from plasma physics and particle dynamics, with 'vehicle moved in bunches at prevailing local speeds derived from speed-density relationships within discretised segments of highways'. In fact, in the overall model described here, the macrosimulation is applied at the microscopic level, by allowing each 'macroparticle' to represent a single vehicle.

The queuing model is a deterministic model of single queues at the end of each link, with time dependent service rate (depending on prevailing conditions).

The route processor has the task of defining the route choice assumed to be available to drivers in the network. (The reason for restricting the choices is that of computational efficiency). There are two distinct cases. For corridors, choice sets are assumed only to include distinct parallel routes (although in the model as a whole drivers may actually use parts of a route and switch over, because of en route diversions modelled by the user decision model - described below). For general networks, on the other hand, the choice sets are restricted to the best k (say) routes.

The route processor also calculates the link (and hence the route) travel times, which are obtained as the sum of the time to cross the link and the on-line estimate of the queue waiting time.

Finally, there is the user decision model, which is based on the concept of bounded rationality (63) (although not necessarily on boundedly rational user equilibrium). This rests on the notion of drivers having a current route and considering whether or not to switch to an alternative. The model assumes that a driver will switch from his current route only if the (relative) improvement in the remaining travel time exceeds some threshold value. Such a model represents the fact that drivers may refuse to change to a quicker alternative if it is unfamiliar, as well as the fact that drivers may consider a change to an alternative route during their journey when experiencing unexpected conditions. The threshold values are modelled by a random variable, distributed across the driver population, to represent differences in the propensity to switch routes.

3.26 TRIPS

The TRIPS assignment model was developed by MVA Systematica (64). It represents traffic at the macroscopic level.

TRIPS requires the input of a time sliced origin-destination matrix; the time dependent flows are known as 'flow profiles'. The model works by shifting the flow profiles from each origin along the time axis, taking into account the time for vehicles to move across the network. However, the model only moves as much flow as the network capacity conditions can serve. When such a capacity limitation is reached on a particular link, trips are removed from routes which use that link - on a pro rata basis - to make the demand flow on that link equal capacity.

In terms of route choice, it is claimed that 'the TRIPS dynamic assignment methodology is amenable to calculating a new routing every time segment, but the computational effort and associated level of detail is not considered to be appropriate'. Instead, TRIPS chooses routes based on average conditions over the study period, with several sets of routes calculated.

It is possible to link together modelling periods which have different, say, demand patterns, capacities or signal settings; in this case, the queues remaining from the simulation of one period are held over to the next period.

3.27 Spiess & Suter

Spiess and Suter (73) proposed an approach for modelling within day variability of traffic flows and route choice, implemented within the EMME/2 transportation planning package (74) and applied to a town in Switzerland (where it was developed). It was designed for considering environmental issues such as energy consumption, and air and noise pollution.

It is a macroscopic model for predicting flows and speeds in a network for each hour over a twenty-four hour period, whilst avoiding the complexity of dynamic assignment models.

The modelling process begins by the user defining a small set of basic states of the network - for example: AM peak, PM peak and off-peak. Each state is represented by a (static) demand matrix. For each state independently, a static, equilibrium assignment is performed.

Each hour of the day is then represented by a characteristic combination of these basic states; that is, the flow on a link for a particular hour of the day is a linear combination of the flows on that link in the basic states. The combination coefficients are determined by multiple linear regression, given hourly traffic counts on a subset of the links.

3.28 STODYN and STODYN2

The modelling techniques of Cascetta and co-workers (77) at Napoli university were developed primarily (initially, at least) to study the effect of day-to-day fluctuations in origin-destination demand on route choice, including auto-correlations over different days. The general approach is rare in that it is a capacity-restrained but non-equlibrium one, with the evolution of the system over successive days modelled as a stochastic process. As well as developing a general framework within which many driver behaviour (choice) and learning models may be implemented, they proposed a specific, behaviourally simple model known as STODYN. Whilst the general framework is condusive to representing traffic at either the microscopic (route chosen by each individual) or macroscopic (route flows or, equivalently, link flows) level, STODYN is essentially a macroscopic model.

This basic approach was later extended to incorporate 'within day dynamics' too (75,76), at the mesoscopic level of detail (it deals with groups of drivers departing in intervals of the 'day'). It was designed as a tool to estimate the effectiveness of traffic engineering measures and/or driver information systems - in particular it is able to simulate real-time information strategies allowing en route path switching. In this more general model, as well as simulating day-to-day adjustments of route choice, there is the ability to account for elastic demand and departure time choice. Again, a general framework is proposed, which may be used in conjunction with different behavioural or dynamic network loading models, as well as a specific form of model known as STODYN2.

We shall now consider the various components of the STODYN2 model in greater detail; firstly, the dynamic demand/supply interaction model. To start with, it is necessary to define the terminology used. Knowledge of the *state* of the system on a particular day is defined as knowledge of the path flows and departure times of users. *Day-to-day dynamics*, on the one hand, refers to variations occurring between successive reference periods (eg the whole day, the morning peak), but for convenience these latter are referred to as 'days'. *Within day dynamics*, on the other hand, refers to variations which occur between the (finite number of) intervals into which the day is divided. In terms of the relationship between paths and links, the links flows during a particular interval on a particular day are determined from the path flows according to the dynamic network loading model (one such suggested later). Average path costs over the population of drivers (for a given day and interval) are generally a function of link costs, which are a function of link flows. Actual path costs may be modelled as deterministic or random variables (but note that the choice of random/deterministic has no bearing on the stochasticity of the process described below).

The second component of STODYN2 to decribe is the behavioural model; this is an adaptation of the random utility model of Ben-Akiva et al. (78) to include a 'habit' effect (in the sense that each day, only a *fraction* of users will reconsider their previous day's route choice). The perceived utility to a user of a given route and departure time is the sum of two components. Firstly, there is a deterministic factor, the 'average predicted utility', the elements of which include: the average predicted travel time; an early/late arrival penalty corresponding to the average predicted arrival time (assuming drivers have a tolerance interval around the desired arrival time); and a habit effect. The second component of perceived utility is a random error, representing perception errors and diversity of driver characteristics. A simple filter is used to form the average predicted travel time, being a weighted average of the previous day's actual and average predicted travel times.

The above model can therefore be used to represent the behaviour of users *without* any kind of information/guidance systems. A static, pre-trip information system could be simulated, it is suggested, by the same basic model but with a reduced perception error and less reliance on historic information in the filtering process. For a dynamic pre-trip system, a slight modification to the model is applied to allow for the possibility that the driver has already departed before the information arrives. For a dynamic en route system, users are allowed to divert (at any node) from their initially chosen route, according to specified behavioural rules; this is implemented during the dynamic network loading stage.

The third and final component of STODYN2 is the dynamic network loading model, which (for a given day) computes time dependent link flows from given dynamic path flows. In general, dynamic network loading may be regarded as a fixed point problem: Defining, for each link a, path k and intervals h and j, the *crossing fraction* to be the proportion of the flow on path k departing in interval j which uses link a during interval h, then (time dependent) link flows may be written as a function of path flows and crossing fractions; on the other hand, the crossing fraction depends on the time needed to reach link a on path k, which (through flow-delay relationships) depends on link flows. The proposed method aims directly to solve this fixed point problem, by decomposing it into a sequence of smaller fixed point problems.

In the proposed dynamic loading method, links are treated separately, according to whether they are 'running links' - where the time taken to traverse the link is continuously spread over the link - or 'queuing links', where delay occurs only at the downstream end and is due to capacity constraints. Four basic assumptions are made:

(i) a set of users leaving in the same interval and following the same path is called a group; all users in a group experience the same trip as the leader - in particular, they depart at the same pre-fixed point (eg centre) of the interval and are deemed to occupy a link in a given interval if the leader does so;

(ii) speed on a running link is the same for all users entering the link in a given interval;

(iii) undersaturation delay on a queuing link is the same for all users entering the link in a given interval; and

(iv) oversaturation delay *for a given group* joining the queue at a queuing link in a given interval is assumed to be equal for all users of the group; the delay, however, depends on the group's arrival time at the link.

In order to implement a dynamic network loading model, a definition of (time dependent) link flow is required. For a running link, the flow is defined as the product of the average density (the ratio of the average number of users per unit time to the link length) and the average speed; expressions for these may be derived by applying the above assumptions. Similarly, for a queuing link the flow is defined as the time average in-flow. The expressions derived for these flows will be in terms of speed on a running link, undersaturation delay, etc; the only remaining assumptions required, therefore, are models (for each link and time interval) for speed on a running link (a function of link flows), undersaturation delay (constant, ie flow independent) and oversaturation delay (a function of link flow, queue length, waiting time and time-dependent capacity, according to a fluid approximation).

3.29 Van Berkum & Van Der Mede

These authors (from a Dutch consultancy) have presented an outline for a behavioural model taking account of choice of route, mode and departure time (79). It was designed to assess the effects of various information systems on travel behaviour. It is implemented as part of a much larger, microscopic, activity-based model, developed by the EUROTOPP consortium (80) within the EC's DRIVE programme. There are four basic behavioural elements to the model: rational decision-making, learning, habit and uncertainty.

On a particular day, a particular driver has a list of activities he wishes to perform, their locations and any time constraints (these are all generated by the larger EUROTOPP model). For each activity in turn, he then determines his desired destination, before beginning the choice process of mode, route and departure time (the point at which the model discussed here is implemented). The model of this process is constructed in two stages. Firstly, the combined mode/route choice problem is considered, consisting of a number of components:

(a) Feasible modes and their disutility. From a user's possible choices of mode (taking into constraints such as not being able to take the car home from work if he cycled to work in the morning), alternative modes are compared according to characteristics, expressed as a disutility, of the best route by each mode.

(b) Determining known alternative routes. The subset of routes known to the user is determined either by generating shortest routes with stochastic disutilities or by determining a given number of the (actual) shortest routes. The basic assumptions made are that the number of known alternatives varies according to trip purpose, but not according to time. The former assumption derives from the premise that the number of known routes will depend primarily on the frequency and number of times the trip has been made in the past; this effect is approximated by supposing, for example, that more alternatives are known for the journey to work than for a leisure trip. The latter assumption means that no account is taken of day-to-day experience in the network increasing the knowledge of alternatives.

(c) (Dis)utility of a route. For each user, the perceived disutility of each known route is drawn independently from a Normal distribution (NB: there is no attempt to account for correlations in a user's perceived disutility between routes). For a route which the user has followed in the past, the mean and variance of this distribution are set equal to the corresponding 'sample' measures computed from previously experienced disutilities on that route. If the route is one which has not been previously used, its mean is set to the free-flow disutility with a high variance.

(d) Uncertainty in the choice process. To represent the fact that it is not certain the user will choose the mode/route combination with smallest disutility, an error term is added to the disutility before the choice is made.

(e) Habit/inertia. Loyalty to previously used routes is modelled by assuming that inertia for a given route depends on the proportion of times the route has been chosen in the past for a given movement and on how recently the route was chosen. A relationship is proposed between these factors and the probability of using a route and this was due to inertia. In the choice process, this is implemented for a given user by assigning him a route according to these inertia probabilities; one minus the sum of these probabilities gives the probability of using no route due to inertia - in this eventuality, then, the basic choice model is invoked in which the user chooses the route which (currently) has the least perceived disutility (subject to the uncertainty of (d)).

The second stage of the modelling process is concerned with departure time choice. This acheived indirectly by considering arrival times, and associating a disutility function for late or early arrival relative to some desired arrival time. That is, the user essentially chooses an arrival time which in combination with his mode and route choice gives rise to a departure time. The process is implemented by dividing into intervals the period over which a user's time constraints allow him to arrive, and computing the disutility for each interval.

3.30 Miscellaneous

There are a number of other existing models, about which the author has (at the present time) been unable to obtain detailed information. The details given have been gleaned primarily from other review articles (66-68,71).

INTRAS (INTegrated TRAffic Simulation) (69) makes use of network theory to relate freeway and arterial traffic, with traffic represented at the microscopic level. It uses a stochastic, time-stepping simulation. It was designed for studying the impact of incidents on a freeway.

FREQ is a family of freeway models, developed at the university of California. They have been designed to evaluate the performance of a freeway and its ramps, given the ramp origin-destination flows. Traffic is modelled at the macroscopic level, making use of user-specified speed-flow relationships. The origin-destination information supplied is time-sliced (15 minute periods) and disaggregated into various vehicle-occupancy classes. The model is able to predict, for example, ramp delay and queues, as well as both spatial and modal traveller responses.

SCOT (Simulation of COrridor Traffic) (70) is a synthesis of two previous models - UTCS-1 (Urban Traffic Control System-1) and DAFT (Dynamic Analysis of Freeway Traffic). UTCS-1 was the name for earlier versions of NETSIM, a microscopic model which was discussed in section 3.23. DAFT, on the other hand, is a macroscopic simulation of freeways, ramps and arterials. In DAFT, vehicles are grouped into platoons and are moved along the freeway according to a single speed-density relation; on non freeway links, vehicles are assumed to move at the free flow speed. At the origins, the SCOT model distributes the origin-destination flows (in the form of platoons of vehicles) across the network, according to minimum cost routes which are calculated frequently on the basis of prevailing traffic conditions. SCOT determines the turning movement at each junction by finding the minimum cost route at that time; so en route path switching may occur.

DYNEV is an emergency evacuation model, related to the TRAFLO model discussed in section 3.15. It was developed to estimate emergency evacuation times. Traffic is represented at the mesoscopic level. DYNEV is basically an iterative procedure, between an assignment and a simulation (cf. SATURN, described in section 3.6). The assignment computes traffic volumes and turning movements using a static equilibrium assignment (via the TRAFFIC package, mentioned in section 3.15). The simulation takes the output from the assignment and replicates the dynamic movements of the traffic streams, using an adaptation of TRAFLO's Urban Level II simulation submodel (itself a refinement of TRANSYT). In DYNEV's simulation, however, the cyclic flow profiles are link-specific, whereas in TRAFLO they were turn-specific. Convergence of the iterations between assignment and simulation is deemed to occur when the output of the simulation is compatible with the assumptions on which the original assignment was based. Both the assignment and the simulation model interact with a traffic capacity sub-model, which computes service rates by turning movement.

An alternative evacuation simulation model is NETVAC (72). Traffic is represented at the macroscopic level. Routing decisions are assumed to be made at each junction by the evacuating traffic. At each junction, the traffic is split amongst the links emanating from it, according to a logit choice model which takes into account the relative congestion and the "directionality" of the outbound links (that is, its ability to take the user to a safe point outside the evacuation zone). Junction capacities are continually adjusted according to prevailing conditions.

4. CONCLUDING REMARKS

This paper has raised a number of issues of relevance to the modelling of DRG systems. Since the implications are complex and are related to an earlier paper (reference 1) it is intended to tie the conclusions together in a forthcoming ITS technical note.

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As usual, however, the views expressed are solely those of the author, and I apologise for any misinterpretation of the capabilities of the models reviewed.

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