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# SOME COMMENTS ON DYNAMIC TRAFFIC MODELLING IN THE PRESENCE OF ADVANCED DRIVER INFORMATION SYSTEMS

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## Abstract.

The emergence of advanced driver information systems sets new challenges in the area of traffic modelling and simulation. The use of techniques such as autonomous route guidance, advanced incident warning or information channels dedicated to traffic information must be incorporated in a new generation of traffic models. This paper first discusses the impact of these new systems on modelling methodology, with an emphasis on some important issues to make the new models both realistic and adaptable to technological and sociological evolution.

The main issues are the avoidance of the "steady state", "perfect information" and "uniform behaviour" assumptions commonly made in traffic simulation. The need of an explicit model for traffic information flow and of behavioural routing methods allowing for the real time use of this information are introduced as consequences of this first conclusion. These in turn have consequences on more technical levels, such as network representation and traffic metaphors.

The argumentation developed is then illustrated using the definition of some of the modelling concept within the PACSIM model for traffic assignment. The dynamic nature of the simulation, the concepts of "packets" (considered as a traffic metaphor) and multi-level network, the structure of the information network (as distinct from the road network itself) and finally the bi-level behavioural routing methodology applied in PACSIM are shown to be coherent with the requirements discussed in the first part of the paper.

# 1 Introduction

The introduction of new information technologies in both urban and regional traffic has already modified the behaviour of many transportation network users in many cities. Indeed, frequent radio bulletins indicating congested areas and incidents are now part of the daily commuter routine, and have substantial impact on his/her transportation strategy. Further and more radical changes are afoot: route guidance techniques (autonomous or interactive), city map updating via radio beacons, variable message signs for traffic control and parking information, road pricing systems are but a few of the techniques studied and applied in the contemporary management of transportation networks. In Europe, international programs, as EUREKA PROMETHEUS and the EEC DRIVE effort, have been set up to analyze and optimize the use of these new technologies (Road Transport Informatics, or RTI, in the DRIVE terminology) in a quickly evolving environment and society, but this line of research and development is also active in the United States and Japan, where similar programs are proceeding.

The very purpose of these new techniques is to modify the road user behaviour in order to improve safety and relieve congestion problems in the network. It is therefore a crucial challenge that the traffic modelling techniques, now widely use for strategical transportation planning, can realistically predict their effect both in qualitative and quantitative terms. Another challenge for the traffic modeller is that the actual behavioural reaction of transportation users to the new information technologies is not correctly known, and will probably be the subject of continued research and refinement for the coming decenny.

It is the purpose of this paper to discuss the impact of those challenges on some classical traffic modelling methodologies. In particular, the difficulties of using equilibrium based methods in this framework will be considered. Some consequences of this discussion will be drawn, hopefully providing directions for further development. Finally, one particular approach along this line (the PACSIM model) will be outlined.

Section 2 reviews traffic modelling methodologies and considers the adequacy of the equilibrium concept to the context where real time driver information systems are used. Section 3 will concentrate on the consequences of this discussion at the methodological level. The approach used in PACSIM to comply with these consequences will be briefly described in Section 4. Finally, Section 5 contains some conclusions and perspectives.

# 2 Yet another view on the equilibrium concept

After Wardrop's famous work [25], many traffic models for both cities and larger areas have been making extensive use of the notion of traffic equilibrium. This notion is expressed by the assumption that "journey times on all routes actually used are equal and less than those which would be experienced by a single vehicle on any unused route" (Wardrop second principle). The work of Beckman, McGuire and Winston [1] was indeed amongst the first to use this principle in a very long line of research (see [4], [10], [11], [13], [23], or [24], for further discussion and references). Despite some shortcomings, as illustated by the well-know Braess paradox (see [3], [12], [5], [14], ...), the equilibrium principle has been and continues to be widely accepted in traffic modelling research and application. It is therefore of interest to consider if this concept can be adapted to handle the new situation created by the wider and wider introduction of driver information systems.

Many classical equilibrium models assume a fixed "design period" in which all trips are supposed to happen and during which congestion in the network is stable (we then say that they are *static.*). This assumption simplifies the route planning decision as only one state of the network needs consideration, which has obvious computational advantages. However, this assumption has often been criticized (see [16], for instance) on the basis that trip timing may itself be dependent on the network congestion. Without diminishing the importance of this remark, we also note that a further difficulty is inherent to static equilibrium models for a situation where real time driver information systems are used: because they compress the whole route decision and trip making in a single moment, no information can reach the driver *during the trip* and no subsequent re-routing is possible[1]. Hence, the only information systems that can be modelled using these techniques are systems that influence driver behaviour (route and mode choice) before departure. This limitation is extremely serious, as it rules out a number of the techniques that are currently practically envisaged, including interactive and autonomous route guidance, advanced incident detection and many applications of variable message signs. We therefore conclude that such models are not well suited to our purpose.

It is interesting to note that we had to dismiss static equilibrium models mostly because of their static nature. One could therefore hope that *dynamic* equilibrium models would be more appropriate. This class of models evolved from the criticism mentioned above concerning the static models. Developments in this area are presented or reviewed in [2], [16], [17], [19] [26] [27], and [28], to cite only a few. They introduce the time dimension and are based on generalizing the notion of Wardropian equilibrium in time: the network must be "in equilibrium" at all moments during the design period (see [26] for a detailed formulation and discussion of this extension). Despite their increased computational cost, these models are indeed conceptually attractive, because they provide the explicit time reference that is missing from the purely static approach. We therefore examine their underlying assumption (equilibrium itself, as opposed to mere static equilibrium) for consistency with the aim of modelling advanced driver information systems.

If we again analyze our statement of equilibrium, we note that a used path has its journey time compared to that "which would be *experienced* by a single vehicle on *any* unused route", where we have highlighted two very important words. The fact that journey time along unused paths must be "experienced" implies that the network users have to acquire that experience and knowledge. This can be achieved in two ways:

1. They acquire it by actually trying these "unused" non-optimal paths.
   This has the unfortunate consequence that the equilibrium principle becomes ipso facto invalid. However, the amount by which it must be violated might be quite small: most drivers can acquire their knowledge of the network over long periods and only

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[1] It is fascinating to note that the some computational methods to compute static equilibrium (see [22] or MICROTRIPS, for instance) proceed incrementally and sucessively assign smaller and smaller fraction of the demand on the network: the iteration procedure in effect simulates the passing of time until convergence occurs to a time independent steady-state result.

use optimal routes in the "steady-state" of the system. The fraction of "exploring" drivers may then be neglected. This however implies that the experience accumulated over time must not be too quickly outdated. This situation can therefore only occur in transportation networks whose load is very *stable* in time.

2. They acquire it from some information system(s).

   This second branch of the alternative does not require stability of the transportation network characteristics, but then implies that the equilibrium state intrinsically depends on the quality of the information system(s) considered. This remark is strengthened by the observation that the equilibrium principle also assumes that the journey time of *all* unused paths is known. Equilibrium in the classical sense therefore requires *complete* and *accurate* information to be available for all network users at *any moment* during the design period Furthermore it also assume that these users have the capacity to correctly process this information in real time.

Thus we see that the very notion of traffic equilibrium can only make sense if either the traffic situation is not varying much over long periods or if some network-wide oracle provides every user with instantaneous, accurate and complete information on the network congestion (we will say that the information is *perfect* in this ideal case), information which can then be optimally processed by all users in real time[2]. We feel that this requirements are very often not satisfied.

- Traffic patterns in large cities do change significantly over long periods. These changes are caused by several factors.
  - Transporation *demand* itself is far from being constant for such periods. Long term variations of the demand are caused, for example, by the evolution of transportation behaviour due to changing life-styles, increasing car-ownership, fluctuations of the costs of private and public transport (due in turn to petrol prices, insurances or public transport operators' marketing policies, for instance) The reader is referred to [20] for an interesting discussion of this and other related issues.
  - It is extremely unusual that the *structure of network* itself does not undergo major modifications in the horizon that would be necessary for "learning" the entire network: new tunnels, bridges, by-passes and one-way systems are indeed created on a nearly monthly basis in major cities. These creations are also often prepared by lasting perturbations to the existing surrounding network caused by the very building of the new infrastructures.

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[2] It is interesting to note here that "quasi-equilibrium" situations may be reached where the information of users is not perfect: one might indeed think of an equilibrium situation where each user optimize his/her journey time over the restricted set of routes within his incomplete and/or inaccurate knowledge of the network. This of course requires that the route actually used is included in this knowledge, but this is not a severe restriction. Despite clear similarities, these situations however *differ* from the classical equilibrium case, which means that the equilibrium based computational techniques must be modified to handle them.

  - Even assuming the network structure and demand to be stable, the *network management* is in constant evolution, as signalling and traffic lights control are adapted.
  - More crucially for our purpose, the effect of introducing advanced driver information systems (if they work at all) will clearly offset the users average behaviour and introduce quick reactions of the network users to its load. This introduces a fast feedback loop whose impact on the traffic pattern is still largely unknown and which transportation models should precisely help to analyze.

  Assuming a network steady-state situation is therefore clearly at best questionable in our framework.

- One of the effects of advanced driver information systems is to produce substantial change in traffic patterns over short periods. Because their redistribute information related to the traffic situation relatively fast, they can (and should) induce re-routing of users just before or even during their trip. These short-term variations of network load are then superposed on top of the slower evolution just discussed, further blurring the user's perception of a network-wide steady-state.
- Complete information on the network status is very often not available to users. Even users connected to specialized dispatching centres only receive selected informations.
- The only information available is most of the time inaccurate, outdated or purely qualitative, making precise comparisons between contending routes impossible or at least very approximative.

  It is not clear at all that users, even provided with perfect information, will actualy choose to use it, and then do so in an optimal way.

It is important to observe that the notion of equilibrium is further based on the assumptions that all network users are "identical" (using the terminology of [17]) in that they have a *common criteria* to optimize their mode choices and routes. However, recognition of variations in user behaviour is highly desirable for realistic modelling of the driver information systems impact, making the equilibrium assumption even more questionable in this context.

Although we have provided arguments to show that equilibrium is not well suited to modelling evolving processes, especially fast ones, one must also admit that commuters in a network usually do not re-examine their transportation strategy every single morning. Hence our conclusions must be somewhat qualified.

We have seen that equilibrium models might be inadequate for three main reasons: they assume stability of network characteristics, rely on perfect information and assume uniform user behaviour. If it is true that those assumptions can be questioned in general, it is also true that their degree of inadequacy varies with the type of effects considered.

1. It still might be a reasonable approach for long term average traffic effects. This could be justified by the fact that not everything changes in the network, even for long

periods. Some "experienced" knowledge is therefore not really outdated, even if it is incomplete, and can play a significant role in the basic unperturbed route decision process.

2. Some information systems deliver information of a very qualitative nature, whose variations in the long term are minimal. For example, congested spots are signalled daily in many radio bulletins: after some learning period, the knowledge that these spots are congested at particular times is incorporated into the broad common knowledge of all network users.

3. Finally, if individual variations in behaviour are obvious, one must still recognize certain major components in the decision rules used by classes of network users. This observation is the very base of the past success of equilibrium models. One might think along this line to use "parallel" equilibrium models for classes of users whose behavioural consistency is greater, either by simultaneously considering different group-dependent representations of the network, and/or different group-dependent cost functions, for instance.

One therefore needs to distinguish between the type of effects and impacts one wishes to analyze before accepting or dismissing equilibrium based models: they might not be suitable for modelling traffic in the presence of fast or unexpected problems or real time information systems, but could maybe play a role to describe general tendancies based on broad network knowledge, that would manifest in the restricted (and somewhat unlikely) case were no unexpected event or information perturbs the traffic situation.

After discussing the notion of equilibrium traffic assignment in some length, we briefly note that the arguments presented in this framework unfortunately also apply to the simpler technique using explicit shortest path computations (see [15], for instance). Indeed, the very concept of shortest paths implies perfect information and uniform behavioural decision mechanism, hence raising again the same difficulties in this simpler setting.

We finally note that Papageorgiou [21], proposes an interesting approach that allows for transient effects in network load to take place, but still assumes perfect information and uniform user behaviour.

## 3 A few desirable features

From the discussion in the previous section, it seems natural to search for an alternative to the equilibrium principle, at least for the modelling of situations involving fast changes in the network and/or incomplete information conditions. It is also clear from the same discussion that any other principle should in this context allow for a better description of user's behaviour in his or her transportation planning. We therefore need to replace the uniform criterion of journey time (or any generalized cost) minimization by rules that could vary from a group of users to the next, in order to capture some of the wide behavioural variations between network users.

## 3.1 A flexible and standardized behavioural mechanism

A first and important problem immediately arises: relevant behavioural theories are still very much in the development stage, and certainly no general agreement has been reached as to which theories do best represent the behaviour of network users in what are potentially extremely diverse situations. Therefore, there seems to be little point in incorporating one particular behavioural theory in a traffic model, and exclude other promising approaches at the same time. New models should therefore provide the capacity to use a particular *behavioural theory as a model parameter.* Furthermore, as several theories are likely to be of interest, the specific way in which models handle behavioural theories must be extremely flexible and adaptable.

Several possibilities exist to fulfill these goals, ranging from parametrized cost functions (probably too restrictive) to complete representation of the theory using knowledge representations systems, as developped in the area of artificial intelligence. A particular choice is indicated in the next section in the limited context of route planning for traffic assignment.

The authors believe it is important that efforts are made towards a coherent way to represent behavioural theories, leading to some *standardization* in this research area. Furthermore, the representation format should allow simple and error free transmission to other researchers and, in the best case, be directly expoitable as such by modelling programs. These requirements are indeed crucial for these theories to play a really practical role in modelling methodology, even if they now appear to be somewhat idealistic. We refer the reader to [18] for a discussion of a potentially useful approach.

## 3.2 A behaviourally coherent traffic metaphor

Every traffic model represents its object, traffic, using some metaphor: flows, vehicles, platoons, ...If the metaphor refers to more than one vehicle, it is customary to assume that all users "part" of one such metaphor share the same decision process, that is the same behaviour. In a behaviourally sensitive modelling, the choice of a traffic metaphor is thus of some importance. In particular, it should be chosen disaggregate enough to allow for *behaviourally coherent* groups of users, to which a common set of behavioural rules can then be applied.

### An explicit time reference

Any behavioural theory for transportation decision making will have to incorporate an explicit reference to time. This reference was already judged crucial for equilibrium models, but is probably even more so when behavioural rules are at the base of the modelling methodology. Network users indeed have clearly different strategies in peak hour as opposed to off-peak, in week-ends as opposed to week days, in day as opposed to night, and the list of examples can easily be made longer.

Furthermore, we have already stressed above the need of such a time reference for the modelling of strongly time dependent traffic management technologies as route guidance and parking information.

Whether this representation of time should be continuous or can be discretized in successive "time-slices" or "events" is not yet clear from the behavioural point of view alone, although the question is of interest. The practical choice in designing traffic models may therefore depend for now on other factors in the chosen methodology.

### A flexible network representation

A very flexible transportation network representation is also extremely desirable in our "behaviourally driven" methodology. Indeed, users can only decide on route and mode choice within the framework of their knowledge of the network. But one knows from the research in mental maps (see [8]) that this knowledge might present relatively severe distortions from reality. It also typically involves some level of network abstraction (only major links are perceived in distant or unfamiliar districts).

The behavioural route or mode decision can then be broadly split into two phases, both driven by behavioural theory: the user knowledge is asserted first, followed by some choice between the decisions that are possible in the restricted context of this knowledge.

It is therefore crucial that the network representation can easily be adapted and modified (according to a given behavioural theory) to better reflect the user's perception of the network. This modification will thus typically involve network abstraction and distortions of various types (link suppression, cost modification, preferred routes, ...). This requirement in turn imposes the use of specialized and flexible date structures.

## 3.5 An explicit model for information flows

We have seen above that behaviourally driven transportation methodology greatly relies on the accuracy, scope and timing of traffic information that is provided to network users. Modelling the end-user interface of the information system (the delivery of information to the user) is then of primary importance. However, a large part of the interest of including advanced information systems in the models arise from the actual evaluation of the impact, performances and failures of such systems. We therefore see that the model must also provide mechanisms to alter the end-user interface quality, reliability, timing, ...as a function of parameters in the information system itself.

Typical examples of relevant factors (that is factors that influence scope, accuracy and/or timing of information delivered to users) are

- the location of traffic monitoring equipment (the actual locations of detection and measurement equipment on the network of course conditions the final information in that it specifies the parts of the network about which infomation could be available),
- the location of information distribution mechanisms (conditioning in turn the locations at which re-routing can occur),
- the accessiblity of information (defining the classes of network users accessing possibly different types of information),
- the strategies used to process information from the network before subsequent redistribution to users,
- the actual interconnection pattern (topology) of monitoring devices, information processing centres and distribution mechanisms.

Besides the classical transportation network, we therefore discover another network, which describes the information flow (the feedback loop) between the transportation network and its users. We call this network the *information network*. The authors feel that explicit modelling of this information network is an important part of the present research challenges in this area.

Of course, these information network models should be flexible, in order to adapt to the many different cases of potential interest. In particular, they should include the relevant factors mentioned above, but also parameters that influence their efficiency (communication links' or detectors' reliabilities, for instance) and thus also permit the modelling of information system breakdowns.

# 4 PACSIM: an approach to behaviourally driven route choice and assignment

After reviewing some desirable features for new traffic models, we devote this section to a brief survey of some of the modelling choices that were made for the traffic model PACSIM in compliance with our above comments.

The work on this model has started in the framework of the IMAURO project within the EEC DRIVE program. The purpose of the model is to provide an RTI sensitive traffic modelling technique which could then be used to assert the qualitative effects of advanced driver information systems.

It is not the purpose of this paper to describe the PACSIM model in detail, which is done in [7]. We instead concentrate on some of the modelling concepts used in this approach, with the aim to show how their definition has taken the arguments developed above into account.

## 4.1 Time-slicing

As discussed before, an explicit time dimension seems necessary for the type of models we have in mind. PACSIM is thus a dynamic model: it represents time as a succession of "time-slices" of varying size, and make the crucial assumption that all modeled quantities (traffic, congestion, information, ...) are constant within a given time-slice. This assumption implies that time-slices should be reasonably short (at least in peak hours) to realistically represent the network varying state of congestion. The time-slice lengths therefore entirely specify the dynamic resolution and limitation of the model.

## 4.2 Network abstraction

Our previous discussion also recommends the availability of network abstraction mechanisms, in order to reflect the different perceptions of a specific network location by users that are close to it and by users that are further away: close locations are perceived with more disaggregate detail while distant ones are perceived in a more aggregated fashion (where only main districts and major links matter).

According to this view, PACSIM uses a three levels hierachical network representation. The three levels correspond to the *main* network, the *strategic* network and the *detailed* network, from the more aggregate to the more disaggregate. Explicit mappings are defined that assign a node of a disaggregate level to a node of the aggregate level just above, assuring operational coherency to the overall structure. This "multi-level" representation of the network of course plays an important role in the definition of the users' knowledge of the network (see Section 4.4), but also in other parts of the model, as described in the next section.

## 4.3 Packets

The traffic metaphor used in PACSIM is *based* on behavioural coherency, therefore complying with the arguments of the Sections 2 and 3 very closely. PACSIM indeed considers traffic as composed of the movements of *packets*, which are groups of vehicle moving on the network with a coherent behaviour. They are created at network locations corresponding to origins of transportation demand at a given time, travel through the network and disappear at their destination. The behavioural coherency of the packets is ensured by the requirement that vehicles belonging to the same packet must have in common

1. their capacity to access driver information systems and the traffic knowledge provided through this channel,
2. their destination in the network,
3. their mode of transportation,
4. their trip purpose.

Although the authors realize that these characteristics might not be sufficient to describe behaviourally coherent classes of users, their specification however constitutes a first attempt in this direction.

Given this definition of the packets, one is quickly faced with the problem that the number of packets present in the network at any moment of the design period might be very large, potentially causing a serious efficiency deterioration, therefore making a behaviourally coherent approach to traffic description questionable. PACSIM proposes one possible approach to control this number to some extent, which is based on the notion of abstracted destination. Given the multi-level representation of the network, the final destination of a trip (at the detailed level) can be abstracted at higher (more aggregate) levels when the trip making packet is still far from its destination. This technique ensures that, at some distance, all destinations within the same district, say, will be aggregated into the same abstracted destination[3]. As packets later approach their aggregate destination, this destination is splitted into its more detailed components, and the packets are themselves splitted accordingly. Thus we see that packets not only move in the network, but also merge and split in a totally dynamic way. Packets at the beginning of their trips are merged with other packets sharing a common abstracted destination, while they can be merged with other packets approaching their true disaggregate destination at the other end of the trip, when the disaggregate destination itself is approached by several packets from possibly different origins.

We should note that the packet approach is not really complete in the present specification of PACSIM. The generation of packets itself, that is the definition of the *dynamic transportation demand* is also of crucial importance. We know of dynamic demand models (as the EUROTOPP model discussed in [9]), that could possibly be interfaced with PACSIM into an *integrated dynamic models*. The authors believe that such behaviourally driven integrated models are indeed very attractive and could well constitue an important step forward in global transportation modelling.

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[3] Specialized data structures are again needed here: the present implementation uses a tree oriented description of the destination aggregation process, called the *destination tree*.

## 4.4 The behavioural mechanism

The behavioural mechanism that drives PACSIM is organized along two complementary stages, broadly corresponding to the two phases for behavioural decisions outlined above. The user perception of the network is first established, and a routing decision is then taken within that restricted framework. We now briefly describes these two stages.

The network as perceived by the user (the packet), the *perceived network*, is first defined using the multi-level network representation, according to the following steps.

1. A position dependent network is built, that contains a detailed view of the links and nodes in its immediate surroundings, with the level of detail fading away with distance. This procedure makes full use of the multi-level network structure.

2. Behavioural rules applicable to the packet then modify this restricted network, according to the packet characteristics and the information it has accumulated in past time-slices. This modification can be of two possible natures:

    - the topology of the perceived network may be modified,
    - the relative costs of the perceived network links may be modified.

    In the first case, links can, for example, be removed from the network because they do not belong to the packet's knowledge of the area; links can also be added or reversed as a consequence of dynamic traffic management decisions (as tidal flows) which are communicated to the packet's via driver information systems. The modification of costs allows to reflect behavioural preferences (heavy goods vehicle drivers tend to prefer major links, for instance) or again to take available broadcasted information on network congestion into account.

Once the packet's knowledge of the network is established, a user optimized route is then computed and assigned to the packet. PACSIM actually uses shortest path computation in the modified network. It also features a further option to randomly perturb the network cost to represent individual variations within a single behaviourally coherent class of network users (in a spirit close to that of stochastic assignment, as described in [6] and [24] for example).

We mentioned above that certain behavioural rules are applicable to packets. The set of all these rules constitutes a behavioural theory of route planning, which is used as input parameter by PACSIM. These rules are specified in a formal language that has been specifically designed for the purpose, and which is described elsewhere (see [18]). We only stress here that this representation technique has several decisive advantages: formulated in such a formal language, the behavioural theory can be perspicuous, unambiguous, concise and machine readable. We also note that rules expressed in this language cover variations in behaviour potentially influenced by a wide range of parameters as availability, quality, accuracy and timing of user's information, location in the network, trip purpose, transportation mode, time of the day, ...

It is also assumed in PACSIM that drivers base their route planning decisions for a given time-slice on the information they have obtained in previous time-slices. It should be noted that this in turn implies that a mechanism is provided for the drivers to memorize some past informations for later use. However, routing information cannot be based on this information only, as has been already observed: in particular, a packet would not be able to start its route in the network because it is just, at this stage, beginning to accumulate information. Some degree of anticipation based on experience is thus necessary. PACSIM provides a mechanism (called the *background network*) to build up such long term dynamic experience of the network, which we saw was admissible in a limited sense. This provides the requested anticipation of traffic effects in the route planning decision process, at the condition that the knowledge of the anticipated effects can be acquired with experience. This long term experience is common to all drivers in the present version of PACSIM, but it might be envisaged to disaggregate it further to better reflect the differences in network experience between different users.

As we noted above, it is not clear what behavioural theory will actually prove to be most useful. Hence, the theory that is presently used by PACSIM (see [7]) is not aiming at completeness or even correctness: the best that can be hoped for is that something of the *character* of driver response to advanced information systems has been elucidated. One of its purposes is to allow the testing of the behavioural theory representation, particularly with regard to flexibility and efficiency. Better theories emerging from ongoing research projects within the DRIVE program and elsewhere can then be used and tested later without further modification to PACSIM.

## 4.5 Modelling the information network

We also stated above that an explicit model of the information flow from the network to its users is desirable. In accordance with this suggestion, PACSIM contains such an explicit model. This model takes itself the form of a network, that features four main type of nodes: detectors, traffic information centres, traffic control centres and information sockets. We now briefly review their function and relations.

The detectors' purpose is to monitor the status of the network and to detect any traffic event therein. For increased realism, detectors have individually adjustable sensibilities[4], reliabilities, reaction delay and can be positioned anywhere on the network.

Traffic information centres are nodes at which information on detected traffic events is

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[4] That is the type of effect and/or event that they are able to detect (as congestion, accident, weather conditions, ...).

centralized, screened according to parametrizable selection criteria, and then distributed to other traffic information centres, traffic control centres and information sockets.

Informations sockets model the various devices that are used to transmit information to network users (radio beacons and dedicated broadcastings, variable message signs, ...). They come in different types, varying according to technology and capacity, but also in the amount of information they can store (memory), time during which information is considered up-to-date (persistence) and ways in which priority conflicts between different messages are handled. They can also be situated anywhere on the network.

Traffic control centres represent instances that decide on traffic management, control and optimization strategies, as opposed to mere information distribution. For instance, they can maintain sets of recommended routes for route guidance applications and fleet management. Recommandations and informations implementing these strategies are also distributed to network users via information sockets.

These four classes of "information network nodes" are themselves linked by communication lines whose reliability and delay can be parametrized. Furthermore, the complete information network configuration (topology and node/link parameters) can be dynamically updated during the design period.

Recalling the suggested features of the information network discussed in Section 3.5, we see that the particular choices made in PACSIM are indeed reasonably coherent with our previous propositions.

Again, the authors realize that the description of the information network in PACSIM might not capture every possible variant of information processing that can be thought of in the context of advanced driver information systems. However, the present definition already covers a fairly wide ground. It is also easily expandable if new technologies have to be modelled, that cause or result in new information flow patterns.

## 5 Some conclusions and perspectives

In this paper, we have provided a brief analysis of the requirements put on traffic modelling techniques by the need to include advanced driver information systems into such models. Noting the fact that these systems produce relatively fast transient effects on network load, we have discussed some of the difficulties associated with (static and dynamic) equilibrium models in this framework. We have attempted to go beyond the simple constatation that these models are not well adapted to the description of transient situations by detailing some of their weaknesses. In this discussion, we stressed that equilibrium models make the implicit assumptions of network stability in time, perfect information and behavioural coherency of users. The validity of these assumptions has been questioned in the case where advanced users information systems are considered.

As a result of this analysis, we isolated a few model features that we believe are of importance for building operational transportation models that incorporate the explicit notion of users information systems.

Finally, we illustrated some of the concepts and requirements discussed in the restricted context of PACSIM, a behaviourally driven model for traffic assignment.

Clearly, we do not pretend to exhaustivity in our brief survey, but merely hope to open a few research perspectives. We realize that a full-scale implementation of integrated models of the type suggested is a formidable task: one reluctantly abandons (at least partly) a well trusted methodological basis (equilibrium principle), exchanging it for a less well defined behavioural mechanism. The challenge is then twofold. The first (and easier) part addresses traffic modellers and covers the actual realization of dynamic behaviourally driven models. The second and most important is the derivation of significant and practically applicable behavioural theories, which would then drive these models. We also hope to contribute here to this second challenge by identifying a few of the behavioural issues that should probably be clarified for a real integration of behavioural theory and modelling.

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