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Calibration and Path Dynamics Issues in Microscopic simulation For Advanced Traffic Management and Information Systems

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Abstract: This paper presents discussions on two critical aspects related to microscopic simulation; a methodology calibration/validation and the integration of path dynamics on large networks, which we consider the most significant two challenges in microscopic simulation for decision support and analysis in Advanced Traffic Management and Information Systems. On calibration/validation, we distinguish between conceptual and operational phases; conceptual phase concerns the basic models such as car-following and lane changing, and the operational phase is associated with the context of the study (O/D, parameters adjustments with respect to network under study, etc). Then a methodology is described which brings to microscopic simulation the kind of capabilities for path processing and storage normally found only with macroscopic models, often due to the network representation being less detailed for those. This is based on a hybrid simulation approach. The example of integrating the *Paramics* microscopic simulation with the routing and behavior response simulation schemes as in the DYNASMART macroscopic model is used to explain a candidate methodology to enhance microscopic models for evaluation of information/routing schemes in ATMIS. The paper is conceptual in nature, raising some relevant problems faced by ATMIS modelers which are worth discussing further – it is not intended to provide extensive results or even to answer all the questions raised. Issues related to abstraction levels based on systems engineering paradigms are outlined.

Keywords : Calibration, micro-simulation, traffic assignment.

1. Introduction

Simulation is used mainly for decision support in transport applications. In the offline mode, it is used for testing scenarios and algorithms while in the online mode it can provide control assistance within an ATMIS (Advanced Traffic Management and Information Systems). Despite extensive work in simulation models over the years, there are still many aspects that remain to be examined in detail. This paper deals with the calibration and validation issues, as well as large network simulations and the associated traffic assignment problems. The paper focuses on microscopic simulation. We discuss macroscopic models only to the extent that certain properties they have are pointed out as attractive for microscopic models as well. Approaches to combine the two kinds of

models in hybrid frameworks is also discussed, in the context of two selected simulation programs.

Most of the discussions in this paper evolved during various research projects related ATMIS in the California PATH program. The paper is intended to raise topics for further discussion, and does not provide answers to all the issues it raises; neither does it provide extensive simulation results to prove any points or derive conclusions. The authors feel that while studying the complicated details of the models used in ATMIS simulation, several previous studies have forgotten to look at certain broad and basic questions. How validated are/should/could these models be ? How can we calibrate them with data being scant on many key variables ? How plausible is the claim by some that microscopic simulation can be attempted in large networks, and how can we achieve that ? Do such models involve certain requisite properties essential in modeling the kind path dynamics and driver route choice under ATMIS, and if not, how can they be enhanced ? These are the kind of issues the paper delves into.

Issues in Calibration and Validation

The state of the art in traffic simulation includes very few references on calibration and validation methodologies and also on quantifying the calibration baseline before starting the process. The decision making is highly dependant on such quantitative details; however, few references talk about the failures and difficulties which are normal in a subject like this where the human being (driver) is present in the loop and hence the models are often not precise. The main objective should be to start building simulation efforts through methodical studies rather than ad-hoc studies. This yields confidence on the stability of any developed model at the operational level for a specific study context, the driver models in the loop becoming a research challenge during model validation.

The validation discussion in this paper is largely on micro-simulations models. A useful starting point is the experience in Smartest project in UK (2), where a variety of traffic data has been collected from a small urban road network. This data was processed and analyzed so that it can be used in the calibration and validation of road traffic micro-simulation models. Three micro-simulation models, initially developed to model traffic in different parts of Europe, have been used to model the traffic in the Leeds network. None of the models could represent all the features found in the test network, and so some modeling assumptions had to be made to cover these cases. The study underscored the importance of validation exercises.

Validation is largely dependent on two major issues

- The context (i.e., model performance could drastically change with the context)
- The extent of the calibration effort at the conceptual and operational levels.

The APAS (3) reports have identified three key issues which need to be tackled in any use of models to solve transport problems, and it applies to ATMIS modeling as well:

- Assumptions that have to be made in the modeling exercise,
- Knowledge on how errors can be generated,
- Knowledge of uncertainties that surround the modeling results.

Many simulation models have been developed to evaluate the benefits ATMIS. Lately more attention has been paid to the microscopic simulation models due to their capability in modeling various necessary details in a wide-range of applications and also due to the assumption that the representation of vehicle movement is realistic. The microscopic simulation models often incorporate many traffic control schemes such as route guidance (in-vehicle navigation systems and variable message signs), adaptive intersection signal controls, incident management schemes, ramp metering, variable speed limit signs and high occupancy vehicle and toll lanes. There are of course macroscopic models that can handle these issues to some extent under macro-scale assumptions on the control details. An example would be vehicle actuated traffic control modeling with macroscopic traffic flow simulation. The logic behind such approaches is not always as appealing as the logic behind microscopic simulation even if the results need not necessarily be substandard. However, microscopic models are tougher to calibrate than macroscopic models, as the underlying models cause interactions between vehicles in the simulation and the observed data variables do not directly relate to the parameters of the underlying models. For instance, the driver response lag term in a car following model affects modeled traffic characteristics, but the observed aggregate flow or occupancy data does not provide an easy way to calibrate such a parameter.

Path-related Issues

To motivate the discussion on path-related issues, we first describe two simulation models (one microscopic and one macroscopic) and their essential characteristics, as implemented as part of an ATMIS research and implementation testbed at the University of California, Irvine. The testbed is based on a large urban network in Orange County, California. This testbed has developed several traffic analysis and control algorithms, and uses a simulation workbench for offline research before real-world testing for which the testbed has real-time connections to the traffic detection infrastructure. The modeling uses the ***Paramics*** (PARAllel MICroscopic Simulation) microscopic simulation model developed in Scotland (17). While microscopic simulation using ***Paramics*** provides many flexible, advanced and useful features, perhaps more than most other existing microscopic simulations, certain limitations were easily observed during modeling and evaluation of ATMIS in the UCI testbed.

Paramics allows vehicle routing according to routing tables and feedback capturing information supply, but does not allow storage of sufficient path trees and storage of individual vehicle's routes, which are essential requirements for the simulation of driver response towards information supply and the resulting route choice. The primary difficulty with microscopic simulations is the inability to handle path dynamics in large networks. The problem arises from the detailed network descriptions used in such microscopic simulation models. The node and link representations for microscopic simulations are often such that any point on a physical link with a change in geometry or

other characteristics results in an extra node in the representation. This results in an order of magnitude more nodes and links in networks used in such simulation, than needed to model the path dynamics which requires only the network made up of the true *decision nodes*, which are the nodes that are of significance in the drivers' route decisions. *Paramics'* scalability permits vehicle simulation of very large networks with additional processors, but if detailed driver response modeling and path processing are to be incorporated, such microscopic models can only be used to simulate small to medium-sized urban areas. This is because many network algorithms show nonlinear increase in storage and computational requirements as network sizes increase.

The testbed also has an implemented macroscopic model for ATMIS that does incorporate efficient modeling of path dynamics for large urban networks, namely DYNASMART (DYnamic Network Assignment Simulation Model for Advanced Road Telematics). While it does model individual vehicles, it is done based on macroscopic flow relations on idealized network links, and the number of nodes in the network model may not be significantly higher than the decision nodes in the actual network. Thus its ability to model certain microscopic details of traffic movement are rather limited, of special concern being the ability to provide realistic simulation of detectors providing acceptable flow and occupancy variations, as required in an ATMIS research simulation testbed where new ATMIS schemes can be studied before real-world implementation.

It was easily apparent that a hybrid simulation approach would be useful in making use of the special capabilities of both the models. The hybrid approach integrates the *Paramics* microscopic simulation with the routing and behavior response simulation schemes as in DYNASMART, so that the integrated simulator can evaluate information/routing schemes with route choice behavior models. This approach is based on integrating networks of two different levels of abstraction and communication of vehicle positions between the detailed network (as in *Paramics*) to the more abstract network (as in DYNASMART). The vehicle route decisions processed at abstract network are then transmitted to the detailed network simulation that controls vehicle movement at the microscopic level. The integrated simulation program allows realistic evaluation of a variety of technologies in advanced traffic management and information systems (ATMIS). Some description of the challenges encountered in such a new approach to simulation, and their solutions, is a focus in the paper.

The paper next describes simulation models in general (section 2), and explains the details of *Paramics* and DYNASMART briefly. The details of their implementation in the testbed in a hybrid manner are provided elsewhere in the paper (section 4). The discussion continues in section 3 with some detailed comments on the calibration-validation issues. Section 5 discusses simulation methodology itself at a broader level, and the paper concludes with final comments in section 6.

2. Simulation models for ATMIS and path-related issues

Recently, increasing attention has been paid to the development of advanced traffic management and information systems (ATMIS) that include dynamic route guidance

systems and integrated and adaptive traffic control strategies. To analyze such systems and strategies, simulation based evaluations have been extensively used. Extensive development of traffic simulation models had produced many effective programs. These simulation models can be classified into two categories, macroscopic and microscopic, according to their representation of vehicle movement, though some macroscopic models (e.g. DYNASMART and the simulation model in DynaMIT) are often classified as mesoscopic models. A few of the well-known models are:

- Macroscopic: FREFLO, NETVACI, KRONOS, METANET, METACOR, AUTOS, METROPOLIS, DYNASMART, and DYNAMIT
- Microscopic: INTEGRATION, INTRAS, FRESIM, NETSIM, CORSIM, THOREAU, FLEXSYT-II, AIMSUN2, MITSIM, TRANSIMS, and **PARAMICS**

Macroscopic approaches are also used for some aggregate traffic models in assignment-simulation schemes (12). Traffic system simulation applications based on the simulation of vehicle-vehicle interactions are normally microscopic in nature (7,10,21).

These models have been successfully applied to particular studies, but their applications are relatively limited. Most of them are designed for particular applications and useful only for specific purposes, missing some components of ATMIS. A few researchers (22, 23) have pointed out the need for the development of more sophisticated simulation tools. More specifically, Jayakrishnan *et al.* pointed out the two primary deficiencies of existing simulation models while introducing DYNASMART (9): (a) the lack of modeling of path-based traffic dynamics and (b) the lack of explicit representation of driver decisions such as route-choice under information. The hybrid micro-macro modeling advocated in this paper (section 4) is based on traffic flow simulation using a microscopic model and path-related modeling using a macroscopic model. The two models are described next.

Microscopic model for hybrid simulation - **Paramics**

Paramics is a suite of high-performance software tools for microscopic traffic simulation. The movement and behavior of individual vehicles are modeled in detail for the duration of their entire trip, providing accurate and dynamic information about traffic flow, speed and congestion.

In **Paramics**, three assignment techniques are used: “all-or-nothing” assignment, stochastic assignment and dynamic feedback assignment. All-or-nothing assignment assumes that all drivers traveling between two zones choose the same route and that link costs do not depend on flow levels. Stochastic assignment methods try to account for variability in travel costs (or drivers perception of those costs). These methods assume that the perceived cost of travel on each network link varies randomly, within predefined limits. Dynamic feedback assignment assumes that drivers who are familiar with the road network will re-route if information on the present state of traffic conditions is fed back to them. This is achieved by taking real time information from the model and using this data to update the routing calculations. It is also possible to run dynamic feedback together with stochastic assignment or with all-or-nothing assignments.

Though the above schemes of vehicle assignment are acceptable for most simulation purposes, the way they are implemented in ***Paramics*** causes difficulties in the simulation of driver response to information and the resulting route choice. The path used by a vehicle is not known in its entirety at any point, and the vehicle only determines its next link at any point, based on the routing tables (effectively path sets stored compactly as trees) which prevail at the time. In reality, path decision modeling requires the vehicles to carry its current path or at least an abstraction of it. This causes a difficulty, since the paths may be selected at a certain time (perhaps based on a shortest path tree prevailing *at that time*) and such a path cannot be associated to a routing table as they are overwritten during simulation. Note that the number of nodes in the network are already increased by an order of magnitude due to geometric and other modeling reasons, and to study region-wide benefits of ATMIS schemes, research needs to now consider large networks where a ***Paramics*** data set with 100,000s of nodes may be used (such as in the Orange County ATMIS testbed). Storing the individual paths of each vehicle with such networks require prohibitive RAM memory even with modern computers and thus models such as ***Paramics*** developed for such purposes will justifiably have limitations in the path processing aspect. It is logical to see that traffic flow modeling requires only local information and can be very scalable. That is, larger networks can be modeled by using more processors and distributing portions of the network to the multiple processors. However, modeling changes in path-related characteristics such as travel times, and path-related decisions by drivers, requires information from possibly all parts of the network, and thus models such as ***Paramics*** need to be augmented with schemes to handle them at a different level of network abstraction, as discussed further below.

One of the nice features is that this model can be customized. Access is available through a functional interface or application programming interface (API). API allows additional functionality by adding more external modeling routines, and this was an essential feature allowing the implementation of the hybrid model discussed in section 4.

Macroscopic model for hybrid simulation - DYNASMART

An example of a macroscopic model for ATMIS that incorporates efficient modeling of path dynamics for large urban networks is DYNASMART. This model was developed at the University of Texas at Austin and at the University of California at Irvine, with funding from Federal Highway Administration and the California PATH program. DYNASMART was specifically developed for studying the effectiveness of alternative information-supplying strategies, as well as alternative information/control system configurations. DYNASMART was used as a simulation tool to find dynamic assignment solutions (15) and was extended to multi-user class real-time assignment (16). It is the simulator used in the models developed at UT-Austin, as part of a US Federal Highway Administration initiative for deployable dynamic traffic assignment (DTA) to be field tested soon. The model is based on simulating individual vehicle movements according to a macroscopic flow model, the driver path selection behavior under information being explicitly modeled. The path-processing component is designed for efficient application of the framework to large and realistic networks. DYNASMART does model individual vehicles, though based on macro flow models. Due to the idealized

network links, and the number of nodes in the network model may not be significantly higher than the decision nodes in the actual network. Using macroscopic traffic speed-flow equations it models link travel times as well as network level traffic details such as path travel times effectively.

In DYNASMART, path dynamics is modeled based on the route or routes that drivers have in their minds, as well as the routes provided by ATMIS guidance. A simple behavior mechanism used often is a comparison between the current route and the best alternate. Thus, the routes in the minds of individual drivers are stored as separate lists for the comparison. The flexibility for modeling various driver response mechanisms and information supply strategies comes from the ability to find and store multiple paths efficiently, using networks of reasonable sizes.

3. Simulation models and Calibration-Validation issues

The failure to realize the limitations of models or to interpret their results can have negative and potentially expensive consequences. The use of a model to assess a situation for which it has not been calibrated can also cast doubts over the results (2). There are two related issues:

- Quantification Calibration and validation
- Risk of assessment of simulation based decision-making

Only the first issue will be addressed in this paper.

The process

We consider the approach for methodology along the following directions:

- Context definition for simulation and data requirements
- Sensitivity analysis, if not done already, and identification of main parameters for future tuning (conceptual calibration)
- Definition of calibration and validation scheme; Fitting tests based on Pearson or Kolmogorov criteria are a useful basis for such scheme.

Sensitivity analysis towards conceptual calibration

During the operational calibration phase, we need to tune many parameters. For instance, in **Paramics**, there are about a dozen input types and parameters; some inputs may need to be pure guesses in a simulation due to data unavailability on inputs such as percentage of vehicles in each type – these inputs may not correspond to reality. There are also some inputs like network geometry, max speed, etc, for which reliable data may be available. Our experience shows that the main parameters for **Paramics** may be mean headway, reaction time, aggressiveness and awareness. These have direct influence on the vehicle flow. There is a need to assess the sensitivity of such parameters for any micro-simulator. The next step is to carry out statistical analysis and tests on the results. Results in (1) have been based on two main parameters, mean headway and mean reaction time.

Experiments have been carried out using the other important parameters such as awareness, aggressiveness and probability seed values (default is system clock). See Figure 1 for some examples of results from *Paramics* while using three different normal distributions for awareness and seed. We notice that we have similar results for two different values for awareness and for the seed. These outputs were selected to show some “strange” phenomenon that can be detected through a Turing test like this.

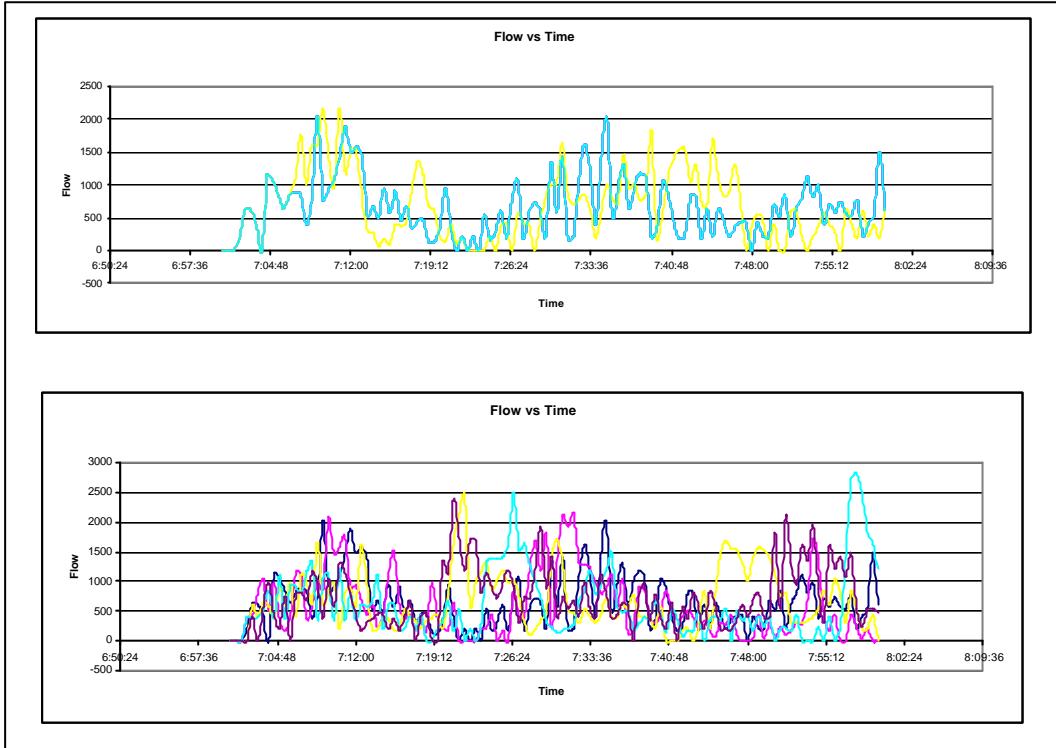


Figure 1: Simulations and Observations – “Strange” results from Turing Tests

Context definition and data requirements

The context may be for studying safety, environmental effects, capacity improvement or congestion mitigation rather than testing ramp metering, the latter being a derived requirement and not a user requirement (5,19). Context variable data is necessary for both calibration and validation; however it is not a simple task, because it is not always clear which variables are significant in any given study.

Conceptual and Operational Calibration

Calibration involves estimating the values of various constants and parameters in the model structure. We are concerned here by the operational calibration; (13,18) provides some more detailed explanation. Calibration is the first step for both phases, as we need data to adjust either the nature of the model for the conceptual phase or parameters for the operational phase; however only the operational phase is context dependant.

Consider the simple case where we have the input parameter, the random number seed; the experiments should be carried with different seed if necessary (use time clock is a possibility); then a variance reduction technique needs to be used.

- Check how the variance can be improved
- Note errors in expected values
- Apply confidence test technique to give quantitative measure
- Furthermore the observed patterns can give some hint about how the models may evolve in the future and preconditions for models parameters to be invariant.

Once satisfactory estimates of the parameters for all models have been obtained, the models must be checked to assure that they adequately perform the functions for which they are intended, that is, to accurately estimate traffic volumes on transit and roadways. Verifying a calibrated model in this manner is commonly called “validation.” The validation process establishes the credibility of the model by demonstrating its ability to replicate actual traffic patterns.

Statistical properties : patterns and confidence test

We distinguish two types of analysis: the first is needed for assessment about distribution used in the model; check that car release is a non-stationary Poisson distribution. The other type concerns standard tests such as KS, Pearson tests, Hoteling or Mahalanobis distance tests and variance reduction techniques on the specific observations. Solving the model equation for the parameters of interest after supplying observed values of both the dependent and independent variables usually yields estimates of model coefficients and constants. The observed values of variables are obtained from the surveys of actual travel patterns. As indicated previously, the estimation process is a trial and error effort that seeks the parameter values which have the greatest probability or maximum likelihood of being accurate within acceptable tolerance of error.

A calibration scheme

The objective is always to have simulation outputs close to field data for the same context. This is an impossible task in many applications and evidently for traffic. We propose different ways of measuring deviations from the field data. We propose to complement it with goodness of fit tests as well. This last type of test checks on the fitted distribution with respect to observed data.

Data analysis and calibration results: we propose a simple case to compute deviations as

$$E = \sum_{j=1}^{j=l} \sum_{i=1}^{i=m} \sum_{k=1}^{k=1,n} (\mathbf{a} \cdot E_1^2(i, j, k) + \mathbf{b} \cdot E_2^2(i, j, k) + \mathbf{g} \cdot E_3^2(i, j, k))$$

We consider E_i error between simulated and field outputs; i, j, k is the lane location, link and time; E is the accumulated Least Square Error. Fewer variables, lanes and links can be selected; however this general scheme gives a reference. At a macro level, we may be

interested in link volumes and not interested by specific lanes. In another case the time dimension may be less important. The a , b , g parameters are weights that can be linked to max value for each E_i

Enhancing/Customizing the scheme can be linked to context and the variables defining the context (queue formation, looking at specific lane, lanes, total link, at specific location and time). It is desirable for modelers to select such a scheme, enhance it if needed, and adopt it as a common standard. Then all modelers can understand when it is said that “*a network has been calibrated and validated*”, what corresponding scheme was used (on speed and headway only for example), how many point locations and time intervals, what was the error, was it stable, etc.

Case study

The work was limited to operational calibration only. As we did not draw much systematic results from sensitivity analysis mainly with mean headway and reaction time; the calibration addressed many parameters and input variables; the black box approach did not help much and we are considering enhancing the models at the conceptual level.

The operational calibration was based on a large numbers of runs and made possible also by the availability of field traffic data from the PEMS database at PATH. Since usable O/D demand matrix was not available and operational calibration was attempted. The calibration exercise was not specific and sample demo simple networks were also used. The full usefulness of the calibration schemes become clear from the real-network example described later in this section.

The calibration procedure for **Paramics** is similar to other traffic models where standard checks are carried out to verify vehicle routing, traffic demand matrices, road layout details etc. After completing these checks and verifying that they are acceptable, the user must output model statistics (link turning flow/delay/journey times) for comparison to observed data. If the comparisons between observed and modeled value comparisons are within recommended guidelines and the graphic visualisation of the vehicles is realistic, then the model is deemed calibrated.

However, if the comparisons are unacceptable then the user should carry out further analyses by

- Checking assess traffic assignment
- Checking road geometry (visualisation)
- Checking routes
- Checking observed data
- Checking traffic demand

The necessary corrections should then be incorporated into the model and the above process repeated until acceptable calibration is obtained. This is a relatively ad-hoc

scheme for calibration and more methodical schemes as presented in the last section were used in our calibration exercises described below.

Assessment of model results

Although each model may be designed to look at a number of different issues, the main objective is to “realistically” replicate the movement of traffic to match the observed conditions. Therefore operational aspects such as lane usage, route choice, volumes of traffic etc. will form the focus of the model assessment.

Network Wide Operation

Assessing the network wide operation of the model is essential so that model runs can be compared in terms of total travel time, total distance traveled and average speed on the network. Such general data gives a good indication of how the model is operating. For example, the level of traffic remaining on the network at the end of the simulation period can show if traffic is being held up in congested networks. Analyzing the amount of traffic released onto the network, and the number of vehicles impeded from entering the network also shows the level of congestion.

Example of a realistic network context for calibration

The network concerns a part of SR-55 (8 miles long, southbound with included arterials) connecting between both I-405 and I-5 in southern California, Orange county; the whole county is actually coded and simulated at the ATMS test bed at University of California at Irvine. The figure shows the highway and arterials; the study was initially made on freeway part only. The operational calibration is highly dependent on demand and assignment. Though conceptual calibration has not been carried out for this network, some sensitivity analysis after operational calibrations can help understanding if the model has conceptual problems. Experiences from *Paramics* calibration in others sites, as reported by Quadston (UK) have indicated that the conceptual models are reasonable.



Figure 2. A snapshot of the network.

We used available and estimated O/D tables with sensitivity analysis for the calibration runs for this network. To illustrate the calibration scheme, let us consider only 2 variables, X and Y , that can be speed, density or flow, headway.

We define XS , YS as the outputs from the simulator, and XF , YF are from the field; the error variables are FE , SE , $V(i,j,k)$ where the variable V corresponds to lane i , at loop/location j at time k . Consider just a portion consisting of 5 loops ($j=1,5$) and consider that all have the same number of lanes ($i=1,4$) and consider one hour of data sampled every 30 sec. The error is a distance-measure from such clouds of numbers; we use the standard least square calculation and add a weighting factor for each error variable. We suppose all data are normalized, $V=V/V_{max}$, so as to prevent any data dominance.

The calibration error is calculated along the variables, lanes, locations and time; we describe here only the principal component analysis framework

$$E = \sum_{j=1}^{j=5} \sum_{i=1}^{i=4} \sum_{k=1}^{k=1,120} (aFE^2(i,j,k) + bSE^2(i,j,k))$$

Now, a squared error minimization can yield the calibration. Comparisons between modeled and observed data should be done on some of the following aspects:

- Traffic flows (based on screen-lines, cordons and individual turning movements)
- Queue lengths (maximum and average) and stop time
- Delays (network wide and at individual junctions)
- Traffic speeds
- Traffic density
- Journey times
- Modeled routing compared to an assessment of actual routing

For the above network case, operational calibrations could be successfully accomplished using the procedures explained above, showing that such approaches could be used as standard schemes for calibration of simulation models in realistic networks contexts.

Online calibration

This may appear to be an “utopian” task; however, based on the experiences with heuristics techniques and complementary results from neural networks (6) we can attempt online calibration as well. Tools for such calibration remain to be developed; of course the availability of on-line data from the field makes this feasible. Training data sets can come from successful validation runs.

4. Macro-models to augment micro-models - The hybrid simulator

Overall Model Structure

The Paramics' capabilities are enhanced with additional routines added through the application programming interface (API). Since various control strategies are tested and evaluated in the Orange County ATMIS testbed, flexibility and data interface are essential part of the simulation model. In addition to the main **Paramics** module, the hybrid simulation framework consists of five additional modules: (1) Monitoring, (2) Adaptive Traffic Control, (3) Data Communication, (4) Route Information, and (5) Route Decision. The latter three are of interest in this paper. Each module consists of one or multiple APIs. The individual APIs have their own functions interfacing with other modules within the simulation framework. The flexible nature of the model framework allows easy incorporation of new technologies and algorithms into the model framework. Figure 3 shows the overall interrelation between modules.

Monitoring and Adaptive Traffic Control

We have developed for ATMIS are travel time estimation or prediction, O/D estimation, incident detection, etc. The monitoring routines are also needed by the adaptive traffic control routines such as for traffic signal control and ramp metering. Individual control devices are modeled independently with APIs for devices such as Type-170 controllers, interfacing with the monitoring module. APIs for statistics are supplementary tools to measure emission and fuel consumption, travel time statistics for individual vehicles, etc.

Data Communication

In this section we describe briefly the process and the assumptions used to construct an abstract network from a detailed **Paramics** network code. The objective of this task is to

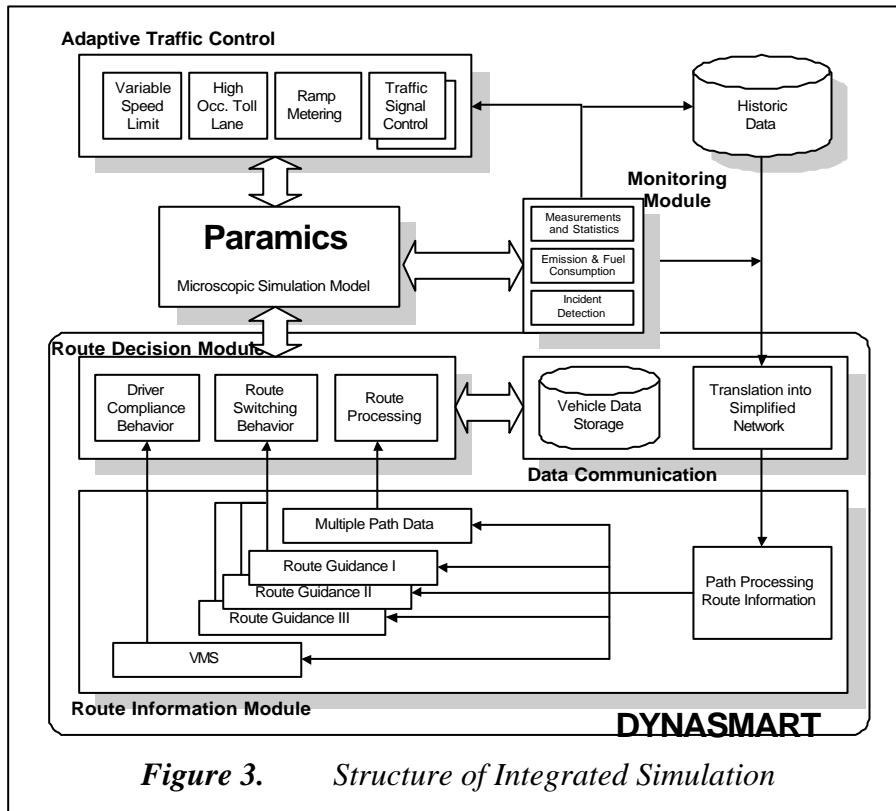


Figure 3. Structure of Integrated Simulation

create a simplified network to be used in route information and decision modules, but consistent with the original one coded for running ***Paramics***. In addition, the process also requires the construction of a lookup table for communication between the two networks, of information related to network level variables like level of service, and also detailed information on individual vehicle positions, speeds, route decisions, etc.

The equivalent abstracted network is made taking into account the following possible simplification. In terms of link characteristics, we aggregate across those ***Paramics*** links, whose end nodes represent only a change in geometry or capacity than a real decision node such as an intersection or an interchange. Calculation of link cost in our abstract network is consistent with the ***Paramics*** link cost calculation, which includes link costs themselves, and turn movement costs. Look-up tables are used to identify the original links that corresponds to the abstracted network links and to aggregate travel times on them.

Route Information and Decision

The importance of path-based routing arises from the drivers' route selection behavior comparing the routes in their mind with the routes suggested by ATIS. In our framework, the path dynamics features of DYNASMART are incorporated into the hybrid scheme via the ***Paramics*** API capability.

The route information module has two folders. The first one is initial route selection mechanism. Initial routes are assigned to individual vehicles from a list of k-shortest paths based on their levels of network familiarity that is assigned along with other characteristics when the vehicle is generated. The vehicle's characteristics and initial route are basis of route decision behavior. The second folder is generation of route guidance. Main source of the route guidance/information could be either path-processing procedure or external algorithms. The route guidance/information can be generated in various ways depending on their capability of network monitoring and/or their objectives or algorithms. Allowing various guidance types, the path processing/route information routine is capable of using historic data as well as real-time data, though basic path processing relies on k-shortest paths from real-time data. Further, any dynamic route guidance generation algorithm such as DynaMIT (4) or DYNASMART-X (5) can be incorporated via API in the route information module and externally processed paths can be also directly fed, while the data for the information generation are provided from the monitoring module. Besides this route guidance that are applied only to equipped vehicles, variable message signs (VMS) provide unequipped drivers with route guidance/information. An algorithm to generate VMS is also modeled via API within this route information module. This feature allows ***Paramics*** to be a test-bed for the evaluation of various route guidance systems.

5. Towards a Simulation Methodology and Associated Laboratory

Too many effort is devoted to simulating a network; it is time to focus on a specific methodology that can be adapted to each type of microscopic simulator; ***Paramics*** offers

the possibility for such idea by adopting the concept: design of experiment and associated laboratory with add on capabilities; such effort is well adapted for simulator that is used at large scale..

The statistical approach integrated to such analysis is necessary because traffic simulation is a stochastic process where several random variables are involved. In principle, there is clear-cut distinction between simulation experiments and observational studies. In particular, with randomized treatment allocation in a simulation study, a conclusion may be drawn about causal differences based on statistically assessed uncertainty, whereas in an observation study there are always additional uncertainties of interpretation.

At the same time, we take into account the assumptions to be made when doing an experimental simulation and how we can guarantee the robustness of the simulation and preservation of the assumption being made. We give in sequence some related aspects

Methodology for simulation

There may not exist a simulation methodology for all situations, as it is certainly context dependent. However, it is clear that using ad-hoc techniques for all cases is not a valid approach either. Based on the discussion above and the experience from the validation case studies, we advocate a rather general bottom up approach. As an example for the validation process, similar to the five steps approach in (15)

S1 Develop a model

S11 Conversations with operators/drivers/users familiar with the network

S12 Existing theory on traffic as distribution of arrivals (cars release)

S13 Observations

S14 Intuitions: this is the most fundamental task for traffic simulation before any formal analysis can be done; as driving maneuvers are intuitive tasks mainly in the Mediterranean countries.

S2 Test assumptions of the model empirically (Conceptual Calibration); considering simple networks

S3 Validate the model

S4 Parameter adjustments by exercising the model on network (context study and context variables) : Operational calibration

S5 test simulation output data (operational validation)

A variety of statistical techniques are now available to build up data analysis on the field data and simulated data and to apply confidence tests on these data; One may run it for a specific field data sample and iterate. It is important to note however that the validation must not rely on a single field data output but on as many specific patterns of the field data as can be found.

A simulation laboratory

The nucleus of such lab is the simulator itself. In order to avoid every users going through all development requirement, we propose the method to integrate all utilities in a simulation lab similar to (20). **Paramics** offers facilities for this through plug-ins (API, as described before). The lab itself need not be fully simulation dependent as there could be generic tasks and canned simulated data. This approach enables us to carry out simulation easily as most utilities are available. These are mainly integration of statistical tools and specific traffic techniques ideally suitable for ATMIS and control (ramp metering, controllers, HOV, lane drop, lane extension, etc.); As an analogy to Matlab type software, there can be a toolbox build upon the simulator. Such toolbox is actually being implemented at the UCI test bed within a distributed platform of software modules and databases, using the CORBA protocol for data communication. Real-world data connections for calibration of the model is very useful, and again the UCI testbed has implemented such capabilities.

6. Conclusion and future work

This paper focuses on two key issues which we believe are the most critical factors involved in simulating ATMIS systems microscopically. They are, model validation/calibration and ability to handle path-related issues on large networks.

Many critical issues have been overviewed in this paper. Calibration and validation is difficult, time consuming and is still a challenging problem in traffic simulation. Some elements corresponding to methodology issue were proposed. It was observed in the case study that traffic assignment, human model integration and O/D estimation are systematically related to these issues. We conclude that care should given on how well is the model fitted, what method we use to measure the fitness and on what risks are involved in any decision based on the “validated” simulated model. There is a need for researchers to agree on criteria for calling any model a “validated” model, i.e., we need to characterize and measure the phrase, “*close to reality*”.

As for the network path-related issues, the need for incorporating methods as in macroscopic models that typically use less detailed network representations, is underscored. In this paper, as a candidate solution to the problems we discuss a newly developed hybrid simulation framework. The hierarchical network structure allows simulating large network microscopically. The importance of route-based routing and behavioral model was stressed for the simulation models evaluating ATMIS technologies and strategies. The path dynamics was achieved in microscopic simulation by network abstraction and communication between macro-scale and micro-scale models. This modeling approach satisfies the needs of comprehensive simulation models. The model framework is currently implemented in an evaluation testbed, showing its capability as an evaluation framework of ATMIS.

Concerning future work, the calibration-validation will be carried out using more detailed calibration schemes and statistical analysis. Tool box utilities will be developed as for specific APIs. Plug and play studies with alternate car following models well adapted to the specific traffic context is another focus. Another task is the extension of the work on

Traffic management and simulation-based decision support. Other tasks include the incorporation of new Monte Carlo techniques in the simulation process and in the analysis of simulation outputs, a topic on which researchers often do not pay enough attention.

7. REFERENCES

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