COMPARISON BETWEEN THREE DIFFERENT TRAFFIC MICRO-SIMULATIONS AND REALITY IN DALLAS

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Abstract

We describe three traffic microsimulations which operate at different levels of fidelity. They are used to iteratively generate a self-consistent route-set based upon microsimulation feedback. We compare the simulation results of all three simulations to aggregated turn count data of actual field measurements.

1 Introduction

It is certainly desirable that transportation forecasting models are “correct” in the sense that the traffic patterns they predict correspond to what would happen in reality under the circumstances assumed in the forecasting model. Unfortunately, it is notoriously difficult to transform the above common sense statement into a technical specification. Since one cannot run controlled experiments in socio-economic systems, it is usually impossible to check the forecasts. Let us mention some of the problems:

- It is very difficult to obtain “clean” field measurements of traffic flow characteristics such as flow density curves. The problem is that needs crowded situations, and crowded regions usually have plenty of “messiness” such as on-/off-ramps, intersections, ... which influence the measured quantity and thus make it context dependent. For example, a bottleneck downstream will cut off most of the data near capacity for a flow-density diagram.
It seems thus that one should add the "context" to the simulation model, i.e. include the complexity of the real world around the measurement site. The problem now is that one suddenly needs more information about the vehicles such as their routes and intended movements through the system. For example, it clearly is important how much of the traffic streams in a weaving section is crossing to the other side.

Yet, reliable origin-destination information is difficult to obtain. In theory, it would be possible to collect for the above situation enough information using license-plate detection, but this is usually costly (and sometimes also has privacy implications).

A possible way out is to generate the origin-destination information from "activities", that is to simulate the complete human decision-making process related to transportation, starting from defining the activities (be at home, work, eat, shop, ...), defining their locations, and selecting mode and routes. This is, in very short, the idea of the TRANSIMS (TRansportation ANalysis and SIMulation System) project [1]. Yet even that is not necessarily robust: For example, a transportation planning forecast usually looks twenty years into the future. But when twenty years later the demographics turn out to be different than what was assumed for the model run, then a precise comparison is already impossible.

The net result is that it is very hard to compare simulation results to reality. For example, if a simulation is driven by route plans (as in this paper), are differences in the turn counts at intersections due to wrong origin-destination relations, due to wrong routing, or due to wrong traffic flow dynamics?

In our intuition, there is currently no satisfying way out of the dilemma (and maybe there will never be). Yet, it is certainly possible to do systematic studies. For example, the sensitivity of the turn counts on variations of the origin-destination tables can be tested. Or one can document emergent traffic flow behavior for simplified, "clean" cases (such as saturation flow from a minor into a major road). Comparison of these cases with reality will still be difficult, but at least one can compare simulations with each other. This would allow, for example, to say something like that the traffic flow dynamics of simulation A allows more turns than simulation B, so the fact that simulation B has higher turn counts is not a result of the traffic flow dynamics but needs to be caused by something else. In this way, it should be possible to systematically enhance our understanding of the intricacies of the simulated dynamics and maybe gain enough practical experience to also be able to say something about the forecasting quality.

This paper contributes a piece to the mosaic. It describes micro-simulations that have been made using data for the Dallas/Fort Worth area (described in Section 2). The micro-simulations (described in Section 3) run on routes; the routes are generated iteratively using fastest path (see Section 4). etc.
2 Context

The context of the work done for this paper is the so-called Dallas–Fort Worth case study of the TRANSIMS project [4]. Most of the details relevant for this paper can also be found in Ref. [9]. Purpose of the case study was to show that a micro-simulation based approach to transportation planning such as promoted by TRANSIMS will allow analysis that is difficult or impossible with traditional assignment, such as measures of effectiveness (MOE) by sub-populations (stakeholder analysis), in a straightforward way. Most of the accompanying studies such as Refs. [6, 9, 11, 14, 17] and also this paper attempt to document the technology leading to and following up on the case study.

The underlying road network for the study (public transit was not considered) was a so-called focused network. It contained all links in a 5 miles times 5 miles study area, but got considerably “thinner” with further distance from the study area.1 A picture of the focused network can be found in Ref. [9].

The TRANSIMS design specifies to use demographic data as input and generate, via synthetic households and synthetic activities, the transport demand from there. The Dallas/Fort Worth case study was based on interim technology: parts of the “front end” were not yet available. For that reason, that study uses conventional 24-hour trip tables (production-attraction matrix, PA matrix) as starting point. The PA matrix were provided by the regional transportation planning authority (the North Central Council of Government NCTCOG). The PA matrix roughly is a 24 hour origin-destination matrix, i.e. the metropolitan area of Dallas/Fort Worth is divided into approximately 800 zones (traffic analysis zones, TAZs), and the number of trips going from each zone to each other zone in a 24 hour period is given.

For the case study, the first thing that was done was to break down the PA matrix into individual trips. For this, a time-of-day distribution according to land use in the destination zone was used (for example, traffic going to commercial zones mostly occurs in the morning). Also, starting and ending locations of trips were specified on the link level. The result was a table of approx. 10 million trips, all with a starting time, a starting location, and a destination location. From this table, all trips starting between 5am and 10am (ca. 3 million trips) were actually used.

Next, an “initial routing” step was done. It is easiest to imagine that all trips were routed according to “fastest path in an empty network” (i.e. using free speeds provided by the transportation authority). All trips that in this step went through the study area were retained, all other trips were removed. Note that this defines a base set of trips for all subsequent studies presented in this paper: All trips thrown out in this step can no longer influence the result of the studies, although they may in reality. This base set contained approx. 300,000 trips.

The reason why this is worth mentioning in so many words is that for the

1Note that this “thinning out” of the network was not done in any systematic way and is explicitly not recommended. It was an ad-hoc solution because more data was not available, and because of limited computing capabilities.
results in this paper, two different base sets of trips were used. That is, the initial routing for the case study was not done using fastest path in an empty network, but instead some untested and undocumented variation of an assignment technique was used. In essence, it routed some trips, calculated new link travel times based on a standard link performance function, routed more trips, etc., until all trips were routed. Since it is somewhat unpredictable what this exactly does, later research studies were based on a base set of trips obtained by routing in an empty network.²

3 The micro-simulations

The above procedure does not only generate a base set of trips, but also an initial set of routes (called initial plan-set). These routes are then run through a micro-simulation, where each individual route plan is executed subject to the constraints posed by the traffic system (e.g. signals) and by other vehicles. Note that this implies that the micro-simulation is capable of executing pre-computed routes (only very few micro-simulation currently have this capability although their number is growing), and it also implies that, in the simulations, drivers do not have the capability of changing their routing on-line.³ Three micro-simulations have been used, all three related to the TRANSIMS project, but with different levels of realism and different intended usages. For simplicity, we will just number them, i.e. "micro-simulation 1", "micro-simulation 2", and "micro-simulation 3" (MS1, MS2, and MS3). MS1 is the most realistic one, MS3 the least realistic one of the three. MS1 and MS2 are based on the so-called cellular automata technique for traffic flow [¹, ¹²] although there is no necessity for this except the requirement of sufficient computational speed, while MS3 is based on a simple queuing model in the spirit of previous work found in [⁵] and [¹⁹].

3.1 Micro-simulation 1 (MS1)

MS1 is the "mainstream" TRANSIMS micro-simulation. As said above, it is the most realistic of the three, including elements such as number of lanes, speed limits, (fixed) signal plans, weaving and turn pockets, lane changing both for speed optimization and for plan following, etc. It also has the most sophisticated output subsystem of the three, allowing the user to specify which data to collect during the simulation. The studies described on this paper were run on five coupled Sparc5 workstations running as fast as real time; newer versions of the module also run on an Enterprise 4000. Details of this micro-simulation are documented in [¹¹].

²As already stated above, we explicitly do not recommend using a study area as we did for Dallas because of a large number of currently unsolved associated problems.
³It is not that on-line re-routing is incompatible with the technology (see, e.g., [¹³, ¹⁸]), but it has not generally been implemented and studied.
3.2 Micro-simulation 2 (MS2, PAMINA)

The second micro-simulation, MS2, does not include signal plans, weaving and turn pockets, and lane changing for plan following. Most other specifications are the same as for MS1, although differences can be caused by the different implementation. MS2 is much better optimized for high computing speed: it ran more than 20 times faster than MS1 for this study, which is a combined effect of using faster hardware (it is much easier to port to different hardware, thus being able to take advantage of new and faster hardware much sooner), less realism, and an implementation oriented towards computational speed. This micro-simulation is documented in [15, 16, 14, 13].

3.3 Micro-simulation 3 (MS3, QM)

The third micro-simulation that we used is significantly less realistic than the other two. In this model, each link is represented by a queue with a service rate proportional to its maximum capacity. When a car enters a link, a travel time is calculated using the length and the free flow speed of the link. The main difference to Gawron's model [5], is the absence of a fundamental diagram to calibrate these speeds. In fact, the diagram is reproduced by this model itself. The car is then put into the queue with an expected arrival time. The vehicle can leave the queue if the current time is higher than the arrival time, if the vehicle satisfies the transition probability of the service rate and if the next link is not full yet. The reason for having a model like this is that we want a micro-simulation model that fits into the overall TRANSIMS framework (i.e. runs on individual, pre-computed plans) but has much less computational and data requirements than the other simulation models. Indeed, MS3 runs on the same data as traditional assignment models, and on a single CPU it is computationally a factor 60 faster than MS2. A parallel version is planned.

4 Feedback iterations and re-planning

The initial plan-set is obviously wrong during heavy traffic because drivers have not (or not well) adjusted to the occurrence of congestion. In reality, drivers avoid heavily congested segments. We model that behavior by using iterative re-planning: The micro-simulation is run on a pre-computed plan-set and travel times along links are collected. Then, for a certain fraction, $X$, of the drivers, new routes are computed based on these link travel times. Technically, each route from the old plan-set is read in, with probability $1 - X$ is is written unchanged into a new file, and with probability $X$ a new route is computed given the starting time, starting location, and destination location from the old route plus the (time-dependent) link travel times provided by the micro-simulation. After this, the micro-simulation is run again on the new plan-set, more drivers are re-routed, etc., until the system is “relaxed”, i.e. no further changes are observed from one iteration to the next except for fluctuations (all micro-simulations are stochastic).
We have used two different implementations of the re-planner. For technical completeness, let us call them RP1 and RP2. RP1 is the re-planner that was used for the Dallas/Fort Worth case study; in this paper, it is used in conjunction with micro-simulation MS1. RP2 is a faster and less memory-consuming version that has been implemented since then. RP1 and RP2 are written according to the same specifications: they compute fastest paths based on 15-minute averages of link travel times using a time-dependent variant of the Dijkstra algorithm. Time-dependence is accounted for in the following way: The micro-simulation reports the average link travel time of all vehicles leaving the link between, say, 8:00 and 8:15. RP2 then uses this link travel time for all Dijkstra calculations that enter the link during the same time period. RP1 uses this link travel time for all Dijkstra calculations that exit the link between 7:45 and 8:00 (thus “anticipating” congestion build-up). Clearly, both algorithms are somewhat sloppy here; newer implementations of our algorithm deal with this in a more precise way by actually calculating when, in the average, the vehicles had entered the link. Both RP1 and RP2 were tested together with the micro-simulation MS2 and no significant differences were seen.

Certainly, there are many questions in this area. How can one tell that an iteration series is relaxed? Do different initial conditions and/or iteration schemes lead to the same overall relaxed state? If so, can one speed up the relaxation process? Is reality at all similar to the relaxed state obtained with this methodology? With respect to the implementations described in this paper, these questions are treated in more detail in [6, 13, 17]. With respect to the results described in this paper, we can say the following:

- MS1 was iterated using a “scheduled” re-planning fraction, i.e. using a re-planning fraction of 10% for the first seven iterations, followed by five iterations of 5% and two iterations of 2%. Later tests using the same re-planner but a different micro-simulation indicate that the resulting state is not yet relaxed, i.e. one would need to make further iterations to bring, for example, the sum of all travel times to an in the average stable value.

- In contrast, MS2 and MS3 were iterated with an “age-dependent” re-planning scheme: The probability of a route being selected for re-planning was made proportional to the number of iterations since the last re-planning event for that route. This was shown to be a much more efficient and robust re-planning scheme as any other scheme we tested [13, 17].

- We could not find an indication that the relaxed states depend either on the initial conditions or on the selected relaxation schedule. If this holds in more general, this would be good news because the final state of the iterations would be fairly robust against changes.

- However, we could find large fluctuations in the traffic patterns by just changing the random seed, i.e. keeping everything (starting times, individual routes, signal plans) unchanged and just changing the sequence of random events that influence acceleration, braking, and lane changing.
These fluctuations seem to be non-Gaussian, i.e. the traffic evolved according to one general pattern most of the time but could be totally different (much more congested) in few of the runs. See [8] for more details.

5 Field measurements of turn counts

The regional transportation authority, NCTCOG, performed systematic turn counts on some of the intersections in the study area in 1996. In general, counts are available for through movements, left, and right turns, for 15-minute bins between 8am and 9am. These counts were all done only once, so no information about variability is available. Also, counts for different intersections were done on different days. The locations of the intersections will become clear from the figures presented later.

6 NCTCOG 1990 LBJ study results

We also had the results of an 1990 “LBJ corridor study” performed by NCTCOG. (The LBJ = Lyndon B Johnson freeway is the freeway going in east-west direction through the study area.) No further details on that study are available.

7 Comparisons using approach volumes

Before turning to quantitative comparisons, it is necessary to point out a problem with the data that significantly reduces comparability. This problem is that the Dallas North Tollway (which is the north-south freeway in the study area) got extended from the large intersection in the center of the study area towards the north sometime around 1990/1991. The result is that the NCTCOG study, our simulations, and the 1996 field data are all inconsistent with each other:

- The NCTCOG study is based on pre-extension trip tables and on a pre-extension road network.
- 1996 reality is based on post-extension trip tables and on a post-extension road network.
- Our simulations are based on pre-extension trip tables but a post-extension road network.

The addition of the freeway most certainly reduced impedance in the north-south direction, thus most probably causing more trips in that direction. This additional travel will be reflected in the 1996 counts, but not in our simulations. The approach counts produced by the simulations look very much alike. The TRANSIMS 'typical run' (Fig. 2) and TRANSIMS 'non-typical run' (Fig. 3) differ mainly on the frontage road. This can be explained by the presence of jams for the non-typical run in the eastern part of the area shown. TRANSIMS
Figure 1: Comparison between the NCTCOG 1990 assignment and the 1996 approach counts
Figure 2: Comparison between a “typical” run of MS1 and the 1996 approach counts
Figure 3: Comparison between a "non-typical" run of MS1 and the 1996 approach counts
Figure 4: Comparison between MS2 and the 1996 approach counts
Figure 5: Comparison between MS3 and the 1996 approach counts
runs (typical and non-typical) generate also a higher traffic volume on Alpha Boulevard than PAMINA (Fig. 4) and the Queueing model (Fig. 5) while the main difference between the last two simulations consists of higher traffic on the frontage road for PAMINA. As notified previously, the observed data, which served as reference in each figure, shows more traffic in the north-south direction.

8 Comparisons using turn counts

Due to smaller aggregation, the turn counts show larger differences between the three simulations and the observed data than the approach counts. Nevertheless the similarities between these, still look very strong. The way TRANSIMS is implemented, it has a tendency of punishing left and right turns. This is what can be observed in Figs. 6-9. Therefore, the TRANSIMS turn counts look much closer to reality than PAMINA and the Queueing model.

The simulations give in overall very consistent results. This is rather surprising considering the differences of traffic the underlying models and the simplicity of the Queueing model.

9 Discussion

The data consistency problem caused by the extension of the Dallas North Tollway is not an unlucky coincidence, but it is a generic problem in the field: The areas that are most interesting for studies are the congested ones, and these are also the areas that change fastest. This clearly points to the need of a methodology that can deal with such changes in a systematic way. Thus, this becomes an example of why the TRANSIMS design wants to go beyond trip tables and generate demand from demographics via activities. Once that demand generation process is sufficiently understood, so the hope is, the additional trips caused by adding a road would be generated by the model so that the model would automatically react correctly and consistently to such infrastructure changes.

Given this data inconsistency problem, it is unclear how much could be learned by further studies. We could certainly change the network back to pre-extension status. However, that would only allow consistent comparison with the NCTCOG study, and this comparison for itself is meaningless. 1996 trip tables, which would allow a systematic comparison to the turn counts, are not available to us. In addition, the restriction of the simulation to the study area causes all kinds of boundary effects. For example, in reality access to the Tollway is really bad north of the simulated area; yet, since the re-planner does not pick this up because it is outside the simulated area, we probably route too much traffic via the Tollway.
Figure 6: Comparison between a "typical" run of MS1 and 1996 turn counts
Figure 7: Comparison between a "non-typical" run of MS1 and 1996 turn counts
Figure 8: Comparison between MS2 and 1996 turn counts
Figure 9: Comparison between MS3 and 1996 turn counts
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