Chapter 1

TRANSIMS for transportation planning

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The TRANSIMS (TRansportation ANalysis and SIMulation System) project at Los Alamos National Laboratory attempts to model all aspects of human behavior related to transportation in one consistent simulation framework. The key to the TRANSIMS design is a radically microscopic simulation of the travelers. In consequence, as the first step, a synthetic population is created from demographic data. Next, another module of TRANSIMS generates synthetic activities (such as sleeping, eating, working, shopping, etc.) and activity locations for each synthetic individual. Each individual in the simulation then plans her transportation, making modal and routing choices. Finally, the plans of each individual are executed in a detailed transportation micro-simulation. Relaxation iterations are necessary to achieve consistence between the modules. Since this means running all modules, especially the micro-simulation, many times, this makes the already considerable computational challenges even harder. Results from micro-simulation runs can be used to extract data, for example for stake-holder analysis or for emissions calculations. In this way, different transportation alternatives can be compared in detail.[1]

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1.1 Introduction

Nobody likes traffic jams. For this and other reasons, most developed economies set aside a significant part of resources to reduce transportation bottlenecks. However, it has become increasingly clear that expansion of capacity may be limited, for example by safety concerns, by concerns about emissions and pollution, by restrictions to open space availability, etc. This means that detailed quantitative techniques would be useful, for example to analyze trade-offs between options.

In addition, it is now clear that increasing capacity increases traffic, often leading to the same bottlenecks as before. This means that transportation is *not* a simple infrastructure problem, where to find a good or optimal solution to move a given demand, but a problem where individual people's values and preferences play an enormously important role. In consequence, any quantitative technique needs to be able to represent aspects of human decision-making.

This leads, maybe naturally, to the idea to approach the problem with an *agent-based* micro-simulation. Each traveler is an agent; agents make plans about what to do during a day; in order to get from one activity location to another, agents can, for example, walk, use bicycles, drive cars, or use busses. This is exactly the idea of the TRANSIMS (TRansportation Analysis and SIMulation System) project: to represent each individual agent in a metropolitan region and to simulate all aspects of his/her decision-making as long as it is related to transportation.

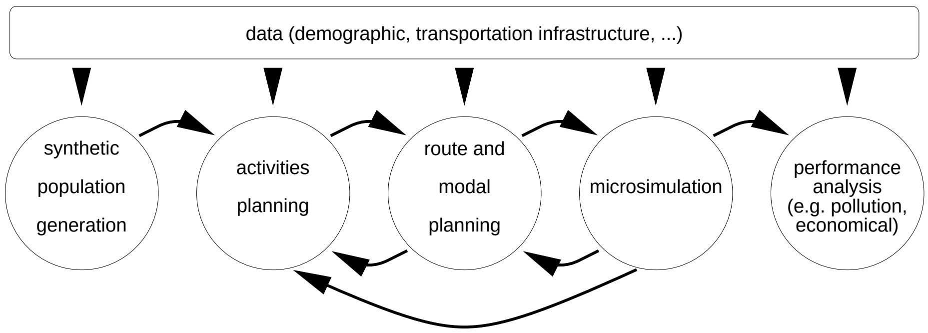

Figure 1.1: Modules of an agent-based simulation approach to transportation.

In principle, this sounds like a straightforward simulation approach (see Fig. 1.1): Derive synthetic individuals from demographic data and locate them on the network; use the demographic information together with land use information to derive activities (working, sleeping, eating, shopping, etc.) and activities locations for them; and let them decide about mode and routing of their transportation. So far, all these are *plans*, i.e. intentions of the simulated individuals. These plans can then all be fed into a realistic transportation micro-simulation, which can be used as the basis for analysis, such as emissions calculations.

However, this approach encounters challenges from several directions:

- **Size of the problem:** Metropolitan regions typically consist of several millions of travelers. Executing a second-by-second transportation micro-simulation on a problem this size within reasonable computing time is only possible with the use of advanced statistical and computational techniques.
- **Behavioral foundation:** We are far from understanding human behavior. For that reason alone, we are unable to predict the behavior of *individual* travelers. However, there seems to be a realistic chance that the *macroscopic* (emergent) behavior that is generated by thousands or ten-thousands of interacting individuals is considerably more robust than the behavior of an individual agent. This would be similar to Statistical Physics, where the trajectory of a single particle is unpredictable, yet, useful macroscopic properties of gases such as equations of state can still be derived.
- **Consistency problem:** The approach outlined above is not as straightforward as it sounds because the plans depend on *expectations* about traffic conditions during execution. For example, if a person expects congestion, he or she may make different plans than when no congestion is expected. Yet, congestion occurs only when plans *interact* during their simultaneous execution. – This problem is not unknown in traditional economic theory and is traditionally overcome by the assumption of rational agents. Both with and without the assumption of rationality, this problem of consistency between plans and micro-simulation makes the computational challenge even bigger.
- **Robustness:** Any approach to a problem needs to have reproducibility of the results under a wide enough range of changes, or otherwise the results are useless for practical purposes.

In the remainder of this paper, we want to give information on how the basics of such a transportation simulation can look like. Because of our own experiences, we will focus on the TRANSIMS project; however, there are other projects in the area (e.g. [5]).

1.2 Traditional approach

Before writing about TRANSIMS, let us introduce the approach that is currently in use in many transportation planning organizations. It is called the "four step process" because it consists of the following four steps (e.g. [10]): (i) **Trip generation** – determine sources and sinks of traffic. Note that this only counts departures and arrivals, but not where traffic comes from or goes to. (ii) **Trip distribution** – connect sources and sinks via traffic streams. The result of this procedure is sometimes called origin-destination (OD-) matrix. (iii) **Modal split** – determine which fraction of travel is done by the respective modes of transportation (walk, transit, car, etc.) (iv) **Traffic assignment** – assign traffic streams on the network, i.e. determine routes for the streams.

This method has several shortcomings, some of which we want to mention here. The most important *fundamental* shortcoming is probably that the mathematical foundation of the traffic assignment is only valid for time-independent problems. A consequence of this is that time-dependent dynamics, such as time-dependent queue-buildup from bottlenecks, or the sequential "chaining" of trips, cannot be represented easily. Probably as a consequence of the resulting difficulty to represent time-dependent processes in detail, practical implementations of the four step process decouple the modules from each other, with for example the consequence that congestion does not reduce the overall number of trips, or that analysis by sub-populations is not possible because there is no information on demographic characteristics of travelers available in step (iv). Also, the representation of the driving dynamics is too unrealistic to for example calculate emissions.

In spite of these shortcomings, the four-step process has the advantage that it has more than 30 years of history, during which the theoretical foundations have been well developed, and much practical experience has been gained. It is therefore understandably a difficult and slow process to build similar confidence in a new technology based on agent-based simulation.

1.3 Synthetic population generation module

The idea behind the TRANSIMS approach is that it simulates *individual* travelers. However, the typically available demographic input data is aggregated over geographical zones. The synthetic population generation module [2] of TRANSIMS generates instances of stochastic populations. These stochastic populations have the property that, if one would take a census off them, they would result in the same demographics as the original input data. The synthetic population can include information about household membership, home location, income, vehicle availability, etc. A functional implementation of such a module is currently available as part of TRANSIMS.

1.4 Activities planning module

The geographical and demographic information of the synthetic individuals is then used to generate activities for them. This can for example be done via complicated activities models with hundreds of free parameters obtained from the estimation of surveys (e.g. [4]), or via simplified "toy" models for research purposes (e.g. [12]). Such models should include activity *location* because that is where the travel demand is derived from.

1.5 Modal and route planning module

Activities at different locations need to be connected by transportation. Synthetic travelers need to select their modes (walk, drive, transit, etc.), and their routes. Again, the methods can range from simple, Dijkstra-type fastest-path algorithms [6] to sophisticated formal language constrained path problems [1].

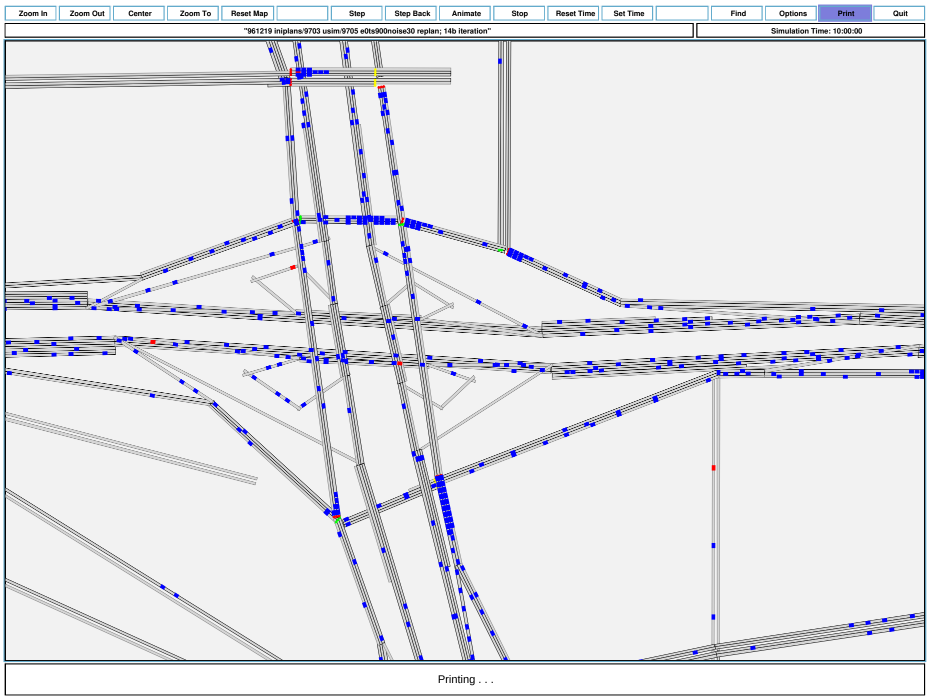

Figure 1.2: Zoomed-in snapshot of a micro-simulation run.

1.6 Micro-simulation module

All agents' plans are executed simultaneously in a transportation micro-simulation. This is the only place where interactions between agents are actually computed, although they could be *anticipated* in the other modules. Micro-simulations, too, can reach from relatively simple queue models [11] to arbitrarily realistic implementations; the currently maybe most realistic implementation that still fulfills the computing requirements is based on a cellular automata technique for car following and lane changing, enhanced by additional rules for elements such as signals, unprotected turns, turn pockets and weaving lanes, etc. [8].

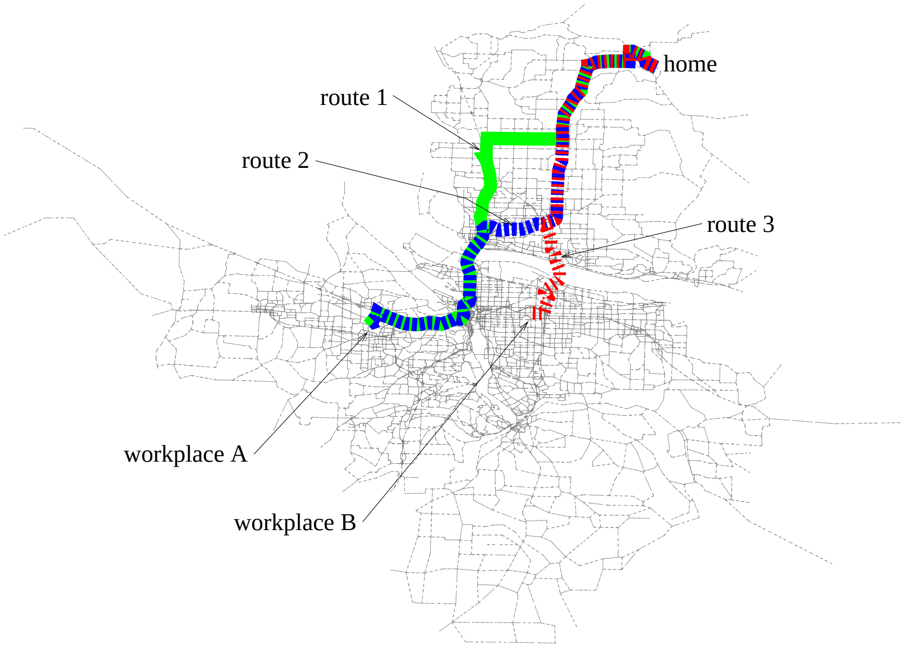

Figure 1.3: Example of re-planning. The traveler first drives to workplace A via route 1. Eventually, he/she decides to switch to a supposedly better route 2. Again later, he/she decides that this results still in too much driving time, and moves to a different workplace B closer to home. The street network shows Portland/Oregon. The example is taken from an actual feedback series.

1.7 Feedback and re-planning

As stated in the introduction, for recurrent situations such as rush-hour traffic, the conditions expected during plans-making need to be consistent with conditions during the execution of the plans. If they are not consistent, people are likely to change their plans. For example, if congestion turns out to be much worse than expected when the plans were made, people may drop less important destinations from their trip. That means that a situation where expected conditions are not consistent with conditions during execution are transient. Since we are currently interested in "average" (i.e. non-transient) results, such inconsistency is undesirable.

Yet, when the plans are made for the first time, no information about the resulting dynamics is available. This is true both for models and for reality. In our simulations, we currently solve this problem by a relaxation method, i.e. by iterating between the plans-making modules and the micro-simulation until expectations during plans making and conditions during plans execution are consistent ([7, 9], see Fig. 1.3). Such an approach does not seem implausible in behavioral terms. However, it is worth noticing that conventional economics solves the same problem by assuming complete rationality and in consequence assumes that agents will be able to find non-transient plans without ever executing them.

1.8 Analysis

Once expected and encountered conditions are consistent, we can assume that we are simulating non-transient scenarios. Such scenarios can be analyzed in detail in any way one wishes. Note that, because of the nature of the microscopic approach, all microscopic variables are still accessible at this stage. For example, information can be separated out by income of the travelers, by trip purpose, by age, etc. Since one can run the simulations for different alternative scenarios regarding the transportation infrastructure, it is straightforward to for example consider the effects of certain infrastructure alternative on certain sub-populations [3]. Also, since driving is –at least in principle– realistically modeled, vehicular emissions can be calculated [13]. All this is perhaps not surprising for people used to thinking microscopically about their problems, but it is a huge step for transportation which traditionally does not have access to these quantities as output from the four step process.

1.9 Summary

An agent-based simulation approach to transportation is possible with current technology, although it is still a significant computational challenge, especially when one strives for a realistic representation of the outside world. It is possible to break up the problem into modules for "population generation", "activities plans generation", "transportation plans generation", "micro-simulation, and "analysis". The computational challenge stems from the necessity to simulate realistic second-by-second driving of metropolitan regions with many millions of travelers. It is made even harder by the fact that the micro-simulation needs to be run several times so that the plans from the plans generation modules can relax towards "consistency" with the micro-simulation.

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