DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.
TRANSIMS: TRansportation ANalysis and SIMulation System
LaRon Smith, Richard Beckman, Doug Anson, Kai Nagel, Michael Williams
Los Alamos National Laboratory

Abstract
This paper summarizes the TRansportation ANalysis and SIMulation System (TRANSIMS) Project, the system's major modules, and the project's near-term plans. TRANSIMS will employ advanced computational and analytical techniques to create an integrated regional transportation systems analysis environment. The simulation environment will include a regional population of individual travelers and freight loads with travel activities and plans, whose individual interactions will be simulated on the transportation system, and whose environmental impact will be determined. We will develop an interim operational capability (IOC) for each major TRANSIMS module during the five-year program. When the IOC is ready, we will complete a specific case study to confirm the IOC features, applicability, and readiness.

Introduction to TRANSIMS
The TRansportation ANalysis and SIMulation System (TRANSIMS) is part of the multi-track Travel Model Improvement Program sponsored by the U.S. Department of Transportation and the Environmental Protection Agency. Los Alamos National Laboratory is leading its development. TRANSIMS will address issues resulting from the Intermodal Surface Transportation and Efficiency Act of 1991, such as considerations of land use policies, intermodal connectivity, and enhanced transit service. It will support analyses of potential responses to the stringent air-quality requirements of the Clear Air Act Amendments of 1990.

The TRANSIMS Project objective is to develop a set of mutually supporting realistic simulations, models, and data bases that employ advanced computational and analytical techniques to create an integrated regional transportation systems analysis environment. By applying forefront technologies and methods, it will simulate the dynamic details that contribute to the complexity inherent in today's and tomorrow's transportation issues. The integrated results from the detailed simulations will support transportation planners, engineers, and others who must address environmental pollution, energy consumption, traffic congestion, land use planning, traffic safety, intelligent vehicle efficacies, and the transportation infrastructure effect on the quality of life, productivity, and economy.

The TRANSIMS methods deal with individual behavioral units and proceed through several steps to estimate travel. TRANSIMS predicts trips for individual households, residents, freight loads, and vehicles rather than for zonal aggregations of households. The Household and Commercial Activity Disaggregation (HCAD) Module creates regional synthetic populations from census data and other data. Using activity-based methods and other techniques, it produces a travel representation of each household and traveler. In this paper we describe methods to disaggregate baseline Synthetic Populations from census data. Aging the population and determining its activities are ongoing research areas.

The Intermodal Route Planner involves using a demographically defined travel cost decision model particular to each traveler. Vehicle and mode availability are represented and mode choice decisions are made during route plan generation. The method estimates desired trips not made, induced travel, and peak load spreading. This allows evaluation of different transportation control measures and travel demand measures on trip planning behaviors.

The Transportation Microsimulation executes the generated trips on the transportation network to predict the performance of individual vehicles and the transportation system. It attempts to execute every individual's travel itinerary in the region. For example, every passenger vehicle
has a driver whose driving logic attempts to execute the plan, accelerates or decelerates the car, or passes as appropriate in traffic on the roadway network.

The Transportation Microsimulation produces traffic information for the Environmental Models and Simulations to estimate motor vehicle fuel use, emissions, dispersion, transport, air chemistry, meteorology, visibility, and resultant air quality. The emissions model accounts for both moving and stationary vehicles. The regional meteorological model for atmospheric circulation is supplemented by a model for local effects. The dispersion model is used for directly emitted contaminants and handles both local and urban scale problems. The air chemistry model includes dispersion, but is designed to deal with secondary pollutant production on larger scales.

The following describes each TRANSIMS module in greater detail. The last section describes our interim operational capability approach to TRANSIMS development.

Baseline Synthetic Populations

This section outlines a procedure for creating a baseline synthetic population of households. The individuals in the households are to be used as travelers in the activity-based TRANSIMS model. This population is created from 1990 census data and is aged to the desired date. At this time we consider only the creation of the baseline population without "aging."

The 1990 census data used to develop the baseline population includes the Census Standard Tape File 3 (STF-3) and the Public Use Microdata Sample (PUMS). We create distinct households for each census tract or block group area (we use census tracts, but the same method is used to construct populations for block group areas). The procedure involves four stages. First, for the census tract in question, we group the census summary tables from STF-3 and the corresponding PUMS sample by family and non-family households. Second, for each type of households, we construct a multiway table of all of the demographics available from STF-3. We create households in the third step by random (according to the probabilities in the constructed multiway table) selection of similar households in the PUMS sample. The last stage consists of aging the population to the desired date. A more detailed procedure follows for family households. The procedure for non-family households and group quarters is similar.

The demographic summary tables in STF-3 for family households are (1) race of householder by household class (a combination of household type and presence and age of children), (2) age of householder, (3) family income, and (4) the number of workers in the family. We use these four summary tables along with the corresponding sample from the PUMS to create the five dimensional multiway table of probabilities for each combination of the five demographic variables. Possible methods used to construct the multiway table include iterative proportional fitting, maximum likelihood, minimum chi-square and Bayesian estimation. We use iterative proportional fitting because it is easy to implement and it converges in a few iterations. However, because the PUMS is a sample from multiple census tracts, iterative proportional fitting is not an exactly correct statistical procedure for this construction. Preliminary studies indicate that iterative proportional fitting performs rather well. It may be more practical than using maximum likelihood, minimum chi-square or Bayesian estimation as each of these require either optimization over hundreds of parameters or potentially long running times.

The multiway table constructed for the five family household demographics is sparse. For example, the table for census tract 1.07 from Albuquerque, NM has 5880 cells but the corresponding PUMS contains only 2213 families. Therefore most cells in the constructed multiway table contain zero counts and hence zero probabilities. These zero probabilities could be replaced with small probabilities representing fractional counts. Additionally, demographics other than the five in the constructed table, such as the number of persons in each household, could be imputed from the PUMS. Both imputation and replacing PUMS zero counts with fractional counts do not improve the aggregated family household characteristics created by this method.
Two options exist selecting households from the PUMS. First, the actual number of households in the census tract may be multiplied by the probabilities in the cells of the table and rounded to determine the number of households to be selected with each combination of demographics. Or, the households may be drawn at random according to the probabilities in the multiway table.

We give methods to validate and verify these household construction procedures. Checks of the constructed population of households can be made from existing census data. For example, STF-3 contains a summary table for the total number of persons in family households. Because the total number of people is not controlled in the construction of family households, this summary can be used as one validation of the resulting population. For validation and verification of household characteristics not in STF-3 (for example the number of vehicles by the number of people in the households), a synthetic collection of "census tracts" and corresponding synthetic "PUMS" samples can be constructed. The construction is relatively simple and requires no external sampling. It is accomplished by considering PUMS samples as "census tracts" and combining approximately 20 neighboring PUMS samples. The resulting population of approximately 100,000 people is then sampled to create the "PUMS" for the constructed "census tracts".

We performed both types of validation. We generated populations of households for census tract 1.07 of Bernalillo County NM. The resulting distribution of persons per household compares favorably with the "true" distribution given in STF-3A for that census tract. We created synthetic "PUMS" samples by combining 22 PUMS from the San Francisco Bay area. Using the 22 PUMS as complete "census tracts", we used the household generation procedure to create synthetic family household populations. The joint distribution of persons by household by the number of vehicles compared favorably with that known from the 22 PUMS. The resulting distributions fit the truth very well except for four PUMS selected from the City of San Francisco. In these four "census tracts" we overestimated the number of vehicles in households with few people. This is to be expected because parking problems and a good mass transit system make owning multiple vehicles undesirable in the City. Therefore, the correlation structure in the individual PUMS taken as "census tracts" is different from "census tract" to "census tract". This leads to the overestimation of the number of vehicles in small households in the four "census tracts" from the City. In actual applications of the method on real census tracts or block groups, the census tracts in a PUMS will be more homogeneous than the PUMS used as "census tracts" to create validation PUMS in the Bay Area validation set. Thus, the characteristics of this procedure will be better when applied to real census tracts than the already good results shown in the validation.

**Intermodal Route Planner**

The Intermodal Route Planner generates regional individual activity-based travel demand.

A "load" is a traveler or a commodity. A trip plan is a sequence of modes, routes, and planned departure and arrival times at the origin, destination(s), and mode changing facilities projected to move the load to its activity locations. We assume that travel demand derives from a load's desire or need to perform activities. The HCAD provides the Planner with disaggregated activity demand and travel behavior. The Planner assigns activities, modes, and routes to individual loads in the form of trip plans. The individual trip plans are input to the Travel Microsimulation for its analysis.

Trip plan selection is related directly to a load's desire to satisfy individual (or in the case of freight, corporate) goals. Goals measure a trip plan's acceptability and depend on the load's socioeconomic attributes and trip purpose. Typical goals include cost, time, and distance minimization, and safety and security maximization. The load's objective is to minimize the deviations from these goals.

Mode and route preferences also are important in the Planner. A preference is the inherent partiality or bias a load has for a particular mode or route. Typical preferences include...
departure time, origin-destination directedness, and congestion avoidance. These preferences reduce the Planner's (activity, mode, and route) solution space and offer significant computational savings.

The travel demand problem is formulated as a mathematical program based on a multi-goal objective function. The Planner's solution method has four phases. In the first three phases, performed independently for each load, the individual's travel behavior preferences are adjusted iteratively to satisfy the travel goals. After every load has a feasible, or reasonable, trip plan, the fourth phase superimposes all trip plans on one another in space and time. The network characteristics then are updated based upon the projected interaction of all trip plans. The method then returns to the individual load trip planning phases and the entire process is repeated. The iterative process terminates when either all trip plans are feasible or after some criteria are satisfied.

The trip plans are evaluated with respect to the individual's travel goals. For some loads, all travel goals are satisfied. For others, the plans may not satisfy some or any of the individual's travel goals. In these instances, those plans that minimize the goal deviations will be retained. The result will be trip plans that represent regional travel demand and its activity, mode, and route choice variability.

The Planner accounts for latent travel demand by travel goal deviations and unplannable activities. Goal deviations measure the load's dissatisfaction with the transportation system. If one must travel longer than desired to get to work, the deviation from one's goal travel time represents an unsatisfied demand. If a transportation infrastructure change is considered, its value can be measured by the reduction in the population's travel goal deviations. Unplannable activities are those that the load must forego because of the transportation system's deficiencies. The Planner will attempt to route the load's low priority activities after all high priority activities have been scheduled. These activities will be planned only if the current and subsequent high priority trip plans are feasible. The second latent demand measure is these unplannable low priority activities. Thus, a measure of effectiveness of any proposed facility change is the change in unplannable activities and the resulting trip plans. Loads plan their trips based on activity requirements, knowledge of the transportation system, travel goals, and assumptions about other load trip plans. The travel-planning decision-making process can be achieved iteratively with the Planner and Microsimulation. Feedback loops between both modules mimic individual's real travel process of plan, execute, and replan.

The Intermodal Route Planner model generates activity-based travel demand at the individual load level. By (1) receiving activity demand and travel behavior from the HCAD, (2) providing individual trip plans to the Transportation Microsimulation, and (3) obtaining feedback from the Microsimulation from the trip plan execution, the Planner forecasts regional travel demand over multiple time scales.

Transportation Microsimulation

The TRANSIMS Transportation Microsimulation module mimics the movement and interactions of travelers throughout a metropolitan region's transportation system. For this discussion, traveler refers both to human travelers as well as freight loads, etc. The Intermodal Route Planner provides a trip plan to each traveler that he then attempts to execute on the transportation network. In the process he interacts with other travelers and the transportation system. The combined traveler interactions produce emergent behaviors such as traffic congestion.

The TRANSIMS Transportation Microsimulation models many transportation modes including automobiles, trucks, buses, light rail, commuter rail, bicycles, and pedestrians. Thus, the microsimulation includes roadway, transit, rail, bikeway, and pedestrian networks. In the following discussion, we illustrate the TRANSIMS microsimulation with roadway transportation examples because of its high use, complexity, and importance to air quality. The roadway
network includes freeways, highways, streets, ramps, turn lanes, grades, and intersections (signalized or unsignalized). In executing their trip plans, vehicle drivers accelerate, decelerate, turn, change lanes, pass, and respond to other vehicles and signs and signals. Drivers exhibit behavior between aggressive and passive. Vehicles have weight and acceleration and deceleration characteristics. Analysis requirements determine the necessary microsimulation detail.

Increasing the microsimulation's detail increases its behavioral representation of real transportation systems, but it also increases its computational burden. The representation quality is called the model's fidelity. One goal is to find the minimum computational detail necessary to produce the fidelity needed for specific analyses. This minimum computational detail is called critical complexity. A hybrid technique uses high-fidelity microsimulations for areas where detailed results are needed and low-fidelity, fast-running microsimulations for areas where there is less interest. This hybrid microsimulation requires matching the microsimulations at their boundaries.

We are studying two approaches to the microsimulation. Applications and investigations with the two approaches will form the basis for deciding which approach will be used in later TRANSIMS versions.

In the first approach, the links (roadway segments) of the network representation of the transportation system are a continuous domain. A vehicle can be positioned along any point on the segment. The vehicle driver evaluates the current situation and decides his next action that advances the vehicle to a new position. The vehicle and driver objects retain their characteristics as they move through the network.

The second approach is to use a cellular automata (CA) microsimulation. CA traffic models divide the transportation network into a finite number of cells. For example, each cell could be approximately the length of a vehicle. At each time step of the simulation, each cell is examined for a vehicle occupant. If a vehicle is present in the cell, the vehicle is advanced to another cell according to a simple rule set. A CA microsimulation may be low fidelity, but provides a means to simulate large numbers of vehicles and maintain a fast execution speed. Increasing the fidelity by decreasing the cell size, adding vehicle attributes, and expanding the rule set results in slower computational speed. We will explore the fidelity and performance limits of the CA microsimulation to establish the computational detail necessary to meet the analysis requirements.

The primary Transportation Microsimulation output is the second-by-second location of each traveler. Analysis of the primary output yields additional information such as velocities, accelerations, decelerations, average speeds, average travel times. Plots such as travel time vs traffic density, traffic flow vs traffic density, vehicle positions vs time; and animation such as vehicle movements on network segments also can be generated. Data on positions, velocities, accelerations, decelerations, and vehicle total travel time also is input to the emissions model to determine effluents at spatial locations throughout the region.

**Environmental Modeling**

The purpose of the environmental module is to translate traveler behavior into consequent air quality, energy consumption, and carbon dioxide emissions. The environmental module will use information from the planner and the microsimulation and it will support the analyst's toolbox. It also could provide information on fog to the microsimulation.

Transportation systems play a significant role in urban air quality, energy consumption and carbon-dioxide emissions. Recently, it has been found that current systems for estimating emissions of pollutants from transportation devices lead to significant inaccuracies. When these inaccuracies are coupled to air quality models and limited meteorological data, it is difficult to tell whether the most appropriate path is being taken to achieve air quality goals. Most existing
emission modules use very aggregate representations of traveler behavior and attempt to estimate emissions on typical driving cycles. However, recent data suggests that typical driving cycles produce relatively low emissions with most emissions coming from off-cycle driving, cold-starts, and evaporative emissions. Furthermore, some portions of the off-cycle driving such as climbing steep grades are apt to be correlated with major meteorological features such as downslope winds. These linkages are important, but they are not treated systematically in the current modeling systems.

We plan to develop a system of linked modules including: (1) emissions modules, (2) regional-scale meteorological models, (3) microscale meteorological modules (street-canyon), (4) dispersion and transport modules, and (5) air chemistry (airshed) modules. The development of these modules will build upon efforts already underway at Los Alamos and the larger air quality community. At Los Alamos we have experience with regional scale (urban metropolitan area) meteorological models that can describe airflow and turbulence driven by terrain and land use without the requirement of many local measurements. We have dispersion and transport models that can take the information from the meteorological model and describe the dispersion that occurs in complex terrain. We also have available an airshed model (through collaboration with investigators at Carnegie Mellon University) that uses the meteorological-module outputs with emissions to describe the air-chemistry in a metropolitan area. We currently are developing an appropriate emissions model and a simplified microscale meteorological module.

The emissions module must take the information on individual traveler behavior and produce NOx, CO, aerosol, and hydrocarbon emissions for input to both the airshed and dispersion models. We will have individual vehicle motion available on one-second intervals from the Transportation Microsimulation. We also will have traveler's plans that describe when vehicles are used and when and where they are stationary. In our preliminary emissions module we will integrate an existing modular emissions model, VEHSIME, with existing models for evaporative emissions, cold-start emissions, and high-emitting vehicle emissions. We also will develop a preliminary micro-scale meteorological model based on adding street-canyon eddies to our dispersion module. At the same time we are adding a capability to treat fog and clouds to our meteorological model.

In the longer term the preliminary emissions module will be replaced by a physics and chemistry-based model being developed at the University of Michigan with additional modifications being developed by other studies. We also will develop or acquire an aerosol emissions model to be used for both diesel and gasoline engines. The air chemistry model will be extended to address organic aerosol production.

Interim Operational Capabilities

We visited six metropolitan planning organizations (MPOs) (Dallas-Ft. Worth, Boston, Portland OR, Oakland, Chicago, and Denver). We presented the overall TRANSIMS approach and obtained information on their responsibilities, transportation and air quality issues, processes for carrying out their activities, potential applications for TRANSIMS, their resources, and user feedback on what TRANSIMS should do for them. We are using this and other information to develop detailed requirements and specifications for the TRANSIMS architecture and design.

To provide greater, more timely interaction and feedback from the TRANSIMS user community, we have formulated an approach for TRANSIMS development in which we will develop an interim operational capability (IOC) for each major TRANSIMS module during the five-year program. As each IOC is completed, we will perform a specific case study to confirm the IOC features, applicability, and readiness. We will complete the specific case study with the collaboration of the staff of a selected MPO. This approach should give us quicker feedback from the user community and provide interim products, capabilities, and applications. This approach maintains our goal of an integrated framework for predicting individual travel behavior and for
supporting transportation planners from travel demand forecasting to assessments of transportation system modifications.

A traffic microsimulation will be the first IOC, with the goal of having it ready for testing near the end of 1995. As this IOC is developed, we will work with the North Central Texas Council of Governments (NCTCOG) (Dallas-Fort Worth) to identify studies that the IOC should support. The second IOC will integrate the air quality analysis capability of TRANSIMS with the Transportation Microsimulation. Again, the IOC development will be driven by studies identified as important to the users and will be followed by the specific case studies. We intend to issue subsequent IOCs for the Intermodal Route Planner and for the Household and Commercial Activity Disaggregation modules. These IOCs may be standalone modules, but will be capable of integration with the other TRANSIMS modules. The case studies will demonstrate the integrated package.

We have developed several microsimulation versions that successfully modeled traffic behavior. In the Albuquerque Demonstration, we simulated traffic on two interstates and at their intersection using vehicle objects on a continuous road network. For the IVHS Incident Detection Testbed, we extended this capability to include many lanes, signalized intersections, incidents, and additional driver behavior. Our single-lane cellular automata (CA) simulation exhibited traffic congestion, shock waves, and roadway capacity. An enhanced CA version runs on distributed processors and dynamically redistributes the computational load during execution. Another CA version with multiple lanes and freeway interchanges simulated critical traffic volumes on the 48,000 km of the entire German Autobahn using a 64-node partition of the Intel Paragon parallel processor machine. This broad microsimulation experience places us in an excellent position to take the best of what we have learned to develop the first Traffic Microsimulation IOC.

Because of the encouraging traffic simulations and computational speed of the CA microsimulations, we are extending this method within the first IOC. It will be supported by interim methods for the household and commercial activity disaggregation and for the planner that take aggregated information used in today's methods and recast it into individual trip plans for the microsimulation. Though not necessarily high fidelity, the traffic microsimulation will produce traffic features necessary to support useful transportation studies. The transportation network will include most roadway features, but the detailed implementations are under development. The first IOC will not support transit, pedestrian, or bicycle transportation modes. It will be neither an activity-based nor land-use simulation. Though it will not have all the proposed TRANSIMS features, it also will not be a throw-away prototype. We expect it will be useful for numerous, different studies.

The overall TRANSIMS software framework and architecture had to be established before work specific to the Traffic Microsimulation IOC could begin. This encompassing planning and design effort has required considerable time, but should result in a flexible, robust structure for research and development of future TRANSIMS capabilities. The methods of the later IOCs should be implemented more quickly within this architecture without significant design changes. To provide computational speed and an operational capability available to end users in the near term, we are developing the first IOC to be distributed with parallel computation on a network of SUN workstations.

The case study done in conjunction with the IOC will provide timely interaction and feedback from the TRANSIMS user community, will identify requirements for features that may or may not be included in the IOC, and will demonstrate how TRANSIMS can be used, even with the IOC limitations. Though we will complete the case study after the IOC is ready, we will design the case study as we develop the IOC. The case study and the IOC depend on one another. The case study's scope will depend on the capabilities and performance of the IOC. To the extent possible, the interim operational capabilities will be driven by the case study requirements. We will test the IOC with subsets of the case study.
We do not expect the case study to be just another demonstration. It should confirm the IOC features, applicability, and readiness through a application of the capabilities to real world problem. In addition the IOC should be capable of other similar studies in other areas. Until we have evaluated the IOC's computational performance, we cannot establish the case study's scope, but we do not expect it to be a complete regional traffic simulation. The case study will not be an integrated analysis with iterations between the intermodal route planner and the microsimulation. It also will not be an air quality analysis.

The Traffic Microsimulation IOC development has spun off several research issues. We are investigating the critical complexity of the cellular automata microsimulation to determine the minimum modeling detail that produces the traffic behavior necessary for useful transportation system analysis. At the same time, we are developing methods and algorithms that maintain or enhance the CA's computational performance as complexity is added. As noted previously, distributed computing is a research area where we are trying to gain the computational edge. In most studies the Traffic Microsimulation IOC will be capable of producing billions of pieces of data. To be useful, this calculational data must be stored, processed, displayed, analyzed, and presented in reports. We will be studying techniques to handle these data efficiently and effectively.