Dynamic User Equilibrium How-To

This document provides basic information on how to configure the various tools available within the TRANSIMS toolbox to develop a model simulation that achieves a dynamic user equilibrium condition using the Microsimulator to simulate person and vehicle movements on a network with travel plans generated by the Router. The How-To specifically outlines the typical TRANSIMS assignment process which involves three iterative phases known as: Router Stabilization, Microsimulator Stabilization, and Dynamic User Equilibrium Convergence.

Revision History

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1.0 Introduction

TRANSIMS is a suite of tools that can be combined in a variety of ways offering great flexibility to model a wide range of analytical needs. The overall software package includes a population synthesizer, activity generator, location and mode choice tools, time-dependent path building and multi-modal network simulation. It also includes numerous tools for data conversion, processing, analysis and graphical presentation of model results.

TRANSIMS models person trips made by households and vehicle trips made by other entities between link-based activity locations, using specified travel modes, on a second-by-second basis during the course of a 24-hour time period. The general modeling process centers on the concept of iterative feedback between model components. Each feedback iteration adjusts the activity patterns, activity locations, travel modes, travel schedules, and/or travel paths of a select number of individual travelers. Network performance stabilization and traveler-based equilibrium convergence concepts are used to manage the iterative process and establish stopping criteria.

The TRANSIMS modeling process is focused on a dynamic traffic assignment using micro-simulated vehicle movements and time-dependent network attributes (e.g., traffic signals, lane-use and parking restrictions, parking and toll costs). The Router generates minimum impedance paths through the network for individual travelers (travel plans) and the Microsimulator implements the plans and calculates the system performance measures.

The Microsimulator is a true capacity constrained process, so it is helpful if the travel plans generated by the Router and input into the Microsimulator are less than or equal to the capacity of each roadway. Over loading the network causes cascading queues that can make the performance results totally unrealistic. It also takes considerable computer processing time for the Router-Microsimulator process to recover from gridlock conditions which would likely occur if travel plans from an initial Router run were simulated immediately with the Microsimulator.

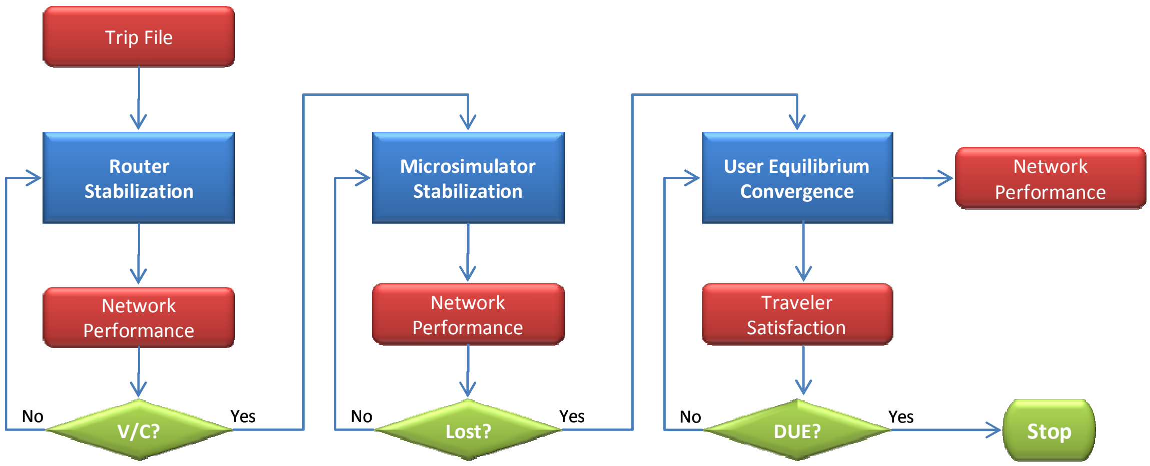
An effective way of initializing the network performance and creating a set of travel plans that the Microsimulator can reasonably simulate is to apply a Router Stabilization process prior to stabilizing the simulated network performance and iterating to a dynamic user equilibrium solution. In other words, a typical TRANSIMS assignment process involves three iterative phases: Router Stabilization, Microsimulator Stabilization, and Dynamic User Equilibrium Convergence.

The Router Stabilization phase develops and distributes the travel paths on roadways based on traditional volume-delay functions like the Bureau of Public Roads (BPR) formula. Other volume-delay functions such as conical or exponential functions can also be selected by the user. Once the trips are distributed and the volume-to-capacity ratios are within reasonable ranges (i.e. less than 1.2), the second iterative feedback phase begins.

This Microsimulation Stabilization phase focuses on minimizing the impacts of bottleneck locations and "excessive" congestion experienced by travelers. This phase involves targeted re-routing of trips traveling through congested areas of the network, network refinements to improve operations (e.g., pocket lanes, lane connectivity, transit schedules, etc.) and adjustments to signal timing plans based on intersection demand. Feedback iterations continue until most travelers are able to complete their trips in a reasonable amount of time.

The Dynamic User Equilibrium condition is achieved when the path travel times on utilized routes connecting an origin-destination (OD) pair are equal and minimal for all OD pairs and for all time increments. The Dynamic User Equilibrium phase therefore focuses on minimizing the travel times or generalized costs of individual travelers by comparing the path used in the simulation to the minimum impedance path based on the network performance from the simulation and rerouting and simulating plans that can be significantly improved.

The figure below illustrates the typical three-phase TRANSIMS model simulation sequence.



The following sections describe each phase in more detail and illustrate the primary TRANSIMS tools used in each. A brief description of the task performed by each tool is also provided.

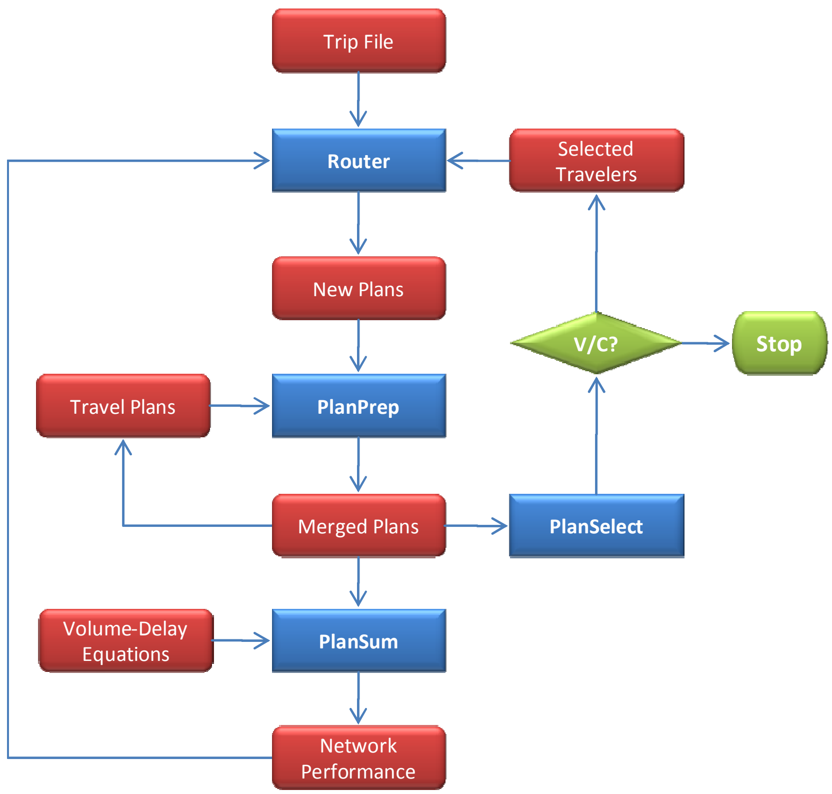
2.0 Creating TRANSIMS Demand and Supply

Before running a Router Stabilization routine it is assumed that TRANSIMS highway and/or transit networks have been developed using the TransimsNet and TransitNet utilities. Please refer to the Highway Network How-To and Transit Network How-To and corresponding user manuals for more detailed information on these processes. It is also assumed that regional travel demand has been developed using TRANSIMS activity-based and/or trip-based tools. Developing activity-based demand requires the use of the population synthesizer and activity generator or another existing activity-based demand model. Please refer to the Population Synthesizer How-To and Activity Generator How-To and corresponding user manuals for more detailed information on these processes. Most typical TRANSIMS applications use trip-based zonal travel demand matrices extracted from a regional travel demand model. The process for converting zonal trip matrices into trip lists that can be used in TRANSIMS is described in the Trip Table Conversion How-To and ConvertTrips user manual.

3.0 Router Stabilization

As described in the introduction, the Router Stabilization process is utilized to effectively provide a "warm-start" for the subsequent application of the Microsimulator. The underlying concept is that volume-delay functions can first be used to establish and stabilize travel plans and network travel times before using the Microsimulator, which has a relatively long run time compared to the Router. In essence the Router Stabilization is used to distribute traffic in a logical fashion using traditional planning methods such as the BPR formula prior to initiating the microsimulation.

The figure below illustrates the typical Router Stabilization routine which utilizes the TRANSIMS Router, PlanPrep, PlanSelect and PlanSum utilities.

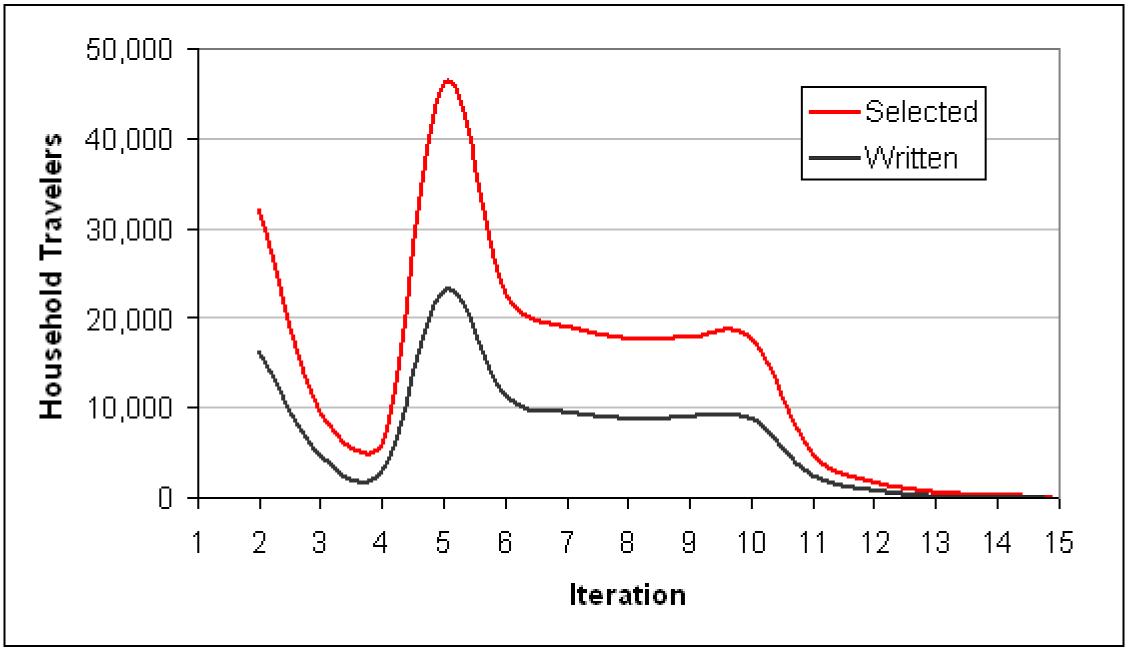


In the first iteration the Trip File is input to the Router to develop the set of outputs called New Plans where the all-or-nothing assignment uses free-flow travel times. The plan file (a list of links or nodes traversed in the path) contains the origin, destination, trip start time, trip end time, and trip path for each household traveler. In this first iteration, the PlanPrep step would simply create the Merge Plans and Travel Plans which at this point are both identical to New Plans. In the next step, the PlanSelect utility is used to identify which travelers should be re-routed based on user-defined selection criteria. In this case, the re-routing criteria could be to select household travelers who traverse links with a V/C ratio say greater than 1.2. Finally, the PlanSum utility is used to apply the volume-delay equations to derive the network performance using 15-minute (or other user-specified time increment) link volumes and capacities.

In the second iteration, the Router develops plans using link travel times from the first iteration. However, only a sub-selection of household travelers are routed, so the resulting New Plans set is smaller than the full set of regional plans in the file Travel Plans. PlanPrep is then used to update the Travel Plans file to incorporate the New Plans for the re-routed travelers. PlanSelect is once again executed to identify those travelers still traversing links with V/C ratios greater than 1.2. Then PlanSum is again run to derive the new links costs given that some travelers will have shifted to new paths. As the iterative process continues, fewer and fewer households should be selected and the Travel Plans file will stabilize and require fewer and fewer updates (using PlanPrep) as the number of travelers satisfying the selection criteria is reduced.

TRANSIMS implementations conducted to date have demonstrated that using a selection criteria set that is modified during the iterative process most efficiently reduces the number of selected travelers. In the example illustrated below, iterations 2 through 4 use a V/C selection criteria of 2.0, iterations 5 through 10 use a V/C selection criteria of 1.5, and finally iterations 11 through 15 use a travel time difference where current iteration travel times are compared to travel times from the previous iteration.

Variables	**Iterations**		
	2 - 4	**5 - 10**	**11 - 15**
Select_VC_Ratios	2.0	1.5	-
Percent Time Difference	-	-	10
Minimum Time Difference	-	-	2
Maximum Time Difference			45
Selection_percentage	50	50	50
Maximum_percent_selected	10	10	10
Select_time_periods	all	all	all

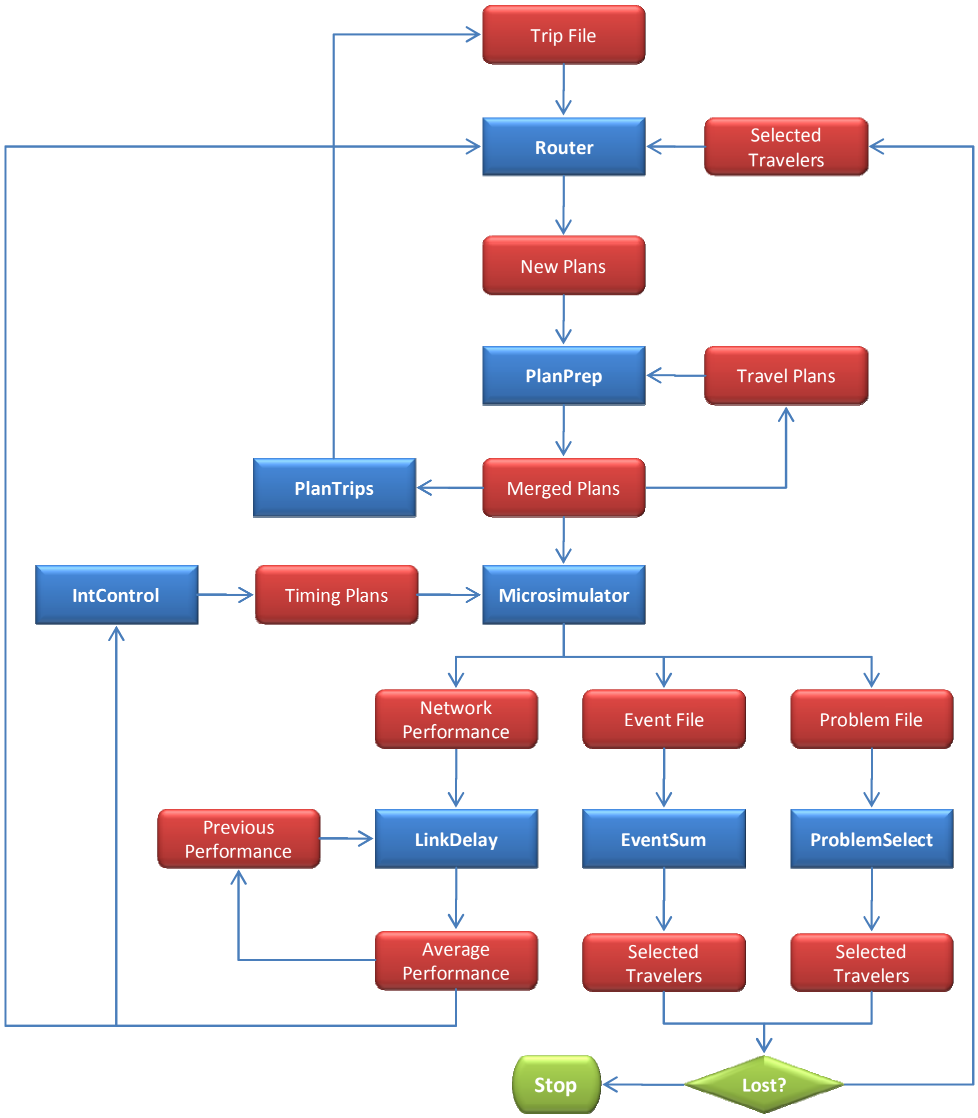


In the example shown above, at iteration 2, roughly 30,000 households were selected for re-routing. However, only half of those selected were written to the household list that identifies the households to be resimulated, since the selection percentage (user-specified parameter setting) is set to 50%. Applying the Router Stabilization process using the iterative scheme illustrated in the table above, there are less than one-hundred households selected for re-routing by the final iteration. At this point the iterative Router procedure can be considered to be stabilized and the Microsimulator Stabilization can be initiated.

4.0 Microsimulation Stabilization

The Router Stabilization phase produces a set of Travel Plans that can be used as input in the Microsimulator. However, the travel times derived by use of the volume-delay functions using PlanSum in the Router Stabilization phase may be different than the travel times derived using the Microsimulator to simulate second-by-second vehicle movements throughout the day. Therefore, another iterative process is required to minimize the impacts of bottleneck locations and “excessive” congestion experienced by travelers and to re-route travelers whose trip duration time in the Travel Plan file is significantly different from the travel time calculated from the microsimulation.

The figure below illustrates the typical Microsimulator Stabilization routine which utilizes the TRANSIMS Router, PlanPrep, PlanTrips, Microsmilutor, LinkDelay, EventSum, and ProblemSelect utilities.



In general, the iterative Microsimulation Stabilization scheme is comparable to the Router Stabilization scheme. However, in this case the Microsimulator is utilized to produce link volumes and times/costs instead of PlanSum. Another substantive difference in the Microsimulator Stabilization is the use of the LinkDelay utility. The LinkDelay program is used to average the link delays from each iteration to mimic the Method of Successive Averages (MSA) approach that is typically applied in aggregate four-step travel models. In TRANSIMS implementations conducted thus far, the use of averaged and/or weighted averaged link delays has been found to reduce the number of iterations required to achieve stabilization.

In the Microsimulation Stabilization, some different utilities are executed to select travelers for re-routing. Note that in the Router Stabilization process, the utility PlanSelect is used to identify which household travelers should be re-routed based on a user-specified selection criteria such as V/C ratios and/or travel time differences. PlanSelect may also be used to perform the traveler selection in the Microsimulator Stabilization feedback. However, the current best practice techniques use the utilities

EventSum and ProblemSelect which read outputs from the Microsimulator to identify the household travelers for re-routing.

EventSum uses schedule constraints from a trip or activity file to adjust the start times in the plan file to enable the trip to reach the destination on-time given simulated travel times and generates a list of households with significant differences between scheduled and actual travel time for re-routing. ProblemSelect also creates a household selection file based on time-of-day, problem link, and/or problem type that can likwise be used as input to the Router.

As with the Router Stabilization process, the Microsimulator Stabilization process iterates until an acceptably small number of households are selected by either EventSum, ProblemSelect and/or PlanSelect. In most implementations conducted to date, attempts are made to iterate the Microsimulator Stabilization until very few households and/or problems are selected, or such as less than 1% of the total household travelers.

5.0 Dynamic User Equilibrium

The third and final phase, Dynamic User Equilibrium, focuses on minimizing the travel times or generalized costs of individual travelers by comparing the path used in the simulation to the minimum impedance path based on the network performance from the simulation and using this information to determine convergence.

In a traditional user equilibrium model, a series of all-or-nothing assignments are built and combined in order to minimize the vehicle hours of travel for all travelers. At the beginning of the process the paths are built based on free flow speeds. This results in link volumes that are converted to congested travel times using volume-delay functions. These new travel times are used for the next set of all-or-nothing assignments. The vehicle hours of travel from the first assignment are compared to the vehicle hours of travel from the second assignment to calculate the combination of the two assignments that minimizes total vehicle hours of travel. The loaded travel times calculated from the combined volumes are used for the next all-or-nothing assignment. The process continues until the factor that combines the new volumes with the previous combined volumes is very small. With some important exceptions, TRANSIMS can mimic this process by chaining together the programs available in the TRANSIMS toolbox in specific ways.

An all-or-nothing assignment is equivalent to running the Router for all trips in the trip file. The link delay file provides the input link travel times and volumes from the previous iteration. The new link volumes and travel times can be calculated using the PlanSum program with volume-delay functions or by running the Microsimulator. The new travel paths can be compared to the previous combined paths using PlanCompare. This program calculates a user equilibrium convergence statistic that is similar to the traditional combination factor described above.

One key difference is that TRANSIMS is limited to one path for each traveler. In a traditional aggregate model, the resulting volumes on the links are comprised of fractional contributions of multiple paths for each traveler. For instance, if there is one trip between two points and there are two paths of equal travel time, a traditional model will assign 0.5 trips to one path and 0.5 trips to the other path. This might be interpreted as on even days the traveler takes path #1 and on odd days the traveler takes path #2. This is all very logical, but it doesn't work within TRANSIMS given the disaggregate nature of the tools. The Microsimulator needs to simulate individual vehicles traveling on a given path on a given day.

Because TRANSIMS simulates individual vehicles, the user equilibrium approach needs to be implemented in a different way. This is partially due to the fact that the Microsimulator is often unable to simulate the types of over capacity conditions generated by all-or-nothing assignments. When the demand exceeds the Microsimulator's ability to process vehicles, queues form that can quickly cascade onto other links and result in system gridlock. The travel times generated by the Microsimulator under these conditions tend not to be useful for making decisions about which travelers to re-route. They simply move the problem to another location on the network.

Rather than combining small percentages of each set of paths, TRANSIMS selects some travelers from a new "improved" plan file to combine with an original plan file. The combined paths should eventually minimize the travel time for each traveler and generate a distribution of traffic that the network can accommodate. This is in essence a cooperative learning process where a small number of travelers change their path and all other travelers continue as they did before. Based on the net result, another set of travelers is provided with an opportunity to respond by changing their paths.

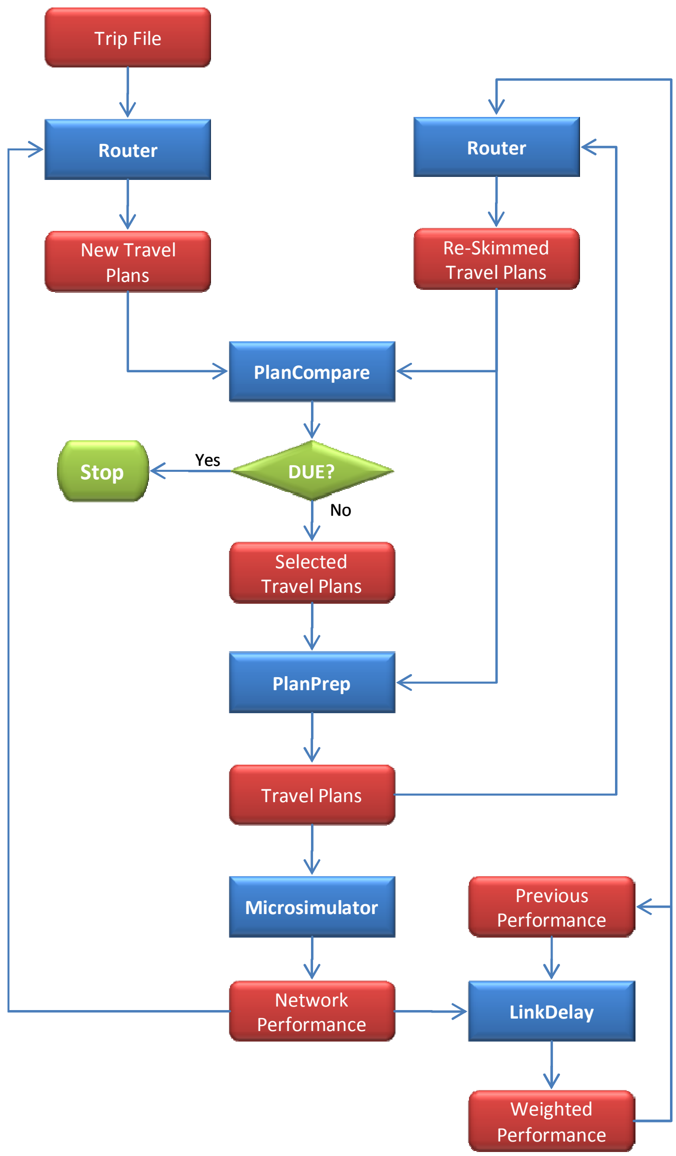
The key to the TRANSIMS assignment process is the strategy used to identify which selection set of travelers to update for the next simulation. Many different approaches have been evaluated and found useful at various points in the process. Early in the process when the loaded travel times are not well defined, travelers may be selected based on differences in travel time/cost from one iteration to the next, or based on volume to capacity ratios. Using volume-delay functions rather than a full simulation to estimate congested speeds is often more effective in initializing the traffic patterns. This is the rationale for applying the Router Stabilization routine.

Once the traffic is more realistically distributed, the simulated travel times provide a better estimate of travel times because these times reflect the "real" impact of vehicle interactions on the roadway, queue spillbacks, and traffic controls, which link-based volume-delay functions are insensitive to. Several targeted feedback iterations are often useful in addressing some of the location or time of day specific problems identified by the Microsimulator that the volume-delay functions will not resolve during the Router Stabilization. This is the rationale for applying the Microsimulator Stabilization routine.

It is at this point that the Dynamic User Equilibrium process can be used to start refining the path choice of individual travelers. The path travel time before the simulation is compared to the path travel time after the simulation to identify travelers whose routed travel time is significantly different from their simulated travel time. A subset of travelers with large differences can then be re-routed and re-simulated until the differences are diminished.

This is an efficient method for finding and fixing the big differences, but it is not a true user equilibrium test. A true equilibrium test requires a comparison of the simulated travel time to the best path for each traveler (the minimum impedance path). Determining the travel time on the best path for each traveler requires an all-or-nothing routing of all travelers based on the simulated travel times by time of day. Comparing this travel time to the simulated travel time on the original path determines how close the simulation was to a user equilibrium solution. If the differences are significant, the simulation has not converged. The travel plans for a subset of travelers with large differences will replace the original path for the next simulation.

The figure below illustrates the typical Dynamic User Equilibrium routine which utilizes the TRANSIMS Router, PlanCompare, PlanPrep, Microsmilutor, and LinkDelay utilities.



The Microsimulator stabilization process was used to clean the network and adjust the link travel times to account for vehicle interactions, travel lanes, and traffic controls. At the end of the process, there were relatively few simulation problems and the overall network performance was reasonable.

This does not, however, mean that each traveler was assigned to a path that satisfies the user equilibrium condition. The equilibrium convergence process re-routes all of the travelers using simulated travel times and compares the trip times of these paths to the original trip times to determine if the total travel time is the same for each traveler. If the times are significantly different, the new plan qualifies to replace the old plan in the full plan set (Travel Plans).

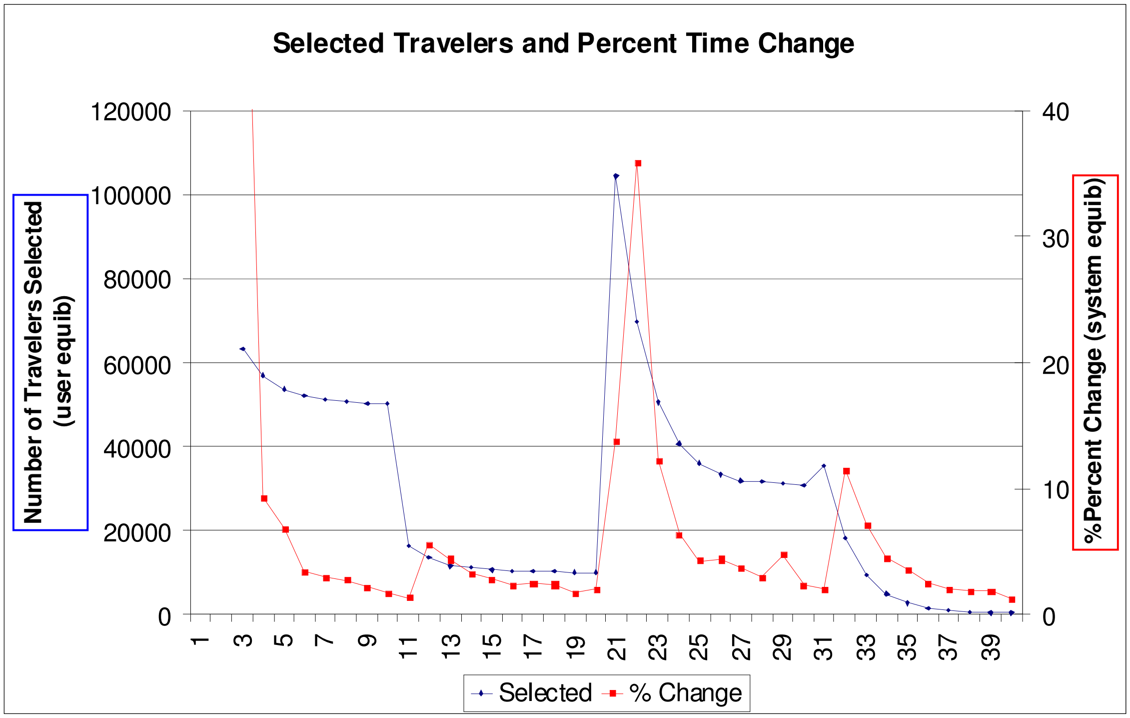
The primary difference between the Dynamic User Equilibrium Convergence process and the Microsimulator Stabilization process is the use of the PlanCompare program. In the Router Stabilizer and Microsimulator Stabilizer processes, the PlanSelect program was used to select a subset of travelers to re-route. In the Dynamic User Equilibrium Convergence process, all of the travelers are re-routed using the latest travel times from the Microsimulator. The PlanCompare program then compares the new travel plans to the travel plans that were previously used as input to the Microsimulator. If the travel time for a given traveler is approximately the same in both plan files, the traveler could not improve their travel time by changing paths and would therefore satisfy the user equilibrium condition. If the times are different, the traveler has not achieved user equilibrium and would therefore qualify for selection. Once again, only a subset of the qualified plans are included in the selected plan file in order to maintain the overall stability of the simulation.

The cost of the minimum impedance path is based on re-routing all of the trips using the Microsimulator network performance results. The generalized cost of the current path is calculated by re-skimming all of the travel paths that were input to the Microsimulator using the weighted average network performance data. Since only a portion of the plans are updated during each iteration, the re-skimming process ensures that the comparison of differences is based on the latest network performance data rather than the network performance at the time the path was originally built.

6.0 Evaluating D.U.E. Convergence

The Dynamic User Equilibrium Convergence process would be iterated until a stopping criteria is achieved. Early implementations relied on the number of travelers selected as a means for determining quit criteria, assuming that a user equilibrium condition had been achieved when less than 2% of the total regional household travelers were selected for re-routing. This traveler selection criterion along with a system measure such as total vehicle hours of travel (VHT) would be used to establish the user equilibrium and system convergence.

The figure below illustrates how the number of travelers selected for re-routing was reduced to near zero at iteration 40 of the model system. In this example Router Stabilization was conducted from iterations 1 to 20, with iterations 1 to 10 applying a time difference selection criteria and iterations 11 to 20 applying a V/C ratio selection criteria. Microsimulation Stabilization was conducted from iterations 21 to 30, and the User Equilibrium phase was conducted from iterations 31 to 40.

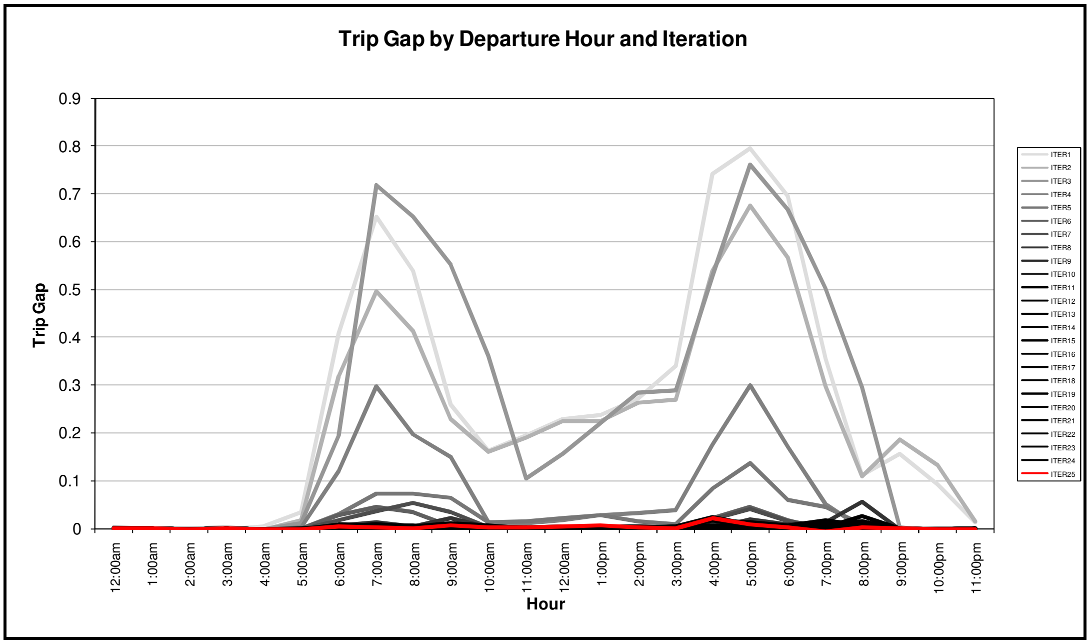


From Burlington Implementation Final Report (see Implementations materials for more details)

The PlanCompare program can be used to report a variety of gap statistics that can be used to define a more typical and quantitative D.U.E. convergence quit criteria. The statistics that are most frequently used are the total time difference or the average absolute difference between the travel times or generalized costs of the two plans for each traveler. The range of the 85th percentile differences are also useful in assessing convergence.

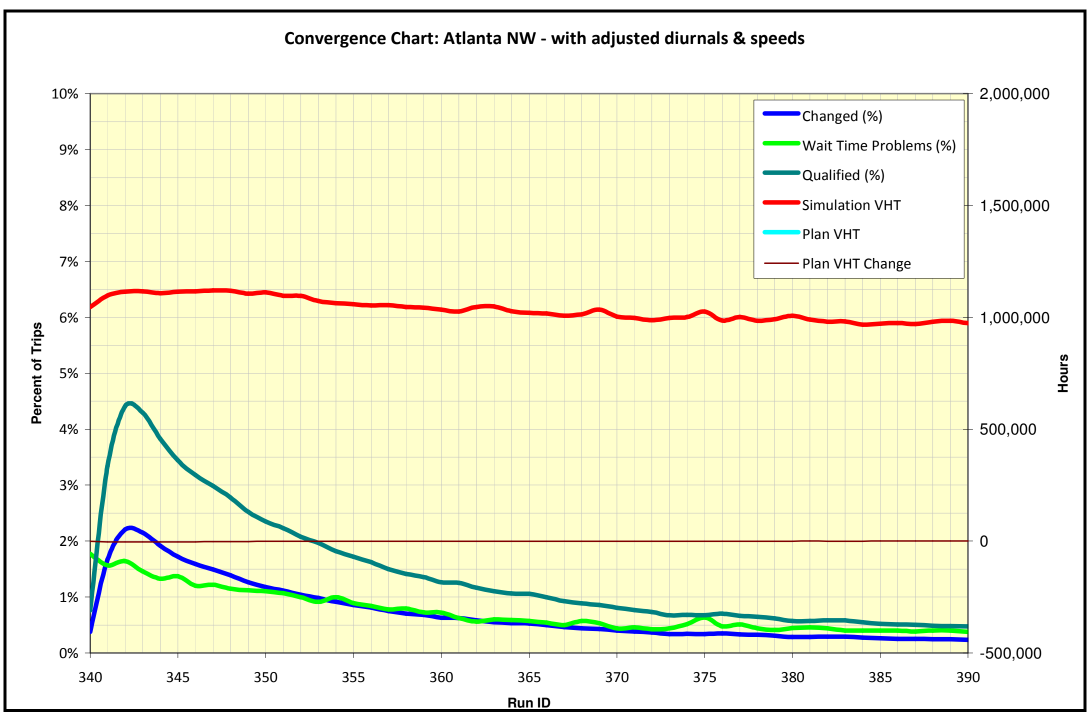
Recent work in Sacramento examined a disaggregate Trip Gap measure for evaluating user equilibrium convergence. This disaggregate measure is calculated at the trip level, and captures the difference between the trip cost using the most recent equilibrium-weighted path and link costs and the trip cost using the shortest path and equilibrium-weighted link costs. This difference is summed across all trips and normalized. The measure is similar in conception to the link-based relative gap measure used in traditional aggregate assignment, but uses the disaggregate information provided by TRANSIMS. Note that for each trip, the trip costs depends on the trip departure time, because trip cost is derived from time-dependent link costs.

The figure below illustrates the calculation of the Trip Gap measure at an hourly temporal resolution (based on departure hour), and across every assignment iteration (1 to 25). The figure clearly shows that the Trip Gap measure varies significantly by hour of day, and also changes with each successive assignment iteration with the final iteration shown in red.



From Sacramento DaySim-TRANSIMS Final Report (see Implementations materials for more details)

In recent work in Atlanta, the number of travelers with significant time differences (percent qualified), the total vehicle hours of travel, and the number of simulation problems (percent wait time problems) are the primary performance measures used to determine the user-equilibrium and system convergence. The following plot shows how these three measures vary over the course of the last 50 model iterations.



From Atlanta Peer Review Read Ahead Report (see Implementations materials for more details)

The intent of this How-To is to provide guidance on how the TRANSIMS tools can be configured and used in sequence to yield a dynamic user equilibrium convergent solution. The convergence measures individual model developers will select to evaluate user equilibrium and system convergence will likely depend on the questions being researched, the size and scale of the microsimulation, the model system runtime, and the level of congestion in the network.

7.0 Description of Relevant TRANSIMS Tools

Router - The Router generates travel plans for household trips and tours that are connected by walk, drive, ride, transit, park-&-ride, kiss-&-ride, and bicycle modes. It builds travel plans from specified origins to specified destinations at specified times of day using a specified travel trip mode. Alternatively, the Router can selectively build paths from specified origins, to specified destinations, and at specified times of day, using specified modes. The Router can also be implemented using an incremental capacity restrained assignment algorithm. The output is an updated plan file based on new skims.

PlanSum - PlanSum summarizes the link demands generated by the Router, and applies volume-delay equations to estimate link travel times. The program produces link volumes, link delays, and turning movements by time-of-day. In addition, it produces zone or district trip tables and skim files by mode and time-of-day.

PlanCompare - PlanCompare compares two plan files and selects the plans that have significantly different travel times or generalized costs. Then it generates convergence statistics and distribution charts by time-of-day.

PlanPrep - The selected plans are input to PlanPrep, which manipulates plan files by sorting, selecting or merging for future use by Microsimulator. PlanPrep generates distribution reports of path and travel time changes.

LinkDelay - This program merges, averages, and/or converts link delay files and smoothes the link delays between time increments.

Microsimulator - The Microsimulator simulates the movement of vehicles in the network on a second-by-second basis as they follow their travel plans defined by the Router. The outputs of the Microsimulator are performance statistics, the ability to track individual travelers, and summaries of events.

PlanSelect - This program selects plans based on traveler ID, time-of-day, activity location, parking lot, transit stop, transit route, V/C ratio, travel time ratio, coordinates, vehicle types, subarea polygon, and path node or link sequences to ultimately create a selection file that can be used as input to the Router in subsequent iterations.

PlanTrips - PlanTrips generates a trip file from a plan file and uses the time constraints from the original trip file and the trip duration from the plan files to update the trip start and end times in the new trip file and optionally the new plan file. The program adjusts the plan start and end times for each leg of a given traveler to remove overlapping travel legs and compress schedule gaps.

EventSum - EventSum summarizes the differences between scheduled and actual start times, arrival times, and travel times and generates difference distribution reports and data file by time period. The program generates travel time statistics for individual traveler trips and merges these data with the results of a previous run to quantify and summarize the travel time impacts of a given alternative on individual travelers. Travel times recorded in the plan file are then updated based on the actual travel times generated by the Microsimulator. EventSum uses schedule constraints from a trip or activity file to adjust the start times in the plan file to enable the trip to reach the destination on-time given simulated travel times and generates a list of households with significant differences between scheduled and actual travel time for re-routing.

ProblemSelect - This program creates a selection file that can be used as input to the Router. ProblemSelect selects problems based on time-of-day, problem link, and/or problem type.

IntControl - Traffic signal data are initially synthesized by and subsequently refined using the IntControl program. During the assignment process, the signal timing plans are periodically updated based on the turning movement demands at the intersection.