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Improving the Application of Existing Methods to Advance Transportation Operations

- Two Case Studies on the Application of Microsimulation in Combination with Travel Demand Models

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Introduction

This report describes two case studies for applying simulation models in combination with travel demand models as part of the FHWA project "Improving the Application of Existing Methods to Advance Transportation Operations."

The main problem of interfacing travel demand models with microsimulation models is that the demands produced by demand models are not as capacity constrained as they need to be for use in microsimulation models. Demand models have a flexible capacity constraint, the traffic assigned to a facility during the analysis period can exceed its capacity by several orders of magnitude. Microsimulation models have a "storage space constrained capacity constraint", the traffic assigned to a facility during the analysis period cannot exceed its capacity plus its ability to store the excess queues of vehicles. The result is that the microsimulation model produces unrealistic facility performance estimates when it is given unrealistic calibration year and future year demands.

The solution is to adjust the travel demand model demands to more realistic levels that reflect the physical limitations of the network (the flow capacity and the storage capacity). The traditional approach described in the first case study performs these adjustments outside of the travel demand model. The second case study is an advanced approach that makes many of the demand adjustments within the demand model.

Objectives

The overall goal of this project is to improve the way existing analysis tools are used to plan for operations in the planning process. The specific objective is to develop reference and resource materials that enable planners and operations professionals to use existing transportation planning and operations analysis tools and methods in a more systematic way to better analyze, evaluate, and report the benefits of needed investments in transportation operations.

This report documents the benefits as well as the pros and cons of integrating travel demand forecasting models with microsimulation tools for freeway operational studies.

Statement of the Problem

Current travel demand models and planning analyses may underestimate the day-to-day benefits of operational improvements targeted at the reduction of vehicular traffic congestion. Underestimation of the on-going benefits of relieving congestion results in a bias in the transportation planning and programming process in favor of capital improvements which increase capacity over operational improvements.

Travel demand forecasting models are usually validated for regional characteristics. For example, the Contra Costa County Transportation Agency's (CCTA) model which was used for Case Study II in this document includes a detailed zone system throughout Contra Costa County and the Alameda County portion of the Tri-Valley area. It was not designed for corridor analysis or sensitivity analysis of various freeway management strategies.

In general, travel demand forecasting models have the following limitations:

Neglect vehicular lane changing behaviors

Travel demand forecasting models usually do not account for reductions in actual roadway capacity due to weaving, merging and diverging characteristics. Even though the link capacity can be adjusted in travel demand models, the adjustment (reduced link capacity) can only be applied throughout whole links with a fixed averaged number. In reality, these adjustments may not be appropriate for the traffic operations.

Neglect roadway characteristics: grades, curvatures (interchanges)

Travel demand models generally contain lesser level of detail of roadway characteristics such as grades, curvatures, etc. These characteristics usually influence traffic operations strongly, especially at freeway interchanges.

Neglect congested roadway conditions: peak hour spreading, traffic diversion

By definition, in a travel demand model where travel demand (assignable trip table) is greater than the capacity of roadway systems, demand will still be assigned onto the network even though this results in links with volume to capacity ratios greater than 1.00. However, these v/c ratios which should represent queuing and potential bottlenecks, do not affect upstream links. In other words, in a travel demand model traffic cannot "back up" from an overcapacity link into an upstream link and vehicular route choices are not affected by the downstream congestion unless the congested link is part of the route.

Because of these limitations of travel demand forecasting models, it is essential to apply microsimulation models for evaluating the full benefits of freeway management strategies.

Case Study #1 – Traditional Application of Travel Demand Models and Microsimulation Models

This first case study involves a conventional application of a microsimulation model in combination with a travel demand model.

The travel demand model is used to estimate existing and future origin-destination (OD) demands for a freeway section. The calibration year OD was then adjusted to match the calibration year counts for the freeway. These calibration year OD adjustments were then carried forward to the future year forecasts and applied to the future year OD trip tables produced by the demand model. The microsimulation model is applied using the adjusted calibration year and future year OD tables.

The freeway performance is estimated exclusively using the microsimulation model. The demand model performance predictions are not used.

Project Description

The goal of the Alameda County Central Freeway Study was to prioritize a funding sequence among various combinations of all potential freeway improvement projects in the jurisdiction.

The Alameda County Central Freeway Study evaluated 10 miles of the I-880 freeway from the Davis Street (SR-112) interchange to Whipple Road and 5 miles of I-238/I-580 freeway from 164th Street to East Castro Valley Boulevard (Exhibit 1 shows the freeway network in the study area). The Alameda County Congestion Management Agency's (ACCMA) official travel demand model (developed in Cube) was used to forecast future travel demand in the corridor, including ramp and mainline volumes on the freeways. Paramics microsimulation software was selected for producing measure of effectiveness (MOE) results of freeway operations for each alternative. Traffic conditions of morning and afternoon (AM and PM) peak hours were evaluated.

Surface streets were not modeled in the microsimulation model. Surface streets were included only in the ACCMA Cube travel demand model. Two freeway interchanges and twenty ramp junctions (on-ramps and off-ramps) were included in the microsimulation network.

Methodology

The approach used is outlined below:

1. Forecast base and future year regional travel demand models,

2. Extract sub-area networks,

3. Produce origin-destination (OD) matrices,

4. Apply OD matrices (trip tables) to microsimulation models,

5. Validate and calibrate the base year microsimulation models, and

6. Create the future base and project microsimulation models.

Exhibit 2 shows the flow chart of this traditional method. The details of these steps are explained in the following paragraphs.

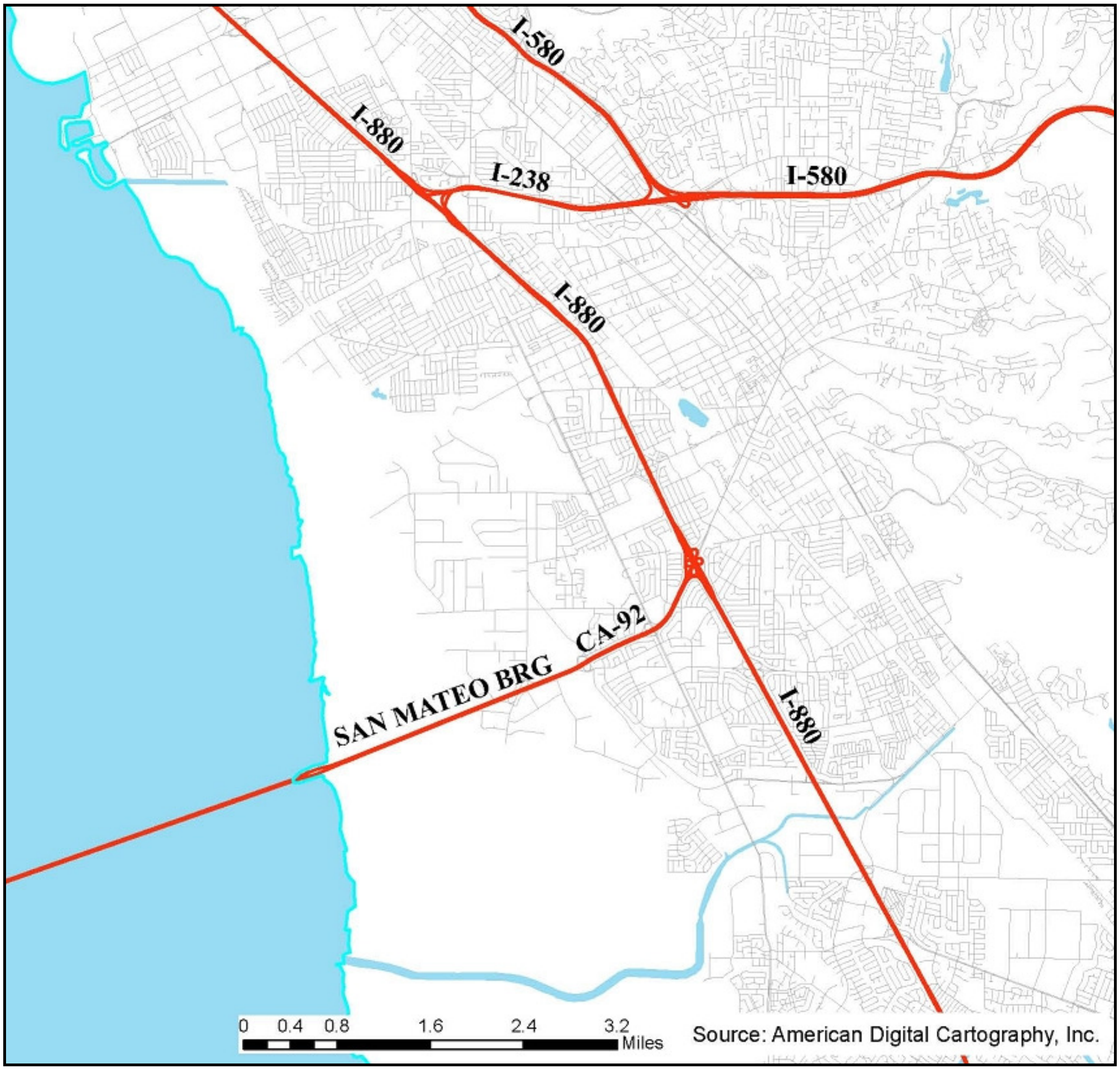

Exhibit 1: Alameda County Central Freeway Study Area

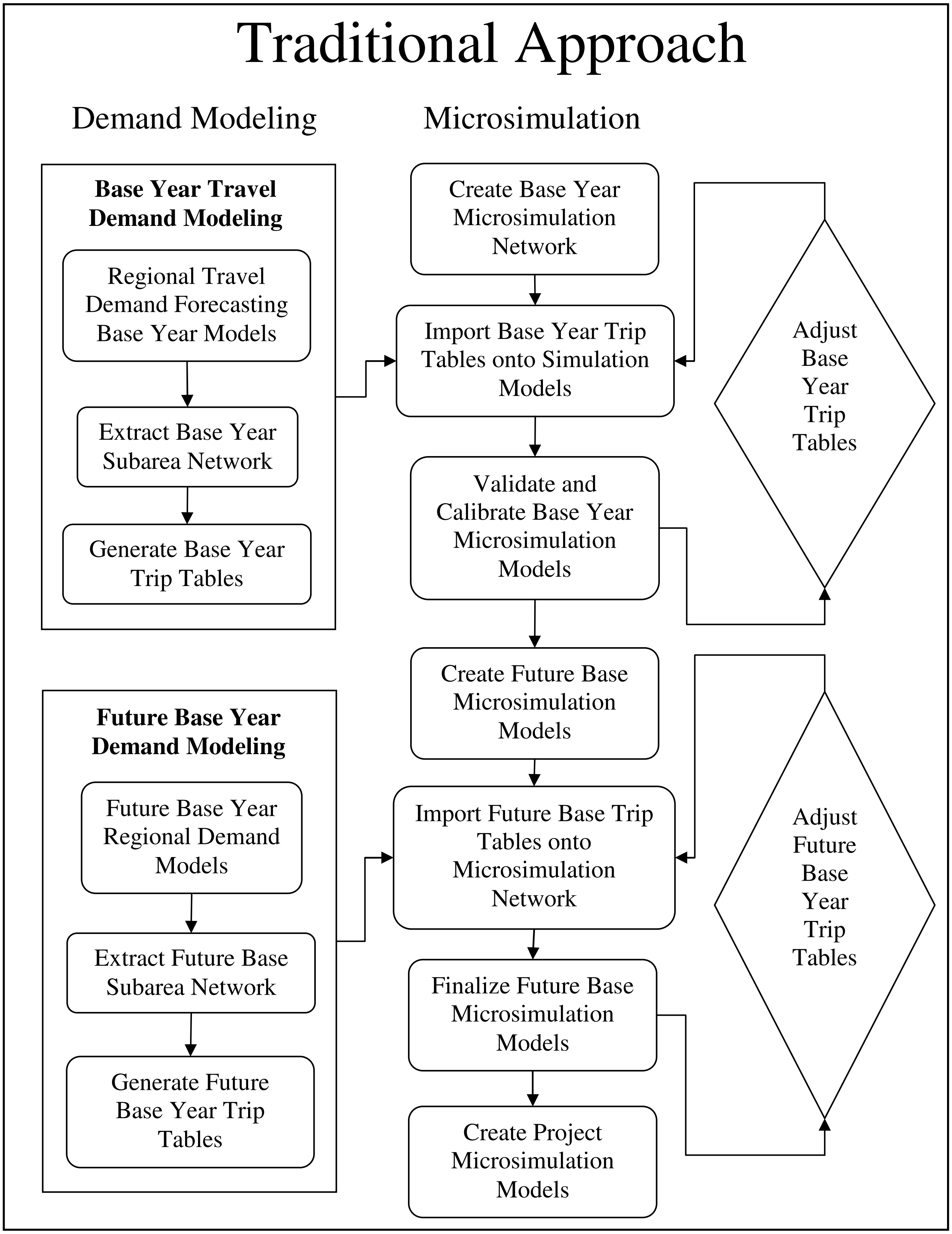

Exhibit 2: Traditional Approach Flow Chart

Prepare the base year OD matrices

The base year travel demand model for this case study contained the land use data for 2005. The model's loaded 2005 network (with traffic assignments) was used to generate the sub-area network. The Cube software has a function to generate OD matrices (AM and PM peak-hour trip tables) based on a sub-area network. Thus, analysts simply "cut" the large regional network into a smaller subset area and then run the scripts. For this case study, this process consolidated 3,000 zones (the regional model) into 43 zones of the sub-area network.

Import the base year OD matrices into a microsimulation model

Each microsimulation software package handles OD matrices differently. In Paramics, multiple OD matrices can be loaded onto the same network file. For example, one network file can contain two OD matrices: AM and PM peak hour. The zone numbers in Paramics network should be consistent with the sub-area demand model's zone numbers.

Once the base year OD matrix is imported into the microsimulation model, analysts start the validation and calibration processes.

Validate and calibrate the base year microsimulation model

In this study area, based on field data at certain locations on westbound freeway I-580, the maximum capacity of the freeway was roughly 2,000 cars per lane. However, the demand model loaded the network with almost 2,500 cars per lane. During the initial microsimulation runs, the traffic flow of the westbound I-580 was completely shutdown near the diverging point of the freeway I-238, so the downstream freeway segments received very few traffic volumes. Since this level of demand cannot enter the network during the single peak hour the analysts needed to reduce the assigned demand by adjusting the base year OD matrices to remove the unrealistic bottleneck. As a result, the downstream freeway segments received reasonable traffic volumes and the measure of effectiveness was able to be gathered and presented properly.

When the assigned traffic flow was reduced to something more realistic on freeway I-580, some bottlenecks were found on both northbound and southbound directions of freeway I-880. Analysts again checked the roadway geometry and adjusted the OD matrices in a second round. These trial-and-error processes require tremendous effort when the study area is relative large. Calibrating and validating the microsimulation model for the base year according to the Federal Highway Administration's microsimulation guidelines[1] consumed a large portion of the budget.

Build future base and project scenario microsimulation models

The year 2025 future ACCMA models (with traffic assignments) were used to create future year trip tables. Analysts extracted the regional models into the smaller sub-area. Cube scripts were applied to the sub-area and generated the future trip tables.

The same percentages of volume adjustments (as were applied to the calibration year trip table) were applied to the future trip tables. In this case study, analysts used Microsoft Excel software to document all adjustments of the base year trip tables. Thus, when future trip tables were created by ACCMA model, analysts were able to simply copy and paste the adjustments (equations) to the future no-project and future project trip tables.

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[1] Traffic Analysis Toolbox, Volume III: Guidelines for Applying, Traffic Microsimulation Modeling Software, Publication No. FHWA-HRT-04-040, June 2004, http://ops.fhwa.dot.gov/trafficanalysistools/toolbox.htm

After the base year microsimulation model was complete, analysts copied the model and saved it as the future "no-project" network. New geometry was added on the network allowing for the incorporation or uploading of future year OD matrices in the models. Simulation runs were performed and the models were also checked. Therefore, project scenario networks were created based on the future base microsimulation networks. All estimates of measures of effectiveness for each project scenarios were gathered and compared with the future "no-project" simulation models.

Pros of the Traditional Approach

This case study demonstrated the benefit of combining a simulation model with a demand model to evaluate the benefits of a freeway improvement project.

The simulation model results showed that some systemwide benefits of certain project scenarios were off-set by the increased volumes. For example, one of the project scenarios was to modify the one-lane on-ramp to two-lane on-ramp at the merging area from the freeway I-238 to the southbound I-880. In existing conditions, this capacity constraint (one-lane on-ramp) caused the queue on the westbound I-238 and sometimes even spilled back onto the freeway I-580. When the ramp capacity increased from one-lane to two-lane, it brought roughly one thousand more vehicles onto the southbound I-880. These increased volumes result in more delay of the traffic flow on the southbound I-880. Thus, the overall travel time saving was less than the agency's presumption.

At the end of this project, the benefits of applying microsimulation in combination with travel demand models were shown and helped the agency to prioritize the funding sequence of all project scenarios.

Cons of the Traditional Approach

The traditional approach (adjusting the demand outside of the demand model) is feasible to perform manually (with the assistance of a spreadsheet) for small microsimulation study areas employing no more than 50 origin and destination zones. This approach becomes too laborious for larger study areas. Larger microsimulation study areas would require greater automation of the post-demand model adjustment process.

Besides the physical limits on the ability of the analyst to manually adjust large OD trip tables, there is also the theoretical concern that the demand adjustments are being made on an "ad-hoc" basis, without taking advantage of the behavioral models already incorporated at great expense in the demand model. The analyst simply reduces the calibration year demands produced by the demand model to match existing counts and then assumes that the same errors are also present in the future year forecasts produced by the demand model. This assumption does not take into account changes in the future network (more transit service for example) or the implications of reducing demand in one corridor on the operation of nearby corridors.

Case Study #2 – Innovative Integrated Applications of Travel Demand Models and Microsimulation Models

The goal of this more innovative approach to combining travel demand models with microsimulation is to reflect the effects of downstream weaving and queuing on upstream locations (the output of the microsimulation model) within the travel demand model itself. This procedure was used for the second case study described below.

Project Description

The Tri-Valley area is nestled between major job centers in Silicon Valley and affordable housing supply areas east of the San Francisco Bay Area (San Joaquin Valley). The cities in the Tri-Valley area (Dublin, Pleasanton and Livermore) are also undergoing massive development in housing and especially employment. The primary transportation corridors serving travel to and through this area are already overcapacity today for several hours during the morning and afternoon peak periods. Significant volumes of traffic divert from the freeways to parallel local streets. The Alameda County Congestion Management Agency (ACCMA) initiated the Triangle Study to evaluate and develop a near term and long-range plan for sequencing improvements for practical traffic relief on the Tri-Valley freeways (I-580, I-680 and State Route 84) in a cost effective manner consistent with the transportation needs in the area.

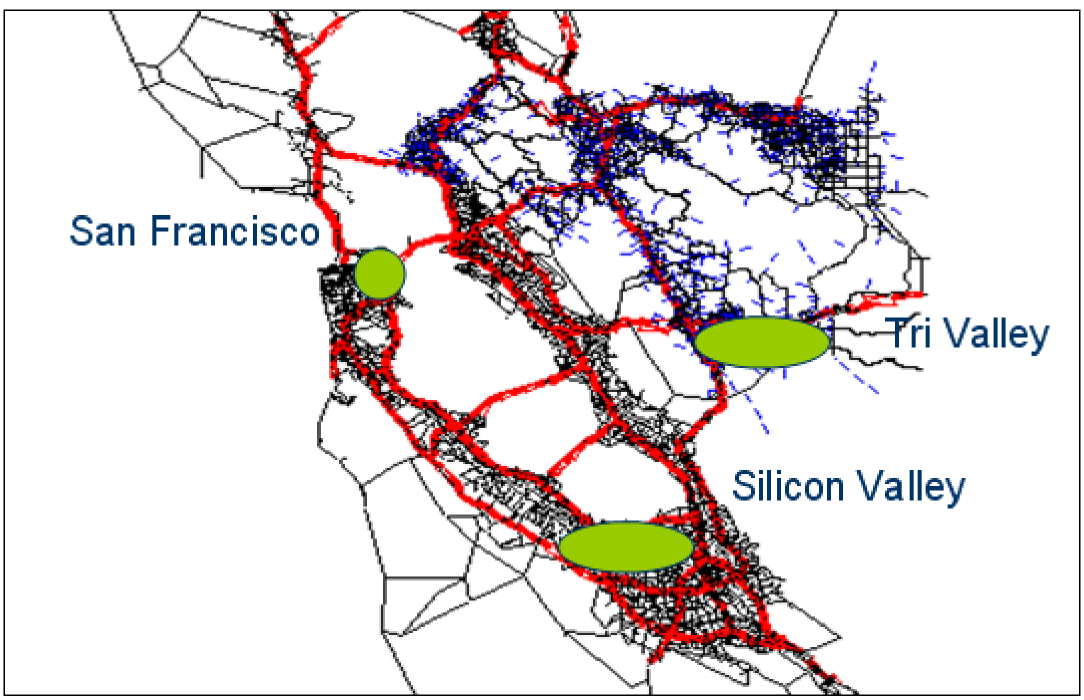

Exhibit 3: Case II – Regional Model Highway Network

The regional travel demand model used for this case study was the Contra Costa Transportation Authority's (CCTA) Decennial model. This regional model has 1,454 traffic analysis zones covering the entire Bay Area (Exhibit 3) with more detail in Contra Costa County and the Tri-Valley area. Full model runs were performed for the existing and future base years and a sub-area highway network and associated trip tables were extracted (Exhibit 4).

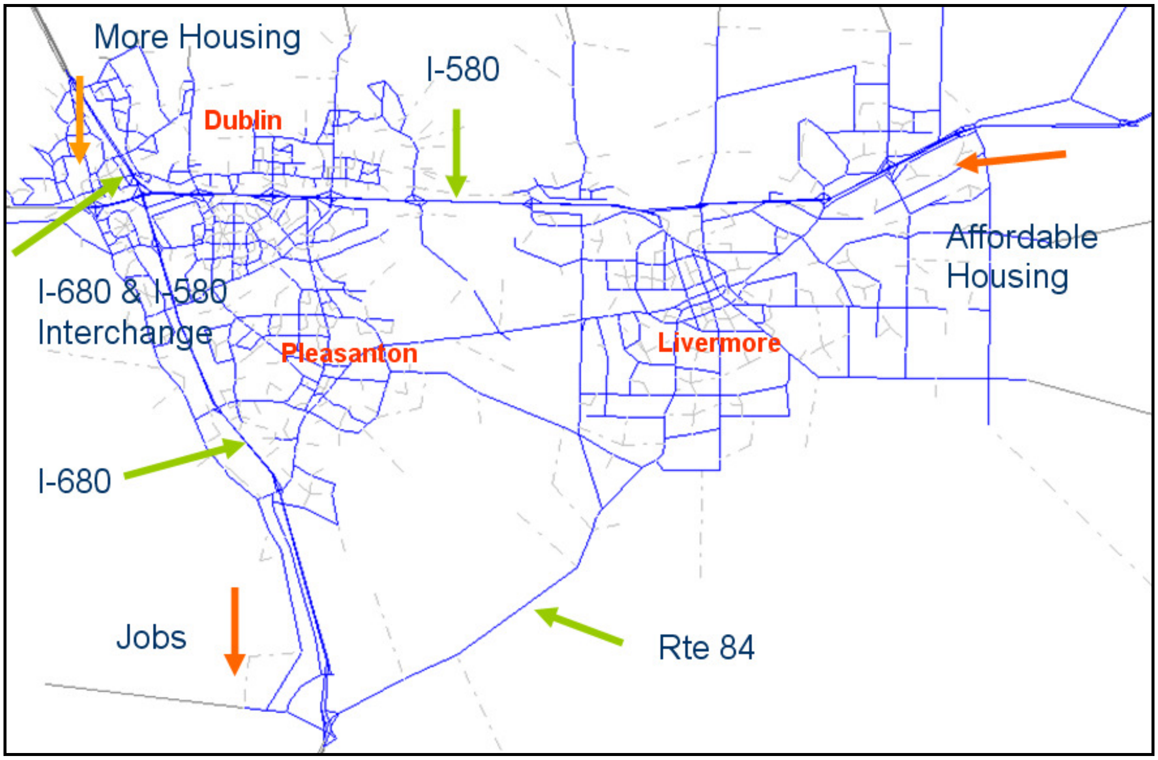

Exhibit 4: Sub-area Highway Network

Methodology

This example of an innovative approach of combining travel demand models with microsimulation models was done as follows:

1. Refinement of the full regional model network and traffic analysis zones to reflect and support the Tri-Valley cities' level of detail,

2. Development of each Tri-Valley city's land use projections for base year and build out scenarios (different from ABAG 2030),

3. Full application of the regional model for base year and buildout scenarios (development of the peak four hour assignments and trip tables.

4. Extraction of the sub-area networks and peak period (4-hour) trip tables for base year and buildout scenarios.

5. Application of the resultant base year trip table matrices onto the existing conditions' microsimulation network,

6. Feedback from the traffic microsimulation model into the travel demand forecasting base year model to reflect travel diversion caused by queuing and weaving.

7. Validation of the sub-area demand models with implementation of a peak hour spreading algorithm using matrix estimation to ensure that the travel demand model reflects *at-capacity* conditions based on existing traffic counts and limits on link capacity due to queuing and bottlenecks,

8. Development of future base build out trip tables using forecast growth in peak period traffic from existing to build out conditions and implementation of the peak hour spreading algorithm using matrix estimation to ensure that the travel demand model reflects *at-capacity* conditions based on future regional capacity constraints.

9. Application of the resultant future base build out trip table matrices onto the build out conditions' microsimulation network,

10. Feedback from the future base traffic microsimulation model into the future base travel demand forecasting model to reflect travel diversion caused by queuing and weaving.

11. Final export of the peak hour at capacity demand trip tables from the travel demand models into the microsimulation models.

Of these steps, the most significant difference from a traditional approach is the implementation of a peak spreading algorithm and the iterative feedback between the travel demand model and the microsimulation model.

Key modeling procedures are described in the following:

Create Sub Area from Regional Travel Demand Model - Existing Conditions

The first step in the process was updating the regional model by adding network detail and splitting traffic analysis zones (TAZ) to allow for analyses of build out of the local city general plans and to reflect local access to the highway network. From the regional model, a sub-area extraction process was used to create sub-area networks and peak period trip tables. The full 4-hour A.M. and 4-hour P.M. traffic assignments were used to create the sub-area networks to ensure that the full demand would be included. The sub-area model had 600 traffic analysis zones.

Adjust Sub Area Demand Model (Validation)

A matrix estimation (ME) was used to create one-hour sub area trip tables from the 4-hour sub-area traffic assignments using known supply (capacity) and demand (counts and cut-through surveys) assumptions. Latest peak one-hour traffic counts were used to validate the base year demand model as well as review of cut-through traffic. In essence, the base year peak trip matrix was factored to better replicate observed traffic counts, cut-through travel patterns, and most importantly regional capacity constraints. This procedure is outlined in Chapter Eight of the report, *National Cooperative Highway Research Program (NCHRP) Publication 255*. Cube software and its companion program Analyst (matrix estimator) was used for this project.

Balanced traffic volumes between intersections are critical for running any matrix estimator relying on traffic counts as a seed into the process. If traffic volumes are not balanced on the freeway and arterial corridors, the process cannot reasonably find optimal solutions which balance. Ideally, counts should be balanced before the matrix estimator process is run. The volume balancing function in Synchro software is a useful tool to perform the volume checking. Exhibit 5 shows all locations of available traffic counts for the Triangle Study.

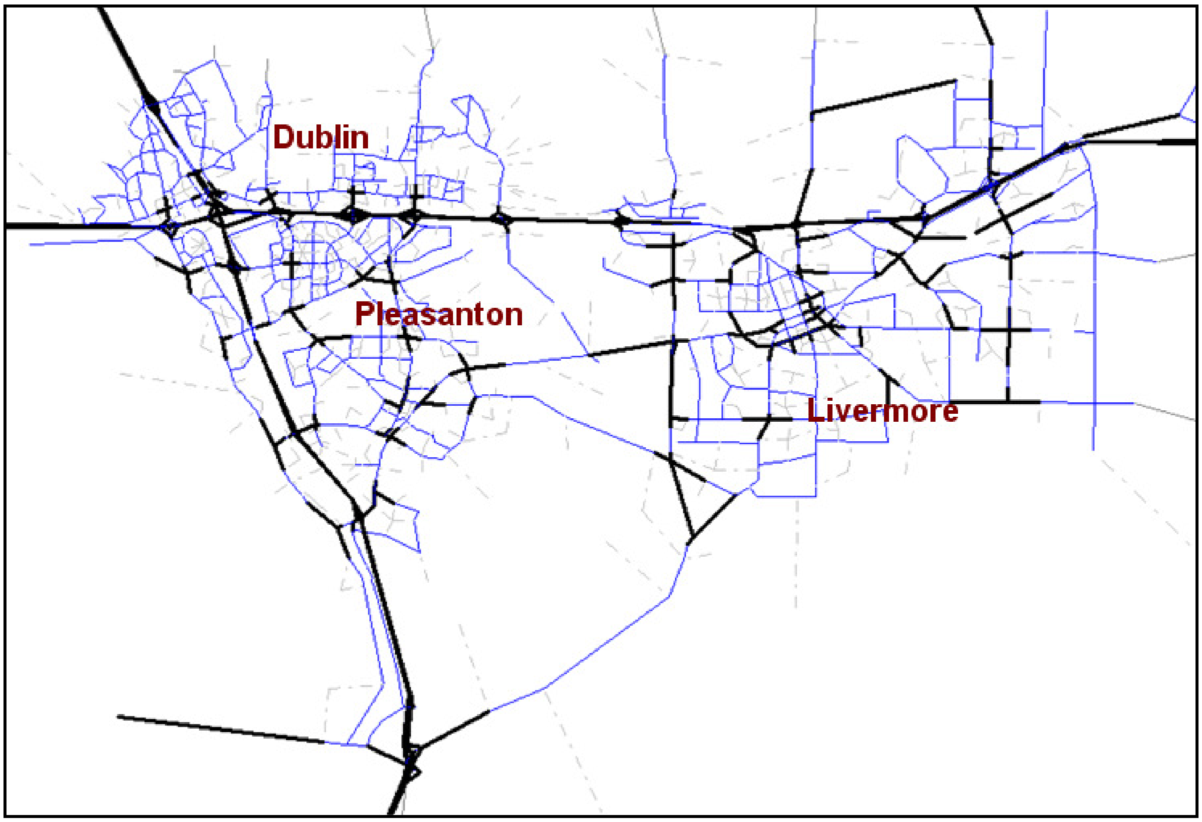

Exhibit 5: Traffic Count Locations

The sub area model was validated to establish criteria including comparisons of model data to vehicle miles of travel (VMT) from the Caltrans Highway Performance Monitoring System (HPMS), total volumes and percent root mean square error (RMSE) by facility types and volume groups, traffic counts across screen lines, and also the percentage of links falling within the FHWA validation curve. A list of the validation criteria used in this case study is provided in appendix.

Apply the Adjustments of Existing Travel Demand to Future Travel Demand Model (Forecast)

After the "fitted" at-capacity vehicle trip matrices were estimated for each time period (AM and PM peak hours), the increment of estimated growth between current and future conditions was calculated directly from the demand model and then added to the adjusted base year trip matrices. This process allows for the interplay of future growth while using a starting trip table which more appropriately represents existing at-capacity traffic patterns. The increments were added to the "unadjusted/original" forecasted models in appropriate time periods to produce adjusted model forecasts.

Adjusted Forecast Model = Future Base Year Forecast – Original Base Year Model + Adjusted Base Model

The adjusted model forecasts were estimated in this manner for each alternative to ensure consistent comparisons of MOEs between project alternatives.

MOE's Feedback and Integration

After the existing and future base year travel demand model trip tables were validated, they were imported to microsimulation models which allow for the analysis of reduced capacity due to merging, weaving and queuing. In this case study, CORSIM software was used to evaluate traffic operations on the individual vehicle level.

Vehicle queuing and throughput information (served vehicles) can be fed back to the demand model. For example, if the freeway congestion is caused by downstream merging/diverging traffic bottlenecks, the constraint of this freeway throughput is not correctly represented in travel demand models. Thus, the delay calculated by microsimulation models can be feedback to the travel demand model to have a more precisely travel demand models.

In this case study, delay information from the microsimulation model (in the form of reduced capacity) was fed back to the demand model. Analysts reran the traffic assignment again of the demand models and came out with a modified trip table matrix which reflects additional rerouting of traffic based on effects of queuing and bottlenecks. This "second round" modified matrix was used by the microsimulation models for validating and calibrating the microsimulation networks.

This feedback loop was applied only once in this case study but, depending upon the number of alternative routes and level of congestions, could be applied iteratively.

Exhibit 6 shows the flow chart of the innovative approach applied in this second case study.

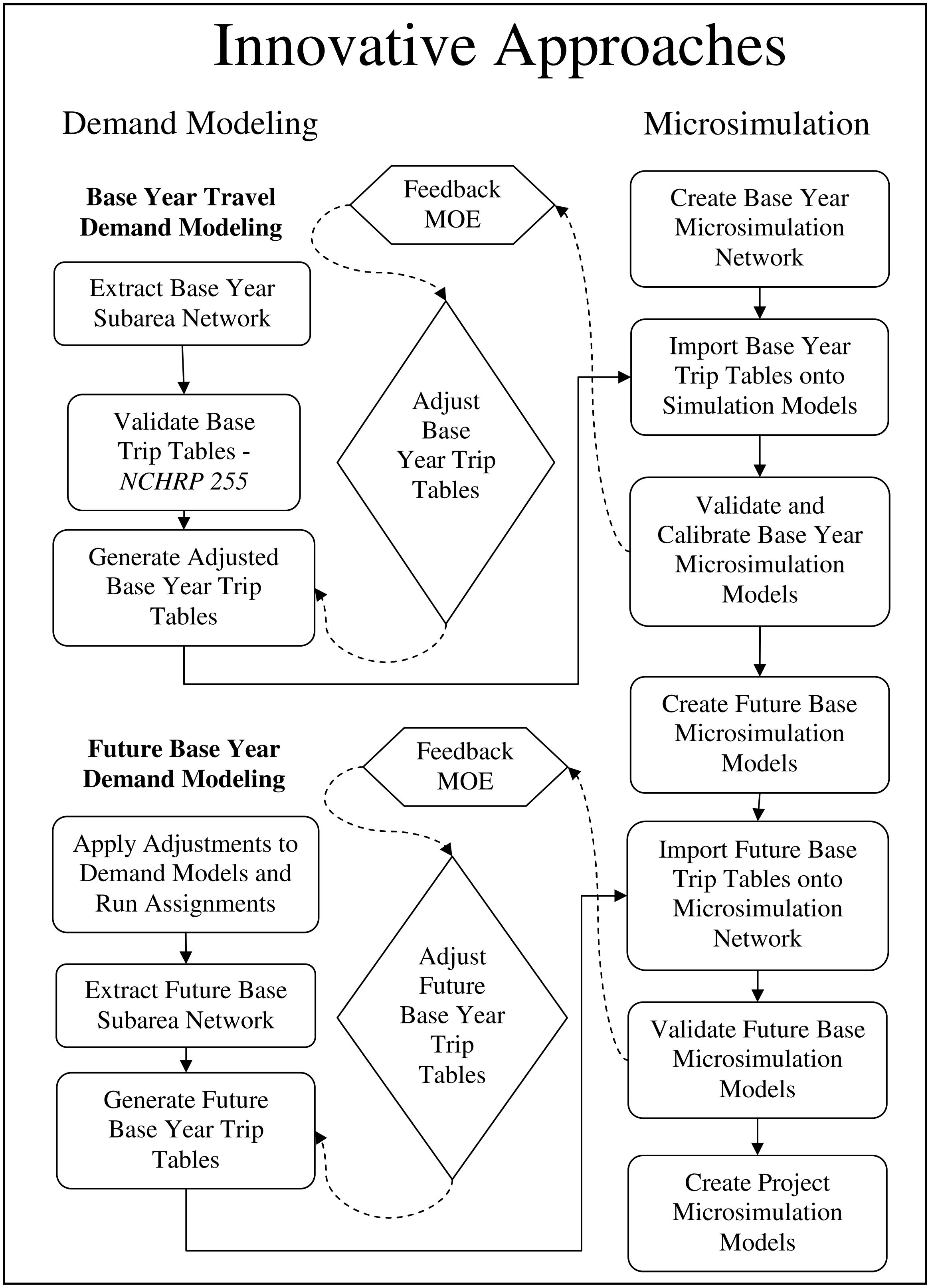

Exhibit 6: Flow Chart of Innovative Approaches

Pros and Cons of the Innovative Approach

The approach applied in this second case study takes into account known information about supply constraints (peak spreading) and travel demand patterns (cut-through traffic) as well as the effects of queuing and bottlenecks (microsimulation) on route diversion. This requires the iterative feedback between the travel demand model and the microsimulation model. While this "extra" step requires a level of effort, there is usually already a correspondence between the two models (since information must go from the travel demand model to the simulation model) which can be used to develop a correspondence in the "other" direction.

Also, as stated above in the discussion about Case Study I, if the trip tables that are fed to the microsimulation model do not take into account some level of peak hour spreading, the microsimulation models are very difficult to calibrate and validate to existing conditions. This is particularly time-consuming and thus expensive for large scale studies. Future levels of congestion simply exasperate the process. On the contrary, if analysts are not familiar with the appropriate application of a matrix estimation process in demand modeling, this procedure may take a significant amount of time.

CONCLUSIONS

While travel demand models reasonably forecast travel demand patterns which reflect a certain level of route diversion due to capacity constraints, they often fail when analysts assign trip tables representing extreme demands resulting in significant over-capacity conditions. By nature, a travel demand model (a macroscopic tool) will assign total volumes, regardless whether the highway network supply can support it. Even though microsimulation models (a microscopic tool) will not allow the over assignment of travel demand (these vehicles are simply counted as "un-served") this does not solve the problem when trying to output MOEs. In reality, the travel demand will "spread" to the shoulders and a certain amount of route diversion will occur. This is the goal of mesoscopic modeling.

Several software packages are developing the bridge between the macroscopic and microscopic (travel demand forecasting and microsimulation). Hopefully in the near future, analysts could have a more seamless integrated process between the two. In the mean time, some mesoscopic simulation tools (such as Cube Avenue) could quantify impacts of upstream traffic congestion and measure queuing at intersections and merge points in a network. These tools integrate the feeding back of reductions in capacity information to the travel demand process. While many of these models are under development, these models have not traditionally been available for the types of studies outlined here. The innovative approach described herein attempts to apply this process without the availability of a reasonable mesoscopic tool.

The recommended approach to applying this process is to direct project resources (time and budget) to the validation of the future base scenario. All stake-holders will need to accept the results of the future base scenario so that the differences between alternatives can be used in the decision-making process. While validation of the models to base conditions is important, it is necessary to ensure that the sensitivity of the models to input growth assumptions is also validated. Then the model can be used to reliably identify the differences in future alternatives.

Appendix - CCTA Model Validation Criteria

Traffic validation shall be consistent with procedures described in the "Model Validation and Reasonableness Checking Manual" (TMIP, June, 2001), "Travel Forecasting Guidelines" (California Department of Transportation, 1992) and "A Manual of Regional Transportation Modeling Practice for Air Quality Analysis" (National Association of Regional Councils, 1993).

Vehicle Miles of Travel. The validation will be set so that the base year VMT estimated by the model is within 3 percent of the HPMS report. If validation to the HPMS VMT values is not consistent with the validation to traffic counts, the differences should be summarizes in a memorandum.

Functional Classification. The requested validation criteria by functional classification are based on the maximum deviation between total assigned traffic volume and total counted traffic volumes for all links that have counted traffic volumes, disaggregated by functional classification (Table 1). In addition, the root mean square error (RMSE) should remain less than 40 percent overall and by functional classification.

Table 1: Validation Criteria by Functional Classification

Functional Classification	Maximum Deviation
Freeway	Less than 10%
Arterials	Less than 20%
Collectors	Less than 25%
Local	Less than 25%

Volume Groups. The requested criteria is for the assigned volumes on 90 percent of road segments with traffic counts to be within a maximum desirable deviation percent error of traffic counts (Table 2). The requested maximum deviations are smaller than those presented in the Caltrans Travel Forecasting Guidelines.

Screenline Validation. It may be desirable to reduce the number of screenlines so as to instead focus the validation on specific roadway segments of interest.