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IMPLEMENTATION OF COMBINED TRAFFIC ASSIGNMENT AND CONTROL FRAMEWORK BASED REGIONAL MODEL FOR THE WASATCH FRONT REGION

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ABSTRACT

The regional travel demand models are generally macroscopic in nature and do not include traffic controls in the traffic assignment process. In travel demand models, the road capacities are kept fixed within the functional classification of roadways and free-flow-speeds are adjusted to accommodate the impacts of traffic controls and traffic operations. Part of the reason this approach is adopted in travel demand models is there macroscopic application, where the focus is extensively on the region wide results for transportation planning. While there are advantages in using this approach, the cost is usually paid in "lost capacity on projects" due to the absence of traffic operations in modeling; more precisely the absence of traffic controls tend to present partially skewed output from the travel models. Combined Traffic Assignment and Control models can address this issue by including the impacts of traffic controls in the modeling process. This paper evaluates the benefits of combined traffic assignment and control modeling framework implemented on a regional scale compared to a traditional four step regional travel demand model. The study quantifies the benefits in terms of providing network travel time information to drivers to make route choice in comparison to improving the traffic controls on a large regional network (on a mesoscopic level). Several experiments were performed on a study area using Static Traffic Assignment (STA) and Dynamic Traffic Assignment (DTA) with fixed and vehicle-actuated controls. The study area network is a regional transportation network for the Wasatch Front Region in Utah. The results suggest that if implemented on regional travel models, the CTAC framework can help reduce the VMT and reduce regional delays by over 6%. Further studies are needed to expand on this idea with multimodal modeling and testing on other regional networks.

Keywords: traffic assignment, traffic controls, mesoscopic, travel demand models.

BACKGROUND

To study the benefits of the combined traffic assignment and control framework, the researchers have been investigating the Combined Traffic Assignment and Control (CTAC) (1) modeling framework for many years now. The framework allows a user to simulate a traffic system under the combined effect of traffic control and driver's route choice. CTAC has been the focus of research for solution algorithms and theoretical modeling formulations for the last three decades. One of the hurdles for implementation of the concept until the mid-1990s was lack of computer technology to perform complex calculations. Advance computers, and software like VISSIM (2), Dynasmart (3) and CUBE-DYNASIM (4) can now simulate complex real-life networks. Due to the availability of advanced computer technology, implementation of CTAC has been the topic of extensive research in academia. However from the perspective of practice, very little research has been done to implement the CTAC modeling framework on large regional scale, especially to identify the benefits of providing network travel time information to drivers with the possibility of improvements in traffic control on mesoscopic level for a region.

This paper evaluates the benefits of combined traffic assignment and control modeling framework implemented on a regional scale compared to a traditional four step regional travel demand model. The study quantifies the benefits in terms of providing network travel time information to drivers to make route choice in comparison to improving the traffic controls on a large regional network (on a mesoscopic level). Several experiments were performed on a study area using Static Traffic Assignment (STA) and Dynamic Traffic Assignment (DTA) with fixed and vehicle-actuated controls. The study area network is a regional transportation network for the Wasatch Front Region in Utah.

REVIEW OF LITERATURE

Allsop conducted one of the first studies on CTAC problem in the 1970s. Allsop (5) suggested that the traffic controls impact route choice. Maher and Akcelik (6), Gartner (7), and Allsop and Charles worth (8) investigated CTAC on a conceptual level by studying the use of signal control to influence route choice. Smith (9, 10) investigated the problem for the existence of equilibrium. Smith formulated conditions that guarantee the existence of equilibrium theoretically. Smith (11, 12) introduced a control policy P_o that ensures the existences of traffic equilibrium. These theoretical approaches by Smith paved the way for one of the initial CTAC implementation efforts by Smith and Van Vuren (13). Meneguzzer (1) and Taale and Zuylen (14) presented an overview of 25 years of research on combined traffic assignment and control. Granato (15) suggested that the transportation planning agency in Iowa is using CTAC model for use limited to long range planning only.

Early efforts on implementation of CTAC models began with a combined focus on solution algorithms and their implementation. Gartner and Al-Malik (16) derived an iterative approach for combined traffic and control problem using a link performance function. Gartner and Stamatiadis (17) presented a theoretical framework for implementation of a joint control and dynamic traffic assignment. Meneguzzer (18, 19) solved a combined route choice control problem using a diagonal algorithm. Taale and van Zuylen (20) investigated CTAC with STA on fixed-time, fixed-time-optimized, vehicle-actuated and vehicle-actuated-optimized control types. The study left other research options open especially using adaptive controls and DTA on latest simulation tools that are available now. Mahmassani and Ta-YIN HU (21) presented a DTA simulation procedure to investigate day-to-day network flows in combination with offline and online traffic controls. The research concluded that real time information and signal control strategies could reduce average delay system wide. Abdelfatah and Mahmassani (22) presented a joint control and assignment problem to optimize the network performance with dynamic route guidance. The research concluded that joint routing and control optimization can lead to improved network performance.

To summarize, conventional traffic assignment and control optimization methods tend to ignore control-driver interaction. The CTAC method can capture control-driver interaction in a single framework. The investigations on solution algorithms, model formulations, and implementation of the method are well documented. However there is no study to date that captures the benefits of provision of network travel time information to drivers to make route choice in comparison to the possibility of improving the traffic controls on a CTAC framework.

METHODOLOGY

Test scenarios

Three scenarios were tested using Cube Voyager, and Avenue based mesoscopic simulation. A brief description of the test scenarios is given below. Table-1 displays the test scenarios.

Table-1. Test scenarios.

Scenario Matrix	Macroscopic	Mesoscopic	
	Scenario 1	Scenario 2	Scenario 3
Assignment Type	Static Assignment	Dynamic Assignment	Dynamic Assignment
Traffic Controls	No Traffic Controls	Fixed Controls	Vehicle Actuated Controls

Static assignment scenarios

Scenario 1 - Due to macroscopic nature of the model, the traffic controls are ignored. Since it is a STA based scenario, the drivers will not have information on network travel times based on past travel experience to make better route choice.

Dynamic assignment scenarios

Scenario 2 - Signal timings are fixed and controls do not respond to changes in traffic flow. Since it is DTA based scenario, the drivers have network travel time information based on past travel experience and they are able to make better route choice.

Scenario 3 - Signal timings may respond to changes in traffic flow due to vehicle actuated type traffic controls. Since it is DTA based scenario, the drivers have network travel time information based on past travel experience and they are able to make better route choice.

Figure-1 displays the sequence of Scenario application process including the intermediate steps where origin destination data, and network data is exported to Avenue software.
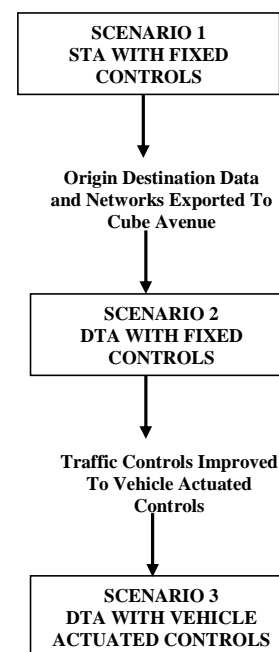

Figure-1. Sequence of scenario testing

OVERVIEW OF TRAFFIC ANALYSIS TOOLS

Modeling and simulation software

A travel demand modeling software Cube version 5.1 with extensions Voyager- a travel demand simulator, and Avenue - a mesoscopic traffic simulator were used to model the test scenarios. Cube uses a modular and script-based structure allowing the incorporation of any model methodology ranging from standard four-step models, activity-based models, and mesoscopic models. Cube Voyager includes highly flexible network and matrix calculators for the calculation of travel demand and for the detailed comparison of scenarios.

Cube Avenue has been proven as a reliable mesoscopic simulation tool that produces virtual traffic flows similar to real traffic flows (23-26). Cube Avenue, an extension to Cube software, offers transportation professionals an innovative tool for analyzing traffic. Cube Avenue is a mesoscopic modeling software. It models traffic at greater levels of detail than macroscopic models, like Cube Voyager's Highway program, and at lesser levels of detail than microscopic models, like Cube DynaSim. With Cube Avenue, analysts can study problems for which traditional aggregate models do not provide enough data and for which microscopic models provide too much data. The mesoscopic modeling environment in Cube-Avenue can be used for transportation planning studies, such as comparing policies for alleviating peak period congestion using the control-driver interaction in a traffic system, or examining the effectiveness of emergency evacuation plans.

Static assignment

A static assignment model based on user equilibrium was used for Cube-Voyager based Scenario 1. The model is fourth step of regional travel demand model (version 7) adopted by Wasatch Front Regional Council (WFRC), and MPO responsible for Transportation Planning for Wasatch Front Region in Utah. The travel demand model is fully calibrated and validated for the regional forecasting, and has been used in several regional planning studies of regional significance by the MPO ranging from studies for regional freeways, regional commuter transit projects, and light rail studies. The assignment model locates a specific route along the links and through intersections for every vehicle trip. The vehicle trips in the form of an origin-destination matrix are "assigned" to the network based on a user equilibrium model. The STA model specifies the effect of road capacity on travel times by means of volume-delay functions (VDF) which is used to express the travel time (or cost) on a road link as a function of the traffic volume. The VDF based on Bureau of Public Roads (BPR) function is used in Static traffic assignment process of Cube-Voyager model in Scenario 1. The function is used to relate changes in travel speed to increases in travel volume. The equation for BPR function can be described as in equation 1.

$$Cs = FFS / [1+X*(V/C) ^Y] \qquad (1)$$

where

Cs	=	Congested Speed
FFS	=	Free Flow Speed
X	=	Coefficient (often set at 0.15),
V	=	Assigned Traffic volume
C	=	the link capacity
Y	=	exponent (often set at 4.0)

Figure-2 shows the volume-delay curves from cube-voyager travel demand model (Scenario 1) for different functional classes. Figure-2 also describes the values of coefficient X, and exponent Y for the calibrated model. The values of X and Y are the two critical parameters in the BPR function that vary by functional roadway classification, and are calibrated accordingly from the field data.
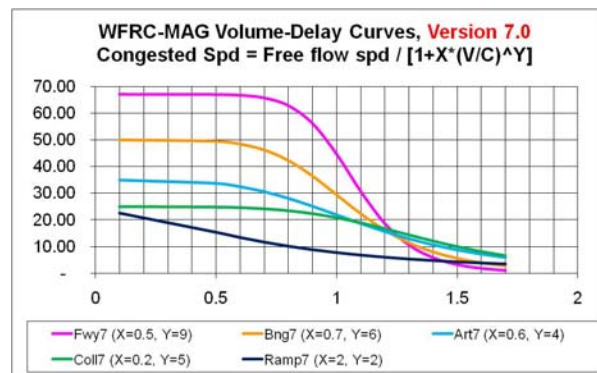

Figure-2. Volume delay curves from scenario 1.

The assignment model uses an iterative process to achieve a best path solution in which travelers' travel costs are the best within the defined travel cost functions. The numbers of iterations for the traffic assignment-runs were fixed at 100 for consistency on comparison with other scenarios, rather than allowing the assignment to stop at an arbitrary iteration. The rationale for fixing the number of iterations in Static Assignment is the stability of traffic assignment is unique by iteration. The static traffic assignment results oscillate or flip-flop from one iteration to the next between alternating shortest paths. This approach attempts to minimize differences between different loaded networks due to oscillations by fixing the number of iterations, preventing different assignments from stopping at different iterations.

Once the STA scenario (SCENARIO 1) simulation was done on Cube-Voyager, the regional loaded network was exported from cube-voyager to Cube Avenue along with all the network attributes. The network with the attribute data files from Cube-Voyager was then used by Scenario 2 and 3 for mesoscopic simulation in Cube Avenue.

Dynamic assignment

Cube Avenue is a dynamic equilibrium assignment model. Cube Avenue loads and tracks the

movement of vehicle packets throughout the highway network. Vehicle packets can be any size ranging from an individual vehicle up to platoons of several vehicles. Cube Avenue explicitly simulates traffic flow and traffic control systems. It models traffic signals, roundabouts, stop-controlled intersections, and ramp merges.

Through an iterative process, Cube Avenue calculates optimal network conditions based on user defined travel costs. Typically, the model converges in several iterations, an extremely fast process for smaller systems and quite feasible for large urban areas. The software is capable of applying DTA to regions with over 3000 zones and 30000 links. The dynamic assignment model is programmed using the Cube scripting language.

For this research, the DTA was applied as an iterative process where drivers made the route choice, based on their travel cost in previous run (previous day travel cost experience in real life). The best path in each run of the simulation is based on defined travel cost which was previous iterations travel times. Travel cost can also be in terms of distance, toll, or any other general cost associated with trip making. The changing traffic conditions in each run may change the travel cost, which leads to more routes with lower costs in subsequent runs. For convergence, Avenue requires that all paths must have a relative change lower than the defined threshold. Acceptable convergence criteria define indicators such as verifying that 95% of all paths are within 10 to 15% (25). Other standard practices look at mean errors.

The travel time on paths was used as cost in DTA. A convergence criterion of 5% travel time difference on paths was used. For each run of DTA simulation, Cube Avenue compares the travel time on paths to the previous run. Based on the threshold, if the difference in travel time on all paths is less than or equal to 10%, the convergence criteria is met. Otherwise, the simulation continues until it reaches the maximum number of runs specified by the user or the convergence criteria whichever comes first. Travel time information files containing travel time for each OD pair were written for every run of DTA simulation using the output processing features of Cube Avenue. DTA based Scenario 2 and 3 met the set convergence criteria after 95 iterations. The data from 95th iteration of STA based Scenario 1 was used in comparisons for consistency on comparisons.

Signal control emulator

A National Electrical Manufacturers Association (NEMA) Standard Signal Control Emulator was used for traffic controls in test scenarios. This controller is embedded in Cube AVENUE and emulates common signal controllers used in North America. With this controller Cube Avenue can simulate fully actuated signal control as well as coordinated and vehicle-actuated coordinated signal control. Traffic control programs for each intersection in the study area network were coded in Cube Avenue.

Traffic controls

Scenario 1 was a traditional four step travel demand model and due to the macroscopic nature of the model not traffic controls were included in Scenario 1. Fixed Controls and Vehicle-Actuated Controls were used in the mesoscopic Scenario 2 and Scenario 3. Fixed controls usually operate on predetermined and repeated sequence of signal plans with fixed cycle length and splits. The signal timing plans are developed off-line and optimized based on historic data of traffic flow. A series of predetermined plans can accommodate variations in traffic volume during the day. Fixed controls are best with predictable traffic volumes.

Vehicle-actuated controls differ from fixed control because they can respond to variations in traffic flow and are typically used is in situations with irregular traffic flow. The actuated controls can be grouped into two types: semi-actuated and fully actuated. Semi actuated systems primarily apportion the green time to the major movement of traffic and minor streets are accommodated at vehicle detection. Fully Actuated control systems detect vehicles on all approaches of the intersection and make adjustments according to the flow. The vehicle actuated controls were used with the limitations that offsets and cycle lengths would not change, and only green splits within the given cycle length framework could be adjusted. The changes in green split could respond to the variation in traffic flow due to different route choices of drivers in DTA simulation.

Study area

The study area covered entire Wasatch Front Region including all of the developable area of Utah, Salt Lake, Davis and Weber counties, with the exception of the canyons and mountains to the east of the urbanized areas. Figure-3 shows the study area and the TAZ structure. TAZs were mutually exclusive (they do not overlap) and they cover the entire model region. The model is a zone-based forecasting tool, modeling travel between aggregate Transportation Analysis Zones (TAZ).
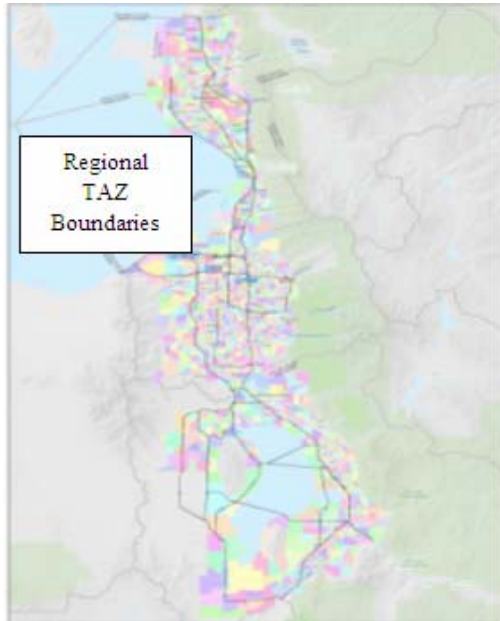
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Figure-3. Wasatch front region traffic area zones.

The 2007 road network used for the model included all facilities functionally designated as collector or above by the Utah Department of Transportation (UDOT). There are approximately 25,000 road links in the base year network and over 13000 nodes including 60 signalized intersections and 60 intersections with 4-Way stop signs, and 2250 zonal nodes. Out of the 60 signalized intersections, 30 were located in urban core of Salt Lake County, 10 in urbanized area of Weber County, 10 in urbanized area of Davis County, and 10 in urbanized Area of Utah County. The same proportion was allocated to 4-Way stop signs among the four counties. Figure-4 shows a portion of the model's road network covering the Kaysville area.

Figure-4. Snapshot of 2007 street network.

Cube voyager based travel demand model

The model is based on a traditional four-step modeling process consisting of trip generation, trip distribution, mode split, and trip assignment steps. The model incorporates these steps and adds an auto ownership step that is sensitive to urban design variables and transit accessibility. The model has a feedback loop between trip distribution and traffic assignment, which is a process that ensures consistency between travel congestion and times that influence trip distribution patterns and that are an outcome of trip assignment. Travel time, is calculated based on outputs from the assignment step, but also is an important determinant of trip distribution and mode split. Therefore, it is customary to iterate these steps in order to reach a convergent solution. Figure-5 outlines the various steps of travel demand model used in Scenario 1.
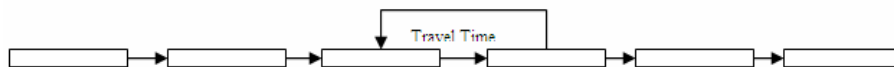

Figure-5. Different steps of cube based model.

At the start of a model run, the auto ownership model estimates household auto ownership levels. The trip generation model then estimates trip-ends by TAZ based on household and employment characteristics. These trip-ends are then paired into trips in the trip distribution model. In the mode choice model, a mode of travel is identified for each trip. Vehicle trips are assigned to the highway network in the trip assignment model, during which congestion levels on each road are estimated consistent with route choices. The travel time feedback loop in the model is run to a convergent solution prior to running mode choice. The origin-destination matrix post mode-choice step was exported to cube avenue in order to include the impact of all trips in the region.

Time periods

The trip generation and trip distribution models are daily models, while the mode choice model distinguishes peak and off-peak periods, and the traffic assignment model estimates traffic flows for four periods of day:

- AM Peak: 6 AM - 9 AM
- Midday: 9 AM - 3 PM
- PM Peak: 3 PM - 6 PM
- Evening/Off-peak: 6 PM - 6 AM

At the end of the STA based scenario, the OD matrix for each peak period was exported for use by Cube Avenue software in DTA based scenarios.

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CALIBRATION AND VALIDATION OF THE MODELS

The regional travel demand model base-run in Cube-Voyager with Static Assignment and no traffic controls (Scenario 1) has been calibrated and validated by WFRC to represent 2007 travel conditions and patterns by adjusting model input data, assumptions and parameters so that the final outputs more closely match observed data. The Cube-Avenue base-run with DTA and vehicle actuated controls (Scenario 3) was calibrated for the mesoscopic traffic assignment simulation process. The mesoscopic assignment model was calibrated for speeds, and travel time data, and was also validated" against field counts data. Figure-6 part a) and part b) show the post validation comparison of field counts with modeled volume. In both cases of Scenario 1 and Scenario 3, the field counts closely matched with $R^2 = 0.9444$, and $R^2=0.952$, respectively.
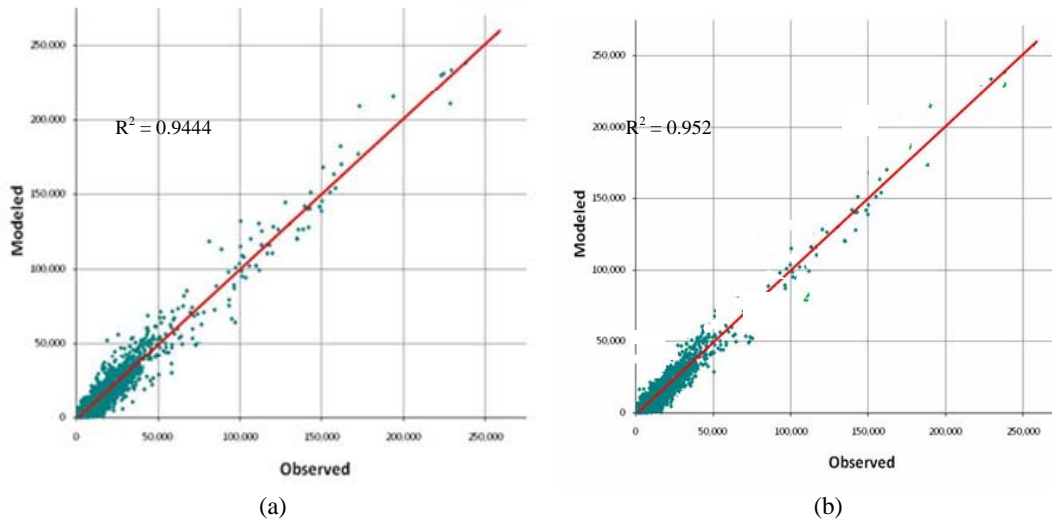

(a)   (b)

Figure-6. Modeled volumes and field counts (a) model vs. counts from scenario 1 (b) model vs. 2007 counts from scenario 3.

For this research the speed and travel time data collected by WFRC and UDOT were used in calibration of the models. The data once compiled, is then transferred to the regional travel demand model Master Network for AM, PM, MD, and EV peak periods. The Master network can be opened in any modeling environment of Cube software (for example Cube-Voyager, and Cube-Avenue).

The data can also be ported and used for various comparisons within the Cube modeling framework, as well as in shape file format using ArcGIS software. Observed vs. modeled speed comparison was a crucial part of the model calibration process for Scenario 3. Figure-7 parts a) and parts b) show the observed vs. modeled speed comparison from the calibrated base-run of Scenario 3.
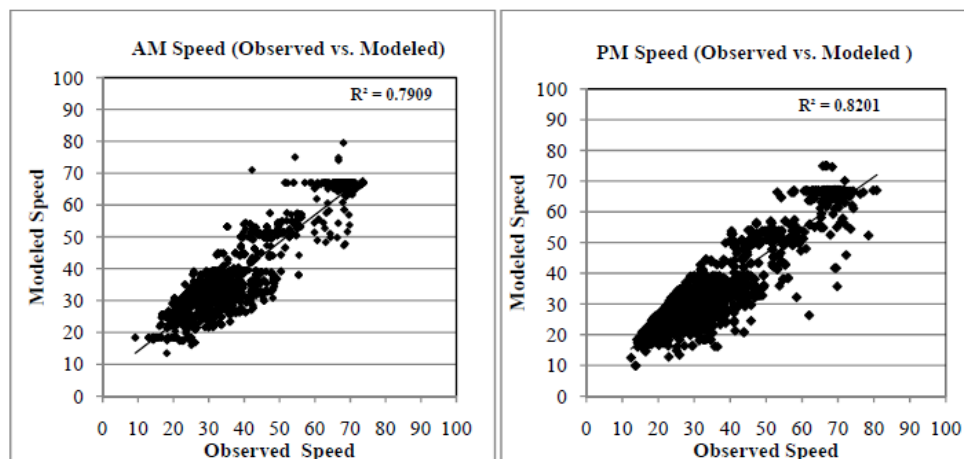

Figure-7. Observed vs. modeled speed a) AM peak observed vs. modeled speed b) PM peak observed vs. modeled speed.

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In addition to field counts vs. modeled volume comparison in Scenario 1 and Scenario 3, the model output was compared with field counts aggregated by peak periods at selected locations. The 2007 base-run peak period count data was collected from WFRC's archived data inventory and was transferred to the Cube-Voyager and Cube-Avenue loaded networks. The Table-2 part a) and part b) shows the validation summary for Scenario 1 (Cube Voyager based scenario) and Scenario 3 (Cube-Avenue based Scenario with Vehicle Actuated Controls). The table shows that in both Scenario 1 and Scenario 3 the percent error was consistent within peak periods. The percent error was 3% higher in case of Arterials in AM Peak, and by 2% in PM Peak.

Table-2. Test scenarios a) scenario 1 validation summary b) scenario 3validation summary.

a)

Period	Cube Voyager							
	Modeled	Counts	Vol Dif	Vol % Error	Model Pct	Count Pct	Pct Diff	Pct Error (%)
All Roadways								
AM	925,856	844,354	81,502	9.7%	18.8%	18.1%	0.74	4.09
PM	1,223,262	1,099,117	124,145	11%	24.8%	23.5%	1.33	5.65
Daily	4,926,848	4,676,910	249,938	5%				
Freeways								
AM	696,035	657,098	38,937	6%	19.1%	19.1%	-0.08	-0.40
PM	899,351	797,369	101,982	13%	24.6%	23.2%	1.41	6.05
Daily	3,650,577	3,432,506	218,071	6%				
Arterials								
AM	229,821	187,256	42,565	23%	18.0%	15.0%	2.96	19.67
PM	323,911	301,748	22,163	7%	25.4%	24.2%	1.13	4.66
Daily	1,276,271	1,244,404	31,867	3%				

b)

Period	Cube Avenue							
	Modeled	Counts	Vol Dif	Vol % Error	Model Pct	Count Pct	Pct Diff	Pct Error (%)
All Roadways								
AM	957,792	844,354	113,438	13.4%	18.9%	18.1%	0.88	4.89
PM	1,292,118	1,099,117	193,001	18%	25.5%	23.5%	2.04	8.70
Daily	5,058,139	4,676,910	381,229	8%				
Freeways								
AM	703,249	657,098	46,151	7%	19.1%	19.1%	-0.04	-0.21
PM	890,082	797,369	92,713	12%	24.2%	23.2%	0.95	4.08
Daily	3,681,496	3,432,506	248,990	7%				
Arterials								
AM	239,334	187,256	52,078	28%	18.4%	15.0%	3.39	22.50
PM	334,446	301,748	32,698	11%	25.8%	24.2%	1.51	6.23
Daily	1,298,392	1,244,404	53,988	4%				

The model output was also compared for Root Mean Square Error (RMSE), and Average Error. The RMSE is a measurement of error that weights the larger errors by more than they would be in an average error computation. The percent RMSE compares the RMSE statistic to the average observed value. The RMSE is always higher than the actual average network error because of the weighting. The percent RMSE should generally be less than 40%, overall, with higher values

acceptable for low volume links and lower values expected for high volume links.

The sum of differences is the average error of the network. This measure is usually expressed as a percent error. The modeling literature on model calibration recommend an average error for VMT and overall traffic volumes between +/-7% for freeways, +/-10% for major arterials and +/-15% for minor arterials. It is common for regional travel models to perform relatively poorly on minor arterials, collector roads and local roads, where the count data resolution is not better. RMSE and Average errors were computed and compared among the scenarios for validation. Table-3 shows the Regional Validation summary for the model. The % RMSE was the highest in case of minor arterials, and was the minimum in case Freeways.

Table-3. Regional validation summary of tested scenarios.

All Facilities	SCN1 CUBE STA NO TRAFFIC CONTROLS	SCN2 AVENUE DTA FIXED CONTROL	SCN 3 AVENUE DTA VEHICLE ACTUATED CONTROL	Principal Arterials	SCN1 CUBE STA NO TRAFFIC CONTROLS	SCN2 AVENUE DTA FIXED CONTROL	SCN 3 AVENUE DTA VEHICLE ACTUATED CONTROL
Average Count Volume	23208	23208	23208	Average Count Volume	30095	30095	30095
RMSE	7043	8697	7712	RMSE	8162	10162	8801
%RMSE	30%	37%	33%	%RMSE	27%	34%	29%
Number of Observations	1508	1508	1508	Number of Observations	301	301	301
Avergae Error	920	1432	1076	Average Error	1002	1769	1134
Average % Error	-4%	-6%	-5%	Average % Error	3%	6%	4%
Freeways				Minor Arterials			
Average Count Volume	102548	102548	102548	Average Count Volume	18460	18460	18460
RMSE	12835	18654	15432	RMSE	6401	7223	6722
%RMSE	13%	18%	15%	%RMSE	35%	39%	36%
Number of Observations	102	102	102	Number of Observations	598	598	598
Average Error	28	41	33	Average Error	774	1129	831
Average % Error	0	0	0	Average % Error	-4%	6%	-4.5%

Figure-7 outlines the average percentage error (counts vs. modeled) across the Scenario1, Scenario 2, and Scenario 3 by highway facility types. The Figure shows that the average percent error was higher by up to two percent in case of mesoscopic simulations except. In Scenario 2 with DTA and fixed controls, the average percent error was up to 6%, suggesting that the minor arterials had higher volume than counts compared to Scenario 1 and Scenario 3.
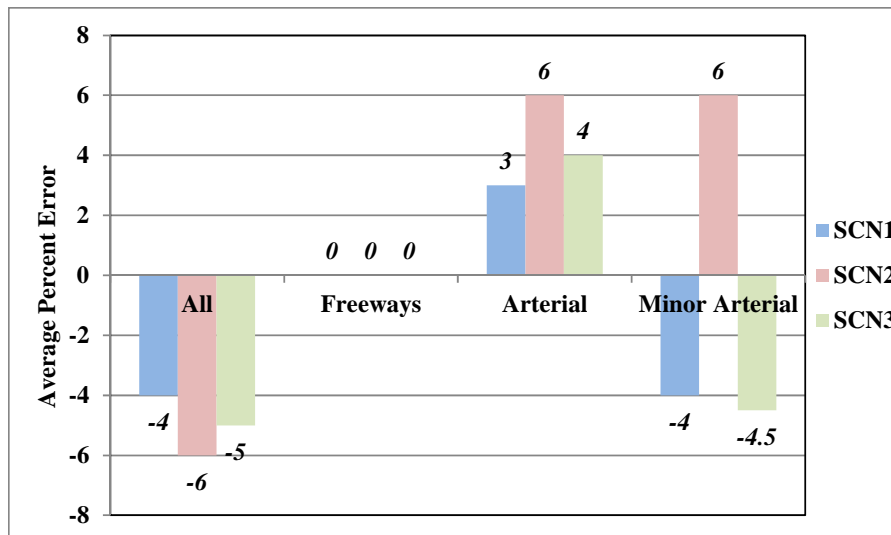

Figure-7. Average percentage error from scenarios.

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Speed estimates from Scenario 1 were compared to GPS speed data collected by WFRC throughout the model region. Once STA based Scenario 1 was simulated, the speed skims were exported for use by Avenue in DTA based scenarios. The simulated speed from mesoscopic Scenario 3 was also compared to field counts during the calibration process.

The traffic assignment based modeled volumes from Scenario 1 (Cube-Voyager Base Scenario) and Scenario 3 Cube-Avenue Base Scenario, were compared for large screen lines across the modeling region. Screen lines are often associated with physical barriers such as rivers or rail- roads however jurisdictional boundaries such as county lines that extend through the study area make excellent screen lines. The Large Screen Line network attributes from Scenario 1 (Cube-Voyager travel model) were transferred to Cube Avenue loaded network, and the screen line modeled volumes were compared to screen line field counts across the screen lines. Figure-8 shows the Selected Screen Lines across the region. Total of 16 Large Screen Lines were used across the region.

In regional models, screen line based comparisons help evaluate the reasonableness of aggregate traffic flows on selected sections of roads in the modeled region that intersects with screen lines. Screen lines are useful to evaluate relatively large flows moving across multiple roads and indicate in general whether the model is moving enough traffic across a certain line in the region. Table-4 shows the comparison of aggregate screen line

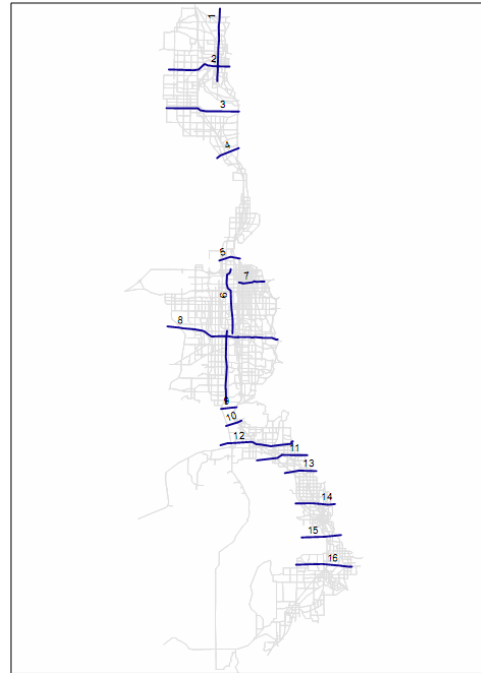volumes to aggregate screen line field counts (week day traffic).

Figure-8. Large screen lines for Wasatch front region.

Table-4. Large screen line comparison (modeled vs. field) count comparison.

Screen	Field Counts	Modeled Volume		Difference		Percent Difference	
Line	Field Counts	SCN1	SCN 3	SCN1	SCN3	SCN1	SCN 3
1	131103	116652	121221	-14451	-9882	-11%	-8%
2	233831	243351	221971	9520	-11860	4%	-5%
3	216583	208590	222963	-7993	6380	-4%	3%
4	149637	151088	143521	1451	-6116	1%	-4%
5	214584	198053	191429	-16531	-23155	-8%	-11%
6	711333	682452	669982	-28881	-41351	-4%	-6%
7	181952	208640	172214	26688	-9738	15%	-5%
8	679653	719947	621381	40294	-58272	6%	-9%
9	154515	161472	167523	6957	13008	5%	8%
10	20831	17965	23259	-2866	2428	-14%	12%
11	192658	217371	212654	24713	19996	13%	10%
12	168887	190707	182541	21820	13654	13%	8%
13	197884	206654	185224	8770	-12660	4%	-6%
14	112972	104342	118341	-8630	5369	-8%	5%
15	145745	123177	139788	-22568	-5957	-15%	-4%
16	146167	112839	127791	-33328	-18376	-23%	-13%

The table shows that the percent error for screen lines with large volumes was among lowers for screen was lower for screen lines with larger volumes. Figure-9 parts a) and b) show the percent error comparison to field counts for Scenario 1 and Scenario 3 respectively. In both scenario 1 (travel demand model on Cube-Voyager), and

Scenario 3 (CTAC based model on Cube-Avenue), as the observed traffic count across a screen line goes up, the acceptable error goes down as recommended and referenced in National Cooperative Highway Research Program (NCHRP) Report 25.
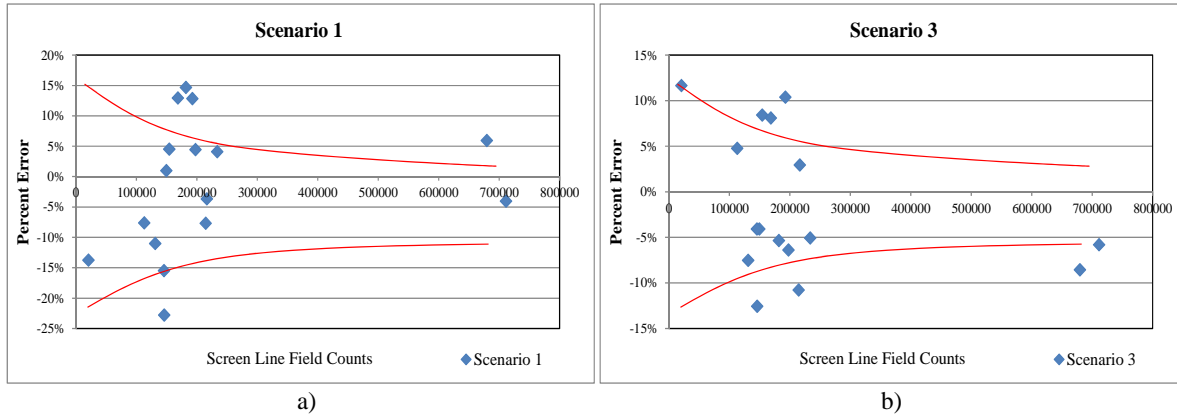
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a)   b)

Figure-9. Large screen line calibration a) percent error (modeled vs. field counts) compared to field counts scenario 1 b) percent error (modeled vs. field counts) compared to field counts scenario 3.

In case of Scenario 1 all but one regional screen line comparison with -23% stood out. Overall in both scenarios, models did well with this calibration measure. The regional screen line comparison was within +/- 15% for most of the screen lines, with several within +/-8%.

RESULTS AND ANALYSIS

In order to evaluate the benefits of implementing the combining traffic assignment and traffic controls framework on a regional scale, the system wide delay among the three scenarios, and modeled vehicle miles traveled (VMT) were compared to VMT estimated by highway performance monitoring system (HPMS). The HPMS is a national level highway information system that includes data on the extent, condition, performance, use, and operating characteristics of the nation's highways. The HPMS contains administrative and extent of system information on all public roads, while information on other characteristics is represented in HPMS as a mix of universe and sample data for arterial and collector functional systems. HPMS was developed in 1978 as a continuing database, replacing the special biennial condition studies that had been conducted since 1965. The HPMS has been modified several times since its inception to reflect changes in the highway systems, legislation, and national priorities, to reflect new technology, and to consolidate or streamline reporting requirements. The HPMS Data on VMT was collected from UDOT by Geography.

VEHICLE MILES TRAVELED COMPARISON BY GEOGRAPHY

One of the key measures used in scenario analysis of regional travel models is vehicle miles traveled. According to the U.S. Bureau of Transportation Statistics, Vehicle Miles Traveled (VMT) is a good indicator of roadway use, and traffic congestion in a traffic system. Vehicle Miles Traveled (VMT) is the total number of miles driven by all vehicles within a given time period and geographic area. It is used by regional transportation and environmental agencies for planning purposes. Average weekday vehicle miles traveled were reported as a post processed data in all three scenarios through a post processing script written in Cube scripting language. Table-5 shows the comparison of VMT by functional type of highway, and by regional geography. The comparison shows that the combined traffic assignment and control framework implemented for this paper lowered the regional VMT by up to 7% on Davis County arterials. On a regional scale, the CTAC framework lowered the VMT by 2% in Freeways, and by 4% on arterials.

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Table-5. Vehicle miles traveled comparison by geography.

Geography	Source	SCN1		SCN2		SCN3	
		Freeway	Arterial	Freeway	Arterial	Freeway	Arterial
Weber County	Modeled	1,132,965	2,399,978	1,126,369	2,491,156	1,088,952	2,555,718
	UDOT	1,105,608	2,638,403	1,105,608	2,638,403	1,105,608	2,638,403
	% Diff	2.50%	-9.00%	1.88%	-5.58%	-1.51%	-3.13%
Davis County	Modeled	3,491,514	2,451,049	3,521,564	2,266,917	3,411,790	2,317,712
	UDOT	3,508,552	2,436,777	3,508,552	2,436,777	3,508,552	2,436,777
	% Diff	-0.50%	0.60%	0.37%	-6.97%	-2.76%	-4.89%
Salt Lake County	Modeled	10,142,361	11,763,713	9,839,453	10,409,147	9,603,245	10,779,213
	UDOT	9,730,230	11,321,725	9,730,230	11,321,725	9,730,230	11,321,725
	% Diff	4.20%	3.90%	1.12%	-8.06%	-1.31%	-4.79%
Utah County	Modeled	4,025,398	4,949,700	4,122,798	4,553,908	3,986,721	4,511,609
	UDOT	4,072,782	4,637,565	4,072,782	4,637,565	4,072,782	4,637,565
	% Diff	-1.20%	6.70%	1.23%	-1.80%	-2.11%	-2.72%
Region	Modeled	18,792,237	21,564,440	18,610,184	19,721,128	18,090,708	20,164,252
	UDOT	18,417,172	21,034,470	18,417,172	21,034,470	18,417,172	21,034,470
	% Diff	2.00%	2.50%	1.05%	-6.24%	-1.77%	-4.14%

Delay reduction by functional type

In addition to the VMT, the daily delay statistics from the three scenarios were compared on county level as well on a regional scale. Table-6 outlines the daily delay in hours by geography.

Table-6. Delay by geography (Hours).

Scenario	WE	% Diff	DA	% Diff	SL	% Diff	UT	% Diff	RE	% Diff
SCN 1	4,797		7,280		39,956		12,454		64,483	
SCN 2	4,602	-4.1	7,119	-2.2	38,401	-3.9	12263	-1.5	62,385	-3.3
SCN 3	4,234	-12	6,791	-6.7	38,131	-4.6	11897	-4.5	61,053	-5.3

The output data on delays in Table-5 shows that the mesoscopic traffic assignment based on CTAC framework with DTA simulations and vehicle actuated controls (Scenario 3) reduced the delay up to 6.7% in sub regions like Davis County, and reduce the overall regional delays by 5.3%. Both Table-4 and Table-5 show that the Combined Traffic Assignment and Control Framework based simulation help reduced the regional VMT and regional Delays compared to traditional travel demand models without traffic controls and combined framework.

LIMITATIONS AND FUTURE RESEARCH

The test network had only 60 signalized intersections region wide. The study can be expanded by adding more signalized intersections on the same set up. Only fixed controls and vehicle-actuated controls were used in this study. More tests can be done with adaptive traffic controls. Similar tests can be done using other software capable of simulating DTA and mesoscopic simulations. A computer with Intel ® Core ™ 2 QUAD CPU with 2.66 GHz processor and 3.24 GB of RAM was used to perform simulations. For larger networks from other regions, it may take more time for convergence on the same computer. However, should the development trends continue, this may prove a smaller obstacle to researchers.

CONCLUSIONS

The paper evaluated the benefits of CTAC framework implemented regionally in comparison to regional travel demand model without traffic controls. A regional network covering the Wasatch Front Region of Utah was used to test three Scenarios. The CTAC framework based mesoscopic simulations used in the tests were able to capture interaction between drivers' route choices and flow responsive traffic controls. The regional Vehicle Miles Traveled and Regional Delays reduced in CTAC based scenarios. The results suggest that the CTAC framework can be implemented on the regional scale networks. If implemented on regional travel models, the CTAC framework can help reduce the VMT and reduce regional delays by over 6%. With growing use of new methods to mitigate traffic congestion, the need for modeling methods that capture control-driver interaction is

growing. CTAC models therefore, can play an important role in regional congestion mitigation projects in practice.

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