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Combined Traffic Assignment and Control Method: Benefits of Capturing Interaction between Drivers' Route Choices and Traffic Controls

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ABSTRACT

Combined Traffic Assignment and Control (CTAC) models have been the topic of academic research for the last three decades. The research problem has been explored by several researchers for solution algorithms, model formulations, and implementation efforts. Although proven in academic research, the use of CTAC models is rare in engineering practice. The practice tends to ignore the interaction between drivers' route choices and controls by keeping the traffic assignment and traffic control optimization processes separate. Previous research emphasizes that CTAC models should be used in practice as they can capture the control-driver interaction very well. The paper presents the benefits of capturing interaction between drivers' route choice and traffic controls. The benefits were computed in terms of providing the drivers with network travel time information from past travel experience with improvements in traffic controls. Six scenarios were tested on Park City, Utah road network using Static and Dynamic Assignments with Fixed-Time, Vehicle Actuated, and Adaptive Traffic Controls. The results show that the improvements of traffic controls to Adaptive Controls alone can substantially reduce total delays and improve total-travel time. Across the six scenarios, the total delay reductions and total travel time improvements were the highest for the traffic system when the drivers had network travel time information from past travel experience with signal-controls improved to Adaptive Controls. Further experiments are needed to compare the benefits for larger regional networks and other simulation software.

KEY WORDS: Traffic Assignment, Dynamic Assignment, CTAC, Combined Traffic Assignment and Controls.

INTRODUCTION

Traffic congestion is one of the major challenges faced by transportation planning agencies across the globe. Several factors contribute to traffic congestion depending on the area including physical bottle necks, traffic incidents, work zones, weather, and changes in traffic controls. Traffic congestion mitigation efforts are used to make the traffic systems efficient. In a traffic system, the drivers' route choice and the signal- controls may have competing objectives. Drivers may like to travel from origin to destination in the shortest possible travel time. The controls settings on the other hand are adjusted for system-wide objectives. In a perfect adaptive traffic control environment, the drivers' route choice may impact the traffic control settings, which in turn may change drivers' travel choices. The researchers have been studying the impacts of the control-driver interaction through Combined Traffic Assignment and Control (CTAC) framework for several years now [Meneguzzer, 1997]. The CTAC models simulate traffic system under the combined effect of changes in traffic controls and drivers' route choices. Until mid-1990s the implementation of the CTAC models was challenging due to lack of computer technology to perform complex simulations. Advance computer technology, and software like VISSIM [Bloomberg and Dale, 2000], DYNASMART [Abdelfatah and Mahmassani, 1998], and CUBE-DYNASIM [Yaldi and Yue, 2006] can now be used to simulate complex real-worldTraffic congestion is one of the major challenges faced by transportation planning agencies across the globe. Several factors contribute to traffic congestion depending on the area including physical bottle necks, traffic incidents, work zones, weather, and changes in traffic controls. Traffic congestion mitigation efforts are used to make the traffic systems efficient. In a traffic system, the drivers' route choice and the signal- controls may have competing objectives. Drivers may like to travel from origin to destination in the shortest possible travel time. The controls settings on the other hand are adjusted for system-wide objectives. In a perfect adaptive traffic control environment, the drivers' route choice may impact the traffic control settings, which in turn may change drivers' travel choices. The researchers have been studying the impacts of the control-driver interaction through Combined Traffic Assignment and Control (CTAC) framework for several years now [Meneguzzer, 1997]. The CTAC models simulate traffic system under the combined effect of changes in traffic controls

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The objective of this paper is to develop a CTAC model and then quantify the benefits of capturing control-driver interaction in terms of travel time improvements and total delay reductions. In a recent research effort Farhan et al [Farhan et al, 2010] evaluated the benefits of providing the network travel time information to drivers with traffic control improvements. A small network from Salt Lake City Area was used. The research work concluded that network travel time information to drivers from past travel experience alone can improve the total travel time and delay by more than 30%. In addition, signal control improvements from fixed-time to vehicle actuated controls could further yield more than 10% improvements in travel time and delay.

This research paper was motivated by writers' aspiration to further investigate the benefits of CTAC when used for a relatively larger network with traffic controls improvement from fixed-time to adaptive controls. Adaptive controls are known for their capability to progress traffic through multiple-intersection networks using adaptive logics [(Luke et al, 1982), (Powell, 1987), (Kergaye et al, 2008)]. Several experiments were performed on a study area using Static Traffic Assignment (STA) and Dynamic Traffic Assignment (DTA) with fixed-time controls, vehicle-actuated controls, and adaptive traffic controls.

LITERATURE REVIEW

The literature on CTAC research can be grouped into two sections: Solution Algorithms/Model Formulations, and Implementation.

Literature Review on Solution Algorithms and Model Formulations

Allsop initiated one of the first efforts to investigate the impacts of control-driver interaction on a traffic system. Allsop based on his investigation was first to suggest that the traffic controls can impact the route choices of drivers [Allsop, 1974]. Maher and Akcelik [Maher and Akcelik, 1975], Gartner [Gartner, 1976], and Allsop and Charlesworth [Allsop and Charlesworth, 1977] investigated the joint route choice and control research problem on a theoretical level. Smith [(Smith, 1979), (Smith, 1981)], and Shefi and Powell [Shefi and Powell, 1982] investigated the problem for equilibrium. Smith presented a control policy P_o that ensures the existence of traffic equilibrium [(Smith, 1980), (Smith, 181)]. Smith and van Vuren based on previous theoretical efforts implemented CTAC model [Smith and van Vuren, 1993]. Heydecker investigated the CTAC problem from traffic control policy perspective [Heydecker, 1983]. Smith and Ghali investigated an algorithm that adjusted the traffic controls by loading small portions of traffic demand until the total traffic demand is loaded [Smith and Ghali, 1990]. Yang and Yagar investigated the optimization model formulation of the CTAC problem [Yang and Yagar, 1995]. Meneguzzer, and Taale and Zuylen presented an overview of 25 years of research on CTAC [(Meneguzzer, 1997), (Taale and Zuylen, 2001)].

Literature Review on Implementation

Gartner and Al-Malik presented an iterative approach for CTAC problem using a link performance function [Gartner and Al-Malik, 1996]. Gartner and Stamatiadis developed a theoretical framework for implementation of joint control and DTA [Gartner and Stamatiadis, 1997]. Meneguzzer solved a combined route choice control problem using a diagonalization algorithm [(Meneguzzer, 1995), (Meneguzzer, 1996)]. Taale and van Zuylen investigated CTAC with STA on different control types [Taale and van Zuylen, 2000]. The study left other research avenues open especially using adaptive controls and DTA.

Mahmassani and Ta-YIN HU presented a DTA based procedure to investigate network flows with offline and online traffic controls [Mahmassani and Ta-YIN HU, 1997]. Abdelfatah and Mahmassani presented a joint control and assignment problem to optimize the network performance with dynamic route guidance [Abdelfatah and Mahmassani, 2000]. Cipriani and Fusco investigated the interaction between signal settings and traffic flows for optimal control settings on CTAC framework [Cipriani and Fusco, 2003]. Granato suggested that the transportation planning agency in Iowa is using CTAC model for use limited to long range planning only [Granato, 1998].

To summarize, traffic assignment and control optimization methods are considered two separate processes in practice, and tend to ignore control-driver interaction. The CTAC models can capture control-driver interaction in a combined framework. Previous research emphasizes on using CTAC in practice.

METHODOLOGY

Test Scenarios

Six scenarios were tested with STA and DTA, and traffic controls improved from Fixed Controls to Vehicle Actuated, and finally to Adaptive Traffic Controls. Table 1 briefly describes the test scenarios.

TABLE 1 Test Scenarios

Scenario Matrix	Dynamic Traffic Assignment	Static Traffic Assignment
Fixed Controls	Scenario 1	Scenario 4
Vehicle-Actuated Controls	Scenario 2	Scenario 5
Adaptive Controls	Scenario 3	Scenario 6

SCENARIOS WITH DTA – The DTA based scenarios represent a situation where drivers have network travel time information from past travel experience.

SCENARIO WITH STA – The STA based scenarios represent a situation where drivers do not have network travel time information based on past travel experience.

The traffic controls in DTA and STA scenarios changed as follows:

SCENARIO 1 and SCENARIO 4 – The Scenarios represent a situation where the traffic controls have not been upgraded for long time because better timings cannot be provided due to multi-modal operation. Fixed-Time Traffic Controls will not respond to changes in traffic flow.

SCENARIO 2 and SCENARIO 5 – The Scenario represents a situation where the traffic flows are unpredictable and congested. Vehicle Actuated Traffic Controls may respond to changes in traffic flow.

SCENARIO 3 and SCENARIO 6 – Adaptive Traffic Controls continuously measure the traffic demand on all roads in a coordinated network and optimize signal timings for detected traffic.

Figure 1 displays the sequence of scenario testing process with DTA based Scenarios, STA based Scenarios and traffic control improvements.

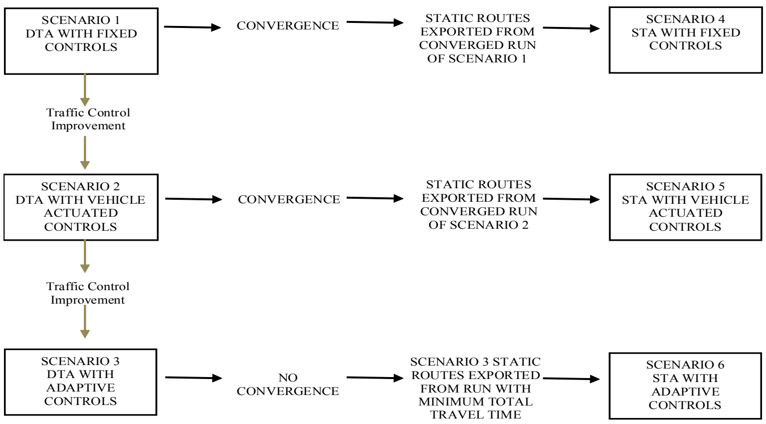


FIGURE 1 Sequence of Scenario Testing Process.

Overview of Traffic Analysis Tools

Study Area

Park City road network described in Figure 2 was used as a test network. The network consists of principal arterials SR 224 and SR 248, and several intersections on them. The study area can be divided into three sections described below:

1. Kimball Junction – Interchange at SR 224 and I-80 with close by signalized intersections at SR224 and Landmark Drive, and SR 224 and Olympic Park. The area generates work and retail trips due to commercial district in the vicinity.
2. Intersections of SR 224 at Bobsled Drive, Bear Hollow, Sun Peak, Canyons, Payday, and Thaynes Drive provide access to downtown area, several residential developments, and Park City recreational facilities.
3. Intersections at Park Avenue and SR 248, Park Avenue and Deer Valley, Deer Valley and Bonanza Drive, Bonanza Drive and SR 248, and Comstock Drive and SR 248 form a number of traffic routes to CBD.

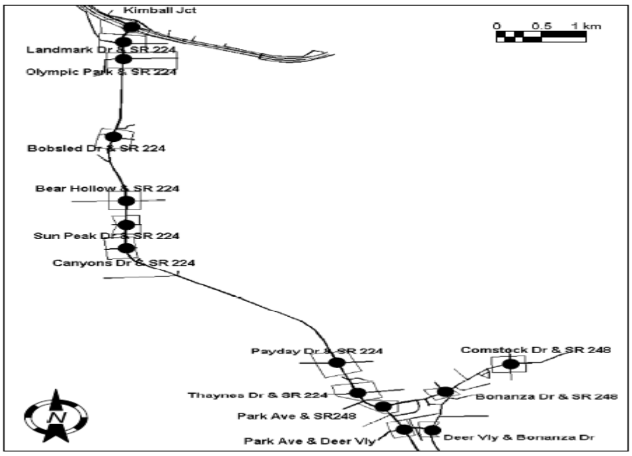


Figure 2 Study Area - Park City road network

Modeling and Simulation Software

The PTV Vision software VISUM, a travel demand modeling software and VISSIM, a microscopic traffic simulator were used to model the scenarios. VISUM 9.4 was used for Origin-Demand (OD) matrix correction. VISSIM 5.00-08 simulation software was used to emulate realistic traffic system. VISSIM has been proven as a reliable micro simulation tool [(Jha et al, 2004), (Fellendorf and Vortisch, 2001)].

Combined Traffic Assignment and Control Framework

The traffic assignment process typically does not include traffic controls while the signal control optimization process in practice takes the traffic flows as known, and post optimization flows are ignored. The two separate processes thus ignore the control-driver interaction. CTAC models can capture the control-driver interaction in a combined framework. Figure 3 describes the typical traffic analysis process with no traffic controls and no feedback on post assignment travel costs, and a CTAC modeling framework with flow responsive traffic controls and feedback on post assignment travel costs.

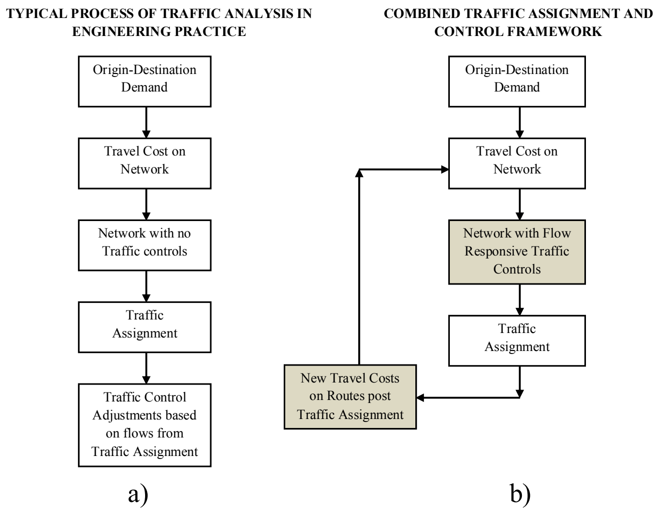


FIGURE 3 Typical Traffic Analyses and Combined Traffic Assignment and Control Framework a) Typical Traffic Analysis, b) Combined Traffic Assignment and Control Framework

Dynamic Traffic Assignment in VISSIM

VISSIM applies DTA as an iterative simulation process. Drivers choose the routes based on travel experience (travel cost) in previous run. VISSIM computes the best paths in each run based on travel cost. Travel cost can be travel time, trip length, toll, or any other general cost associated with trip making. The changing traffic conditions in each run may change the travel cost, leading to more routes with lower costs in subsequent runs. For convergence, VISSIM 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%.

For this paper, the travel time on paths was used as cost in DTA. A convergence criterion of 10% travel time difference on paths was used. Travel time evaluation files containing travel time for each OD pair were written for every run of DTA simulation using the "Evaluation Files" feature of VISSIM. DTA based Scenario 1 with fixed-time controls and Scenario 2 with vehicle actuated controls met the set convergence criteria after 95 iterations, yet both the Scenarios were ran for 100 iterations after convergence for consistency in comparisons. DTA based Scenario 3 with Adaptive Traffic Controls did not reach convergence even after 100 iterations.

Static Traffic Assignment in VISSIM

VISSIM provides an option to convert current state of the DTA into STA by static routes, volumes on the routes, and current state DTA data files. The data files with extensions WEG, BEW, and FMA contain the list of discovered paths, costs for paths, and OD information respectively. The use of static routes based assignment means the routes are frozen and vehicle inputs, routing decisions are created using the static data files. The Static Routes were exported from the converged runs of scenario 1 and 2. Since the Scenario 3 did not converge within 100 iterations, the run with minimum total travel time was used to export static routes. The Static Routes with the data files were then used by Scenario 4, 5 and 6 for 100 STA simulations for each Scenario.

Fixed-Time and Vehicle Actuated controls

Fixed-Time controls 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-Time controls are best with predictable traffic volumes.

Vehicle-actuated controls can respond to variations in traffic flow and are typically used for irregular traffic flow. The actuated controls can be grouped into two types: semi-actuated and fully-actuated. Semi-actuated controls primarily apportion the green time to the major movement of traffic and minor streets are accommodated at vehicle detection. Fully-actuated controls detect vehicles on all approaches of the intersection and make adjustments accordingly. 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.

The vehicle-actuated controls in the simulations had the traffic control programs from the old field data prior to installation of SCATS on Park City network shown in Figure 3. The field traffic control programs were collected from the Utah Department of Transportation (UDOT).

Adaptive Traffic Controls (SCOOT)

Split Cycle Offset Optimization Technique (SCOOT) was used for Adaptive Traffic Controls. SCOOT is developed by Transportation Research Laboratory (TRL) of U.K. in the early 1980s [Hunt et al, 1981]. The recent version of SCOOT is "Managing Congestion, Communications and Control" or MC3 [Bretherton, 2007]. In one of the recent research efforts, Kergaye *et al* comparatively evaluated SCOOT and Sydney Coordinated Adaptive Traffic Control System (SCATS) with vehicle actuated-coordinated- traffic control in Park City, Utah [Kergaye et al, 2008]. SCOOT and SCATS, individually were found to reduce overall network delays and stops by at least 14% and 9%, respectively, when compared to actuated-coordinated control from the field. For SCOOT principles, evaluations and features, the reader is referred to SCOOT User Guide Version 4.2 [Siemens Traffic Controls LTD., 2003]. For basic setup between SCOOT and micro simulation, we refer to previous studies done by Martin and Feng [Martin and Feng, 2002], and by Feng et al [Feng et al, 2003].

Signal Control Emulator

A National Electrical Manufacturers Association (NEMA) Standard Signal Control Emulator was used for traffic controls. With this controller VISSIM can simulate fully actuated signal control as well as coordinated and vehicle-actuated coordinated signal controls. The interface to the controller is accessed through VISSIM but saves its settings to an external data file with the extension (NSE). To use the NEMA standard emulator in VISSIM, traffic control programs for each intersection in the study area network were exported to NEMA format using VISUM software.

SCOOT Setup

VISSIM simulations with SCOOT need interface between SCOOT and VISSIM. The SCOOT-VISSIM interface was developed as a partial Hardware-In-the-Loop Simulation (HILS) and Emulation-In-the-Loop Simulation (EILS) setup [8]. The central SCOOT kernel is based on Alpha-DEC computer connected to an IBM compatible PC running VISSIM micro-simulation. The interface between the two computers is through EILS, which is used to communicate between VISSIM's traffic model, SCOOT, and emulation of local intersection controllers in VISSIM. The SCOOT-VISSIM system for the Park City network was carefully and extensively built, calibrated, and fine-tuned according to process established by Stevanovic and Martin [Stevanovic and Martin, 2008]. The process involves building network, coding the traffic control programs, and validating the SCOOT performance in VISSIM. The SCOOT settings were iteratively adjusted to minimize the deficiencies. Figure 4 describes the result of successive iterations of SCOOT calibration. Total stops in the micro simulation model were gradually reduced in more than 45 iterations.

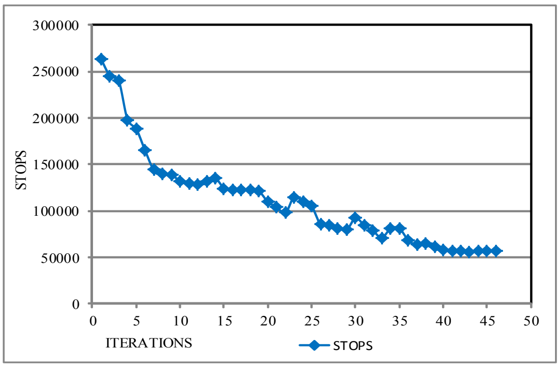


FIGURE 4 Reductions in Number of STOPS in SCOOT Calibration

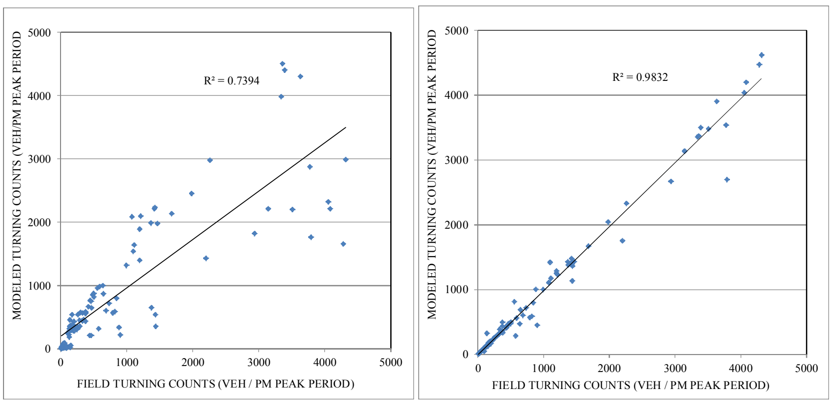
Validation and Calibration of the Park City Network

Data used in this study were collected between 4 PM and 7 PM on weekdays, under fair weather and dry pavement conditions. The collected data was stopped delays at intersections, saturation flow rates, turning movement counts, and corridor travel times. The VISSIM model calibration was based on turning movement counts, saturation flow rates, desired speed decisions, control delays. Model validation was based on travel times, and turning movement counts vs. modeled volume.

Origin-Demand (OD) Matrix Correction Process

Initial OD matrix for the selected pm peak period was obtained from the Wasatch County Regional Planning Organization travel demand model. The travel demand model is calibrated and validated for the Heber region and is used for regional transportation planning purposes. Due to the macroscopic nature of the RPO model, OD information extracted from the model was susceptible to some errors. The comparison of modeled volumes to field counts was therefore necessary. VISUM has several routines to assign travel demand specified in OD-matrix [VISUM 9.0 Manual, 2004]. A multi-equilibrium assignment routine was used to assign demand from initial OD matrix. Volume-Delay functions were specified as Bureau of Public Roads (BPR) curves. The assignment process did not give a close match of modeled volume to the field counts.

In order to better fit the field-counts, the initial OD matrix was corrected using VISUM based TFlowFuzzy matrix correction module which is based on well-known entropy maximization algorithm [van Zuylen and Willumsen, 1980]. The output from each run of OD matrix-correction is a synthetic matrix, which by assignment reduces the difference between the counts and modeled data. For this paper, the matrix was calibrated for the turning-movement counts only. The counts included left -turns, right-turns, and through movements at the intersections. The process with 77 iterations led to an OD matrix with R^2 of 0.98 for modeled vs. field counts, a decent match to the turning movement counts in the study area. Figure 5 parts a) and b) display the scattered plot for modeled versus count data for initial and calibrated OD matrices.



(a) (b)

FIGURE 5 Calibration of OD Matrix: a) Modeled vs. Field counts from initial OD Matrix b) Modeled vs. Field counts from calibrated OD Matrix.

RESULTS AND DISCUSSION

Evaluation of Results

Table 2 displays the mean and standard deviation of total delay and total travel time from the simulation-runs in six test scenarios. For consistency in comparisons 100 simulation-runs were applied in each scenario.

TABLE 2 Total Delays and Total Travel Time Comparison

Description	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Mean Total Delay (Hours)	18543	13785	10940	22987	21407	17018
Standard Deviation (Total Delay)	861	730	708	1934	1927	1684
Mean Total Travel Time (Hours)	23572	19636	17967	28117	26907	22926
Standard Deviation (Travel Time)	704	561	404	1897	1687	1340

Percentage changes in mean delay and mean travel time from Table 2 were compared across the scenarios to compute the relative delay reduction and travel time improvement benefits. Figure 6 part a) displays percent reduction in total delay and part b) displays percent improvement in total travel time.

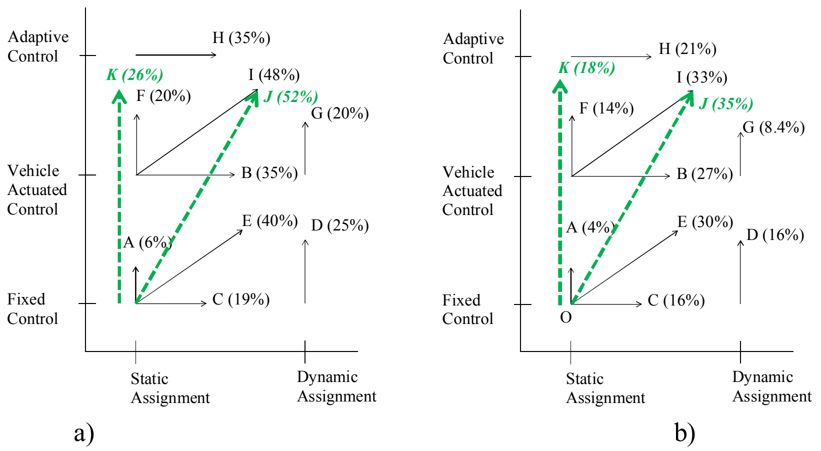


FIGURE O al Delay Reductions and Total Travel Time Improvements a) Total Delay Reductions, b) Total Travel Time Improvements.

Figure 6 part a) and b) compares the delay reduction and travel time improvement benefits in terms of provision of network travel time information to drivers from past travel experience (STA vs. DTA) with the possibility of improvements in traffic controls.

Fixed Time Controls to Vehicle Actuated Controls Improvements

Pont O**:** represents Scenario 4 with fixed traffic controls and static assignment.
Point A: If only the traffic controls are changed from fixed-time to vehicle-actuated while drivers do not have network travel time information, the total delay can be reduced by 6% and total travel time can be improved by 4%.
Point B: In addition to changing the controls from fixed-time controls to vehicle-actuated, if the drivers have information on network travel time, the total delay can be further reduced by 35% and total travel time can be further improved by 27%.
Point C: If the traffic controls are kept fixed-time while the drivers have information on network travel times, the total delay can be reduced by 19% and total travel time can be improved by 16%.
Point D: In addition to network travel time information to drivers, if the traffic controls are changed from fixed-time to vehicle-actuated, the total delay can be further reduced by 25% and total travel time can be further improved by 16%.
Point E: If the traffic controls are changed from fixed-time to vehicle-actuated and at the same time drivers have network travel time information, the total delay can be reduced by 40% and total travel time can be improved by 30%.

Vehicle Actuated Control to Adaptive Control Improvements

Point F: If the traffic controls are further improved from vehicle actuated to adaptive traffic controls while the drivers do not have network travel time information, the total delay can be further reduced by 20%, and travel time can be further improved by 14 %. These travel time and delay benefits will be in addition to the benefits already achieved at point A.
Point G: If the drivers have network travel time information, and traffic controls are further improved from vehicle actuated controls to adaptive traffic controls, total delay can be further reduced by 20% and travel time can be further improved by 8%. These travel time and delay benefits will be in addition to the benefits already achieved at point D.
Point H: In addition to further improving the traffic controls from vehicle actuated to adaptive traffic controls, if the drivers have network travel time information, the total delay can be further reduced by 35% and total travel time can be further improved by 21%.

Point I: If the traffic controls are further improved from vehicle actuated to adaptive controls and at the same time drivers have network travel time information, the total delay can be reduced by 48% and total travel time can be improved by 33%.

Fixed Controls to Adaptive Control Improvements

Point *J*: If the traffic controls are changed from fixed controls to adaptive controls and at the same time drivers are provided network travel time information, the total delay can be reduced by 52% and total travel time can be improved by 35%. Point *K*: If the traffic controls are improved from fixed controls to adaptive traffic controls while the drivers do not have network travel time information, the total delay can be further reduced by 26%, and travel time can be further improved by 18 %.

To evaluate the convergence and existence of system-level stable traffic flows, the total travel time and the total delay from all the runs were compared. Figure 7 parts a)-d) show that in Scenario 1-2 with DTA, the traffic flow converged and stabilized at lower congestion levels compared to Scenario 4-5 with STA which stabilized at higher congestion levels. In Scenario 3 with adaptive controls and DTA the traffic flow stabilized at even lower congestion levels yet did not converge in 100 simulation-runs. In Scenario 6 with adaptive controls and STA the flow stabilized at relatively lower congestion levels compared to Scenario 4 and Scenario 5 yet at higher congestion levels compared to Scenario 3 with DTA and Adaptive Controls.

LIMITATIONS AND FUTURE RESEARCH

A computer with Intel ® Core ™ 2 QUAD CPU with 2.66 GHz processor and 3.24 GB of RAM was used. Achieving model convergence through DTA simulation process took over 65 hours for 100 iterations. However, should the development trends continue, this may prove a smaller obstacle to researchers.

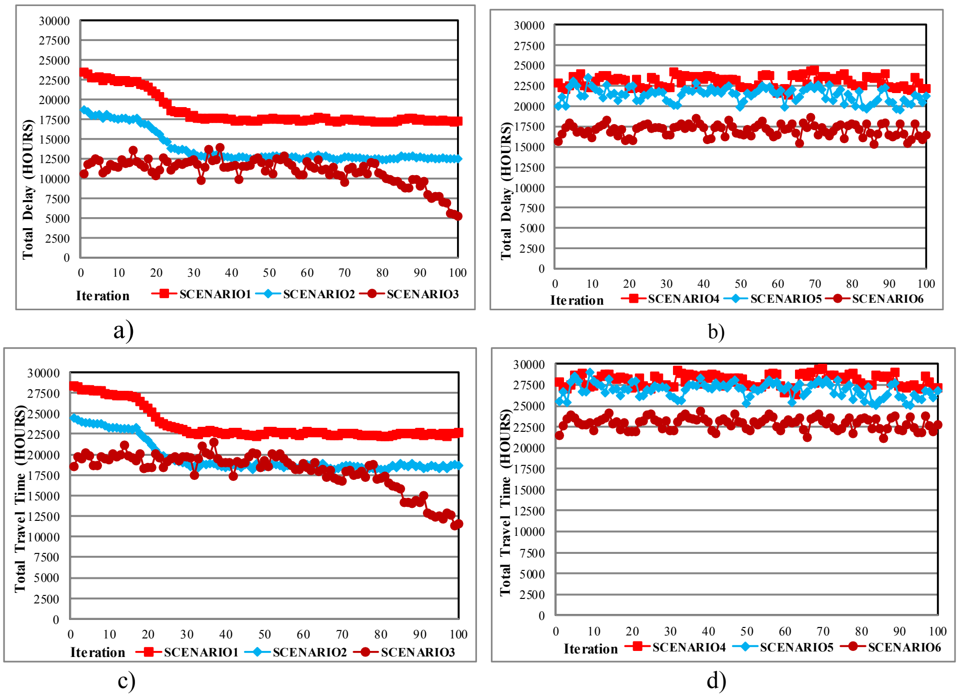


FIGURE 7 Total Delay and Total Travel time a) Total Delay in DTA Scenarios, b) Total Delay in STA Scenarios c) Total Travel Time in DTA Scenarios d) Total Travel Time in STA Scenarios

CONCLUSION

The paper evaluated the benefits of providing network travel time information to drivers from their past travel experience with improvements in traffic controls. A network from Park City, Utah was used to test six scenarios using VISSIM micro-simulator. The CTAC framework used in these tests was able to capture interaction between drivers' route choices and flow responsive traffic controls in a combined framework. The results suggest the following:

1. Provision of network travel time information to drivers from their past travel experience alone can reduce the total delays by 19% and total travel time by 16%.
2. Traffic control improvements from Fixed-Time to Adaptive Controls alone can reduce the total delay by 26% and improve the total travel time by 18%.
3. Provision of network travel time information to drivers from past travel experience combined with improvements of Fixed-Time controls to Adaptive controls can reduce total delay by 52% and improve total travel time by 35%.
4. With growing use of Adaptive and Vehicle Actuated traffic controls 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 congestion mitigation projects in practice.

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