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APPLICATION OF THE STOCHASTIC OPTIMIZATION METHOD IN OPTIMIZING TRAFFIC SIGNAL CONTROL SETTINGS

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Abstract:

Traffic congestion has greatly affected not only the nation’s economy and environment but also every citizen’s quality of life. A recent study shows that every American traveler spent an extra 38 hours and 26 gallons of fuel per year due to traffic congestion during the peak period. Of this congestion, 10% is attributable to improper operations of traffic signals. Surprisingly, more than a half of all signalized intersections in the United States needs to be re-optimized immediately to maintain peak efficiency. Even though many traffic signal control systems have been upgraded from pre-timed controllers to actuated and adaptive controllers, the traffic signal optimization software has not been kept current. For example, existing commercial traffic signal timing optimization programs including SYNCHRO and TRANSYT-7F do not optimize advanced controller settings available in the modern traffic controllers including minimum green time, extension time, and detector settings. This is in part because existing programs are based on macroscopic simulation tools that do not explicitly consider individual vehicular movements. To overcome such a shortcoming, a stochastic optimization method (SOM) was proposed and successfully applied to a signalized corridor in Northern Virginia.

This study presents enhancements made in the SOM and case study results from an arterial network consisting of 16 signalized intersections. The proposed method employs a distributed computing environment (DCE) for faster computation time and uses a shuffled frog-leaping algorithm (SFLA) for better optimization. The case study results showed that the proposed enhanced SOM method, called SFLASOM, improved the total network travel times over field settings by 3.5% for Mid-Day and 2.1% for PM-Peak. In addition, corridor travel times were improved by 2.3% to 17.9% over field settings. However, when the new SOM timing plan was compared to the new field timing plan implemented in July 2008, the improvements were marginal, showing slightly over 2% reductions in individual vehicular delay.

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ABSTRACT

Traffic congestion has greatly affected not only the nation's economy and environment but also every citizen's quality of life. A recent study shows that every American traveler spent an extra 38 hours and 26 gallons of fuel per year due to traffic congestion during the peak period. Of this congestion, 10% is attributable to improper operations of traffic signals. Surprisingly, more than a half of all signalized intersections in the United States needs to be re-optimized immediately to maintain peak efficiency. Even though many traffic signal control systems have been upgraded from pre-timed controllers to actuated and adaptive controllers, the traffic signal optimization software has not been kept current. For example, existing commercial traffic signal timing optimization programs including SYNCHRO and TRANSYT-7F do not optimize advanced controller settings available in the modern traffic controllers including minimum green time, extension time, and detector settings. This is in part because existing programs are based on macroscopic simulation tools that do not explicitly consider individual vehicular movements. To overcome such a shortcoming, a stochastic optimization method (SOM) was proposed and successfully applied to a signalized corridor in Northern Virginia.

This study presents enhancements made in the SOM and case study results from an arterial network consisting of 16 signalized intersections. The proposed method employs a distributed computing environment (DCE) for faster computation time and uses a shuffled frog-leaping algorithm (SFLA) for better optimization. The case study results showed that the proposed enhanced SOM method, called SFLASOM, improved the total network travel times over field settings by 3.5% for Mid-Day and 2.1% for PM-Peak. In addition, corridor travel times were improved by 2.3% to 17.9% over field settings. However, when the new SOM timing plan was compared to the new field timing plan implemented in July 2008, the improvements were marginal, showing slightly over 2% reductions in individual vehicular delay.

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INTRODUCTION

Out of about 300,000 traffic signalized intersections in the United States (Texas Transportation Institute [TTI], 2007), 56% of them are in urgent need of re-optimization of their traffic signal timing plans (Oak Ridge National Laboratory [ORNL], 2004). Traffic engineers scored themselves a "D" grade on their traffic signal operations performance (National Transportation Operations Coalition, 2007). Many factors have led to such low scores including staff shortages, limited funding, and lack of adequate optimization software.

With respect to the optimization methods, none of the existing traffic signal optimization programs such as SYNCHRO (Husch and Albeck, 2004), TRANSIT7-F (Hale, 2005), and PASSER-V (TTI, 2002) explicitly optimizes advanced controller settings including minimum green time, extension time, detector recall mode, etc. This is because the fidelity of the traffic simulation logic used in these programs is not adequate for the optimization of these advanced settings. While basic parameters such as cycle length, offsets, and max green times can be easily obtained from existing tools, traffic engineers have to use default parameters or choose parameters based on a trial-and-error method for more advanced settings.

In addition, the existing tools, which are based on macroscopic simulation models, are unable to account for individual vehicular driving behaviors. The two key components in traffic signal optimization are (1) adequacy of the simulation tools used in the evaluation of the timing plans, and (2) the quality of the optimization method used. A microscopic simulation model, once properly calibrated, can be very effective in modeling individual vehicular driving behaviors. A few studies (Park et al., 2001; Park and Schneeberger, 2003a; Park and Schneeberger, 2003b; Yun and Park, 2006; Stevanovic et al., 2007) have already demonstrated that the stochastic optimization methods (SOM), which are based on a microscopic traffic simulation model and an optimizer, can be effective in optimizing advanced controller settings.

PURPOSE AND SCOPE

The purpose of this study was to apply a recently developed SOM to an arterial network in Northern Virginia and quantify the benefits via a before-and-after study. To this end, this project streamlined the SOM originally developed by Park and Yun (2006) to accommodate a case study site in Northern Virginia. The scope of this project was limited to a single coordinated actuated traffic signalized arterial network on Route 50 in Northern Virginia; however, the methodology can be applied to any coordinated actuated traffic signal system.

METHODS

The project team worked collaboratively with the Virginia Department of Transportation (VDOT) Northern Region Operations (NRO) personnel during the entire research effort. The following tasks were performed to achieve the study objectives.

Task 1: Modify/Enhance Original Stochastic Optimization Method

This task updated the SOM originally developed by Park and Yun (2006) to make it applicable to the study network. A detail description of the SOM can be found in Park and Yun (2006).

The original SOM consisted of a genetic algorithm (GA)-based optimizer, written in MATLAB code, and a microscopic simulator, CORSIM. In this study, CORSIM is replaced by VISSIM, another microscopic model gaining popularity in VDOT when simulation modeling is required. In addition, given that the MATLAB program was not readily available within VDOT, the team transformed the previous stochastic optimization program using a MATLAB .NET Builder to a single standalone application. An interface was developed using an independent commercial programming language, C#. The team also employed a shuffled frog-leaping algorithm (SFLA) to improve the performance of the SOM.

Task 2: Set Up Stochastic Optimization Method for Case Study Site

The project team selected a coordinated actuated traffic signal system in Route 50 as a case study site. Route 50 (i.e., Lee Jackson Memorial Highway) passes through several residential areas and retail shopping centers and serves as a major access arterial to the Northern Virginia area. One of the reasons the team selected Route 50 was that a VISSIM network was already coded for 11 signalized intersections (i.e., east of Route 28 to Rugby Road) and required less effort to calibrate and extend the coverage area. The VISSIM network was built and/or extended by converting the SYNCHRO network developed by the NRO and later was manually fine-tuned.

Task 3: Conduct Field Data Collection and Calibrate VISSIM Model

Data Collection

The project team collected field data to calibrate and validate the VISSIM microscopic simulation model for the selected case study site. These included traffic counts and travel times as performance measures used in the calibration and validation. Field data collection was conducted for both Mid-Day and PM-Peak. The traffic counts were collected by video recordings at the entry/exit points of the study corridor. Turning movements and existing signal timing plans at intersections were provided by the NRO Database. A total of seven GPS-equipped probe vehicles collected the travel time data along the study corridor.

Model Calibration

The study corridor was modeled in VISSIM. After checking on VISSIM network in terms of accuracy in geometry, volume, timing plan, etc., the simulation model was calibrated by a Latin-Hypercube Sampling (LHS) (McKay et al., 1979) with 200 samples for each Mid-Day and PM-Peak, and five replications were made for each sample. The LHS has been used in previous studies (Park et al., 2006; Park and Won, 2006) to reduce the number of combinations into a reasonable level while still adequately covering the entire parameter surface.

Task 4: Develop Traffic Signal Control Settings for Study Site

The project team applied the modified/enhanced program developed in Task 1 to obtain the optimal signal control settings for the case study site and then evaluated its performance in the laboratory. At the end of this task, the team presented the evaluation results to NRO personnel and sought approval for field deployment of the proposed signal control settings.

Task 5: Conduct Field Implementation and Evaluation

This task was intended to implement the signal control settings found in Task 4 to the traffic signal system used in the case study site and compare its performance with that of field setting. A before-and-after study was intended to measure travel times along the corridor using a couple of probe vehicles and delays from selected key approaches. In addition, the team planned to collect traffic counts from major entry and exit points.

Task 6: Write Final Report

A final report summarizing the findings from this project and recommendations for VDOT was written. In this task, the prototype software for the SOM was updated according to the recommendations provided by VDOT.

RESULTS AND DISCUSSION

Task 1: Modify/Enhance Original Stochastic Optimization Method

The previously developed SOMs used meta-heuristic algorithms such as GA, Tabu Search Algorithm, Simulated Annealing (SA), and so forth. Among these, GA showed an outstanding performance finding an optimal solution. This is why GA was considered as an optimizer at the initial stage of this study. However, it was frequently observed that the GA optimizer was not able to obtain an optimal solution for the case study network consisting of the 16 traffic signalized intersections. In addition, the amount of time required to conduct the search was extremely long. Even with over 20 days' worth of optimization runs, the optimal solution was not achieved. As such, the remainder of this section discusses proposed enhancements to the existing SOM program.

Shuffled Frog-Leaping Algorithm

An SFLA (Eusuff and Lansey, 2003), an evolutionary algorithm, was recently developed and successfully applied to several optimization problems in a few engineering applications (Elbehairy et al., 2006; Elbeltagi et al., 2007). SFLA is based on the evolution of memes carried by individuals and a global exchange of information within the population (Eusuff and Lansey, 2003). Figure 1 depicts a conceptual idea of SFLA.

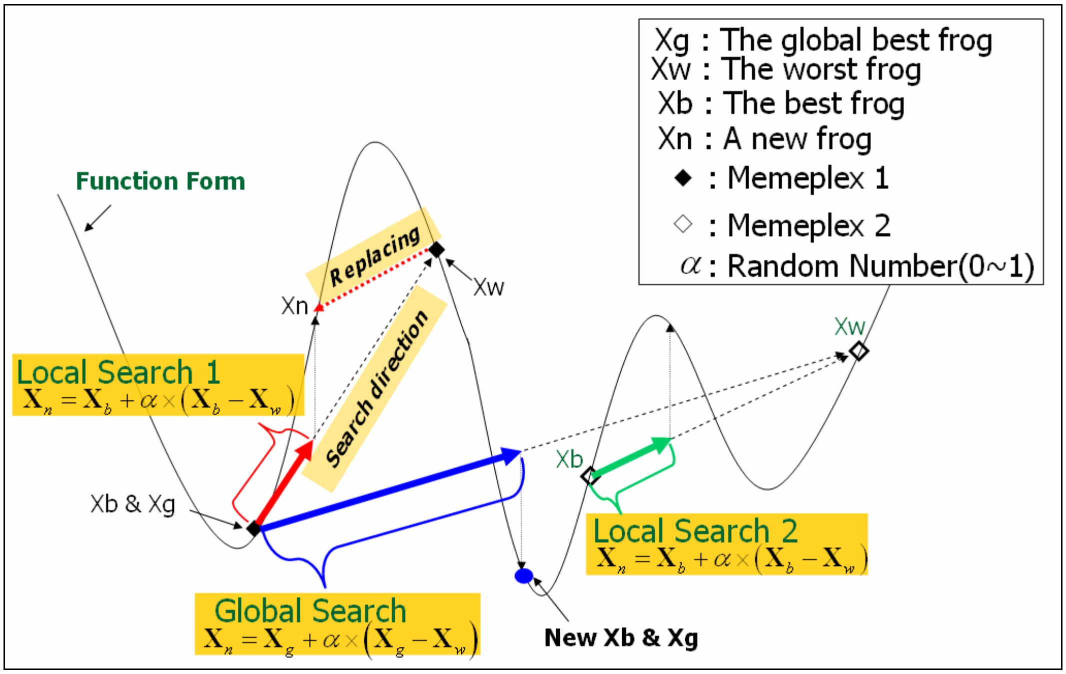

Figure 1. Conceptual Idea of SFLA

In each meme, named memeplex, the performances of individual frogs, which act as chromosomes in GA, were examined and the best frog showing the best performance was selected. The best frog then carried out a local search by exchanging its information with the worst frog showing the worst performance within the same memeplex. The exchanging scheme was formulated in Equation 1. If the performance of the new frog was better than that of the worst frog, it was replaced with the new one. Otherwise, a new frog, which was randomly created, replaced the worst frog. These local searches were simultaneously and independently performed in each memeplex. Once the local searches were complete, the global best frog over all memplexes was selected, and it exchanged its information with the worst frogs in each memeplex by using Equation 2. The same replacing procedure as in the local search was implemented, and this task was called the global search. The memeplexes were recreated after both local and global searches, and the same procedures were replicated until a stopping criterion was satisfied. Figure 2 explains the procedural framework of SFLA.

$$\mathbf{X}_n = \mathbf{X}_b + \alpha \times \left(\mathbf{X}_b - \mathbf{X}_w\right) \qquad \text{Eq. (1)}$$

$$\mathbf{X}_n = \mathbf{X}_g + \alpha \times \left(\mathbf{X}_g - \mathbf{X}_w\right) \qquad \text{Eq. (2)}$$

Where,

$\mathbf{X}_n$: A new frog

$\mathbf{X}_b$: The best frog

$\mathbf{X}_w$: The worst frog

$\mathbf{X}_g$: The global best frog

α : Random number (0.0~1.0)

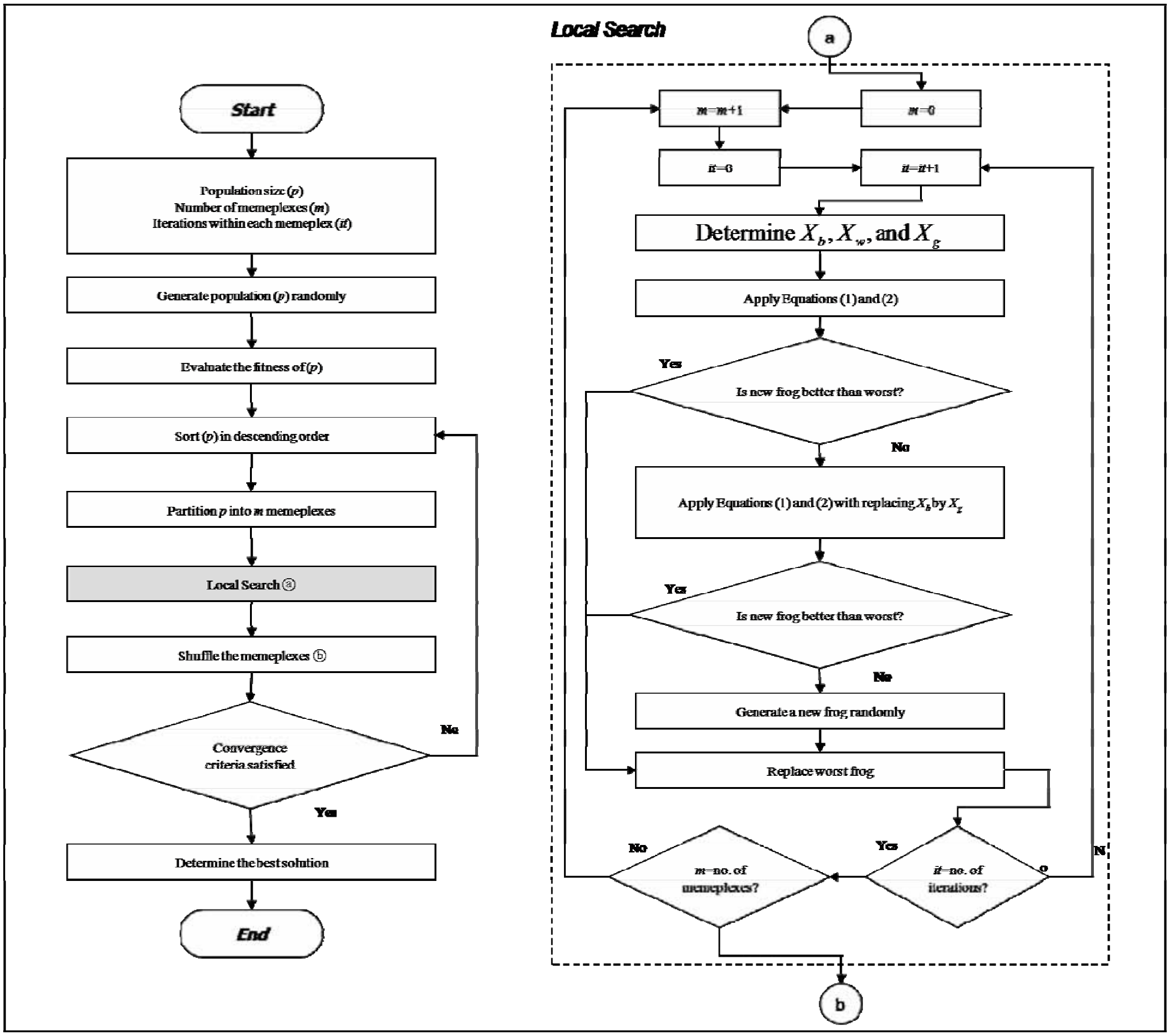

Figure 2. Procedural Framework of SFLA (Elbehairy et al., 2006; Elbeltagi et al., 2007)

Distributed Computing Environment

Given that SOM employed a microscopic simulation model for the evaluation of traffic signal control settings during the optimization runs, the amount of time required for such optimization was not trivial. For example, consider the situation where an optimization needs to make 200 independent evaluation runs with 5 replications and each run takes 100 seconds. The total simulation time required for a computer to run would be over 27 hours. If two computers were used at the same time, the run time would theoretically be reduced by half.

This project employed a distributed computing environment (DCE) to reduce the simulation computation time, and tried to obtain the results within a reasonable amount of time. The conceptual framework of master-slave-type DCE was illustrated in Figure 3. The master of DCE ensures communications between the master and the slaves that were dedicated for simulation runs, as well as assigned a new simulation job to an idling slave. Evaluation results were transmitted back to the master for further process.

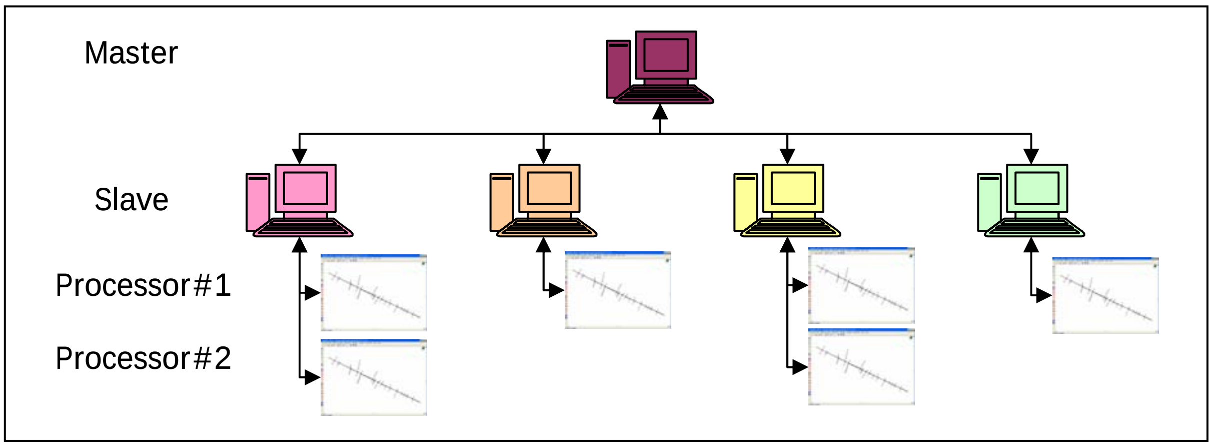

Figure 3. Conceptual Framework of DCE

Table 1 presents an experimental result demonstrating the time savings of simulation evaluations under the DCE. The experiment was implemented with a single master and up to 5 slaves, in which all CPUs were using an Intel Pentium, 3.6 GHz, and were connected by their IP addresses. Elapsed times taken to run 50 VISSIM replication runs were collected by the number of slaves in the DCE. It was observed that the time savings increased as the number of slaves in the DCE increased. As expected, the rate of time savings gradually diminished. This is, in part, due to the communication time lags between the master server and slave computers. In any event, significant time savings can be achieved with the DCE.

Table 1. Time Savings by DCE

Number of Slaves in DCE	1	2	3	4	5
Elapsed Time (Min:Sec)	70:37	36:53	25:56	18:50	14:38
Time Saving (%)	-	33:44 (47.7%)	44:41 (63.3%)	51:47 (73.3%)	54:59 (77.8%)

Standalone Application

As noted, the previous SOM program developed by Yun and Park (2006) was implemented within a MATLAB programming environment (Mathworks, 2006). While MATLAB had several advantages including easy programming, high performance numerical computing, a reliable random number generator, and so forth, it required the MATLAB to implement the SOM program.

In order for the enhanced SOM program to run stand alone (i.e., without the MATLAB program), the cores of the previous SOM program were recompiled by the MATLAB .NET Builder (Mathworks, 2006), and transformed to external dynamic linked libraries (DLLs). These DLLs were fed into a single standalone program, named SFLASOM, written by Microsoft .NET C# (Schmidt, 2004). In addition, SFLA and DCE were added into SFLASOM. Figure 4 features a snapshot of SFLASOM.

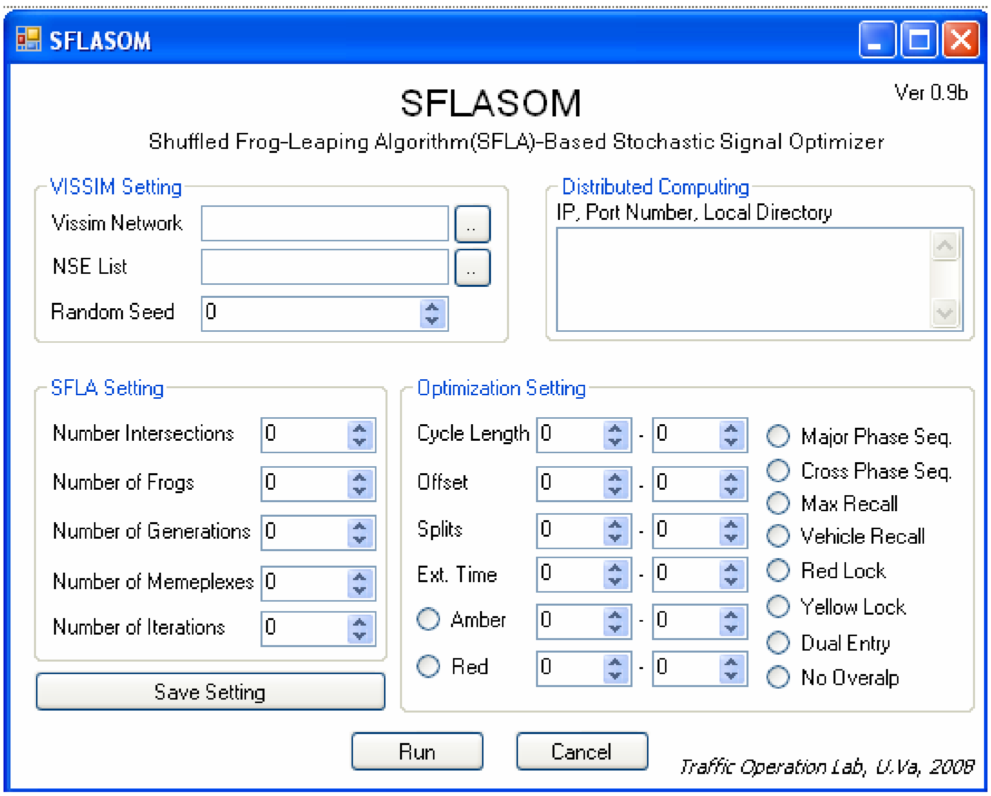

Figure 4. SFLASOM Main Menu Screenshot

Task 2: Set Up Stochastic Optimization Method for Case Study Site

A 6-mile-long section with 16 signalized intersections on the Route 50 corridor in Northern Virginia was selected. The study corridor, located between the intersections of Pleasant Valley Road and Rugby Road, is being operated by coordinated-actuated traffic signal control. The proposed method was implemented for both Mid-Day and PM-Peak periods. Figure 5 shows an aerial photo of the study corridor, and Figure 6 shows the entire study corridor modeled in VISSIM.

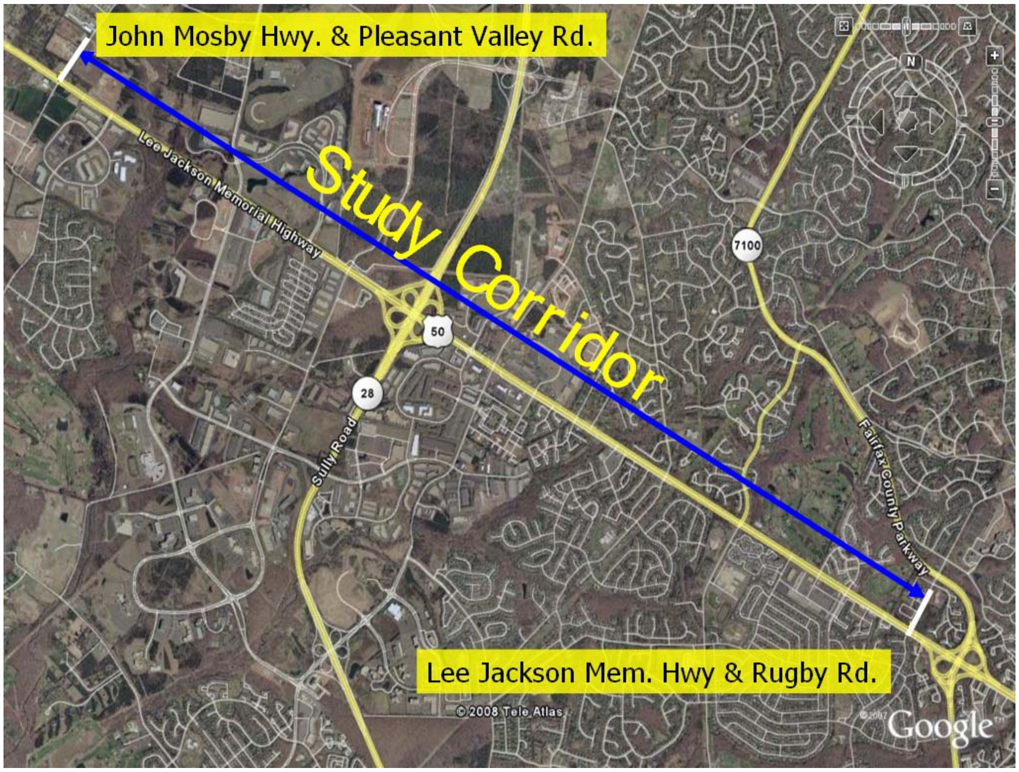

Figure 5. Aerial Photo of Study Corridor (Google, 2008)

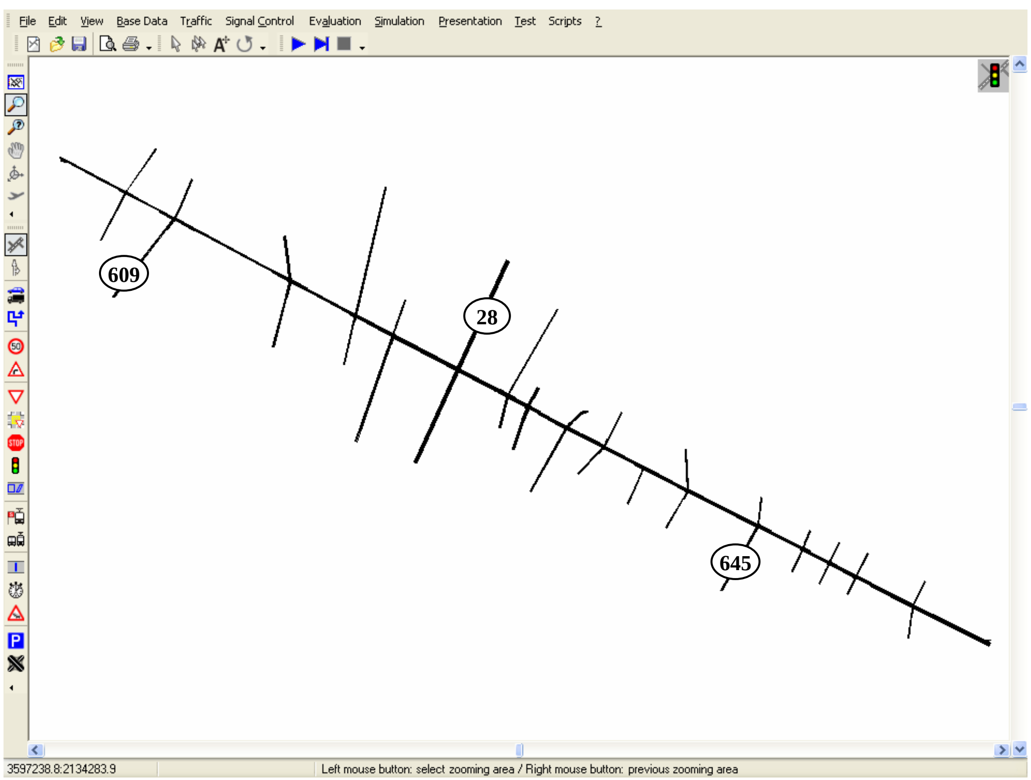

Figure 6. VISSIM Network of Study Corridor

Task 3: Collect Field Data and Calibrate VISSIM Model

Table 2 summarizes the initial ranges of parameters used for the calibration of the VISSIM model. The ranges of parameters covering lane changing, car following, and driving behaviors were obtained from the VISSIM manual, while those of desired speed distributions were determined on the basis of posted speed limit and reasonable ranges. Drivers in the VISSIM model were assigned their individual desired speeds by the desired speed distribution. The distribution could be any shape of statistical distribution, but its minimum and maximum values should be specified. There were four speed limit sections in the study corridor: 35 mph, 45 mph, 50 mph, and 55 mph. It is assumed that drivers would not exceed the posted speed limit by 10 mph or more. As such, the maximum speed of the distribution was specified to be 10 mph above the posted limit and apparently the minimum speed was the posted limit. This project assumed a triangular distribution consisting of minimum, maximum, and mean values for the desired speed distribution.

Table 2. Calibration Parameters for the VISSIM Model

Category	Parameter	Unit	Initial range	
			Min	Max
Lane Changing	Diffusion time	sec	30	90
	Min headway	ft	1.5	5
	Maximum deceleration	ft/sec^2	-16	-7
	Reduction rate	ft	164	492
	Accepted deceleration	ft/sec^2	-5	-1.6
Car Following	Number of preceding vehicles	veh	0	6
	Maximum look ahead distance	ft	0	0
	Maximum look ahead distance	ft	650	985
	Average standstill distance	ft	3	9
	Additive part of desired safety distance	ft	2	5
	Multiple part of desired safety distance	ft	3	6
Driving Behavior	Lead gap of conflict area	sec	1	5
	Safety Distance Reduction Factor	-	0	1
Desired speed distribution	Dist. #1 (30mph~45mph, Post Speed Limit:35mph)	mph	30	45
	Dist. #2 (40mph~55mph, Post Speed Limit:45mph)		40	55
	Dist. #3 (45mph~60mph, Post Speed Limit:50mph)		45	60
	Dist. #4 (50mph~65mph, Post Speed Limit:55mph)		50	65

In general, driving behaviors would be somewhat different depending on time-of-day (TOD). For example, most drivers during the morning and evening peak periods would use roads for commuting purpose while Mid-Day drivers would travel for different purposes such as shopping or social. In addition, drivers' characteristics such as age and gender during the Mid-Day would be different from those during Peak periods. To incorporate such differences, the project team calibrated the VISSIM model for two parameter sets: one for Mid-Day and the other for PM-Peak.

Figures 7 and 8 show XY plots of simulated EB and WB travel times from the 200 LHS samples for Mid-Day and PM-Peak, respectively. Each point represents an average over five replications. Depending on the parameter sets used in the experimental design, the ranges of simulated travel times vary significantly. The boxed area indicates field measured travel times by each direction. The parameter sets belonging to the squared box properly represented field conditions. Among these eight parameter sets, the best parameter set was selected by comparing individual link travel times.

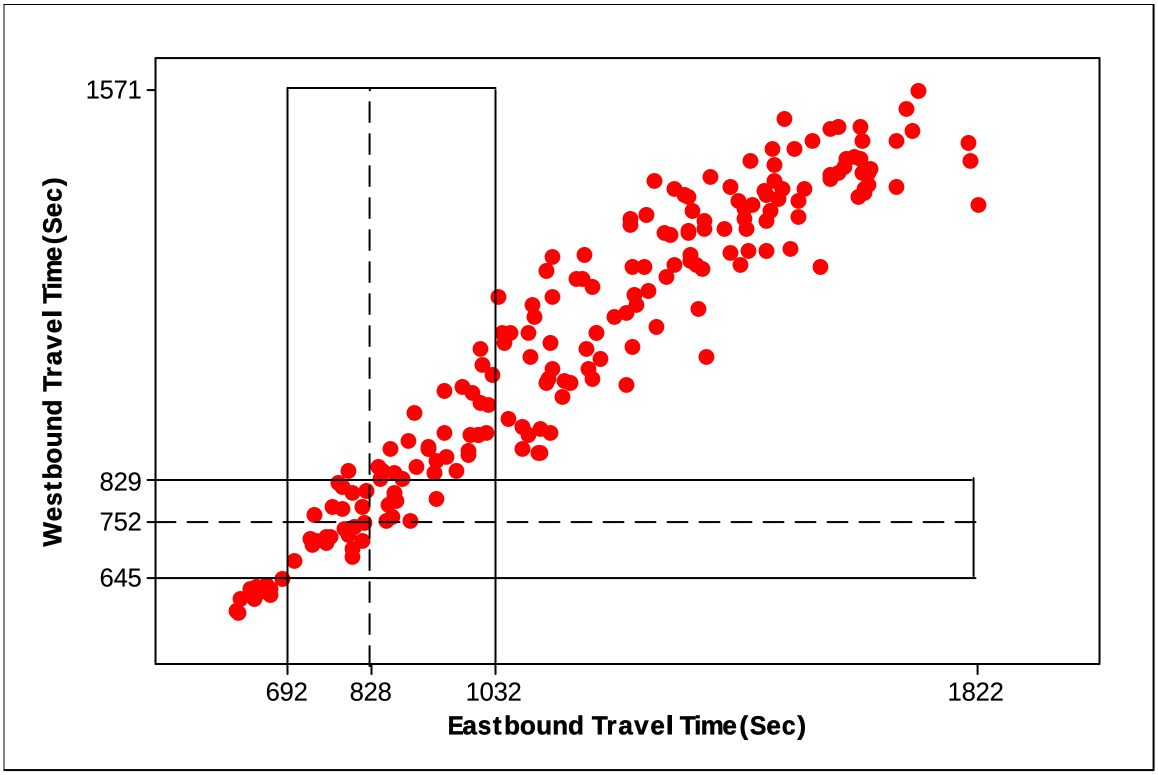

Figure 7. Selecting the Best Sample for Mid-Day VISSIM Network Calibration

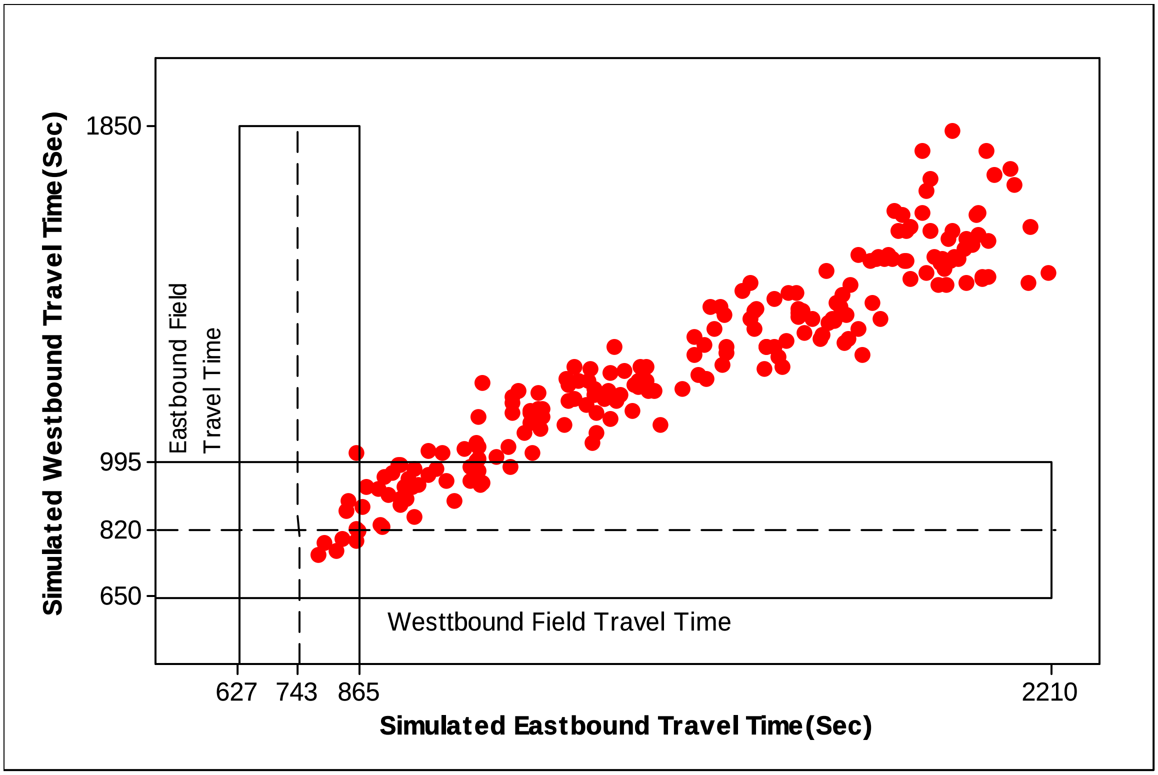

Figure 8. Selecting the Best sample for PM-Peak VISSIM Network Calibration

The selected eight parameter sets were investigated on the basis of the magnitude of how close they were to the mean of collected field travel times (i.e., dashed lines) for each directional travel time. Table 3 summarizes the corridor travel times for Mid-Day and PM-Peak by field observation and simulation results based on default and calibrated parameters. The calibrated corridor travel times were much closer than those of default parameter sets, and the *t*-test results indicated that calibrated parameters adequately represent field conditions.

Table 3. Summary of Calibration Results

Period	Case	Westbound Travel Time (Sec)			Eastbound Travel Time (Sec)		
		Mean	STD	t-value	Mean	STD	t-value
Mid-Day	Field Observation	752.0	67.1	-	828.8	134.1	-
	Default Parameter	846.1	55.0	-2.66	930.7	49.4	-1.73
	Calibrated Parameter	725.1	35.1	0.90	790.2	31.8	0.68
PM-Peak	Field Observation	820.3	104.3	-	743.7	89.3	-
	Default Parameter Set	931.1	106.1	-1.84	966.8	89.3	-4.56
	Calibrated Parameter	787.0	78.6	0.65	796.8	48.1	-1.52

Task 4: Develop Traffic Signal Control Settings for Study Site

To obtain the optimal signal control settings, the SFLA-based SOM program under DCE was implemented. Table 4 summarizes the parameters of SFLASOM running for Mid-Day and PM-Peak.

Table 4. SOM Implementation Parameters

	SFLA			DCE
	Total Populations	Total Memeplexes	Replications	Total Slaves
Mid-Day	200	20	15	8
PM-Peak	250	25	15	12

The evaluations of developed traffic signal control settings by using SFLASOM (based on the enhancements made in Task 1) were performed for three scenarios for Mid-Day and PM-Peak periods, respectively. These scenarios were labeled as SYNCHRO, Field, and SOM. *SYNCHRO* refers to the optimal timing plans obtained from the SYNCHRO program. *Field* represents the timing plan actually implemented in the study corridor. The NRO staff optimizes a traffic signal timing plan using SYNCHRO but implements it only after extensively tweaking it based on simulations and actual field observations. Thus, the Field timing plan generally works better than SYNCHRO. Finally, *SOM* represents a timing plan optimized by the proposed SFLASOM approach. It is important to mention that the main difference between SYNCHRO and SFLASOM is the simulation fidelity used in the optimization; that is, SYNCHRO treats vehicle movements as flow while SFLASOM models individual vehicles based on a microscopic simulation. As such, the proposed SFLASOM can adequately integrate additional network components including ramp metering strategy while SYNCHRO cannot.

The performance of each scenario was determined by two measures of effectiveness: vehicle hours traveled (VHT) and directional corridor travel time. VHT was selected as it considers the entire system performance including those remaining vehicles at the end of the simulation run. In addition, the corridor travel time was chosen as it directly considers progression along the corridor.

In order to account for day-to-day variations, each scenario was replicated 50 times and the distribution of MOE was used in the comparisons. Table 5 summarizes the evaluation scenarios and their descriptions. SFLASOM optimized the minimum green time, minimum of maximum green, and vehicle extension time.

Table 5. Scenario Descriptions

Parameter	Scenario		
	SYNCHRO	Field	SOM
Cycle Length (Seconds)	Fixed (MD=150, PM=200)	Fixed (MD=150, PM=200)	Fixed (MD=150, PM=150)
Offset	Optimized	Tweaked from SYNCHRO	Optimized
Max Green	Optimized	Tweaked from SYNCHRO	Optimized
Min Green	Fixed (Major St.:15,20 sec) (Cross St.:5~10 sec)	Fixed (Major St.:15,20 sec) (Cross St.:5~10 sec)	Optimized
Minimum of Max Green	Fixed (10 sec)	Fixed (10 sec)	Optimized
Vehicle Extension Time	Fixed (4~7 sec)	Fixed (4~7 sec)	Optimized
Amber & Red Clearance	Fixed (5~7 sec)		
Phase Sequence	Fixed (Current Field Setting)		

Performance Comparisons

Comparison of System Performance

Figures 9 and 10 show the evaluation results of each scenario for Mid-Day and PM-Peak. As clearly demonstrated in these figures, the traffic signal timing plans obtained from SFLASOM outperformed SYNCHRO and Field. In Mid-Day, SFLASOM improved the total travel time of the entire system by 7.5% and 3.5% over SYNCHRO and Field, respectively. In addition, the system performances of PM-Peak were also improved by 8.8% over SYNCHRO, and 2.2% over Field. The benefits of the SOM are summarized in Table 6. The differences among SFLASOM, SYNCHRO and Field were statistically significant at the 95% confidence level.

It is of interest to see that the evaluation results of both Mid-Day and PM-Peak obtained from Field settings were better than those from SYNCHRO. The fact that SFLASOM outperformed Field indicated that a systematic approach used in the SFLASOM appeared to be more effective than tweaks made in Field over the SYNCHRO optimized timing plan.

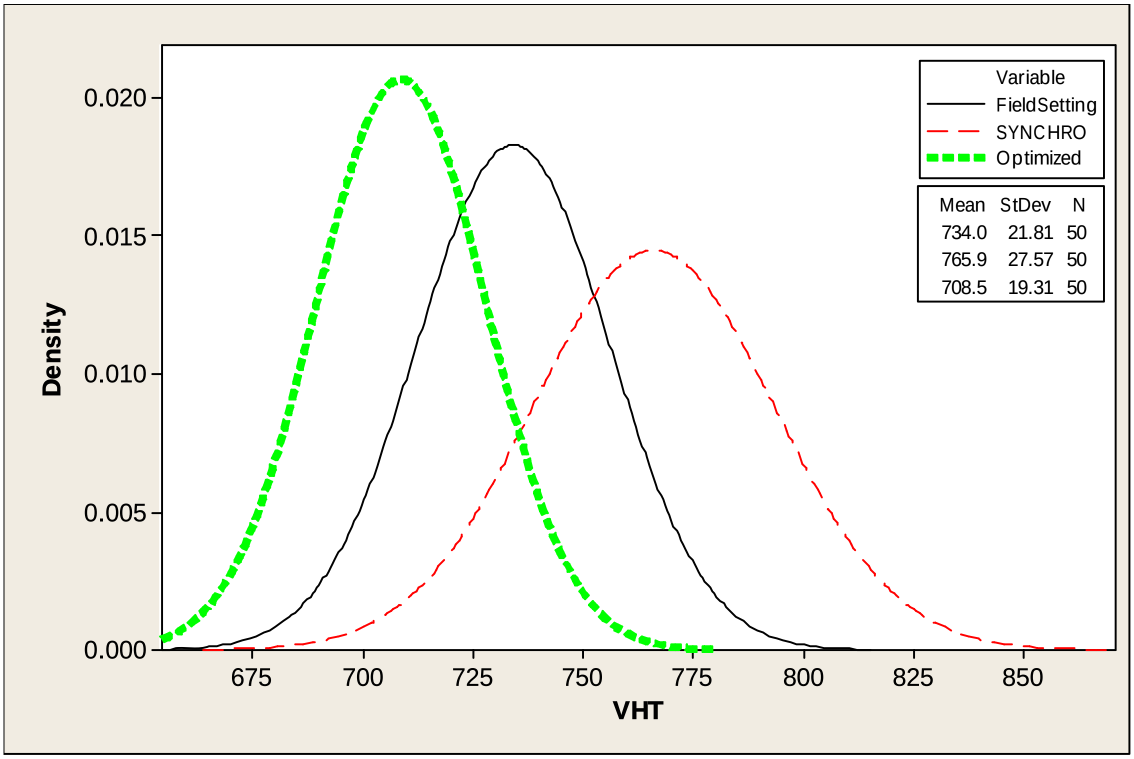

Figure 9. Mid-Day Evaluation Results of VHT

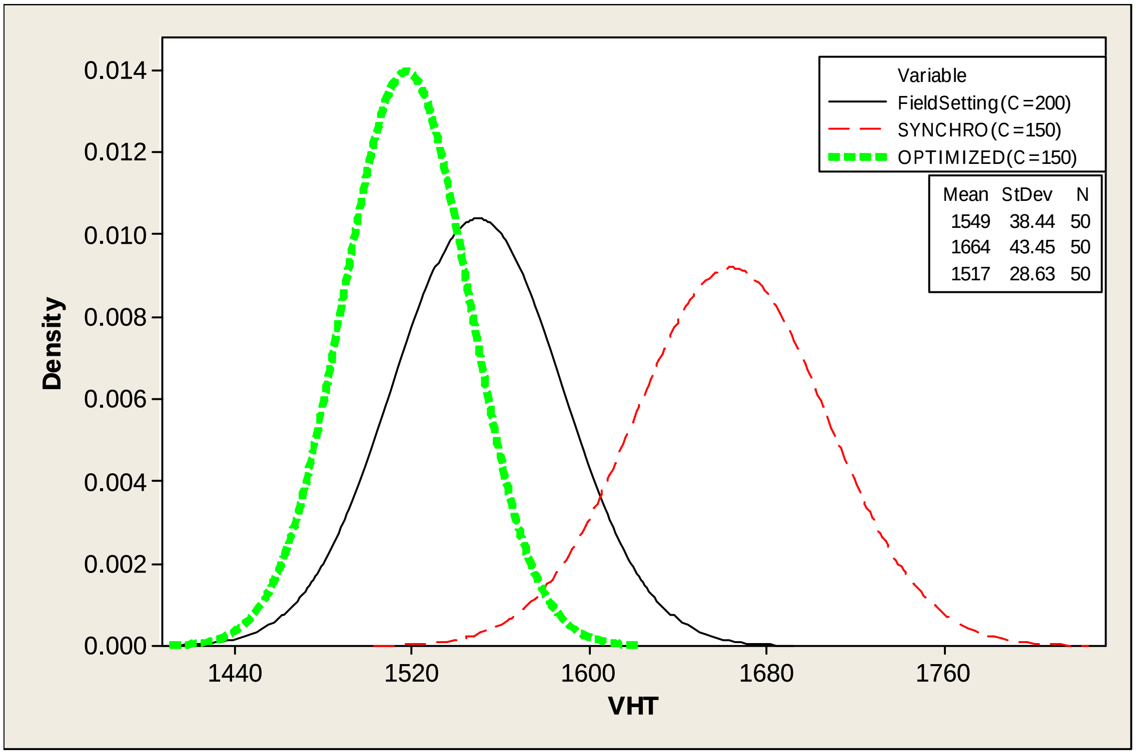

Figure 10. PM-Peak Evaluation Results of VHT

Table 6. Summary of System Performance

Scenario		VHT Mean (of 50 evaluations)	Standard Deviation
Mid-Day	SOM	709	16.3
	Field	734	21.8
	Gain(%)	25 (3.5%)	-
	SYNCHRO	766	27.6
	Gain(%)	57 (7.5%)	-
PM-Peak	SOM	1517	28.6
	Field	1549	38.4
	Gain(%)	32 (2.1%)	-
	SYNCHRO	1664	43.45
	Gain(%)	147 (8.8%)	-

Comparison of Corridor Travel Time

As noted, westbound and eastbound travel times on the study corridor were examined. The evaluation results of Field and SOM were compared. Figures 11 through 14 show the distributions of the corridor travel times for both directions during Mid-Day and PM-Peak periods. The corridor travel times of SYNCHRO were not shown because Field outperformed SYNCHRO as demonstrated in the system level evaluations.

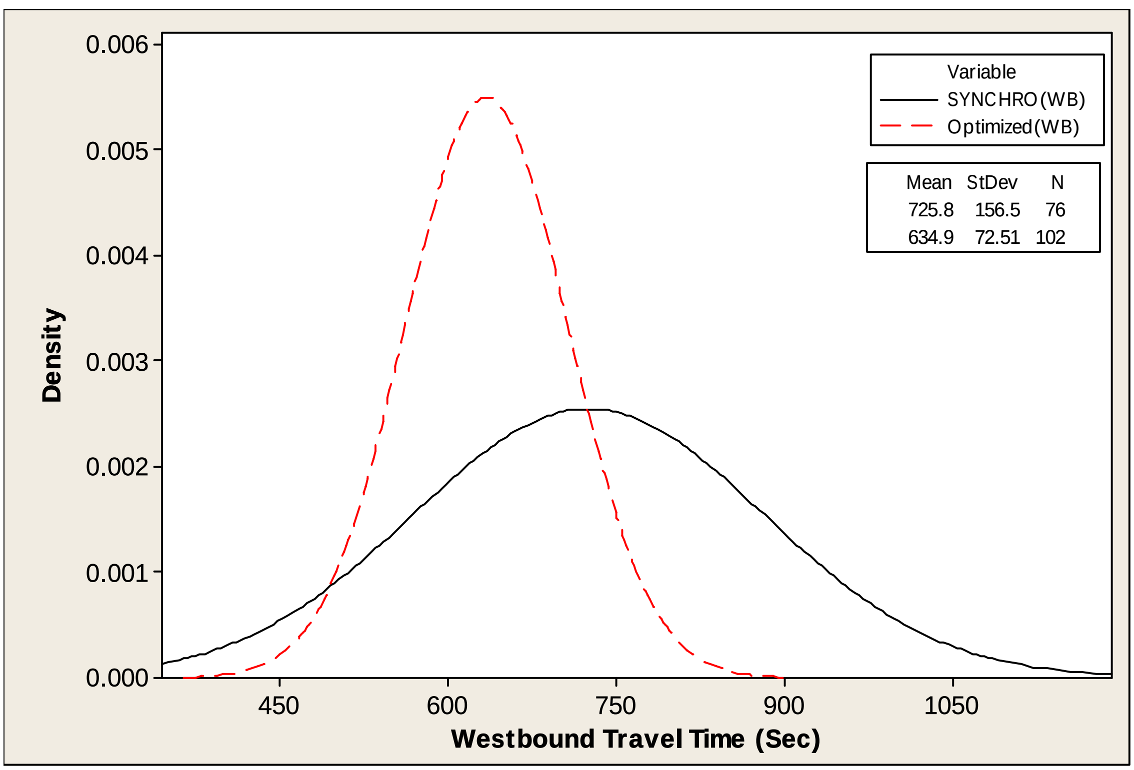

Figure 11. Mid-Day Evaluation Results of Westbound Travel Time

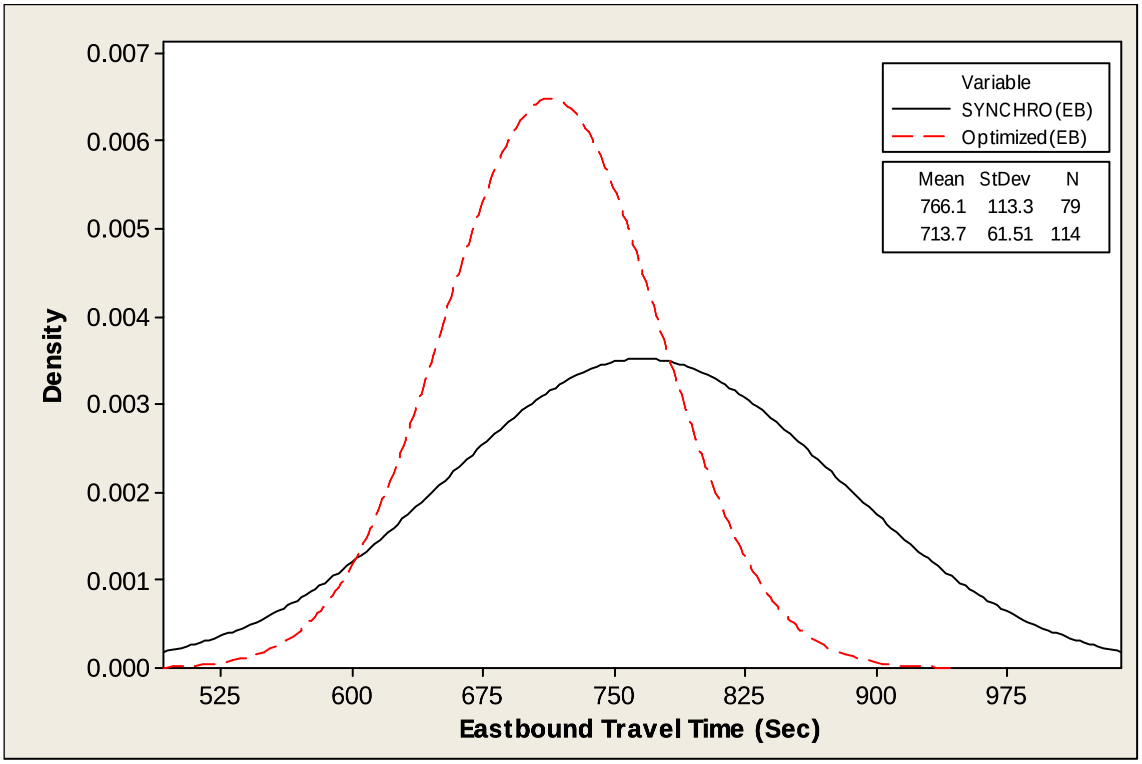

Figure 12. Mid-Day Evaluation Results of Eastbound Travel Time

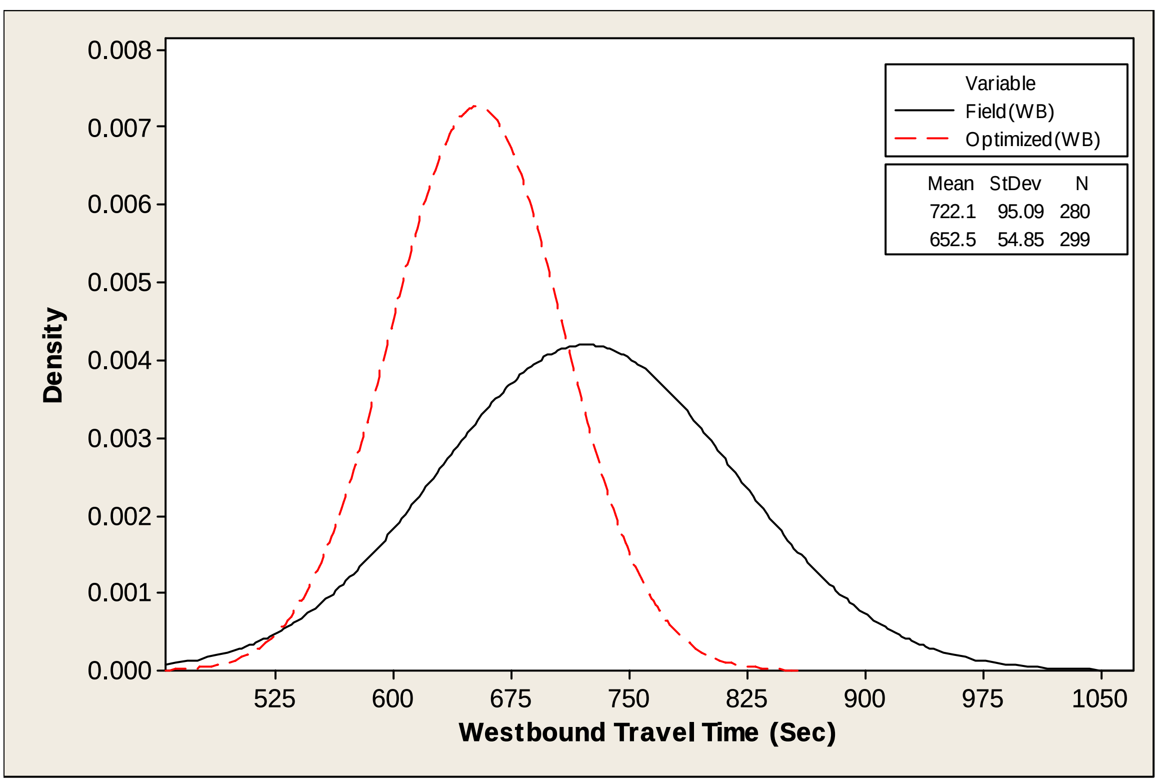

Figure 13. PM-Peak Evaluation Results of Westbound Travel Time

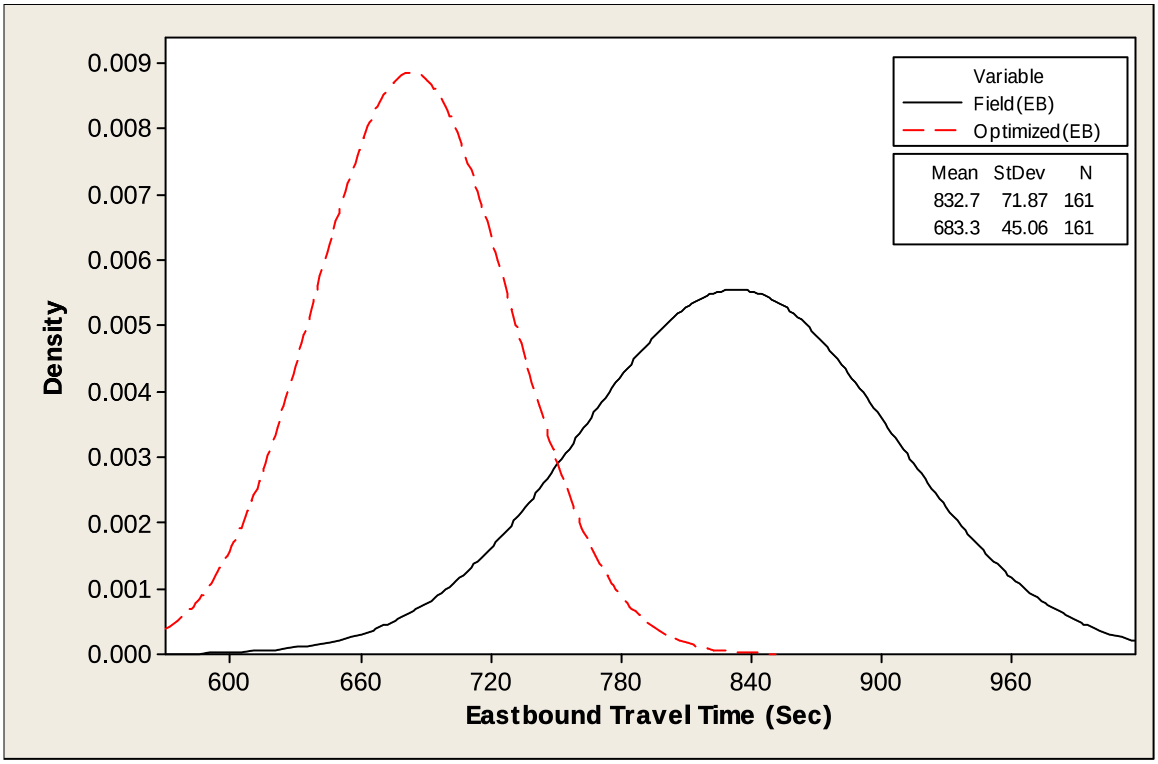

Figure 14. PM-Peak Evaluation Results of Eastbound Travel Time

The SFLASOM-based timing plans outperformed the Field timing plans. The average travel times between SFLASOM and Field were significantly different at the 95% confidence level. When the standard deviation was compared, it was clear that the SFLASOM timing plans were more robust than the Field timing plans (see Table 7). It is of interest to see that the SFLASOM for PM peak timing plan showed a much narrower distribution, indicating a more reliable performance with respect to variations in day-to-day traffic demand.

Table 7. Comparison of Corridor Travel Times

Period	Direction	Scenario	Mean	St. Dev.
Mid-Day	Westbound Travel Time (seconds)	Field	677.9	77.02
		SOM	563.4	75.67
		Gain (%)	*114.5 (16.9%)*	-
	Eastbound Travel Time (seconds)	Field	734.6	56.72
		SOM	717.5	50.19
		Gain (%)	*17.1 (2.3%)*	-
PM-Peak	Westbound Travel Time (seconds)	Field	722.1	95.09
		SOM	652.5	54.85
		Gain (%)	*69.6 (9.6%)*	
	Eastbound Travel Time (seconds)	Field	832.7	71.87
		SOM	683.3	45.06
		Gain (%)	*149.4 (17.9%)*	

Task 5: Conduct Field Implementation and Evaluation

VDOT's NRO just completed an optimization of the Route 50 corridor traffic signal timing plan and implemented a new timing plan in July 2008. During the optimization, the corridor was divided into two coordinated actuated traffic signal systems: one with the cycle length of 160 seconds, and the other with the cycle length of 140 seconds. This study optimized the entire system with a single cycle length of 150 seconds. This along with a tight schedule and NRO's move to a new office made implementing the newly optimized timing plan in the field impractical. As such, it was decided not to conduct field implementation. Instead, simulation runs were conducted and a field observation of NRO's new time plan was conducted to ensure the validity of the simulation runs.

Evaluation of New Field and New SOM Timing Plans

The new field timing plan developed and implemented in July 2008 by VDOT's NRO and the new SOM timing plan were evaluated using the calibrated VISSIM model (see Task 3) for Mid-Day. The new SOM timing plan had to be developed as the traffic patterns (e.g., traffic volume and turning movement percentages) had changed since it was optimized. The comparison results based on 50 VISSIM replications are summarized in Tables 8 and 9 for the network-wide travel times and delays and corridor travel time, respectively.

While the network-wide performances and the westbound corridor travel time of the new SOM were improved, eastbound travel time became worse than that of new field. This could be due to the nature of the fitness function (i.e., total travel time) used in the SOM optimization; that is, the SOM optimizer sought to improve the entire system travel time and happened to favor westbound traffic. The VISSIM simulation results showed that the new SOM timing plan marginally improved the system performance over the new field timing plan: over 1% total travel time and 2% vehicular delay. Statistical *t*-tests comparing the performance of these two timing plans were conducted. The results show that the differences are statistically significant, indicating that the new SOM outperformed the new field (see the *p*-values in Table 8). However, the corridor travel times showed mixed results: the new SOM outperformed the new field on westbound travel time, while the new field outperformed the new SOM for eastbound travel time. An investigation on each approach at the intersection level confirmed that the new SOM improved cross street delays while maintaining a similar performance on major corridor approaches.

Table 8. Comparisons of Total Travel Times and Network Delays

Performance Measure	New Field		New SOM		p-value
	Mean	Std. Dev.	Mean	Std. Dev.	
Total Travel Time (VHT)	737	14.8	729	13.5	0.007
Network Delay (Sec/Veh)	142	4.1	139	4.7	0.000

Table 9. Comparisons of Corridor Travel Times

Direction	New Field		New SOM		p-value
	Mean	Std. Dev.	Mean	Std. Dev.	
Westbound Travel Time (Sec)	686	156.7	637	57.9	0.001
Eastbound Travel Time (Sec)	660	59.6	707	55.3	0.000

Field Evaluation of New Field Timing Plan

Field Travel Time and Volume Data Collection

In order to validate the predictions made by the calibrated VISSIM network for the new timing plans, field travel times were collected on August 27, 2008. In addition, traffic volumes were collected at the entry and exit points of the corridor using video cameras. This was because traffic demand might have changed since the data collection conducted for the new field timing plan. As summarized in Table 10, the traffic volume differences between the two data sets appear to be fairly small given that field collected data did not use peak hour factor (PHF) because only 15-minute counts were taken.

The corridor travel times for westbound and eastbound were collected by two GPS device-equipped probe vehicles. A total of four probe runs were made during Mid-Day, and each of these travel time is summarized in Table 11.

Table 10. Comparisons of Entry/Exit Volumes at Study Corridor

	Westbound Volume (VPH)			Eastbound Volume (VPH)		
	Field Collected	New Field Plan	Diff.	Field Collected	New Field Plan	Diff.
Entry	2,111	2,240	-5.7%	1,253	1,310	-4.3%
Exit	1,293	1,358	-4.8%	2,471	2434	1.5%

Table 11. Probe Vehicle Travel Time Runs (in Seconds)

	Run 1	Run 2	Run 3	Run 4
Westbound	548	766	580	612
Eastbound	879	592	822	637

Validation of New Field Timing Plan Predictions

While the bars in Figures 15 and 16 indicate the frequencies of individual vehicles' corridor travel times that were obtained from the VISSIM evaluation for the new field timing plan, each arrow presents the observed field corridor travel times collected by the probe vehicles. As these figures clearly demonstrate, all collected travel times are within the range of predicted travel times by the VISSIM model. Moreover, more field measured travel times hit the high frequency travel time bars. After the actual corridor travel time variations are taken into consideration, the results clearly support the assertion that the calibrated VISSIM model adequately predicts the performance of the new field timing plan. Thus, the new SOM evaluation results obtained from the VISSIM are considered to be reliable.

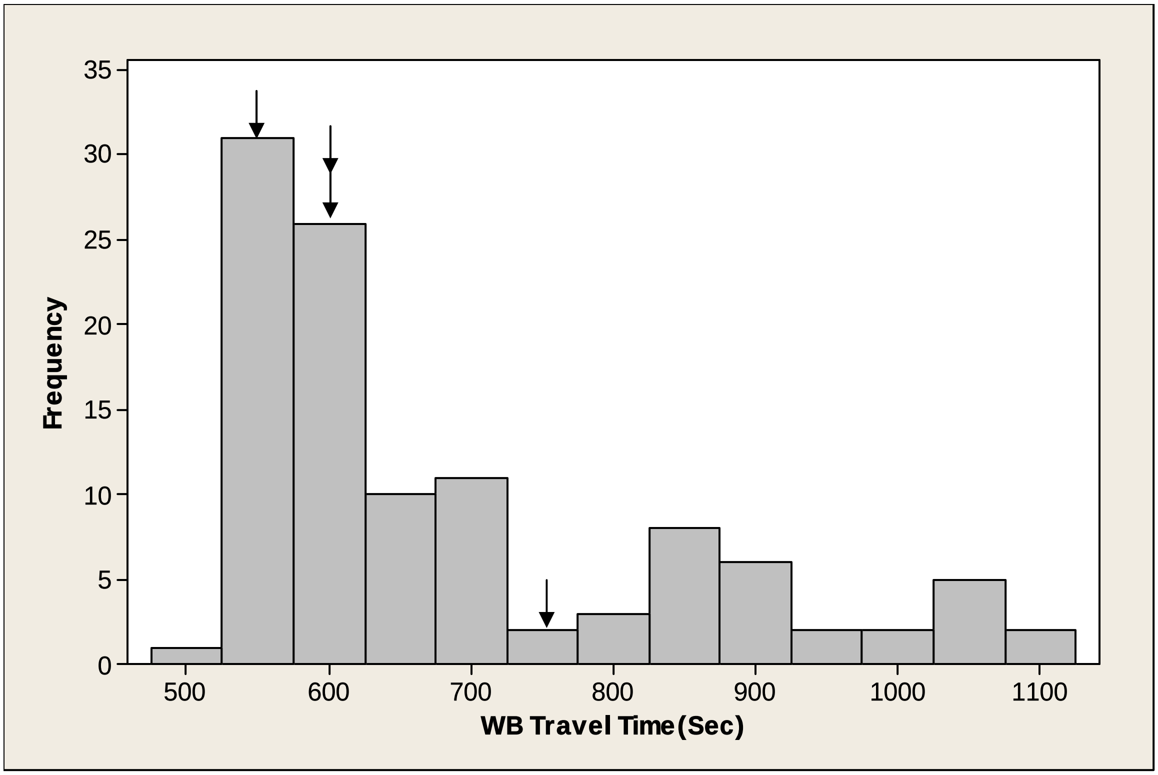

Figure 15. Westbound Corridor Travel Time by Simulation (bars) and Probe Vehicles (arrows)

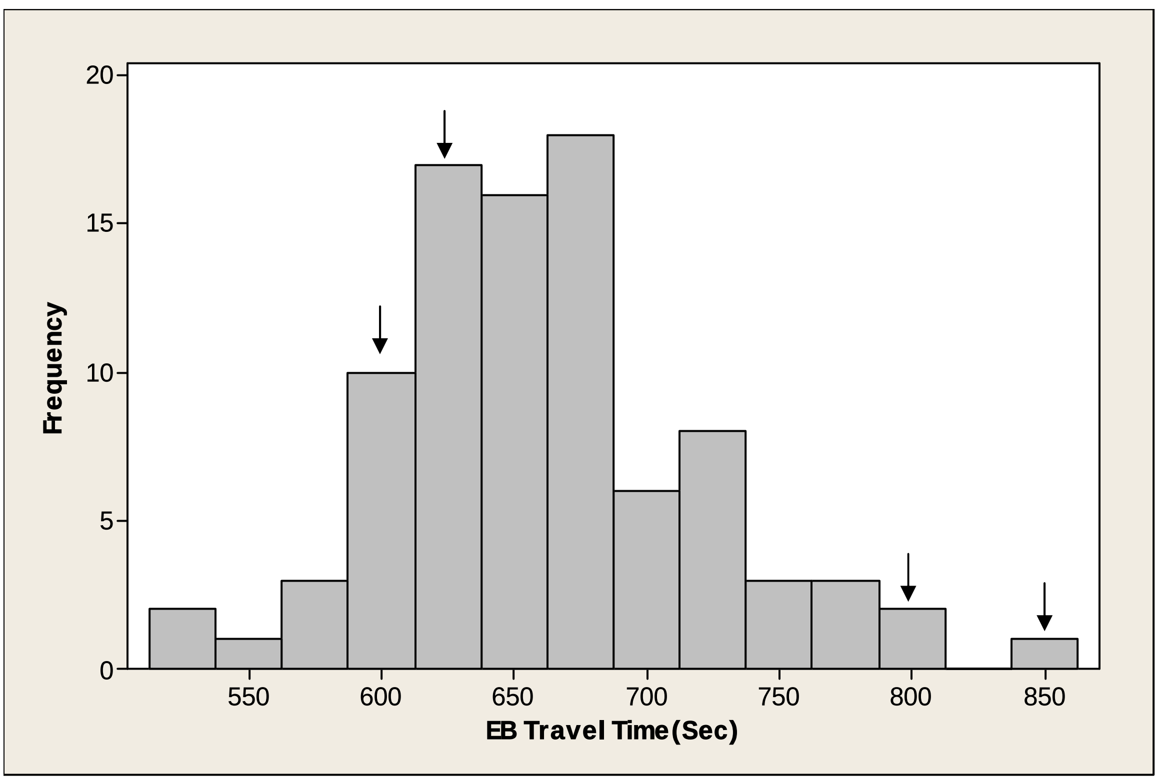

Figure 16. Eastbound Corridor Travel Time by Simulation (bars) and Probe Vehicles (arrows)

FINDINGS AND CONCLUSIONS

- *The SFLASOM program developed in this study provides a more efficient method of traffic signal timing optimization when compared to other methods.* SFLASOM combines an SFLA with a DCE technique. SFLASOM reduced the total number of evaluations during the optimization, while GA-based SOM frequently failed to converge. In addition, the total simulation run times required for the entire evaluations were largely reduced by the DCE.

- *The graphical user interface improved the usability of the program over earlier versions of SOM.* While the previous SOM program required the MATLAB program to execute, the enhanced SOM was newly developed as a standalone MATLAB-embedded version with an integrated graphical user interface.

- *Compared to current field settings, SFLASOM improved the total network travel times over field settings by 3.5% for Mid-Day and 2.1% for PM-Peak. When compared to SYNCHRO settings, the total network travel times were reduced by 7.5% and 8.8% for Mid-day and PM-Peak, respectively.* The performance of the enhanced SFLASOM was investigated at a corridor with 16 signalized intersections using multiple simulation runs.

- *NRO's traffic signal timing optimization practice is significantly better than the national state of the practice.* The performance of field settings over SYNCHRO settings showed fairly large improvements. Current field settings improved the total network travel time by 4.2% for Mid-Day and 6.9% for PM-Peak.

- *Compared to current field settings, SFLASCOM improved the performance of corridor travel times over field settings by 16.9% for westbound and 2.3% for eastbound travel times for Mid-Day and 9.6% for westbound and 17.9% for eastbound travel times for PM-Peak.*

- *A significant benefit of SFLASOM is the applicability of the method to cases that the standard SYNCHRO-based approach cannot address.* One such case is the integrated optimization of ramp metering rates and traffic signal control settings.

- *The calibrated VISSIM model is capable of accurately predicting the field performance of developed signal settings.* This was demonstrated by comparing field observations based on probe vehicles to the model output. This finding supports the validity of the VISSIM evaluation results on the SFLASOM timing plans that were not implemented in the field.

RECOMMENDATIONS

1. *VDOT regional traffic operations managers should carefully consider the adoption of SFLASOM for the optimization of traffic signal timing plans, particularly where integrated freeway and arterial operations are desired.*

2. *VDOT traffic signal operations engineers should implement the DCE technique when SFLASOM is adopted*. The DCE reduced the simulation running time by 63% with three slave computers. Thus, a large scale network optimization could be implemented within a reasonable amount of time.

3. Given that the methodology developed in this study can be implemented beyond traffic signal control systems optimization, *VDOT regional operations managers should consider implementing the proposed approach in the optimization of systems operations strategies.* The development of incident management strategies and evacuation plans are two activities that could potentially benefit from this method.

COSTS AND BENEFITS ASSESSMENT

Estimation of Annual Travel Time Savings

The calculation of travel time savings was based on the total network travel time in vehicle hours traveled (VHT) obtained from the VISSIM simulation runs. It was assumed that the total travel time savings were accrued from two time periods: Mid-Day (Noon to 1 P.M.), and PM-Peak (4 P.M. to 5 P.M.). Savings from these two periods were treated as daily time savings and then multiplied by 261 normal workdays per year to obtain annual travel time savings.

While this study was being conducted, VDOT's NRO implemented a new field timing plan in July 2008. Thus, the cost-benefit analysis considered benefits from both time periods (i.e., before and after July 2008).

The resultant total annual travel time savings on the 16-intersection corridor was estimated to range from 4,698 to 14,877 VHT per year as summarized in Table 12.

Table 12. Estimated Travel Time Savings

	Time Period	Benefit (Vehicle Hours)	Annual Savings (Vehicle Hours per Year)
Old Field (before July 2008)	Mid-Day	25	6,525
	PM-Peak	32	8,352
	Sum	57	14,877
New Field (implemented in July 2008)	Mid-Day	8	2,088
	PM-Peak*	10	2,610
	Sum	18	4,698

*PM-peak benefit is interpolated.

Estimation of Annual Benefit and Costs

To calculate the annual benefit achieved by SFLASOM, a cost of $17.02 per person-hour of travel was used (TTI, 2005). Assuming one person per vehicle, after multiplying by the annual time savings, the annual benefit of optimizing timing plans on the 16-intersection corridor was calculated to be from $79,960 (= 4,698 VHT × $17.02 for new field timing) to $253,206 (= 14,877 VHT × $17.02 for old field timing plan).

Based on recent studies, the costs to optimize traffic signal timing plans ranged from $2,500 to $3,500 per intersection from 2004 through 2006 (U.S. Department of Transportation

ITS Joint Program Office, 2008). Using the most conservative cost of $3,500 an intersection, the total cost of optimizing timing plans on the 16-intersection test corridor is $56,000. When the minimum value of the yearly benefit was considered, this resulted in an estimated total savings for 1 year for 16 signalized intersections of $23,960, or $1,498 per intersection; under the maximum value of the estimated benefit, the total savings was estimated to be $197,206, or $12,325 per intersection

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