Misc. Contracts and Agreements
No. 27146

Research Project Work Plan

For

CRITERIA FOR THE SELECTION AND APPLICATION OF ADVANCED TRAFFIC SIGNAL SYSTEMS: PHASE I

Project Number SPR 729

Submitted by

Yinhai Wang, PhD
Associate Professor

Smart Transportation Application & Research Laboratory (STAR Lab)
Department of Civil and Environmental Engineering
University of Washington
Seattle, WA 98195-2700

for

Oregon Department of Transportation
Research Section
200 Hawthorne Avenue SE, Suite B-240
Salem, Oregon 97301-5192

January 2011

Research Project Work Plan
for

CRITERIA FOR THE SELECTION AND APPLICATION OF ADVANCED TRAFFIC SIGNAL SYSTEMS: PHASE I

1.0 Identification

1.1 Organizations Sponsoring Research

Oregon Department of Transportation (ODOT)
Research Section
200 Hawthorne Avenue SE, Suite B-240
Salem, OR 97301-5192 Phone: (503) 986-2700

Federal Highway Administration (FHWA)
Washington, D.C. 20590

1.2 Principal Investigator

Yinhai Wang, Ph.D.
Associate Professor
Department of Civil and Environmental Engineering
University of Washington
Seattle WA 98195-2700 Phone: 206-616-2696

1.3 Technical Advisory Committee (TAC) Members

Galen McGill, Manager ODOT ITS Unit
Doug Bish, ODOT Traffic Services Engineer
Scott Cramer, ODOT Traffic Signal Engineer
Fraser Groves, ODOT Traffic Operations Coordinator
Roger Boettcher, ODOT Traffic Signal Control Specialist
Tiffany Slauter, ODOT Signal Manager, Region 1
Bill Link, ODOT Traffic Signal Services Unit (TSSU) Manager
Stacy Shetler, Washington County
Nathaniel Price, FHWA
June Ross, ODOT Research Coordinator

1.4 Project Coordinator

June Ross
ODOT Research Section

1.5 Project Champions

Galen McGill, Manager ODOT ITS Unit
Doug Bish, ODOT Traffic Services Engineer

2.0 Problem Statement

2.1 ODOT has been using Model 170 controllers and the Wapiti software for traffic system operations over the past decades. Since Model 170 controllers have limited memory and slow processing speeds that limit their functionality, ODOT and major cities in Oregon have recently begun upgrading traffic controllers to Model 2070 with Voyage software (and, in some cases, the Sydney Coordinated Adaptive Traffic System (SCATS) and the InSync adaptive system) at signalized intersections. Model 2070 controllers are now required on new construction and are being installed at some locations such as high-volume actuated-coordinated arterial signal systems where the additional functionality of the controller offers the option of traffic responsive and adaptive traffic signal controls. These systems offer advantages over pre-timed and conventional actuated systems and lead to improved traffic flow, reduced congestion and delay, and increased safety through reduced rear end crashes.

2.2 The problem facing ODOT and local agencies is a lack of criteria and guidance in determining the most appropriate traffic signal systems to match the prevailing or expected roadway conditions. The issue is further complicated by the number of vendors and emerging technologies whose appropriateness of application and true cost to benefit ratio is not well understood. Guidance is needed to help determine the most cost effective traffic signal system solution(s), particularly as Intelligent Transportation Systems (ITS) solutions are stressed as alternative treatments to traditional capacity enhancement projects.

2.3 To develop such selection and application criteria for advanced traffic signal applications, two research phases are needed. As a beginning point to develop the criteria, state of the practice in advanced traffic signal system applications must be sufficiently understood. This will be accomplished in Phase I through a combination of a literature review, survey, and on-site visits. Phase I will also include analysis of data from traffic signal systems operating and development of a preliminary framework for a comparison of signal systems. Work being accomplished through the FHWA funded project, Model Systems Engineering Documents for Traffic Signal System Control Alternatives, will be considered throughout Phase I and the applicability to this research project and Oregon will be studied. Phase II will be dependent on the results of Phase I and the continued need for research on this topic.

2.4 Background and Significance of Work

2.4.1 According to the 2009 Urban Mobility Report (Schrank and Lomax, 2009), the annual average delay per peak traveler in the 439 surveyed-urban areas was 23 hours in 2007, a 130% increase compared to that in 1997. Considering that two-thirds of urban vehicle-miles of travel in the U.S. are on signal-controlled roadways (McCracken, 1996), quality and safety of travel on arterial networks tie closely to the performance of signalized intersections. However, a recent evaluation on the more than 272,000 traffic signals in the U.S. identified that the overall performance of these traffic signals was disappointingly rated at a level of D (NTOC, 2007). This implies that the existing traffic signal operations are far from satisfactory. Therefore, improving the efficiency of travel on urban networks using advanced signal control technologies is crucial for sustainable transportation system development.

2.4.2 Typically, traffic signal control systems can be classified into three types: pre-timed, actuated (including semi-actuated), and adaptive (Park and Chang, 2002). Traffic Control Systems Handbook by the Dunn Engineering Associates and the Federal Highway Administration (FHWA) (2005) more specifically divided a Central Control System into the following categories: Uncoordinated Control, Time Base Coordinated Control, Interconnected Control, Traffic Adjusted Control, Traffic Responsive Control, and Traffic Adaptive Control.

2.4.3 Since 1980s, several responsive control systems were developed. For example, Northwest Signal Supply Inc. (2008) started to develop controller software in 1999 and released Voyage Traffic Control Software for responsive control and other advanced traffic signal applications with Model 2070 controllers. Although Voyage has been in use for several years, no published material was found regarding the performance of Voyage.

2.4.4 Over the past decades, the Split, Cycle, and Offset Optimization Technique (known as SCOOT) developed in UK, SCATS developed in Australia, and the Adaptive Control Software Lite (ACS-Lite) developed in the U.S. got popular as the representative adaptive control systems (Stevanovic, 2010). These systems were proven effective in reducing travel delays at signalized intersections. Since 1990s, several more adaptive traffic control systems were developed in the US (e.g. Mirchandani and Head, 2001; Li and Prevedouros, 2004; and Gartner et al., 2002). Compared with traffic responsive control, one of the major differences is that traffic adaptive control is designed to be even more responsive and optimal because it has the built-in optimization mechanism to respond very quickly and effectively to handle random fluctuations in traffic flow. Both traffic responsive and traffic adaptive control are categorized as advanced traffic control systems of interest in this study.

2.4.5 These advanced traffic control systems are powerful but expensive. They need to be applied to suitable locations that can fully utilize their strengths. However, these systems are still new and their performances under various application scenarios are not fully understood. Over the past twenty (20) years, evaluating signal control system performance has gained more attention because of the engineering needs and also because of the fact that the advancements of the communication and traffic sensing technologies have made such evaluations feasible. Many studies focusing on the evaluation of traffic signal systems have been published, including

Batanovi (1986), Bloomberg et al. (1997), Andrews et al. (1997), Abdel-Rahim et al. (2006), Hawkins et al. (2009), Kosmatopoulos et al. (2006), and Martin et al. (2006). However, these studies focused mainly on the evaluation of specific on-site systems with fixed configurations rather than providing guidelines for selecting the signal control systems before they are installed. Thus the evaluation results are case-dependent and not site-transferrable. Some research projects (e.g. Shelby 2004 and Mudigonda et al., 2008) used traffic simulation tools to obtain more comprehensive results. However, the "black-box" control algorithms may not be accurately implemented, and this may lead to suspicions toward their results.

2.4.6 In practice, many transportation agencies provide guidelines for selecting traffic signal control systems. Manual of Traffic Signal Design developed by Institute of Transportation Engineers (Kell and Fullerton, 1991) determines the type of traffic control system based on volumes of minor and major streets. Lee and Lee (1996) developed guidelines for selection of traffic signal control strategies at isolated intersections based on 24 hour volumes. The FHWA Traffic Control Systems Handbook by Gordon and Tighe (2005) provides fundamental guidance suggesting the selection process should require self-examination and consideration for life-cycle issues regarding system acquisition, operation, and maintenance. The guidance in these references is simple and does not provide any systematic approach to selecting advance traffic control system. Even though Manual on Uniform Traffic Control Devices (MUTCD) (FHWA, 2009) provides a more systematic approach, the selection criteria are specifically developed for more conventional signal control systems, including pre-timed, semi-actuated, full-actuated, and coordinated control systems. The selection guidelines for advanced traffic signal systems, e.g. responsive and adaptive signal control systems, are rarely covered in the existing practical manuals/handbooks. Therefore, this study is of utmost importance for both research and engineering practice in traffic signal operations. The criteria to be developed in this study (including both Phases I and II) for the selection and application of advanced traffic signal systems will fill up the gap between new signal control technology development and engineering practice at ODOT.

2.4.7 Recent practice in advanced signal systems at ODOT also provides a great opportunity for data collection and analysis on these systems. For example, the Transportation Operations Innovation and Demonstration Program (IDP) includes projects that are implementing different types of advanced traffic signal systems utilizing SCATS, Voyage, and Voyage with TransSuite software. Evaluations are being completed on each system. The timeframe for completing all the evaluations is uncertain.

3.0 Objectives of the Study

The final objectives of this research project (including both Phases I and II) are as follows:

a. To understand the state of current practices in advanced traffic signal system applications.
b. To develop criteria for the selection and application of advanced traffic signal systems.
c. To make recommendations regarding how the criteria developed should be incorporated into policies, guidance manuals, and training materials as well as specifications and standard drawings.
d. To set up measures to evaluate effectiveness of advanced traffic signal systems.

This Phase I study will focus on the first two objectives.

3.1 Benefits

3.1.1 Two-thirds of urban vehicle-miles of travel in the U.S. are on signal-controlled roadways. Poor signal timing causes approximately 300 million vehicle hours of extra delay annually on major roadways alone (Chin et al., 2004). Huge benefits are potentially obtainable through properly selecting and deploying effective traffic signal control systems.

3.1.2 The results of this research will help signal managers considering the application of advanced signal control techniques to determine the most cost-effective solution by providing comparative information about benefits of each technique and conditions under which each technique is most applicable. This can be expected to lead to wider acceptance of advanced traffic control systems and implementation. Advanced traffic signal systems have been proven to increase capacity, reduce delay, improve transit operations, improve preemption recovery, accommodate pedestrians better, improve special event traffic control, provide better traveler information, and reduce emissions.

3.1.3 From national research, improved signal coordination and improved signal timing produce crash reductions of between 10 and 20 percent. Responsive and Adaptive signals systems should also result in reductions of crashes. The impact will vary due to variations in the degree of congestion and the effectiveness of signal timing plans in place prior to the upgrades.

4.0 Implementation

4.1 The deliverables of this Phase I research include a summary of the literature review, survey report, performance analysis report on the recently implemented systems including the planned Mission Street Voyage Test Corridor. The applicability of work being accomplished through the FHWA funded project, *Model Systems Engineering Documents for Traffic Signal System Control Alternatives*, to Oregon will be identified. Phase II will be dependent on results of Phase I and the continued need for research on this topic. The Phase 1 report will include a description of what should be included in Phase II. A work plan will not be developed until it is determined that a second phase is needed.

5.0 Research Tasks

This research project will be conducted in collaboration with ODOT experts in traffic operations. Through collaborations with ODOT, vendors of advanced traffic signal systems, and consultants, the research team will identify the most suitable research approach for the following scheduled tasks. The time schedule for this project is premised on all systems implemented and the initial evaluation results made available to the University of Washington and ODOT Research Section as well as completion of the work on the Mission Street Voyage Test Corridor.

5.1 *Task #1*: Literature Review and Agency Survey

As the first step of this study, a literature review and agency survey will be conducted in Oregon and throughout the United States to summarize past experiences, benefits, and costs associated with traffic signal operations. This effort covers not only the applications of the targeted "advanced" traffic signal systems, including Voyage (with and without enhancements that are still under development), SCATS, ACSLite, and InSync, but also success stories with more conventional traffic control systems. When possible, data collected about pre-and post implementation of "advanced" traffic signal systems in other jurisdictions will be requested for use in this study. The evaluation reports being done by Kittelson on the recently implemented and planned signal systems or work in progress will also be carefully reviewed under this task. Specific issues to consider include: capacity status; both hardware and software solutions; methods of vehicle detection; impediments to implementation; measures of effectiveness; and manpower requirements for setting up and maintaining systems, for both isolated intersections and coordinated systems. The literature review will not include an assessment of specific software options for adaptive traffic signal systems as the NCHRP synthesis 403 by Stevanovic (2010) provides a summary on the topic. On-site visits to some sites will be made as needed to interview involved staff and collect data.

Time Frame: 3 months from 01/1/2011 through 03/31/2011
Responsible Party: Dr. Yinhai Wang
Cost: $30,000
Deliverable: A summary of literature review and survey report. The review summary should cover specific issues identified above, existing approaches for intersection performance measurement, performance measures widely accepted, and criteria under application and development for the selection and application of advanced traffic signal systems. It will include a summary of the systems that will be looked at further in Task #2.
TAC Decision/Action: Review the summaries and meet with the Principal Investigator (PI) to provide feedback.

5.2 *Task #2*: Performance Analysis and Preliminary Framework

Field traffic demand data and roadway geometric data as well as data from the evaluation studies on Oregon corridors being revised will be analyzed using facilities available in the STAR Laboratory. Traffic signal systems in place in other jurisdictions that were identified in Task #1 will be included in the analysis so that there as broad a spectrum of traffic signal systems included as possible. With data from all the application cases collected through Task #1, quantitative analysis will be conducted to identify the performance of each identified advanced traffic control system under various traffic flow and intersection geometry conditions at both the individual intersection level and the corridor/network level. Such condition-based performance information is essential for the development of a decision matrix that helps transportation agencies make decisions on the selection and application of advanced traffic signal systems. However, field observations may not cover the entire spectrum of domains to be analyzed. To fill up the gaps, simulation modeling and experiments may be needed. Given the constraints of microscopic traffic simulation models and the proprietary issues with the advanced traffic signal systems, the feasibility of simulating the advanced traffic signal systems is unclear and needs further investigation. In this task, an Oregon corridor recently revised with advanced traffic signal applications will be identified through discussions with the TAC members as the study site for developing a simulation-based analytical platform. If successful, the platform will be expanded in Phase II of this study to include more corridors and advanced traffic signal systems so that it can cover more application scenarios to better support the development of the decision matrix.

Based on the results of this analysis and Task 1 and ongoing consideration of work being done in the FHWA-funded work, the researchers will present a preliminary framework for comparison of systems. Included will be a comparison of what the systems are designed to do and what they have shown to achieve in their implementation in Oregon and elsewhere.

Time Frame: 3 months from 03/01/2011 through 05/31/2011

Responsible Party: Dr. Yinhai Wang

Cost: $30,000

Deliverable: Interim Report that summarizes the data analysis results and simulation experimental results.

TAC Decision/Action: Review report, meet with PI, and provide feedback.

5.3 *Task #3*: Prepare Phase I Final Report

The project team will write the Phase I final project report. The draft report will be prepared first and be circulated to the TAC for their review and comments. Review findings, survey results, simulation models and experiments, analytical methods, data used in this study, and identified optimal Voyage settings (to be provided by ODOT) will be described in detail in the report. An executive summary of the project findings will also be produced under this task. The Phase I report will include a description of what should be included in Phase II.

<u>Time Frame</u>: 2 months from 05/01/2011 through 06/30/2011
<u>Responsible Party</u>: Dr. Yinhai Wang
<u>Cost</u>: $5,000
<u>Deliverable</u>: Phase I final project report and project presentation at the final TAC meeting.
<u>TAC Decision/Action</u>: Review the Phase I final research report. Meet with PI and provide feedback.

5.4 *Table 1: Summary of Tasks*

Table 1: Task Summary

Task	Responsible Party	Cost
Task #1: Literature Review and Agency Survey *Time Frame:* 3 months from 01/01/2011 through 03/31/2011 *Deliverable:* A summary of literature review and survey report *TAC Decision/Action:* Review the summaries and meet with the Principal Investigator (PI) to provide feedback.	Dr. Y. Wang	$30,000
Task #2: Performance Analysis and Preliminary Framework *Time Frame:* 3 months from 03/01/2011 through 05/31/2011 *Deliverable:* Interim report. *TAC Decision/Action:* Review the interim report, meet with PI, and provide feedback.	Dr. Y. Wang	$30,000
Task #3: Prepare Phase I Final Report *Time Frame:* 2 months from 05/01/2011 through 06/30/2011 *Deliverable:* Phase I final project report *TAC Decision/Action:* Review the Phase I final research report. Meet with PI and provide feedback.	Dr. Y. Wang	$5,000

6.0 Time Schedule

The Phase I project timetable is based on a January 1, 2011 start date. Actual start date will be used to adjust the delivery schedule. Table 2 shows the bar chart of the project schedule and expected delivery time of the deliverables.

Table 2: Project Time Schedule

Project Tasks	FY2011					
	Qtr 3			Qtr 4		
	Jan	Feb	Mar	Apr	May	Jun
Task 1: Literature Review and Agency Survey	■	■	■			
Deliverable: Summary of literature review and survey report			D			
Task 2: Performance Analysis and Preliminary Framework			■	■	■	
Deliverable: Interim report					D	
Task 3: Prepare Phase I Final Report					■	■
Deliverable: Phase I Final Report					D	
Meeting with TAC				M	M	M

Notes:
D stands for "Deliverable";
M stands for "Meeting". A presentation will be made by PI at each meeting.

7.0 Budget Estimate

An itemized budget for the project is included Table 3, showing expenditures for each item by fiscal year and in total.

Table 3: Itemized Budget

	FY2011	FY2012	Total
Personnel			
Yinhai Wang	$5,592	$0	$5,592
Graduate RA	$11,130	$0	$11,130
Total Salaries	*$16,722*	*$0*	*$16,722*
Fringe Benefits			
Yinhai Wang	$1,443	$0	$1,443
Graduate RA	$1,636	$0	$1,636
Total Fringe Benefits	*$3,079*	*$0*	*$3,079*
Total Personnel Costs	**$19,801**	**$0**	**$19,801**
Travel	**$2,600**	**$0**	**$2,600**
Equipment	**$2,270**	**$0**	**$2,270**
Tuition	**$7,905**	**$0**	**$7,905**
Services and Supplies	**$3,600**	**$0**	**$3,600**
Subcontract to DKS	**$9,600**	**$0**	**$9,600**
Total Direct Costs	**$45,775**	**$0**	**$45,775**
Total Indirect Costs	**$19,225**	**$0**	**$19,225**
Total Project Costs	**$65,000**	**$0**	**$65,000**

Notes:
The subcontract amount of $9,600 to DKS covers 60 hours of Jim Peters' time at an hourly rate of $160/hr to help the research project as a consultant. Specifically, Mr. Jim Peters will help the UW research team on the following issues:

(1) Task 1 – Provide a list of transportation agencies with success stories in traffic signal operations for the research team to contact for the agency survey.
(2) Task 2 – Provide a list of recommended adaptive traffic signal system research studies for the literature review.
(3) Task 3 – Provide a one day overview of Voyage, InSync, ACSLite, and SCATS traffic signal control systems at the University of Washington.
(4) Task 4 – Provide graphics illustrating detector requirements for the Voyage, InSync, ACSLite, and SCATS traffic signal control systems.
(5) Task 5 – Provide monthly updates to the UW research team on the progress of the FHWA contract project undertaken at DKS.
(6) Task 6 – Review the draft Phase I report.

8.0 References

Abdel-Rahim, A., M.P. Dixon, and M. Luo, 2006. *Development and Utilization of an Evaluation Process for Traffic Signal Control Systems*. Publication KLK212 (N06-11). National Institute for Advanced Transportation Technology, University of Idaho.

Andrews, C. M., S. M. Elahi, and J. E Clark, 1997. Evaluation of New Jersey Route 18 OPAC/MIST Traffic-Control System. In Transportation Research Record 1603, TRB, National Research Council, Washington, D.C., pp. 150-155.

Batanovi, V. 1986. Multicriteria evaluation of motorway traffic control systems. In: *Final Report, COST-30*, EEC, Brussels.

Bloomberg, L., J. Throckmorton, and T. Klim, 1997. Development and Application of Portland Traffic System Performance Evaluation System. *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 1603, pp. 1-11.

Chin, S.M., O. Franzese, D.L. Greene, H.L. Hwang, and R.C. Gibson. 2004. Temporary Losses of Highway Capacity and Impacts on Performance: Phase 2. Oakridge National Laboratory Report No. ORNL/TM-2004/209, Oak Ridge, TN: November 2004.

Dunn Engineering Associates and the Federal Highway Administration (FHWA). 2005. Traffic Control Systems Handbook. U.S. Dept. of Transportation, Federal Highway Administration, Washington D.C.

FHWA. 2009. Manual on Uniform Traffic Control Devices. 2009 Edition. Accessible online at http://mutcd.fhwa.dot.gov/pdfs/2009/mutcd2009edition.pdf.

Gartner, N.H., F.J. Poorhan, and C.M. Andrews. 2002. Implementations and Field Testing of the OPAC Adaptive Control Strategy in RT-TRACS. Presented at the 81st Annual Meeting of the Transportation Research Board, Washington, DC.

Gordon, R.L., and W. Tighe, 2005. Traffic control systems handbook: 2005 edition. United States. Federal Highway Administration. Office of Transportation Management.

Hawkins, H.G., A.M. Pike, and M. Azimi, 2009. Evaluation of Traffic Control Devices: Fifth-Year Activities. Publication Report 0-4701-5. Texas Transportation Institute.

Kell, J.H., and I.J. Fullerton, 1991. Manual of Traffic Signal Design (2nd Edition), Institute of Transportation Engineers.

Kosmatopoulos, E., M. Papageorgiou, C. Bielefeldt, V. Dinopoulou, R. Morris, J. Mueck, A. Richards, and F. Weichenmeier, 2006. International Comparative Field Evaluation of a Traffic-Responsive Signal Control Strategy in Three Cities. Transportation Research Part A: Policy and Practice, Vol. 40, pp. 399-413.

Lee, S., and J. Lee, 1996. Consideration of 24-hr Volumes in Selection of Traffic Signal Control Strategies for Isolated Intersections. Transportation Research Record: Journal of the Transportation Research Board, Vol. 1553, pp. 18-27.

Li, H. and P. D. Prevedouros. 2004. Traffic Adaptive Control for Oversaturated Isolated Intersections: Model Development and Simulation Testing, Journal of Transportation Engineering, ASCE, Vol. 30, No. 5, pp. 594-601.

Martin, P.T., A. Stevanovic, and I. Vladisavljevic, 2006. Adaptive Signal Control IV: Evaluation of the Adaptive Traffic Control System in Park City, Utah: University of Utah.

McCracken, J. 1996. Demonstration Project 93 – Making the Most of Today's Technology, Public Roads, Vol. 59, No. 3, pp. 7-9.

Mirchandani, P.B. and K. L. Head 2001. A Real-Time Traffic Signal Control System: Architecture, Algorithms and Analysis, Transportation Research. Part C: Emerging Technologies Vol. 9 No: 6.pp. 415-432.

Mudigonda, S., K. Ozbay, and H. Doshi, 2008. Evaluation and Selection of Adaptive Traffic Control Strategies on Transportation Networks: Decision Support Tool Based on Geographic Information System. Transportation Research Record: Journal of the Transportation Research Board, Vol. 2064, pp. 51-64.

Northwest Signal Supply Inc, 2008. ODOT Selects Northwest Signal Voyage Traffic Controller Software, Northwest Signal Supply Inc News. Available online at http://nwsignal.com/pressroom/odot_northwest_signal_voyage-001/

NTOC (National Transportation Operations Coalition). 2007. *National Traffic Signal Report Card: Technical* Report. Available online at http://www.ite.org/REPORTCARD/technical_report%20final.pdf.

Park B. B., and M. Chang. 2002. Realizing Benefits of Adaptive Signal Control at an Isolated Intersection. Transportation Research Record: Journal of the Transportation Research Board, Vol. 1867, pp. 183-192.

Shelby, S., 2004. Single-Intersection Evaluation of Real-Time Adaptive Traffic Signal Control Algorithms. Transportation Research Record: Journal of the Transportation Research Board, Vol. 1867, pp. 183-192.

Shrunk, D. and T. Lomax. 2009. *The 2009 Urban Mobility Report*. Texas Transportation Institute. The Texas A&M University System. Available at http://mobility.tamu.edu/ums/ [Accessed 10/5/2010].

Stevanovic, A. 2010. Adaptive Traffic Control Systems: Domestic and Foreign State of Practice. NCHRP Synthesis 403. Available online at http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_syn_403.pdf