Arterial Control and Integration

WA-RD 188.2

Final Report
March 1990

Washington State Department of Transportation
Planning, Research and Public Transportation Division

in cooperation with the
United States Department of Transportation
Federal Highway Administration

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO. WA-RD 188.2	2. GOVERNMENT ACCESSION NO.	3. RECIPIENTS CATALOG NO.
4. TITLE AND SUBTITLE ARTERIAL CONTROL AND INTEGRATION		5. REPORT DATE March 1990
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) G. Scott Rutherford, Margaret Schroeder, Leslie N. Jacobson, Mark E. Hallenbeck		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Washington State Transportation Center (TRAC) University of Washington, JE-10 The Corbet Building, Suite 204; 4507 University Way N.E. Seattle, Washington 98105		10. WORK UNIT NO.
		11. CONTRACT OR GRANT NO. GC8286, Task 30
12. SPONSORING AGENCY NAME AND ADDRESS Washington State Department of Transportation Transportation Building, KF-10 Olympia, Washington 98504		13. TYPE OF REPORT AND PERIOD COVERED Final Report
		14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

This study was conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

16. ABSTRACT This report documents the Washington State Department of Transportation's examination of the potential application of adaptive signal control and integrated traffic control systems in the Seattle Metropolitan area. The research project had two sets of objectives, one for advanced, or adaptive, signal control systems and one for control system integration. The primary objectives for the advanced signal control portion of the project were to (1) investigate adaptive signal control systems, such as SCOOT, SCAT, and OPAC, (2) evaluate the UTCS 1.5 generation signal system, (3) determine applicability of, and interest in, advanced signal systems in the Puget Sound Region, and (4) provide coordination with local agencies on research efforts in arterial traffic management. The primary objectives for the control system integration portion of the project were to (1) determine regional needs and interest in integrating control systems, and (2) provide coordination with local agencies on research efforts in integrated control systems.

The researchers reviewed previous work in adaptive signal control and evaluated the Bellevue UTCS 1.5 signal system to determine the applicability of adaptive control in the Seattle area. Then they developed a framework for investigating integrated control system needs and met with jurisdictions throughout the Seattle Metropolitan area to discuss adaptive signal control and control system integration. Finally, they formulated conclusions and recommendations to help achieve improved coordination and integration of neighboring control systems.

The UTCS 1.5 signal system has improved traffic flow on Bellevue's arterial network (volumes increased 17 percent with no significant changes in travel time), and the new system is easier to operate than the old UTCS 1.0 system. Of the adaptive control strategies investigated, UTCS 1.5 and OPAC show the most promise for implementation in the Seattle Metropolitan area. WSDOT should investigate the possibility of OPAC demonstration or test sites in the Seattle area. Local jurisdictions are interested in improved coordination and some degree of system integration. The WSDOT should keep local jurisdictions involved in and informed of the upcoming freeway and arterial control system integration project. The corridor traffic management teams that will be established should take up and help direct the area's advances in control system integration.

17. KEY WORDS Adaptive signal control, freeway and arterial integrtation, traffic signals	18. DISTRIBUTION STATEMENT No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22616

19. SECURITY CLASSIF. (of this report)	20. SECURITY CLASSIF. (of this page)	21. NO. OF PAGES	22. PRICE
None	None	60	

DOT FORM 310-022 (11/86) -1216-

Final Report

Research Project GC 8286, Task 30
Arterial Control and Integration

ARTERIAL CONTROL AND INTEGRATION

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U.S. Department of Transportation
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March 1990

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SUMMARY

The research project for which this report was written had two sets of objectives, one for advanced, or adaptive, signal control systems and one for control system integration. The primary objectives for the advanced signal control portion of the project included the following:

- investigate adaptive signal control systems, such as SCOOT, SCAT, and OPAC,
- evaluate the UTCS 1.5 generation signal system,
- determine applicability of, and interest in, advanced signal systems in the Puget Sound Region, and
- provide coordination with local agencies on research efforts in arterial traffic management.

The primary objectives for the control system integration portion of the project included the following:

- determine regional needs and interest in integrating control systems, and
- provide coordination with local agencies on research efforts in integrated control systems.

This report documents the efforts taken to meet these objectives.

The researchers reviewed previous work in adaptive signal control and evaluated the Bellevue UTCS 1.5 signal system (no previous, documented evaluation of such a system was found in the literature search) to determine the applicability of adaptive control in the Seattle area. Then they developed a framework for investigating integrated control system needs and met with jurisdictions throughout the Seattle Metropolitan area to discuss adaptive signal control and control system integration.

The following are the principal conclusions and recommendations that resulted from this project:

- The Bellevue UTCS 1.5 signal system has improved traffic flow on Bellevue's arterial network (volumes increased 17 percent with no significant changes in travel time), and the new system is easier to operate than the old system.
- Of the adaptive control strategies investigated, UTCS 1.5 and OPAC show the most promise for implementation in the Seattle Metropolitan area. Local jurisdictions showed the most interest in the OPAC system. WSDOT should investigate the possibility of OPAC demonstration or test sites in the Seattle area.
- Local jurisdictions are interested in improved coordination and some degree of system integration. The WSDOT should keep local jurisdictions involved in and informed of the upcoming freeway and arterial control system integration project. This project should be used to answer questions and increase interest in system integration.
- The corridor traffic management teams that will be established should take up the issue of control system integration. These teams, made up of representatives of various operating agencies, should provide the direction for system integration and build the constituency necessary to design and implement integrated control in the Seattle Metropolitan area.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions and recommendations are presented below in three categories: evaluation of the Bellevue UTCS 1.5 signal system, adaptive control for the Seattle Metropolitan area, and integrated control systems for the Seattle Metropolitan area.

EVALUATION OF THE BELLEVUE UTCS 1.5 SIGNAL SYSTEM

Conclusions

The Bellevue UTCS 1.5 signal system has improved traffic flow on Bellevue's arterial network. Systemwide, volumes increased 17 percent from the "before" case to the "after" case. Travel times did not change on a statistically significant basis, although there was a measured 2 percent decrease.

The operation of the Bellevue signal system has improved. The new system significantly reduced the effort required to update traffic signal timing plans. Changes that took 2 hours to an entire day to implement with the old system now take about 30 minutes. Data collection is also streamlined with the enhanced use of system detectors. The operators can be more responsive to special events and unusual traffic conditions. The new system also reduced maintenance costs of the computer system from $17,000 per year to $8,000 per year

Recommendations

With the success of the UTCS 1.5 operation on four arterials, the research team recommends that the UTCS 1.5 operation be expanded to all signals in the Bellevue system. As part of this expansion, the researchers recommend that additional system detectors be installed. The ultimate goal is to provide sufficient detectors to allow generation of timing plans without manual data collection. Finally, the researchers recommend that the remaining leased lines be replaced by city-owned cable wherever economically feasible.

ADAPTIVE SIGNAL CONTROL

Conclusions

Of the four advanced signal control systems investigated in this project, UTCS 1.5 and OPAC are the only ones that were designed for use on equipment manufactured in the United States. One UTCS 1.5 system is operating in the City of Bellevue, and the City of Seattle is investigating a possible application within its signal system. The cost of the development necessary to implement SCOOT or SCAT is prohibitive to the jurisdictions in the Seattle area. There was very little interest in these two systems among the jurisdictions. On the other hand, several jurisdictions are interested in the OPAC system.

Recommendation

The WSDOT should investigate possible tests or demonstrations of the OPAC system in the Seattle area. WSDOT should play the lead role in this effort by maintaining contact with the FHWA research office developing the software, determining the state of readiness of the next version of OPAC, coordinating the local jurisdictions so that the appropriate arterials are selected for the tests, and ensuring that the participating cities and agencies both benefit from such a test and are eager participants in that test.

INTEGRATED CONTROL SYSTEMS

Conclusions

Most jurisdictions in the Seattle area are interested in improved communication and coordination. Most jurisdictions are either interested in or are currently exchanging traffic and/or signal timing data with neighboring jurisdictions. Most are interested in computer communication among control systems within five years and in some kind of regional control system integration within 10 years. However, the jurisdictions showed very little interest in implementing a regional supervisory computer that automatically selects or develops control strategies. In fact, a great deal of concern was voiced over this option -- the jurisdictions did not want to lose autonomy or control over their systems.

Recommendations

First, integrated control of the WSDOT freeway and arterial control systems is needed. The pilot demonstration project that will begin in late summer 1989 will provide the first integrated control in this region. This project should be undertaken as a demonstration of how integrated systems can be incrementally implemented on existing systems, and how information from neighboring control systems can be shared and used to enhance control of individual arterials and groups of arterials. It should be conducted with a considerable amount of participation by local jurisdictions so their questions and concerns can be addressed.

Second, the corridor traffic management teams will provide an opportunity to build a constituency for a regional communication system. The teams will also provide an opportunity to build trust among agencies that will enhance the likelihood that jurisdictions will be willing to participate in a truly integrated control system.

Finally, the conceptual design of an integrated system that will allow control system computers to communicate with one another should be one of the tasks of the corridor traffic management teams. This task should be taken up only after the integrated system demonstration project has been completed and if the jurisdictions involved decide that such a system would be beneficial.

CHAPTER 1

INTRODUCTION AND BACKGROUND

Traffic congestion is one of the top problems identified by citizens in the nation's urban areas. From Phoenix to San Francisco to Washington, D.C., citizens are identifying transportation as their number one concern, outweighing issues such as pollution, overpopulation, unemployment, and crime. Traffic congestion is certainly the primary reason for this concern over transportation issues. (1)

Increased reliance on the automobile and growth in population, jobs, and households, have combined to create severe and alarming levels of congestion in our urban areas. Delay on urban freeways in the United States increased by 57 percent from 1983 to 1985 and is projected to increase at a yearly rate of 8.8 percent through the year 2005. This rate of increase will result in a 435 percent increase in delay from 1985 to 2005. The increased congestion will also affect urban signalized arterials. Projections indicate a 240 percent increase in delay on urban signalized arterials from 1985 to 2005 (6.3 percent increase per year). (2)

In Washington state, these trends are also evident. Growth in travel demand will accompany an increase in population. Total trips in the central Puget Sound area are predicted to increase by 42 percent from 1980 to 2000. Vehicle miles of travel (VMT) will increase even more. Freeway VMT will increase 73 percent, and arterial VMT will increase 71 percent during the same time. (3) Because of this increased travel demand, average speeds on the roadway system will decrease from 25 mph in 1988 to 15 mph by 2000. (4) Currently, about 50 percent of the VMT is handled by freeways. By 2020, only 44 percent of the VMT will be handled by freeways. (5) The importance of the arterial system and of integrating the control systems for freeways and arterials will increase accordingly.

THE NEED FOR ADVANCED ARTERIAL CONTROL SYSTEMS

The congestion problem, while most dramatically shown by bumper-to-bumper traffic on freeways, is prevalent on arterial streets as mentioned above. One way to reduce congestion on arterials is to implement improved control techniques. The existing traffic control systems in the Puget Sound area rely on signal timing patterns generated off-line by computer models such as TRANSYT. Generation of timing patterns in this way is expensive and time consuming.

Most jurisdictions in the region have computer controlled signal systems. Recent developments in signal control techniques have resulted in the development and implementation of systems that either need no set timing patterns or automatically generate patterns. Preliminary studies of these control techniques have shown that these system can achieve significant savings to motorists, however, the extent to which they actually achieve these savings is heavily debated within the profession. Additional research into the question of achieved savings from these new control systems is warranted.

Since the development of modern traffic signal controls, traffic engineers and signal system designers have attempted to make signals as responsive as possible to prevailing traffic conditions. Increased responsiveness is believed to lead to improved traffic performance. However, the extent to which traffic responsiveness is achieved depends on a variety of factors, including control hardware, software capabilities, surveillance equipment, and operator qualifications. In fact, research work in the development of efficient and effective real-time, demand-responsive traffic control systems represents one of the leading edges of the traffic control field. (6, 7, 8)

To date, many generations of computerized urban traffic control systems, also termed area traffic control systems, have been developed and implemented. These systems gather data on traffic volumes and network link occupancies from vehicle detectors (sensors). On the basis of these data, they then alter the signal settings at intersections in the network to control traffic flow.

THE NEED FOR INTEGRATED SYSTEMS

Because the region's transportation network acts as a system, conditions on any given link during the peak periods affect many other links within the system. Conditions on the freeway affect arterial links and vice versa. Conditions on links in one jurisdiction affect links in another jurisdiction. Therefore, traffic control strategies must start to examine and treat congestion on a regional basis, not simply address congestion on a single facility.

As traffic continues to increase, the need to coordinate separate arterial systems and the need to coordinate arterial and freeway systems increases. The state of the art in computer controlled signal systems has not reached a point where separate systems are coordinated routinely. Work is needed to investigate potential methods for coordinating these disparate systems. In addition, since these systems cross jurisdictional boundaries, close coordination with local agencies is essential when the coordination strategies are developed.

PROJECT OBJECTIVES AND REPORT ORGANIZATION

The research project for which this report was written had two sets of objectives, one for advanced, or adaptive, signal control systems and one for control system integration. The primary objectives for the advanced signal control portion of the project included the following:

- investigate adaptive signal control systems, such as SCOOT, SCAT, and OPAC,
- evaluate the UTCS 1.5 generation signal system,
- determine applicability of and interest in advanced signal systems in the Puget Sound Region, and

- provide coordination with local agencies on research efforts in arterial traffic management.

The primary objectives for the control system integration portion of the project included the following:

- determine regional needs and interest in integrating control systems, and
- provide coordination with local agencies on research efforts in integrated control systems.

This report documents the efforts taken to meet these objectives. The second chapter of this report describes the development of four demand-responsive traffic control systems, namely, UTCS 1.5 and OPAC in the United States, SCOOT in England, and SCAT in Australia. Chapter 3 describes the evaluation of the UTCS 1.5 generation system in Bellevue, Washington. Chapter 4 documents the discussions on adaptive signal control between the researchers and representatives from local agencies. Chapter 5 discusses the findings and conclusions concerning adaptive signal control which resulted from those discussions and the evaluation of the Bellevue system. Chapter 6 describes the framework that the researchers developed for integrated control system investigation. Chapter 7 documents the discussions on integrated control systems between researchers and representatives of local agencies. Chapter 8 contains the findings and conclusions regarding integrated control systems which resulted from those discussions. Finally, Chapter 9 discusses how the research results can be applied in the Puget Sound region.

CHAPTER 2

REVIEW OF PREVIOUS WORK

This chapter summarizes an earlier paper that discussed four state-of-the-art urban traffic control systems. (9) It examines the benefits that these systems achieved in earlier tests and discusses their potential for implementation in the U.S.

SCOOT

The first technique, the Split, Cycle, Offset Optimization Technique (SCOOT), is a signal control strategy that can be implemented as a stand alone system or in conjunction with an existing system. Data from detectors on all approaches to intersections are processed and stored in link cyclic flow profiles that determine the best way to coordinate adjacent pairs of signals. Three optimizing routines calculate incremental changes to the splits, cycles, and offsets of the timing plan to maintain optimum traffic flows. Recent research has enhanced SCOOT so that split and offset weightings can now be assigned in the network. These weightings can improve vehicle progression and give the operator some degree of override control.

In the spring of 1979 and spring of 1980, tests of SCOOT were carried out in Glasgow, Scotland, and Coventry, England. In each of the tests, SCOOT results were compared with TRANSYT results.

The first trial took place in Glasgow's central business district with a network of 40 signals on the SCOOT system. To collect the comparison data, floating car travel time studies were made over a five week period. (10: p. 60) Table 2.1 shows the percentage of improvement of SCOOT over TRANSYT in Central Glasgow for the morning, evening, and off-peak hours (10: p. 60).

Three separate tests were conducted in Coventry. In the spring of 1980, a five-week SCOOT trial was conducted in the Foleshill Road subarea of Coventry. The sub-area was described as "a major two-way radial arterial road surrounded by industrial and

Table 2.1. Results of the Survey in Central Glasgow*

		AM Peak	Off Peak	PM Peak
Average distance travelled (veh km/hr)		3933	3769	4456
Time to travel 1 km (sec.)	Fixed time	245	302	263
	SCOOT	248	280	248
Improvement of SCOOT (%)		-1	7[a]	6[a]

residential premises." (10: p. 60) Table 2.2 shows the percentage of improvement of SCOOT over fixed time methods on the basis of travel time.

A second test was conducted in Spon End. The Spon End sub-area of the Coventry street network was mainly a residential area. Because of delay at a few intersections, the floating car survey results showed no noticeable difference between TRANSYT and SCOOT.

Surveys were also conducted at four Coventry intersections to determine SCOOT's performance during evening and night periods. Researchers found that SCOOT caused fewer stops than fixed-time controllers in all cases, with an average reduction in stops of 17 percent.

Table 2.2. Results of the Survey on Foleshill Road, Coventry, England*

		AM Peak	Off Peak	PM Peak
Average distance travelled (veh km/hr)		5228	4661	5814
Time to travel 1 km (sec.)	Fixed time	135	123	151
	SCOOT	128	118	139
Improvement of SCOOT (%)		5	4[a]	8[a]

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*Source: Hunt, P.B., Robertson, D.I., Bretherton, R.D. and Winton, R.I. "The SCOOT on-line Traffic Signal Optimization Technique," Procs. Intern. Conf. on Road Traffic Signalling, Institute of Electrical Engineers, London, U.K. 1982, pp. 59-62.

[a]Statistically significant at the 95 per cent level.

SCATS

The Australian-developed Sydney Coordinated Adaptive Traffic System (SCATS) is a hierarchical system that controls delay and stops. The SCATS network is divided into subsystems of one to ten intersections, which form the basic level of control. Each subsystem contains one critical intersection for which the subsystem's green split plans, internal and external offset plans, and cycle lengths are selected on a cycle by cycle basis. Adjacent subsystems can be linked together when the differences in cycle length are consistently less than 9 seconds, when a linkage is defined as permanent, or when the flow measured by the detectors exceeds a preset value.

A seven-week 1980 survey comparing SCATS with TRANSYT was performed in Parramatta, Australia, in three different areas: the central business district, the Great Western Highway, and Church Street. (12: 72) The central business district (CBD) in Parramatta was essentially a grid network of 14 signals adjoining an arterial system of eight signals. Although some congestion in the CBD was caused by curbside and pedestrian activity, there were no large traffic flows. The arterial system, on the other hand, had much heavier flows (60,000 AADT). Table 2.3 shows the results from the comparison of SCAT and TRANSYT.

Table 2.3. Comparison of SCAT and TRANSYT*

	Journey Time (% Diff.)				Stop (% Diff.)				Performance Index			
	Total	Lunch	Peak	Late	Total	Lunch	Peak	Late	Total	Lunch	Peak	Late
CBD	2.6	-6.3[b]	0.3	-0.9	1.2	-1.5	1.8	9.1[b]	-5.4	-15	2.3	2.3
GWH	4.4	-0.4	2.4	8.6	25[b]	27[b]	21[b]	26[b]	19	8.0	19	19
CS	-26[b]	-31[b]	-31[b]	-8.6	-43[b]	-66[b]	-34[b]	-50[b]	-24[b]	-26[b]	-35[b]	-7.9

*Source: Luk, J.Y.K. "SCATS-application and field comparison with a TRANSYT-optimized fixed time system," Proceedings of International Conference on Road Traffic Signalling, IEE, 1982, p. 71-74.

[b]Indicates result significant at the 5% level.

The last evaluation of SCATS was done on a 13.5-km section of the Maroondah Highway in 1982. Since then, real-time evaluations have been too expensive to conduct on a large scale. In fact, the costs for completing a before and after study often have been found to be comparable to the costs of implementing the coordination project under study. (Andrew Garrett letter) The survey completed in Melbourne compared three different traffic control systems: SCATS, Linked Vehicle Actuated (LVA), and Isolated. Table 2.4 shows the percentage of difference between SCAT and the other modes of control for the average value of variables at the overall average level of demand during each survey period. (13: p. 8) SCATS came out ahead in journey time averaged over all the survey periods for both LVA (SCATS was 5 percent better) and Isolated (SCATS was 21 percent better). The results for delay were mixed, showing an increase in delays and stops on the side-street approaches. Table 2.5 shows the percentage of differences in delay calculated per vehicle and aggregated over all the intersections. (13: p. 8) Overall, though, SCATS performed significantly better than its competitors. (13: p.1).

Table 2.4. Instrumented Vehicle Survey — Percentage Difference from SCAT (All vehicles)

Variable	Morning Peak		Morning Business		Afternoon Business		Evening Peak		Totals	
	LVA	ISO	LVA	ISO	LVA	ISO	LVA	ISO	LVA	ISO
TIME	-7.5*	-27.3*	0.1	-11.8*	0.9	-14.2*	-6.8*	-22.1*	-4.6*	-21.3*
AGFUEL	-4.3	-19.7*	-2.1	-17.1*	-11.2	-14.7	-11.1	-8.3	-6.1	-13.6*
STOPS1	-42.2*	-128.1*	2.5	-62.2*	4.6	-69.5*	-23.8*	-84.1*	-21.5*	-93.1*
DELAY1	-19.3*	-89.6*	0.6	-56.8*	2.9	-52.5*	-13.8	-65.7*	-12.2*	-74.6*
STOPS2	-24.2*	-100.6*	-0.3	-65.6*	6.5	-61.8*	-26.0*	-87.3*	-16.4*	-85.6*
DELAY2	-28.7*	-105.4*	1.2	-53.3*	3.3	-57.6*	-13.3	-68.3*	-14.8*	-80.3*
AGPKE	-1.0	-24.7	-0.1	-30.5*	-2.4	-16.2*	-10.5*	-22.1*	-4.2*	-22.0*
SPEED	6.6*	22.3*	0.2	10.6*	-1.7	11.5*	6.1*	18.1*	3.3*	17.0*

Note: $\text{Percent Difference} = \frac{(\text{Avg. SCAT - Avg. MODE})}{\text{Avg. SCAT}} * 100$

*Statistically Significant at the 5% Level.

Source: Luk, J.Y.K. "SCATS--application and field comparison with a TRANSYT-optimized fixed time system," Proceedings of International Conference on Road Traffic Signalling, IEE, 1982, p. 71-74.

Table 2.5. **Intersection Delay Study – Percentage Difference from SCAT of Delay per Vehicle**

Period	Co-ordinated Approaches				Side Road Approaches			
	Eastern		Western		Northern		Southern	
	LVA	ISO	LVA	ISO	LVA	ISO	LVA	ISO
Morning Peak	4.8	-2.3	-7.3	-37.4	5.3	25.4	6.3	27.6
Morning Business Hours	3.1	-10.4	2.3	-17.3	9.6	23.2	8.6	12.1
Afternoon Business Hours	8.2	-1.8	12.9	-8.1	13.9	18.7	11.1	16.6
Evening Peak	-2.9	-14.7	18.5	-7.8	13.6	22.3	4.7	19.2

Note: Percent Difference $= \frac{\text{(Avg. SCAT - Avg. MODE)}}{\text{Avg. SCAT}} * 100$

Source: Luk, J.Y.K. "SCATS--application and field comparison with a TRANSYT-optimized fixed time system," Proceedings of International Conference on Road Traffic Signalling, IEE, 1982, p. 71-74.

Results of an evaluation of the Bellevue UTCS 1.5 system are presented in the next chapter.

UTCS 1.5

UTCS 1.5, primarily developed to alleviate the problems of manually producing signal timing plans, is the least demand responsive of the four traffic control systems. It provides real-time traffic surveillance and offline optimization of timing plans. UTCS 1.5 is capable of developing new timing plans, printing and displaying timing plan performance statistics, and transferring new timing plans into the library of timing plans at the operator's request. Wall map displays can also be generated in addition to the normal CRT displays and line printer reports to provide an overview of the traffic signal network. At the end of each traffic control period, when a new timing plan is implemented, the volumes and speeds from the previous period are evaluated. The operator can then choose to develop a new timing plan for that period on the basis of that evaluation.

OPAC

Optimization Policies for Adaptive Control (OPAC) is a strategy meant to be a building block for demand responsive decentralized traffic signal control. At this point, OPAC is only a single intersection control method, although its potential for use in a traffic network is under investigation. OPAC uses the rolling horizon technique to find the optimal policy for each stage (i.e., stages in OPAC are similar to cycle lengths). The optimal strategy for the first part of the stage is based on measurements from upstream detectors for the beginning of the projection period and the smoothed average flows for the end of the projection period.

Gartner points out that the OPAC traffic flow model is good for application in a demand responsive, decentralized, flexibly coordinated system. (6) OPAC is useful in structuring flows in a network to maintain coordination and respond to variation in flows The system would require local analysis capabilities and communication with adjacent controllers. (8: p. 79)

OPAC is the name of the computer program that implements the above strategy. It has been tested in Arlington, Virginia, and Tucson, Arizona, and simulated with NETSIM, a simulation model in which arriving traffic streams can be externally specified. The traffic flow data for the simulation tests were from five different 30-minute sets of data from signal controlled intersections in Tucson, Arizona. OPAC achieved a 30 to 50 percent reduction in initial delay and an increase in average speeds of 10 to 20 percent over the existing fixed time algorithms. (8: p. 79)

The first field test was conducted in Arlington, Virginia, using two-phase control. In this case, OPAC reduced delay by 3.9 to 4 percent. It also reduced stops by a very small percentage. This first field test was conducted under very low traffic volumes. OPAC's performance was hurt by its requirement that minor side streets be serviced even if there were no vehicle calls. In the second field test in Tucson, Arizona, volumes increased under OPAC control, and delay was reduced by 15 percent. Stops, on the other hand, increased by 4 percent. In the third field test (with the eight-phase, dual ring control), in Tucson, OPAC reduced delay by 7.7 percent and increased stops by 9.5 percent. (14)

The smoothing factor, used by the model to find the smoothed average of past arrival data, was calculated to be 0.4 from the results of the first field test. This factor must be input by the user, but the past arrival data are automatically obtained from upstream detectors.

IMPLEMENTATION ISSUES

Aside from the differences in traffic control system strategies, some compatibility issues would have to be solved before SCOOT and SCATS could be implemented in the U.S. Neither of these systems is compatible with U.S. standard controllers. OPAC would need some hardware refinements if it were to be implemented. Detectors for OPAC are also farther upstream than current U.S. practice. In addition, in SCOOT, vehicle detectors are placed closer to the upstream intersection than in most current U.S. systems. Therefore, in order for SCOOT or OPAC to be installed in the U.S., the detectors would have to be replaced. Costs for SCOOT and SCATS are roughly the same, while UTCS and OPAC are significantly less expensive.

SUMMARY AND CONCLUSIONS

The four systems described in this report represent the state-of-the-art in traffic control. Each system has its advantages and disadvantages; no one system is the ultimate solution to traffic control problems. For the SCOOT and SCAT systems, implementation in the U.S. is a prohibiting factor, since the controllers and detector locations are not compatible with U.S. standards. Table 2.6 shows a comparison of software and costs. SCOOT is considered to be a UTCS 2-GC equivalent system. UTCS 1.5, on the other hand, is compatible with United States technology, but it is not as traffic-responsive as SCOOT and SCATS. The primary advantage to UTCS 1.5 is its ability to facilitate the timing plan calculation process. OPAC, the fourth system, has demonstrated (at the test intersections in Arizona and Virginia) its ability to reduce delay at individual intersections; however, in its present stage of development, it has not been demonstrated for network traffic control. Compared to the other systems, OPAC is relatively inexpensive to implement, since no central computer nor communications equipment are required.

Table 2.6. Comparison of Real Time Traffic Signal Control Systems

Item	SCOOT	SCATS
Software-central	Remote diagnostics are possible over modem Link from the U.K. It appears unlikely that arrangements could be made for full support in Toronto.	Arrangements would have to be made for support in Toronto.
Software-field	??	Arrangements would have to be made for support in Toronto.
Costs		
License	Proprietary but may be feasible to provide source. £30,000 for user rights; £150,000 for full knowledge.	Proprietary $160,000 US, $10.000 US annual update fee.
25 signal system	$1,723,200	$1,658,300
25 signal system	$2,289,500	$2,547,800
Expected traffic flow requirements.	SCOOT operates effectively in arterial and grid networks and is more effective in areas experiencing dynamic, less predictable, moderate to heavy congestion traffic conditions.	SCATS is designed as a complete traffic system accommodating all traffic conditions.

Source: "Feasibility of a pilot project for downtown Toronto to a produce 'real time' traffic control system," Supplement Study Report prepared by Delcan Corporation for Metropolitan Toronto Department of Roads and Traffic, December, 1988.

CHAPTER 3

BELLEVUE SIGNAL SYSTEM EVALUATION

The City of Bellevue, Washington, replaced its traffic control system in April 1987 with a state-of-the-art arterial traffic control system known as the Urban Traffic Control System (UTCS) 1.5. Although a new central computer communicates with all of the intersections in Bellevue's traffic control system, only four arterial sections use UTCS 1.5. These sections are shown in Figure 3.1.

UTCS 1.5 was developed primarily to alleviate the problems of manually producing signal timing plans. The first generation UTCS system (UTCS 1.0) required operators to develop a large library of timing plans with volume data that had to be entered manually. UTCS 1.5 can generate timing plans from detector data that are automatically collected and formatted by the system.

This chapter summarizes a technical report that compared the Bellevue UTCS 1.5 system with the former Bellevue traffic control system, a UTCS 1.0 system. (15) It compared "before" and "after" traffic control conditions on the basis of both the system's operation and its effect on travel times.

SYSTEM EVALUATION

Several improvements in system performance were outlined during discussions with Bellevue's traffic engineers and system operators, Dirk Mitchell and Fred Liang. The evaluation of the new traffic control system included the following factors:

- travel time changes,
- equipment,
- operation,
- maintenance,
- staff,
- detectors,
- incident detection,
- special events, and
- public perception.

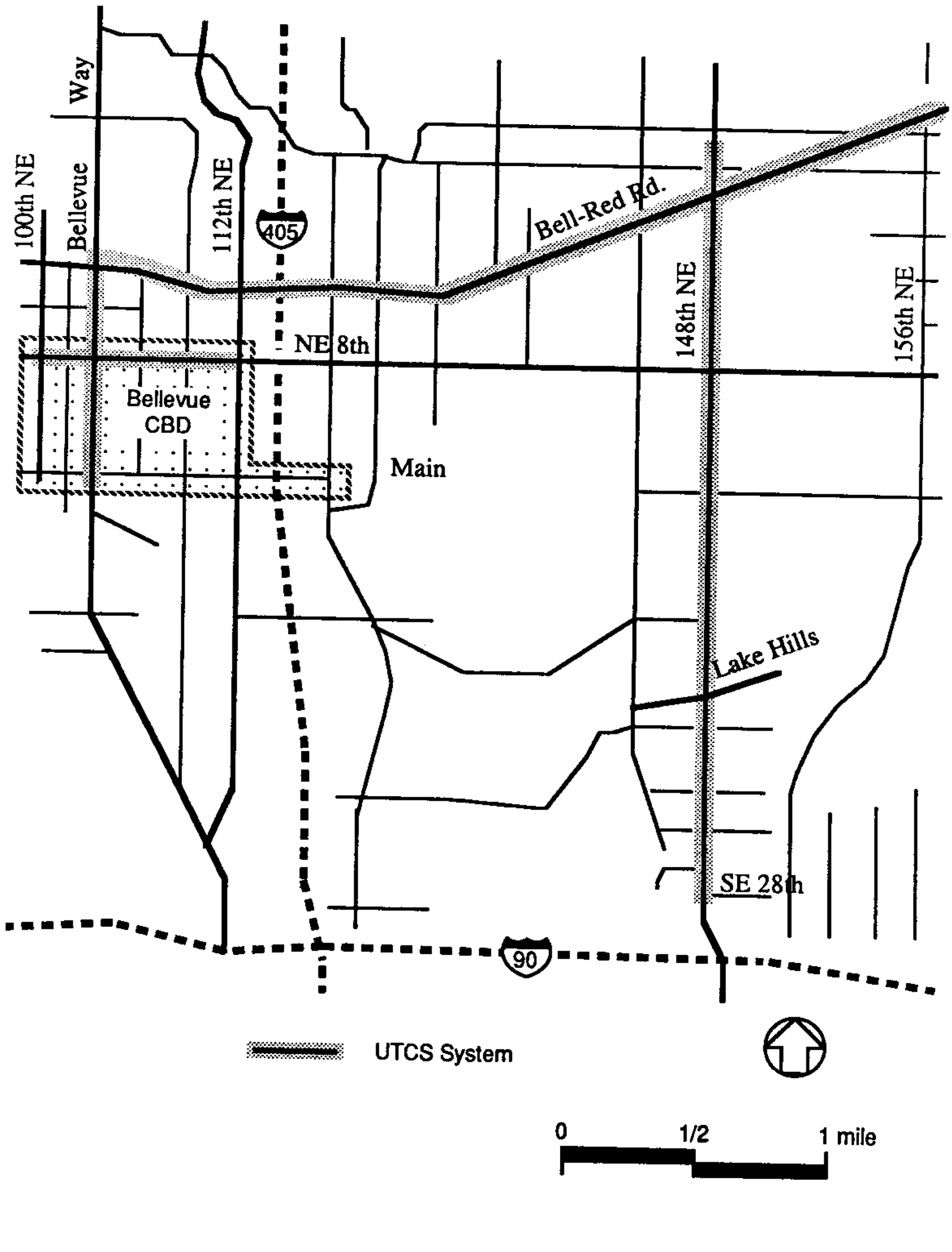

Figure 3.1. Bellevue UTCS 1.5 System

Travel time studies were conducted to determine quantitative measures of system performances. To evaluate changes in mean travel times, travel time studies were conducted before and after the implementation of the UTCS 1.5 system. "Before" travel times were collected (for the peak hour in the morning, noon, and evening) with the floating car method. The research team collected the "after" travel times during the same peak hours with the computerized license plate method. Some floating car runs were conducted at the same time as some license plate collection times to determine that the times were comparable.

The other nine factors were presented in a qualitative form. The evaluation of these factors was based on discussions with system operators.

EVALUATION OF THE SYSTEM OPERATION

As previously mentioned, the new and old UTCS systems were compared on the basis of nine qualitative factors, each of which is discussed below.

Equipment

Communicating with the central computer became much easier once the operators could use five IBM terminals instead of a Teletype machine. The new mainframe also has two Megabytes of core memory, as opposed to the old system's 350K, and is capable of communicating with 160 intersections as opposed to 45 intersections.

Operation

Timing plan selection and development was particularly difficult on Bellevue's old system. Updating timing plans was so time consuming that operators were frequently unable to make improvements on a regular basis. Instead, they spent their time trying to keep the traffic control system functioning and on-line.

With the new system, operators are able to change the timing plan at the keyboard in 30 minutes, rather than the 2 hours to 8 hours it previously took. Operators can now focus their attention on improving timing plans by choosing from a variety of optimization programs, including FORCAST, which was not an option on the old system.

Maintenance

While the firm that provides maintenance for the new signal system has not changed, the cost of maintenance has substantially decreased from $17,000 a year to $8,000 a year. The communications equipment on the former system was very sensitive to short disconnections in the phone line connection, and as a result, it was frequently off line. The UTCS 1.5 system, on the other hand, is able to re-boot itself every 15 minutes to reconnect off-line signals.

Staff

With the installation of the new UTCS 1.5 system, staff time can be used more productively. The number of staff operating the system has not changed, but the operators are doing different types of work. Instead of focusing on keeping the computer on-line and operating intersections, the operators have time to improve timings and phasings at the intersections.

Detectors

Programming the detectors to report volume data has become much easier with the UTCS 1.5 system. Obtaining volume data does not involve the complex FORTRAN programming that the former system required. Operators are hoping to install more system loop detectors so that they can more accurately detect volumes. Previously, they did not have time to install new detectors because they were concentrating on keeping the traffic control system functioning and on-line.

More detectors are needed to alleviate the need to collect volume data manually. One of the benefits of the UTCS 1.5 system is its ability to automatically load the detector data into the optimization programs. As long as not all intersections have this capability, the system will not be used to its full capability.

Incident Detection

Incident detection has not changed with the new system. Cameras are still used to detect incidents, but once the incident has been detected, timing plans can be changed much more easily.

Special Events

The former system did not allow the operators to even consider planning for special events such as holidays or increases in traffic caused by civic or sports events. The process involved in making changes to the timing plan was simply too long and complex. With the new system, the operators can program a holiday schedule any time in advance.

Public Perception

Public perception refers to any changes in convenience or reliability perceived by the user. The operators reported that the number of complaints has remained about the same (one complaint a week), but they have received more positive feedback. Another advantage to the new system is that when a caller makes a complaint, the operators are able to make a small change in the system. For example, in response to changing traffic conditions at Bellevue Community College, operators can now change the signal timing at the school entrance when the college is in session. Previously, nothing could be done to change the signal timing because of the complex process involved.

TRAVEL TIME STUDY

The UTCS 1.5 and 1.0 systems were also compared on the basis of the travel time studies and traffic volume comparisons. Overall, the volumes for the entire system increased by 17 percent, and the travel times decreased by 2 percent (Table 3.1). In other words, the UTCS 1.5 system maintained travel times while volumes increased 17 percent. (The system wide travel time improvement was not statistically significant.)

The differences in percentage of improvement varied among the peak periods (Table 3.2). The morning peak hour (7:30 a.m. - 8:30 a.m.) mean travel time for all the

Table 3.1. **Mean Travel Time Improvements by Arterial**

Arterial	Before Mean Travel Time (seconds)	After Mean Travel Time (seconds)	Percent Improvement	Percent Increase in Volume
N.E. Eighth	173	216	-25	24
Bellevue Way	155	156	-0.5	4
148th Avenue	447	421	6	16
Bel-Red Road	509	468	8	26
System	—	—	2	17

Table 3.2. **Percent Travel Time Improvement by Peak Hour**

Peak Hour	a.m.	Noon	p.m.	System
Percent Improvement	9	-2	-1	2
Percent Increase in Volumes	5	26	15	17

Table 3.2. **Veh-Miles/Hour in Thousands for the Peak Hours**

Peak Hour	Morning (7:30-8:30)	Noon (11:30-12:30)	Evening (4:30-5:30)
Before	95	137	138
After	106	166	151

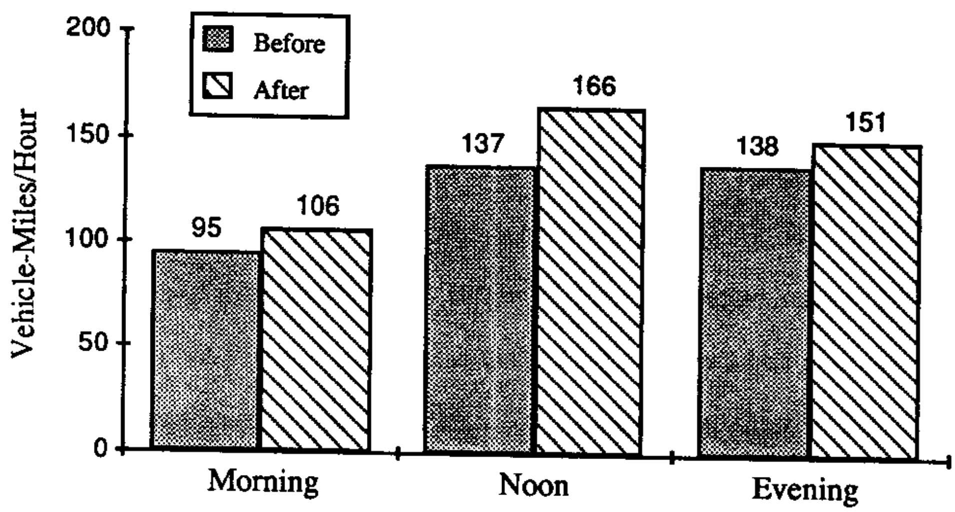

Figure 3.2. Vehicle-Miles/Hour for the Peak Hour

arterials decreased by 9 percent with the implementation of the new traffic control system, while the morning volumes increased by 5 percent. Noon travel time increased by 2 percent, while volumes increased by 26 percent. The evening hour showed a 1 percent increase in travel times, although the change would probably not be noticeable to individual drivers. A 15 percent increase in volume accompanied the insignificant increase in travel time.

Vehicle-miles/hour (vmh) was used as a means of combining travel time and volume into one statistical measurement of improvement. It was calculated by multiplying volume by distance in miles and dividing that product by the travel time in hours. This measure was intended to compensate for cases when the travel time increased as the volume increased, as might be expected under heavier traffic conditions. As Table 3.3 and Figure 3.2 indicate, the vmh for each peak hour on each arterial increased.

Several recommendations were made to improve system performance and the response to public needs. Improving system performance is a matter of adding the equipment necessary for the system to operate at its full capability. For instance, more detectors are needed. A second recommendation was to install interconnect cable to replace phone lines. This would allow the system to operate almost completely free of communication disconnections.

In addition to maintaining travel times with increased volumes, the automatic operation of the UTCS 1.5 system showed substantial advantages over the former UTCS 1.0 system.

CHAPTER 4

ADAPTIVE SIGNAL CONTROL DISCUSSION WITH LOCAL AGENCIES

In order to share information regarding adaptive signal control techniques and to gauge interest in these techniques, the researchers met with traffic engineering personnel from several jurisdictions within the Seattle metropolitan region. They held three meetings in April and May 1989. The following jurisdictions were represented:

- Meeting #1 (April 26, 1989) — Cities of Auburn, Kent, Renton, and Tukwila; King County; and WSDOT District 1;
- Meeting #2 (April 27, 1989) — Cities of Edmonds, Everett, Lynnwood, and Mountlake Terrace; Snohomish County; and WSDOT District 1; and
- Meeting #3 (May 4, 1989) — Cities of Bellevue, Redmond, and Seattle; King County; and WSDOT District 1.

After describing the SCOOT, SCAT, UTCS 1.5, and OPAC control strategies and summarizing the results of the evaluations described in Chapter 3, the researchers asked the representatives of the jurisdictions several questions about current signal control systems in their jurisdiction, plans for improvements, and their interest in any of the four adaptive control strategies presented. This chapter will discuss the responses to these inquiries during each meeting.

All of the jurisdictions indicated that they either have coordinated systems or are planning to upgrade their equipment to coordinated systems. Most of the jurisdictions had systems with either a microcomputer or minicomputer central. A variety of control systems were represented: Multisonics, Traconet, Econolite, and Computran. Most of the jurisdictions indicated that they do not own the software source code to be able to modify the control functions of their central computer. Some owned their own communication lines, while others leased their communication lines. About half of the jurisdictions indicated that they have plans to upgrade the systems in at least a portion of their networks.

On the subject of adaptive control techniques, one jurisdiction, the City of Bellevue, has a UTCS 1.5 system in operation and another, the City of Seattle, is investigating its use. Little interest was voiced in either SCOOT or SCAT. Lynnwood, Edmonds, Mountlake Terrace, Snohomish County, and WSDOT District 1 indicated some interest in the OPAC system, primarily as a critical intersection control technique for their busiest intersections. (In earlier meetings, personnel from the City of Bellevue also voiced their interest in OPAC.)

Overall, interest in adaptive control varied. Growth in some of the jurisdictions, particularly in the jurisdictions in South King County, is so pronounced that just keeping up with the need for new signalized intersections and keeping the existing equipment timed to reflect the changes in traffic is all the traffic engineering departments have staff to do. They do not have the staff nor the resources to install and debug new software.

In summary, the two largest cities in the region either have or are investigating UTCS 1.5. No interest was shown for SCOOT or SCAT, and a few jurisdictions were interested in OPAC, perhaps even in becoming sites for further tests of the program.

CHAPTER 5

ADAPTIVE SIGNAL CONTROL
CONCLUSIONS AND RECOMMENDATION

CONCLUSIONS

On the basis of the review of adaptive signal control systems and the discussions held with representatives of local jurisdictions, several conclusions can be drawn.

1. Adaptive control techniques have a start in the Puget Sound region with the UTCS 1.5 system and the investigation of the UTCS 1.5 system by the City of Seattle.
2. The expense and subsequent risk involved in purchasing and installing a large, centrally controlled adaptive system that has not been demonstrated in the United States make SCOOT and SCAT very unattractive options to most jurisdictions. Few jurisdictions can afford the initial installation within their own budgets. Those that could afford the cost do not want to take the risk of implementing these systems given the amount of development that would be required. The most likely way for either of these two systems to be installed in the U.S. would be through a demonstration project funded by state and/or federal contributions, but no local jurisdiction currently wishes to perform this task.
3. The OPAC system has the potential to provide very cost-effective improvements to signal system control. OPAC could be utilized as the critical intersection control technique within an existing coordinated system, or could provide the control logic for all the intersections in the system. Either of these applications would require some testing and perhaps some development work. There is sufficient interest in OPAC to pursue a test site located in the Puget Sound region. OPAC offers a flexible system that can

be incrementally implemented within a jurisdiction. The risk is low and the potential for improvement is high.

RECOMMENDATION

The WSDOT should investigate possible tests or demonstrations of the OPAC system in the Seattle area. WSDOT should play the lead role in this effort by maintaining contact with the FHWA research office developing the software, determining the state of readiness of the next version of OPAC, coordinating the local jurisdictions so that the appropriate arterials are selected for the tests, and ensuring that the participating cities and agencies both benefit from such a test and are eager participants in that test.

CHAPTER 6

INTEGRATED CONTROL SYSTEMS INVESTIGATION

A second aspect of this research project was to investigate traffic control system integration techniques for the Puget Sound area. The term traffic control system integration refers to managing physically separate traffic control systems as if they were part of one overall traffic control system. It can be applied on many levels, from personal communication between operating agencies to a sophisticated central computer that supervises individual traffic control systems on arterials and on freeways throughout a given area. It allows operating agencies to manage the transportation system better and to more efficiently use personnel.

This chapter summarizes a working paper written for this project. (16) It discusses some of the approaches available for integrating control of traffic control systems among various jurisdictions. After defining some general system integration techniques, the chapter describes possible implementation approaches and the project team's approach to evaluating the best method for performing that implementation.

METHODS OF INTEGRATION

Six methods of system integration were discussed in the previous working paper. These six methods can be condensed into three basic categories:

1. manual information exchange,
2. integration through computer communication, and
3. fully integrated control systems.

Manual Information Exchange

Information exchange, as mentioned earlier, is one of the key elements of system integration. Information exchange may take very sophisticated forms or very simple and straightforward forms. The most straightforward approach is exchanging information on paper or in person. This may involve sending a hardcopy of data to operators or managers of other systems so they can use the information for planning purposes or for developing control strategies. The data usually come from historical databases. Operators of one system can identify trends in other systems that may affect the operation of their system.

Information exchange may also take the form of periodic meetings to exchange status information on ongoing projects. Traffic or corridor management teams are an example of a formalized information exchange that leads to an integrated approach to transportation management.

Integration through Computer Communication

There are two approaches to this method. The first is to provide on-demand communication between systems. One computer sends data to another, over dial-up phone lines, when information is requested. Primarily, historical data for analysis purposes and for generating signal patterns and control strategies are transmitted.

The second approach is to provide dedicated communication between systems individually or through a regional computer that communicates with all the control systems. Communication is regular, and real-time data are exchanged.

The data shared are used by each control system independently. The jurisdiction that is responsible for a given system has complete control over the operation of the system and chooses to use the data from the neighboring system in the most appropriate way. The data shared may be

- historical, to be used for analysis and pattern generation,
- real-time, to be used in pattern selection, or
- special occasion, to be used only for special events or incidents.

One possible application is to use data from other systems as input to traffic responsive operation.

Fully Integrated Control Systems

The most sophisticated form of system integration employs a centralized master computer to supervise individual control systems. The central computer supervises different control systems under one jurisdiction or systems controlled by many jurisdictions.

The fully integrated control system operates under one of two general philosophies. The first philosophy uses an expert system approach, in which a computer program recommends control action for each local system being supervised. The recommended action must then be approved by an operator before it can be implemented. This approach is operator intensive. No action can be taken without operator approval. However, the benefits come from reliability because operators can ensure the integrity of the decision before allowing an action to be implemented. For example, malfunctioning detectors may not cause as much of a problem as they would if the system automatically implemented control strategies. The logic in determining control strategies may not need to be as foolproof, either. If the control strategy recommended does not truly fit a unique set of conditions, the operator simply does not approve the plan. Finally, this approach places ultimate control of the system with the responsible agency. No other system can override this control; they choose whether they want to implement the action that the regional computer recommends.

The second philosophy is a fully automatic approach. The central computer calculates or selects control plans or strategies for each local system being supervised. The integrated system has to be designed to assure data integrity. The control algorithms must be more sophisticated to cover greater ranges of field conditions. The system can be set up to allow local systems to manually override central commands when desired. On the other hand, the system can be set up so the central computer may only override local control in extreme circumstances, such as during severe incidents. The INFORM system on Long Island has the capability of automatically selecting an arterial signal plan on the basis of freeway conditions. The Smart Corridor Project is being designed to be a fully integrated system as well.

IMPLEMENTATION OF AN INTEGRATED SYSTEM

Many of the methods mentioned above could be used in concert. A regional computer may supervise some local systems, only automatically communicate with others, be available for dial-up data requests for others, while in the same center, operators manually make decisions for one system on the basis of conditions they see on another. Hardcopy output may be generated and sent to other system operators/managers. The entire communications system for all of the systems may be shared, and subregional computers/controllers from different systems may be located in the same facilities. Most importantly, the system integration concept must be flexible to meet the needs and concerns of the various agencies and individuals involved. Any level or method of integrating information, resources, or control is better than no integration at all.

CANDIDATE INTEGRATION APPROACHES

One of the primary thrusts of this project was to determine the needs and desires of the various agencies and jurisdictions in the region regarding coordinating or integrating control systems. Researchers polled several of the larger jurisdictions to determine their interests and needs. Each jurisdiction was asked to comment on its need for and interest in the different methods of system integration described earlier in this chapter. Their responses and the other results from this project will be used to drive future efforts towards designing an integrated system. Each agency was given the opportunity to choose a different method of integration. The idea was to develop a plan that will provide incremental implementation of a system that will eventually meet the needs or desires of all the agencies. These results are described in the next chapter.

CHAPTER 7

INTEGRATED CONTROL SYSTEMS DISCUSSIONS WITH LOCAL AGENCIES

During the meetings with local jurisdictions referred to in Chapter 4, researchers presented the integration framework and the options set out in Chapter 6. After presenting the reasons for integrating control systems and the methods for carrying out system integration, the researchers asked the jurisdictions which levels of integration they were currently undertaking and in which they would be interested in 5 and 10 years. The specific integration levels presented were

- no integration,
- manual information exchange,
- on-demand information communication between system computers,
- dedicated computer communication to share data,
- a region-wide supervisory computer that would recommend control strategies (expert system approach), and
- a region-wide supervisory computer that would select or develop control strategies to be implemented automatically.

Most of the jurisdictions surveyed currently share or are interested in sharing traffic and/or signal timing data with neighboring jurisdictions. The jurisdictions within a geographical subarea of the region meet on a regular basis to discuss upcoming projects. These meetings provide a forum to discuss operational issues as well. Coordination of projects and operations often result from these meetings.

Current levels of coordination vary among jurisdictions. The cities of Lynnwood, Edmonds, and Mountlake Terrace and WSDOT District 1 "share" a Multisonics system. The system supervises control of 39 intersections. Each jurisdiction has operational responsibility for some of the intersections in the system. Lynnwood has primary responsibility for operating the system. This represents the largest integrated system within the region.

Coordination of control and operation exists among other agencies as well, primarily at boundaries between two jurisdictions or when intersections controlled by one jurisdiction fall in the middle of a system controlled by another jurisdiction. However, currently no two separate control systems interact with each other's central computer.

Several jurisdictions showed interest in on-demand or dedicated computer communication to share data for current conditions. Specifically, the city of Bellevue is interested in on-line communication with the WSDOT freeway management computer so it can directly receive I-405 traffic condition information. The cities of Lynnwood, Edmonds, and Mountlake Terrace are also interested in an on-line communication connection between their central computer and the WSDOT freeway management computer so their signal system and the WSDOT ramp control system on I-5 can work in concert.

All jurisdictions voiced interest in increased coordination and integration in the future. Some jurisdictions were concerned with personnel requirements in development and operation of any advanced communication system. Other jurisdictions pointed out that the level of trust between jurisdictions would have to be improved before any integrated systems could be implemented. Most jurisdictions indicated that they would be interested in on-demand or dedicated computer communication within 5 years. Within 10 years, many jurisdictions indicated an interest in a regional supervisory computer system that would recommend control strategies, the expert system approach, if the algorithms used by the system met their needs and they had approval authority over the algorithms. Autonomy to implement strategies and control plans were important considerations to all agencies. Only Snohomish County and WSDOT District 1 showed any interest in a regional computer that would select (or develop) and implement control strategies automatically.

The researchers asked what the jurisdictions would like to see investigated in upcoming tests of integrated arterial/freeway control in the I-5 corridor in northern King

County. The jurisdictions that responded to this question indicated that they were particularly interested in evaluating the benefits that an integrated system can produce. They were also interested in investigating methods to accurately predict traffic diversion during various types of freeway incidents.

To summarize, most jurisdictions are either interested in or are currently exchanging traffic and/or signal timing data with neighboring jurisdictions. Most are interested in computer communication among control systems within 5 years and in an expert system approach to regional control system integration within 10 years. Finally, the jurisdictions showed very little interest in implementing a regional supervisory computer that automatically selects or develops control strategies. In fact, a great deal of concern was voiced over this option -- the jurisdictions did not want to lose autonomy or control over their systems.

CHAPTER 8

INTEGRATED CONTROL SYSTEMS
CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

On the basis of the review of integrated control systems and the discussions held with representatives of local jurisdictions, several conclusions can be drawn.

1. The local jurisdictions want better information transfer between traffic control systems as a prelude to integration of the actual control functions of those systems. Corridor traffic management teams appear to provide the best means to promote this information transfer and to lead to more automated methods for performing this function. The teams are best suited for this function because WSDOT involvement in these teams has already been funded; they already provide close operational coordination on day-to-day problems encountered by the jurisdictions; and they provide a strong basis on which to build the increased level of trust necessary before more formal integrated systems can be implemented. The teams will also provide the basis on which to build constituencies for any major traffic improvement proposed by any of the participating jurisdictions.
2. Local jurisdictions are interested in integrated control of signal systems, although they are skeptical of the costs of integrated systems and wary of the implications these systems have for traffic conditions on streets within their jurisdictions.
3. The best method for promoting integrated control of signal systems will be to demonstrate such a system at a location that has little or no impact on those jurisdictions, but where its impacts can be readily viewed and interpreted by those local agencies. Thus the first test of an integrated control system should be entirely within the WSDOT freeway and arterial

control systems. Also, it should investigate the types of control algorithms that can be used and the impacts integrated control plans have on traffic performance.

RECOMMENDATIONS

The researchers recommend the following actions:

1. WSDOT should pursue the opportunity to integrate its arterial and freeway systems in the north end of King County and the southern portions of Snohomish County. This portion of the metropolitan area has been selected because of the high level of cooperation that already exists between the jurisdictions in the north end and the fact that the necessary equipment is already in place and/or currently being installed. The proposed system will provide an excellent test bed for examining integration techniques, motorist reaction to the control systems, and impacts the integrated system has on arterial congestion.
2. WSDOT should consider establishing traffic management teams in the metropolitan region. Initially one team should be developed, with the possibility of expanding the team into three teams to cover the three major traffic corridors, north, east, and south. This aggregation of jurisdictions will place agencies and communities with similar concerns in the same corridor management team and promote information flow without making the teams so large that they are unwieldy.
3. The WSDOT should consider including transportation agencies and law enforcement agencies operating within these corridors as permanent members of the teams. Emergency service agencies, towing services, and traffic reporters should be invited to meetings when the agenda concerns their areas of expertise. While this recommendation is not directly related to

integrated control systems, it does relate heavily to the need for better information transfer among agencies working within the road system in neighboring geographic areas. It was also a topic of discussion within the meetings held for this project.

4. In addition to the control system demonstration described above, a communication system should be designed and the appropriate computer architecture selected to meet the medium-term data transfer and integration needs and desires of the agencies in the Seattle area. The system will allow different levels of communication among control systems. These communication levels will be based on the level of participation desired by the individual jurisdictions involved, with the results of this project as a starting point. The corridor traffic management teams should be used as the forum to develop the requirements of the system. The teams should also be used to build consensus on the need for the system and the priority in funding the system.

CHAPTER 9
APPLICATION AND IMPLEMENTATION

Application and implementation of the results of this research fall into two distinct categories: results that can be directly applied, either through planned research projects or through planned WSDOT action, and results that can only be applied by programing additional projects. The results are discussed below within these two categories.

DIRECT APPLICATION OF RESULTS

Two results are discussed below that fall into this category.

WSDOT Freeway and Arterial Control System Integration

As mentioned in Chapter 8, a project scheduled to begin in late summer 1989 will investigate and develop integrated control strategies that will be implemented on a pilot basis and tested in the I-5 north corridor. The I-5 ramp metering system and the WSDOT arterial control systems on Bothell Way (SR 522) and Aurora Avenue North (SR 99) are the systems that will be used for this pilot project.

The pilot project is a direct application of the results of the research project for which this report was written. In conversations with representatives of local jurisdictions, the researchers found that one of the barriers to development of a regional, multi-jurisdictional integrated system was a lack of tangible, documented benefits derived from integrated systems. By beginning with a system integrating control of WSDOT systems, local jurisdictions can observe the operation of a working system that integrates control of two separate and existing systems without risking disruptions to traffic on their systems. The pilot system provides a low cost, low risk initial step in integrated control.

The pilot project should involve interested jurisdictions as deeply as they desire. The project will provide the jurisdictions with a concrete, low cost example of integrated control that is developed within an existing structure. It will also provide an example of the flexibility possible in such a system.

Corridor Traffic Management Teams

Another need identified as a result of this project is the need to provide a framework for coordinated approaches to traffic problems. The jurisdictions that took part in the meetings held in the spring of 1989 recognized the need to be more involved in coordinated activities. Corridor traffic management teams will provide the forum for such coordination. The teams will also provide the first step in developing a regional system to share data and, perhaps, integrate control of traffic systems across jurisdictional boundaries.

WSDOT involvement in the teams was funded through a decision package approved in the 1989 legislative session. The first step in implementing these teams is to appoint a WSDOT District 1 staff person responsible for establishing the teams. After this appointment has been made, the precise number of teams, make up of each team, and functions and objectives of the teams must be decided upon. These decisions should be made in consultation with local jurisdictions to build a constituency and ownership within the various jurisdictions.

FUTURE APPLICATION OF RESULTS

Two results fit in this category and are described below.

OPAC Traffic Signal Control Strategy

The OPAC control strategy provides the best direction for adaptive signal control in the Puget Sound area. Several jurisdictions are interested in further investigation of OPAC. Several potential demonstration sites are available in the Puget Sound region.

OPAC has not been tested as part of a traffic control system. The most logical next step in the development of OPAC appears to be application on a linear arterial or application as a critical intersection control strategy within a traditional signal system. There are candidate locations within the Puget Sound region for both of these applications. WSDOT should make FHWA aware of the willingness of Puget Sound jurisdictions to participate in a pilot application of OPAC.

Whether or not a pilot study is performed in this region, WSDOT should closely follow the continued development of OPAC. If the test results continue to be positive, as they have thus far, OPAC should be considered for implementation when a production version is available.

Integrated Electronic Communication System Design

Implementation of a system to communicate among various control systems will be a major undertaking. Careful consideration of the potential benefits and level of participation is needed before a decision is made to design and install such a system. The decision to proceed with this activity should be made on the basis of strong support from several jurisdictions as evidenced in the corridor traffic management teams. This activity should proceed on a corridor by corridor basis when the jurisdictions within the corridor agree to participate in the system by allowing the central computer to communicate with their computers.

Funding is an issue that must be decided upon. One possible funding scenario would be that some source of regional funds, such as the Transportation Improvement Board, be used for the central computer. The computer communication system could be designed to communicate with many different computer systems. Each individual agency would be responsible for the communication line to the central computer and for providing its system's communication protocol. The decision on how to fund this system should be made by consensus by the corridor traffic management team members.

ACKNOWLEDGMENTS

The authors would like to thank the efforts of many people instrumental in the conduct of this project. First, the Technical Review Committee provided their time and expertise on an on-going basis. The members of the committee were Dave Crippen, Bill Haro, Don Hoffman, and Brian Patton. The authors would also like to thank the time and efforts of those individuals that participated in the meetings with local jurisdictions.

The efforts of several WSDOT staff were critical to the project: Miguel Gavino, Bill Garing, and Toby Rickman.

The authors also wish to acknowledge the special efforts of the Washington State Transportation Center staff, particularly Amy O'Brien and Ron Porter. The data collection effort could not have been accomplished without the efforts of Jim Chan, Cindy M. Hirsch, Ruth Kinchen, Cory Lawson, Ron Mar, and Dave Thorkelson.

Finally, a special thanks to those individuals that sent reports and gave information over the telephone:

- Christina M. Andrews, Farradyne Systems, Inc.
- David Foster, GCG Dillon Consulting Ltd., Edmonton, Alberta
- Les Kelman, Dept. of Roads and Traffic, Municipality of Metropolitan Toronto
- Fred Laing, City of Bellevue
- Chi Y. Lee, Traffic Engineer, City of Red Deer, Alberta
- Dirk Mitchell, City of Bellevue

REFERENCES

1. Institute of Transportation Engineers. "Urban Traffic Congestion: What Does the Future Hold?" ITE Publication No. IR-040. 1986.

2. "Urban and Suburban Highway Congestion". The Future National Highway Program -- 1991 and Beyond. Working Paper No. 10. Federal Highway Administration. December 1987

3. Puget Sound Council of Governments and Municipality of Metropolitan Seattle. Summary Report: Multi-Corridor Project. November 1986.

4. Puget Sound Council of Governments. Twenty Twenty Vision. August 1988.

5. Puget Sound Council of Governments and Municipality of Metropolitan Seattle. Summary Report: Multi-Corridor Project. November 1986.

6. Gartner, N.H.; "Prescription for Demand-Responsive Urban Traffic Control," TRB 881, 1982

7. Gartner, Nathan H.; "Demand-Responsive Traffic Signal Control Research," Transportation Research, Part A, Vol. 19A, No. 5/6 pp.369-373, 1985

8. Gartner, Nathan H.; "OPAC: A Demand-Responsive Strategy For Traffic Signal Control," TRR 906, 1983, PP.75-81

9. Schroeder, Margaret. State-of-the-Art Review of Adaptive Arterial Control Systems. Washington State Transportation Center. June 1989

10. Hunt, P.B., Robertson, D.I., Bretherton, R.D. and Winton, R.I. "The SCOOT on-line Traffic Signal Optimization Technique," Procs. Intern. Conf. on Road Traffic Signalling, Institute of Electrical Engineers, London, U.K. 1982, pp. 59-62.

11. U.S. Department of Transportation. Traffic Control Systems Handbook, Federal Highway Administration, FHWA-IP-85-11, Revised, April 1985.

12. Luk, J.Y.K. "SCATS-application and field comparison with a TRANSYT-optimized fixed time system," Proceedings of International Conference on Road Traffic Signalling, IEE, 1982, p. 71-74.

13. Negus, B.J. and Moore, S.E. "The Benefits of SCRAM: The Maroondah Highway Survey," Proceedings of the 12th Australian Road Research Board Conference, Vol. 12, Part 4, August 1984.

14. "Evaluation of the Optimized Policies for Adaptive Control (OPAC) Strategy," Final Report prepared by Ferradyne Systems, Inc. for U.S. Department of Transportation Federal Highway Administration, February, 1989.

15. Schroeder, Margaret. Evaluation of Bellevue's New Traffic Control System. Washington State Transportation Center. August 1989

16. Jacobson, Leslie N. Integrated Freeway/Arterial Management in Washington State. Washington State Transportation Center. February 1989.