Evaluation of the Bellevue UTCS 1.5 Signal Control System

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16. ABSTRACT

The research project had two sets of objectives, one for advanced, or adaptive, signal control ystems 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 the 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 (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.

TheBellevue 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. WSDOT should investigate the possibility of OPAC demonstration or test sites in the Seattle area. Local jurisidictions 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 the issue of control system integration.

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Research Project GC 8286, Task 30
Arterial Control and Integration

EVALUATION OF THE BELLEVUE UTCS 1.5 SIGNAL CONTROL SYSTEM

by

Margaret Schroeder
Research Assistant

Mark Hallenbeck
Senior Research Engineer

Leslie N. Jacobson
FAME Project Manager

Washington State Transportation Center (TRAC)
University of Washington, JE-10
The Corbet Building, Suite 204
4507 University Way N.E.
Seattle, Washington 98105

Washington State Department of Transportation
Technical Monitor
Leslie N. Jacobson
FAME Project Manager

Prepared for

Washington State Transportation Commission
Department of Transportation
and in cooperation with
U.S. Department of Transportation
Federal Highway Administration

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DISCLAIMER

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

SUMMARY

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 the new central computer communicates with all of the intersections in Bellevue's traffic control system, only four arterial sections were evaluated. These sections are shown in Figure 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 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 by the UTCS system.

This study compared the Bellevue UTCS 1.5 system with the former Bellevue traffic control system, a UTCS 1.0 system. It compared "before" and "after" traffic control conditions on the basis of both the system's operation and its effect on travel times.

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, and
- special events.

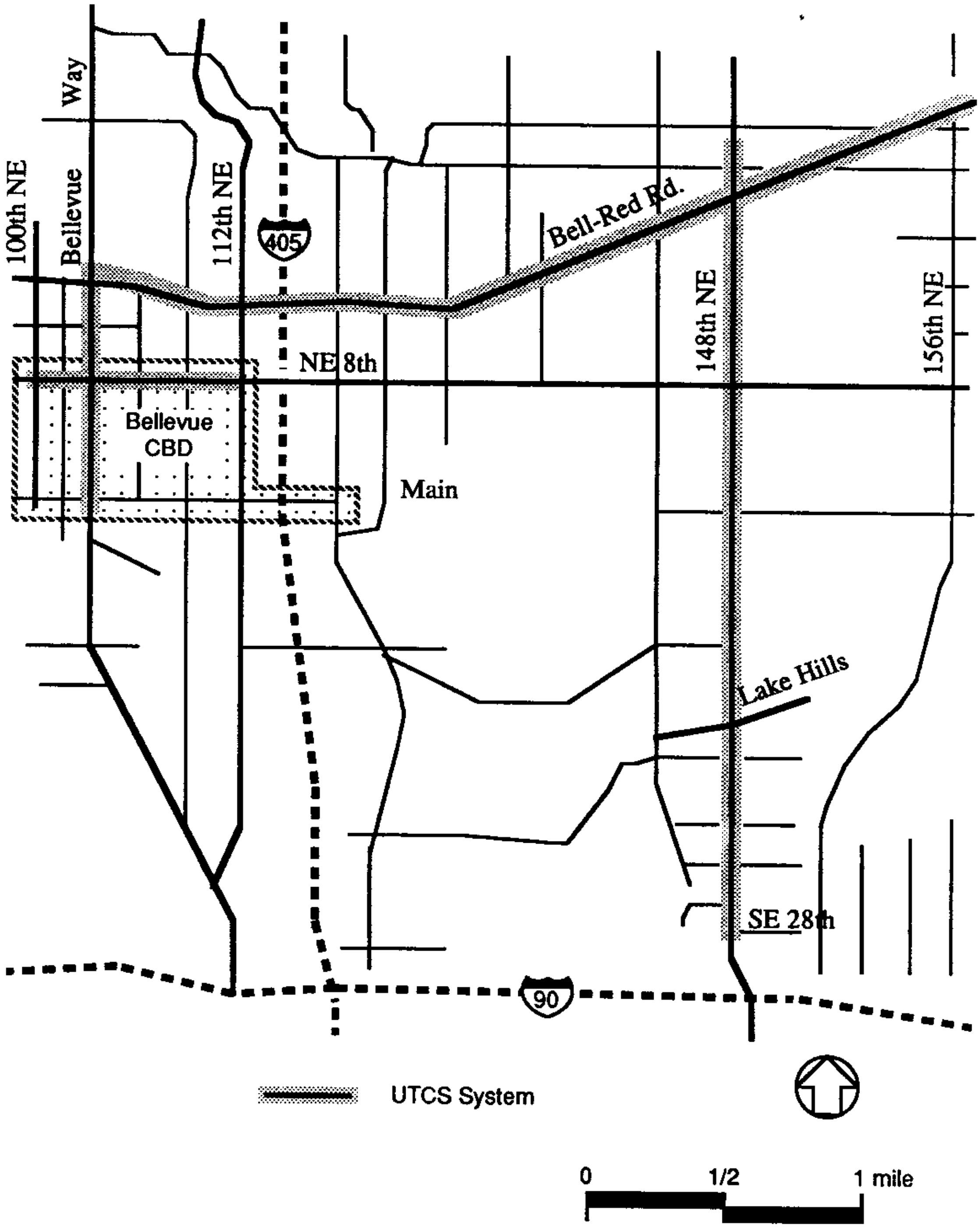


Figure 1. Bellevue UTCS 1.5 System

To evaluate changes in mean travel times, travel times 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. In this collection method a driver and a recorder, following the average speed of traffic, travel along the test section recording delay and travel times. The research team collected the "after" travel times during the same peak hours with the computerized license plate method, supplemented with a few floating car runs. The license plate. method stores license plates and the corresponding travel times in lap top computers. A personal computer back at the office then analyzes the information to provide the travel times in the subject arterial. The. floating car runs were conducted at the same time as some license plate collection times to determine that the travel times measured by the two methods were comparable.

Floating car travel times from the before study and license plate method travel times from the after study were then compared on the basis of time and volumes. A third statistic, vehicle-miles/hour, was also used to compare changes in the system, since this measure combined volume and travel times into one value that could measure the increased throughput of the system. It represents the total usage of the system during the measured time periods.

Table 1 shows the increases or decreases in travel times that were statistically significant and the changes in traffic volumes that accompanied these changes. Differences in measured mean travel times for other data collection periods were not statistically significant. Three statistically significant increases in travel times occurred on NE Eighth, while significant decreases in travel times occurred on 148th Ave and on Bel-Red Road. These changes in travel times did not appear to correspond consistently to changes in volume.

Table 1. Significant Changes in Mean Travel Times

	NE Eighth AM WB	NE Eighth NN EB	NE Eighth PM EB	148th Ave AM SB	148th Ave NN SB	Bel-Red AM EB	Bel-Red PM EB
Before Travel Time	127 seconds	196 seconds	169 seconds	504 seconds	416 seconds	436 seconds	631 seconds
After Travel Time	170	291	264	392	365	389	495
% Change Travel Time	+33	+48%	+56%	-22	-12	-11	-21
Percent Change in Volume	-26	39	0	30	20	-10	47
Confidence Level	93	98	90	99	92	91	98

When conditions throughout the day were aggregated into a single statistic, the data collected showed that travel times throughout the system decreased by 2 percent. Although this measured change was not statistically significant, the measured 2 percent decrease did occur at the same time that traffic volumes rose. Volume counts indicated that the new system controlled 17 percent higher volumes (Table 2). Thus, despite the mixed results of the simple travel time measurements, specific time periods and directions experienced traffic flow improvements as a result of the Bellevue UTCS 1.5 system because the system was able to maintain travel times when traffic volumes increased significantly.

Table 2. Average Daily Changes in Travel Time and Volume

Arterial	Before Mean Travel Time	After Mean Travel Time	Percent Time Improvement	Percent Increase in Volume
NE Eighth	173 seconds	216 seconds	-25	24
Bellevue Way	155	156	0	4
148th Ave.	447	421	6	16
Bel-Red Road	509	468	8	26
System	-	-	2	17

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 from increased congestion. While vehicle miles/hour occasionally decreased in the off-peak direction, the combined estimate for the arterials used in the evaluation showed an increase during all three time periods (Table 3).

Table 3. Vehicle-Miles/Hour in Thousands for the Peak Hours

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

The new system was also found to be much easier to use, allowing operators to update timing plans more easily. Improvements to the timing plans and small changes for special events or incidents could be made through the keyboard rather than with punch cards, providing a significant time savings. Since most of the communications cable is no longer rented from the telephone company and the system is capable of retrying failed communications equipment every 15 minutes, the system was on line for much greater periods of time than with the former system. The use of system detectors has allowed automatic data collection to replace some manual data collection. Maintenance costs for the new computer system have declined from $17,000 to $8,000 per year.

Several recommendations are made based on the study's evaluation. First, the research team recommends that the UTCS 1.5 computerized control be expanded to all signals in the system, as feasible. By expanding the system, the city would gain additional benefits from their existing investment, and more fully utilize the capabilities of the UTCS system. More system detectors are desirable as part of the system expansion. The increase in system detectors will allow the automated collection of more traffic information, and will continue to improve the ability of the city to maintain and improve signal timing plans.

Finally, the project team recommends that the city continue to replace leased phone lines with city owned communication lines (as funds permit), because of the improved performance the city-owned lines provide for the system as a whole.

CHAPTER 1

INTRODUCTION AND RESEARCH APPROACH

In April 1987 the City of Bellevue (Figure 1.1) installed an Urban Traffic Control System (UTCS) 1.5 to replace a UTCS 1.0 system. (1) While the new central computer communicates with all of the intersections in the City of Bellevue traffic control system, the UTCS 1.5 system was evaluated on the only four major arterials for which traffic data from before the system's implementation were available (Figure 1.2),

- NE Eighth, from 100th to 112th,
- Bellevue Way, from Main to 12th,
- 148th Avenue, from Northup to SE 28th, and
- Bell-Red Road, from Bellevue Way to 156th Avenue.

These arterials are the focus of this report.

The purpose of the project was to evaluate Bellevue's new UTCS 1.5 system by comparing it with the former system. Both the ease of the system's operation and any improvements to travel times were evaluated. Changes in ease of operation were measured through several short conversations in fall 1988 and a longer, more detailed conversation in March 1989 with the system operators, Dirk Mitchell, and Fred Liang. Travel time changes were measured through a license plate and floating car travel time study conducted in the fall of 1988 and March of 1989.

SYSTEM OPERATION

Conversations with Dirk Mitchell and Fred Liang revealed that the UTCS 1.5 system is much easier to use than the former system. The discussion focused on several specific features of the system that have changed since the installation of the new system, including

- travel time changes,
- equipment,

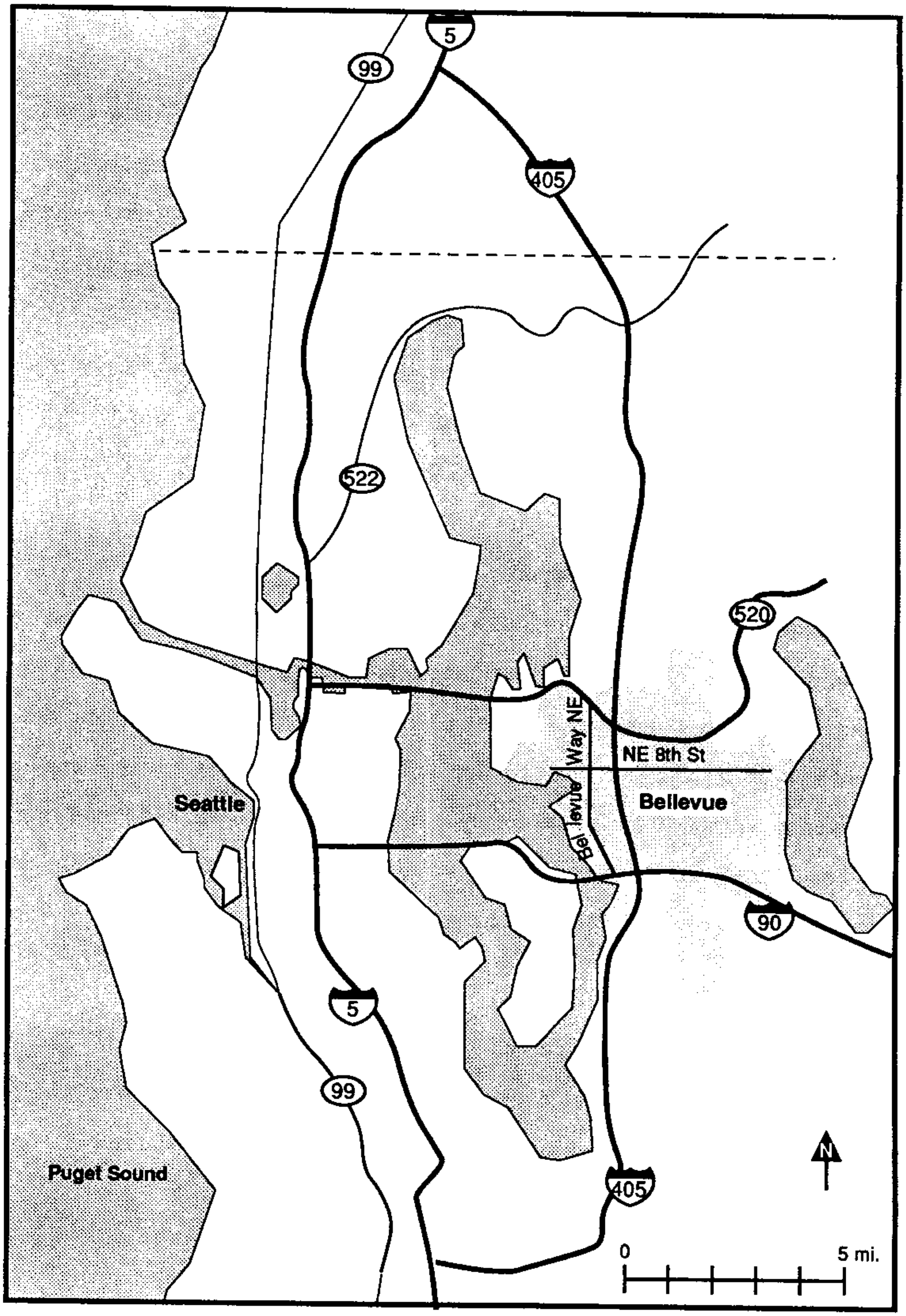


Figure 1.1. Bellevue, Washington

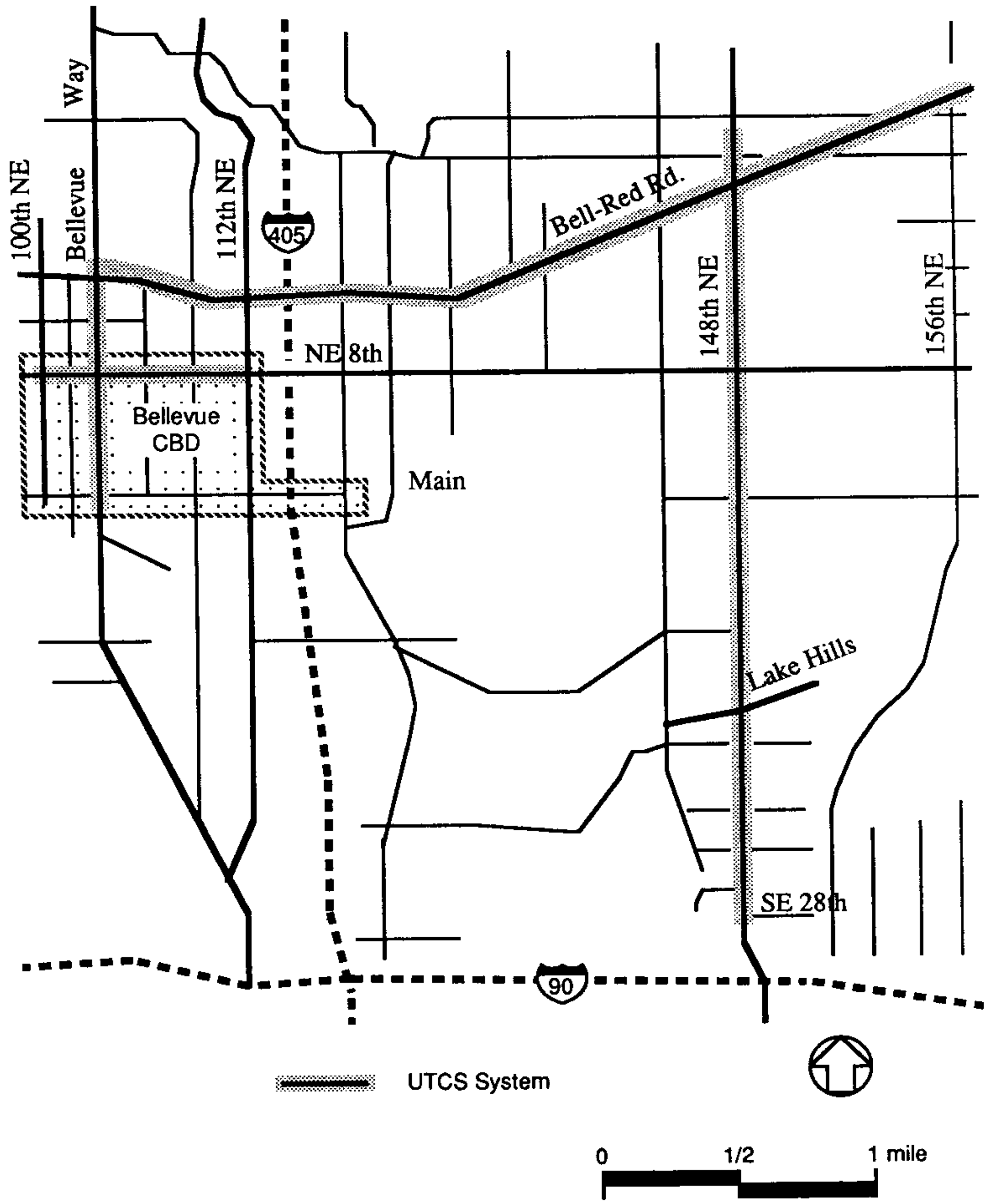


Figure 1.2. Bellevue UTCS 1.5 System

- operation,
- maintenance,
- staff,
- detectors,
- incident detection, and
- special events.

For each of these factors, the former and current conditions are compared and documented in Chapters 2 and 4 of this report.

TRAVEL TIME STUDY

The travel time study was intended to determine whether the installation of the UTCS 1.5 system had improved traffic flow on the four arterials. The City of Bellevue had conducted a floating car survey with the former system, and these results were used as a basis of comparison for the "after" study.

A method of obtaining travel times, the computerized license plate method, was used for the "after" study. This method allowed the researchers to obtain many more travel times for the same number of resources as the floating car method. However, to ensure that the travel times from the two methods were comparable, several additional floating car runs were conducted at the same time researchers collected license plate data.

The travel time results from the before and after study were compared, and the observed differences were examined statistically. Volumes were also considered, since an increase in travel times could have been due to an increase in volumes. A synthetic measure, vehicle-miles/hour, was calculated to include volume increases in the analysis, since volumes and travel times were easier to compare when they were combined into one measure rather than as separate values.

Finally, the researchers examined the evaluation of the system operation and travel time results and determined conclusions and recommendations. These recommendations represent suggestions for making the system more effective.

REPORT ORGANIZATION

The first part of this report introduces specific features of the UTCS 1.0 and 1.5 systems. Next, a discussion of the before and after data collection procedures is presented and discussed. Then the UTCS 1.5 system's operation is evaluated in light of the data collected in the before and after travel time studies. Conclusions and recommendations are then given in the final chapter.

CHAPTER 2

DESCRIPTION OF OLD AND NEW BELLEVUE TRAFFIC CONTROL SYSTEM

The Urban Traffic Control System (UTCS) 1.0 was the primary traffic control system in Bellevue since 1975 until it was replaced in August 1987 by the new UTCS 1.5 system.

The first generation UTCS system (UTCS 1.0) allowed operators to develop a prestored library of timing plans. The operators developed these plans off line with historical data. They could select them directly, by time of day, or by matching the measured traffic conditions with a plan from the existing library. However, few, if any, jurisdictions have the staff to develop the number of timing plans necessary to demonstrate the full benefits of this system. As a result, a more advanced UTCS system, UTCS 1.5, was developed to alleviate the burden of designing a huge library of timing plans with manually collected and entered volume data. Computran System Corporation developed FORCAST, a computer software model capable of using system collected detector data to generate timing plans that can be automatically loaded into the UTCS system. (2) This is one of several features that the operator could accomplish manually on the UTCS 1.0 system but that is now automated on the UTCS 1.5 system.

UTCS 1.0 SYSTEM

Equipment

The old system, capable of communicating with 45 intersections once per second, comprised a Perkin-Elmer 7/32 computer with 350 K of memory and an ADC Communications system. Peripheral equipment included four 5 Megabyte disk drives and a tape drive. Sperry Systems Management supplied the software, a 1975 FORTRAN-based version of UTCS. To communicate with the computer, the operators used a Teletype machine and a system console. Wall maps displayed the operation of the signal system.

Operation

Most of the arterial timing plans implemented in the old UTCS 1.0 system were developed with the Progressive Analysis and Signal System Evaluation Routine (PASSER), a traffic signal optimization model, although some timing plans on NE Eighth and Bellevue Way were developed with TRANSYT-7F. (2) Updating timing plans, or making even small changes, were very time consuming and inconvenient operations on this system. Making small changes entailed collecting data by hand, analyzing the data (entering data in PASSER and running, analyzing, and reviewing the results), and finally, card punching and reading the data to generate the new plan.

System operators planned to update timing plans once a year, but staff changes interfered with this goal. In the two years before the new system was installed, only minor changes had been made other than to change some of the patterns on Bel-Red Road in the morning peak period.

One of the most difficult parts of generating new timing plans was inputing the data. The old system used punch cards to enter data, a tedious, time-consuming process. For small changes such as altering one offset, the operators were forced to complete a two-hour process that involved creating the input cards, taking the computer off-line, reading the card deck, decoding any error messages, and putting the system back on-line. If a larger change was required, the data for the entire timing plan had to be entered, a full day's process.

Maintenance

Computer maintenance for the old system cost $17,000 a year and was provided by Concurrent Computer Inc., the same firm that maintains the new system. The computer itself rarely failed; however, the communications equipment was much more error-prone. For instance, if the phone line was disconnected for as little as 2 seconds at 5:01 p.m., the intersection remained off-line until the operator arrived the next morning to put the intersection back on-line. The operators estimated that communications failed at least once a day with the old system. They also estimated that only 70 to 80 percent of the equipment was on-line at any one time, mainly because of communications difficulties.

Staff

The same number of staff operate the new system as did the old system. This includes two traffic engineers and three electronics technicians with a minimum of 2 years' vocational training.

With the old system, the primary function of the staff was to keep the computer and intersections communicating and on-line. No formal training on the operation of the system was available to the staff, and no documentation existed other than what the staff themselves wrote. The engineer needed to have a strong background in FORTRAN programming to understand the operation of the system database and to make changes to the timing plans.

Detectors

With the old system, the FORTRAN programming requirements were very complex, and the operators were never able to hook up the system detectors so that they would reliably report the volume data back to the central computer.

To supplement the loop detectors, one camera, located on the corner of Bellevue Way and NE Eighth, allowed operators to monitor the traffic conditions at this intersection from the office.

UTCS 1.5 SYSTEM

Equipment

The new system is a Concurrent (Perkin-Elmer) 3210. It has 2 Megabytes of core memory, four 20 Megabyte disk drives, two of which are removable disk drives essentially functioning as floppy disks, and four 5 Megabyte disk drives, two of which are removable, and a magnetic tape drive. Sonex communications equipment allows the system to communicate with 160 intersections. The new software is supplied by Computran. Instead of the old system's single console, operators now communicate with the mainframe via five IBM terminals and a portable system console (used for field work).

Operation

With the new system, operators can make major timing plan changes in 30 minutes or less. To implement a change, the operators enter the new information at the keyboard while the system stays on-line. Furthermore, the operators are able to choose from a variety of optimization programs not available on the old system, including the FORCAST optimization program.

Maintenance

The cost of computer maintenance ($8,000 a year) has declined significantly with the new system. The new system is also able to re-boot itself every 15 minutes after system crashes and communication failures and is thus not susceptible to lengthy service interruptions.

Staff Training

Since the new system has been installed, the staff have received a significant amount of training from Computran, Concurrent, and Sonex. Both Bellevue traffic engineers have received four weeks of additional training. The electronics technicians have had one week of training on the new computer hardware. They received less training than the traffic engineers because the job of the electronics technicians has not changed very much with the new system.

The operators are doing different types of work with the new system. While they previously concentrated on keeping the computer and intersection controllers running, they are now improving the timing of the intersections. Instead of simply operating the system, operators have time to make changes in the timings and phasings and to install detectors. Overall, staff time is now used more productively.

Detectors

The UTCS system uses two type of detectors: system loop detectors and advance loop detectors. The system loop detectors are, generally, located 300 feet before the intersection (and thus are not as influenced by normal queuing) and can record volume information more accurately than the advance loop detectors. The "advance"-type loop detectors are located 100 feet before the intersection and can be used both for recording volumes and as part of an actuation system for each intersection. The operators would prefer to have more system loop detectors in order to automatically collect better information on traffic volumes throughout the day. Theoretically, all of the intersections have the ability to transfer volume from eight detectors at each intersection to the central computer, but not all are doing so now.

The camera at NE Eighth and Bellevue Way is still operating, and the operators hope to have cameras located at three or four other intersections by December 1989.

CHAPTER 3

RESULTS OF THE TRAVEL TIME STUDY

A COMPARISON OF TWO METHODS USED FOR TRAVEL TIME STUDIES

The floating car method (described below) has traditionally been used to measure travel times, but recently the development of portable lap top computers has made other methods possible. This section compares the floating car method with a recently developed method that uses lap top computers and license plate matching.

Floating Car Method

The floating car method is the most commonly used because of the "reliability of the data collected and the ease with which it is compiled." (3) It requires at least one car with a driver, or a driver and recorder, who can mark the travel and delay times as the car travels along the arterial. Following the average speed of traffic, the recorder uses a form to note the time the car crosses the stop line at the intersection and any other times that the car is delayed.

Computerized License Plate Method

The computerized license plate method is a development made possible by recent advances in portable lap top computers. The procedure involves two people equipped with lap top computers located at each end of the arterial or freeway study section. (If researchers want intermediate travel times, they can locate additional typists at the intermediate intersections.) Each person types in the three numbers on the license plate, as well as the adjacent letter, four characters in all. A BASIC program listed in Appendix A prints a time, in seconds, to correspond with each license plate number when it is entered. The output files from each of the computers can then be matched by another program listed in Appendix B to determine the travel times for the pairs of matching license plates.

March Travel Time Study Methodology

Three floating car surveys were conducted on two arterials (NE Eighth and Bel-Red Road) in December 1988 and three more surveys were conducted on three arterials (NE Eighth, Bel-Red Road, and 148th) in March 1989. Both the floating car and license plate methods were used. Additional license plate surveys were conducted in the fall, but they did not include floating car surveys. The results were compared on the basis of mean travel time and the standard deviation of those travel times.

Findings and Evaluation

While differences in mean travel times did occur, the license plate method appeared to produce a larger number of reliable travel times that potentially represented the true range of travel times better than the floating car runs, since considerably more data could be collected. (The complete results are given in Appendix C.) Results from the floating car method can be distorted by one or two travel times that happen to be longer or shorter than usual. With the license plate method, many more travel times can be collected so that the average is less disturbed by one extreme travel time. Also, the larger number of data values means that travel time differences are significant with a lower t-statistic value. The test for significance is given in Appendix D. In other words, smaller travel time differences can be shown to be statistically significant. However, the drawback to the lap top technique is that data on the specific location of delays and intermediate travel times cannot be collected without additional typists.

DATA COLLECTION METHODS

"Before" Data Collection

The city of Bellevue used the floating car method to collect "before" data in late March and early April of 1987 on four major arterials where the UTCS 1.5 system was to be installed. For each arterial it performed at least three floating car runs in each direction from 7:30 to 8:30 in the morning, 11:30 a.m. to 12:30 p.m., and 4:30 to 5:30 in the evening. One car carried a driver and a recorder, and the driver attempted to follow the average speed of traffic without going over the speed limit. The driver made no attempt to enter the stream of traffic at any particular time. Delay time was calculated by measuring the amount of time that was spent in the queue. Travel time was measured from stop line to stop line. The recorder/passenger made all the necessary notations on a form while the driver followed the flow of traffic.

In addition to travel times, volume data were also collected for most sections in each direction during the peak hours. From the cumulative travel and delay times, the average travel and running speeds could be determined, as well as the arterial level of service. The recorder, the passenger in the floating car, also noted the weather on each field worksheet.

The Bellevue "before" data included sections of streets that were not part of the UTCS system. As a result, these sections were omitted from "before" and "after" travel time comparisons.

The "before" data were collected in seven different sections; three streets (NE Eighth, Bellevue Way, and 148th Ave.) were divided into two parts. Since these streets were treated as whole sections when the "after" data were collected, the two parts of the "before" data had to be combined even though they were not collected on the same days. To combine the two parts, the travel times were simply added together. Because the "after" travel times did not include delay time for the final intersection, that delay time was also subtracted from the "before" times presented later in the evaluation section of this report.

"After" Data Collection

To evaluate the recently implemented UTCS 1.5 traffic control system, this project included a travel time study to collect travel times on four arterials on which the UTCS 1.5 system was to be evaluated. This study employed the license plate method. Traffic volumes from the same locations used in the previous travel time studies were obtained for comparison of changes in road volumes. Whenever possible, traffic counts were obtained for those days during which travel time studies were performed.

RESULTS

This section describes the basic findings of the travel time runs and other data collection activities. Statistical analysis of these data is presented in the following chapter.

NE Eighth Street

In the original study, volume counts performed east of the Bellevue Way intersection were used as representative of that portion of NE Eighth Street included in the study area. The traffic counts showed that NE Eighth Street had the highest noon volumes of any street in the study area. In fact, the noon volumes were higher than the morning and evening peak hours. The noon and evening traffic on this street has been especially influenced by the presence of Bellevue Square, a very large shopping mall that opens at 10 a.m. on weekdays. Because of Bellevue Square, traffic in the westbound direction east of Bellevue Way was heavier than the eastbound direction throughout the day. Commuters who would normally be expected to travel eastbound on NE Eighth in the evening apparently avoid the area because of the traffic at Bellevue Square and congestion leading to I-405.

The "after" traffic counts also revealed volumes along NE Eighth that were heavily influenced by the presence of Bellevue Square (Table 3.1, Figure 3.1). Noon volumes, especially in the westbound direction, were easily the highest of the peak hours throughout the day.

In the "before" study, morning and evening travel times were faster in the westbound direction, even though this was the direction with heavier volumes. Noon travel times were similar in both directions.

Table 3.1. NE Eighth Street Volumes

	7:30 a.m. - 8:30 a.m.		11:30 a.m. - 12:30 p.m.		4:30 p.m. - 5:30 p.m.	
	Before	After	Before	After	Before	After
Eastbound	302 veh.	522	1025 veh.	1429	891 veh.	888
Westbound	808	601	1324	1848	1051	1425

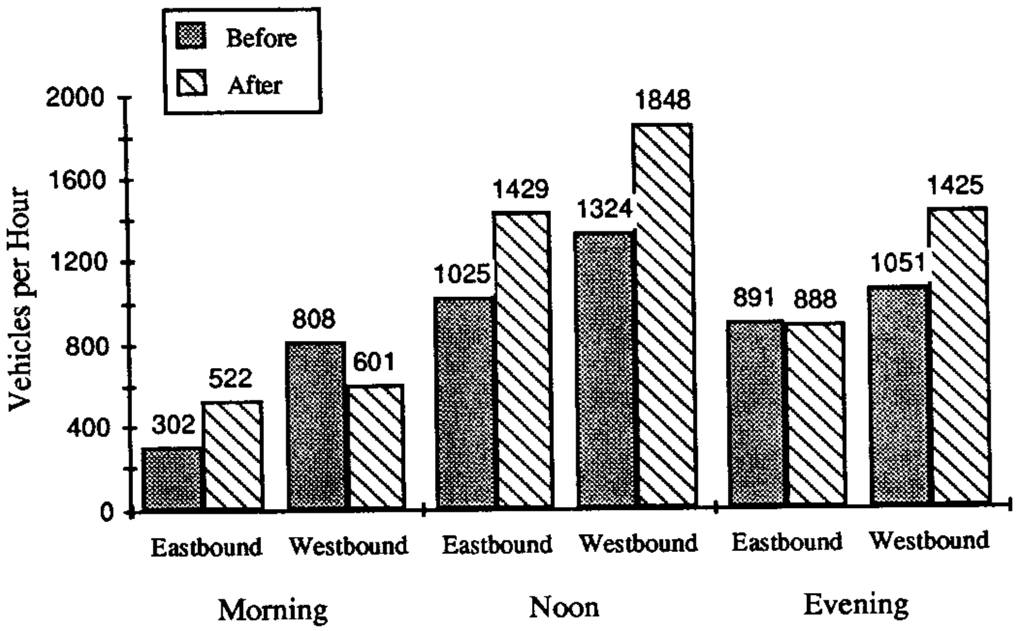


Figure 3.1. NE 8th St. Before and After Volumes
(per hour)

In the "after" study, progression appeared to be better in the westbound direction on NE Eighth, even with the much heavier westbound traffic, except in the morning (Table 3.2, Figure 3.2). In the morning, the difference in travel times was statistically insignificant, while the volumes were relatively close in size.

Measured travel times varied considerably during the "before" data collection effort. The largest variation occurred on the morning westbound direction, which also had the lowest mean travel time. For example, the morning westbound times ranged from 87 seconds to 214 seconds, a difference of 114 seconds. This was more than 90 percent of the mean travel time of 127 seconds. The least variation occurred in the noon westbound direction, where travel times ranged 17 seconds, 9 percent of the mean travel time.

After implementation of the UTCS 1.5 system, the variation in travel times measured by the project team was also significant, ranging from 210 percent to 84 percent of the mean travel time. For instance, the morning eastbound travel times varied from 80 seconds to 449 seconds, a difference of a little over 6 minutes. With six traffic signals within a distance of 0.75 mile, this route provided a large number of causes for drivers to experience very different travel times.

Bellevue Way

The original volume counts for Bellevue Way were performed north of the NE Eighth Street intersection. These counts showed that volumes on Bellevue Way were highest at the noon peak hour and were second only to those on NE Eighth. The southbound direction carried a much heavier volume in the morning, while the northbound direction had the heavier volume in the evening. The difference in the two directions was much greater in the morning than in the evening, perhaps because the evening traffic included shoppers as well as commuters. Noon volumes were not significantly different in the north and southbound directions.

Table 3.2. NE Eighth Street Mean Travel Times

	7:30 a.m. - 8:30 a.m.		11:30 a.m. - 12:30 p.m.		4:30 p.m. - 5:30 p.m.	
	Before	After	Before	After	Before	After
Eastbound	184 sec.	176	196 sec.	291	169 sec.	264
Westbound	127	170	186	177	174	218

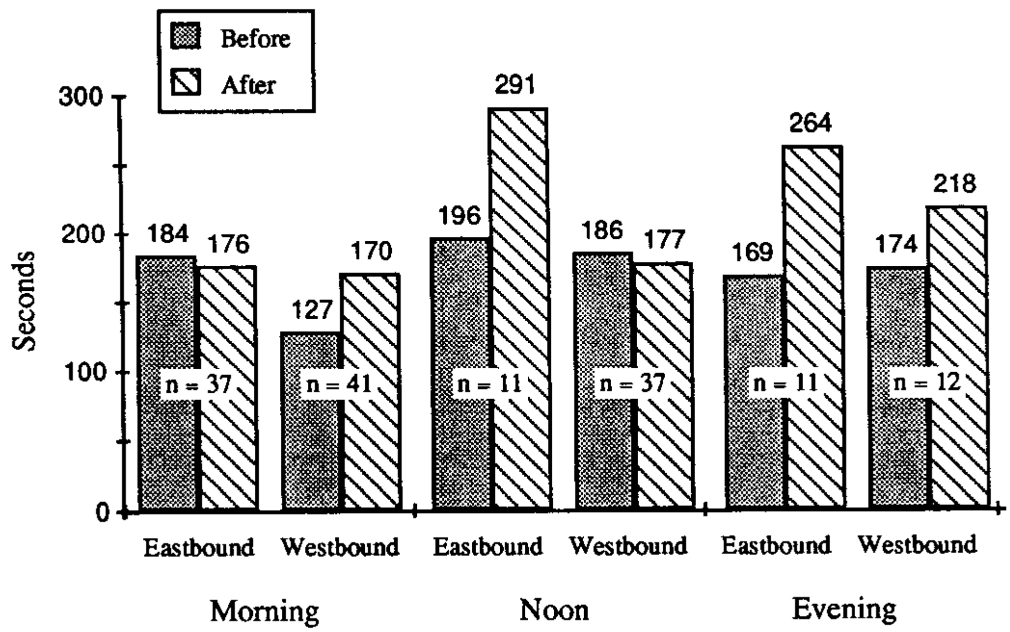


Figure 3.2. NE Eighth St. Before and After Travel Times
(in seconds, based on 3 Travel Time runs)

The "after" study also found that the volumes on Bellevue Way were highly directional for the morning and evening peak hours (Table 3.3, Figure 3.3). The morning southbound and evening northbound directions had much heavier flows than the reverse directions. Volumes at noon were roughly the same in both directions; the combined noon volume was the heaviest of the all the peak hours, similar to the pattern on NE Eighth.

In the "before" study, the travel times on Bellevue Way were always larger for the direction with heavier volumes. The morning and evening times are almost exactly opposite of each other, with the southbound direction being slower in the morning and faster in the evening when the volumes were lower. Although the northbound noon volume was not much higher than the southbound noon volume, the travel time was noticeably longer.

After implementation of the UTCS 1.5 system, progression was always better in the northbound direction, although the difference was insignificant for the evening peak hour (Table 3.4, Figure 3.4). Faster morning travel times occurred in the northbound direction (which had lighter traffic), but travel times were also faster in that direction at noon, by about the same margin, when volumes were almost equal. Results indicated nearly identical mean travel times for the evening peak hour, even when the volumes in the northbound direction were much heavier.

Before installation of the UTCS 1.5 system, only two time periods had large variations in travel times, the southbound morning and noon times. The morning southbound range of travel times was 104 seconds, 62 percent of the mean travel time. Noon southbound travel times had a range of 76 seconds, or 43 percent of the mean travel time. The remaining periods had travel time ranges that represented between 3 and 16 percent of the mean travel times for their direction in the peak hour.

The "after" study found that the variation in the southbound travel times was consistent, with differences in travel times ranging from 106 to 108 percent of the mean

Table 3.3. Bellevue Way Volumes

	7:30 a.m. - 8:30 a.m.		11:30 a.m. - 12:30 p.m.		4:30 p.m. - 5:30 p.m.	
	Before	After	Before	After	Before	After
Northbound	323 veh.	318	999 veh.	1074	946 veh.	1029
Southbound	757	655	926	1044	744	774

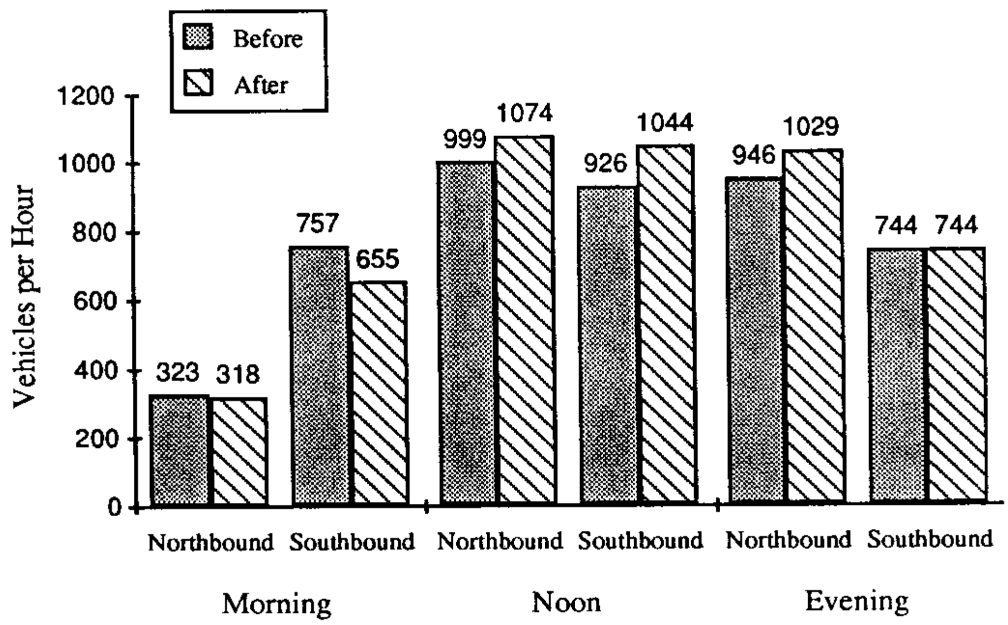


Figure 3.3. Bellevue Way Before and After Volumes (per hour)

Table 3.4. Bellevue Way Mean Travel Times

	7:30 a.m. - 8:30 a.m.		11:30 a.m. - 12:30 p.m.		4:30 p.m. - 5:30 p.m.	
	Before	After	Before	After	Before	After
Northbound	135 sec.	126	150 sec.	167	166 sec.	157
Southbound	169	144	177	182	133	159

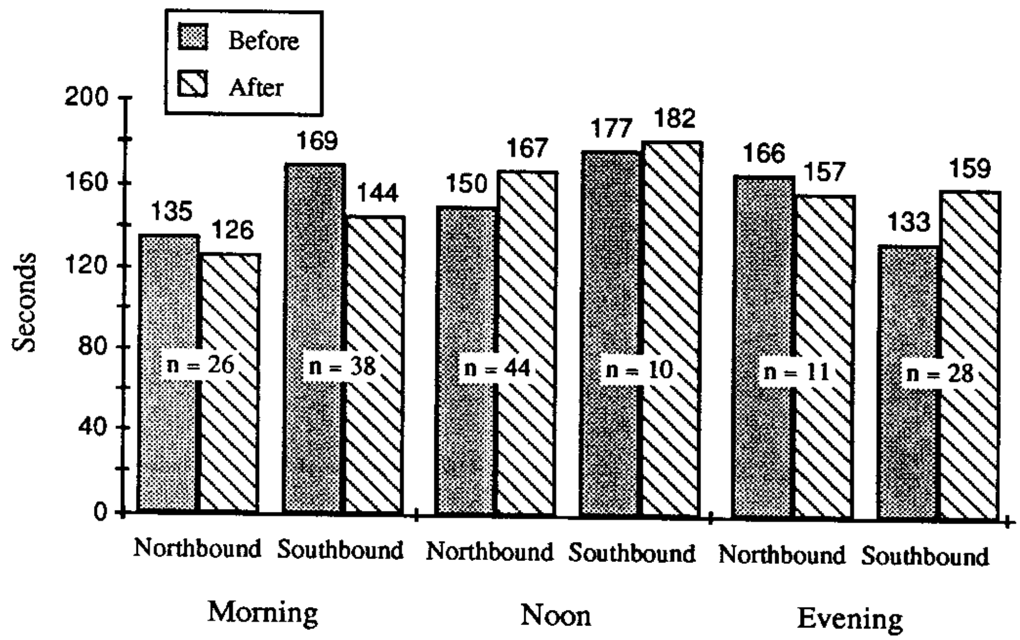


Figure 3.4. Bellevue Way Before and After Travel Times
(in seconds, based on 3 Travel Time runs)

travel times. Variation in the northbound direction ranged from 112 to 122 percent of the mean travel times. These ranges represented differences of between 152 and 307 seconds, or as much as 5 minutes in travel time.

148th Avenue

A number of volume counts were made on 148th Avenue for the "before" study. The present study used the volumes counted between NE Eighth Street and Bel-Red Road as representative of volumes along 148th. Peak hour volumes on 148th Ave increased throughout the day. The heaviest occurred at the evening peak hour. The northbound direction was heavier in the morning and lighter in the evening than the southbound direction. Noon volumes were heavier than the morning volumes and larger in the northbound direction than the southbound direction.

The "after" counts showed that volumes on 148th were especially heavy throughout the day in the northbound direction (Table 3.5, Figure 3.5). Only in the evening peak hour did southbound volumes come close to the level of traffic flow that the northbound direction experienced. While on other streets the morning peak hour volumes were substantially less than the evening peak hour volumes, the morning peak hour volumes on 148th were also very large and much closer in size to the evening peak volumes than on the other three arterials.

Before installation of the UTCS 1.5 system, travel times were slower in the direction of heavier volumes for the noon and evening peak hours, but not for the morning peak hour. The northbound morning volume was much higher than the southbound morning volume; the mean travel time, however, was more than a minute and a half shorter. Northbound progression was apparently favored by the original timing plans for this route.

The "after" counts found that travel times on 148th did not always reflect the corresponding volumes (Table 3.6, Figure 3.6). The northbound noon volumes were significantly higher than the reverse direction, and the northbound travel times were also

Table 3.5. 148th Avenue Volumes

	7:30 a.m. - 8:30 a.m.		11:30 a.m. - 12:30 p.m.		4:30 p.m. - 5:30 p.m.	
	Before	After	Before	After	Before	After
Northbound	858 veh.	1032	917 veh.	1100	959 veh.	1185
Southbound	565	733	739	876	1180	1106

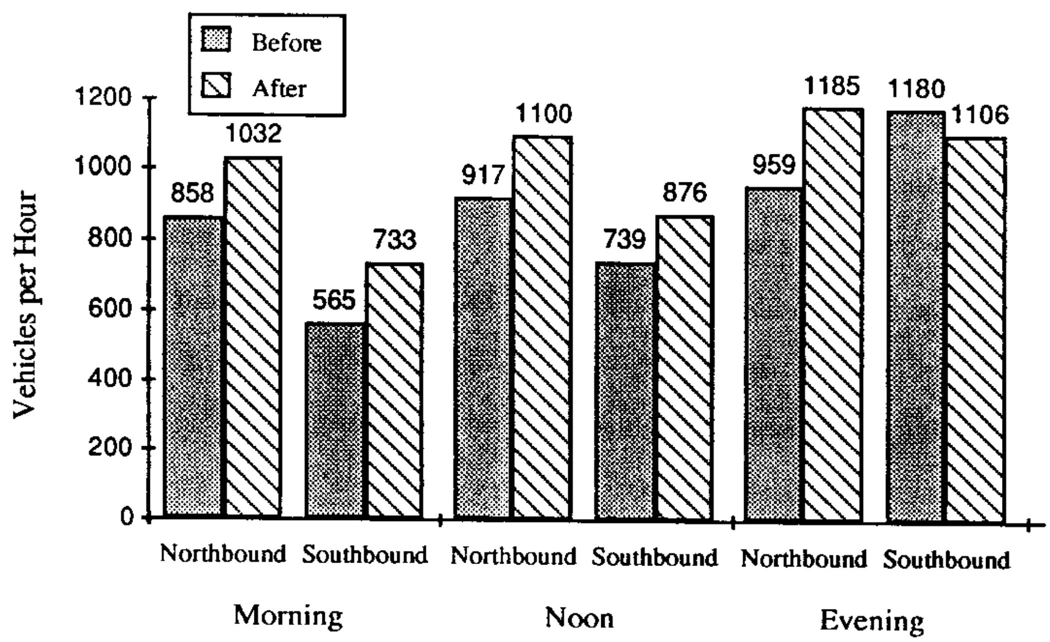


Figure 3.5. 148th Ave. Before and After Volumes (per hour)

Table 3.6. 148th Avenue Mean Travel Times

	7:30 a.m. - 8:30 a.m.		11:30 a.m. - 12:30 p.m.		4:30 p.m. - 5:30 p.m.	
	Before	After	Before	After	Before	After
Northbound	412 sec.	393	431 sec.	477	447 sec.	437
Southbound	504	392	416	365	473	460

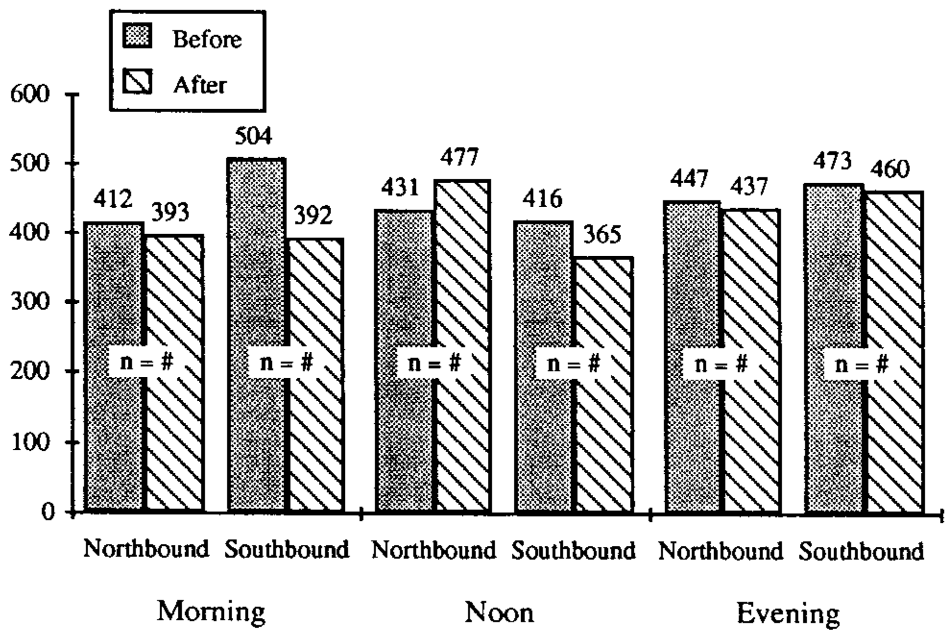


Figure 3.6. 148th Ave. Before and After Travel Times
(in seconds, based on 3 Travel Time runs)

slower by over 1-1/2 minutes. On the other hand, the evening volumes are about even in the two directions, but the northbound mean travel time was lower than the southbound mean travel time.

Before the UTCS 1.5 system, the difference in the maximum and minimum north and southbound directions in the morning peak hour travel times were 23 and 28 percent of the mean travel times, respectively. The evening northbound direction also had a large variation, over 2 minutes (140 seconds) of difference between the largest and the smallest travel times, or 31 percent of the mean travel time.

After the UTCS 1.5 system, variation in travel times was also very high on 148th, especially considering the length of the street. The northbound direction, whose highest variation was 101 percent of the mean, had less variation than the southbound direction, which had variations ranging from 119 to 169 percent of the mean travel time. For example, the collected travel times varied more than 10 minutes for the southbound noon direction.

Bel-Red Road

Only "before" traffic counts from east of Bellevue Way on Bel-Red Road were available for use in the current study. Bel-Red Road volumes were higher in the eastbound direction for the a.m. peak hour and in the reverse direction, westbound, for the p.m. peak hour. The difference in the two directions was much larger for the evening peak hour, when volumes in general were heavier. The noon volumes were heavier in the westbound direction, although both volumes were high. In fact, the combined noon volume was the highest of the three peak hours.

In the "after" study, peak hour traffic on Bel-Red Road seemed to be nearly the same in both directions for the morning and noon peak hours, with heavier traffic in the westbound direction in the evening (Table 3.7, Figure 3.7). The heaviest volumes occurred in the evening peak hour in the westbound direction. The combined evening volumes were slightly higher than the noon volumes, by 141 cars.

Table 3.7. Bel-Red Road Volumes

	7:30 a.m. - 8:30 a.m.		11:30 a.m. - 12:30 p.m.		4:30 p.m. - 5:30 p.m.	
	Before	After	Before	After	Before	After
Eastbound	449 veh.	404	702 veh.	857	572 veh.	839
Westbound	349	385	855	935	903	1094

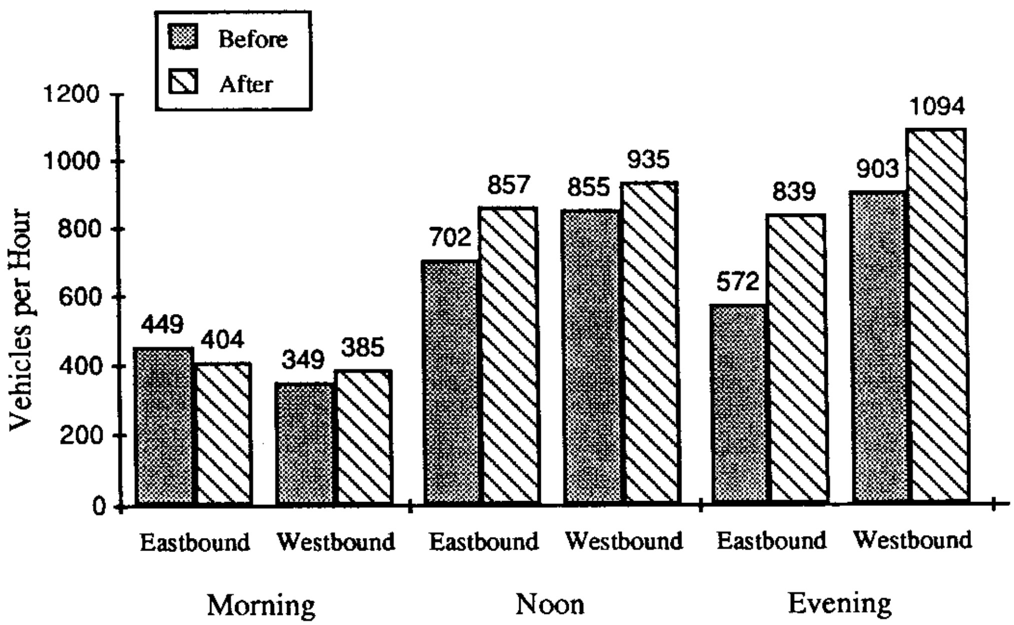


Figure 3.7. Bel-Red Rd. Before and After Volumes (per hour)

Before implementation of the UTCS 1.5 system, travel times were slightly longer in the direction of larger volumes for the morning and noon peak hours, but shorter (in the direction of larger volume) for the evening peak hour. The westbound direction was favored in the evening enough to make up for the heavier traffic in that direction.

After the UTCS 1.5 system had been installed, travel times for Bel-Red Road were always faster in the eastbound direction. (Table 3.8, Figure 3.8). The significantly heavier volumes in the evening westbound direction, however, did correspond to westbound travel times that were more than a minute longer than the reverse direction. Slightly higher volumes and slower travel times also occurred at the noon peak hour in the westbound direction.

Before the UTCS 1.5 system, noon times were the most variable, with travel time differences ranging from 37 to 41 percent of the mean travel times in the east and westbound directions, respectively. This indicates that the differences in the largest and smallest travel times were over 3 minutes for each of these directions. The morning and evening westbound peak hours showed less variability, 4 and 11 percent, respectively.

After the UTCS 1.5 system, the variation in mean travel times on Bel-Red Road was lower than on the other three streets, possibly because this was the longest of the four arterials in the UTCS 1.5 system evaluation. The least variation occurred in the morning eastbound direction, when the difference in maximum and minimum travel times, 113 seconds, represented only 29 percent of the mean travel time. The difference in the morning westbound travel times, on the other hand, represented 100 percent of the mean travel time for a range of 398 seconds.

Table 3.8. Bel-Red Road Mean Travel Times

	7:30 a.m. - 8:30 a.m.		11:30 a.m. - 12:30 p.m.		4:30 p.m. - 5:30 p.m.	
	Before	After	Before	After	Before	After
Eastbound	436 sec.	389	493 sec.	473	631 sec.	495
Westbound	430	400	515	481	547	573

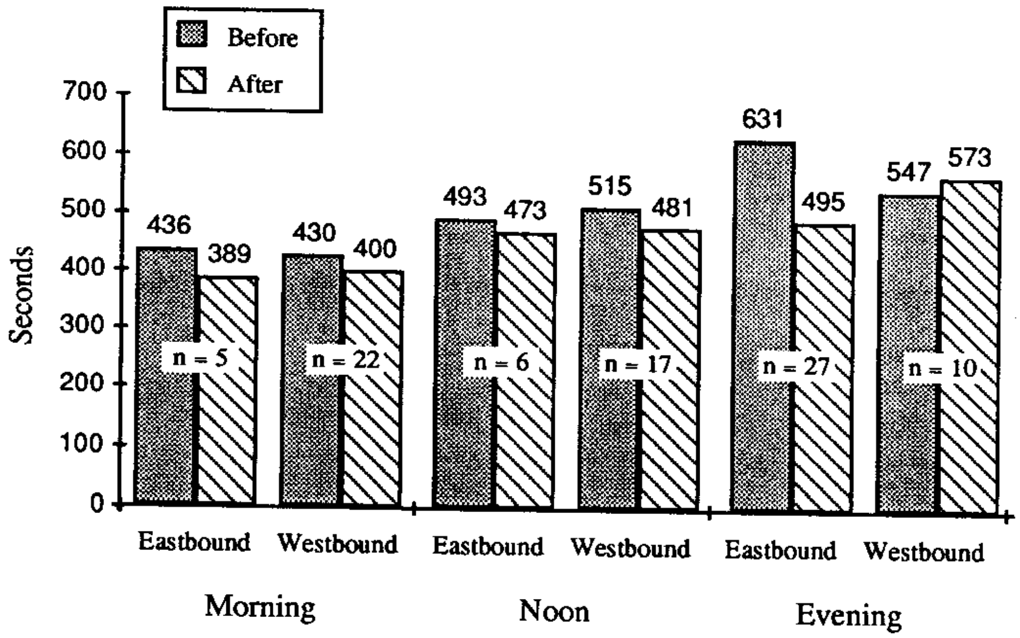


Figure 3.8. Bel-Red Rd. Before and After Travel Times
(in seconds, based on 3 Travel Time runs)

CHAPTER 4

EVALUATION OF RESULTS

A comparison of the operation of the new UTCS 1.5 traffic control system and the old UTCS 1.0 system is presented below. In addition, the results from the City of Bellevue's floating car survey before the implementation of the new UTCS 1.5 system and the results from the license plate travel time study after the implementation are compared and evaluated.

EVALUATION OF THE SYSTEM OPERATION

As previously mentioned, the new and old UTCS systems were compared on the basis of seven factors, each of which is discussed below. This section also includes an evaluation of side street effects and human perceptions of the system.

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 2 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 in at least 2 hours to an entire day. 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, and as a result, it was frequently off line. The UTCS 1.5 system, on the other hand, is able to retry failed equipment itself every 15 minutes and reboot itself after power failures. Consequently, it functions better and with fewer disconnected signals than prior to the conversion to the new system.

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 and intersections running, the operators have time to improve timings and phasings at the intersections. This time should lead to the continual improvement of timing plans within the city. The operators also no longer need to be FORTRAN programmers in addition to traffic engineers to make changes to and understand the operation of the system.

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 measure changes in traffic volumes, and develop and implement timing plans accordingly. 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 reduce the amount of data that have to manually collected. One of the benefits of the UTCS 1.5 system is its ability to automatically load the detector data into the optimizer. Until all intersections are reporting traffic volumes back to the central computer, the system will not make full use of this cost-saving 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 program holiday and special event schedules any time in advance.

Side Street Effects

While no data exist for side street delays before the implementation of the new system, the operators said they suspect that since cycle lengths are longer now, more delay has been induced on the side streets. However, they also perceive that Bellevue residents are not as concerned about delay on the side streets as on the main line. Most of all, the residents complain about having to stop. The number of stops can be a function of what optimization program is used to develop the signal timing plan.

Human Evaluation

The human evaluation 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 complexity of the process involved.

TRAVEL TIME STUDY

The UTCS 1.5 and 1.0 systems were also compared on the basis of the travel time studies. While the overall system showed a statistically insignificant decrease in travel time of 2 percent, the volume for the entire system increased by 17 percent. However, some statistically significant mean travel time changes were noticeable in specific time periods and on NE Eighth Street. The morning peak hour (7:30 a.m. - 8:30 a.m.) mean travel time for all the arterials decreased by 9 percent with the implementation of the new traffic control system, while the noon travel time increased by 2 percent, and the evening mean travel times increased 1 percent.

When changes in travel times are considered, the high variability of travel times should also be taken into account. Improvements of 10 seconds or less are hardly noticeable to the individual driver, especially when the travel times vary so much for different drivers, for different times within the peak hour, and for different starting times within each hourly period.

Some other factors may also have prevented large travel time improvements. The "before" condition used recently updated timing plans. Since timing plans were very difficult to update on the old system, these timing patterns might have aged and might not have been updated to reflect changes in traffic conditions. With the new UTCS 1.5 system, the timing plans are easily updated, and long-term improvements are expected. Of course, the before and after travel time studies only took into account the peak period travel times; some off-peak improvements might also be expected, since the new system has the flexibility to develop more timing plans for different traffic conditions.

Mean travel time changes varied from arterial to arterial (Table 4.1). Bellevue Way was the only arterial on which the travel times and volumes remained approximately the same during all peak periods. None of the measured mean travel times indicated a significant difference on this arterial. NE Eighth, on the other hand, experienced noticeably heavier volumes, especially at noon and in the evening in the westbound direction. Mean travel times indicated three significant increases in the morning westbound direction and in the noon and evening eastbound off-peak directions. The mean travel times on 148th Avenue did not change very much, except in the morning and noon southbound directions, when there was also an increase in volume. Volumes on this arterial increased by over 100 vehicles during all peak periods, except in the evening in the southbound direction, when there was a slight decrease in volume. Bel-Red Road's mean travel times also had two significant changes, in the morning eastbound direction, when volumes decreased slightly, and in the evening eastbound direction, when volumes increased significantly.

Table 4.1 Mean Travel Time Improvements by Arterial

Arterial	Before Mean Travel Time	After Mean Travel Time	Percent Improvement	Percent Increase in Volume
NE Eighth	173 seconds	216 seconds	-25	24
Bellevue Way	155	156	0	4
148th Ave.	447	421	6	16
Bel-Red Road	509	468	8	26
System	-	-	2	17

The differences in percentage of improvement varied among the peak periods (Table 4.2). The morning peak period showed the most improvement; this was unexpected since the morning travel times were already very good. At noon, however, the travel times increased the most of all the peak hours. Timing plans for this period are especially difficult to generate because of the changing travel patterns within the peak hour. Noon volumes are generally much larger than morning volumes; in fact, the noon volumes are the largest of all the peak hour volumes on NE Eighth and on Bellevue Way.

The evening hour showed a small increase in travel times, although the change would probably not be noticeable to individual drivers.

Table 4.2. System Changes by Period

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

Vehicle-miles/hour (vmh) was used as a means of combining travel time and volume into one statistical measurement of improvement. An increase in vmh would indicate that the arterial provided better vehicle throughput under UTCS 1.5 than under the UTCS 1.0 system. The researchers calculated vmh 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 from increased congestion. As Table 4.3 and Figure 4.1 indicate, the vmh for each peak hour on each arterial increased even if one of the direction's vmh value decreased. The timing plans seem to be favoring the peak direction, since in all but one case, the decreased vmh value occurred in the off-peak direction. Favoring the peak direction allows the total number of cars traveling through the system to increase. The system can process more cars in the peak hour now than with the old system, although the travel times may not have decreased.

Table 4.3. Vehicle-Miles/Hour in Thousands for the Peak Hours

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

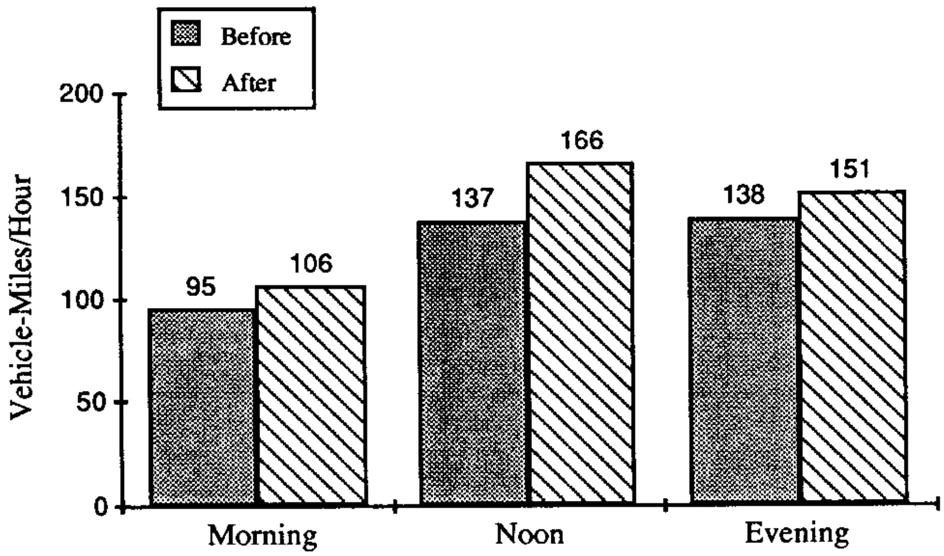


Figure 4.1. Vehicle-Miles/Hour for the Peak Hour

The following Tables 4.4 and 4.5 show those cases with significant changes in mean travel times (Figure 4.2) and their corresponding vehicle-miles/hour (Figure 4.3).

Table 4.4. Significant Changes in Mean Travel Times

	NE Eighth a.m. WB	NE Eighth NN EB	NE Eighth p.m. EB	148th Ave a.m. SB	148th Ave NN SB	Bel-Red a.m. EB	Bel-Red p.m. EB
Before Travel Time	127 seconds	196 seconds	169 seconds	504 seconds	416 seconds	436 seconds	631 seconds
After Travel Time	170	291	264	392	365	389	495
Confidence Level	93	98	90	99	92	91	98
Percent Change in Volume	-26	39	0	30	20	-10	47

Table 4.5 Vehicle-Miles/Hour Tables

NE Eighth

Time/Direction	Before VMH	After VMH	Percent Difference
7:30-8:30 Eastbound	4432	8008	81%
7:30-8:30 Westbound	17178	9545	-44
11:30-12:30 Eastbound	15461	13259	-14
11:30-12:30 Westbound	19219	28190	47
4:30-5:30 Eastbound	14235	9082	-36
4:30-5:30 Westbound	16309	17649	8

Bellevue Way

Time/ Direction	Before VMH	After VMH	Percent Difference
7:30-8:30 Northbound	6460	6814	5%
7:30-8:30 Southbound	12094	12281	2
11:30-12:30 Northbound	17982	17364	-3
11:30-12:30 Southbound	14125	15488	10
4:30-5:30 Northbound	15387	17696	15
4:30-5:30 Southbound	15104	12634	-16

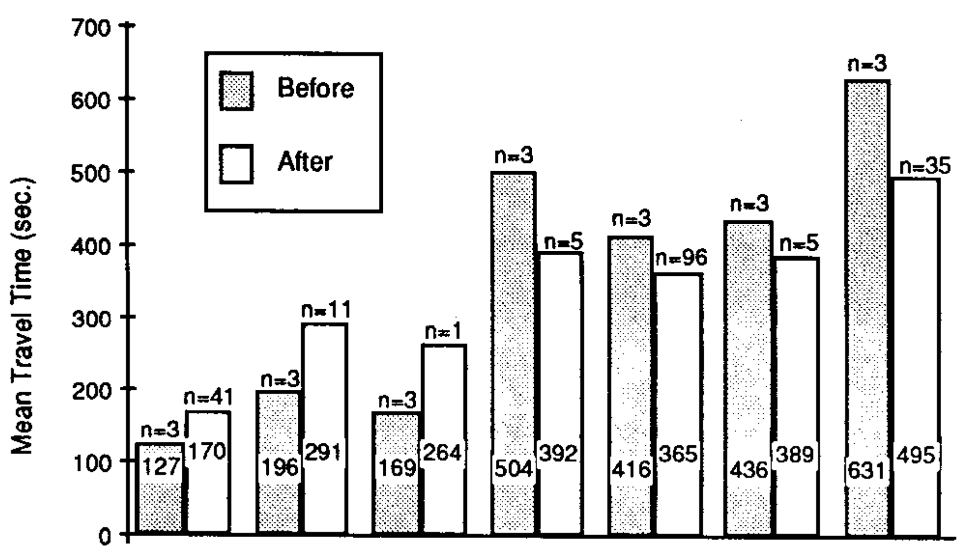
148th Avenue

Time/ Direction	Before VMH	After VMH	Percent Difference
7:30-8:30 Northbound	22116	27888	26%
7:30-8:30 Southbound	11905	19858	67
11:30-12:30 Northbound	22595	24490	8
11:30-12:30 Southbound	18866	25488	35
4:30-5:30 Northbound	22784	28798	26
4:30-5:30 Southbound	26494	25534	-4

Table 4.5 Vehicle-Miles/Hour Tables - continued

Bel-Red Road

Time/Direction	Before VMH	After VMH	Percent Difference
7:30-8:30 Eastbound	11344	11441	1 %
7:30-8:30 Westbound	9069	10603	17
11:30-12:30 Eastbound	15686	19959	27
11:30-12:30 Westbound	12963	21414	65
4:30-5:30 Eastbound	9986	18672	87
4:30-5:30 Westbound	18185	21032	16



Location	NE 8	NE 8	NE 8	148th	148th	B-R	B-R
Time	a.m.	noon	p.m.	a.m.	noon	a.m.	p.m.
Direction	WB	EB	EB	SB	SB	EB	EB
Before Volume	808	1,025	891	565	739	449	572
After Volume	601	1,429	888	876	876	404	839

Figure 4.2. Significant Changes in Mean Travel Time

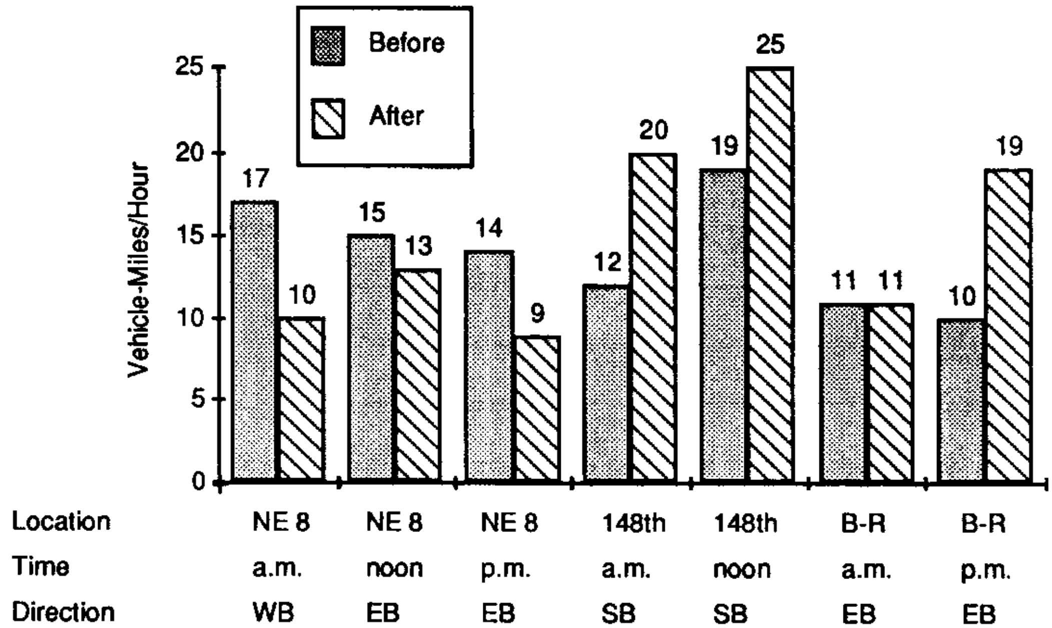


Figure 4.3. Vehicle-Miles/Hour for Cases of Significant Change

Of the three decreases in vmh that corresponded to significant changes in travel time, the morning westbound NE Eighth value was the only one that was in the peak direction. (Table 4.5) In the noon and evening cases (11:30 a.m. to 12:30 p.m. and 4:30 p.m. to 5:30 p.m.), the off-peak direction suffered the increase in travel times and decrease in vmh. Since vmh improved for the peak direction at this time, the timing plan appears to be serving vehicles better in the direction of heavier demand. It compensates by decreasing the amount of progression in the off-peak direction.

Volumes increased, decreased, and stayed the same in the seven cases of significant change in travel times. (Figure 4.2)

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

Two primary conclusions may be drawn from the study of the City of Bellevue's traffic signal control system. First, a significant increase in volume occurred, along with a 2 percent decrease in travel times that was not statistically significant. Second, the operation of the system has improved with the implementation of the UTCS 1.5 system. In fact, the ease of operation is the major benefit of the new system.

Recommendations stemming from the travel time study and evaluation of the system operation include extending the UTCS 1.5 system and making full use of the added features of the UTCS 1.5 system, especially its ability to automatically enter detector data into the timing plan optimization software.

CONCLUSIONS

As mentioned above, volumes increased by 17 percent, although travel times decreased overall by a statistically significant 2 percent. In other words, the Bellevue UTCS 1.5 system handled more traffic without allowing the level of service provided to degrade.

The differences in percentage of improvement varied among the peak periods. The morning peak hour (7:30 A.M.. to 8:30 A.M.) mean travel time for all the arterials decreased by 9 percent with 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 time. A 15 percent increase in volume accompanied the insignificant increase in travel time. In each of these cases, the change in travel time was probably not noticeable to individual drivers.

Vehicle-miles/hour (vmh) was used as a means of combining travel time and volume into one statistical measurement of improvement. The vmh for each peak hour on each arterial increased, indicating improved traffic performance.

As for the operation of the system, the major improvement is in its ease of operation. The new system is much more flexible, and operators now have time to improve the system rather than simply keeping the system on line and functioning. Changes that took 2 hours to an entire day to implement with the old system now take about 30 minutes. With the increased reliability and ease of use, jurisdictions can now emphasize traffic engineering (i.e., improving the timing plans), rather than using the operators' programming skills to keep the system on line. This means that the timing plans will be updated more frequently and more plans will be generated for different traffic conditions, especially special events. Because it is more flexible, the system can be more responsive to changing traffic patterns than it was in the past. Overall, system performance is expected to improve in time over the old system.

While 20 to 30 percent of the old system was frequently off line, the new system is considerably more reliable. Further, it is easier to fix when it does suffer a communications failure. The new system, in addition to reducing maintenance costs from $17,000 to $8,000, allows operators to make changes in response to variable traffic conditions. Long-term improvements in performance should be evident as more conditions are addressed by timing plans and plans are updated more often.

Finally, the UTCS 1.5 system helps operators to more readily respond to public needs and special conditions by allowing them to easily make small changes to the timing plans. For example, in response to special events, such as the Fourth of July fireworks and Christmas shopping, operators are able to observe the traffic patterns and call up the most suitable timing plan for that situation.

RECOMMENDATIONS

The first recommendation for improved system performance is to expand the UTCS 1.5 system to all the arterials in the City of Bellevue, as feasible. Since it is the most traffic-responsive system available, the other arterials could benefit from its flexibility in responding to changing traffic patterns.

As part of this expansion, the project team's second recommendation is for the City of Bellevue to continue to install more detectors at intersections in the network. This addition to the system should allow replacement of some of the data that are collected manually. Until more detectors are installed, the system's timing plans will not necessarily be developed in response to the most accurate volume information.

The final recommendation is that the remaining phone lines should be replaced with city owned interconnect cable as funding becomes available. The former traffic control system was frequently off-line because of its poor communication system. With the new system, more reliable city-owned, interconnect cable replaced many of the phone lines, and significant improvements in system communications have been achieved. Still, some sections of the arterial system continue to rely on phone lines for communications, and these sections suffer from too many phone line disconnections. Continued installation of city owned communications cable should decrease these interruptions, result in additional travel time savings to motorists, and decreased staff time requirements from the city.

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