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ALUATION OF FIRST GENERATION CS/BPS CONTROL STRATEGY

Vol. I. Technical Report

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16. Abstract

This report presents the results of the evaluation of the alternatives of the first-generation traffic control strategy for the computerized Urban Traffic Control System and Bus Priority System in Washington, D. C. Five traffic control alternatives were evaluated to assess their relative impact on traffic during typical weekday morning, midday, and evening periods. Significant differences between alternatives were identified through measurements from the UTCS/BPS surveillance system and moving-car studies.

This volume is the first of three reports and contains a discussion of the overall project and findings. The others are:

Vol. No.	FHWA No.	Short Title	NTIS (PB) No.
2	75-	Technical Appendices	(not yet available)
-	75-	Executive Summary	

The technical appendices contain the detailed discussion of field studies, sample forms, and the documentation and user guides for the computer programs developed for processing and evaluating detector and moving car data. The executive summary includes a project overview and a discussion of the conclusions.

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INTRODUCTION

This report describes the results of the project for "Evaluation of the First-Generation UTCS/BPS Control Strategy." This project is the first part of an overall effort to identify and quantify the effects of the three strategies for traffic control currently being developed for the Urban Traffic Control System/Bus Priority System (UTCS/BPS) in Washington, D. C. The overall UTCS project is a major research program of the U. S. Department of Transportation, Federal Highway Administration. The program has the purpose of improving network traffic control techniques.

The objective of this first work effort is to measure and compare the effects of the alternatives of the first-generation traffic control strategy and the District of Columbia's three-dial timing patterns which were implemented in the UTCS area. The UTCS area, located as shown on Figure 1, includes a portion of the central business section and two primary arterials within the District of Columbia.

BACKGROUND

As noted, the Urban Traffic Control System (UTCS) project focuses on the development and testing of alternative strategies for network traffic control. The primary tool for implementing the strategies is a real-time computer-based traffic signal control system. Additionally, a second, complementary component is provided as a Bus Priority System (BPS). This second component has the design goal of developing and assessing the benefit of techniques to reduce delays to transit users by providing buses with preferential treatment at signalized intersections. The BPS component is being conducted as a cooperative effort of the Federal Highway Administration and the Urban Mass Transportation Administration.

UTCS/BPS Program

The UTCS/BPS program includes several software development and evaluation phases. The program also includes elements of software support activities which are intended to enhance the transferability of the developed control strategies. Given the fact that the software must be implemented on an operating system, certain hardware activities have also been included in the UTCS/BPS program. Although these activities are significant in themselves, they are not critical in the evaluation of the strategies for traffic control. When hardware elements are described

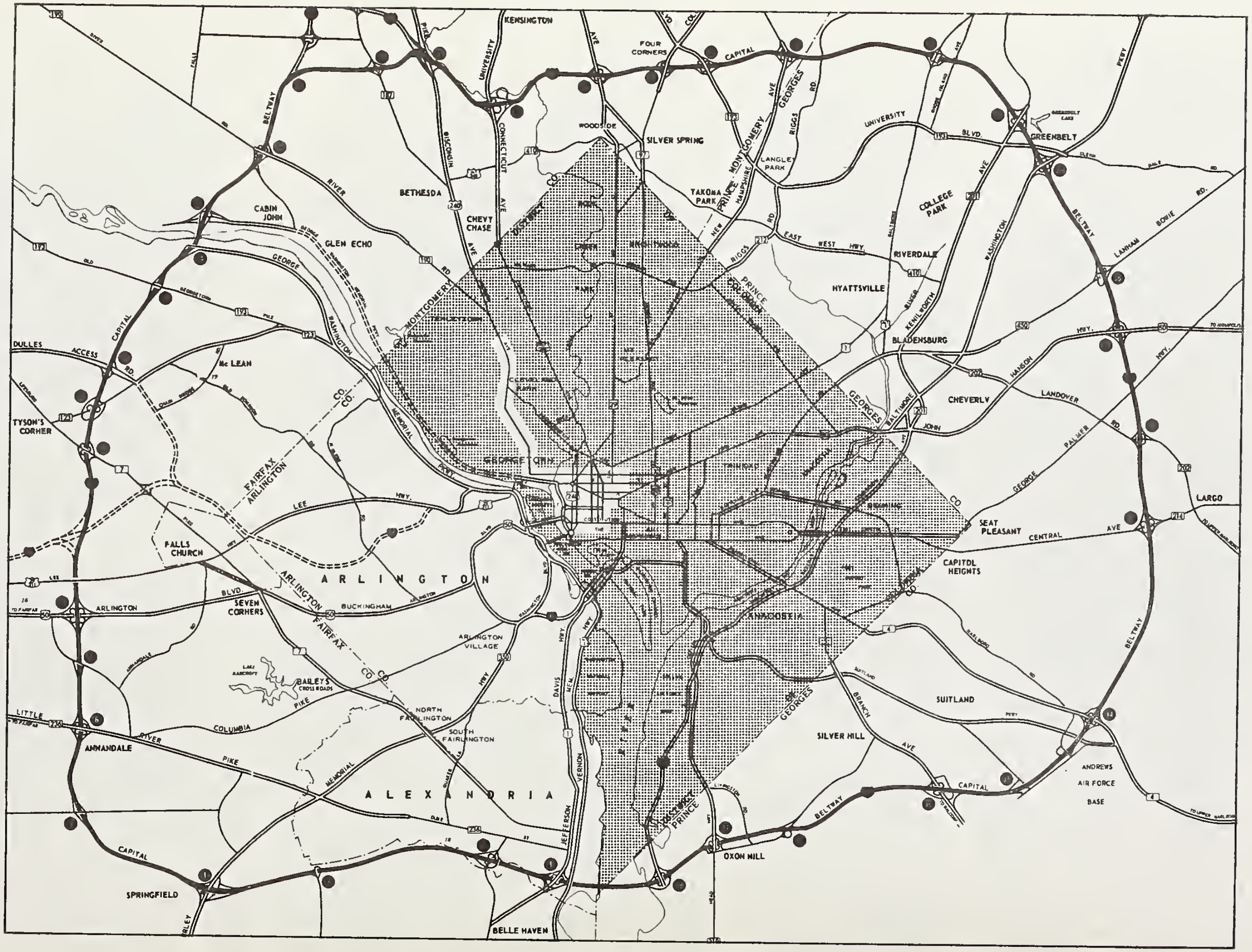

Figure 1. UTCS/BPS location in Washington, D.C. Metropolitan Area.

in this report, they are noted for information only and not as aspects of the software strategy.

The strategy development efforts have been defined in three "generations." The generations become increasingly sophisticated in concept from the first through the third. Table 1 summarizes the important features of the three strategies.

First-Generation UTCS/BPS Alternatives

Within each of the three generations, or strategies, alternatives for application may be considered. As noted, this report includes the alternatives for the first-generation control strategy as well as the three-dial timing patterns of the District of Columbia. For convenience of description, the three-dial timing pattern was considered as an "alternative." The alternatives evaluated under the first generation of control are:

Alternative 1 - District of Columbia, three-dial traffic control timing plans (3-dial)[1];

Alternative 2 - First-generation control timing plans selected for implementation by time of day (TOD);

Alternative 3 - First-generation control timing plans selected for implementation by a traffic-responsive pattern matching algorithm (TRSP);

Alternative 4 - First-generation control timing plans selected as in Alternative 3 and including a critical intersection control algorithm (CIC);

Alternative 5 - First-generation control timing plans selected as in Alternative 3 and including a bus priority system control algorithm (BPS).

[1]The parenthetical notation at the end of each description is the abbreviation used for the alternative when listed in tables or figures.

Table 1. Features of UTCS/BPS strategies.

FEATURE	FIRST GENERATION	SECOND GENERATION	THIRD GENERATION
Optimization	Off-Line	On-Line	On-Line
Frequency of Update	15 Minutes	10-15 Minutes*	3-6 Minutes
No. of Timing Patterns	Up to 40 (7 used)	Unlimited	Unlimited
Traffic Prediction	No	Yes	Yes
Critical Intersection Control	Adjusts Split	Adjusts Split and Offset	Adjusts Split, Offset, and Cycle
Hierarchies of Control	Pattern Selection	Pattern Computation	Congested, Medium Flow
Fixed Cycle Length	Within Each Section	Within Variable Groups of Intersections	No Fixed Cycle Length

*Not fully determined

Source: "The Urban Traffic Control System in Washington, D. C., U. S. Department of Transportation, Federal Highway Administration, September, 1974.

Given that the total evaluation project will ultimately consider computer-based strategies in all three generations of sophistication, Alternative 3 was chosen as the base case for analysis. It is expected that this alternative of first-generation control will serve as the base case throughout the long-term evaluation process. This alternative was chosen because it represents the expected minimum level of sophistication to be provided by computer based traffic control systems as implemented throughout the United States.

UTCS/BPS PROJECT AREA

The first-generation alternatives were implemented and tested in the Washington D. C. area as was shown on Figure 1. The UTCS/BPS test network included 114 signal controlled intersections within the central area of Washington, D. C. and along two primary arterials. The area of coverage is shown on Figure 2. The UTCS/BPS area serves as the real world laboratory for testing the control strategies as they are developed. The overall control area is being expanded to provide computer control of approximately 90 additional intersections in the District of Columbia. Although important to the District's traffic control program, the expansion does not impact this evaluation project and the expanded area will not be included in subsequent stages.

The control area includes portions of the central business section of the District, sections of dense private and Government office usage, multiple-family residential units, a major university, hospitals, and other components typical of urban centers. Two arterials, serving commercial areas and acting as commuter routes, extend beyond the dense grid network of the UTCS/BPS area. Portions of the control area are impacted by tourist travel.

PROJECT METHODOLOGY

The evaluation effort included two parallel procedures. The first procedure was based on utilizing information gathered by the surveillance component of the UTCS/BPS system itself. The second evaluation procedure was based on moving-car studies conducted throughout the control area. The results of the two primary procedures and applicable special studies were also compared with one another to evaluate the procedures themselves. Special studies of bus activity were conducted during evaluation of the BPS alternative. Secondary studies using film, counter, and manually collected delay data were also undertaken to evaluate specific aspects of the system. The evaluation effort

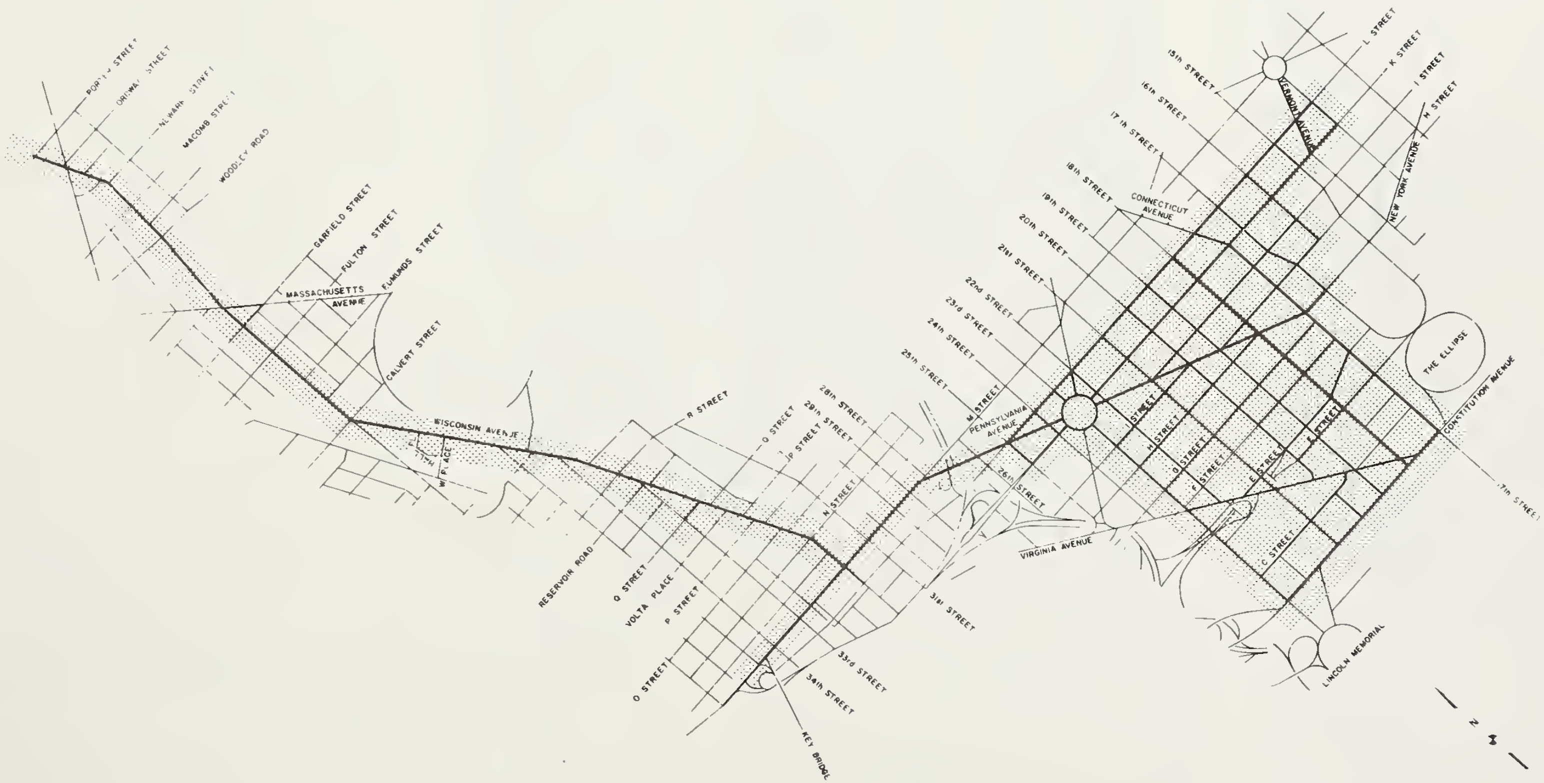

Figure 2. UTCS/BPS Project Area.

centered on performance of the alternatives <u>relative</u> to the base case--traffic-responsive, first-generation control. The evaluation covered three time periods of the normal weekday. The periods encompassed the following times of day.

<u>Morning Peak</u> - 7:00 a.m. to 9:45 a.m. (a.m.)[1.]

<u>Midday Peak</u> - 1:00 p.m. to 3:00 p.m. (midday)

<u>Evening Peak</u> - 4:00 p.m. to 6:30 p.m. (p.m.)

<u>Surveillance System Procedure</u>

The UTCS/BPS control system gathers and processes surveillance information and records the information at 15-minute intervals. This information can be maintained on magnetic tape and processed at a later date. The information includes distinct reports for individual detector locations. The individual locations may be a single detector or multiple detectors[2.] in a single lane approaching a given intersection. When recording information for a multiple detector approach, an average of the individual detector values is used. Approximately 250 detector locations were included in the surveillance system analysis and detector summary tapes were maintained for the detectors during the testing of (the) alternatives.

For the single detector locations; volume, speed, and occupancy data were available. For multiple detector locations, additional values for delay, stops, travel time, and queue length were available. The majority of the analyses centered on the delay measure of effectiveness (delay MOE).

For each alternative, approximately eighty 15-minute intervals were covered during each of the three time periods (a.m., midday, p.m.). This meant that a data set with approximately 80 entries for the MOE's noted above were available for each alternative for each period. The values in these data sets were compared relative to the base case

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1. Parenthetical notations are those used throughout the report to identify the time periods described.

2. The general condition is for three detectors to be used, however, some multiple detector approaches have two detectors.

to provide an evaluation of the effectiveness of the alternatives. The comparisons were made using a computerized process[1] which included statistical test routines.

Moving Car Procedure

Travel time studies were made on four routes in the study area. The four routes included approximately 181 single direction approach links of the 343 links approaching the 114 controlled intersections. The studies included information on travel time, stops, and delays. They were conducted concurrent with the collection of the surveillance system data. The number of runs completed for each link for each time period for each of the alternatives varied from 21 to over 35. The majority of the data sets for the moving-car runs included over 30 entries.

The moving-car data was collected using both manual and automated techniques. The manual collection activities occurred only when there were equipment problems and accounted for a relatively low percentage of the total.

The data was recoded to permit computer processing. After initial edit checks were conducted and appropriate clerical corrections made, the link specific moving-car data were processed using the same computerized techniques as for the surveillance system data.

Data Collection Schedule

The data for all alternatives were scheduled to be collected during the spring months of 1974. Each alternative was to be covered during a given two-week period and one week was to be allowed between alternatives to permit normal maintenance and programming activities at the control system center. The collection schedule was delayed by a strike by the transit drivers and a schedule slippage in developing and debugging final versions of the alternatives. These changes resulted in data being compiled during parts of the spring, summer, and fall months of 1974. A base case data set was developed for each of the periods of activity to permit relative comparisons which reflect similar traffic conditions.

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1. The process was a modification of the post-processor component of the UTCS-I simulation model which was developed at an earlier stage of the UTCS program. The procedure is described in detail in later sections of this report.

REPORT ORGANIZATION

This report is presented in two volumes as noted on the title page, with this volume being the technical report and the second volume containing technical appendices. In addition to the introductory chapter, this report contains the following chapters.

Situation and Approach

This chapter provides the details of the work plan of the project exclusive of the detailed analytical methodology. The discussion includes information on the field studies and compilation of surveillance data. The detailed instruction sheets and related elements of the field studies are included in Volume 2. Statements of network conditions during the test with specific comments concerning the periods for each alternative are also noted. Descriptions of the measures of effectiveness (MOE's) are also included.

Analytical Methodology

This chapter presents detailed discussions of the procedures used in evaluating the alternatives. The chapter is complemented by the documentation of the computer programs which is presented in Volume 2.

Evaluation of Alternatives

A step-by-step discussion of the evaluation of first-generation alternatives is presented in this chapter. The chapter also discusses the relative results of the two primary evaluation procedures and the products of the secondary studies.

Conclusions

This chapter discusses conclusions reached by the research team in the areas of study design, methodology, and evaluation of alternatives. The conclusions for the first two items provide insight into problems encountered and changes which should be considered in subsequent analyses. The conclusions also note the positive aspects of the procedure. The conclusions for the evaluation provide an overview of the detailed evaluations and generalized observations of the research team.

SITUATION AND APPROACH

INTRODUCTION

This chapter discusses the work required to provide data for the analysis of alternatives and to provide information regarding the UTCS/BPS network and system. Elements of the INTRODUCTION are repeated as a base for expanded descriptions as required. As noted in the INTRODUCTION, detailed on data collection forms are included in Volume 2, TECHNICAL APPENDICES.

OVERVIEW

A detailed work plan was developed as the initial task in performing the evaluation project. The work plan reflected discussions held with the Contract Manager, other representatives of the Federal Highway Administration involved in the UTCS/BPS effort, the District of Columbia Department of Highways and Traffic, and the contractor-operator of the system. The discussions centered on the availability and format of information and the interrelationship of various schedules for work with the UTCS/BPS system. Additionally, minor studies of data gathering from system hardware (the CRT displays) and correlation of field observation to short-term displays were undertaken to assist in refining procedures. The work plan was related to the specifed contract tasks to:

- "Develop study design and final work plan;"
- "Conduct traffic field studies;"
- "Analyze strategy effectiveness."

The studies were developed to evaluate the five alternatives noted in the INTRODUCTION and were each tested in the a.m., midday, and p.m. periods. Data was not gathered during Monday morning or Friday afternoon periods to avoid what were felt to be atypical traffic conditions. Friday midday periods were used if needed to insure fulfilling sample size requirements. The following MOE's were used; volume, travel time, average speed, number of stops, delay, queue length[1], and, for bus analyses; bus route travel time,

1. Several forms of "queue length" are used in the UTCS/BPS system. Definition of the applicable measures is provided as required.

cross street delay, dwell time, and intersection area travel time.

The measures were developed primarily from the surveillance component of the UTCS/BPS system and from moving-car data and secondarily from machine volume counts, time-lapse photography, stopped-time delay studies, and special bus studies. The evaluation process was conducted at the four basic levels as follow:

- Link-specific comparisons of each UTCS MOE, based on samples of data generated for each combination of timing pattern and time period identified previously.

- A parallel set of subnetwork comparisons of each UTCS MOE for each timing pattern/time period combination, based on aggregations of specific link data into five selected subnetworks.

- Network-wide and subnetwork analyses of total vehicle miles of travel, vehicle minutes of travel, and effective "network speed."

- Evaluation of bus performance at selected intersections and basic bus routes at the points where they enter and exit the test network.

The sample sizes for each data collection activity were designed to permit measurement of significant differences in traffic performance between alternatives and time periods for each of the different levels of analysis identified above.

Normally 11 consecutive 15-minute detector summary periods were covered for each detectorized link in each day for the a.m. peak period (7 a.m. to 9:45 a.m.), eight such summaries in each day for the midday period (1:00 p.m. to 3:00 p.m.), and ten such summaries in each day for the p.m. peak (4:00 p.m. to 6:30 p.m.). These data were extracted from the UTCS/BPS detector system 15-minute summary tape data. Given the two-week sample period for each alternative, approximately 80 data points were developed for each detector in each time period.

Each such sample point was identified by day, time-of-day, average network volume level, and a notation made of the occurrence of unusual or potentially disruptive traffic conditions. The sample sizes noted above permitted the elimination of erratic or apparently non-representative sample points, together with an estimation of the variance in total traffic volumes.

For the moving-car studies, a minimum of four runs along each route was obtained each day for each time studied. This produced a desired minimum total of 32 data points for each time period and control alternative studied. The actual number of runs varied with the length and complexity of the route, the traffic conditions, and other external factors. The moving-car sample sizes, although smaller than those discussed above for the UTCS/BPS surveillance system data, were still sufficiently large to permit the elimination of erratic or biased data points and the identification of the confounding effects of volume level and/or unusual traffic condition on traffic performance.

As noted, data were collected for each control alternative for approximately a two-week period. Because of the overall length of calendar time which elapsed between the testing of the alternatives, three separate sets of base case data were developed, all based on the same traffic responsive settings. This was done to avoid comparing base data collected in March with test data collected in July, when the volume and pattern of traffic moving through the network is very different. For each analysis, statistically significant differences in traffic performance were identified at the 5%, 2%, and 1% levels. The analytical methodology is described in a following chapter.

UTCS/BPS SITE AND TRAFFIC CONDITIONS

The UTCS test area, as shown earlier on Figure 2, covers a major portion of downtown Washington, D. C., plus two arterial streets leading into the city center. A more detailed map is shown on Figure 3.

The downtown segment consists of a roughly L-shape grid bounded by 17th Street, Constitution Avenue, 23rd Street, L Street, 14th Street, and a line running from the intersection of 14th and K Streets to the north to the junction of 17th Street and Pennsylvania Avenue to the south. The area includes several major traffic arteries running in both the north-south and the east-west direction. It contains a large amount of commercial office space, plus several federal government offices, the campus of George Washington University, and a number of hospitals and medical buildings. It does not include any major concentration of retail activity; however, the system is adjacent to a major retail area and impacted by shopping activities.

The first of the two arterial segments covers a length of Pennsylvania Avenue and M Street running from the southwestern edge of the downtown grid through Georgetown to Key Bridge. The second segment consists of a three-mile length of Wisconsin Avenue running north from Georgetown to a point just beyond the National Cathedral.

Both arterial streets are lined with strip-commercial development, and both carry heavy volumes of commuter traffic into the city center from the Virginia and Maryland suburbs.

Both the downtown grid and the arterial segments carry significant volumes of bus traffic. Bus traffic is particularly high on the downtown section of K Street during the a.m. and p.m. peak periods.

For the purposes of analysis, the entire UTCS/BPS test area has been divided into four major subnetworks or "sections." These sections are also shown on Figure 3. The first of these includes all of M Street through Georgetown. The second section includes all of Wisconsin Avenue. Section three includes all of the downtown grid northeast of (and including) Pennsylvania Avenue. The fourth and final section includes the remaining portion of the downtown grid lying to the southwest of Pennsylvania Avenue. The remaining links on Pennsylvania Avenue lying to the northwest of Washington Circle are also in section one.

All sections of the network are subject to time-variant traffic controls. These include peak-period parking and turning restrictions; reversible lanes; and the designation of certain streets as reversible one-way corridors during peak traffic periods. The one-way streets are shown on Figure 4. The basic number of approach lanes are shown on Figures 5, 6, and 7. The lanes are shown for each of the three periods, a.m., midday, and p.m., respectively. The numbers shown are generalized and do not consider bus stops, illegal parking, or lane distribution.

A considerable amount of construction activity took place within the study area during the period of data collection. The most significant of this was related to Metro subway system construction centering along Eye Street and Connecticut Avenue (see Figure 4). This activity seriously disrupted certain traffic movements. It also either eliminated or impaired the operation of several UTCS/BPS detectors within the downtown grid. System detectors on Eye Street and on cross street approaches were generally out of service.

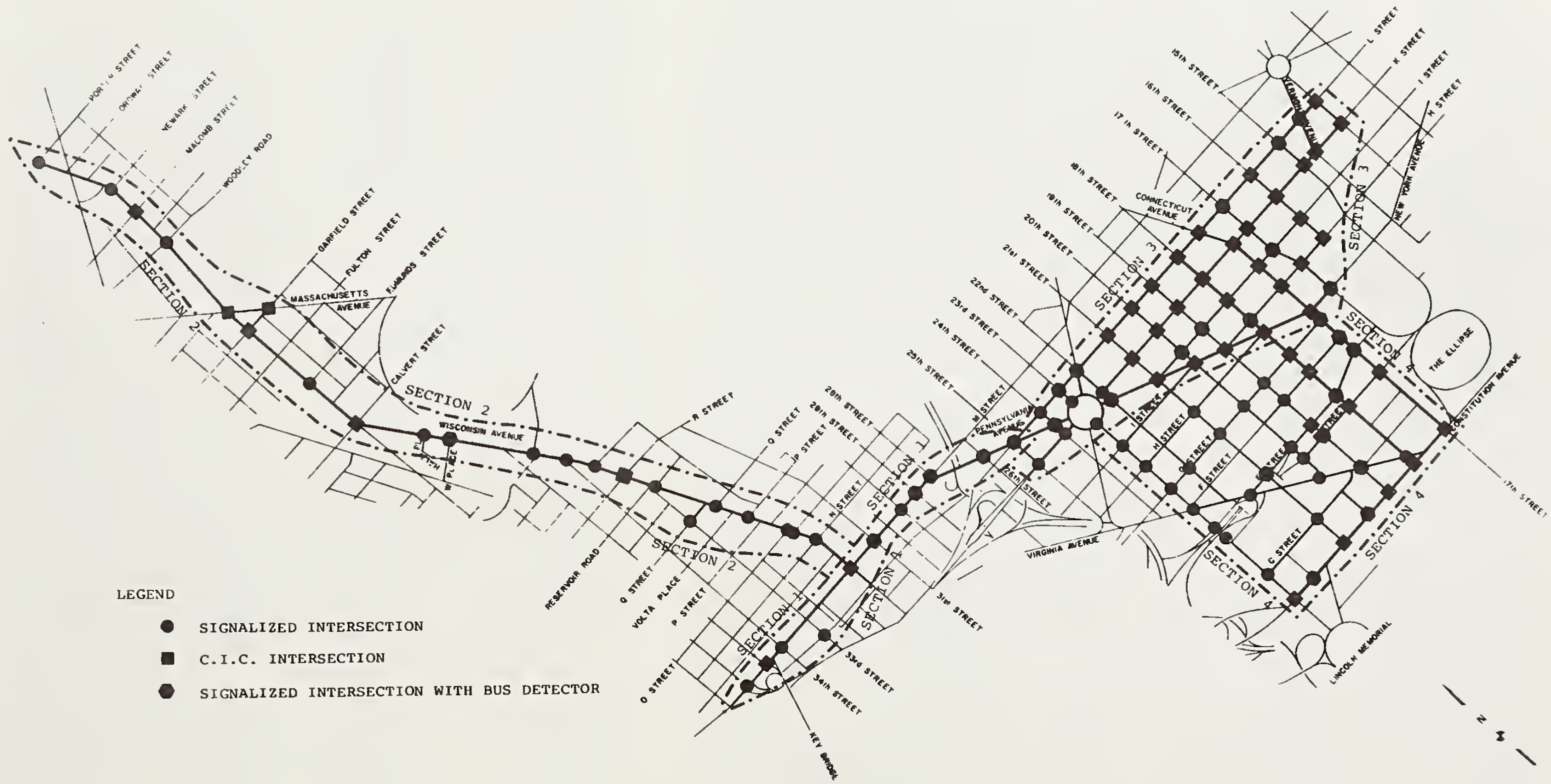


Figure 3. Network map of signal system.

LEGEND

ONE-WAY STREET SYSTEM

METRO CONSTRUCTION ZONE

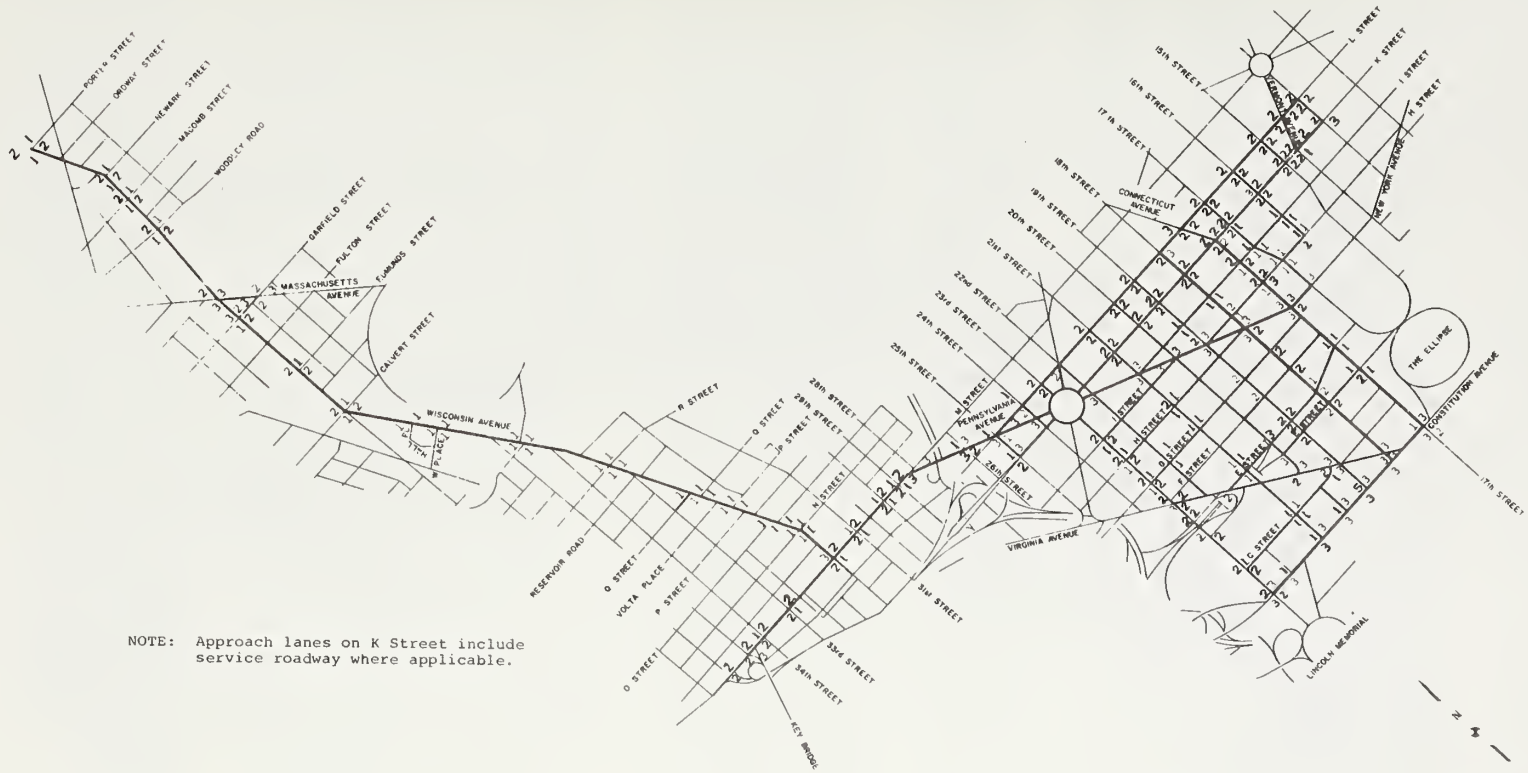
NOTE: 17th Street, Mass. Avenue to Eye Street is one-way southbound 7:00 to 9:30 A.M.

15th Street, Eye Street to Mass. Avenue is one-way northbound 4:00 to 6:30 P.M.

Figure 4. One-way streets and primary construction areas.

NOTE: Approach lanes on K Street include service roadway where applicable.

Figure 5. Approach lanes, a.m. period.



NOTE: Approach lanes on K Street include service roadway where applicable.

Figure 6. Approach lanes, midday period.

NOTE: Approach lanes on K Street include service roadway where applicable.

Figure 7. Approach lanes, p.m. period.

During the periods when the control strategies were being tested, several additional activities occurred which impacted on overall traffic operations, including the following:

- Installation of additional conduit on L Street from Connecticut Avenue to 14th Street for electrical service by a utility contractor. This increased congestion during the midday test. In accordance with permit regulations under which the utility contractor operated, no activity was begun prior to the end of the morning peak period and was suspended prior to the beginning of the evening peak period.

- Resurfacing of some sections of Eye Street and Connecticut Avenue was begun.

- Some sections of Eye Street were closed in order that the resurfacing might be expedited. Traffic normally using Eye Street was rerouted as a result.

- After settlement of the strike by the Metro bus drivers, it appears that former bus riders failed to return immediately to the use of the transit system for their work trips. Traffic volumes within the system appeared to remain higher than at the beginning of the study.

SURVEILLANCE SYSTEM STUDIES

This UTCS/BPS study area with 114 signalized intersections includes approximately 343 approaches.[1] UTCS surveillance detectors were originally installed on 221 of these approaches. Detectors were in most instances installed in a single lane, usually the center lane in the case of a multi-lane approach. At a number of complex intersections involving heavy turning movements, two separate lanes (usually the center lane and a turning lane) were detectorized. A total of 255 detectorized lanes was theoretically available within the study

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1. The actual number of "approaches" varies slightly depending on the definition used and on the time of day. Peak-period transitions from two-way to one-way operation, for example, for certain streets, alter the total number of approaches within the test area.

area during the period of data collection.

Approximately 16 of these detectorized lanes were rendered inoperative during the study, due either to Metro construction or the transition of a street from two-way to permanent one-way operation. Several additional detectors were rendered inoperative during portions of the data collection due to construction activity.

The detector installations are of two types. The simplest installation consists of a single, inductive-loop detector located 35 feet upstream from the stop line of an approach. Such detectors can record information on traffic volume, speed, and vehicle occupancy. Slightly less than half (111) of the original total of 255 detectorized approaches are of this variety.

The remaining 144 locations involve either two or three inductive-loop detectors located at varying distances upstream from the stop line. The first detector is again located 35 feet from the downstream stop line, the second at a distance of 210 feet upstream and, in the case of links of sufficient length, the third at a point between 300 and 400 feet upstream of the stop line.

These "multiple-detector" installations can detect the same information as the single detector, plus data on queue length, delay, and number of stops. In the case of failure of the second or third detector, the installation defaults to operating as a single detector.

Fourteen of the initial multiple-detector installations were either rendered inoperative by Metro construction, made obsolete because of permanent transitions from two-way to one-way traffic operation, or reduced permanently for another reason to single-detector operation. A large number of other multiple-detector locations failed periodically throughout the course of the study. This had the effect of limiting the availability of data on queue length, delay, and number of stops to between 80 and 90 locations for any "test"/"base-case" comparison.

The surveillance system also includes 72 "bus detectors" used in the operation of the bus priority system (BPS) control algorithm. These are located mainly along the arterial streets carrying significant bus traffic. A small number of these detectors also operated only part of the time due to construction activity.

Figure 8 shows the location and UTCS reference number for the detector installations used in the study. The solid arrows or circles represent multiple-detector installations which were operational during at least a portion of the analysis period. The hollow arrows or circles indicate single-detector installations. These latter include both those which were designed originally for single-detector operation and those where a multiple-detector installation defaulted permanently to the single-detector mode. Several of the locations illustrated, particularly those lying along the line of the Eye Street Metro route, seldom produced reliable data durung the course of the study and were generally eliminated from the analysis.

The passage of a vehicle over one of the detectors is recorded as a pulse which is transmitted to a central UTCS control center. The resultant information is then used both as raw input to the various UTCS control algorithms and also as the basis for monitoring performance. This is done, as noted earlier, by computing selected MOE's for each link, accumulated by 15-minute period and stored on computer tape.

Although the system computes other values for usage as part of the control operation and computes certain values on a running average basis, only the MOE's derived from the standard 15-minute summary reports are used in this study.

MOE Definitions

The following definitions and computational procedures apply only to those MOE's and not to other similarly named measures employed elsewhere in the UTCS system. They are based on information contained in the UTCS/BPS "Software Manual."[1]

Volume

"Volume" is estimated as a simple count of the number of vehicles passing over a detector within a 15-minute time period. If a link contains more than one detector, the estimate is based on the sum of the observations for each detector divided by the number of detectors.

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1. Sperry-Rand Corporation, "Urban Traffic Control and Bus Priority System Software Manual", (PB 220-867/868), Federal Highway Administration, Washington, D. C., February, 1973.

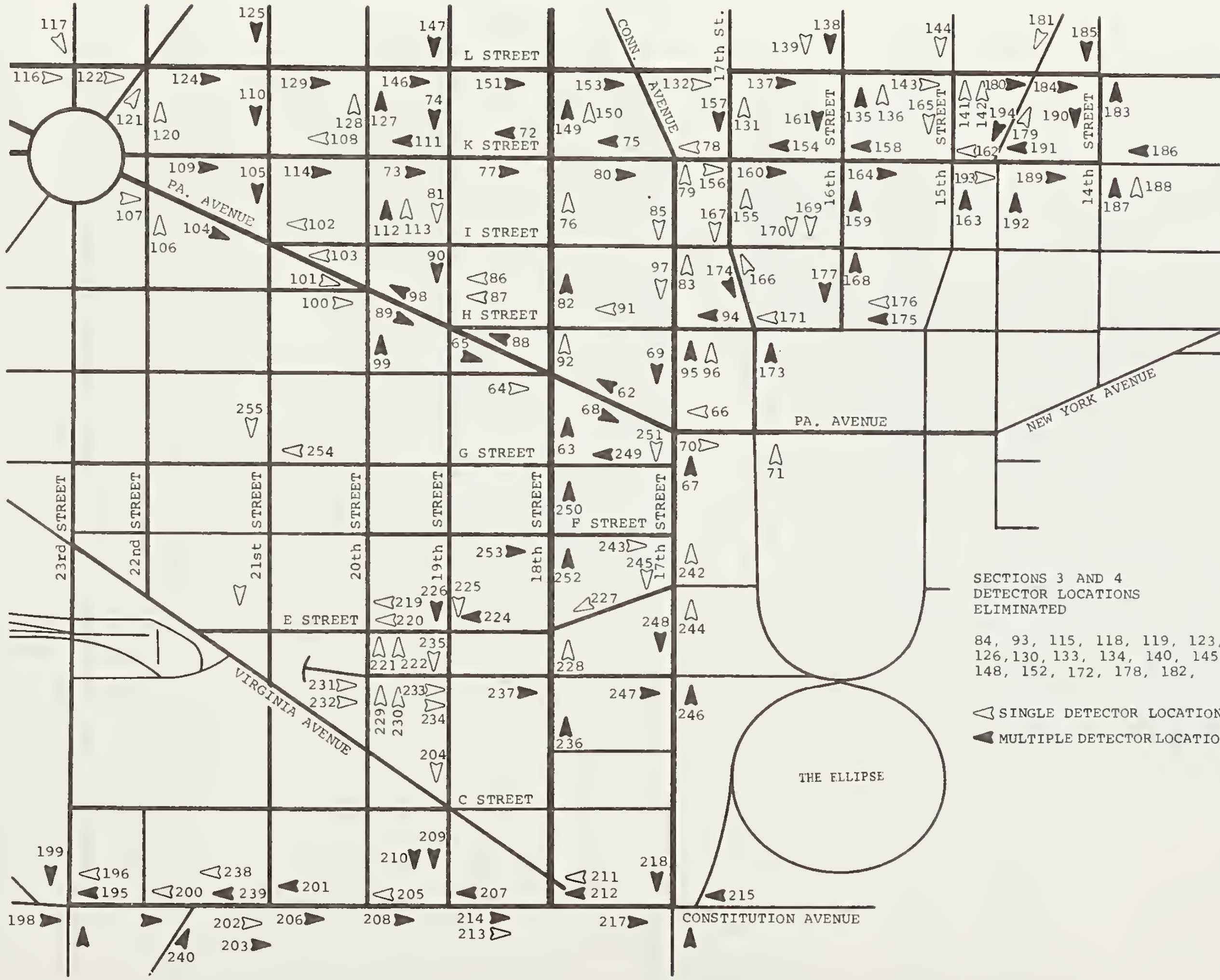

Figure 8. Location and type of UTCS/BPS detector installations.

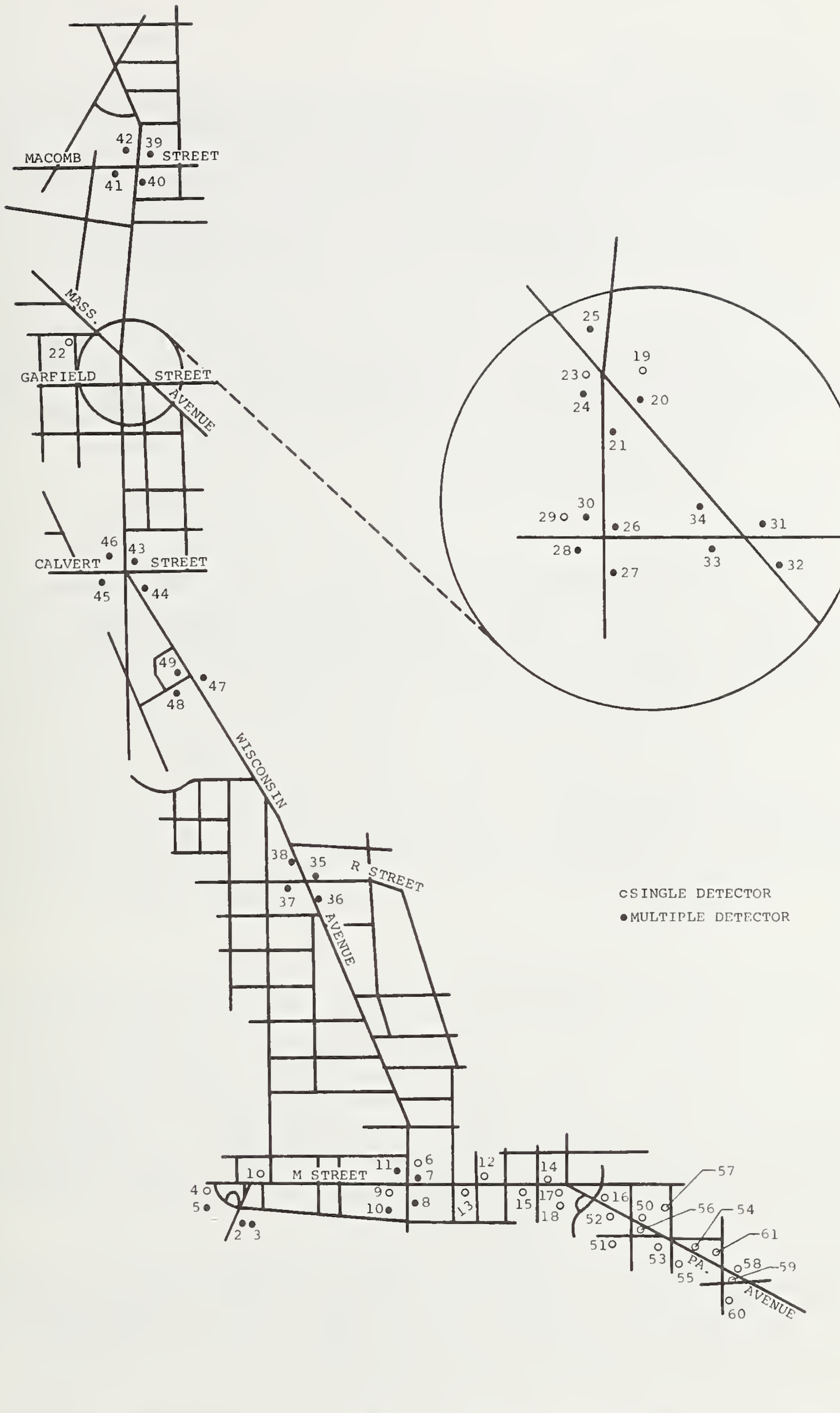

Figure 8. Location and type of UTCS/BPS detector installations. (continued)

Average Speed

Estimates of "Average Speed" are based on the time a vehicle takes to traverse a single-loop detector. It is based on an assumed average vehicle length, and includes adjustments for finite loop length and detector "bias." In the case of multiple-detector installations, speed observations are again averaged across all detectors.

Occupancy

The measure "Percent Occupancy" reflects the proportion of time that a detector is occupied or covered by the vehicles traversing a link. Observations are again averaged where appropriate across two or more detectors to produce a single value for each link.

Queues

The "Queues" MOE is a relatively complex measure reflecting average link occupancy rather than simply the length of a standing queue. Each multiple-detector link is divided into two or three zones, defined by the end of block and downstream stop lines and the individual detector locations.

The number of vehicles "queued" in each zone is then estimated at the start of each green phase and summed across all zones to provide an estimate for the link as a whole. These estimates are in turn summed for all green phases and divided by the number of such phases in each 15-minute period (normally 11 or 12) to produce the final 15-minute MOE.

The count of vehicles in each zone is estimated by an input-output count that is adjusted by observing individual vehicle speeds at the upstream detector of the zone and applying this data to a pre-calibrated relation between observed detector speed and downstream queue length. Separate relationships have been calibrated for links of different lengths within the UTCS network. The resultant "zone count" is automatically reduced whenever a vehicle passes the downstream detector.

The first zone (between the upstream stop line and the first detector in the link) is long enough only to accommodate a single vehicle and, according to the reference, is assumed to be empty unless the count for the next upstream zone is equal to three or more vehicles.

Delay

"Delay" is also a relatively complex measure. It is computed as the difference between the observed time taken by a vehicle to traverse a link and an assumed equivalent free-flow travel time under uncongested conditions.

The estimate is based in part on the zone count (queues) data outlined above estimated at two points in the cycle, the beginning of the red phase and the beginning of the green phase. Two assumptions are made: (1) vehicles arrive at the upstream end of the link at regular intervals during the red phase, and (2) vehicles discharge from the downstream end of the link at a fixed rate during the green phase.

Average delay per vehicle is then computed in two parts. First, all vehicles in the link at the beginning of the red phase are assumed to suffer a delay equal to the duration of that phase (this is based on the assumption that queue formation and dispersal rates are equal). Next, vehicles arriving during the red phase are assumed to experience a delay related to the number of vehicles already present, with the average time that they spend in the link being computed from the estimated zone count information referred to above and the assumed queue dispersal rate.

An estimate of net delay is then obtained by subtracting from this value the assumed free-flow travel time for the link and the individual vehicle observations accumulated for each 15-minute period.

It should be noted that the delay calculation pertains to the detectorized segment of the link only and that the calculation is made for all multiple-detector locations.

Number of Stops

Estimates of the "Number of Stops" encountered by vehicles traversing a link are also based on the "zone count" data. Vehicles which traverse a link without stopping are assumed to follow a standard time-space trajectory. This in turn yields a critical arrival time for the vehicle at each detector location relative to the time it entered the link. Vehicles which arrive at a downstream detector after the appropriate critical time has elapsed are assumed to have stopped.

Separate calculations are made for two and three detector installations. Adjustments are also made to allow for potential green extensions under BPS operation.

Travel Time

The estimate of "Travel Time" is based on the initial portion of the "Delay" calculation described above. It is again accumulated for all vehicles traversing the link within the 15-minute period.

It should be emphasized that the seven MOE's outlined above are not intended to precisely duplicate the standard traffic engineering measures of the same name, but rather to be realistic surrogates for them based on the data generated by the UTCS surveillance system. Their values should, therefore, be interpreted in the context of the definitions.

15-Minute Summary Tape Forms

The magnetic tapes from the UTCS/BPS system are in seven track, 556 bpi format as output by the system's XDS Sigma Five computer. For each 15-minute period, the summary tape contains two records of binary integer data. The first four words of the first record contain information on the date and time of the observations. This information is followed by an additional four words for each detectorized link in the system, containing the link identification number and the observed values of each of the seven MOEs, for the 15-minute period, each expressed as integer half-words. Data are provided for each of the 255 detectorized links referred to above, plus 15 additional detector locations which provide "advance warnings" information for use in system control. These latter data were not used in the evaluation project.

This initial information is followed by a single-spacer word and two integer half-words for each of the bus detectors included in the BPS system. Originally, these two words were designed to contain counts of the number of buses using the bus priority option and the resultant "intersection gain" at each location. The latter measure, however, has now been dropped and no data are produced.

The total length of the first record on each 15-minute summary tape is thus 1,157 words.

The second record on each tape is 290 words long. It contains 15-minute "failure" data, including information on UTCS control operator actions, plus data on controller, detector, and communications malfunctions. As in the case of the "advanced warning" information, there was no need to use this information in the course of the evaluation study.

MOVING CAR STUDIES

Four basic routes were selected over which moving car runs were performed. These routes, shown on Figure 9, were designed to form a data base representative of operating conditions on a majority of the system links. The moving car data consisted of average speeds, number and duration of stops, and average delay throughout the system, and were gathered for each alternative. Two of the routes followed the arterial streets (Wisconsin Avenue and M Street with Pennsylvania Avenue) and were run separately for each direction. The other two were closed loop routes within the grid network area. The following is a description of the routes as shown on Figure 9.

1. Beginning on Wisconsin Avenue at M Street, north on Wisconsin Avenue to Porter Street. After turning around--beginning at Porter Street, south on Wisconsin Avenue to beginning point at M Street. Trip distance is approximately 2.3 miles for each direction. The route was noted as Route 11-Northbound and Route 13-Southbound.

2. Beginning on Pennsylvania Avenue at 17th Street, northwest on Pennsylvania Avenue around Washington Circle to M Street; west on M Street to Key Bridge. After turnaround, return trip starts on M Street at Key Bridge and continues east on M Street to Pennsylvania Avenue; southeast on Pennsylvania around Washington Circle to 17th Street. The distance is approximately 1.7 miles for each direction. The route was noted as Route 22-Eastbound and Route 24-Westbound.

3. Beginning on 22nd Street at F Street, travel north on 22nd Street to K Street; east on K Street to 14th Street; south on 14th Street to H Street; west on H Street to 17th Street; south on 17th Street to Constitution Avenue; west on Constitution Avenue to Virginia Avenue; northwest on Virginia Avenue to 18th Street; north on 18th Street to L Street; east to L Street to Connecticut Avenue; south on Connecticut Avenue to K Street; south on 17th Street to New York Avenue; west on E Street, north to Virginia Avenue; northwest on Virginia to 22nd Street; north to 22nd Street to F Street and beginning point. The trip distance is approximately 4.6 miles.

Figure 9. Moving car Routes.

The route was run one-way and was noted as Route 30.

4. Beginning on 23rd Street at D Street, travel north on 23rd Street to Washington Circle; around Washington Circle to New Hampshire Avenue; northwest on New Hampshire Avenue to L Street; east on L Street to 14th Street; south on 14th Street to K Street; west on K Street to service road turn around at Washington Circle; east on K Street service road to 19th Street; south on 19th Street to Constitution Avenue; west on Constitution Avenue to 23rd Street; north on 23rd Street to D Street and beginning point. The trip distance is approximately 4.1 miles. The route was run one-way and was noted as Route 40.

The intermediate check points and distances are shown in Volume 2 along with sample forms and instruction sheets.

The majority of the moving car data was gathered with four vehicles equipped with Greenshields Traffic Analyzers. Using these analyzers, speedometer revolutions are used to measure travel time and distance for each link and route. For purposes of this study, the information was printed out on paper tape only when the printing mechanism was manually activated by an attached push-button. Since the analyzer was relatively easy to operate, the driver of the vehicle was able to drive the vehicle and operate the analyzer. This reduced the required manpower to one person per vehicle. During the initial stages of the UTCS/BPS data collection program, the travel time data was collected manually using a stop watch and forms prepared for each route. This method was also employed whenever there was a malfunction in the operation of the analyzers.

Generally, four runs were made for each route for each time period and each day of operation. The drivers were instructed to attempt a fifth run whenever there was sufficient time to complete the run prior to the end of the test period. The drivers were trained in the operation of the Greenshield's Analyzer. Their instructions included procedures for resetting the machine before the beginning of each run, re-starting the analyzer, and print button activation before the initial link discharge point. When continuing the run, the "print" button was pushed at each occurrence of one of three events: crossing of a stop bar at an intersection, stopping of the vehicle in traffic, and starting of the vehicle after the stop. After each stop bar was crossed, the tape was manually advanced slightly so that a gap in the printed data indicated the end of an intersection-to-intersection link. This physical gap in the printed data facilitated subsequent data reduction and coding.

Each driver was instructed to maintain the speed of the platoon with which he was traveling. If he was not in a platoon, he was to maintain the posted speed limit. The maximum allowable speed was 30 mph. Lanes were selected at random with the intent of having a nearly equal number of runs in each available lane. Lane changing was to be kept to a minimum.

A minimum of two drivers were acquainted with each route and two standby drivers (full-time technicians of the research team) were available to fill-in when crew members were absent. The drivers were hired on a temporary basis and three sets of drivers were needed; one for each primary phase of data collection. The full-time technicians trained the drivers in the procedures to be followed and rode with the drivers on several occasions throughout the collection effort. Driver results were examined daily and questionable runs were voided and re-collected as required. The same drivers were used, insofar as possible, for a given route through a base case and alternatives examined in one of the three periods; spring, summer, and fall.

A master run was made for each route before data collection began in order to calibrate the distance (in hundredths of a mile) between each checkpoint. The distances obtained from the master runs were used, when necessary, to verify runs, for correction of driver errors, and to determine which segments of data were unsuitable for further analysis.

As noted in the INTRODUCTION, the moving car studies included approximately 181 of 343 approach links to the controlled intersections.

MACHINE VOLUME COUNTS

Machine volume counters were placed at 25 intersection approaches. The approaches were selected to provide a representative sample of the traffic flows within the system. The machine volume data were designed for estimating the total traffic volume within the system and as a check of the system detectors. The latter purpose proved to be the primary usage. The surveillance system was used to indicate volume levels in the network.

Of the 25 locations, five were in areas where there were no detectors or where the detectors were out of operation because of Metro construction. The other 20 were located in the vicinity of system detectors and on streets with various geometric and operational characteristics, ranging from one to four lanes and involving one-way and two-way operation. The counter locations are shown in Figure 10. Those counter locations where no detectors were operational are noted on the figure.

Data was recorded at 15-minute intervals corresponding to the recording time of the system detectors. The counters were placed far enough from intersections to avoid the double counting effect of turning vehicles. Counters were left running for the full week intervals during the evaluation periods, but only the data during the hours of 7-10 a.m., 1-4 p.m., and 4-7 p.m. were coded for use in the project. The machines were checked once each day to insure that they were operating properly and were turned off Friday afternoon to Monday morning to reduce battery usage.

TIME-LAPSE PHOTOGRAPHY

Three intersections, indicated by a "circle" on Figure 10, were selected for study by time-lapse photography to relate surveillance data to observed data. The intersections were 20th and K Streets, 18th and L Streets, and 17th Street at Pennsylvania Avenue. The intersections are all located in the grid network portion of the UTCS area. The approaches examined were detectorized and had BPS surveillance hardware as well.

All photography was done from roof-tops of buildings located at the intersections. A 16 mm camera, equipped with an automatic advancing mechanism, was used. All films were taken at a speed of one frame per second. The films were taken in color with natural light and a wide-angle lens. Filming was generally done for two hours during each of the three periods at each location. Starting times were correlated with a 15-minute interval such that a comparison could be made with the UTCS/BPS surveillance data. The films were run through a 16 mm projector equipped to permit forward and back-up operation at rates varying from a single frame per actuation to several frames per second under automatic advancing.

Initially, volume and turning movement data were extracted from the films. Undetected camera problems (intermittent aperture failure) reduced the usability of several rolls of film. This caused gaps to occur in data sets and

Figure 10. Traffic counter & Time lapse photography locations.

resulted in the questionable accuracy of a base case. The detector surveillance data provided the information needed for the overall evaluation and the questionable data was not used.

The film data was reviewed to determine queue length (as defined in the surveillance system) and this data set was compared with the output of the surveillance system.

BUS OPERATIONS STUDIES

As noted, bus surveillance detectors are located at approximately 72 locations as part of the UTCS/BPS system. These detectors are used to sense the presence of a bus so that the bus priority system algorithm can provide preferred service to the buses at critical intersections. These bus detector locations are shown on Figure 11. A transmitter is required on the bus to activate the bus detectors. Of the approximately 2,200 buses operated by the transit company (WMATA)[1], 450 were originally equipped with the special transmitters. At the time of the study, approximately 300 buses had functioning transmitters; 150 units having been lost through the transit equipment replacement program.

The 300 equipped buses operate from three of the eight WMATA garage divisions--the Bladensburg, Northern, and Western garages. This has the effect of limiting the buses to those routes served from these three garage facilities. WMATA was requested to have the equipped buses in service during the test periods, however, limited compliance appeared to occur.

Special studies were developed to monitor bus activities and the overall effect on traffic was measured by the surveillance and moving car studies. The bus studies were designed to measure both intersection specific and route wide effects of the buses. The intersection studies were conducted at 18th Street and Pennsylvania Avenue, 14th and K Streets, 17th Street and Pennsylvania Avenue, and Wisconsin Avenue at Macomb Street. Route studies were conducted along Pennsylvania Avenue, M Street, and Wisconsin Avenue and along K Street in the commercial core. The intersections and routes are shown on Figure 12.

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1. Washington Area Metropolitan Transit Authority (WMATA).

Figure 11. Bus detector locations.

Figure 12. Bus study locations.

The intersections and routes were selected to cover a range of traffic operating conditions and to include the routes served by the three garages where the equipped buses were located.

The intersection studies were conducted only for instrumented approaches. This included three approaches at 18th Street and Pennsylvania Avenue; the two approaches of Wisconsin Avenue at Macomb Street; and all four approaches at 14th and K Streets.

At each location, the observers recorded the following information:

- The arrival time of the bus at the upstream bus receiver-detector;
- The route number, vehicle number, and block number (the headway control number) of the buses;
- Estimate of passengers on bus, passengers loading and off-loading;
- Dwell time if bus stopped;
- If the bus stopped, the cause of the stop (red signal indication, passenger loading/off-loading, and/or both);
- The time the bus departed the far side of the intersection; and,
- Whether or not the "transmitter indication"[1] was displayed.

When the number of buses passing the selected locations was too great to allow the observation of all these items for all buses, only as many buses as could be accurately timed were recorded by the observer. Priority in data collection was given to buses with the transmitter designation in an attempt to equalize the equipped-not equipped samples. The observers used two stop watches; the first to record the travel time of the bus from the detector location to the

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1. A white card with a large letter "P" was to have been displayed in the window of transmitter-equipped buses. Because of low driver compliance, the bus number was ultimately used to identify equipped buses.

intersection exit and the second to determine the dwell time of the bus if it stopped.

The route studies were conducted by clocking the buses into and out of a given segment of the system. The bus route numbers covered by the study are noted on the previously referenced Figure 8. The points where the buses were logged in and out are also shown on the figure. The observers' watches were synchronized before each study period and accuracy verified at the end of the period. Buses covering the route were "matched" using the bus, route, and block numbers and the travel time computed.

At each location, the observer recorded the following information:

- The time the bus crossed the predetermined point, i.e., the upstream detector or the crosswalk;

- The route number, vehicle number, and block number (the headway control number);

- Estimated number of passengers; and,

- Whether or not the transmitter indication was displayed.

Each observer was required to record data only for those buses with route designations matching the series listed which included travel throughout the pre-established area. This reduced the total size of the data set and allowed greater concentration on selected routes. This in turn facilitated matching the in-out data.

The data was collected during those hours specified for the overall evaluation. Starting times for the "in" observers were approximately 15 minutes earlier than for the "out" observers to allow for route travel time and minimize the number of missed opportunities for matching. After completion of data collection, the data was recorded on coding sheets for punching on computer cards for processing. Route details, samples of all coding forms, and instructions for collection and coding are included in Volume 2.

DATA COLLECTION SCHEDULE

Data collection occurred over a calendar period of approximately eight months. Conditions varied somewhat during this period because of normal seasonal traffic fluctuations. The daily variations were taken into account by a volume matching concept described in the chapter on ANALYTICAL METHODOLOGY. Separate base cases were taken by during each of the three seasons spanned by the data collection effort. Data collection began on March 4, 1974, and was completed on November 8, 1974. The schedule for the collection activities for the various alternatives is shown below.

CONTROL ALTERNATIVE		COLLECTION PERIOD (1974)
NUMBER	NAME	
1.	3 Dial	March 4 - March 15
1.	3 Dial (Data Augmentation)	June 5 - June 11
2.	TOD	March 26 - April 5
3(1)	TRSP (Spring base-case)	April 15 - April 23 April 26-April 30 and May 1
4.	CIC	May 20th - June 4
5.	BPS	July 22 - August 2
3(2)	TRSP (Summer base-case)	August 5 - August 16
3(3)	TRSP (Fall base-case)	October 9 - October 23
4.	CIC (Test Repeat)	October 24 - November 8

CONDITIONS DURING ALTERNATIVE TESTS

The basic traffic conditions within the UTCS/BPS project area have been summarized earlier in this chapter. The purpose of this section is to highlight conditions during the tests for each of the alternatives.

Alternative 1. 3 Dial

This alternative is the basic fixed time, three-dial, three offset/split system used by the District of Columbia, Department of Highways and Traffic. Controller dial number one is used seven days per week during all non-peak traffic periods. Dial number two is used during the a.m. peak period from 7:00 a.m. to 9:30 a.m., Monday through Friday. Dial number three is used during the p.m. peak period from 4:00 p.m. to 6:30 p.m., Monday through Friday. Dial settings for splits and offsets have been developed over time and are based on a regular analysis of traffic volume data. The system is designed for normal traffic flow patterns. The control patterns used to test Alternative 1. were those in service through January, 1973.

Data collection for this alternative began on March 4th continuing through March 15th. The data collection began during the time when the critical shortage of fuel was still having an apparent impact on total vehicular volume. Auto usage appeared to be restricted to those trips considered necessary. Traffic volumes were approximately percent lower than normal and it was apparent that a higher percentage of work trips were made in car pools and transit facilities. The weather was generally good with light rain on two days.

Alternative 2. TOD

This control alternative utilizes time-of-day control patterns developed using the TRANSYT signal optimizing program. The timing patterns are computed off-line based on data gathered within each control zone. Seven separate timing plans have been developed for UTCS application.

Data collection for this control alternative was to begin on Monday, March 25th. An unscheduled failure within the central processing unit delayed the start until Tuesday, March 26th. Data collection was completed on April 5, 1974.

Traffic volumes appeared to be consistent. No unusual traffic conditions were noted and weather conditions did not have a significant impact during the period.

Alternative 3. TRSP (base cases)

This alternative was used as the base case for evaluating the first-generation strategy. It is also expected to serve as the base case for evaluating the second and third generation algorithms. The TRSP alternative uses the same basic time plans as those noted for Alternative 2. (Seven plans were developed using TRANSYT). It has the added capability of selecting the plans based on a pattern-matching principle which responds to measured on-street traffic conditions.

Data collection began on April 15th and continued through May 1, 1974. Two normal collection days were aborted in April and made-up by extending the test into the third week.

The data collection for this alternative occurred when the first significant variations in traffic volumes were beginning. The most apparent change was that additional midday volumes appeared to occur because of the visitors during the Easter season. The midday volumes were observed to be higher than for the first two alternatives. The weather was good and did not effect traffic operations.

Initial data for use in evaluating the bus priority system were also collected during this period. The data was to be used as the base control in comparing the effectiveness of priority bus treatment that was to be collected for Alternative 5. The data collected during this period for BPS evaluation was not used, however, due to a transit strike which caused the rescheduling of the BPS control strategy beyond the spring 1974 period.

Data under this alternative were collected in August and in October to serve as base cases for Alternatives 5. and 4., respectively. No unusual conditions occurred during these periods.

Alternative 4. CIC

This alternative uses the basic timing and operation as Alternative 3. TRSP. In addition, a critical intersection control mode is implemented for those intersections where approaches become highly congested and intersection blockages occur. These approaches have been instrumented and provide the CIC algorithm with on-street demand information. The intersection splits are recomputed each cycle to reflect the measured demand on the critical approach for each signal phase.

The scheduled start of data collection for this alternative was for May 6, 1974. A five-day strike by Metrobus operators and the need for additional refinement of the control algorithms for this alternative delayed the actual start until May 20th. Data collection continued through June 4th.

The strike by Metrobus drivers forced all bus passengers to seek other means of transportation to and from work. Many returned to using their private automobile for their work trips. After settlement of the strike, a significant number of these people did not return to use of the bus. Because of this, there was a noticeable increase in the network traffic volumes for this collection period. In addition to the increase in commuter traffic volumes, the initial traffic increases due to tourist attractions began. Inasmuch as most of the attractions are not in the study zone, the overall impact was not major.

After completion of the data collection for Alternative 4, an additional five days of data was collected for Alternative 1. This data was used to enlarge the data set and to compare with initial data to identify significant changes in traffic volumes within the network since the beginning of the data collection activities.

Data collection was suspended until July 22nd to permit refinements in the control algorithms. The delay was also prompted by changes in the traffic patterns caused by Metro subway construction progress and to insure that traffic volumes within the network were similar.

An error in the UTCS system calculation of the measures of effectiveness was discovered during analysis of the CIC data. Data collection for evaluation of this alternative was repeated. The period of this data collection was from October 24 through November 8, 1974. As was noted earlier, a new data set for Alternative 3. was collected during the fall, 1974 period to provide a comparable base case for the fall data for Alternative 4.

Alternative 5. BPS

As noted, approximately 300 buses in the Metrobus fleet are equipped with specially designed near field radio transmitters. The units are designed to transmit a signal to an antenna embedded in the traffic lanes approaching selected intersections. This signal is interpreted as a request to the computer to either extend the green phase or truncate the red phase (depending on signal state), permitting the bus to clear the intersection without being delayed by the signals. When the bus clears the intersection, the signal is returned to its normal phase durations. This system also measures traffic volumes at the intersection and inhibits the bus priority system if the intersection becomes saturated.

Data collection began on Monday, July 22nd. A malfunction in the operation of the computer at the system control center could not be resolved and all data collection was suspended until midday Tuesday, July 23rd. Data collection for this alternative was completed on August 2, 1974.

Traffic operations during this period were affected by changes in the Metro construction phases and the influx of tourists. A summer data set for Alternative 3. TRSP was collected to provide parallel evaluation information. Light to moderate rain occurred on three days and a major fire disturbed traffic one a.m. period on upper Wisconsin Avenue. Link data impacted by the fire was voided.

ANALYTICAL METHODOLOGY

INTRODUCTION

This chapter describes the analytical methodology used in comparing the control alternatives of the first-generation UTCS/BPS system. The chapter includes a discussion of data assembly and data processing procedures and the statistical analysis techniques. A package of computer programs was developed for use in data assembly and analysis. These programs were designed to be of use also in the testing of second and third generation UTCS control strategies subsequent to this project. Documentation of these computer programs is included in Volume 2. Technical Appendices to this report. The results of the analyses and the conclusions reached are presented in subsequent chapters. As described previously, two parallel primary analyses, based on surveillance system data and moving car data and special studies, were used.

PROCESSING THE UTCS/BPS SURVEILLANCE DATA

The data from the 15-minute summary tapes were used to create a series of standard arrays. These may be considered conceptually to be of the form illustrated in Figure 13. Separate arrays were produced and maintained for each control alternative and base-case studied, and for each of the three time-of-day intervals.

The rows in Figure 13 represent individual links in the network. For each link, MOE data are assembled by 15-minute time periods over a series of several days. The major columns in Figure 13 represent one such 15-minute time period; the minor columns represent data collected during that time period on a particular day. If all data is usable, each major column will contain eight minor columns, corresponding to the eight days for which data were collected for each control alternative.

The minor columns themselves may be further defined as containing seven separate "cells" for each link, corresponding to the seven measures of effectiveness for which data were assembled.

The analysis process outlined later in this chapter compares any two of these arrays on the basis of similar links and similar 15-minute time periods. That is, the data assembled on different days are used to construct a distribution of observations for each link and each 15-

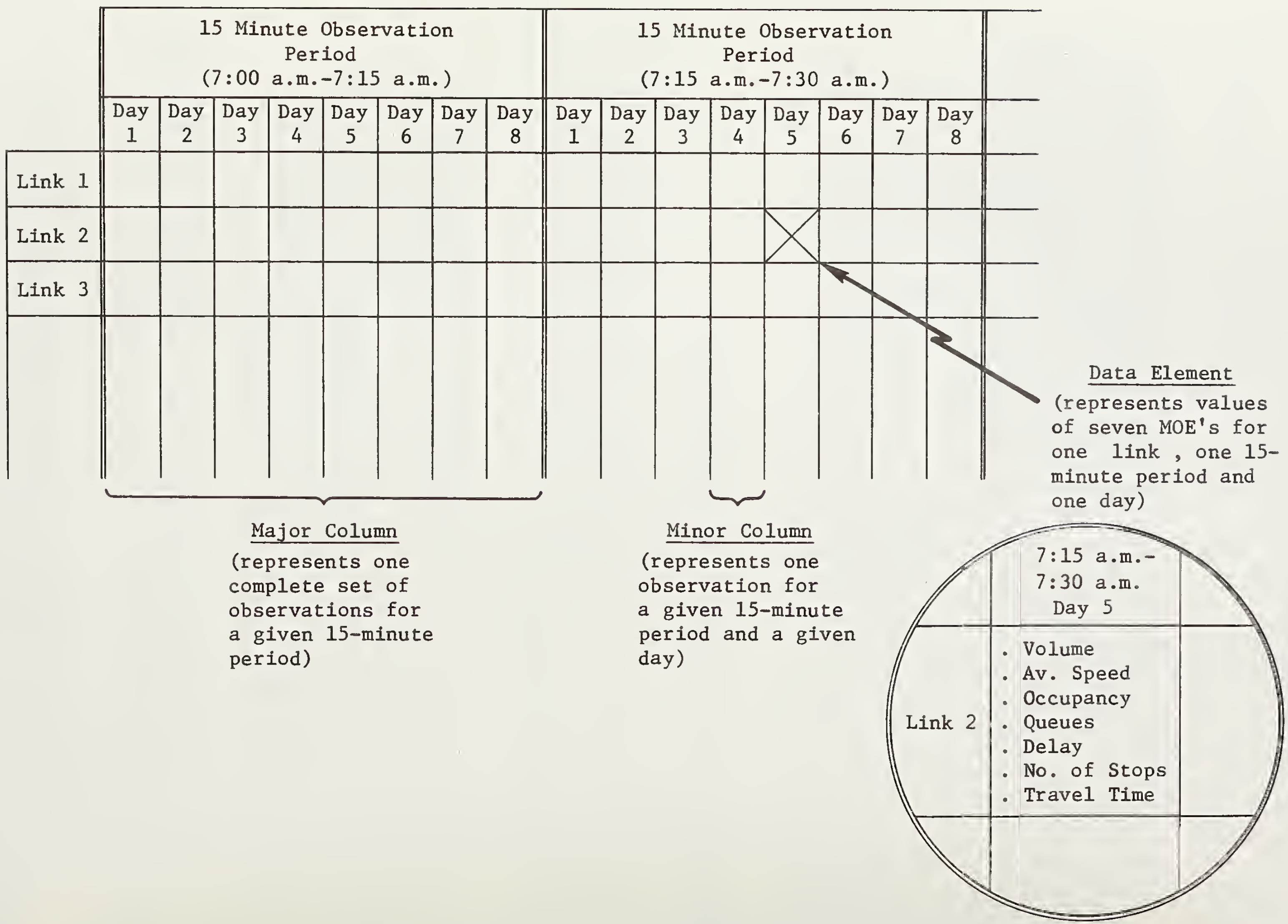

Figure 13. Conceptual structure of detector data array.

minute period. Comparison of these distributions then forms the basis of the statistical analysis.

The following standard terms are used throughout the discussion of these arrays:

1. Observation - the term "observation" means a full set of MOE data developed for all links to be analyzed for one 15-minute time period on one particular day; i.e., an "observation" corresponds to one minor column in Figure 13.

2. Time-of-Day - the term "time-of-day" means one of the three time intervals for which data are assembled for each alternative; i.e., a.m., midday, and p.m.

3. Data Element - the term "data element" is defined as a single set of seven MOE's developed for a specific link during a particular 15-minute observation period on a particular day; i.e., a "data element" corresponds to the intersection between a row and a minor column in Figure 13.

Data Processing Software

A package of eight computer programs was written to extract data from the 15-minute summary tapes and prepare it for analysis in the form of the arrays described above. The programs were designed to perform a series of diagnostic checks on the data and to eliminate any erroneous or inadequate data points from the analysis.

Figure 14 lists the programs in the order of their use. All are operational on the FHWA IBM 360 computer installation in the Department of Transportation Nassif Building, Washington, D. C.

The following paragraphs outline the functions of each program and describe the major steps followed in the extraction and processing of the summary tape data prior to statistical analysis. More detailed documentation of the programs is given in Volume 2. Technical Appendices of this report.

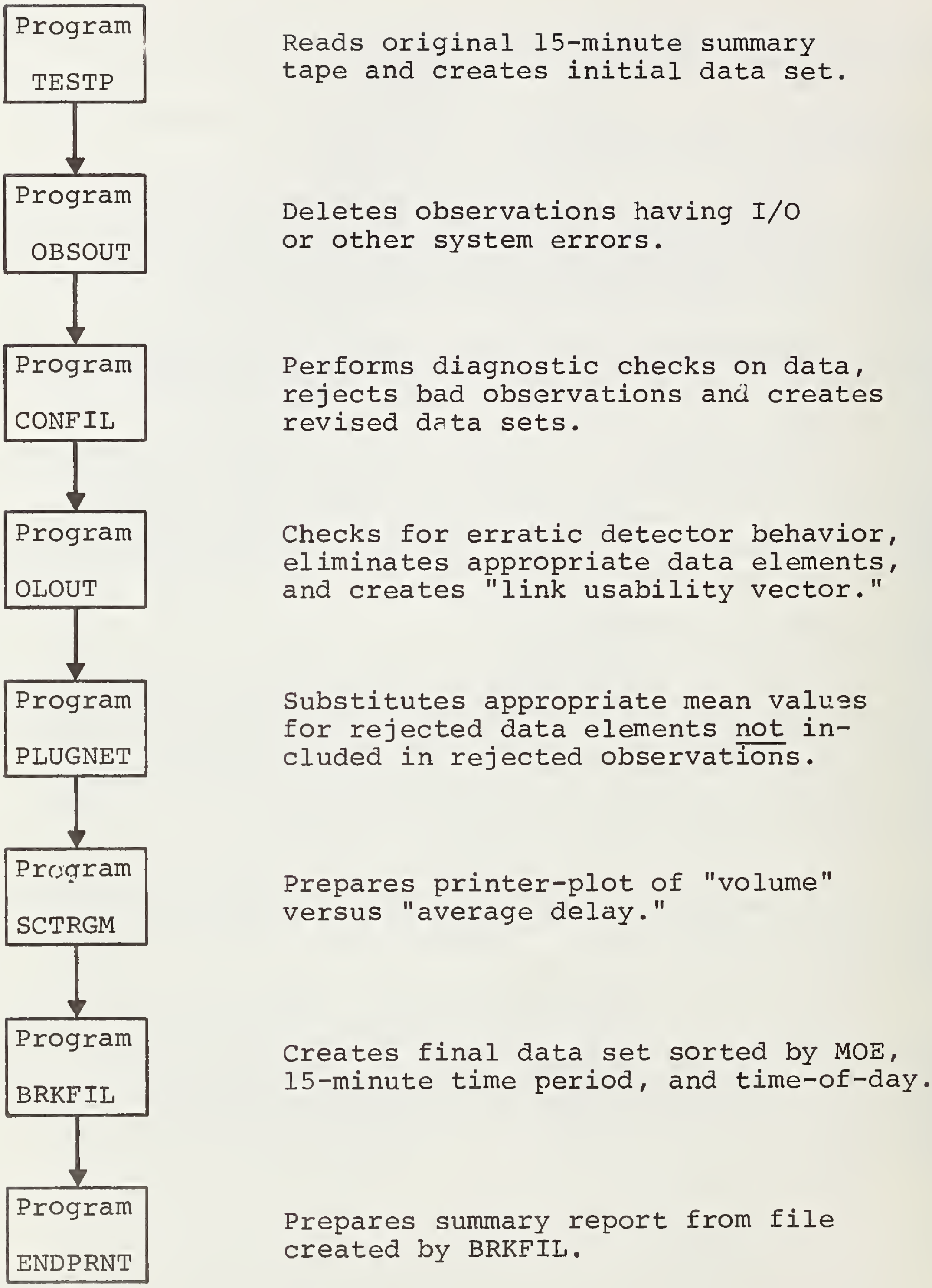

Figure 14. UTCS/BPS evaluation software data assembly and edit routines.

Program TESTP

The first program in the package is designed to read the 15-minute summary tapes as generated by the XDS Sigma Five computer, perform an initial set of error checks, and produce a summary data set in standard format for subsequent processing.[1]

Program TESTP reads each record on the original tape, ignoring data on system failures. Information on time and date is checked against control records and any errors noted. Next, the data corresponding to the three standard time-of-day intervals are extracted and summarized in chronological order.

As noted, the three time intervals were defined as:

- a.m. peak period (a.m.) 7:00 a.m. - 9:45 a.m.;
- midday period (midday) 1:00 p.m. - 3:00 p.m.; and
- p.m. peak period (p.m.) 4:00 p.m. - 6:30 p.m.

All records except those corresponding to the time periods identified above are eliminated from the file. A check is also made to determine if information is available for the 15-minute period immediately preceding the time-interval to be analyzed. If this record is missing, it indicates that a system failure may have occurred and that complete data may not be available for the first 15-minute period to be evaluated--i.e., the original tape may not include information for the early portion of the first 15-minute period due to a system malfunction or late start-up.

The program then extracts and reformats all of the MOE and link identification data for each of the 270 detectorized links in the test network. A summary of the data for the first few and last few links is printed for visual checking and examination. The program also produces a count of the number of "vehicles helped" by the bus priority system.

The output of program TESTP is a simple data set produced in standard format for each day, containing a header

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1. A number of difficulties were encountered early in the project in reading the tapes created on the UTCS XDS Sigma Five computer. Most of these were traced to tape drive maintenance problems which were corrected by instituting more rigorous maintenance and quality control procedures.

record for each 15-minute period followed by the MOE values for each of the 270 links.

Program OBSOUT

The second program in the sequence, OBSOUT, is designed to delete observations from the data set generated by program TESTP which are found to be in error due to data I/O or similar machine processing problems. Program OBSOUT produces a data set identical in format to that produced by program TESTP, but containing fewer records. The deletions are based on coarse logic and limit checks which identify "nonsense" values. The program is bypassed if no deletions are necessary.

Program CONFIL

The third program, CONFIL, is one of the more important ones in the series. It performs a number of functions, including a lengthy series of diagnostic checks on the data sets created by TESTP and OBSOUT. It then eliminates any data points which fail to pass these tests and creates a smaller edited data set.

The program first break down the data set for an entire day and divides it into three files defined by time-of-day (e.g., a.m., midday, p.m.). Each data item within these files is then examined to determine whether or not it represents a valid point for analysis.

The UTCS system automatically diagnoses a large number of detector and operating system failures and "flags" these as part of the standard output record. Program CONFIL identifies all instances which are "flagged" in this manner, and records the total number of links so indicated within each 15-minute observation.

The program next checks each individual data element to eliminate obviously erroneous information. This is done by comparing selected MOE values with equivalent "acceptable" standards. The standards were themselves developed empirically as the study progressed, as analytical problems were identified and traced back to poor input data. The program permits the values used for the standards to be varied at the option of the analyst.

Six such checks are made, with a data element being rejected if one or more of the following conditions apply:

1. The observed 15-minute volume for the link is less than eight vehicles per hour;

2. The observed 15-minute volume exceeds 1,500 vehicles per hour;

3. The average 15-minute speed for the link exceeds 50 miles per hour;

4. The average 15-minute travel time for the link is greater than 187.5 seconds;[1]

5. Any measure of effectiveness has a negative value; and,

6. The link identifier is out of sequence.

The program then classifies each detectorized link as an effective single or multiple-detector installation for each 15-minute time period. This is done by first checking the nominal classification of each installation. The operation of all multiple-detectors is then verified by checking the more complex multiple-detector MOE's. If all of these are zero for the 15-minute observation period, the installation is presumed to have defaulted to single detector operation and is so classified.[2] A catalog is then prepared summarizing the status of each detected installation for the 15-minute period.

CONFIL performs a further composite check on the data based on the combined number of "flagged" links identified by the UTCS control system and "rejected" links identified by the logic outlined above. Serious data problems warranting further examination are assumed to exist if either more than four links are "rejected" within a 15-minute observation period; or the sum of "rejected" and automatically "flagged" links in a 15-minute period exceeds 74.

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1. Data on the UTCS tapes for travel time are scaled by a factor of 32. The value above corresponds to 6000 on the original tape.

2. Normally, if more than one detector at a multiple-detector installation is operational during the 15-minute period making up the observation, these MOE's will have non-zero values. The complex MOE's cannot be computed for single-detector locations nor for multiple-detector installations where only a single detector is operational.

If a 15-minute observation fails either of these tests, it is automatically deleted from the data set.[1]

The output of program CONFIL is a revised data set in standard format, from which all "flagged" and "rejected" observations have been eliminated.

Program OLOUT

The next program in the series, OLOUT, is designed to check for consistently erratic detector behavior over an entire study period. The program first classifies each link as functioning predominantly as a single- or a multiple-detector installation for the set of observations in question (e.g., midday). The number of times each multiple detector link defaults to a single-detector operation is then recorded. If this occurs more than 20 times (i.e., for 20 separate links) within a single 15-minute observation interval, the entire 15-minute observation interval is deleted. This situation never actually occurred in the course of the present study.

A "link usability vector" is then computed. Each individual link is classified as either (1) "usable" as a multiple-detector installation; (2) "usable" as a single-detector installation, or (3) "unusable." If the number of "unacceptable" observations identified by program CONFIL for the link exceeds four, the link is automatically considered "unusable" and eliminated from the analysis. If 40 percent or more of the 15-minute observations for a given link are either "flagged" automatically by the UTCS control system or defined as unacceptable by program CONFIL, the link is also classified as "unusable" and eliminated from the analysis.[2]

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1. It should be noted that only three such instances occurred in the present study. All of these were due to system I/O problems on the original UTCS summary tape, rendering the observations in question non-usable.

2. The presence of excessive "flagged" values for a given link is indicative of systematic failures of the detector system and casts considerable doubt on the reliability of the remaining, apparently valid observations.

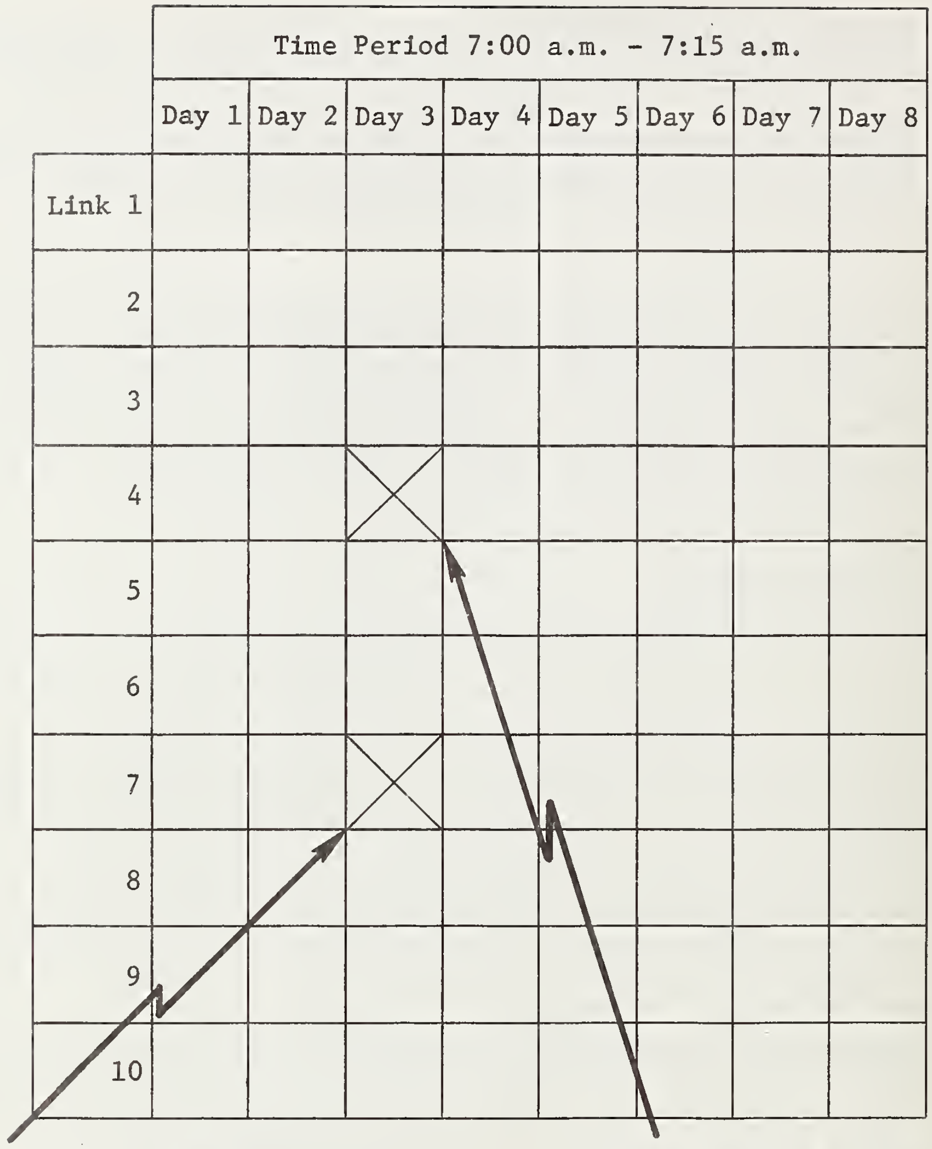
The output of program OLOUT is expressed in the form of a "link usability vector". This vector is used subsequently as input to a number of other programs in the evaluation package. All "unusable" data elements are indicated by a "-1" entry in the appropriate position in the data array. The final number of usable observations is noted and written into a control data set for use in subsequent analyses.

Each of the three time-of-day files developed by program OLOUT is then sorted using the IBM Sort/Merge utility program. The sort is made by clock time, so that all observations for a given 15-minute period are located physically adjacent to one another in the final file. This step is a necessary precursor for the sample selection procedure described later in this chapter.

Program PLUGNET

The fifth program in the package, PLUGNET, replaces the value of individual data elements rejected by project CONFIL with an equivalent mean value computed from the appropriate, non-rejected elements. This provision is incorporated in the package in order to minimize the elimination of entire 15-minute observations due to the presence of only one or two bad "links" from within the total sample of 80 or 90 links included in the observation. It is invoked only for case observations which have passed all of the preceding tests in the series and affects only those data elements in an observation which have been rejected as unrealistic.

Separate mean values are computed for each MOE for each link, using the non-rejected data elements contained in the total sample of observations developed for each 15-minute time period. The process may perhaps best be illustrated by an example. In Figure 15, eight observations have been developed for the time period 7:00 a.m. to 7:15 a.m., based on data collected on eight separate days. Such observations contain information on the links and all seven MOE's. Two data elements in one observation--observation #3 in the figure involving temporary detector malfunctions on links #4 and #7--are found to be unacceptable according to the criteria of program CONFIL and are rejected. The number of elements rejected is not enough to cause the entire observation to be eliminated. Later analysis programs, however, require a complete data set, i.e., missing data points must be replaced, rather than eliminate the entire observation. Therefore, MOE values for the two rejected data elements are replaced by appropriate mean



<u>Observation 3, Link 7</u>
<u>Bad Data Element</u>

Replace original MOE values with the average values computed across remaining seven observation (columns) for same link (row 7)

<u>Observation 3, Link 4</u>
<u>Bad Data Element</u>

Replace original MOE values with average values computed across remaining seven observations (columns) for same link (row 4)

Figure 15. Operation of program PLUGNET.

values computed from the seven non-rejected observations for the two links in question. All other data elements in the array are unaffected by the substitution.

After making the appropriate substitutions for rejected data elements, PLUGNET produces an updated data set in identical format to that generated by OLOUT.

Program PLUGNET also computes three data items for the network as a whole: (1) "total volume"; (2) "total queue"; and (3) "total vehicle minutes of delay." The latter value is computed using data on "average delay" and "volume." "Total volume" is computed using data from all operative detectors; the other two measures are computed from operative multiple detectors only. The resultant network-wide measures, particularly total volume, are important inputs to the sample selection procedure discussed below. They are also used as a further manual check on the overall data.

Program SCTRGM

Program SCTRGM produces a simple printer-plot of volume against average delay. This is used mainly as a further check on the data. Program SCTRGM is followed by a second utility sort routine which sorts the 15-minute observations by total network volume within each set of 15-minute periods.

Program BRKFIL

The next program, BRKFIL, disaggregates the file generated by the sort routine into separate data sets defined by MOE.

Program ENDPRNT

The final program in the sequence, ENDPRNT, prepares a printed report of selected summary information from the file generated by BRKFIL including the link-use vector and the header records, sorted by network volume within each overall 15-minute time period.

ASSEMBLY AND PROCESSING OF MOVING CAR DATA

The second major data set used in the analysis was developed from a series of travel time runs through the network. The routes involved and the procedures used to collect and code the data have already been described previously. A series of computer programs was prepared to reduce and check the raw data. The programs compute a series of "moving car" measures of effectiveness similar, but not identical to, those used in the UTCS detector analysis. Standard data sets are then constructed which are used as input to statistical evaluations.

Calculation of Measures of Effectiveness

Each of the moving car routes was divided into a series of links, bounded by signalized intersections. During each run, note was made of the times when the vehicle entered each link, stopped in traffic (due either to traffic delay or a change in signal indicators), and started moving after a stop. All times were recorded cumulatively from the start of each run. Where multiple stops and starts occurred, all were recorded. Separate measurements were also made to determine the length of each individual link in the field.

The data from the original travel time records were then coded for machine processing. For each link, link identifier was first noted, followed by the clock times associated with each of the events noted above. If the vehicle moved directly through the link without stopping, only a single time was recorded, that of link entry. If the vehicle stopped one or more times, two additional times were recorded for each stop. Finally, the entry time to the next link downstream was recorded and any coding or unusual traffic conditions flagged.

These data are used to construct four simple MOE's for each link and, subsequently, for the entire travel-time route:

- Total travel time (seconds),
- Stopped time delay (seconds),
- Number of stops, and
- Average speed (mph).

Travel time is computed simply as the difference in entry times for successive links. Average speed is then calculated from the estimated link travel time and the appropriate link length. Number of stops is estimated by counting the number of time observations recorded for each link and subtracting two from the total. Stopped time delay is calculated as the sum of the differences of the observed "stop"-"start" times for the link.

As in the case of the UTCS detector data, groups of successive links along the line of a travel time run are clustered together into subnetworks to provide an additional base for analysis. These subnetworks are illustrated in Figure 16. The overall routes have been shown previously on Figure 9. Each of the MOE's is then aggregated across each subnetwork, speed being recomputed from the total travel time and the sum of all link lengths for the subnetwork.

Processing the Data

A second set of computer programs was developed to process the travel time data.

Program MC2

The first computer program, MC2, was developed to perform the MOE calculations noted above. The program also performs extensive error checks on the raw data. Because of the volume of data involved and the relative complexity of the manual operation, these checks are extremely important.

Most of the errors discovered by the checks were caused by simple coding or key-punching mistakes and were readily rectified. A lesser number resulted from problems in interpreting the raw data and were resolved by making appropriate estimated based on the observed trajectory of the vehicle through the link. In instances where this could not be done, the observation was flagged as "unusable."

Program MC2 produces a standard output data set, containing a header record for each observation and the MOE values for each link.

Program MCPLUG2

A second routine MCPLUG2 was written to substitute appropriate average values for each of the unusable data items identified by MC2. Averages across all observations for each link are computed and substituted for the elements flagged by MC2. The program operates in the same general fashion as program CONFIL described earlier. It produces an output data set identical in format to that generated by MC2.

Program MCSTRIP

A third program, MCSTRIP, takes the output of MCPLUG2 and separates the various MOE's into individual data sets for use in statistical comparisons. A header record is also produced, containing the route, date, start time, and duration of each run. These records are used in the sample

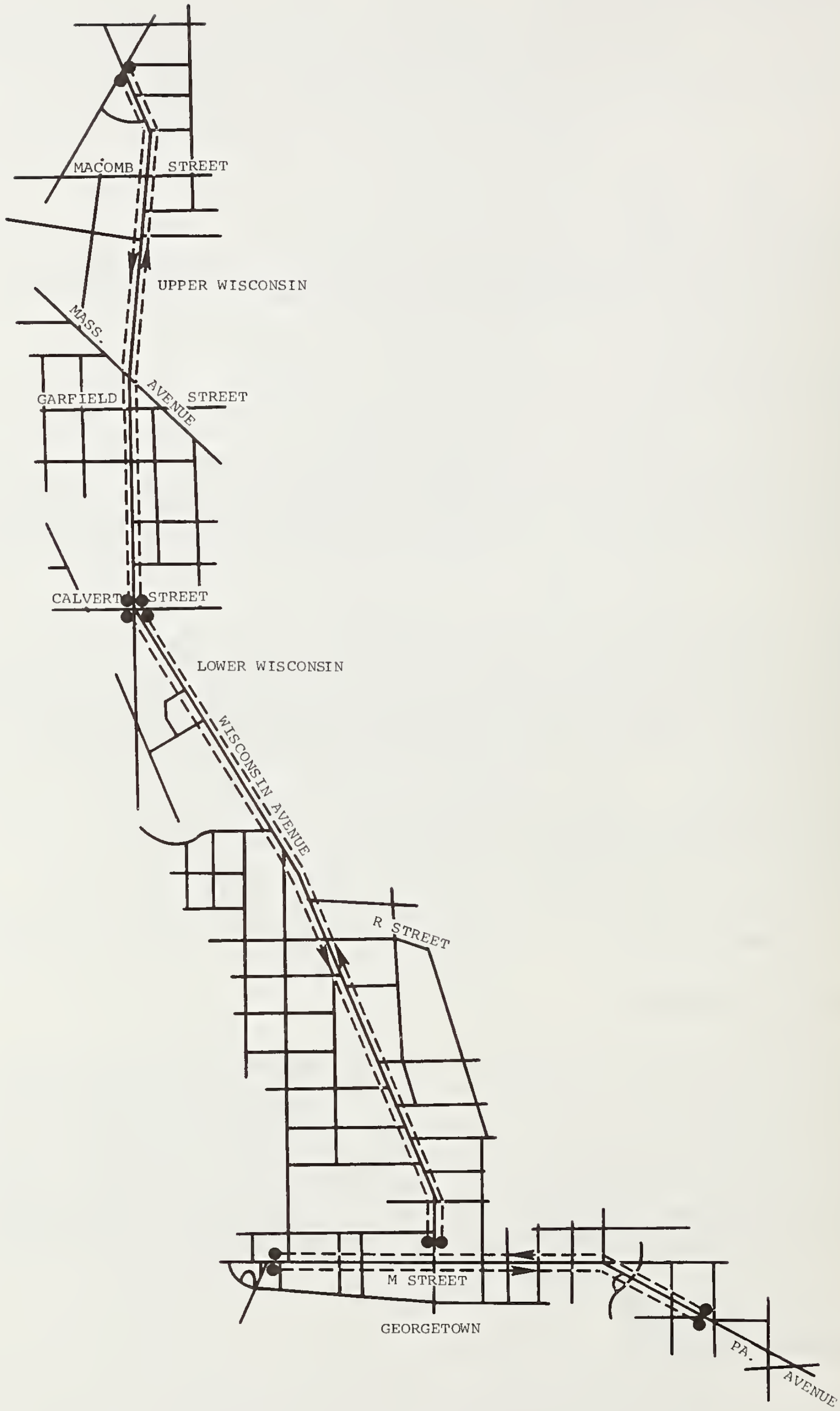


Figure 16. Subnetworks of moving car routes.

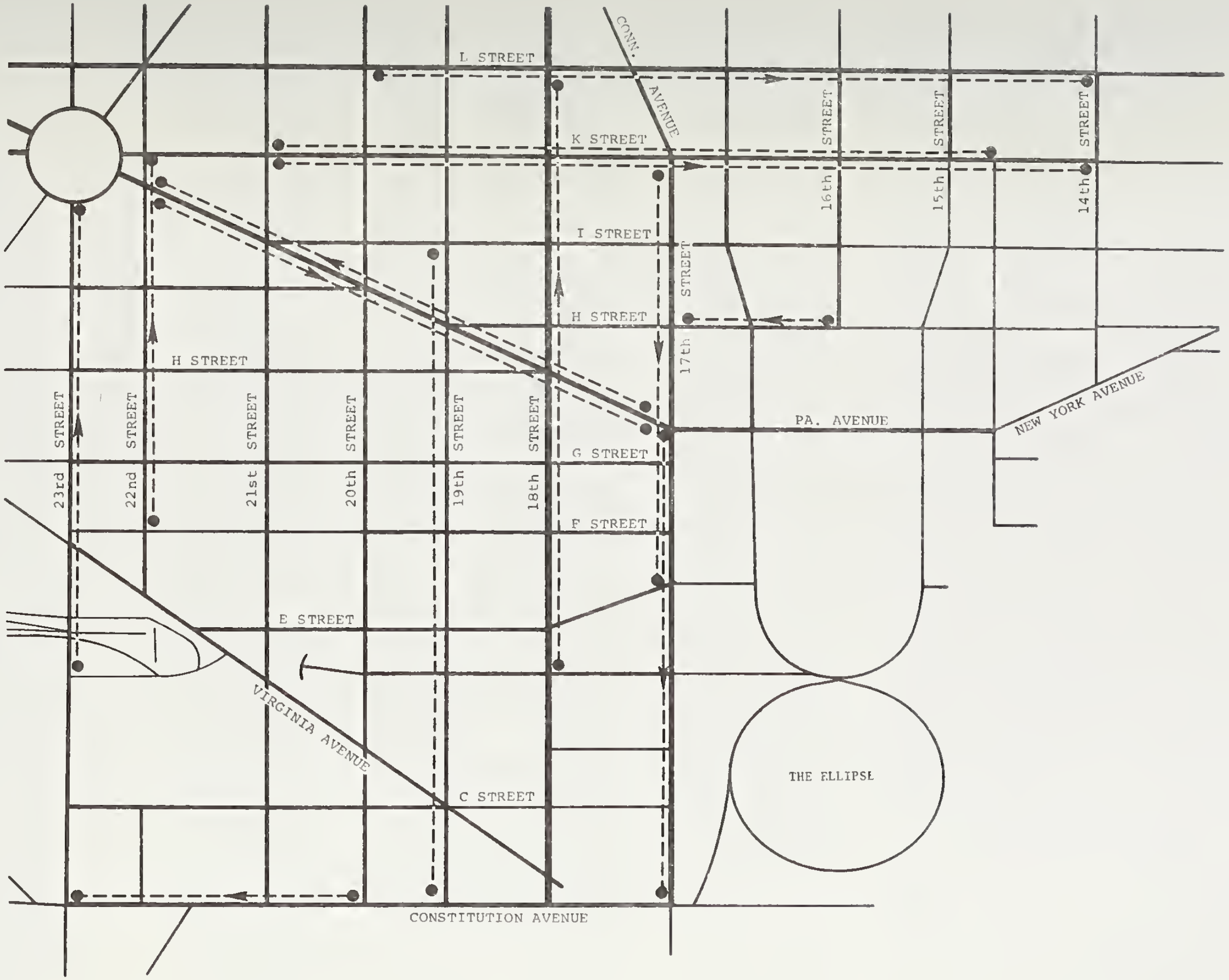


Figure 16. Subnetworks of moving car routes (continued).

selection process described subsequently.

Program MCOND

The link level MOE's are used as input to a fourth program, MCOND, which computes aggregate MOE estimates by subnetwork. They currently consist of all consecutive links along individual streets, excluding the first link following a turn. As noted earlier, estimates of "Total Travel Time", "Total Stopped Time Delay", and "Total Number of Stops" for each subnetwork are computed by simply summing the original link values. "Average Speed" for the subnetwork is recomputed from the appropriate "Total Travel Time" and the cumulative sum of link lengths. An output data set similar to that produced by MCSTRIP is prepared, with one record identified for each subnetwork and for the route as a whole.

STATISTICAL ANALYSIS

The data sets developed from the UTCS detector information and the moving car runs were used as input to a series of statistical analyses.

The analyses were designed to compare each control strategy alternative with its equivalent "base-case" and to identify any statistically significant differences in traffic performance. The comparisons were made on a link-specific, subnetwork, or network-wide basis for each of the three different times of day identified earlier. In addition, comparisons were also made of the results obtained from the detector data and those obtained from the travel time runs.

All of the statistical calculations were performed using a modified version of the UTCS-1 Network Simulation Model "Post-Processor", developed previously for the Federal Highway Administration.[1]

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1. Peat, Marwick, Mitchell & Co. and KLD Associates, Inc., "Network Plan Simulation for Urban Traffic Control System", (Phase II: Technical Report), Report No. FHWA-RD-73-83, U. S. Department of Transportation, Federal Highway Administration, Office of Research and Development, Washington, D. C., 1973.

Structure of Statistical Comparisons

The basic structure of the statistical comparisons of alternative strategies is illustrated through references to Figure 17. Two separate data arrays are developed, one for the experimental strategy, the other for the equivalent "base-case". Each matrix consists of a sequence of observations made across all links in the network for a particular time-of-day. Separates matrices are developed for each MOE.

In the case of the detector data, the observations take the form of standard, 15-minute MOE summaries, defined in terms of successive 15-minute time periods for a particular time-of-day. Multiple observations for one 15-minute time period are obtained by collecting data on several successive days. The resultant information is then pooled to create a sample of observations for each link.

For the moving-car data, the observations are based simply on successive moving-car runs through the network, with several runs being made on successive days for each time-of-day interval. Each run corresponds to a single observation. The data are again pooled to create a single sample of observations for each link.

Comparisons between the two data sets are then made by comparing the equivalent distributions of data developed for each link and subsequently for specific subnetworks and for the network as a whole.

As noted earlier, data were developed for four different experimental alternatives and three equivalent base-case alternatives. The four experimental alternatives are: 3 Dial, TOD, BPS, and CIC. All of the base-case data were based on a common set of traffic responsive control (TRSP) signal settings. Three sets of base-data were developed to allow for seasonal changes in traffic demand resulting from the relatively long calendar period over which the experimental data were collected.

Sample Selection Process

The data sets developed for input to the statistical analysis programs are based on a relatively complex sample selection process. This process is designed to control for two potentially confounding sources of variation which may otherwise significantly impact the analysis. These are: (1) changes in the overall volume of traffic traversing the network within a given time-of-day interval, and

	Observation No.							
Link	1	2	3	4	5	6	7	----------
Link 1								
Link 2								
Link 3								
⋮								

a). <u>Experimental Strategy</u>

	Observation No.							
Link	1	2	3	4	5	6	7	----------
Link 1								
Link 2								
Link 3								
⋮								

b). <u>Base Case</u>

Figure 17. Structure of statistical comparisons.

(2) changes in the pattern of traffic movements within the network over the same interval. These effects, if uncontrolled, may dominate the effects of changes in signal control settings on the selected measures of network performance. That is, they may mask differences observed between the experimental alternative and the equivalent base-case. The structure of the data precludes handling these effects ex-post facto, by means of covariance or similar statistical analysis. It is, therefore, necessary to control for the effects in sample selection. The following is offered in discussion of the situation.

The UTCS network is relatively large and non-homogenous. The level and pattern of traffic traversing the network changes appreciably over even relatively short time periods (e.g., the two and one-half hours of the a.m. period). This is due in part to variations in working hours, and hence traffic volumes in different parts of the network over the study period, and in part to pre-programmed changes in traffic control measures.

The problem is particularly acute in the a.m. and p.m. periods. Traffic volumes in both cases tend to peak at different times in different parts of the network. Lane utilization changes markedly, turning controls vary, and there is significant variation in the level and enforcement of parking regulations. Many of these controls are not uniformly in effect throughout the analysis periods.

The fact that the field experiments were, by necessity, performed over several months leads to an additional set of concerns about systematic changes in overall traffic volumes and network travel patterns. The former issue is particularly important in light of driver response to the energy problems, which developed in the course of the study, and which affected the level of both regular commuter traffic and also more general business and recreational traffic. Significant variations in the total volume of traffic using the network occurred over the period during which the data were collected.

The successful evalation of the various control alternatives clearly requires that these volume and pattern differences be considered. Adequately sized total samples of data were deliberately collected so that selective sample control could be invoked to allow for these conditions.

One approach which was considered was the stratification of the various data samples into a set of homogeneous subgroups for analytical purposes. This approach was rejected, since it would have led to such a large number of comparisons that synthesis into meaningful evaluative statements would have been extremely difficult, if not impossible.

An alternative approach was therefore adopted, in which a single, large sample was developed as the basis for each set of control alternative and time-of-day comparisons. This sample was then subjected to a structural edit to insure that all statistical comparisons involved compatible traffic conditions. The eidt (or sample selection procedure) was designed to control for two major sources of variation; changes in traffic patterns, and changes in traffic demand.

Major variations in both pattern and demand were first eliminated by the exclusion of Monday mornings and Friday afternoons from all data collection. Similarly, the process of data collection was designed to produce roughly equal amounts of data for the same days of the week in each sample.

The basic control used to adjust for remaining pattern differences is clock time. The peaking characteristics of individual links were established and found to be extremely regular from one day to the next. Similarly, it was found that changes in traffic controls usually occurred at the same specific times each day. Assuming that the pattern of traffic movements does not change markedly over a 15-minute interval, a sample of UTCS detector data, controlled for pattern differences, may therefore be obtained by selecting equal numbers of 15-minute observations from the two data sets to be compared for each 15-minute time period within a time-of-day interval.

Systematic changes in demand are somewhat more difficult to control. A reasonable surrogate, however, would appear to be total network volume, summed over all links for each 15-minute observation period. A simple test of overall volume compatibility was therefore developed. This test is invoked after the control for traffic pattern variation outlined above.

Operationally, the approach used is to sort the available data file for each control strategy first by 15-minute time period and then by aggregate network volume. Thus, the basic output file contains all records for a given 15-minute period, followed by those for the next period, etc.

Within each 15-minute period, the records are further ranked by network volume. A simple volume matching technique is then used to eliminate gross biases caused by systematic differences in overall volume levels. This is done by insuring that the data points selected for final analysis span roughly-equivalent volume ranges.

The procedure is based on an examination of the differences between the upper and lower extremities of the distributions of value levels developed for the two control alternatives under analysis. If the difference exceeds a pre-specified maximum value, the extreme value is rejected. The revised extremes are then tested, successively, until the distributions meet the criteria for comparability. The criterion used to eliminate data points may be summarized as:

$$k = (\max(H_1, H_2) - \min(L_1, L_2))/(\max(n_1, n_2) - 1)$$

where H_1 and H_2 are the highest observed values for distribution 1 and 2 respectively, L_1 and L_2 are their lowest values, and n_1 and n_2 are the respective sample sizes. Nominally the values of n_1 and n_2 are equal and in practice seldom differ by more than one.

This criterion was selected over several potentially more stringent standards. It is designed to avoid the extreme case in which alternating points are eliminated from the two distributions in turn, leaving only a very small final sample size. This obviously is a condition to be avoided when each sample has a nominal initial size of only 8. The criterion is also relatively robust over a wide range of volume conditions.

Once compatible distributions have been identified in terms of their relative volume ranges, the resulting sample sizes are compared. If they are equal, the sample is accepted and the process advances to the succeeding 15-minute period. If they are unequal, the point closest to the mean is eliminated from the larger distribution until the two samples are the same size. In actual practice, it is seldom necessary to eliminate more than one point in this manner. The process, it should be noted, preserves the range compatibility developed earlier while also reducing the variance of the distribution in question by a minimal amount.

In summary, the sample selection process outlined above is designed to insure that statistical comparisons are made between alternatives containing measures computed under compatible conditions. Adjustments are made for pattern changes by insuring that equal samples are drawn from each 15-minute period. Systematic changes in demand are addressed by matching distributions of network volume ranges within each 15-minute period.

The result is a pair of compatible data matrices, containing equal numbers of observations developed under comparable traffic conditions. Figure 18 illustrates the process in terms of a simple, numerical example. Figure 19 summarizes the final joint sample sizes employed for each experimental/base-case comparison as compared to the original number of observations available from the raw data. The reasons for eliminating points from the data sets are also summarized.

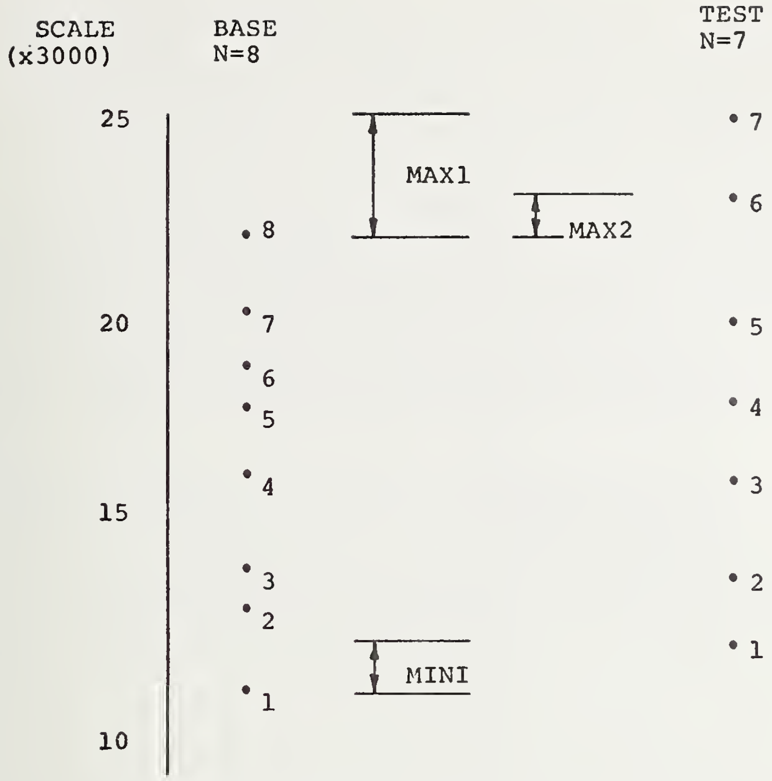
Note that in no instance did the final joint sample size fall below 37 points and that in all but three instances it exceeded 50. Of the points eliminated, slightly less than half were removed as a result of demand matching rather than pattern matching. On the average, the match process resulted in an effective decrease in the maximum possible sample size of roughly 20 to 25 percent.

While it is in no sense argued that this approach is the only one to be followed, it is felt that it permits the analyst to identify systematic changes in network traffic performance which are attributable primarily to changes in the traffic control system, as opposed to fluctuations in traffic demand. The sample sizes involved are sufficiently large to permit the selective exclusion of data points, without endangering the viability of the statistical comparison. The selection procedures are structured so as to reinforce rather than reduce the rigor of the tests employed.

Statistical Tests

Once compatible data matrices have been developed, they are subjected to each of three major statistical tests. Three tests were employed rather than one to permit different types of comparisons to be drawn, and also to allow for varying assumptions concerning the nature of data. The three tests employed are:

- Two-Sample Student's "t" test;
- Mann-Whitney "U" test, and
- Kolmogorov-Smirnov two-sample test.



CRITERION = (25-11)/7 = 14/7 = 2

MAXI = 25-22 = 3 CRIT; ELIMINATE TEST POINT #7

MINI = 12-11 = 1 CRIT; OR

MAX2 = 24-23 = 1 CRIT; OR

∴ 2 EXTRA POINTS/N BASE

AVERAGE BASE EQUALS 16.6

DEVIATION POINT #4 = 0.6
#5 = 1.4
#3 = 2.6

∴ ELIMINATE BASE POINTS #4 AND #5

Figure 18. Illustration of matching logic.

TEST	TIME	(TRSP) BASE OBS.	TEST OBS.	SAMPLE USED	OBSERVATIONS ELIMINATED			
					BASE		TEST	
					OUTLIER	EQUALITY	OUTLIER	EQUALITY
3-Dial	A.M.	74	80	53	12	9	17	10
	MD	64	59	46	11	7	8	5
	P.M.	80	76	63	8	9	8	5
TOD	A.M.	74	75	53	10	11	8	14
	MD	64	62	53	8	3	3	6
	P.M.	80	70	59	11	10	8	3
CIC	A.M.	82	94*	69	11	2	17	8
	MD	61	62	51	4	6	5	6
	P.M.	77	69	54	12	11	11	4
BPS	A.M.	79	50**	37	25	17	11	2
	MD	59	50	46	3	10	3	1
	P.M.	73	70	57	4	12	12	1
TOTAL		867	817		119	107	111	65
%					13.7	12.3	13.6	8.0

* 9 Days of Data

** Serious Machine Malfunctions

Figure 19. Results of detector sample matching.

The two-sample Student's "t" test is used to compare the mean values of the two data sets. It requires a stringent set of assumptions concerning the nature of the data and the independence of the two samples. Provided these assumptions are met, it is an extremely powerful discriminator.

The Mann-Whitney "U" test is a non-parametric alternative to the "t" test. It is used here to test whether the "experimental" and "base-case" data sets could have been drawn from a common statistical population. The "U" test requires significantly less stringent assumptions than the "t" test, and, particularly for large samples, is virtually as powerful a tool as its parametric alternative.

The Kolmogorov-Smirnov two-sample test is used to test for overall differences in the distributions of the two data sets under analysis. It is also non-parametric in nature and requires less rigorous assumptions concerning its input data than the "t" test. It is a somewhat more powerful test statistically than the "U" test when only very small samples are involved.

All three tests are employed in both the "one-" and the "two-tail" mode at different points in the analysis.[1] Significant differences, where they occur, are identified at the 5%, 2% and 1% level.[2] No attempt will be made here to describe the structure of the individual tests in detail. Excellent discussions are given in several statistical texts. For example:

- U. S. Department of Commerce, National Bureau of Standards, "Experimental Statistics", Handbook #91, U. S. Government Printing Office, Washington, D. C., 1963.

- Siegel, S., Non-Parametric Statistics, McGraw-Hill, New York, 1956.

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1. The "one-tail" mode is used to identify situations in which the experimental data are significantly larger (or significantly smaller) than the equivalent base-case data. The "two-tailed" test is used to simply identify the presence of a difference between the two, independent of direction.

2. Where a 1% level of significance implies, for example, that an observed difference between the two data sets could have arisen by chance only one time out of a hundred were both samples drawn from the same population.

A number of additional, general points should, however, be noted. It was originally intended to base the analysis on a succession of paired-comparisons of individual data elements (e.g., one 15-minute observation on a Tuesday, for Link #1 under the base-case, versus an equivalent, single observation from the experimental data set). This idea was dropped because of the difficulty involved in developing meaningful matched pairs for comparison. The three tests finally used were selected as those most meaningful for successive, two-sample comparisons where the structure of the data sets being compared varied from one comparison to the next.

It should be emphasized in this context that the analysis was explicitly designed as a succession of two-sample comparisons. It was not designed to be a pooled analysis of all data sets performed simultaneously.[1]

This latter approach would be theoretically desirable as a complement to the two-sample comparisons described here, provided that a single common data base for comparison could be developed. The variation both in volume and traffic patterns across the network for the various experimental alternatives, however, precludes such an analysis unless these confounding effects are ignored. That is, it is not possible from the data available to develop sufficiently large compatible data samples, matched over a full range of volume levels, traffic patterns, and common links, for all four experimental alternatives, to permit a meaningful pooled analysis to be performed.

The effect of restricting the analysis to two-sample tests only is to slightly overstate the significance of observed "experimental/base-case" differences compared to the equivalent results which would be obtained from a rigorous pooled analysis. For example, a difference between two sample means which is found to be significant at the 5% level on the basis of the two-sample tests outlined here is equivalent to approximately a 10% significance level for a pooled, three-sample analysis and a 14% level for a pooled, four-sample test. Similarly, a 2 and 1/2% significance level for a two-sample test is equivalent to a 2% level for

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1. The term "pooled" is used here to denote an analysis to determine whether all "experimental" and "base-case" data sets could have been drawn from the same statistical population, considering all information simultaneously. This differs markedly in concept from the sequence of successive, two-sample comparisons called for in the discussions above.

a three-sample comparison and a 3% level for a four-sample comparison.[1]

The set of tests outlined above would have to be modified and/or replaced with other forms of analysis in order to make any such "pooled" comparisons more formally. This could be done by replacing the Two-Sample Student's "t" test with a multiple sample "t" test utilizing the studentized range "q" rather than the standard student's "t" distribution. The two non-parametric tests employed here cannot be extended directly to the multiple sample case. They would have to be replaced with either an Extended Median Test or a Kruskal-Wallis One-Way Analysis of Variance by Ranks.

It should be emphasized that this discussion in no sense invalidates the use of successive, two-sample comparisons. It simply underlines the importance of interpreting their results correctly. A further examination of the tests and procedures is being developed for the next series of evaluations (second and third generation testing).

DATA PROCESSING SOFTWARE

Two sets of computer programs were developed to perform the sample selection and subsequent statistical analyses. The first of these (see Figure 20) was designed around the UTCS detector data; the second around the moving car information. The function of each of the major programs in each set is outlined below. More detailed documentation is again given in Volume 1. Technical Appendices.

Program Chain for UTCS Detector Data

Program NETCON

The first program in the chain is NETCON which matches the two "link usability" vectors for the two data sets to be analyzed and creates a single, common vector representing the lowest common status of the two original data sets.

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1. For a more detailed exposition of this point, reference may be made to the National Bureau of Standards Handbook #91, "Experimental Statistics" cited earlier (pp. 3.40-3.42) and to C. W. Durnett, "A Multiple Comparison Procedure for Comparing Several Treatment with a Control", Journal, American Statistical Association, December, 1955.

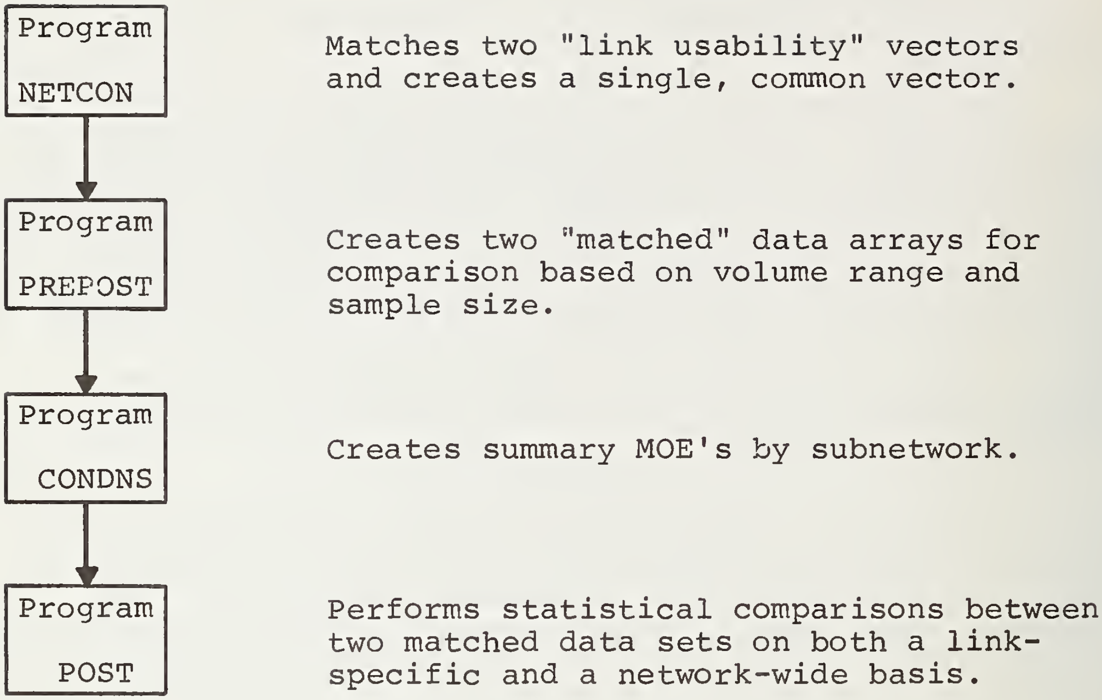

Figure 20. UTCS/BPS evaluation software program chain for two sets of UTCS detector data.

Estimated network volumes are then recomputed for each data set based solely on the set of matched links. An exogenously-specified link usability may be used if desired, primarily to exclude certain links which would otherwise be included in the analysis. Two output header records, one for each alternative, are produced which are then resorted by revised network volume within each 15-minute time-of-day period.

Program PREPOST

The sorted header records are next read by program PREPOST, a volume matching routine. The program examines each 15-minute time-of-day period successively and compares the range of the two volume distributions against a pre-set criterion value. This criterion "c" corresponds to the range matching criterion discussed previously. It is represented in the program as:

$$c = \frac{\max(\mathrm{MAXVOL1},\ \mathrm{MAXVOL2}) - \min(\mathrm{MINVOL1},\ \mathrm{MINVOL2})}{\min(\mathrm{NOBS1},\ \mathrm{NOBS2})}$$

This indicates that the criterion "c" is the difference between the larger of two maximum volumes and the smaller of the two minimum values divided by the smaller of the two numbers of observations. The resulting value is essentially an expected volume interval. If the differences between the two maximum values exceeds the criterion, the larger of the two points is eliminated. A similar test is applied to the minimum values. The tests are continued between the resulting extreme values until the criterion is no longer exceeded.

After removing the appropriate extreme values, the two samples are next reduced to equal size by eliminating observation(s) from the larger sample. In order to maintain similar ranges, values closest to the mean of the larger sample are eliminated. This procedure again corresponds to that described earlier.[1]

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1. Nominally, each 15-minute period should contain eight observations for each alternative. In practice, one or more missing observations frequently occurred, so that a sample size balancing operation was necessary even without eliminating any points because of extreme differences in volume. Sufficient points (nominally 88, 64, and 80 for a.m., midday, and p.m., respectively) were included in the data collection design, so that a well-structured sample could be developed and retain a large size for statistical purposes.

PREPOST produces only a revised observation usage vector which is subsequently used by the post processor to select data points for statistical analysis. A printed summary of the matching process is prepared as well.

Program CONDNS

An additional program, CONDNS, is next run to accumulate all MOE's by subnetwork. The definition of the subnetworks may be specified by the user. The same links may, if necessary, appear in more than one summary subnetwork, while certain links may be eliminated entirely.

For the purposes of the present study, summaries were prepared for the following subnetworks:

- UTCS network sections #1, #2, #3, and #4 separately; sections #1 and #2, and #3 and #4 together;

- All major streets in UTCS sections #3 and #4; I Street, K Street, Pennsylvania Avenue, Constitution Avenue, 17th Street, 18th Street, and 19th Street;

- The entire network.

Four "aggregate MOE's" are computed for each subnetwork, based upon the common link use vectors specified for the comparison in question. As defined earlier, the MOE's are; total average queue, total number of stops, total vehicle minutes of travel, and total vehicle minutes of delay.

The first two of these aggregate MOE's are computed simply by summing individual link values. The latter two measures are computed by multiplying the average travel time and average delay for each link, respectively, by the total volume for the link and then summing the resultant products across all links in the subnetwork. Meaningful network-type statistics cannot be developed from the original, link-specific speed or occupancy data.

Program POST

The link and observation use vectors derived from programs PREPOST and NETCON are used as control for two separate runs of the statistical evaluation program, POST. As noted earlier, this program is based on a modification of the Post Processor module developed as part of the UTCS-1 Network Simulation Model.

For the link level analyses, the original data sets from program BRKFIL are used as input to POST, modified as appropriate by the revised link and observation vectors generated by program NETCON. Aggregate subnetwork MOE's from CONDNS are used as input to a second POST run, subject to the same link/observation selection controls. Although the same subnetworks are always used, the composition of the links used in computing the MOE's may differ among various runs, depending upon the link use vector control over CONDNS.

Program POST next performs the set of three standard statistical tests described earlier and prepares a standard output report for each MOE. An example of this report is shown in Figure 21. It includes a statement of the two alternatives being compared; the MOE involved; the mode of analysis (e.g., link, subnetwork, etc.); and the sample size used. For each link (or subnetwork), the following data are then summarized:

1. link name;

2. estimated mean values and variances for the MOE for the base case (Condition "A") and the experimental case (Condition "B");

3. difference between the two mean values, computed as a percentage of the base case;

4. the values and significance of the test statistics for each test.

This latter information is displayed as a series of asterisks, with one asterisk representing a difference significant at the 5% level, two asterisks representing a 2% significance level, and three asterisks a 1% level. The Kolmogorov-Smirnov test also includes an indication of which of the two distributions being compared is the "larger."

Program Chain for Moving Car Data

The moving car analysis proceeds in a similar fashion as discussed below.

Program MCVOL2

The header records from MCSTRIP are read by a volume assignment program, MCVOL2, together with the header records from the equivalent detector runs, after the matching operation performed in PREPOST has been completed. MCVOL2

CONDITION A : AGGREGATE A3MD30
CONDITION B : AGGREGATE A2MD30
COMPARISONS MADE BY LINK AGGREGATE

STATISTICAL SAMPLE SIZE USED: 23

BASIS OF COMPARISONS: TRAVEL TIME BY AGGREG.

LNKNT /	CONDITION A		CONDITION B		DIFFERENCE	T TEST	U TEST	KOLMOGOROV-SMIRNOV			
OBSERV.	MEAN	STDV	MEAN	STDV	OF MEANS	T	U/Z	T+	T-	T2	SIG.
22ND	135.3	33.7	119.4	33.7	12.4	1.593	-1.384	1	6	6	
K ST	307.6	104.7	356.8	123.1	-14.8	1.460	-1.648	7	0	7	
H ST	74.2	35.7	55.5	12.7	28.9	2.370*	-1.725	4	9	9>	*
17-1	189.9	89.4	137.1	32.2	32.3	2.664**	-2.581***	1	9	9>	*
18TH	283.8	60.2	274.9	65.3	3.2	0.480	-0.923	1	6	6	
17-2	215.7	79.2	182.5	51.7	16.7	1.684	-1.505	0	6	6	
E ST	106.7	55.7	64.9	42.6	48.7	2.855***	2.735***	1	12	12>	***
TOTL	1312.2	216.1	1191.1	204.9	9.7	1.965	2.472**	0	11	11>	***

NOTE: * = Significant difference at the 5% level
** = Significant difference at the 2% level
*** = Significant difference at the 1% level

Figure 21. Statistical comparison of a measure of effectiveness for conditions "A" and "B".

computes a matrix of network volumes for each date and 15-minute period, estimating any missing values and extrapolating volumes into the preceding and following 15-minute periods, i.e., 3:45 and 6:45 for the p.m. comparisons.

The starting time for each moving car run is matched against this matrix. The network volume for the period closest to the starting time is recorded. If the duration of the moving car run exceeds 15 minutes, volumes for successive time periods are extracted and averaged. If no matching time period is found, an error message is generated and the observation is flagged unusable. The program then writes an updated header with the averaged network volume for the period during which the run was made. Separate runs of MCVOL2 are made for each of the two data sets being compared.

Program MCMTCH2

The header records from MCVOL2 are then sorted by volume and the two data sets are read by a volume matching routine, MCMTCH2, adapted from the equivalent detector program, PREPOST. Similar logic is employed to eliminate outlying points from the two distributions and then sample sizes are balanced. Again, this match is made with the entire set of observations, nominally 25 to 30 or more without regard to time period. An observation usage vector is produced, equivalent to that generated for the detector analyses.

Program MCCNTL2

The various observation and link use vectors and other control cards required for the statistical analysis program, POST, are generated by a special purpose routine, MCCNTL2. Control for both the link level and subnetwork POST runs are prepared. MCCNTL2 has the capability to accept exogenously specified link and observation usage parameters, particularly to eliminate links in the case of special events or traffic control problems. The control cards from MCCNTL2 and data from MCSTRIP and MCOND are used as input to the two post processor statistical analysis runs. As noted previously, all moving car analyses were performed separately for each route, primarily because of differences in sample sizes.

NETWORK-WIDE ANALYSES

Simple comparisons of traffic performance for individual links and subnetworks do not necessarily present a complete picture of overall, network-wide performance. In particular, the relative importance of specific links (e.g., along the line of a major arterial route) may be obscured when average values alone are examined. Therefore, some mechanism for "weighting" the link results by the "importance" of the link was desirable. Several approaches to this problem were examined. The final approach chosen focused on a simple comparison of network-wide vehicle minutes/vehicle miles of travel.

Analysis of vehicle minutes and vehicle miles of travel permits a number of comparisons that cannot be readily accomplished using other measures of effectiveness. Two chief benefits are the establishment of a measure incorporating volume as a weighting factor, and the capability of summing results across a sequence of links.

For the current study, limited data of this type could be developed from the field data collection, using data collected from road tubes for volume and average travel times on selected routes. However, as noted in the next chapter, the coverage across time was found to be extremely sketchy, as all of the road tubes were seldom fully operational. More importantly, almost none of the locations consistently produced data for all different alternatives so that comparative analyses would have been impossible.

Therefore, it was decided to use the UTCS detector outputs as the base data for the analysis. Since the performance measures are computed only for the detectorized portion of the link, the total "trap" length is used for computing vehicle miles. Vehicle minutes of travel and vehicle minutes of delay are both computed from other detector MOE's.

A special purpose computer program, VEHMIN, was written to perform the necessary computations. Measurements of individual link performance are made by computing both vehicle minutes of travel and vehicle minutes of delay measures for two alternatives to be tested and displaying the positive and negative differences in average values across 15-minute sampling periods. Vehicle minutes are also accumulated for each of the four sections of the UTCS network and for the network as a whole.

The relationship between vehicle minutes and vehicle miles can be conveniently shown graphically. A regression line fitted to this display then yields a quasi-spread-related performance measure for the network as a whole. Such vehicle minutes/vehicle miles plotting and regression analysis has been successfully used by FHWA in the evaluation of alternative signal settings in San Jose. However, serious congestion did not occur in the San Jose network and reasonably stable relationships could be generated.

The UTCS network is extremely congested over much of the day and for many of the links. As congestion increases, vehicle minutes begin to accumulate much more quickly than vehicle miles. Eventually, breakdown occurs so that further increases in vehicle minutes actually result in lower vehicle miles. A "backward-bending" curve of the sort shown in Figure 22 then results. This curve is generally well defined at lower traffic levels and much less well defined at higher levels of vehicle miles of travel. In particular, the distribution of points about the "nose" of the curve is typically extremely broad and erratic.

The data collected in the present study, unfortunately, fell almost exclusively in the "nose" of the curve. Graphical plots for each control strategy were prepared for each subnetwork and for the network as a whole. In nearly every case, most of the points fell in the "nose" area, with a short "tail" in the rising portion of the curve, made up of points observed before congestion developed. In a few instances, many points appeared to have been collected past the "nose" and the curve showed the backward-bending character noted above.

Plots were prepared for each alternative being compared. In some cases, distinction between the plot of one alternative versus the other was discernible, but frequently the points simply yielded an undifferentiated cluster. Obviously, regression coefficients for such data were virtually meaningless and their use in inputing a pseudo-speed is invalid. Some other mechanism for overall evaluation was required.

After lengthy consideration of alternatives, a simple subnetwork speed was determined to be the most appropriate, simple measure. These values are computed by summing vehicle miles and vehicle minutes for all links in the subnetwork, then dividing the former by the latter and converting to miles per hour. A simple numeric average speed for all observations is then computed as a single evaluation measure. These computations are performed for all comparisons and are included in the results of primary comparisons in the next chapter.

SUPPORTING ANALYSES

A number of supporting analyses were undertaken for specific purposes during the conduct of the study. Some of these were directed at measuring the performance of the

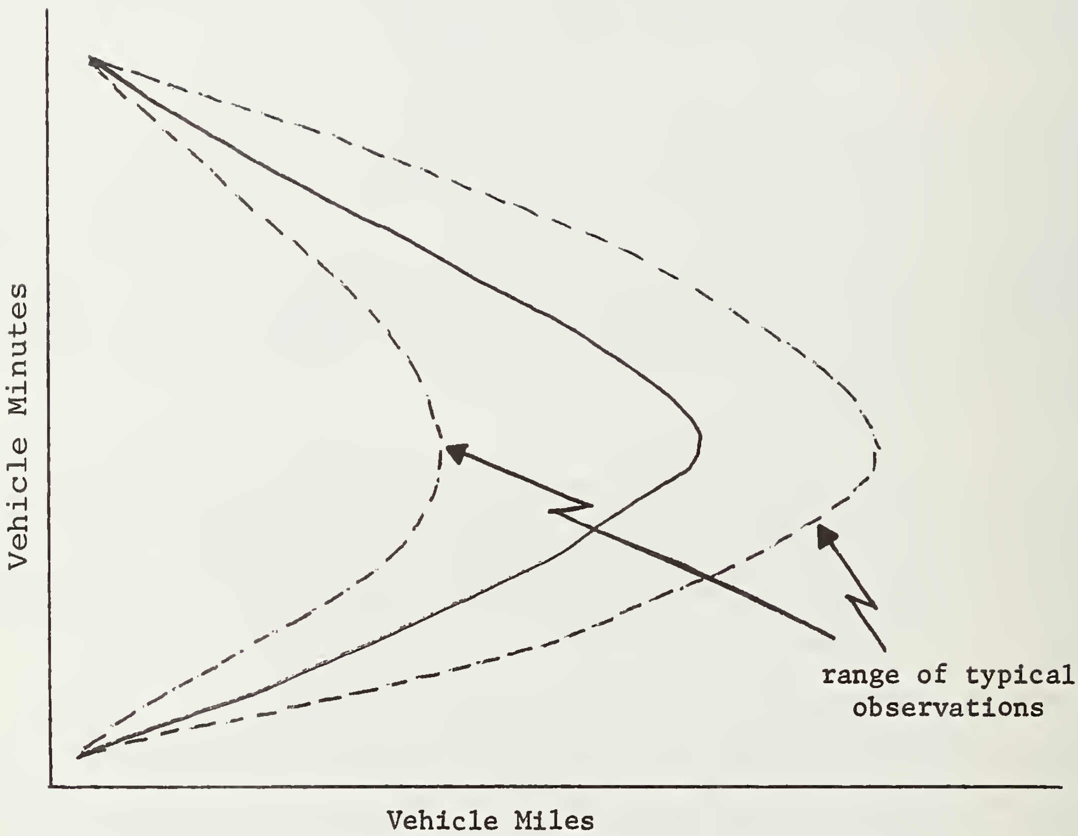

Figure 22. Relation between network-wide vehicle minutes and vehicle miles of travel.

UTCS detectors against field observations. Others were performed upon specific data elements collected for only certain comparisons or at a limited number of locations. Each of the major supporting analyses is noted briefly in the following paragraphs. They are discussed much more completely, with selected results and conclusions, in the next chapter.

A special study was initiated early in the project to compare the traffic volumes noted from the UTCS detectors with direct field observations. Observers were stationed at several representative locations and recorded volume counts by lane by cycle. Other observers recorded cycle-by-cycle volumes from the cathode ray tube monitors at the UTCS control center. These latter volumes, which are "smoothed" by the system, were subsequently converted to actual counts and compared with the field data. Comparisons between detectorized lanes and for the total approach were made.

During the conduct of the first several evaluations, road tubes were installed on 25 representative approaches. Continuous counts were maintained at many of the locations and 50% sampling at the remainder. These data were reduced for the time periods used in the other analyses and compared with lane volumes measured by the system detectors.

Films of traffic performance at several key locations were made from 16 mm cameras mounted on roof tops. Difficulties were encountered in obtaining adequate field of view and with the mechanical aspects of the cameras. Some data were collected on link content, analogous to the queue measurement recorded by the detector system, and the suitable comparisons were made.

An alternative to film data collection was undertaken on a pilot basis during the collection of data for the revised CIC evaluation. Stopped time delay was measured at a critical intersection and summarized by 15-minute intervals. Simple comparisons were made between the two alternatives and between the detector measurement of average delay and the computed stopped time delay for the 15-minute summaries.

Finally, a great deal of data were collected on bus performance under BPS and during the equivalent base data collection period. These data included detailed bus performance at critical locations and overall performance of buses along major routes. Special analyses were also performed for the effect of the BPS operation on link performances as measured by the UTCS detectors and derived measures of effectiveness. A description of the analyses follows.

BPS Analysis

The operation of BPS may have profound effects upon overall link performance as measured by the detectors and reflected in the MOE computations. The direct impact, of course, is the increase of green time for the link where the BPS actuation was received. This time obviously is available to other traffic on the link, as well as serving the bus for which it was granted.

This extension could have negative long-term impacts, however, as the green increase effectively destroys the offset of the intersection and the progression along the link. For congested conditions in the downtown grid, this effect may be minimal. On an arterial, particularly at critical offset locations, the effect of offset shifts might be quite harmful.

The effect upon offset is magnified somewhat by the relative rarity of actuations at several locations. In these cases, the offset may be changed to a particularly poor setting and then remain at that setting for some time before another bus equipped with a detector passes by. Thus, the intuitive notion of perpetually shifting offsets caused by frequent bus actuations may not be accurate under current conditions.

The link green extension also affects the opposing traffic (traffic on the same street going in the opposite direction). In most cases the phase extended runs concurrently with opposing direction movement. The green extension, therefore, impacts this opposing flow in the same manner as the activated link. However, in some instances, the change in offset may be such as to favor the opposing approach, particularly if it contains the lesser volume and less favorable nominal offset.

The increase in green time for a link also affects the cross traffic. An initial delay occurs, of course, whenever an increase is granted and the effect upon offset is similar to that for the other approaches. Although a minimum green time is assured for the cross traffic, the total amount of green time over an extended period must be reduced as the effect of the extensions cannot be "madeup". This potential problem in all likelihood arises very seldom, since for those locations where a small loss in overall green time would seriously compromise performance, the BPS control would be overridden by the volume and weighted occupancy criterion before capacity problems developed.

Finally, the granting of green extensions can occur both when a bus is traveling loaded in the peak direction and when it is returning or "dead-heading" for a subsequent run. In these cases, the green extensions would be granted to the lesser volume direction and the offsets altered accordingly. Since the "dead-heading" buses would be running with the traffic stream against the signal progression, it is probable that they would activate the BPS system.

Detector Analysis

A detailed examination of bus activity from the 15-minute summary tape was undertaken to classify the bus locations. Data for approximately forty 15-minute periods were examined. Off-peak conditions were not examined due to the extremely small number of detector-equipped buses on the street.

BPS activity was estimated by summing the total number of buses helped at each location and also noting the number of 15-minute periods for which activity occurred. Although a few locations showed activity in 80 percent or more of the periods, the average values were much lower. Similarly, the total number of buses helped exceeded 50 at only a limited number of locations. This is indicative of rather low BPS activity, since the 40 sample points of 15 minutes each represent approximately 450 cycles.

In spite of the low overall levels, the locations did show definite groupings. Some locations were eliminated as they recorded almost no activity. The remaining locations were classified into low, medium, and high activity locations, with "high" being a relative term and still representing low absolute activity. The locations eliminated due to virtually no activity reduced the total sample of BPS locations to 40 for the a.m. period and 36 for the p.m. period, with 45 different locations being represented overall.

Each location was first classified as to the peak bus flow direction. A few links, such as on K Street, had buses on different routes with both characteristics. All other links were then classified as either peak or off-peak direction for the a.m. analysis and the opposite classification for p.m. Links with both types of buses were included with the peak direction data for both analyses.

Opposing and cross flows were then identified for each link. In most instances, since the BPS detectors covered multiple approaches to an intersection, each detector was classified both as an analysis link and as an opposing link and cross link for other comparisons. For each bus detector, the corresponding link detector was identified.

The vehicle minutes of delay values computed as part of the vehicle minutes/vehicle miles analyses were considered to be the best measures for assessing BPS impact on link statistics. Specifically, the net savings or loss in vehicle minutes of delay with BPS over the base case was taken as the primary measure.

Each link was assigned to one or more cells, classified by BPS activity, bus flow direction, and analysis link, opposing link, and cross link. The net change in vehicle minutes of delay was recorded for each occurrence of a link within this matrix. The average vehicle minutes per link was then computed, together with the number of links appearing in the cell as a sample size.

Field Data Analysis

Bus performance data was collected manually at three intersections and along two physical route sections covering three series of bus routes. The concentration of the data collection was to insure that a data sample would be large enough to adequately measure the impact of the BPS operation.

For the analysis of bus performance at the individual intersections, data was collected for three time periods and four days at each location.

For the examination of bus performance over a designated route, data was collected for three time periods over four days at the two designated entrance and exit points within the system. This special BPS analysis supplements the detector and moving car evaluation of network performance under the BPS alternative as described earlier.

Data collected for each approach was first divided into specific groups. These groups included buses equipped with transmitter, buses without transmitter, and all observations during the TRSP alternative.

A detailed examination of the data was undertaken to identify the differences in the observed bus delay under the three operating conditions. The resulting data base summaries were then analyzed focusing on the performance of those buses equipped with the transmitter-detector.

The buses were first separated by classification, i.e., equipped or not equipped, and by control alternative. Their delay times were then aggregated by time period and by direction. A total summary of bus performance was then computed. The results were then tabularized with the departure time being the time required for the bus to travel the link distance, including the dwell time for passenger loading or unloading and/or traffic signal delay. The link is designated as the distance from the upstream detector to the point of the extended curbline across the intersection.

At the first location, 18th Street and Pennsylvania Avenue, N. W., a total of 1,079 buses was observed during the BPS alternative data collection period. This number includes 416 buses (39 percent) equipped with the detector-transmitter. During the data collection period for the base case TRSP, a total of 1,541 buses was observed.

For the route analysis, simple travel time by time period, route, and equipped/non-equipped status was used. Differences in travel time were computed.

The results to these studies and the others described in this chapter are discussed in the next chapter, EVALUATION OF ALTERNATIVES.

EVALUATION OF ALTERNATIVES

INTRODUCTION

This chapter presents the results of the evaluation of the five first-generation UTCS traffic control alternatives. The analysis focused on the measures of effectiveness produced by the UTCS detector surveillance system and parallel measures derived from the moving car runs. Traffic performance was also assessed, by special field studies conducted to examine certain operational characteristics of the individual traffic control alternatives, e.g., bus travel times under BPS. Additionally, field studies were performed to assess the validity of several of the evaluation measures generated by the UTCS surveillance system.

PERFORMANCE OF THE CONTROL ALTERNATIVES

This section analyzes the effectiveness of the traffic control alternatives. The evaluation is based on the analysis of the comprehensive data collection effort described in earlier chapters. The discussions are structured around the three major data bases: MOE's produced by the UTCS/BPS detector surveillance system; travel time and delay profiles from the moving car runs; and special field studies.

DETECTOR-BASED ANALYSES

Traffic performance was monitored by the UTCS/BPS detector surveillance system on a continuous basis throughout the test periods for each of the five control alternatives. The resulting data base of measures of effectiveness summarized by individual links, subnetworks, and for the network as a whole provided the primary means of differentiating between the performances of the first generation control alternatives. In addition, a parallel analysis of total network vehicle miles/vehicle minutes utilized two of the detector MOE's.

Network Level Performance and Comparative MOE's

The relative effectiveness of each of the five traffic control alternatives during a.m. period conditions is illustrated in Table 2. Four detector-generated performance measures are provided--average delay per vehicle; average vehicle travel time; average queue length; and percent of vehicles stopped. The table entries are expressed as

Table 2. Percentage differences in aggregate MOE's: a.m. period.

Comparison	Subarea	Delay	TT	Queue	Stops
TRSP vs 3 - dial	1	- 1.5	- 0.6	6.9	- 4.2
	2	- 2.7	- 1.8	3.4*	0.3
	3	- 4.0	- 3.2	1.7*	0.4
	4	- 5.9	- 2.9	3.0	2.4
	TOTAL	- 4.0	- 2.8	2.4**	0.4
TRSP vs TOD	1	3.9	2.9	- 1.0	2.7
	2	- 5.8	- 3.8	0.9	- 4.3
	3	- 1.8	- 0.7	1.8	- 1.4
	4	- 1.3	- 1.6	- 2.1	- 2.8
	TOTAL	- 1.8	- 1.1	0.7	- 1.9
TRSP vs CIC	1	6.9	6.2	2.4	3.2
	2	3.3	3.5	- 1.2	- 0.7
	3	- 2.7	- 2.6	- 5.3	- 4.8
	4	4.9	4.0	- 2.1	- 1.5
	TOTAL	0.7	0.5	- 3.5	- 3.0
TRSP vs BPS	1	3.6	3.3	2.7	0.9
	2	- 5.7*	- 4.3	- 8.5***	- 4.8**
	3	- 1.5	- 1.6	- 4.7	- 2.2
	4	- 8.6**	- 8.0*	- 10.2	- 8.5**
	TOTAL	- 2.5	- 2.4	- 5.4*	- 3.2

* = Significant differences at 5% level
** = Significant differences at 2% level
*** = Significant differences at 1% level

NOTE: A (-) indicates a degradation in the system as compared to the base system (TRSP) and a positive value indicates an improvement.

percentage differences in comparison to the base case (TRSP); a negative value for any measure indicates degradation in traffic performance under the given control alternative. Statistical significance of the difference as measured by the Kolmogorov-Smirnov test is denoted by the presence of one, two, or three asterisks indicating, respectively, significance at the 5%, 2%, or 1% level. The evaluation results are summarized for four subnetworks--corresponding to the four UTCS control sections illustrated on Figure 23--and for the network as a whole.

At the overall network level, the results indicate general degradation in performance under 3-dial, time-of-day (TOD), and bus priority (BPS) control contrasted with slight improvement--in delay and travel time--under critical intersection control (CIC). These findings are generally reinforced by the subnetwork results, although Section 1 is usually enhanced. Sections 2 and 4 under BPS show statistically significant decreases in vehicle (non-bus) performance for several of the MOE's. The CIC alternative, however, showed decreases in delay and travel time for all subnetworks except Section 3. The small overall performance gain by CIC can be attributed to the relative importance of Section 3, wich is comprised of the relatively congested central business area.

An interesting aspect of the results is the apparent lack of consistency of the queue measurement with the delay and travel time measurements. This result may be attributed to the fact that the queue measure is actually link content, and high values may be generated either with poor progression and large delay or good progression and low delay.

The comparable performance results for the midday traffic period are presented in Table 3. The network summaries of delay indicate that only the 3-dial control strategy showed improvement in the midday period. Similar to the pattern which occurred during the a.m. period traffic conditions, the performance of Sections 1 and 3 often appeared to be negatively correlated with the performance of the other subnetworks for a given control alternative.

Table 4 illustrates the corresponding results of the p.m. traffic conditions. The network-wide statistics show significant degradation of performance under the 3-dial and CIC control methods. In contrast, the TOD strategy exhibited slight but consistent improvement for all MOE's.

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1. The analysis tables are summarized in the SUMMARY AND CONCLUSIONS chapter for convenience. No attempt is made in the text to explain each element of each table.

Figure 23. UTCS/BPS Section map.

Table 3. Percentage differences in aggregate MOE's: midday.

Comparison	Subarea	Delay	TT	Queue	Stops
TRSP vs 3 - dial	1	- 5.7*	- 4.0	- 3.1	- 2.7
	2	- 6.4***	- 1.8	2.5	- 13.3***
	3	2.7	1.9	4.7***	7.6***
	4	- 2.6	- 0.3	10.3***	10.4***
	TOTAL	0.3	0.8	5.0***	3.9***
TRSP vs TOD	1	4.2	3.9	4.6	2.1
	2	- 4.6	- 2.6	- 1.4	- 4.4
	3	- 4.2**	- 3.5**	- 1.2	- 5.0***
	4	3.7***	2.1	1.7	1.7
	TOTAL	- 2.8*	- 2.4**	- 0.6	- 3.6***
TRSP vs CIC	1	2.2	2.2	- 0.6	- 1.3
	2	- 4.1	- 2.7	- 5.9***	- 4.6***
	3	- 1.0	- 0.6	- 0.9	- 0.8
	4	1.5	1.4	- 0.8	- 0.2
	TOTAL	- 0.5	- 0.2	- 1.6**	- 1.2**
TRSP vs BPS	1	6.2***	6.5***	2.6	- 0.7
	2	- 6.8***	- 6.0***	- 11.4***	- 9.4***
	3	0.3	- 0.2	- 4.2***	- 2.4
	4	- 5.1*	- 2.2**	- 4.5	- 2.9
	TOTAL	- 0.8	- 0.6	- 4.9***	- 3.5***

* = Significant differences at 5% level
** = Significant differences at 2% level
*** = Significant differences at 1% level

NOTE: A (-) indicates a degradation in the system as compared to the base system (TRSP) and a positive value indicates an improvement.

Table 4. Percentage differences in aggregate MOE's: p.m. period.

Comparison	Subarea	Delay	TT	Queue	Stops
TRSP vs 3 - dial	1	- 15.3***	- 12.2**	- 9.5	0.8
	2	- 10.3***	- 3.8***	9.2***	- 3.2**
	3	- 2.2	- 1.6	3.3***	1.3
	4	- 3.2**	- 0.2	7.9**	- 3.7*
	TOTAL	- 3.9*	- 1.9	4.7***	- 0.3
TRSP vs TOD	1	8.8	7.6	- 4.8	13.1
	2	- 0.7	0.4	0.3	- 1.0
	3	1.3	0.7	1.5	1.1
	4	5.0	4.1	2.4	0.0
	TOTAL	2.0	1.5	1.3	1.0
TRSP vs CIC	1	- 7.6	- 5.5	- 5.0	- 3.3
	2	- 2.8***	- 3.3**	- 3.8***	- 3.4***
	3	- 3.1***	- 2.2	- 3.1*	- 2.5**
	4	0.0	0.0	0.0	1.4
	TOTAL	- 2.8***	- 2.2**	- 2.7*	- 1.8*
TRSP vs BPS	1	4.0	3.5	- 3.2	5.1**
	2	- 5.2**	- 4.0***	- 16.0***	- 7.0***
	3	0.6	0.6	- 4.9*	- 3.6
	4	- 3.2	- 0.8	- 3.5	- 5.0***
	TOTAL	- 0.3	0.0	- 6.6***	- 3.5**

* = Significant differences at 5% level
** = Significant differences at 2% level
*** = Significant differences at 1% level

NOTE: A (-) indicates a degradation in the system as compared to the base system (TRSP) and a positive value indicates an improvement.

Substantial variations occurred between different subnetworks under the same control strategy, e.g., under the BPS alternative Section 1 showed a 4.0% decrease in delay while Section 2 showed a statistically significant 5.2% increase in delay. Traffic performance as measured by average queue length again appeared inconsistent with the average delay measurements. This was particularly apparent for Section 2 under 3-dial control where delay increased by 10.3% while average queue decreased by 9.2%; both differences were statistically significant at the 1% level.

The results for the three analysis periods indicate that the computer base case, TRSP, generally performed as well as any alternative and generally better than the TOD and 3-dial alternative. It is also apparent that the relative differences for the three periods--either positive or negative--were very small in magnitude, e.g., the range in average network delay was less than 5%. Traffic performance at the subnetwork level varied markedly by time period, although Section 1 appeared to remain relatively stable under each of the traffic control alternatives.

Comparisons between the individual measures of effectiveness illustrate a high degree of consistency between delay and travel time. The percent stops measure also appears generally consistent with delay, although the magnitude of the differences varies considerably. As mentioned previously, the queue measure does not correlate highly with the other three performance measures. This inconsistency together with the definitional difficulty in interpretation of the measure resulted in the removal of queue from further consideration as an important indicator of traffic performance during the remainder of the evaluation effort. As noted earlier, queue at a given level can relate to two different conditions.

<u>Subnetwork Performance</u>

The overall network of detectorized approaches was partitioned into two additional sets of subnetworks. The first set was organized on the basis of cardinal direction of flow, e.g., all westbound links. The second set of subnetworks was organized along major arterials within the network, e.g., all approaches on K Street. The following discussion of subnetwork performance focuses on average delay per vehicle as the most representative and important MOE. It should be noted that Section 1 is composed solely of two major intersections, M Street at Key Bridge and M Street and Wisconsin Avenue. Mo more than five detectors were operational for any of the comparisons, with as few as two or three for some.

The subnetwork results for the a.m. traffic period are illustrated in Table 5. Using the TRSP base cases for comparison, traffic performance on L Street was noticeably poorer under all four control alternatives. Considering the remaining arterial subnetworks, substantial differences in average delay are apparent between the control alternatives. Under 3-dial control, only 17th Street was better than the TRSP base case. The TOD method appears somewhat more comparable in that the magnitude of the performance degradation from TRSP is smaller and two arterials were improved. This is reasonable in that TOD and TRSP use the same basic timing. The CIC control alternative resulted in less delay for most of the arterial subnetworks. The small overall performance improvement with CIC can be largely attributed to the much poorer performance on L Street, relative to the TRSP base settings which had been adjusted to give preferential treatment to L Street. The BPS control alternative exhibited mixed results with improvement on K Street, 17th Street, and 19th Street contrasted with increased delay on the remaining arterials.

Overall midday traffic performance revealed more pronounced differences between the subnetworks as shown on Table 6. The small overall performance gain shown under the 3-dial case, in particular, masked substantial (and statistically significant) differences between the subnetworks: L Street was improved by 18.8% while 19th Street suffered a 15.9% increase in average delay. The three remaining control alternatives also produced mixed results, but the differences appeared to be of smaller magnitude.

Table 7 presents the comparable results for the p.m. period traffic conditions. The 3-dial case again demonstrates substantial variation in the performance of the arterial subnetworks; the 37.0% reduction in average delay on L Street, because of the preferential signal adjustments, somewhat offsets the substantial performance degradation on other major arterials (L Street under the 3-dial settings had been given high importance for p.m. traffic). The TOD signal settings produced a small but generally consistent improvement in the subnetworks. The CIC case showed statistically significant improvement along 18th and 19th Streets which was more than offset by degradation along K Street and Pennsylvania Avenue. These differences reflect more balanced delay against the base settings which favored the east-west movements. The BPS alternative appeared to have little effect on non-bus traffic performance in the p.m. period.

Table 5. Percentage differences in delay by aggregate: a.m. period.

Subarea	Control Alternative (Compared to TRSP)			
	3-dial	TOD	CIC	BPS
S 1	- 1.5	3.9	6.9	3.6
S 2	- 2.7	- 5.8	3.3	- 5.7*
S 3	÷ 4.0	- 1.8	- 2.7	- 1.5
S 4	- 5.9	- 1.3	4.9	- 8.6**
S 1 & 2	- 2.3	- 2.5	4.3	- 1.8
S 3 & 4	- 4.4	- 1.7	0.1	- 2.7
East	- 4.8	- 2.3	- 1.9	- 7.1
West	- 13.9***	- 6.9	- 2.1	2.5
North	- 3.0	0.4	6.4	- 1.5
South	2.8	1.3	- 3.0*	- 5.4
L Street	- 12.6**	- 6.0	- 19.8***	- 9.3*
K Street	- 11.8**	- 0.4	- 6.6	5.0
Pennsylvania Ave.	- 10.5	- 7.8	- 0.3	- 6.2
Constitution Ave.	- 6.4	- 4.0	8.4	- 8.7
17th Street	1.4	2.7	3.6	3.8
18th Street	- 8.4*	- 1.4	9.6	- 9.3
19th Street	- 1.8	1.7	- 2.2**	13.3**
TOTAL	- 4.0	- 1.8	0.7	- 2.5

* = Significant differences at 5% level
** = Significant differences at 2% level
*** = Significant differences at 1% level

Note: A (-) indicates a degradation in the system as compared to the base system (TRSP) and a positive value indicates an improvement.

Table 6. Percentage differences in delay by aggregate: midday.

Subarea	Control Alternatives (Compared to TRSP)			
	3-dial	TOD	CIC	BPS
S 1	- 5.7*	4.2	2.2	6.2***
S 2	- 6.4***	- 4.6	- 4.1	- 6.8***
S 3	2.7	- 4.2**	- 1.0	0.3
S 4	- 2.6	3.7***	1.5	- 5.1*
S 1 & 2	- 6.2***	- 2.3	- 1.4	- 0.4
S 3 & 4	1.7	- 2.9	- 0.3	- 0.9
East	20.6***	- 2.3	- 4.0***	1.4
West	2.8*	- 4.0***	0.6	- 3.4
North	- 4.9**	0.0	0.8	- 2.6
South	- 12.7***	- 5.2***	3.2*	- 0.2
L Street	18.8***	- 5.5	- 8.3**	- 3.1
K Street	17.7***	0.0	- 1.0	2.5
Pennsylvania Ave.	9.6***	- 4.2**	- C.4	4.7**
Constitution Ave.	3.1	3.8	- 3.0**	- 4.0
17th Street	13.7***	4.1**	2.8	- 2.1*
18th Street	- 13.7***	5.0**	5.3**	- 3.3
19th Street	- 15.9***	- 7.4	13.4**	1.4
TOTAL	0.3	- 2.8*	- 0.5	- 0.8

* = Significant differences at 5% level
** = Significant differences at 2% level
*** = Significant Differences at 1% level

Note: A (-) indicates a degradation in the system as compared to the base system (TRSP) and a positive value indicates an improvement.

Table 7. Percentage differences in delay by aggregate: p.m. period.

Subarea	Control Alternatives			
	3-dial	TOD	CIC	BPS
S 1	- 15.3***	8.8	- 7.6	4.0
S 2	- 10.3***	- 0.7	- 2.8***	- 5.2**
S 3	- 2.2	1.3	- 3.1***	0.6
S 4	- 3.2**	5.0	0.0	- 3.2
S 1 & 2	- 11.5***	1.8	- 4.5***	- 1.0
S 3 & 4	- 2.4	2.0	- 2.3*	- 0.1
East	- 1.7	2.4	- 3.8***	3.3
West	- 6.6**	- 0.8	- 8.7***	- 1.5
North	1.5	3.6	5.5	- 1.6
South	- 3.2	2.4	- 3.1*	- 2.2
L Street	37.0***	- 0.7	0.4	8.0*
K Street	- 11.9***	5.4	- 9.6***	- 1.3
Pennsylvania Ave.	- 17.4***	- 4.0	- 7.4***	0.3
Constitution Ave.	- 10.2***	0.9	0.6	- 2.2*
17th Street	3.8	5.4	- 5.3	- 3.2
18th Street	14.8***	2.8	14.4***	- 2.9
19th Street	1.1	1.3	6.9*	- 6.2
TOTAL	- 3.9*	2.0	- 2.8***	- 0.3

* = Significant differences at 5% level
** = Significant differences at 2% level
*** = Si-nificant differences at 1% level

Note: A (-) indicates a degration in the system as compared to the base system (TRSP) and a positive value indicates an improvement.

Link Performance

The individual link results for the a.m. traffic period have been summarized in Table 8. The entries correspond to the number of links which were statistically different for average delay as indicated by the Kolmogorov-Smirnov test. The actual magnitudes of the differences are not presented here, but have been reflected in the previously tabulated subnetwork results.

The 3-dial signal settings produced far more statistically significant differences from TRSP than the other control alternatives. A total of 35 links showed statistically significant performance losses at the 5% level while 26 links were similarly improved. In contrast, the TOD control alternative produced statistically significant delay increases for only nine links; however, only three links performed significantly better than in the base traffic responsive case. The CIC alternative also produced relatively few statistically significant differences. An examination of the links affected, however, shows that several intersections were subjected to delay trade-offs, i.e., statistically significant improvements on one approach in conjunction with a significant delay increase on the competing "cross street" approach. Like the TOD and CIC cases, the BPS test produced very few statistically significant changes; a detailed discussion of the incidence of these differences is presented in a later section of this report.

The number of links which was statistically different during the midday analysis period is tabulated in Table 9. The 3-dial alternative again exhibited substantially larger fluctuations than the other control alternatives. A total of 28 links was improved while 26 links were degraded. The TOD signal settings produced nine performance decreases and five links for which delay was significantly decreased. The CIC control alternative generated only four significant decreases in delay under midday traffic conditions. The BPS signal settings impacted 16 links with increased delay and eight links with reduced delay.

The statistical significance summary for the p.m. period analysis period is given in Table 10. As in the previous time periods, the 3-dial case produced the most statistically significant differences. The TOD control alternative, in contrast, produced only three delay increases and five delay decreases; a total of 64 links did not show a statistically significant difference at the 5% level.

Table 8. Number of links statistically different for delay: a.m. period.

Level of Significance	Control Alternative B (Compared to TRSP - "A")			
	3-dial	TOD	CIC	BPS
Insignificant	34	85	42	52
5 %, A> B } Performance Loss	35	9	11	12
1 %, A> B } Performance Loss	29	5	7	6
5 %, A< B } Performance Improved	26	3	11	6
1 %, A< B } Performance Improved	24	1	5	5

Table 9. Number of links statistically different for delay: midday.

Level of Significance	Control Alternative B (Compared to TRSP - "A")			
	3-dial	TOD	CIC	BPS
Insignificant	24	61	55	43
5 %, A> B } Performance Loss	28	9	10	16
1 %, A> B } Performance Loss	23	4	7	10
5 %, A< B } Performance Improved	26	5	4	8
1 %, A< B } Performance Improved	26	4	2	5

Table 10. Number of links statistically different for delay: p.m. period.

Level of Significance	Control Alternative B (Compared to TRSP - "A")			
	3-dial	TOD	CIC	BPS
Insignificant	18	64	46	47
5 %, A> B } Performance Loss	34	3	23	11
1 %, A> B } Performance Loss	26	0	16	8
5 %, A< B } Performance Improved	30	8	4	4
1 %, A< B } Performance Improved	26	3	4	3

The CIC results also provided a somewhat different pattern than in the earlier analysis periods; 23 links were significantly degraded while only four links demonstrated an improvement in performance. An examination of the locations of these links indicates that many of the problems occurred at intersections subject to heavy p.m. traffic flows. The BPS case again exhibited few statistically significant differences in the individual link results.

Global Performance

In addition to the detector MOE evaluation described above, a parallel series of analyses was undertaken in an attempt to determine the network-wide or global performances of the traffic control alternatives. This investigation focused on the computation of total network vehicle miles and vehicle minutes utilizing the data base provided by the UTCS/BPS detector surveillance system.

Table 11 tabulates vehicle minutes of travel and vehicle minutes of delay as computed for a comparison of the 3-dial control alternative and the base case (TRSP). These statistics are presented for the network as a whole and for the four component sections (subnetworks). Results for individual links are summarized separately for those showing absolute performance improvements (+) and absolute performance losses (-). A net figure is given as well.

For the total network, the results appear quite consistent with the percentage differences tabulated in Tables 5 to 7. Since the actual values are given, however, the relative contributions of the subnetworks to the aggregated network value can be understood, i.e., the substantial influence of Section 3 can be noted. It is apparent that the net delay differences substantially mask the gains and losses of the individual links; this is particularly true for the network summaries. The relatively good performance of the 3-dial alternative in the midday period can be attributed to the substantial improvement in Section 3.

The comparable TOD summaries, listed in Table 12, stand in sharp contrast to the 3-dial results. The net differences in vehicle minutes of travel and delay are somewhat similar in magnitude. However, the actual performance gains and losses are considerably smaller in most cases. The sizeable impact of Section 3 is again discernible in the midday traffic performance.

Table 13 illustrates the vehicle-minute summaries for CIC. As in the previous cases, the small net differences

Table 11. Vehicle minutes summary (TRSP vs 3-dial).

Time	Area	Vehicle Minutes of Travel					Vehicle Minutes of Delay				
		Trsp.	3-Dial	+	-	Net	Trsp.	3-Dial	+	-	Net
AM	S 1	1085	1092	79	- 86	- 7	752	763	72	- 83	- 11
	S 2	2248	2287	120	- 159	- 39	1386	1426	111	- 151	- 40
	S 3	11164	11526	500	- 862	-362	7052	7338	422	- 708	-286
	S 4	3151	3244	253	- 346	- 93	2001	2124	207	- 330	-123
	NET	17648	18149	952	-1453	-501	11191	11651	812	-1272	-460
MD	S 1	453	471	11	- 29	- 18	354	375	9	- 30	- 21
	S 2	1814	1844	127	- 157	- 30	1118	1189	94	- 165	- 71
	S 3	9079	8912	706	- 539	167	5958	5797	659	- 498	161
	S 4	2006	2010	145	- 149	- 4	1320	1355	130	- 165	- 35
	NET	13352	13237	989	- 874	115	8750	8716	892	- 858	34
PM	S 1	438	495	0	- 57	- 57	363	423	0	- 60	- 60
	S 2	2036	2116	160	- 240	- 80	1207	1338	125	- 256	-131
	S 3	10512	10682	685	- 855	-170	6604	6757	640	- 793	-153
	S 4	2833	2839	300	- 306	- 6	1695	1750	239	- 294	- 55
	NET	15819	16132	1145	-1458	-313	9869	10268	1004	-1403	-399

Note: + = Improvements of 3-dial over TRSP

- = Losses of 3-dial from TRSP

Table 12. Vehicle minutes summary (TRSP vs TOD).

Time	Area	Vehicle Minutes of Travel					Vehicle Minutes of Delay				
		Trsp.	TOD	+	-	Net	Trsp.	TOD	+	-	Net
AM	S 1	1074	1043	31	0	31	744	715	29	0	29
	S 2	2197	2284	36	-123	- 87	1352	1435	26	-109	- 83
	S 3	10768	10845	220	-297	- 77	6805	6923	157	-275	-118
	S 4	3974	4040	98	-164	- 66	2557	2589	70	-102	- 32
	NET	18013	18212	385	-584	-199	11458	11662	282	-486	-204
MD	S 1	459	441	18	0	18	358	344	14	0	14
	S 2	1617	1663	11	- 57	- 46	963	1009	9	- 55	- 46
	S 3	9120	9447	154	-481	-327	6024	6276	104	-356	-252
	S 4	1893	1851	99	- 57	42	1212	1167	83	- 38	45
	NET	13089	13402	282	-595	-313	8557	8796	210	-449	-239
PM	S 1	456	424	32	0	32	380	347	33	0	33
	S 2	1762	1758	24	- 20	4	1026	1031	22	- 27	- 5
	S 3	9731	9665	257	-191	66	6200	6121	216	-137	79
	S 4	2758	2649	156	- 47	109	1644	1564	115	- 35	80
	NET	14707	14496	469	-258	211	9250	9063	386	-199	187

Note: + = Improvements of TOD over TRSP
- = Losses of TOD from TRSP

Table 13. Vehicle minutes summary (TRSP vs CIC).

Time	Area	Vehicle Minutes of Travel					Vehicle Minutes of Delay				
		Trsp.	CIC	+	-	Net	Trsp.	CIC	+	-	Net
AM	S 1	557	523	34	0	34	376	351	25	0	25
	S 2	1499	1448	62	- 11	51	919	889	40	- 10	30
	S 3	6921	7103	215	-397	-182	4480	4606	156	-282	-126
	S 4	4066	3905	215	- 54	161	2770	2638	172	- 40	132
	NET	13043	12979	526	-462	64	8545	8484	393	-332	61
MD	S 1	1305	1276	45	- 16	29	938	918	32	- 12	20
	S 2	1873	1922	30	- 79	- 49	1160	1208	26	- 74	- 48
	S 3	7140	7183	196	-239	- 43	4699	4744	153	-198	- 45
	S 4	2661	2627	87	- 53	34	1925	1896	72	- 43	29
	NET	12979	13008	358	-387	- 29	8722	8766	283	-327	- 44
PM	S 1	1047	1105	4	- 62	- 58	748	808	0	- 60	- 60
	S 2	2379	2461	37	-119	- 82	1425	1466	33	- 74	- 41
	S 3	8911	9108	257	-454	-197	5762	5937	191	-366	-175
	S 4	2965	2967	74	- 76	- 2	1980	1977	63	- 60	3
	NET	15302	15641	372	-711	-339	9915	10188	287	-560	-273

Note: + = Improvement of CIC over TRSP
- = Losses of CIC from TRSP

conceal significant link variations. The strong performance of this alternative in the a.m. period for Section 4 is apparent from the table.

The analogous vehicle-minute summaries for the BPS alternative are presented in Table 14. The relative insignificance of this control method to total traffic performance can be observed in the extremely small gains and losses recorded for Sections 1, 2, and 4, as well as in the small total network change in the p.m. analysis period.

A summary of vehicle-minute link-level results is given in Table 15 for all time periods and control strategies. Links were classified by the direction and percentage of the difference in comparison to the base case. The extreme sensitivity of the vehicle-minute measures is apparent for the 3-dial control strategy; the majority of the links showed a greater than 10% difference, where only a few links differed by this amount for the other alternatives.

In a further attempt to reduce the evaluation data into one representative performance measure, derived speeds for the total network and component sections were computed on the basis of total vehicle miles and total vehicle minutes. These values are displayed in Table 16. One interesting result of this analysis is that only two of the possible 12 time period/control alternative combinations demonstrate higher speeds than the TRSP case for the total network. It is also apparent that the range in speeds is extremely small. As might be expected, the subnetwork values fluctuate considerably more than the aggregated network totals. The relatively low values in this table are discussed further in the "Measurement of Queue" section near the end of this chapter.

MOVING CAR ANALYSIS

Traffic performance was also monitored by a comprehensive series of moving car routes. The detailed study design of this data collection effort was discussed in an earlier chapter. Although complete coverage of the entire network was not feasible, the moving car paths did traverse most major arterials. Because of the continuity of the routes, the moving cars could effectively measure performance over complete segments of arterial streets, not just at locations which were detectorized. This data could therefore be compared to the performance measures provided by the UTCS detector surveillance system to assess the validity of that evaluation data.

Table 14. Vehicle minutes summary (TRSP vs BPS).

Time	Area	Vehicle Minutes of Travel					Vehicle Minutes of Delay				
		Trsp.	BPS	+	-	Net	Trsp.	BPS	+	-	Net
AM	S 1	1043	1009	40	- 6	34	729	703	32	- 6	26
	S 2	1587	1656	30	- 99	- 69	995	1054	23	- 82	- 59
	S 3	8454	8591	334	-471	-137	5354	5437	302	-385	- 83
	S 4	1690	1831	16	-157	-141	1037	1130	13	-106	- 93
	NET	12774	13087	420	-733	-313	8115	8324	370	-579	-209
MD	S 1	1502	1408	94	0	94	1132	1063	69	0	69
	S 2	1757	1869	34	-146	-112	1105	1181	28	-104	- 76
	S 3	7245	7261	272	-288	- 16	4672	4656	259	-243	16
	S 4	1910	1949	45	- 84	- 39	1251	1315	30	- 94	- 64
	NET	12414	12487	445	-518	- 73	8160	8215	386	-441	- 55
PM	S 1	1341	1294	58	- 11	47	1022	982	50	- 10	40
	S 2	1844	1922	63	-141	- 78	1160	1220	58	-118	- 60
	S 3	7491	7440	216	-165	51	4663	4636	176	-149	27
	S 4	1562	1576	21	- 35	- 14	973	1006	11	- 44	- 33
	NET	12238	12232	358	-352	6	7818	7844	295	-321	- 26

Note: + = Improvement of BPS over TRSP
- = Losses of BPS from TRSP

Table 15. Vehicle minutes link level summary.

Comparison	Time	Total Links	Vehicle Minutes of Travel					Vehicle Minutes of Delay				
			>10%+	<10%+	0	>10%-	<10%-	>10%+	<10%+	0	>10%-	<10%-
TRSP vs 3-dial	a.m.	95	23	19	0	24	29	25	17	0	14	39
	midday	78	16	24	1	12	25	21	15	1	17	24
	p.m.	82	23	15	0	15	29	28	7	2	14	31
TRSP vs TOP	a.m.	97	6	29	3	49	10	7	31	3	41	15
	midday	75	4	18	4	35	14	7	15	5	31	17
	p.m.	76	5	40	3	24	4	10	34	1	24	7
TRSP vs CIC	a.m.	64	8	29	2	14	11	10	26	3	11	14
	midday	69	4	31	1	27	6	6	28	2	23	10
	p.m.	73	6	24	2	28	13	6	20	3	28	16
TRSP vs BPS	a.m.	70	9	21	2	19	19	13	17	2	17	21
	midday	67	7	26	3	18	13	9	23	2	15	18
	p.m.	62	5	25	2	25	5	12	19	0	19	12

Table 16. Derived average speed from vehicle miles/vehicle minutes.

Comparison	Area	TIME					
		a.m.		midday		p.m.	
		TRSP	Test	TRSP	Test	TRSP	Test
TRSP vs. 3-Dial	S 1	6.32	6.04	4.46	3.98	3.58	2.85
	S 2	8.65	8.42	8.66	7.94	9.16	8.17
	S 3	7.01	6.74	6.30	6.50	6.57	6.56
	S 4	8.10	7.74	7.96	7.74	8.38	8.44
	NET	7.36	7.07	6.80	6.79	7.12	6.96
TRSP vs. TOD	S 1	6.36	6.48	4.44	4.55	3.44	3.79
	S 2	8.79	8.46	9.23	8.88	9.37	9.35
	S 3	7.06	6.88	6.23	6.00	6.44	6.57
	S 4	7.86	7.71	8.39	8.68	8.41	8.83
	NET	7.38	7.22	6.84	6.67	7.04	7.21
TRSP vs. CIC	S 1	6.11	6.34	3.82	3.95	4.54	4.05
	S 2	7.19	7.37	7.65	7.46	7.59	7.26
	S 3	6.62	6.49	6.12	6.08	6.15	5.93
	S 4	6.93	7.14	6.78	6.81	8.01	7.86
	NET	6.73	6.75	6.24	6.21	6.61	6.35
TRSP vs. BPS	S 1	6.28	6.42	3.55	3.74	3.95	4.10
	S 2	8.25	7.90	8.34	7.98	8.17	7.94
	S 3	6.94	6.66	6.32	6.20	6.68	6.58
	S 4	7.88	7.37	8.01	7.57	8.26	8.03
	NET	7.16	6.86	6.52	6.39	6.78	6.68

Network Level Performance and Comparative MOE's

The overall results of the moving car runs during the a.m. analysis period are summarized in Table 17.[1] The four first-generation signal alternatives are compared to the base (TRSP) case for all four measures of effectiveness as computed over each of the six moving car routes. A further comparison of the speed measure with detector results is given in the "Measurement of Speed" section near the end of this chapter. As before, asterisks denote various levels of statistical significance as indicated by the Kolmogorov-Smirnov test.

The 3-dial strategy again exhibited a wide variation in traffic performance, similar to the pattern identified by the detector surveillance system.[2] The 13.3% decrease in travel time recorded for route 22--and which was statistically significant at the 1% level--contrasts sharply with the 8.2% performance loss on route 11. A comparison of the delay and number of stops differences with the travel time differences shows the relatively high sensitivity of these performance measures. The TOD control alternative showed improvement for three of the routes which was offset by degraded performance (for total travel time) of the remaining routes. The CIC control alternative produced somewhat mixed results with gains on the Wisconsin Avenue routes (11 and 13) cancelled by increases in delay and travel time for the other routes. Traffic performance under BPS was consistently worse, with substantial delays occurring on routes 11 and 30.

Similar patterns occurred during the midday analysis period, with substantial variations evident between the individual route performances within each traffic control alternative as shown on Table 18. The 3-dial patterns showed performance improvements for routes 22 and 30 which were offset somewhat by poor performance on route 40. The TOD case exhibited poorer results than occurred during the a.m. period, although the net effect of the control alternative appeared to be positive. Routes 30 and 40 were significantly improved under CIC, with all measures of effectiveness registering gains. Traffic performance under BPS again suffered with sizeable losses on all routes except route 11.

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1. The numerical values for comparisons in Tables 17, 18, and 19 are provided in Volume 2. Technical Appendices.

2. See Figure 9 for route designations.

Table 17. Percentage differences in aggregate moving car MOE's: a.m. period.

Comparison	Route	TT	Delay	Stops	Speed
TRSP vs 3-Dial	11	- 8.2**	- 4.1	-12.6	- 8.5*
	13	- 1.3	6.1	7.0	- 1.0
	22	13.3***	47.5***	53.4***	17.7***
	24	- 5.1*	-11.7*	10.0	- 6.9
	30	- 5.9	-38.9**	-17.2	- 4.3
	40	4.1	16.4	23.7*	4.2
TRSP vs TOD	11	- 0.2	- 8.1	- 2.6	0.7
	13	3.3	- 0.6	4.1	2.1
	22	4.7	19.7*	12.3	4.9
	24	4.6	14.2	9.4	1.6
	30	- 9.6	-41.2*	2.3	- 8.4
	40	-10.2**	4.4	-13.0	-11.2*
TRSP vs CIC	11	4.2	-26.3	- 3.1	4.8
	13	7.1*	- 4.5	- 8.1	9.6
	22	- 4.1*	4.0	6.9	- 7.0
	24	- 9.7	-11.5	- 5.0	-10.8
	30	-11.2**	-17.9	-15.5*	-10.6*
	40	- 0.5	- 3.1	-10.9	2.0
TRSP vs BPS	11	- 2.3**	-25.5***	-19.8**	- 3.4
	13	- 1.8	- 0.7	-18.9**	- 2.4
	22	- 4.6	-14.2	-22.6**	- 2.8
	24	- 8.1	-14.6	-22.1	- 5.3
	30	-14.4	-40.8	-37.5	-14.4
	40	- 1.2	- 1.9	0.0	1.0

* = Significant differences at 5% level
** = Significant differences at 2% level
*** = Significant differences at 1% level

NOTE: A (-) indicates a degradation in the system (TRSP) and a positive value indicates an improvement. (See figure 9 for route identification.)

Table 18. Percentage differences in aggregate moving car MOE's: midday.

Comparison	Route	TT	Delay	Stops	Speed
TRSP vs 3-Dial	11	- 2.1	27.2	28.3	- 2.6
	13	- 7.4	6.0	28.2	- 7.5
	22	34.8***	63.3***	69.5***	33.3***
	24	6.7	13.5*	39.1***	6.6
	30	22.4***	34.8***	52.1***	20.9***
	40	-17.4***	-37.5***	-19.6***	-15.3***
TRSP vs TOD	11	- 1.0	- 8.9	- 5.6	- 0.8
	13	1.9	9.3	7.0	1.3
	22	10.6**	20.3**	22.2**	9.9**
	24	- 4.5	- 8.0	- 7.9	- 3.8
	30	9.7***	6.9	55.5***	10.4**
	40	- 7.7*	- 8.8	- 4.5	- 7.6
TRSP vs CIC	11	0.3	- 8.4	1.7	- 1.7
	13	4.1	12.6	- 9.3	2.1
	22	- 1.4	3.0	6.9	0.0
	24	- 4.3	3.9	7.3	- 4.4
	30	7.1*	15.6**	13.7*	5.5
	40	10.5***	19.8***	11.0	10.4***
TRSP vs BPS	11	- 4.6	-30.1	-40.0*	- 4.6
	13	- 5.9	-33.4**	-45.7***	- 5.0
	22	12.4***	22.9**	10.7	12.7*
	24	- 3.1	- 0.7	-22.3***	- 1.2
	30	-20.5***	-45.3***	-45.7***	-21.2***
	40	-13.3***	-23.0***	-18.3***	-12.1**

* = Singificant difference at 5% level
** = Significant difference at 2% level
*** = Significant difference at 1% level

Note: A (-) indicates a degradation in the system as compared to the base system (TRSP) and a positive value indicated an improvement.

The moving car results for the p.m. peak traffic period are listed in Table 19. The 3-dial signal settings produced significantly increased travel times for routes 11, 13, and 22 which were matched by improvements in routes 24 and 30. The TOD control alternative resulted in a relatively consistent pattern of improvement. The extreme sensitivity of the delay measure is apparent for routes 11 and 24. The CIC case demonstrated overall deterioration in this time period. The substantial improvement for number of stops which was registered for route 22 is interesting in view of the increased overall travel time for that route. The BPS control alternative again performed relatively poorly for nonbus traffic in comparison to the base TRSP case, although the impact on travel time did not appear to be excessive.

The overall moving car results appear relatively consistent with the patterns identified during the analysis of the detector-generated MOE's. An examination of the individual measures reveals the (expectedly) high correlation of travel time with average speed. The average delay per vehicle and number of stops MOE's is generally consistent with the travel time values in direction, but appear to be considerably more sensitive. Although these measures can potentially yield useful information on the performance of the signal settings, measurement and definitional problems (e.g., determination of when a vehicle is "stopped" or simply "creeping" by different drivers) can be expected to produce misleading results. Therefore, the remainder of the moving car analysis focuses on the use of travel time as the prime evaluation measure.

Subnetwork Performance

The individual links which comprise the moving car routes were aggregated into a series of segments or subnetworks in order to facilitate analysis; these subnetworks were illustrated on Figure 16.

The percentage differences in average travel time for the moving car subnetworks during the a.m. analysis period are given in Table 20. The 3-dial signal settings demonstrated substantial improvements on eastbound Pennsylvania Avenue, westbound Constitution Avenue, 22nd Street, and 23rd Street. Substantial increases in travel time were found on Pennsylvania Avenue, H Street, E Street, and K Street, all in the westbound direction. The differences in travel time resulting from the TOD signal settings were smaller in magnitude; only 18th Street and 19th Street were substantially degraded. Traffic performance under the CIC control alternative suffered along eastbound M Street

Table 19. Percentage differences in aggregate moving car MOE's: p.m. period.

Comparison	Route	TT	Delay	Stops	Speed
TRSP vs 3-Dial	11	-15.3***	-32.9*	18.0*	-13.9***
	13	-13.1***	- 3.6	-17.6	-13.4**
	22	-10.2***	-21.5	13.1	- 9.8*
	24	6.2	7.5	46.1***	6.8
	30	9.4	4.0	15.3	4.9
	40	- 0.7	5.1	0.0	- 2.3
TRSP vs TOD	11	- 1.2	-19.3**	- 7.9	- 0.8
	13	4.9	- 0.6	4.6	3.7
	22	2.2	9.6	7.2	2.9
	24	2.1**	10.2**	3.5*	6.1**
	30	1.1	-14.1	27.9	- 2.1
	40	- 4.7	8.5	4.2	- 2.4
TRSP vs CIC	11	4.2	- 6.5	- 6.9	5.5
	13	- 1.1	-12.5	- 1.6	0.6
	22	- 3.5	5.9	18.7**	2.2
	24	-29.7	-43.8	-21.3	-12.3
	30	- 6.7	- 7.5	- 9.1	-10.4
	40	- 4.4	- 6.4	-15.8	- 6.5
TRSP vs BPS	11	- 7.7	-51.6*	-53.1**	- 8.8
	13	-11.5***	-39.0***	-53.6***	- 8.9*
	22	- 1.2	- 1.7	- 8.5	- 1.8
	24	1.1	- 0.9	- 7.8	- 3.2
	30	- 6.8	-16.7	-24.5	- 6.2
	40	- 5.2	-10.0	- 4.8	- 6.8

* = Significant differences at 5% level.
** = Significant differences at 2% level.
*** = Significant differences at 1% level.

Note: A (-) indicates a degradation in the system as compared to the base system (TRSP) and a positive value indicates an improvement. See Figure 9 for route identification.

Table 20. Percentage differences in travel time for moving car aggregates: a.m. period.

		Alternatives compared to TRSP			
Route	Subarea	3-Dial	TOD	CIC	BPS
11	NB Wisc. - Lower	-12.2***	4.1	3.9***	4.2
	NB Wisc. - Upper	- 2.4	- 5.6	5.0	-10.6**
13	SB Wisc. - Upper	- 0.4	0.2	13.4***	- 4.2
	SB Wisc. - Lower	- 2.0	5.7	5.5	0.0
22	EB M Street	11.8***	7.6	-14.7***	3.6
	EB Pennsylvania Avenue	15.3***	1.0	6.9	-12.5
24	WB Pennsylvania Avenue	-19.6***	- 3.1	-24.9	-18.8
	WB M Street	5.3	9.7	1.2	- 0.3
30	WB 22nd Street	26.0**	- 7.4	1.0	-10.3
	EB K Street	-10.4	-11.9	-28.3*	- 2.8
	WB H Street	-38.0*	- 8.4	17.4*	14.4
	SB 17th Street - 1	8.1	4.0	4.5	- 4.2
	NB 18th Street	- 3.7	-19.0	- 9.2	-38.3*
	SB 17th Street - 2	- 5.3*	- 1.0	- 5.9	- 5.3
	WB E Street	-19.7***	- 6.0	-20.8**	-15.7
40	NB 23rd Street	30.9	- 8.7	9.9	12.4
	EB L Street	8.5*	-10.7	- 2.8	-18.3**
	WB K Street	-22.6***	- 7.4*	- 1.2	4.3
	SB 19th Street	-10.4	-20.9***	- 2.0	1.5
	WB Constitution Avenue	52.7***	- 1.0	- 4.6	3.5

* = Significant differences at 5% level
** = Significant differences at 2% level
*** = Significant Differences at 1% level

Note: A (-) indicates a degradation in the system as compared to the base system (TRSP) and a positive value indicates an improvement.

westbound Pennsylvania Avenue, eastbound K Street, and E Street. These problems were offset somewhat by improvements on Wisconsin Avenue and, to a small degree, along H Street. The BPS case exhibited increased travel time along 18th Street and L Street.

The comparable travel time summaries for the midday analysis period are presented in Table 21. The 3-dial settings exhibited extreme differences between the subnetworks. Several arterials were substantially improved; however, L Street was subjected to a 43.4% increase in travel time. The TOD control alternative also showed substantial gains and losses. Eastbound M Street, H Street, 17th Street, and E Street were significantly improved while eastbound K Street, L Street, and westbound Constitution Avenue incurred increased travel times. The CIC alternative provided a general pattern of improvement, although 17th Street was degraded somewhat. In contrast to CIC, the BPS case showed considerable increases in travel time for the subnetworks.

Table 22 illustrates the moving car results for the p.m. period. The typical 3-dial variation between subnetworks is apparent. While many of the improvements were made on relatively minor streets (e.g., H Street), the incidence of the performance penalties appears greatest on the major arterials. The TOD alternative produced mixed results. The gains on 17th Street were offset by substantial losses on Constitution Avenue. The CIC signal settings produced substantial increases in travel time for Pennsylvania Avenue and 17th Street; these results are consistent with the results of the detector analysis. BPS again caused greater travel time for most subnetworks; however, only westbound Pennsylvania Avenue and 18th Street appeared to be severely affected.

Link Performance

The impacts of the alternatives on individual link performance during the a.m. traffic period are summarized in Table 23. The entries correspond to the absolute numbers of links which exhibited statistically significant differences in average travel time as indicated by the Kolmogorov-Smirnov test.

The 3-dial signal settings again recorded the widest differences from the base case; 23 links showed increased travel times while 25 links showed improvements. The TOD alternative yielded 17 statistical differences for which travel time was increased against only six differences for which travel time was decreased. CIC was the only alternative

Table 21. Percentage differences in travel time for moving car aggregates: midday.

Route	Subarea	Alternatives compared to TRSP: 3-Dial	TOD	CIC	BPS
11	NB Wisc. - Lower	- 2.7	- 0.4	1.7	1.7
	NB Wisc. - Upper	- 0.8**	- 2.0	- 4.7	-16.0***
13	SB Wisc. - Upper	- 8.6	4.6	- 0.5	-17.4***
	SB Wisc. - Lower	- 6.9	0.7	5.0	- 0.2
22	EB M Street	42.0***	16.2***	13.1	15.4
	EB Pennsylvania Avenue	22.1***	0.5	- 7.6	7.4
24	WB Pennsylvania Avenue	8.0*	- 7.5	- 8.7**	-22.3***
	WB M Street	6.0	- 2.7	- 1.5	9.9
30	WB 22nd Street	2.4	12.4	4.7	-22.4
	EB K Street	12.6**	-14.8	10.3	-10.3
	WB H Street	-11.3	28.9*	- 0.8	7.3
	SB 17th Street - 1	45.5***	32.3*	- 2.8	-11.7
	NB 18th Street	29.8***	3.2	21.0	-28.1***
	SB 17th Street - 2	27.2***	16.7	-17.9	-42.3***
	WB E Street	44.3**	48.7***	25.3	-26.8
40	NB 23rd Street	- 2.6	3.0	1.6	-11.3
	EB L Street	-43.4***	-13.8	9.9	-26.6**
	WB K Street	5.0	- 3.8	14.8	3.4*
	SB 19th Street	-13.2***	- 1.8	14.2	-15.5**
	WB Constitution Avenue	25.9***	-19.7*	- 2.9	- 1.2

* = Significant differences at 5% level
** = Significant differences at 2% level
*** = Significant Differences at 1% level

Note: A (-) indicated a degradation in the system as compared to the base system (TRSP) and a positive value indicates an improvement.

Table 22. Percentage differences in travel time for moving car aggregates: p.m. period.

Route	Subarea	3-Dial	TOD	CIC	BPS
		Alternatives compared to TRSP			
11	NB Wisc. - Lower	-10.6***	- 2.0	1.7	- 5.0
	NB Wisc. - Upper	-23.1***	0.2	14.3	-12.0
13	SB Wisc. - Upper	-16.4***	3.1	- 1.3	- 5.8
	SB Wisc. - Lower	-11.0**	6.0	- 1.0	-14.8*
22	EB M Street	6.8	3.3	6.8**	- 4.5
	EB Pennsylvania Avenue	-28.8***	0.9	-14.9	2.8
24	WB Pennsylvania Avenue	8.1	- 3.8	-34.1	-24.0**
	WB M Street	5.2	5.3*	-27.4	16.0
30	WB 22nd Street	- 5.1**	- 7.1	-17.4	- 5.9
	EB K Street	- 0.9	1.7	- 3.1	-11.2
	WB H Street	19.2	-25.3	15.8	18.5
	SB 17th Street - 1	28.2	27.4	-20.7	3.8
	NB 18th Street	7.0	- 7.8	- 6.4	-30.9*
	SB 17th Street - 2	5.0	11.6	-15.0	2.6
	WB E Street	32.8**	- 3.3	12.0	- 2.5
40	NB 23rd Street	0.6	- 4.5	1.2	- 2.2
	EB L Street	29.2***	- 3.3	- 7.6	-10.3
	WB K Street	-22.8**	6.3	1.3	4.6
	SB 19th Street	-14.6*	-12.9	- 6.5	-10.8
	WB Constitution Avenue	-22.8***	-26.8**	- 5.9	5.0

* = Significant differences at 5% level
** = Significant differences at 2% level
*** = Significant Differences at 1% level

Note: A (-) indicates a degradation in the system as compared to the base system (TRSP) and a positive value indicates an improvement.

Table 23. Number of moving car links statistically different for travel time: a.m. period.

Level of Significance	Control Alternative B (Compared to TRSP - "A")			
	3-Dial	TOD	CIC	BPS
Insignificant	96	121	105	121
5 %, A > B (Performance Loss)	23	17	14	14
1 %, A > B (Performance Loss)	21	5	3	2
5 %, A < B (Performance Improved)	25	6	17	9
1 %, A < B (Performance Improved)	16	3	6	2

Table 24. Number of moving car links statistically different for travel time: midday.

Level of Significance	Control Alternative B (Compared to TRSP - "A")			
	3-Dial	TOD	CIC	BPS
Insignificant	82	123	125	103
5 %, A > B (Performance Loss)	27	9	4	30
1 %, A > B (Performance Loss)	14	3	2	21
5 %, A < B (Performance Improved)	35	12	7	11
1 %, A < B (Performance Improved)	19	4	0	4

Table 25. Number of moving car links statistically different for travel time: p.m. period.

Level of Significance	Control Alternative B (Compared to TRSP - "A")			
	3-Dial	TOD	CIC	BPS
Insignificant	88	124	121	129
5 %, A > B (Performance Loss)	32	11	5	11
1 %, A > B (Performance Loss)	19	3	1	4
5 %, A < B (Performance Improved)	24	9	10	4
1 %, A < B (Performance Improved)	12	1	5	0

to produce more gains (17) than losses (14) at the 5% level of significance. BPS appeared to perform slightly worse than the base case with nine statistically significant decreases in travel time against 14 increases.

The midday link significance summaries are presented in Table 24. The 3-dial alternative produced 35 positive differences against only 27 losses. The TOD signal settings also recorded relative gains with 12 instances of improvement. The CIC results showed very few links for which significant travel time differences were found. BPS, on the other hand, produced 30 increases in travel time against only 11 improvements.

The analogous statistical tabulations for the p.m. period analysis are illustrated in Table 25. Under these conditions, the 3-dial settings produced substantially more losses than gains. The TOD alternative generated mixed results; only four links were statistically different at the 1% level. The CIC signal settings showed improvement for 10 links against only five losses. This gain, however, was not substantiated in the subnetwork results given in Table 19. The BPS signal settings again showed an overall deterioration in performance: improvements for nine links offset by 14 links for which travel times increased.

The performance patterns exhibited by these link statistics appear relatively consistent, with minor exceptions, with the other moving car analyses.

BPS IMPACT STUDIES

The bus studies were described in the ANALYTICAL METHODOLOGY chapter. As was noted, the vehicle minutes of delay values computed as part of the vehicle minutes/vehicle miles analyses were considered to be the best measures for assessing BPS impact on link statistics. Specifically, the net savings or loss in vehicle minutes of delay with BPS over the base case was taken as the primary measure.

Each link was assigned to one or more cells, classified by BPS activity, bus flow direction, and analysis link, opposing link, and cross link. The net change in vehicle minutes of delay was recorded for each occurrence of a link within this matrix.

The average vehicle minutes per link was then computed and is shown in Table 26, together with the number of links appearing in the cell as a sample size. Positive values

Table 26. Vehicle minutes of delay averages for BPS intersection approaches.

BPS Activity	Bus Flow Direction	a.m. Link	a.m. Opposing Link	a.m. Cross Links	p.m. Link	p.m. Opposing Link	p.m. Cross Links
High	Peak	+5.8 (9)	+5.6 (7)	-8.3 (11)	+0.5 (2)	-7.0 (1)	-0.8 (4)
	Off-Peak	+5.0 (7)	-1.3 (4)	+2.8 (4)	-6.0 (6)	+15.3 (3)	-6.5 (6)
Medium	Peak	-10.8 (4)	-3.5 (2)	-27.0 (2)	-4.8 (5)	+6.3 (3)	+4.2 (6)
	Off-Peak	+3.0 (2)	-11.0 (2)	-19.0 (1)	-2.0 (4)	+10.0 (1)	-1.0 (4)
Low	Peak	-23.4* (8)	-0.5 (4)	-15.9* (8)	+3.3 (3)	+2.3 (4)	+3.0 (2)
	Off-Peak	+4.5 (4)	-29.5* (4)	-2.0 (1)	-3.3 (3)	N.A. (0)	-9.5 (2)

Notes:

- Data shown are average differences per link, positive values indicating less delay with BPS.
- Number of links (sample size) in parentheses.
- Values assigned to peak direction if bus flows exist both ways

* Indicates inclusion of very large change in delay for Link 190.

indicate less delay under BPS than for the base case. Separate computations were performed for a.m. and p.m. conditions and the reversal of the individual link classifications between the peak and off-peak bus flow direction should be borne in mind.

In this table, for the a.m., links with high BPS activity are generally helped, while those with medium or low activity are almost universally harmed. Of particular interest is the fact that links in the off-peak direction are helped nearly as much as those in the peak direction for high BPS activity locations, and are helped somewhat for medium and low locations while the links in the peak direction show much poorer performance. Opposing links are worse, except for the high activity locations in the peak direction, although the sample sizes in other cells make the results somewhat questionable. Cross links are almost always worse, as would be expected.

For the p.m. period, the situation is somewhat different and the results are not so pronounced. The link flows are generally worse but the opposing flows show improvement, although the latter again reflect sample size problems. Cross links again are generally worse, although not nearly so pronounced as in the a.m.

The net vehicle minutes of delay were also summarized in absolute terms in Table 27. All links within a cell showing positive and negative changes were summed separately and a net value indicated as well. Totals are shown for all high, medium, and low BPS locations and a grand total.

The pattern of the net values is, of course, identical to that given in the previous figure. However, the magnitude of both positive and negative numbers in many cells indicates that results in many cases are far from consistent. Also, the magnitude of the a.m. numbers far exceeds that of the p.m. values, indicating much greater disruption to the nominal traffic pattern in the a.m.

The last comment must be tempered by the fact that many more BPS locations were operating in the a.m. bus flow direction. The number of buses helped in the a.m. peak direction was 68 percent of the total, but since twice as many locations were present in the sample, the average number of buses helped per location was almost identical. For the p.m. analysis, the peak direction bias was almost eliminated and the total number of buses helped and the average per location were quite similar.

Table 27. Vehicle minutes of delay summary for BPS intersection approaches.

BPS Activity	Category	Direction	a.m. +	a.m. -	a.m. Net	p.m. +	p.m. -	p.m. Net
High	Link	Peak	93	41	+52	5	4	+1
		Off-Peak	71	36	+35	15	51	-36
	Opposing	Peak	64	25	+39	0	7	-7
		Off-Peak	25	30	-5	50	4	+46
	Cross	Peak	69	160	-91	16	19	-3
		Off-Peak	42	31	+11	14	53	-39
	Total		364	323	+41	100	138	-38
Medium	Link	Peak	1	44	-43	18	42	-24
		Off-Peak	10	4	+6	4	12	-8
	Opposing	Peak	0	7	-7	19	0	+19
		Off-Peak	0	22	-22	10	0	+10
	Cross	Peak	0	54	-54	41	16	+25
		Off-Peak	0	19	-19	16	20	-4
	Total		11	150	-139	108	90	+18
Low	Link	Peak	15	202	-187	12	2	+10
		Off-Peak	29	11	+18	1	11	-10
	Opposing	Peak	27	29	-2	12	3	+9
		Off-Peak	7	125	-118	0	0	0
	Cross	Peak	50	177	-127	11	5	6
		Off-Peak	0	2	-2	7	26	-19
	Total		128	546	-418	43	47	-4
	Grand Total		503	1,019	-516	251	275	-24
Non-BPS			122	176	-54	95	126	-31

Note: - indicates improvement
+ indicates degradation

In general, buses proceeding in the off-peak direction, or "dead-heading", were almost as likely to trigger a BPS extension as those traveling with a full load of passengers. Although this result seems somewhat undesirable, it is offset partially by reducing bus "turnaround" time and aiding in schedule adherence.

Also, it must be noted that relatively few of the total buses passing through the network were equipped with detectors. Since most of the buses were traveling with other vehicles in the traffic stream, they were subject, at least in part, to the changes in delay for other vehicles noted above. To the extent that the overall system performance deteriorated, vehicle minutes lost by these non-detectorized buses may be offset against gains to the buses triggering the extensions.

Individual Link Performance

For the p.m. period, only four links showed substantial declines in excess of 20 vehicle minutes, but three of these were in the Massachusetts-Wisconsin-Garfield triangle. Two of the three did not have bus detectors. At the same time, the largest improvement in vehicle minutes was also observed in the same area, northbound on Wisconsin Avenue at Garfield Street.

Bus traffic northbound on Wisconsin Avenue undoubtedly received green increases, and this link shows a decrease of 45 vehicle minutes. However, only one other link in the triangle, that was operational, showed a decrease while five others, including the three significant ones, showed increases. The net for the triangle as a whole was a 60 vehicle minute increase.

Presumably, the extensions granted at Garfield Street aggravate the southbound movement which is known to be sensitive to offset. Also, the green extensions simply increase the delay northbound at Massachusetts Avenue. Increased delay on the third approach, westbound Garfield, is probably caused by a combination of altered offsets for that short block and perhaps some loss in green time.

Additional losses, although smaller in number, occur southbound on Wisconsin Avenue at Massachusetts Avenue and eastbound on Massachusetts at Wisconsin. Although a number of factors could be acting, including spillback from Wisconsin Avenue and Garfield Street, the slight increase for eastbound Garfield may be due to metering of the left turn or, again, change in offset. Unfortunately, the remaining two detectors on Massachusetts were not functioning.

An almost identical pattern holds for the a.m., although the relative intensities are altered somewhat. Northbound Wisconsin Avenue is helped at Garfield Street and hurt at Massachusetts Avenue. Substantial increases in delay are also recorded westbound on Garfield Street and southbound on Wisconsin Avenue at Garfield Street, with the remaining locations either not functioning or showing no change.

The increase in delay southbound at Garfield Street is particularly noteworthy, since the measurement is taken in the left-turn lane and this movement is quite heavy in the a.m. for buses inbound from Maryland. It might be concluded, therefore, that gains to individual buses through actuations have disturbed this sensitive offset and increased overall delay. The effect of extensions granted northbound for "dead-heading" buses might also be a factor, since these are conflicting movements.

Three other substantial increases in delay for the a.m. peak occurred on all three approaches at 18th Street and Pennsylvania Avenue. In addition, increases were recorded at four of the five upstream and downstream locations where data were available, indicating a general failure in the area. The effects of the surrounding locations must be tempered by the existence of additional BPS detectors on each of them.

Identifying a causal pattern at this location is quite difficult. Field observations during the collection of detailed bus performance data indicate that additional pedestrian interference, particularly with the right turn from 18th Street onto Pennsylvania Avenue, might be a contributing factor, as pedestrians disobey the walk signals and continue to cross when the extension is granted.

Few well-defined relationships are apparent for other locations with substantial gains or losses in delay. In fact, three of the four approaches showing gains over 20 vehicle-minutes in the p.m. are at locations with little or no BPS control. (The fourth location is in the triangle discussed above). Significant improvement occurred westbound on K Street in the a.m. at most intersections and although this might be traced to an improvement in offset triggered by "dead-heading" buses, it might also be caused by changes in traffic response at the "metering point" caused by Metro construction at Connecticut Avenue.

An extremely large increase in delay was recorded for southbound 16th Street at K Street. No apparent reason can be determined for this result, and in the absence of further information, detector problems might be presumed to be causing erroneous readings. Several additional locations showed substantial changes both with and without BPS activity and probably represent only normal fluctuations.

BPS Intersection Impact Analysis

This section describes the impact of the BPS alternative on bus travel at intersections. The data for studies at 18th Street and Pennsylvania Avenue are shown on Table 28. Departure time as used on the table means the total travel time, in minutes, from the upstream bus detector to the far side of the signalized intersection (as noted by the crosswalk). Dwell time is the time, in minutes, that the bus was stopped at the intersection regardless of cause. Comparisons are between buses with and buses without transmitters as measured during the BPS test period. The table represents data summarized for the a.m., midday, and p.m. periods. The table indicates a reduction in travel time of 4.2% for buses with transmitters. The information for this intersection broken down by time period is shown on Table 29.

During the midday period, there is a significant reduction in delay time for all directions. Although there is a proportionate reduction in the total number of buses, the percentage of the transmitter-equipped buses remains approximately the same.

At 18th Street and Pennsylvania Avenue during the a.m. peak period, a 19.1% increase in delay to northbound buses was noted. This is attributable in part to the conflict with pedestrians at this location. As indicated on the measures of effectiveness summary tapes of the UTCS system, priority was given to buses by extension of the green time. However, pedestrians utilized the additional time to cross the street, thus preventing full utilization of this time by the buses. This is especially apparent for the northbound buses on 18th Street where the major movement is a right turn onto Pennsylvania Avenue. Other buses were, to a large extent, helped.

At the second location, 14th and K Street, 2,695 buses were observed during the data collection period for the BPS alternative. This total includes 873 buses (32 percent) equipped with the detector-transmitter device. In addition to the buses from the three division where the detector-transmitter equipped buses are stored, most of the routes assigned to a division serving the Virginia suburbs pass through this intersection traveling eastbound and westbound. None of these buses are equipped with detector transmitters, although they have a significant

Table 28. Summary of BPS intersection performance.

Intersection 18th Street & Pennsylvania Avenue

	MEAN TIMES IN MINUTES		PERCENTAGE DIFFERENCE
	B.P.S. Transmitters		With vs Without
	With	Without	
DEPARTURE TIME			
Northbound	1.194	1.241	+ 3.8
Eastbound	.798	.873	+ 8.6
Westbound	.700	.740	+ 5.4
Average all approaches			+ 5.93
DWELL TIME			
Northbound	.714	.776	+ 8.0
Eastbound	.374	.455	+17.8
Westbound	.419	.418	- 0.2
Average all approaches			+ 8.53

Note: + indicates improvement with transmitters
- indicates degradation with transmitters

Table 29. Time period breakdown of intersection performance - BPS.

Intersection 18th Street & Pennsylvania Avenue

	Time Period	MEAN TIMES IN MINUTES B.P.S. Transmitters With	Without	PERCENTAGE DIFFERENCE With vs Without
DEPARTURE TIME				
Northbound	a.m.	1.09	.915	- 19.1
	midday	1.09	1.337	+ 18.5
	p.m.	1.353	1.436	+ 5.8
Eastbound	a.m.	.841	.965	+ 12.8
	midday	.686	.759	+ 9.6
	p.m.	.822	.822	0
Westbound	a.m.	.748	.702	- 6.5
	midday	.481	.831	+ 42.1
	p.m.	.794	.734	- 8.1
DWELL TIME				
Northbound	a.m.	.627	.513	- 22.2
	midday	.57	0.89	+ 35.9
	p.m.	.874	.906	+ 3.7
Eastbound	a.m.	.414	.515	+ 19.6
	midday	.269	.349	+ 22.9
	p.m.	.399	.439	+ 10.0
Westbound	a.m.	.463	.432	- 7.1
	midday	.241	.331	+ 27.2
	p.m.	.488	.45	- 8.4

Note: + indicates improvement with transmitters
- indicates degradation with transmitters

impact on the flow of traffic through this intersection.

The summary of delay for all observations at this location, shown on Table 30, indicates a significant decrease in delay time for detector-transmitter equipped buses when compared to the bus delay for the non-equipped buses. Review of Table 31, showing a breakdown by time period, reinforces the summary data. In all but two entries, significant improvement occurred.

There are high volumes of pedestrian traffic at this intersection. The impact is not, however, as significant as are the high pedestrian traffic volumes at 18th and Pennsylvania Avenue. Most of the routes continue through this intersection without turning. The buses are able to fully utilize the priority timing when it is granted by the system. The results at 14th and K Street are the most consistent and impressive of those found during the study.

Wisconsin Avenue and Macomb Street was selected as a location because it was representative of a collector street crossing a principal arterial with bus traffic on the arterial. Because of this, the potential of each instrumented bus receiving priority was considered to be high. The size of the sample was limited by the fact that only one principal route used this section of the system.

The analysis of the delay summaries, shown on Table 32, indicate significant reduction in delay for the instrumented buses when compared to the non-instrumented buses observed during the same control alternative. An overall time reduction of 7.0% was observed. Of special note is that spacing of vehicles was such that most of the buses arrived independently of other buses. The minimum of demand from cross street traffic permitted granting of priority when requested.

<u>BPS Route Analysis</u>

The performance of buses traveling through the system on scheduled routes was evaluated from the data recorded as noted earlier. The observations were limited to buses on three basic routes. The "Pennsylvania Avenue" routes entered or exited at 17th Street and Pennsylvania Avenue and exited or entered at Wisconsin Avenue at Macomb Street, a distance of approximately 3.5 miles. The other routes entered on K Street at 14th Street and exited on 20th Street at L Street westbound. The lines entered on 21st Street at L Street and exited on K Street at 14th Street. The distance is approximately .93 miles.

Table 30. Summary of intersection performance - BPS.

Intersection 14th Street & K Street

	MEAN TIME IN MINUTES		PERCENTAGE DIFFERENCE
	B.P.S. Transmitters		With vs Without
	With	Without	
DEPARTURE TIME			
Northbound	.917	1.003	+ 8.6
Southbound	1.203	1.349	+ 10.8
Eastbound	.701	.755	+ 7.2
Westbound	.580	.676	+ 14.2
Average all approaches			+ 10.2
DWELL TIME			
Northbound	.593	.679	+ 12.7
Southbound	.885	1.033	+ 14.3
Eastbound	.451	.500	+ 9.8
Westbound	.327	.424	+ 22.9
Average all approaches			+ 14.92

Note: + Indicates improvement with transmitter
- Indicates degradation with transmitter

Table 31. Time period breakdown of intersection performance - BPS.

Intersection 14th Street & K Street

	Time Period	MEAN TIMES IN MINUTES B.P.S. Transmitters With	 Without	PERCENTAGE DIFFERENCE With vs Without
DEPARTURE TIME				
Northbound	a.m.	.808	.950	+ 14.9
	midday	.962	.915	- 5.1
	p.m.	.978	1.132	+ 13.6
Southbound	a.m.	1.24	1.366	+ 9.2
	midday	1.049	1.303	+ 19.5
	p.m.	1.253	1.368	+ 8.4
Eastbound	a.m.	.655	.716	+ 8.5
	midday	.661	.755	+ 12.5
	p.m.	.785	.800	+ 1.9
Westbound	a.m.	.558	.633	+ 11.8
	midday	.528	.641	+ 17.6
	p.m.	.616	.743	+ 17.1
DWELL TIME				
Northbound	a.m.	.532	.650	+ 18.2
	midday	.659	.629	- 4.4
	p.m.	.611	.752	+ 18.8
Southbound	a.m.	.951	1.055	+ 10.0
	midday	.759	.979	+ 22.5
	p.m.	.892	1.051	+ 15.1
Eastbound	a.m.	.404	.464	+ 13.3
	midday	.423	.495	+ 14.5
	p.m.	.531	.544	+ 2.4
Westbound	a.m.	.322	.397	+ 18.9
	midday	.296	.373	+ 20.6
	p.m.	.342	.483	+ 29.2

Note: + indicates improvement with transmitters
- indicates degradation with transmitters

Table 32. Summary and time period breakdown of intersection performance - BPS.

Intersection Wisconsin Avenue & Macomb Street

	Time Period	MEAN TIMES IN MINUTES B.P.S. Transmitters With	Without	PERCENTAGE DIFFERENCE With vs Without
DEPARTURE TIME				
Northbound	a.m.	.336	.313	- 7.3
	midday	.445	.468	+ 4.9
	p.m.	.366	.390	+ 6.2
Southbound	a.m.	.344	.406	+ 15.3
	midday	.531	.416	- 27.6
	p.m.	.350	.431	+ 18.8
Average all approaches				+ 2.58
DWELL TIME				
Northbound	a.m.	.159	.133	- 19.5
	midday	.212	.230	+ 7.8
	p.m.	.166	.189	+ 12.2
Southbound	a.m.	.136	.186	+ 26.9
	midday	.283	.196	- 44.3
	p.m.	.149	.212	+ 29.7
Average all approaches				+ 3.2

Note: + indicates improvement with transmitters
- indicates degradation with transmitters

Table 33 summarizes the data for the shorter routes using K Street for their primary path. The route travel time was reduced somewhat in essentially all cases. An overall reduction of approximately three percent was noted.

Table 34 shows information for the longer routes using Pennsylvania and Wisconsin Avenues. The overall impact of the observations was negative. Although no specific rationale is apparent for this result, it is probable that the signal impact on the long travel time was overshadowed by other stream characteristics. Further, the sample size on the long route proved to be too small for assessing high level significance of the results.

UTILITY OF THE DETECTOR-BASED EVALUATION MEASURES

Although the primary focus of this study was on the evaluation of the first-generation traffic control strategies, an additional objective was to assess the efficacy of the UTCS/BPS detector surveillance system for purposes of evaluation. The extensive set of travel time data produced by the moving cars provided the primary means of comparison. In addition, several field investigations were conducted to examine three detector-generated MOE's: volume, average delay, and average queue length.

Detector/Moving Car Comparisons

The performance measurements produced by the UTCS detector surveillance system and by the moving cars were different in several important respects. While the detector measures of effectiveness were generated as 15-minute averages of overall traffic performance on an intersection approach, the moving cars recorded only one (presumably representative) vehicle's performance. The travel times derived from the latter technique were therefore considerably sensitive to fluctuations in traffic as well as to differences in the control system. Both methods were subject to measurement error: the detector computations involved assumptions about uniform traffic behavior which were somewhat unrealistic (e.g., lane discipline, average vehicle length) while the moving car travel times were probably influenced by the characteristics of the individual drivers. In addition, the sets of intersection approaches covered by the detector surveillance system and by the moving car routes were substantially different, although some overlap was present, particularly along the major arterials.

Table 33. Summary of route performance - BPS.

Eastbound
Entry Location - 21st Street at L Street, N. W.
Exit Location - K Street at 14th Street, N. W.
Distance - .93 miles

Westbound
Entry Location - K Street at 14th Street, N. W.
Exit Location - 20th Street at L Street, N. W.
Distance - .82 miles

	Time Period	MEAN TIMES B.P.S. Transmitters With	MEAN TIMES B.P.S. Transmitters Without	PERCENTAGE DIFFERENCE With vs Without
Eastbound	a.m.	7.92	8.46	+ 6.38
	midday	8.88	8.59	- 3.37
	p.m.	10.00	10.24	+ 2.34
	All	9.06	9.21	+ 1.62
Westbound	a.m.	6.45	6.79	+ 5.00
	midday	7.33	7.44	+ 1.47
	p.m.	9.96	9.11	+ 1.64
	All	7.52	7.86	+ 4.32
Average all Directions		8.32	8.57	+ 2.91

Note: + Indicates improvement with transmitters
- Indicates degradation with transmitters

Table 34. Summary of route performance - BPS.

Eastbound
Entry Location - Wisconsin Avenue at Macomb Street, N. W.
Exit Location - Pennsylvania Avenue at 17th Street, N. W.

Westbound
Entry Location - Pennsylvania Avenue at 17th Street, N. W.
Exit Location - Wisconsin Avenue at Macomb Street, N. W.

Distance - 3.5 miles

	Time Period	MEAN TIMES B.P.S. Transmitters With	Without	PERCENTAGE DIFFERENCE With vs Without
Westbound	a.m.	22.78	22.12	- 2.98
	midday	23.93	23.99	+ 0.25
	p.m.	27.34	26.50	- 3.16
	All	25.13	24.43	- 2.85
Eastbound	a.m.	24.11	23.56	- 2.33
	midday	23.70	23.08	- 2.68
	p.m.	25.50	25.64	+ 0.54
	All	24.36	23.86	- 2.09
Average all directions				- 1.73

Note: + Indicates improvement with transmitter
- Indicates degradation with transmitter

Despite these problems and apparent differences, both methods could be expected to produce somewhat similar assessments for locations where traffic performance was monitored by both the detectors and the moving cars. These locations were identified for each signal alternative/time period comparison; the number of locations varied from 29 to 46 depending on the set of operational detectors. For each location within each comparison, the presence--if any--of a statistically significant difference at the 5% or greater level as indicated by the Kolmogorov-Smirnov test was recorded for both the detector-generated delay measurement and the moving car travel time measurement. The consistency of the statistical inferences for each individual location was then determined.

Table 35 illustrates the comparisons of the detector and moving car results for the a.m. traffic period. The table is divided into three major categories which correspond to the level of consistency between the two measurement techniques. The first category, comprised of the first four rows, identifies the number of locations (for each comparison) for which both the detectors and the moving cars produced the same statistical inferences. The second category, comprised of the next five rows, identifies the number of locations for which one measurement technique produced significant differences between the traffic control alternative while the other did not. The third category illustrates the number of locations for which the detector and moving car results were contradictory, i.e., one method indicated improvement while the other method indicated degradation--both results being statistically significant at the 5% level. Within each section, the locations are classified according to the direction of the results, e.g., "A > B" in the first column indicates that the base (TRSP) produced lower travel times than the other control alternative under consideration (i.e., Alternative B). To further illustrate, there were four locations (13.8%) in the CIC/TRSP comparison for which the moving car travel times were not statistically different but the detector-generated average delay differences showed significant improvement under CIC.

The high level of consistency of the detector and moving car performance measures is illustrated in the results for the 3-dial case. Over 45% of the links showed agreement, while only 9% of the locations exhibited contradictory results. The remaining control alternatives produced substantially fewer statistically significant differences, resulting in a somewhat different pattern. Specifically, most of the locations failed to produce statistically significant differences under either of the measurement

Table 35. Comparison of statistical results of moving car and detector analyses: a.m.

			3-DIAL		TOD		CIC		BPS	
	MCAR	DET	n	%	n	%	n	%	n	%
SAME INFERENCE	A>B	A>B	8	17.4	1	2.2	2	6.9	4	11.1
	insig.	insig.	9	19.6	32	69.6	13	44.8	22	61.1
	A<B	A<B	4	8.7	0	0.0	1	3.5	0	0.0
	total		21	45.6	33	71.7	16	55.2	26	72.2
DIFFERING SIGNIFICANCE	insig.	A>B	11	23.9	6	13.0	3	10.3	3	8.3
	insig.	A<B	4	8.7	0	0.0	4	13.8	1	2.8
	A>B	insig.	2	4.3	6	13.0	1	3.5	3	8.3
	A<B	insig.	4	8.7	1	2.2	5	17.2	3	8.3
	total		21	45.6	13	28.3	13	44.8	10	27.8
CONFLICTING INFERENCE	A>B	A<B	2	4.3	0	0.0	0	0.0	0	0.0
	A<B	A>B	2	4.3	0	0.0	0	0.0	0	0.0
	total		4	8.7	0	0.0	0	0.0	0	0.0
	grand total		46	100.0	46	100.0	29	100.0	36	100.0

Note: A = base case (TRSP)
B = control alternative
> = better, e.g., less delay
N = number of locations

methods. One important observation is that no location produced statistically significant contradictory results (i.e., no entries in the last three rows) under the TOD, CIC, and BPS control strategies.

Table 36 presents the analogous summary for midday traffic conditions. As in the a.m. period, the 3-dial case showed a high proportion of statistically significant differences under both measurement methods. For 23% of the locations, the moving cars and detectors both produced significant differences; only 8% of the locations generated contradictory results. The three remaining comparisons closely resemble the a.m. results, although almost 20% of the locations under BPS were found to change significantly (in the same direction) under both measurement techniques.

The statistical comparisons for the p.m. peak are listed in Table 37. The patterns identified for the a.m. and midday traffic periods are also apparent in this table. Although over 80% of the locations under TOD are consistent in that both the detectors and the moving cars did not generate statistically significant changes, it is interesting to note that of the seven locations where differences were found, none were statistically different under both measurement strategies.

These comparisons demonstrate a relatively high degree of similarity between the evaluation results produced by the detector surveillance system and the moving cars for individual links. Actual contradictory inferences are extremely rare. The "nonsignificant" entries may, however, mask some inconsistencies. In addition, the magnitudes of the differences between the control strategies as measured by the detectors and the moving cars for an individual link may indeed vary substantially even though the statistical inferences may be identical.

Measurement of Volume

The volume measurements generated by the UTCS detector-based surveillance system were extremely important in the evaluation effort for two reasons. First, the detector volumes were used to estimate the level of network "demand" which in turn permitted the selection and matching of observations for statistical purposes. The matching procedures which were developed for the detector data and the moving car data were described in the preceding chapter. Second, these volumes were used in the actual computations of the other detector-based MOE's. Erroneous volumes could be expected to also be reflected in the computed delay values.

Table 36. Comparison of statistical results of moving car and detector analyses: midday

			3-DIAL		TOD		CIC		BPS	
	MCAR	DET	n	%	n	%	n	%	n	%
SAME INFERENCE	A>B	A>B	2	5.3	1	2.9	1	2.9	5	13.9
	insig.	insig.	6	15.8	22	62.9	25	73.6	17	47.2
	A<B	A<B	7	18.4	0	0.0	0	0.0	2	5.6
	total		15	39.5	23	65.7	26	76.5	24	66.7
DIFFERING SIGNIFICANCE	insig.	A>B	7	18.4	4	11.4	4	11.8	4	11.1
	insig.	A<B	8	21.1	1	2.9	2	5.9	3	8.3
	A>B	insig.	2	5.3	5	14.3	1	2.9	5	13.9
	A<B	insig.	3	7.9	1	2.9	1	2.9	0	0.0
	total		20	52.6	11	31.4	8	23.5	12	33.3
CONFLICTING INFERENCE	A>B	A<B	2	5.3	1	2.9	0	0.0	0	0.0
	A<B	A>B	1	2.6	0	0.0	0	0.0	0	0.0
	total		3	7.9	1	2.9	0	0.0	0	0.0
	grand total		38	100.0	35	100.0	34	100.0	36	100.0

Note: A = base case (TRSP)
B = control alternative
> = better, e.g., less delay
N = number of locations

Table 37. Comparison of statistical results of moving car and detector analysis: p.m.

			3-DIAL		TOD		CIC		BPS	
	MCAR	DET	n	%	n	%	n	%	n	%
SAME INFERENCE	A>B	A>B	8	21.1	0	0.0	2	5.9	2	5.9
	insig.	insig.	5	13.2	30	81.1	20	58.8	19	55.9
	A<B	A<B	2	5.3	0	0.0	0	0.0	0	0.0
	total		15	39.5	30	81.1	22	64.7	21	61.8
DIFFERING SIGNIFICANCE	insig.	A>B	7	18.4	0	0.0	10	29.4	5	14.7
	insig.	A<B	10	26.3	3	8.1	1	3.0	4	11.8
	A>B	insig.	1	2.6	3	8.1	0	0.0	4	11.8
	A<B	insig.	1	2.6	1	2.7	0	0.0	0	0.0
	total		19	50.0	7	18.9	11	32.4	13	38.2
CONFLICTING INFERENCE	A>B	A<B	1	2.6	0	0.0	0	0.0	0	0.0
	A<B	A>B	3	7.9	0	0.0	1	3.0	0	0.0
	total		4	10.5	0	0.0	1	3.0	0	0.0
	grand total		38	100.0	37	100.0	34	100.0	34	100.0

Note: A = base case (TRSP)
B = control alternative
> = better, e.g., less delay
N = number of locations

The central importance of the detector volumes resulted in two separate studies to assess the accuracy of this measure. The first study compared actual field observations of lane-specific and total approach volume against the corresponding detector volumes. The second study utilized conventional mechanical counters to produce approach volumes for comparison against the (lane-specific) detector measurements.

Field Study

The primary objective was to determine the degree to which the detector measurements of volume corresponded to actual field measurements of volume in the detectorized lane. A secondary objective was to explore the feasibility of developing a set of generalized factors which could be applied to the detector volumes in order to approximate total approach volumes.

A total of 53 approach links from 19 intersections were examined. These approaches were felt to be representative of all types of geometric and traffic conditions found within the UTCS study area. The durations of the counts typically ranged from 45 to 60 minutes; most approaches were counted only once, although six approaches were counted in two separate time periods to assess the variability resulting from changes in traffic conditions.

Cycle-by-cycle volume measurements were recorded directly from the CRT displays at the UTCS control center concurrently with the manual vehicle counts at the intersections. These field volume measurements were taken by lane to facilitate later analyses. Because of problems associated with unpacking the smoothed cycle-by-cycle volume measurements taken from the CRT displays and synchronizing the field counts with the cycle-specific detector data, only the 15-minute volume measurements from the UTCS summary tapes were used for purposes of comparison.

For each individual approach, the ratios of field lane volume/detector lane volume and field approach volume/detector lane volume were computed for each 15-minute interval. The average ratios were then computed separately for all one, two, three, and four lane approaches. These average ratios and their corresponding standard deviations are listed in Table 38. In order to assess the stability of the ratios under different traffic conditions, separate tabulations were prepared for the six approaches which were counted in separate time periods. These ratios are presented in Table 39.

Table 38. Comparison of field volumes to detector volumes.

No. Lanes	Sample Size	Field Lane Vol./Det. Lane Vol.		Field Approach Vol./Det. Lane Vol.	
		Avg. Ratio	Stan. Dev.	Avg. Ratio	Stan. Dev.
1	6	.955	.333	--	--
2	77	.949	.426	1.761	.895
3	47	.940	.194	2.287	.780
4	47	.883	.193	2.472	.653

Table 39. Stability of field/detector volume ratios.

Inter-section	Approach	No. Lanes	Time Period	Field Lane Vol./ Det. Lane Vol.	Field Approach Vol./ Det. Lane Vol.
Wisconsin & M	WB	4	A.M.	.952	1.615
	WB	2	M.D.	.874	2.463
	NB	2	A.M.	1.107	1.770
	NB	2	M.D.	.986	1.573
	EB	2	A.M.	1.025	2.841
	EB	4	M.D.	.956	1.636
Wisconsin & Garfield	WB	1	A.M.	1.060	--
	WB	1	P.M.	.849	--
	EB	1	A.M.	.859	--
	EB	1	P.M.	.657	--
	SB	3	A.M.	1.114	3.160
	SB	3	P.M.	1.043	3.871

The lane-to-lane volume comparisons across all observations (Table 38) demonstrate the high overall accuracy with which the detector surveillance system can measure volume. However, the relatively large standard deviations illustrate the substantial variations in accuracy to be found among the individual approaches. The 15-minute volume ratios, in fact, varied from .391 to 3.107. The stability of the individual approach ratios over time is indicated in Table 39. The approach links at Wisconsin Avenue and M Street were relatively stable with differences in the volume ratios computed for the a.m. and (late) midday time periods, ranging from 7% to 12%. The ratios of the Wisconsin Avenue and Garfield Street intersection approaches were considerably less stable; the differences in the a.m. and p.m. ratios ranged up to 27%.

A field inspection of several "problem" detectors by FHWA personnel appeared to indicate that the inaccuracies were not due to detector malfunctions. The most probable causes of detector inaccuracy are directly related to traffic behavior. Since the volume counts are averaged for all detectors on a link, vehicle movements either into or out of the detectorized lane will result in unrealistic discharge volumes. The field examination of detector operation showed that vehicles which straddle the lane boundary can occasionally trip the detectors; this problem could be expected to occur at locations where the lanes are narrow or poorly marked (e.g., cross streets along Wisconsin Avenue).

Based on the results of the field study, several detectorized approaches which exhibited substantial measurement errors were eliminated from the set of links used in the actual evaluation of the first-generation alternatives. It is interesting to note that during initial tests of the UTCS evaluation software (described in the preceding chapter) many of these inaccurate detector links were eliminated by internal data checking routines.

The average ratios of total approach volumes (from field counts) to detectorized lane volume (from the surveillance system) are also presented in Table 38 for approaches with two, three, or four lanes. Although the ratios are larger for approaches with greater numbers of lanes, the increases are not proportional. Also, the standard deviations are very high, indicating substantial variations among the approaches. An examination of the last column in Table 39 illustrates the extreme instability of these ratios, even for individual approaches, over time. This instability was the major reason why factors to "weight" the detector output MOE's proved to be impractical; this problem was further investigated in the study described in the following section.

Road Tube Analysis

An extensive program of machine volume counts was established in a further attempt to develop factors to expand the lane-specific detector measurements to represent total approach performance. It was also felt that these volume counts could be used in the estimation of overall network traffic demand to permit effective statistical matching of observations collected several months apart.

Twenty-five locations were selected as being representative of all intersection approaches in the network and road tubes were installed at each. Counters were attached to approximately half of the locations full time and on alternate weeks at the remaining. The list of road tube locations together with the associated UTCS detectors is given in Table 40.

Detectors were located at 23 of the 25 sites. For comparative purposes, detectors at the next detectorized intersection downstream were identified for the other two locations. Of the remaining, two detectors were generally not functioning during the study. Intermittent failures were also detected at locations 15 and 25; other malfunctions were suspected but could not be readily identified.

In order to compare road tube and detector readings under a variety of conditions, data were assembled for each location for approximately a two-week period at 15-minute sampling intervals. Detector data were extracted from the 15-minute summary computer tapes and road tube data were coded directly from the counter tapes. Separate analyses were conducted for the a.m., midday, and p.m. periods.

A special purpose computer program was written to extract and match the detector and road tube volumes. A second program was developed to prepare computer plots for each location and time of day, and to compute the regression of the road tube data upon the detectors. The purpose of the latter exercise was to develop regression coefficients that could be used to expand detector data to total approach volumes.

Unfortunately, the exercise was not overly successful. At best, about a half dozen locations showed consistent relationships. An example of this is shown in Figure 24. Many locations show considerable scatter of points and only very slight directionality. Figure 25 is a typical example,

Table 40. Road Tube Locations.

Road Tube	Detector	Location
1	42	SB Wisconsin @ Macomb
2	20	NW Massachusetts @ Wisconsin
3	36*	NB Wisconsin @ R
4	11	SB Wisconsin @ M
5	151	EB L @ 18th
6	114	EB K @ 20th
7	158	WB K @ 16th
8	187	NB 14th @ K
9	98	NW Pennsylvania @ 20th
10	171*	WB H @ Connecticut
11	177	SB 16th @ H
12	99	NB 20th @ H
13	63	NB 18th @ Pennsylvania
14	69	SB 17th @ Pennsylvania
15	68	SB Pennsylvania @ 17th
16	255	SB 21st @ G
17	(1)	SB 19th @ G
18	249	WB G @ 18th
19	242	NB 17th @ F
20	224	WB E @ 19th
21	237	EB E @ 18th
22	(2)	SB 23rd @ C
23	198	EB Constitution @ 23rd
24	202	EB Constitution @ 21st
25	215	WB Constitution @ 17th

* Detector not functioning properly.

(1) No detector; location 226 (SB 19th @ E) used for comparisons only.

(2) No detector; location 199 (SB 23rd @ Constitution) used for comparisons only.

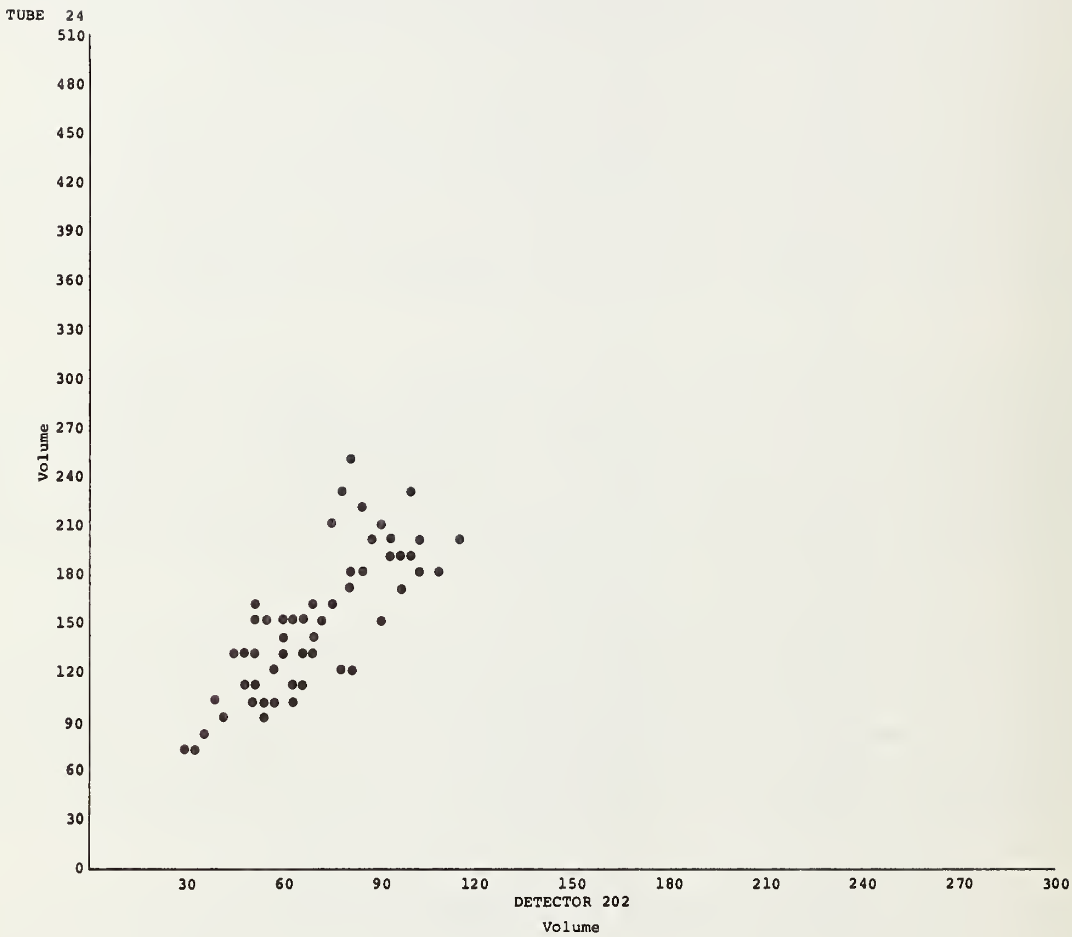

Figure 24. Eastbound Constitution Avenue at 21st Street.

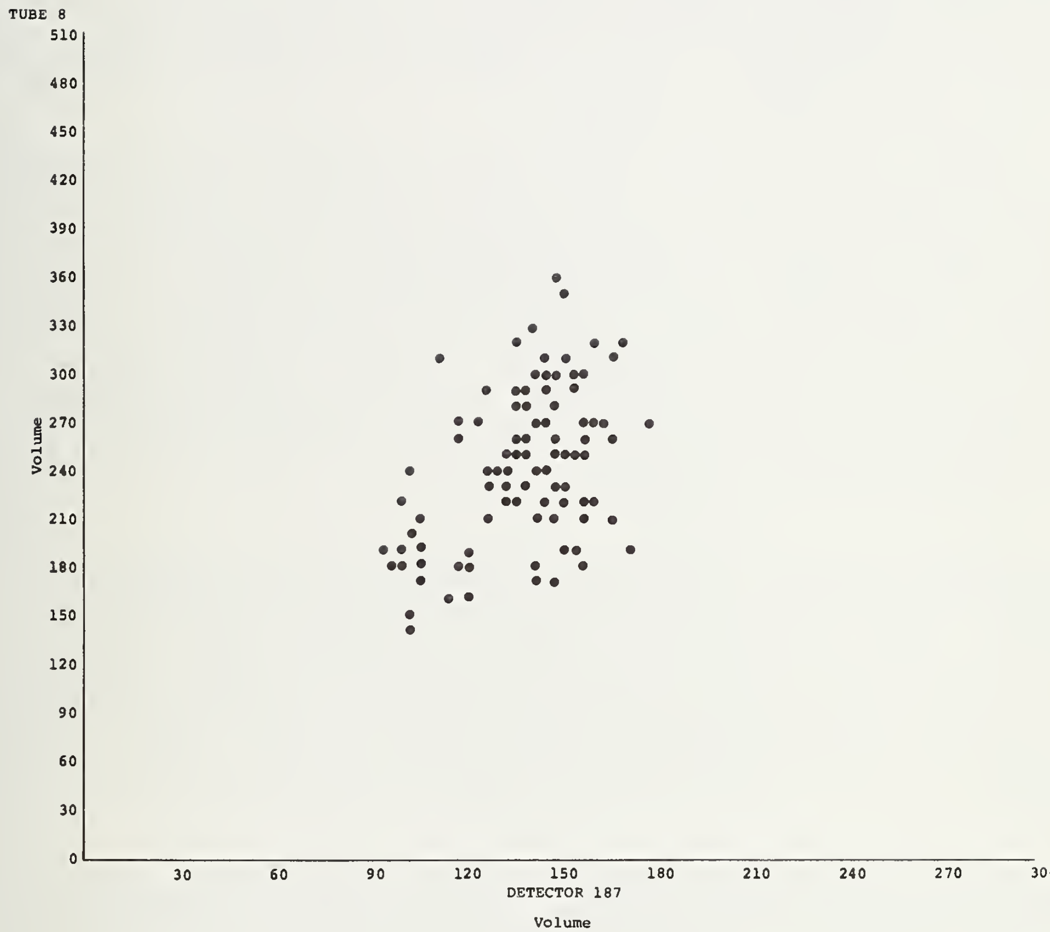

Figure 25. Northbound on 14th at K Street.

although some others were even less well identified or showed negative slopes.

Some of the inconsistency should be anticipated, as a linear relationship may not hold with increasing volume. Since the detector is typically in a "preferred" lane, it will record a greater proportion of total approach flow under low volume conditions than under high volumes. Moreover, as the street approaches saturation, the detector volume will reach a maximum value while the approach volume may continue to rise, at least over a limited range. Some of the locations, such as shown in Figure 26, appear to show this asymptotic effect.

Some discrepancies might also be explained by the nature of the detector counts. At multiple detector sites, recorded values are averages over the two or three detectors which could, under certain circumstances, produce a count which is not representative of traffic performance. Lane changing, parking, buses, construction, and other obstacles destroy lane discipline and smooth flow. In some cases, this could give faulty readings on one or more detectors of a multiple installation. Similarly, detector placement on narrow streets or locations with poor lane discipline may yield multi-lane actuations.

However, if a persistent lane blockage existed for a substantial portion of a 15-minute period, the detector readings might be quite correctly different than if the blockage did not occur. If the detectorized lane itself were blocked, then the readings would be low with respect to the road tube volumes and, presumably, the actual volumes. If another normally traveled lane were blocked, then the detector volumes would record a greater proportion of total traffic.

All consistent and "explainable" cases do not, however, cover all of the observations. In some cases, detector malfunctions of various kinds were suspected. In addition to normal failures caused by tubes pulling loose or counters sticking and data which were eliminated before analysis, some systematic problems were observed. For example, poor pavement condition at some locations appeared to cause counting problems as the tubes were not crossed smoothly.

Therefore, few general conclusions can be drawn from the analysis. The data collection technique itself, while far from perfect, does yield results similar to those found in a preliminary examination involving manual volume counts. Thus, the problems may relate more to the complexity of

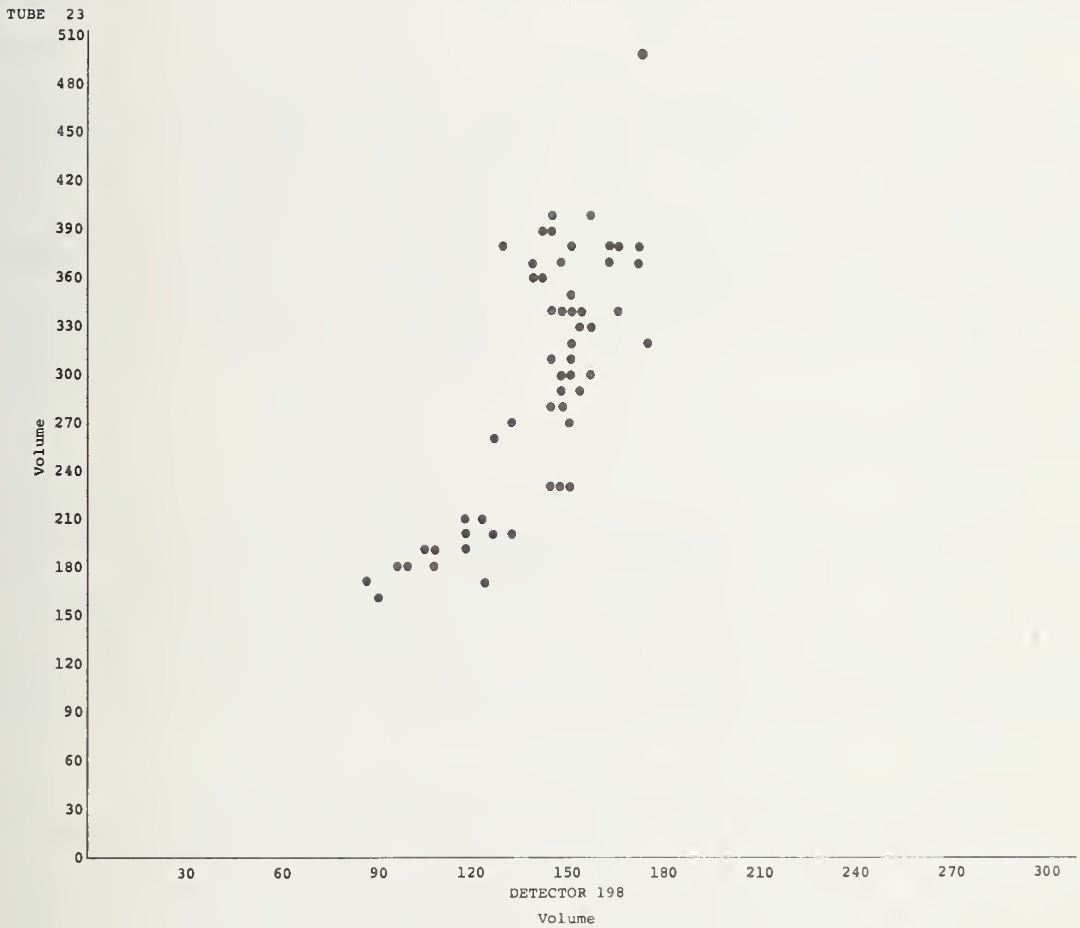

Figure 26. Eastbound on Constitution Avenue at 23rd Street.

phenomena and the inability to measure compatible events, than to any inherent errors or data problems. The questions are being approached under the on-going project.

The regression summaries were not considered reliable indicators of the relationship between road tube and detector readings. A simple computation of the ratio between the average volumes may be compared to effective available lanes. Such a comparison is made in Table 41, with surprising agreement among the computed values for the three time periods and a reasonable "correlation" with number of lanes.

Although the ratios listed in Table 41 appear to be substantially more stable than those examined in the field investigation described in the preceding section, the variations between individual count locations suggested that generalized factors to expand the lane-specific detector measures of effectiveness were impractical. The variations, coupled with the relatively poor coverage of the network by machines, resulted in the use of the volume data provided by the UTCS surveillance system in the statistical analysis procedures.

Measurement of Delay

Stopped time delay data were collected in a traditional traffic engineering fashion on eastbound Pennsylvania Avenue at 18th Street during the evaluation of the CIC control pattern. This data collection effort has been described more fully in an earlier chapter. The procedure was designed partly as a pilot test to a more extensive stopped time delay effort which may be proposed for second and third generation software evaluations.

The data were collected for two primary purposes. First, the information was to be used in comparing stopped time delay computing in a traditional traffic engineering fashion with the average delay measure of effectiveness produced by the UTCS software. Second, a direct comparison of the stopped delay values under CIC and its related base case would provide an additional and independent evaluation measure, one related directly to microscopic intersection performance.

The stopped time delay calculations were made and summarized by 15-minute periods. The observations were then matched with the average delay from the corresponding UTCS detector installation for the appropriate 15-minute period. Separate summaries were then made for the CIC base case and each of the three time periods: a.m., midday, and p.m.

Table 41. Road tube/detector volume ratios.

Tube	AM		MD		PM	
	Ratio	Lanes	Ratio	Lanes	Ratio	Lanes
1	1.75	3	1.88	2	1.63	2
2	1.97	2+RT	2.00	2+RT	1.91	2+RT
3						
4	2.26	2	1.98	1+	2.33	2
5	3.16	3+	3.28	3	3.28	3
6	1.84	2	2.36	2	1.84	2
7	2.33	2	2.17	2	1.85	2
8	1.94	2+ LT	1.90	2+LT	1.83	2+LT
9	2.16	2	1.83	2	1.88	3
10						
11	1.13	1+	1.09	1+	1.24	1+
12	2.76	3	1.48	1+	1.83	2
13	2.27	4	1.56	2	1.68	2
14	1.96	2+	1.78	2	2.19	2+
15	1.98	3	1.92	2	2.12	2
16	1.87	2	1.49	1+	1.75	2
17	3.39	3	2.04	2	1.98	3
18	1.39	2±	1.30	1±	1.63	2±
19	1.16	2	1.11	1+	1.02	1+
20	2.27	3	2.13	2	3.68	4
21	2.27	4	2.09	2	1.92	2
22	2.15	3	2.22	3	2.31	3
23	2.14	3	1.93	3	1.92	3
24	2.52	3+LT	2.20	3+LT	2.22	3+LT
25	3.24	3	3.00	3	3.42	4

Between 29 and 50 matching values were found for each of the six comparisons.

Mean values of delay from the detector and field measures were computed for each of the periods and are summarized in Table 42. As can be seen, the field values are considerably larger in all cases, ranging from 30% to 80%. However, the detector values are higher under CIC for all three time periods, while the field results are higher only for the p.m. period. This results in the smaller ratios for CIC.

An attempt was made to compute a correlation coefficient between the field and detector results. Although the p.m. and midday periods showed some consistency, the a.m. showed an almost total lack of correlation. When the a.m. data were examined in detail, however, a very interesting pattern emerged. For the earliest time periods (7:15 and 7:30), the detector values are approximately double the field values. About 8:00, the two values are very similar; while from 8:15 through 9:30, the field observations are from two to three times the detector values. Thus, a very considerable time bias exists in the a.m. data and simple correlations are meaningless.

A simple comparison of the differences between CIC and the base case were examined and are summarized in Table 43. In addition, similar results from the general evaluation of detector performance and moving car results for the link in question are shown. The stopped time delay results do not closely agree with the findings from the other data collection procedures.[1]

The differences in magnitude of the delay values do not in any way suggest that the detector computations are incorrect. Rather, the measures reflect two different aspects of the same phenomenon. However, it is believed that the results are influenced strongly by the character of the approach. A relatively heavy left-turning movement exists

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1. The calibration and evaluation detector results are taken from the same source, with the former consisting of about one-third to one-half of the points included in the latter. The rather large differences in the p.m. results are due to the exclusion of a number of rather large points for which field data were not collected. This was partly caused by the fact that the sample of field data was not uniform across the peak perid.

Table 42. Stopped time delay from field observation vs. average daily from detector.

Test	Time	Sample Size	Average Delay Detector	Field	Field/Detector
BASE	AM	33	12.7	22.7	1.79
	MD	29	16.1	27.2	1.69
	PM	33	8.5	13.5	1.59
CIC	AM	50	14.8	19.2	1.30
	MD	47	16.6	24.2	1.46
	PM	47	11.7	16.4	1.40

Table 43. Percentage differences in delay under CIC.

Time	Calibration		Evaluation	
	Field	Detector	Detector	Moving Car
AM	16.9	-15.3	-12.0	0.1
MD	11.7	- 3.0	- 2.4	-22.2
PM	-19.4	-31.7	-54.1	-31.2

which causes considerable delay except in the very early parts of the a.m. peak. The stopped delay, being measured across all lanes, is highly sensitive to the left-turn queue. The detector results, and to a lesser degree, the moving car measurements, reflect only through traffic in another lane.

The differential impact of the two control alternatives on left turn performance might explain the differences in inferences noted in Table 43. If, for example, the signal offsets under one pattern produced different gaps in the oncoming traffic, then the left turn delay might be altered significantly. Also, since the delay measured by the detectors is imputed largely from speeds and inferred queues, slight differences in signal progression might yield different results.

In summary, this study, while not highly successful, points up many of the complications in dealing with traffic performance measures derived from an automated system. It also points toward several phenomena that must be considered in the detector placement study as part of the ongoing work program.

Measurement of Queue

A special calibration study was performed to assess the accuracy of the average queue length measure of effectiveness produced by the UTCS surveillance system and summarized by 15-minute period. Detector generated queue values were compared to field measurements derived from rooftop photography.

The location selected for analysis was the eastbound approach on K Street at 20th Street. This location gave the best field of view for an approach and the most consistent data throughout the study. Queues were measured from the films in a manner analogous to that used by the UTCS surveillance system; i.e., vehicle content of "zone counts" in the detectorized lane (up to the last detector) at the beginning of the green phase. The cycle-by-cycle counts were then averaged over 15-minute periods.

The corresponding detector queue counts for matching 15-minute periods were extracted from the summary tapes. Although 55 matches were initially made, four observations were subsequently eliminated. Two observations were deleted because of traffic disturbances caused by stalled vehicles; the other two were eliminated because detector problems in adjacent time periods made the values suspect.

The queue measurements from the field and detector sources were averaged across all observations for the a.m., midday, and p.m. time periods and the sample as a whole. These averages are shown in Table 44, together with the field-to-detector ratios. The overall comparison is quite good for the a.m. and p.m. periods but rather poor for the midday. For the latter, nearly every observation showed higher queue counts from the detector than was measured from the films.

This finding may be partially explained by the increased amount of lane changing activity that occurs during the midday. Since left turns are permitted during this time, vehicles were frequently observed changing lanes at the last minute to avoid a left-turning vehicle waiting for an acceptable gap. The vehicles were thus counted crossing the two upstream detectors but did not discharge over the last detector near the stop line and thus caused misleading queue counts to be generated. During the peak periods, much smoother flow and less lane changing was observed.

Some additional measurement error may have been introduced due to construction traffic entering the roadway at mid-link. This traffic could cause perturbations in the traffic stream leading to improperly inferred queue lengths. The construction traffic was also observed to swing into the detectorized lane and cut the middle detector only, producing additional spurious readings.

Simple correction coefficients were computed for each of the comparisons. These coefficients were rather low, with a value of 0.32 for the sample as a whole. These results are partly caused by the small sample sizes used and partly because of the small values of the measures make them extremely sensitive to single vehicle measurement errors.

A closer examination of the two observations deleted because of the presence of stalled vehicles also illustrates the sensitivity of the queue measurement to traffic performance. For the two observations, detector averages of 7 and 8 vehicles, respectively, corresponded to values of 2.2 and 3.0 from the films. Thus, the presence of the stalled vehicles apparently introduced turbulence in the traffic stream, reduced speeds over the upstream detectors, and caused fallaciously large queue values to be inferred.

Finally, the measurement of queue from the detector produces values that are difficult to interpret for evaluation purposes. High queue values could be generated with

Table 44. Comparisons of detector and field measurements of average queue.

Time	Sample Size (15 minutes)	Average Queue		
		Detector	Field	Field/Detector
a.m.	11	4.45	4.25	0.95
midday	16	4.81	3.39	0.71
p.m.	24	2.50	2.45	0.98
Total	51	3.65	3.14	0.86

good progression and a moving platoon of vehicles in the detectorized portion of the lane at the start of green. Similar values, however, could be generated by a standing queue indicating poor progression. Thus, considerable care must be taken in evaluating performance using this measure, and it must be used in conjunction with other values such as delay.

In summary, this special study indicates that the queue measurements recorded by the detectors are reasonably accurate in the absence of undue traffic disturbance. The values appear to be biased upward, however, if appreciable lane changing occurs along the link, particularly near the downstream intersection. This is the case at a number of locations where the approach at the intersection is wider than for the link as a whole and extra lanes of vehicles may be formed. The measure must be used with caution as well in performance evaluation because of its definitional structure.

Measurement of Speed

Speed was measured in a variety of manners during the evaluation. The UTCS system produces speed as a measure of effectiveness, defined as the spot speed over the detectors. Average speed over an entire link was computed for the moving car analysis, simply by dividing link length by overall travel time. A very similar measure was used in preparing the inputed speeds in the vehicle minutes/vehicle miles analysis. Although computed only for aggregations of links, the inputed speed on a link basis is equivalent to dividing the trap length by the travel time over the trap.

The spot speeds from the detectors are obviously quite a different measure from a speed computed from total travel time. Delay time accrued while vehicles are moving is explicitly included in the latter calculations, while the spot speeds are much more highly influenced by moving (especially free-flowing) traffic.

Although the average speed from the moving car runs and the speed inputed from the vehicle minutes/vehicle miles analysis are computationally very similar, substantial difference exists in the areas over which the speeds were measured, thus profoundly affecting the magnitude of the results. The inputed speeds are developed solely for the detectorized portions of the links. Thus, the average values are prepared only for the most congested portions of the most important links. The moving car runs, on the other hand, reflect speeds over entire links, including the less congested upstream portions. Moreover, the moving car results, particularly for Sections 1 and 2, include data collected on low-delay, non-detectorized links, while the detector results for the multiple installations are limited to the most congested approaches.

Thus, the inputed speeds in Table 16 have very low values. The measures are not, therefore, fully representative of the overall speeds throughout the various sections, but rather reflect conditions for the detectorized portions of the major links included in the surveillance system for those sections. Overall speeds, to the extent that such a concept is meaningful, would be much closer to the values computed for the various arterial streets from the moving car analysis and would be much higher.

Speeds for individual links may be compared between the detector spot speeds and the average values from the moving car runs for those links where both data elements exist. A summary for 24 typical links is shown in Table 45. This represents over half of the total links for which data were available and excludes links for which the moving car travel would necessarily differ substantially from the detector data due to lane selection. For illustrative purposes, data for the TRSP base case as used in the evaluation of TOD settings are presented for the a.m. and p.m. periods.

In many cases, the speeds are surprisingly similar. These links are usually characterized by relatively uncongested flow so that the spot speeds are representative of the overall travel performance. In other cases, the moving car values are less than the detector values, illustrating the delay component of the former measure. In a few cases, the moving car values are slightly higher; this result probably is due primarily to the relatively low sample of moving car results, although it may also indicate a lane distribution problem. The detectors are normally placed in the most critical lane, which usually translates to the highest volume one, while the moving car runs were made to simulate "typical" performance.

A few links show extraordinary differences. On westbound Constitution Avenue at 23rd Street, all of the moving car runs showing a stop and a very lengthy delay (average of 46 seconds), resulting in the very low overall speed of four mph. This approach has light volume in the morning and a poor offset. A similar situation exists for eastbound Pennsylvania Avenue at 19th Street in the evening, where

Table 45. Link level speed comparisons.

Location	Det. Link	MCAR Link	AM		PM	
			Det.	MCAR	Det.	MCAR
SB Wisc. @ Mass.	25	4-13	22.7	15.6	--	18.2
NB Wisc. @ Garf.	27	15-11	23.4	12.6	--	17.8
NB Wisc. @ Calv.	44	13-11	23.1	21.3	23.0	21.1
SB Wisc. @ Calv.	46	8-13	20.8	18.5	22.9	16.1
WB M St. @ Wisc.	7	16-24	20.5	15.5	--	8.8
EB M St. @ Wisc.	10	3-22	21.9	21.4	--	16.1
EB L St. @ 18th	151	14-40	23.0	21.9	18.0	13.1
EB L St. @ 16th	137	17-40	20.7	16.3	17.0	15.4
WB K St. @ 16th	158	24-40	22.0	19.1	21.1	14.2
EB K St. @ 16th	160	10-30	18.2	20.3	16.9	12.1
WB K St. @ 19th	72	28-40	23.2	24.1	18.3	17.5
EB K St. @ 19th	73	6-30	24.9	23.5	21.4	13.8
EB Penn. @ 19th	89	16-22	22.2	13.1	19.8	7.3
WB Penn. @ 18th	62	1-24	20.5	14.6	19.6	11.1
EB Penn. @ 18th	65	17-22	23.7	20.4	23.6	18.3
WB Const. @ 23rd	195	47-40	17.2	4.0	19.1	22.8
WB Const. @ 21st	201	44-40	25.8	26.4	23.5	28.2
SB 19th @ Penn.	90	36-40	16.6	8.9	15.7	10.3
SB 19th @ E St., N.	226	39-40	23.8	28.5	21.9	19.8
NB 18th @ L St.	149	36-30	18.2	12.7	18.3	12.0
NB 18th @ Penn.	63	32-30	16.3	11.8	17.8	13.7
NB 18th @ F St.	252	30-30	20.8	20.3	23.9	20.6
SB 17th @ Penn.	69	41-30	20.9	10.7	16.7	7.3

Note: Data are for TRSP base case.

the moving car analysis shows that approximately half the vehicles stop and the average stopped time delay is about 24 seconds.

SUMMARY AND CONCLUSIONS

INTRODUCTION

This chapter presents a summary of the findings and conclusions reached during the evaluation of the alternatives of the UTCS/BPS first-generation traffic control strategy. The chapter covers two distinct elements, namely, a summary discussion of the overall findings from the evaluation as reported in the previous chapter, and a discussion of the inferences drawn from the methodological, analytical, and evaluative processes. The former presents an analytical statement of observations and the latter includes judgments and analytical inferences as drawn throughout the evaluation process. The analytical findings are presented in the order of network-wide, subnetwork link, and special studies. The inferences are noted in terms of methodology and an interpretation of results.

ANALYTICAL RESULTS

Evaluations of the control alternatives were performed for a series of measures, derived from several sources, and summarized at different levels of geographic detail. Specifically, results were developed from both the detector MOE's and from moving car analyses. The detector analyses were also used in the computation of the global measures of vehicle minutes and vehicle miles. Evaluations were performed for the entire UTCS/BPS network and its four sections, by subnetworks (defined in terms of successive links on specific streets and in other specified ways), and upon the measures derived for individual links.

Additional studies were performed for special characteristics of the different control alternatives, particularly the impact of the BPS alternative on link performance. Comparisons of the detector and moving car results were also made at a hierarchy of levels, to assess the use of the surveillance system generated measures versus conventional field measurement techniques. The latter analysis was developed by conducting a series of special studies focusing on individual performance measures.

Network-Wide Analyses

Detector data are available for many of the major links throughout the UTCS/BPS network. These data may be combined into four specific subnetworks (sections) which were aggregated provide a network evaluation. The measures computed in this way were total vehicle minutes of travel, total vehicle minutes of delay, total number of stops, and total queue (actually link content). A summary of the results for the UTCS/BPS network, expressed as percentage differences between each of the four pair-wise comparisons (alternatives to TRSP) made in the analysis, is shown in Table 46. Several specific conclusions may be drawn from this table, which is supported by more detailed data in Tables 2-4 in the previous chapter. The conclusions are:

- no alternative provided consistently significant improvement over the base case (TRSP),[1]

- the delay and travel time measures produced very similar results,

- the queue measure yielded noticeably different results from the other MOE's; the results were similar to these for delay in only four of the 12 comparisons and were in direct conflict for four comparisons.

The similarity between the delay and travel time results, the apparent inconsistencies with the queue measure (caused largely by definitional problems), and the difficulty in relating stops to field measures, resulted in delay being selected as the primary measure for all evaluations. Additional comparisons between alternatives and the base case (TRSP) are summarized for both the entire network and the four major control sections in Table 47. Conclusions which may be drawn from the tables regarding the specific alternatives include:

- only two alternatives(TOD and BPS) show improvement over TRPS for each time period and those are for Section 1;

- CIC shows a 0.7% improvement for the a.m.;

- 3-dial is 0.3% better in midday;

- TOD is 2.0% better in the p.m.;

- BPS performance is poorer than TRSP in all periods, but it is never the poorest alternative for a given time period.

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1. The term "significant" as used here implies an improvement in network-wide performance which is statistically significant at the 5% level.

Table 46. Detector analysis - percentage differences in aggregate MOE's - total network.

Comparison	Time Period	Delay	TT	Queue	Stops
TRSP	a.m.	-4.0	-2.8	2.4**	0.4
vs	midday	0.3	0.8	5.0***	3.9***
3-Dial	p.m.	-3.9*	-1.9*	4.7***	-0.3
TRSP	a.m.	-1.8	-1.1	0.7	-1.9
vs	midday	-2.8*	-2.4**	-0.6	-3.6***
TOD	p.m.	2.0	1.5	1.3	1.0
TRSP	a.m.	0.7	0.5	-3.5	-3.0
vs	midday	-0.5	-0.2	-1.6**	-1.2**
CIC	p.m.	-2.8***	-2.2**	-2.7*	-1.8*
TRSP	a.m.	-2.5	-2.4	-5.4*	-3.2
vs	midday	-0.8	-0.6	-4.9***	-3.5***
BPS	p.m.	-0.3	0.0	-6.6***	-3.5**

* = Statistical significance at 5% level.
** = Statistical significance at 2% level.
*** = Statistical significance at 1% level.

Note: Positive values indicate improved performance of the alternative over TRSP, i.e., less delay, fewer stops, etc.

Table 47. Detector analysis - percentage differences in aggregate delay in section.

Comparison	Section	TIME PERIOD		
		a.m.	Midday	p.m.
TRSP vs 3-Dial	1	-1.5	-5.7*	-15.3***
	2	-2.7	-6.4***	-10.3***
	3	-4.0	2.7	- 2.2
	4	-5.9	-2.6	- 3.2**
	TOTAL	-4.0	0.3	- 3.9*
TRSP vs TOD	1	3.9	4.2	8.8
	2	-5.8	-4.6	- 0.7
	3	-1.8	-4.2**	1.3
	4	-1.3	3.7***	5.0
	TOTAL	-1.8	-2.8*	2.0
TRSP vs CIC	1	6.9	2.2	- 7.6
	2	3.3	-4.1	- 2.8***
	3	-2.7	-1.0	- 3.1***
	4	4.9	1.5	0.0
	TOTAL	0.7	-0.5	- 2.8***
TRSP vs BPS	1	3.6	6.2***	4.0
	2	-5.7	-6.8***	- 5.2**
	3	-1.5	0.3	0.6
	4	-8.6	-5.1*	- 3.2
	TOTAL	-2.5	-0.8	- 0.3

* = Statistical significance at 5% level.
** = Statistical significance at 2% level.
*** = Statistical significance at 1% level.

Note: Positive values indicate less delay with alternative.

- For Section 1 (M Street), TOD, CIC, and BPS show improvement over TRSP in all but one comparison, ranging from 2.2% to 8.8% (these are the largest improvements in any section);

- 3-dial was much poorer for the arterial sections (Sections 1 and 2) in all periods, ranging from -1.5% to -15.3% (these were the largest negative differences in any section);

- CIC performed better in Sections 1, 2, and 4 with arterial or dominant grid patterns than in Section 3 with a more complex and balanced grid system (for the latter, CIC was from -1.0% to -3.1% poorer).;

- no statistically significant differences were found in the a.m. for any alternative and for any section.

The nature of the moving car data precludes its summarization directly for the network as a whole. Therefore, the primary evaluations were performed upon the combined results for the six routes. Four measures of effectiveness: travel time, delay, number of stops, and average speed were evaluated. The latter is not an independent measure in that it is derived from total travel time divided by link (or route) length. Delay and number of stops were considered highly susceptible to the performance of individual drivers and somewhat unstable as evaluation measures.

Total travel time was, therefore, used as the most representative measure from the moving car analyses. Values were computed for individual links, consecutive links along major streets, and the routes as a whole. The latter measures excluded travel time on links outside the evaluation area and other links excluded from the analysis but necessary to provide a continuous vehicle path. A summary of travel time results by route is given in Table 48, from which the following conclusions may be drawn:

- no alternative showed completely consistent improvement over TRSP;

- 3-dial performed noticeably poorer than TRSP along routes 11 and 13 (Wisconsin Avenue) in all time periods; ranging from -1.3% to -15.3%;

- BPS was almost uniformly poorer than TRSP for all routes and time periods, the exceptions being two cases for routes 22 and 24 (M Street)

Table 48. Moving car analysis - percentage difference in travel time by route.

Comparison	Route	TIME PERIOD a.m.	midday	p.m.
TRSP vs 3-Dial	11	-8.2**	-2.1	-15.3***
	13	-1.3	-7.4	-13.1***
	22	13.3***	34.8***	-10.2***
	24	-5.1*	6.7	6.2
	30	-5.9	22.4***	9.4
	40	4.1	-17.4***	- 0.7
TRSP vs TOD	11	-0.2	-1.0	-1.2
	13	3.3	1.9	4.9
	22	4.7	10.6**	2.2
	24	4.6	-4.5	2.1**
	30	-9.6	9.7***	1.1
	40	-10.2	-7.7*	-4.7
TRSP vs CIC	11	4.2	0.3	4.2
	13	7.1*	4.1	-1.1
	22	-4.1	-1.4	-3.5
	24	-9.7	-4.3	-29.7
	30	-11.2**	7.1*	-6.7
	40	-0.5	10.5***	-4.4
TRSP vs BPS	11	-2.3**	-4.6	-7.7
	13	-1.8	-5.9	-11.5***
	22	-4.6	12.4	-1.2
	24	-8.1	-3.1	1.1
	30	-14.4	-20.5***	-6.8
	40	-1.2	-13.3***	-5.2

* = Statistical significance in 5% level.
** = Statistical significance in 2% level.
*** = Statistical significance in 1% level.

Note: Positive values indicate lower travel time with alternative.

with improvements of 1.1% and 12.4%;

. CIC performed better in all but one case on Wisconsin Avenue, ranging from 0.3% to 7.1% but uniformly poorer for M Street;

. differences tended to be most pronounced in the midday, ranging from 34.8% to -20.5% and with the greatest number of differences over 10%;

. the greatest number of statistically significant differences (9) occurred with the 3-dial comparisons.

Vehicle minutes of travel were computed from the detector data by multiplying the average travel time over the detectorized section of the link by the measured volume. These values were then tabulated by link for each comparison, differences taken, and results summed for the entire network, maintaining the values for links with positive and negative changes separately. The results of this analysis are shown in Table 49, from which the following conclusions may be drawn:

. the total positive and negative differences under 3-dial are much larger than those observed under the other alternatives, indicating much greater localized differences;

. the net differences under the 3-dial alternative are not significantly different from the other alternatives, indicating a great number of tradeoffs between the 3-dial and TRSP alternatives.

. net savings in the a.m. occurred only under the CIC alternative.

. net savings in the midday occurred only under the 3-dial alternative.

. net savings in the p.m. occurred under TOD and BPS; the former was the largest savings for any comparison of alternatives.

Vehicle miles of travel were also computed for each link with multiple detectors by multiplying the observed volume by the distance from the stop line to the upstream detector. The vehicle miles were then totaled by section for the entire network. A derived effective "network-wide" speed was then computed from the ratio of the vehicle miles to the vehicle minutes summaries noted above. Values for

Table 49. Vehicle minutes of travel summary - total network.

Comparison	Time Period	SUM OF LINK DIFFERENCES		
		Positive	Negative	Net
TRSP vs 3-Dial	a.m.	952	1453	-501
	midday	989	874	+115
	p.m.	1145	1458	-313
TRSP vs TOD	a.m.	385	584	-199
	midday	282	595	-313
	p.m.	469	258	+211
TRSP vs CIC	a.m.	526	462	+ 64
	midday	358	387	- 29
	p.m.	372	711	-339
TRSP vs BPS	a.m.	420	733	-313
	midday	445	518	- 73
	p.m.	358	352	+ 6

Note: Positive values indicate more delay under TRSP and hence alternative represents improvement.

the entire network are summarized in Table 50. From this table, the following may be concluded:

- the low values in this table result from the computation of an average speed for only the most congested segments of the heaviest volume links;

- the overall range of "network-wide" speeds was quite small, from 6.21 to 7.38 mph;

- in only two instances was the speed for the alternative higher than for TRSP, in the midday for CIC (6.75 versus 6.73) and in the p.m. for TOD (7.21 versus 7.04);

- BPS showed the most consistently lower speeds (0.10 to 0.30 mph).

Subnetwork Analysis

The detector results were aggregated for links possessing certain similar features. In addition to the sections discussed above, links were also summarized by cardinal direction (north, south, east, and west) and were combined for certain streets. The average delay differences for the streets showing the greatest sensitivity to the control alternatives, L Street and 18th Street, are summarized in Table 51. The following may be concluded from the subnetwork analysis.

- changes for individual links were much greater than those for the network as a whole; for example, L Street differences range from 37.0% to -19.8%;

- tradeoffs were quite evident by subnetwork; 18th Street was greatly improved under CIC and L Street was generally worse;

- the greatest differences were observed under the 3-dial alternative;

- the above conclusions generally pertain, as well, to other subnetworks but are not in as pronounced a fashion;

- priority given to certain east-west streets, notably L Street, under TRSP led to generally poorer relative performance under the other alternatives. (with the obvious exception of two periods under 3-dial where optimum settings

Table 50. Derived average speed from vehicle miles/vehicle minutes - total network.

Comparison	Basis	TIME PERIOD		
		a.m.	midday	p.m.
TRSP vs 3-Dial	Base Test	7.36 7.07	6.80 6-79	7.12 6.96
TRSP vs TOD	Base Test	7.38 7.22	6.84 6.67	7.04 7.21
TRSP vs CIC	Base Test	6.73 6.75	6.24 6.21	6.61 6.35
TRSP vs BPS	Base Test	7.16 6.86	6.52 6.39	6.78 6.68

Note: Values expressed in vehicle-miles per vehicle hour.

Table 51. Detector analysis - percentage differences in aggregated delay for most sensitive subnetworks.

Comparison	Time Period	SUBNETWORK	
		L Street	18th Street
TRSP vs 3-Dial	a.m.	-12.6**	-8.4*
	midday	18.8***	-13.7***
	p.m.	37.0***	14.8***
TRSP vs TOD	a.m.	-6.0	-1.4
	midday	-5.5	5.0**
	p.m.	-0.7	2.8
TRSP vs CIC	a.m.	-19.8***	9.6
	midday	-8.3**	5.3**
	p.m.	0.4	14.4***
TRSP vs BPS	a.m.	-9.3*	-9.3
	midday	-3.1	-3.3
	p.m.	8.0	-2.9

* = Statistical significance at 5% level.
** = Statistical significance at 2% level.
*** = Statistical significance at 1% level.

Note: Positive values indicate less delay with alternative.

had been previously implemented).

Subnetworks were also identified as successive links along major streets of the moving car routes. Aggregate values of travel time were computed for each street. A summary for three of the streets showing the greatest differences is given in Table 52. The following may be concluded from the moving car analysis.

- all alternatives except 3-dial performed poorer for Pennsylvania Avenue with values ranging from -3.1% to -34.1%;

- BPS results were poorer in all three time periods for each of the three streets shown, ranging from -10.3% to -38.3%;

- TOD results were generally poorer (the exception being 18th Street during midday), decreases ranged from -3.1% to -19.0%.

Link Analysis

The results for individual links are not readily subject to direct interpretation, since so many trade-offs, representing improvements in one direction against decreases in another, exist throughout the network. Some simple conclusions may be reached, however, by examining the aggregate results of a series of link level comparisons. For the detector analysis, the following conclusions may be drawn:

- in the a.m. period under 3-dial, 61 of 95 links showed statistically different results, compared with only 22 of 64 links under the "most different" remaining alternative (CIC). This confirms that individual signal settings were substantially more different under 3-dial than for any of the computer-generated values;

- the TOD settings produced the fewest number of statistically different results, ranging from 12 of 97 in the a.m. to 14 of 75 in the midday, confirming that the TRSP and TOD settings were very similar;[1]

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1. The "timings" are in fact identical, however, the time of day when a given plan is implemented may be different.

Table 52. Moving car analysis - percentage difference in travel time for most sensitive subnetworks.

Comparison	Time Period	SUBNETWORK		
		Westbound Pennsylvania Avenue	L Street	18th Street
TRSP vs 3-Dial	a.m.	-19.6***	8.5*	-3.7
	midday	8.0*	-43.4***	29.8***
	p.m.	8.1	29.2***	7.0
TRSP vs TOD	a.m.	-3.1	-10.7	-19.0
	midday	-7.5	-13.8	3.2
	p.m.	-3.8	-3.3	-7.8
TRSP vs CIC	a.m.	-24.9	-2.8	-9.2
	midday	-8.7**	9.9	21.0
	p.m.	-34.1	-7.6	-6.4
TRSP vs BPS	a.m.	-18.8	-18.3*	-38.3*
	midday	-22.3***	-26.6**	-28.1***
	p.m.	-24.0**	-10.3	-30.9*

* = Statistical significance at 5% level.
** = Statistical significance at 2% level.
*** = Statistical significance at 1% level.

Note: Positive values indicate lower travel time with alternative.

- the number of links showing statistically worse results equalled or exceeded the number of links showing superior results in all but one comparison (TOD for p.m.).

Vehicle minutes of travel was computed by individual detectorized link, as noted above. Statistical tests were not performed on these data, but differences were computed and classified as greater, or less than, 10%. Some conclusions from this analysis are:

- in only one case (TOD in the p.m.) was the number of links with 10% or more decrease less than the number of links with a 10% or more increase;

- the number of links showing 10% or more changes exceeded the number of links showing a less than 10% change for all comparisons except one under 3-dial;

- for the other alternatives, in no case did the number of links showing a 10% or more change exceed the number of links showing a less than 10% change.

Link level comparisons of statistical significance were performed for each of the moving car routes as well. The following general conclusions may be drawn:

- except for 3-dial the number of statistically significantly different links are very small for all time periods, ranging from 11 of 136 under CIC for the midday to 41 of 144 under BPS for the midday;

- for 3-dial, the number of significantly different links ranges from 48 of 144 to 62 of 144;

- the number of significantly different improved links overall is not greatly different from the number of significantly worse links.

Special Studies

The nature of the BPS alternative required that a detailed examination of the impact of bus actuations on link performance be conducted in addition to the overall evaluations performed for the other alternatives. For this analysis, each link with a bus detector was classified as experiencing a high, medium, and low level of bus activity, based on a summary of the number of actuations from the

UTCS/BPS detector tapes. Each link was further classifed as to whether the predominant bus flow was in the peak bus passenger direction, or in the off-peak direction, i.e., the "dead-heading" portion of the bus route. Finally, the opposing and cross links for each BPS intersection were identified.

Data for the BPS impact analysis was developed from the vehicle minutes of delay calculations. These values were computed in the same way as for vehicle minutes of travel, noted above, except that average delay rather than average travel time was used. Various aggregations of the link level data were then prepared. These comparisons lead to the following general conclusions:

- links with high BPS activity were improved by 5.8% in the a.m. and 0.5% in the p.m., while the cross links at these locations were degraded by 8.3% in the a.m. and 0.8% in the p.m.;

- links with moderate BPS activity were adversely affected by 10.8% in the a.m. and 4.8% in the p.m.;

- in the a.m., buses in the offpeak direction (dead-heading) produced greater improvements than buses traveling in the peak direction, with increases of 3.0% at moderately active locations and 5.0% at high activity locations;

- general degradation was observed in the Wisconsin-Massachusetts-Garfield triangle area, indicating adverse BPS impact in areas where offset relationships between intersections are critical;

UTILITY OF DETECTOR MEASUREMENTS

The use of MOE's produced by the surveillance system has a number of advantages over conventional manual data collection methods and it was considered quite important to assess the adequacy of the detector MOE's for discriminating between the performance of alternatives. Comparisons of the statistical inferences drawn at the link level for locations where both types of data were available resulted in the following conclusions:

- consistency in terms of a statistical inference was observed for most of the comparisons, ranging from 45.6% to 72.2% of all links in the a.m., 39.5% to 76.5% in the midday, and 39.5% to 81.1%

in the p.m. with the 3-dial alternative having by far the poorest match relationship;

. as important, direct conflicts in statistical inference occurred rarely, (again dominated by 3-dial with values ranging from 7.9% to 10.5% of all links) only two conflicting links were observed in total for the comparisons outside of these for 3-dial;

. the number of links for which the moving car results were non-significant when the surveillance system showed significant differences far exceeded the number of cases where the detector results were non-significant and the moving car results were significant;

. under all alternatives except 3-dial, the number of links in agreement were primarily those for which neither measurement technique showed significant differences.

A number of special studies were undertaken to further examine the reliability of the detector measures. In the first study, manual volume counts were made in the field and compared with cycle-by-cycle counts taken from the CRT at the UTCS center. The following general conclusions were drawn:

. the ratio of field volume to detectorized lane volume ranged from 0.88 for four-lane approaches to 0.96 for one-lane approaches;

. the field measured approach volume ranged from 1.76 of the detectorized lane volume for two-lane approaches to 2.47 for four-lane approaches;

. both ratios varied considerably by time of day at specific locations which indicates different lane distributions by time of day.

An additional volume-related study was undertaken, comparing the data collected from conventional road tubes to the detectorized lane volumes from the UTCS system. The following conclusions were drawn from this study:

. variations in the ratio of road tube to detector volumes appeared closely related to number of lanes;

- the changes in lane distribution as links approached saturation precluded the development of simple linear relationships between detector volume and road tube measured approach volume.

Another study was performed to compare the overall delay as recorded by the UTCS detectors with stopped time delay measured in the field. A conventional stopped time delay study was undertaken for the eastbound approach of Pennsylvania Avenue at 18th Street. Data was recorded by 15-minute intervals and compared with detector data for the same period. The data were also used to compare intersection approach performance under the BPS and TRSP alternatives during which data were collected. The following conclusions were drawn:

- the presence of a heavy left-turn volumes seriously affected the field measurements and was not correspondingly reflected in the average delay computed for the detectorized lane;

- the ratio between field observations and detector measurements was lower under CIC, perhaps reflecting a difference in offset which in turn altered the left-turn delays and gap acceptance characteristics;

- the direct inference to be drawn from the field data regarding the relative performance of BPS and TRSP differs from those developed from the detector moving car analyses. It is believed that the lane change problem caused this.

Another special study was undertaken to verify the queue measure produced by the detectors. This measure, which is a measurement of the content of the detectorized portion of the link rather than a standing queue, was validated from a series of rooftop time-lapse photographs on K Street at 20th Street. The following general conclusions were drawn:

- the link content measurement correlates well in peak periods when lane discipline is good; the ratio of field to detector results was 0.95 for the a.m. and 0.98 for the p.m.;

- the measurement is less reliable in the midday, probably reflecting lane changing when the approach is well under capacity and when left turning vehicles cause perturbations; the ratio of field to detector values was 0.71.

Finally, a comparison was made between the spot speeds recorded by the detectors and the overall speeds from the moving car runs for those links for which data on both were available. The following conclusions were drawn:

- for links with little delay and free-flowing traffic, the speed measurements are very similar;
- for congested links, the moving car speeds, incorporating a large stopped time component, are considerably lower than the values computed by the detector-based surveillance system.

INFERENCES FROM EVALUATION PROCESS

The following inferences may be drawn from the evaluation process completed for the alternatives of the first-generation UTCS/BPS traffic control strategy.

Methodology

The amount of "noise" in a congested urban network, such as covered by the UTCS/BPS system, makes it very difficult to identify differences at the level expected from a control change. For this reason, numerous (32) travel time runs are required. This is difficult to control from a pure man-power sense and is costly in terms of "dollars per data point." The surveillance system data was statistically significant, at the 5% level, more often than the moving car data. This is probably directly related to the fact that the surveillance system provides a larger data set and each set, theoretically, represents a 100% sample during a 15-minute period while a moving car is but one vehicle on a link in a given time slice. The surveillance data and moving car data agreed in implication much more often than it was in conflict (45-72% versus 8-11%). It was also apparent that certain of the differences are related to detector placement and lane usage. It is expected that the more apparent of these problems will be corrected before testing the second and third generation alternatives.

The research team believes, in light of the above, that future testing should maximize the use of the surveillance data. It is believed that a more complete sample can be developed in that manner and work done on improving its characteristics. This would appear to be more cost effective than the procedure that places equal emphasis on surveillance and moving car data.

It is also felt that the procedures and programs (related to surveillance data) prepared as part of this project are a valuable adjunct to the overall UTCS/BPS package. The programs provide a comprehensive method for processing the output of the surveillance system to give analytical informance on performance. To the UTCS/BPS package user, this offers two specific benefits: (1) he may evaluate the performance of his system, and (2) the evaluation output can identify those portions of the network which should be examined in depth to see if traffic engineering improvements (both physical and control timing) are practical.

The time periods selected for the tests also raise a question--in the light of the results found. That is, what portion of the benefits of the alternatives occur during the periods observed? This question is particularly of concern when evaluating the TRSP versus 3-dial alternatives. Assuming that much of the rationale for implementing a computer based system is to provide timing plans to closely fit traffic changes (from several predeveloped plans for TOD to continuously varying plans under third generation), it would seem that an evaluation limited to those periods for which the 3-dial plans were designed minimizes the statement of benefits. Given the apparent fact that the surveillance system can provide evaluation data, it is suggested that evaluation which covers 16-18 hours of the day be considered.

Evaluation

Based on the conclusions reported in the ANALYTICAL RESULTS section of this chapter, the research team offers the following observations.

1. The computer-based TRSP alternative generally matched or exceeded the performance of the 3-dial, TOD, CIC, and BPS alternatives. The greatest number of points where statistical differences were observed was the TRSP versus 3-dial comparison. This is to be expected since the TOD, CIC, and BPS alternatives all use the same basic timing plans as TRSP.

2. On a network-wide basis, the differences in performance were relatively small (a +2% to -4% around the TRSP base). This small difference may indicate several items, including:

- Network traffic "noise" in a dense urban area overshadows the performance of the control systems;

- Evaluation periods need to consider a broader base of conditions, or

- There was very little difference in the performance of the alternatives.

If the latter point is taken as the sole "proved" item, an argument could be made that the computer-based alternatives were successful because of the fewer man-hours devoted to developing the TRANSYT timings for the system.

3. The CIC alternative had the effect of equally distributing delay on the approaches to a given intersection. This resulted in conflicting results of the algorithm when compared on a line-by-link basis. That is, approaches which had, under TRSP, good offset relationships and low delay were generally harmed by the CIC algorithm. Those which were poor, relative to other approaches, were helped substantially. It would appear that CIC can be used to equalize delays or help to resolve offset problems at critical locations. It may also prove to be more useful on arterials than in grids because of the fewer offset and capacity conflicts.

4. The BPS algorithm appeared to work well when offset was not extremely critical for the total traffic movement. Overall traffic delays were increased only .03 to 2.5 percent, indicating that there was not an extreme penalty paid by motorists for the bus priority. Buses delays were reduced as much as 35% on a given approach and 6% on a given route. There appears to be a level of bus activity beyond which the BSP operation would be unstable. The level has been estimated at 30 to 50 buses per hour. As congestion at a BPS intersection increases, the effects of the congestion appear to be such that the BPS algorithm should be switched off (as it is in the present form).

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