MAINTENANCE COSTS OF TRAFFIC SIGNALS

by

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A major research project currently is developing guidelines for the selection of type of traffic-signal control at individual (non-interconnected or "isolated") intersections. The choice of pretimed, semi-actuated, basic full-actuated or density full-actuated weighs the low price and economical maintenance of the pretimed controllers against the reduced costs, delays, etc., of the traffic-responsive models. The project staff found that traffic engineers generally prefer to install full-actuated signal control at individual intersections. However, there is some concern over the cost of the incremental maintenance required by full-actuated control, as compared to semi-actuated or pretimed control. The professional literature sheds little light on the magnitude of these incremental costs. Therefore traffic engineers are at present unable to document the cost effectiveness of their preference for traffic-responsive control.

An essential element in the selection of type of traffic-signal control is a knowledge of the maintenance burden of the various designs. This paper is believed to be the first to provide that information.

The project staff found that traffic-signal maintenance costs are of some concern throughout the country. These costs seem to be a particular worry, however, in some states of the northeast and upper midwest. Loop detection needs to be of especially high quality there in the "Snow Belt", because of severe winters, deteriorating pavements and other reasons. There have been low-bid barriers to the purchase of high-quality "amplifiers", and difficulties in hiring and retaining technicians capable of installing and maintaining modern, sophisticated detectors and controllers. There has been a growing feeling that if a full-actuated controller cannot be kept in full-actuated operation, but instead must be placed on Recall to one or both phases, then it would have been more economical to select semi-actuated or pretimed control at the outset. It was this climate of concern that prompted the research to determine the maintenance costs of traffic signals.

Research Approach

Telephone contacts were made with many state and local traffic engineering agencies throughout the United States in an effort to obtain maintenance data. Most of the agencies responded that their data are in raw form -- handwritten malfunction reports - - which could not be summarized at reasonable cost. However, a few were found to have manual tabulations, or computerized summaries, or raw data in a form susceptible of tabulation at reasonable expense. These were as follows:

State of California D. O. T. (CALTRANS)-The CALTRANS Maintenance Management System (MMS) includes data for 23 recent months on the total cost to maintain 121 actuated traffic signals of various designs. "Total" cost includes field maintenance, bench repair, travel and parts.

New York State D. O. T. - New York maintains a computerized file of the man-hours required for the field maintenance of the approximately 2500 pretimed and actuated traffic signals in its jurisdiction. The costs of bench repair, travel and parts are not included. Data for two recent years were obtained.

Ohio D. O. T. - Ohio furnished approximate data for 1976 on the frequency of repair of their 558 actuated traffic signals, divided into three levels of sophistication.

State of Minnesota Department of Highways - The Minneapolis District furnished data covering several years for the frequency of repair of 135 actuated controllers and several hundred detectors of various types.

City of Cincinnati, Ohio - Two and one-half years of computerized maintenance summaries were obtained for the frequency of repair of over 700 controllers and their detectors, of various types and ages.

City of Tampa, Florida - A computerized record of frequency of repair was obtained for almost 400 controllers of various types and ages for the year 1974.

City of Charlotte, North Carolina - In 1977 Charlotte purchased 72 micro-processor controllers of Type 190 design. As of May, 1978, 50 had been installed. The project staff obtained 14 months of maintenance data on these signals, and six months of data on the other 388 signals in that city.

City of Springfield, Illinois - Data on the frequency of repair of Springfield's 144 pretimed and actuated signals were obtained for 1976.

City of Winston-Salem, North Carolina - Four years of detailed maintenance cost data were obtained for one example each of pretimed and full-actuated traffic signals.

Washington, D. C. - A total of 497 loop detectors were installed in connection with the UTCS Research Project. One year of maintenance data was obtained.

CALTRANS Data

Traffic-signal maintenance-expense records for 121 selected locations are stored on the CALTRANS computer. These costs, from Reference 1, include the dollar expense of all scheduled and non-scheduled, field and bench maintenance of all electrical equipment at the location, including lampouts, detector malfunctions, knock-downs, etc. (CALTRANS has a group relamping program; therefore lamp-outs should be negligible in these statistics.) Table 1 shows data for the 23 months from July 1, 1976, to May 30, 1978, adjusted to 12 months (by multiplying the raw cost data by 12/23).

For two-phase digital controllers, Table 1 shows that the annual maintenance cost varies from \$354 to \$694, depending on the brand of manufacture. The weighted average of these data is \$575.

Table 1 data for three- and four-phase, solid-state, digital machines are complicated by the fact that the Brand B digitally timed controllers had to be modified in design by CALTRANS personnel in order to keep them operating acceptably. The model was soon dis-continued by the manufacturer. If the maintenance costs for this model are therefore rejected as atypical outliers, then the average of the remaining data is \$646. This is very close to the \$657 for analog equipment, somewhat less than the \$753 required to maintain the electro-mechanical controllers of basic (non-density) design, and

Table 1. California D. O. T. Annual Maintenance Costs for Selected Locations

Controller Type	Cost ($) Per Signal for Various Phasings			
	2Ø	3-4Ø	5-8Ø	All
ELECTRO-MECHANICAL, ACTUATED				
Full Volume-Density	--	$1162[a] (1)	$1506[a] (5)	$1449
Three Phase, Basic (Non-Density)	--	753 (6)	1209[a] (4)	935
SOLID STATE, ACTUATED				
Analog timing, Transistors	--	657 (4)	1610 (7)	1263
Digital Timing, Non-Computer				
Brand A	429 (1)	796 (4)	815 (9)	782
Brand B[b]	--	949 (5)	2600 (5)	1775
Brand C, 2Ø	597 (6)	--	--	597
Brand C, 2 - 4Ø	694 (2)	612 (11)	--	625
Brand C, 5 - 8Ø	354 (1)	--	1623 (10)	1508
Digital, Minicomputer	--	--	1004 (33)	1004
Digital, Microprocessor	--	421 (1)	757 (4)	690

NOTE: The number of controllers of each type is shown in parentheses

[a] Using minor movement controllers, apparently

[b] Omitted from subsequent calculations for reasons given in text

far less than the $1162 spent to maintain a single electro-mechanical, volume-density controller of early vintage. Of all of the three- and four-phase machines, the microprocessor design is lowest, at $421. The significance of the microprocessor advantage here is clouded by the fact that only one location is included.

Controllers of five to eight phases vary widely in maintenance cost, with an average of $1067 for solid-state, digital models (again omitting Brand B). Once more the basic electro-mechanical models are somewhat higher than the digital machines, and the volume-density machines are much higher. The solid-state, analog controllers were the highest of all, at $1610 per year, even after discarding a five-phase outlier that consumed $8065 of maintenance funds over the 23-month period. Again, the microprocessor design is significantly less expensive to maintain.

After 16 months of maintenance data had been obtained CALTRANS removed all of the electro-mechanical volume-density controllers, half of the 10 basic machines, and several solid-state controllers. The 16-month data for these controllers were properly annualized for inclusion in Table 1.

Table 1 suggests these general conclusions:

- The five microprocessor controllers average significantly less in maintenance costs than do the other types. These microprocessors are not the new Type 170, but are of the special-purpose type with non-volatile memory.

- Electro-mechanical, volume-density controllers are particularly costly to maintain, as compared to solid-state counterparts.

• The incremental maintenance cost of three-to-four phase controllers over two-phase models is very small, probably less than $100 per year. However, the jump from two-phase to five-to-eight phases could easily double maintenance costs to over $1000 unless a microprocessor controller is specified.

CALTRANS presently (1978) has a program underway to replace all 800 of its electro-mechanical traffic-actuated controllers over a three-year period. During that time the State plans to install nearly 3000 microprocessor controllers of Type 170 design. (These are purchased without factory software and the programs are loaded by the State.) As of early 1978 fifty Type 170 controllers had been installed as CALTRANS' standard unit for intersection or ramp metering signal control on all safety or operational improvement projects. Inasmuch as the first unit was installed in the field in September, 1977, there were no maintenance data available as of April, 1978. However, CALTRANS expects that the fewer connection points and lower component parts count, as compared to other controllers, will produce an improved MTBF. The 170's design should also result in a shorter Mean Time to Repair (MTTR), because it is electrically organized in a more logical manner than earlier designs. It contains several self-test features intended to expedite bench repair.

Although the available California data do not include the pretimed-controller data needed for this project, they do furnish total-cost benchmarks for other types. These benchmarks are incorporated into comprehensive conclusions below.

New York State D. O. T.

New York maintains a computerized inventory of its more than 2500 stop-and-go signals, flashers, and beacons. The man-hours for the field portion of the maintenance of all of these signals are similarly catalogued. Table 2 is a summary furnished by the State (2) for a recent 12-month period for all of the regions except one. It includes controller maintenance only, not detector maintenance as well. Table 2 shows that, although the man-hours per call are relatively independent of the type of controller, the man-hours per signal increase with greater sophistication of controller. At the request of the project staff, the NYSDOT furnished a detailed computer printout of the controller and detector maintenance experience for the next 12-month period, which is October 1, 1976, to September 30, 1977 (4). Selected data from the controller printout were tabulated by the project staff and are shown in Table 3. (In order to expedite the manual tabulation of the computer output, only those models installed at four or more locations in the State were included.) The heading "Mixed E-M and SS" refers to the New York practice of grouping together the data of controllers similar in function but perhaps of different electrical design. Table 3 is much more detailed in its breakdown of controller type than is its counterpart (Table 2) for the previous year.

Table 4 reduces the data of Table 3 to a dollar cost of the man-hours for field maintenance for each type of controller. Table 4 was prepared using New York-supplied labor costs of $9/hour for

Table 2. Controller field-maintenance data for a portion of NYSDOT's jurisdiction for the period October 1, 1975, to September 30, 1976

Controller Type	No. of Signals	No. of Calls	Calls per Signal	Regular Man-Hours	Overtime Man-Hours	Total Man-Hours	Man-Hours Per Call	Man-Hours Per Signal
Pretimed	168	479	2.85	704	605	1,309	2.73	7.79
Semi Veh. Act.	1243	5500	4.42	8201	5442	13,643	2.48	10.98
Full Veh. Act.	557	3960	7.11	6577	6277	12,854	3.25	23.08
Flashing	506	537	1.06	950	744	1,694	3.15	3.35
Beacon	43	36	0.84	63	36	99	2.74	2.30
TOTALS	2517	10,512	4.18	16,496	13,103	29,599	2.82	11.76

Table 3. Selected controller-only maintenance date from New York State DOT's jurisdiction for the period October 1, 1976, to September 30, 1977

Controller Type	No. of Signals	No. of Calls	Calls per Signal	Regular Man-Hours	Overtime Man-Hours	Total Man-hours	Man-Hours Per Call	Man-Hours Per Signal
ELECTRO-MECHANICAL								
Pretimed	84	154	1.83	412	234	646	4.19	7.69
Semi-Actuated	583	1520	2.61	3918	1345	5263	3.46	9.03
Full-Actuated	251	994	3.96	2692	1142	3834	3.86	15.27
Volume-Density	24	115	4.79	246	139	385	3.35	16.04
MIXED E/M AND SS								
Semi-Actuated	473	1037	2.19	3666	1501	5167	4.98	10.92
Full-Actuated	194	626	3.23	1772	826	2598	4.15	13.39
SOLID STATE, ANALOG TIMING								
Semi Actuated	28	27	0.96	178	36	214	7.93	7.64
Full-Actuated								
2 - 4Ø	72	260	3.61	713	376	1089	4.19	15.12
5 - 8Ø	22	162	7.36	305	274	579	3.57	26.32
SOLID STATE, DIGITAL TIMING								
Full-Actuated								
2 - 4Ø	37	54	1.46	155	154	309	5.72	8.35
5 - 8Ø	14	58	4.14	145	155	300	5.17	21.43
TOTALS	1782	5007	2.81	14,202	6182	20,384	4.07	11.44

Table 4. Cost of man-hours for field maintenance of selected controllers only, from New York State DOT's jurisdiction for period October 1, 1976, to September 30, 1977.

Controller Type	Cost ($) Per Signal for Various Phasings			
	2Ø	3-4Ø	5-8Ø	All
ELECTRO-MECHANICAL				
Pretimed	--	--	--	82
Semi-Actuated	92	--	--	92
Full-Actuated	134	197	--	158
Volume-Density	208	109	--	170
MIXED E-M AND SS				
Semi-Actuated	113	--	--	113
Full-Actuated	113	155	--	140
SOLID STATE, ANALOG TIMIMG				
Semi-Actuated	75	--	--	75
Full-Actuated	166	154	293	191
SOLID STATE, DIGITAL TIMING				
Full-Actuated	70	144	243	135

regular time and $13.50/hour for overtime (including an 80-percent overhead factor) (3).

Tables 2, 3 and 4 are incomplete because of their omission of detector-maintenance data. Such data are tabulated by the NYSDOT by manufacturer rather than by type of traffic signal. For the 1976-77 year the tabulation showed that 6,190 detector-related service calls required 17,713 regular man-hours and 7483 overtime man-hours. The project staff distributed these calls and man-hours among the various types of actuated controllers as judiciously as it could, according to the number of actuated phases of each controller-type. These data were then merged with the controller-only data of Tables 3 and 4. The results are shown in Tables 5 and 6, both of which are captioned as "estimated" data because of the role of the project staff. Like Table 4, Table 6 uses the New York-supplied wage rates.

The reader can easily determine the influence of the detector-maintenance data by comparing Table 3 with Table 5, and 4 with 6.

Table 6 is the most important as it presents controller-plus-detector costs, just as does Table 1 for CALTRANS. (However, there are important differences between the two tables: Table 6 includes only the cost of field man-hours, while Table 1 includes also the cost of repair vehicles, parts and bench labor.) Using pretimed control as a baseline at a field-maintenance cost of $82 per year, Table 6 suggests these general conclusions:

- A step up to two-phase, semi-actuated control will add approximately $110 per year to the cost of maintenance, regardless of whether the controller is of electro-mechanical or solid-state design.

Table 5. Estimated maintenance data for selected controllers and detectors from New York State DOT's jurisdiction for period October 1, 1976, to September 30, 1977

Controller Type	No. of Signals	No. of Calls	Calls per Signal	Regular Man-Hours	Overtime Man-Hours	Total Man-Hours	Man-Hours Per Call	Man-Hours Per Signal
ELECTRO-MECHANICAL								
Pretimed	84	154	1.83	412	234	646	4.19	7.69
Semi-Actuated	583	2874	4.93	7797	2984	10,781	3.75	18.49
Full-Actuated	251	2385	9.51	6678	2826	9504	3.98	37.86
Volume-Density	24	245	10.21	618	296	914	3.73	38.08
MIXED E-M AND SS								
Semi-Actuated	473	2132	4.51	6801	2825	9626	4.52	20.35
Full-Actuated	194	1820	9.39	5191	2270	7461	4.10	38.46
SOLID STATE, ANALOG TIMING								
Semi-Actuated	28	95	3.39	373	118	491	5.17	17.54
Full-Actuated								
2 - 4Ø	72	687	9.54	1936	893	2829	4.12	39.29
5 - 8Ø	22	366	16.64	890	521	1411	3.86	64.14
SOLID STATE, DIGITAL TIMING								
Full-Actuated	37	259	7.00	740	401	1141	4.41	30.84
2 - 4Ø								
5 - 8Ø	14	188	13.43	517	312	829	4.41	59.21
TOTALS	1782	11,190	6.28	31,953	13,680	45,633	4.08	25.61

Table 6. Cost of man-hours for estimated maintenance of selected controllers and their detectors from New York State DOT's jurisdiction for period October 1, 1976, to September 30, 1977

Controller Type	Cost ($) Per Signal for Various Phasings			
	2Ø	3-4Ø	5-8Ø	All
ELECTRO-MECHANICAL				
Pretimed	--	--	--	82
Semi-Actuated	189	--	--	189
Full-Actuated	330	489	--	391
Volume-Density	398	398	--	398
MIXED E-M AND SS				
Semi-Actuated	210	--	--	210
Full-Actuated	309	619	--	399
SOLID STATE, ANALOG TIMING				
Semi-Actuated	177	--	--	177
Full-Actuated	365	449	684	474
SOLID STATE, DIGITAL TIMING				
Full-Actuated	268	448	633	411

- A further step up, from two-phase, semi-actuated control to any two-phase, full-actuated controller that is not digital will cost $143 per year. A digital machine will reduce that incremental cost to only $76.

- A two-phase, electro-mechanical, volume-density controller costs about $65 more per year to maintain than any basic controller of non-digital design, and $130 more than a digital model.

- Basic actuated controllers of three and four phases cost an average of $462 per year to maintain (if the "Mixed E-M and SS" data are discarded as outliers). This is $380 more than pretimed control, $127 more than two-phase, full-actuated, non-digital control, and $194 greater than digital control.

- Solid-state controllers of five to eight phases average $659 per year to maintain. This is $210 more than a three-or-four phase analog or digital machine.

State of Ohio D.O.T.

Ohio (5) furnished maintenance data for their 558 traffic signals (Table 7). The table shows primarily that electro-mechanical volume-density controllers require significantly greater maintenance than do their basic counterparts, and much more than modern, solid-state controllers.

State of Minnesota Department of Highways

Table 8 shows the frequency of repair of 135 controllers in the Minneapolis District of the Minnesota Department of Highways. The table indicates a distinct advantage of solid state over electro-mechanical design. As expected, the greater the number of phases the more frequent the repair. The bottom of the table indicates that the frequency of repair of solid-state controllers does not increase with the age of the unit.

Table 7. Frequency of traffic-signal repair by the Ohio D. O. T. in 1976

Controller Type	No. of Signals	No. of Calls	Calls/Signal Per Year
ELECTRO-MECHANICAL			
Actuated (Basic)	296	412	1.39
Volume-Density	84	169	2.01
SOLID STATE			
Analog Timing	178	237	1.33
Digital Timing	Few	Unknown	----

Table 8. Frequency of controller repair by the Minneapolis District, Minnesota Department of Highways

Controller Type	Age, yrs.	Years of Data	No. of Signals	Calls/Signal Per Year
ELECTRO-MECHANICAL				
Full-Actuated, 2Ø	0-5	5.0	8	2.40
Full Actuated, 3-5Ø	0-5	3.0	4	4.70
All E-M	0-5	---	12	2.92
SOLID STATE, ANALOG TIMING				
Semi-Actuated	0-5	5.0	2	1.10
Full-Actuated				
3Ø	0-5	4.9	11	1.84
5Ø	0-5	5.0	27	3.19
5Ø	6-10	2.5	23	2.40
SOLID STATE, DIGITAL TIMING				
Full-Actuated				
3Ø	0-5	3.45	13	1.34
5-8Ø	0-5	3.0	24	2.05
ALL SOLID STATE	0-5	---	100	2.37
	6-10	2.5	23	2.4

The available data included the frequency of repair of the 811 loop detectors and 12 magnetic detectors used with the 112 controllers of Table 8. It was found that the loop detectors averaged 0.24 failures per detector per year, and the magnetic models averaged 0.26.

City of Cincinnati, Ohio

Cincinnati has used a computerized Traffic Control Equipment Maintenance Summary for five years. These summaries have been used to reduce the number of chronically malfunctioning intersections from 17 to 1973 to only two today. The City has a total of over 700 traffic signals.

Table 9 is a summary of two and one-half years of computerized record-keeping, from March, 1975, to August, 1977 (7). The project staff removed all "normal cycle" reports (indicating no malfunction found by the repair crew). The staff also removed all failure reports associated with system features such as coordination units, as the emphasis in this project is on individual intersections.

Table 9 does not indicate any significant increase in maintenance load with an increase in sophistication from pretimed to semi-actuated to full-actuated. Rather, the evidence is that the solid-state actuated equipment is more reliable than the pretimed.

Table 9 shows that the frequency of repair of electro-mechanical equipment increases with age to approximately the tenth year and then decreases with greater age. This same phenomenon is evident also in the data presented below for Tampa, Florida.

Detector maintenance over two years in Cincinnati is shown in Table 10. The data indicated that the pressure detector is

Table 9. Frequency of controller repair by the City of Cincinnati, for the period March, 1975, to August, 1977

Controller Type	Age, yrs.	No. of Signals	Calls/Signal Per Year
ELECTRO-MECHANICAL			
Pretimed	0-5	31	1.81
	6-10	35	2.17
	11-15	--	--
	16-20	139	1.99
	>20	72	1.74
	All ages	277	1.92
Semi-Actuated	0-5	2	1.50
	6-10	48	2.58[a]
	11-15	80	1.70
	16-20	54	1.65
	>20	38	1.68
	All ages	222	1.87
Full Operated Semi	0-5	16	1.13
	6-10	45	2.76[b]
	All ages	61	2.33
SOLID STATE			
Semi-Actuated	0-5	2	1.50
Full Operated Semi	0-5	12	1.00
	6-10	7	1.14
	All	19	1.05

[a] High because of a single model

[b] High because of 20 units of an early design of phase-modular controller that experienced 3.85 calls/signal/year

Table 10. Frequency of detector repair by the City of Cincinnati for the period March, 1976, to August, 1977

Detector Type	No. of Detectors	Failures/Detector Per Year
Pressure	23	0.17
Magnetic	81	0.26
Loop	151	0.29
Sonic	37	0.32

significantly more reliable than the other types listed. The data for magnetic and loop detectors are strikingly similar to the Minneapolis data reported above.

City of Tampa, Florida

A computerized record of frequency of repair was obtained for almost 400 controllers for the year 1974 (8). The record is summarized in Table 11. Detector-maintenance data are not included in Table 11. Except for the pretimed controllers at 2.26 calls per signal per year, and the most recently purchased solid-state controllers operated semi-actuated (at 1.75), the maintenance load is extremely heavy as compared with that reported above for Ohio, Minnesota and Cincinnati. The higher rate for Tampa may be due to the severe lightning storms experienced frequently in Florida. Many of the Tampa rates are of the same order of magnitude as those obtained for New York State (Table 5).

City of Charlotte, North Carolina

Charlotte has a variety of actuated equipment of both electromechanical and solid-state design, and has for many years provided adequate funding for traffic engineering operations. Therefore maintenance data were readily available, and in addition there was experience with a significant number of microprocessor controllers (9).

Their total of 438 controllers includes 72 Type 190 microprocessors received in 1977. Unlike the five microprocessors reported by CALTRANS (Table 1), the Charlotte models are of the type that include volatile memory with battery back-up in the event of power failure. Unlike the Type 170, the program for the 190 is provided by the factory.

The installation of the Charlotte microprocessors began in

Table 11. Frequency of controller repair by the City of Tampa, Florida, for the year 1974

Controller Type	Age, yrs.	No. of Signals	Calls/Signal Per Year
ELECTRO-MECHANICAL			
Pretimed	0-5	32	1.69
	6-10	93	2.33
	11-15	5	0.40
	16-20	1	1.00
	>20	45	2.76
	All ages	176	2.26
Semi-Actuated	0-5	1	0
	6-10	11	6.82
	11-15	38	8.71
	16-20	11	4.45
	>20	12	9.08
	All ages	73	7.73
Full-Actuated	0-5	1	1.00
	6-10	3	4.33
	11-15	5	11.80
	16-20	4	7.50
	>20	1	5.0
	All ages	14	7.71
Semi Operated Fixed	0-5	1	2.00
	11-15	1	11.00
	All ages	2	6.5
Full Operated Semi	11-15	1	3.0
	16-20	2	5.0
	All ages	3	4.33
ALL ELECTRO-MECHANICAL			4.09
SOLID STATE			
Semi-Actuated	0-5	--	--
	6-10	29	5.48
	11-15	4	6.00
	All ages	33	5.55
Full-Actuated	0-5	35	6.17
	6-10	33	9.09
	11-15	2	30.0
	All ages	70	8.23
Full Operated Semi	0-5	8	1.75
	6-10	8	5.00
	11-15	2	23.0
	All ages	18	5.56
ALL SOLID STATE			7.04

March, 1977. At the time of the visitation by project personnel in October, 1977, 24 microprocessors had been installed for an average period of only about three months. As of this writing the latest data were as of May, 1978, and fifty microprocessors had been installed.

Table 12 summarizes six months of 1977 data for 438 Charlotte signals, with the exception that the microprocessor-controller data were updated to May, 1978. Although the overall period of March, 1977, to May, 1978, suggests 14 months of microprocessor data, in fact the 50 controllers were installed gradually over this period. Two installed less than a month prior to the May update were discarded, leaving 48 with service records ranging from one to 14 months. The project staff calculated the frequency of calls per year for each microprocessor individually, using the number of months that each had been in place. This procedure was more precise than one that assumed that all 48 controllers had been in service for an average of seven months.

Table 12, which is for both controllers and detectors, shows that Charlotte's electro-mechanical signals require service once or twice per year, and that the new microprocessor controllers are closer to one service call annually.

City of Springfield, Illinois

Springfield furnished maintenance data for a 12-month period in 1976-77 (10). These data for 144 signals are summarized in Table 13, which shows an unusually high failure rate for semi-actuated controllers. The City Traffic Engineer explained that the City had excellent operational results with two-phase semi-actuated controllers for many years. Their maintenance problems began in

Table 12. Frequency of traffic-signal repair by the City of Charlotte, North Carolina, for the period April - September, 1977.

Controller Type	Age, yrs.	No. of Signals	Calls/Signal Per Year
ELECTRO-MECHANICAL			
Semi-Actuated	>20	75	1.95
Semi-Actuated (PR)	16-20	37	2.49
Full-Actuated Mostly 3Ø	0-5	3	0.67
	11-15	63	1.43
	>20	13	0.91
	All Ages	79	1.29
ALL ELECTRO-MECHANICAL			1.83
SOLID STATE			
Pretimed[a]	6-10	167	0.54
Semi-Actuated	0-5	1	2.00
	6-10	3	0.00
	All ages	4	0.50
Semi-Actuated (TPR)	6-10	11	1.82
	11-15	6	0.00
Full-Actuated			
Digital, non-computer	0-5	4	0.00
Microprocessor[b]	0-5	48	1.21
Analog, non-computer	11-15	7	0.57

[a] These have four-phase frames. Almost all of them are in the CBD, operating two phase, with only two load switches, without detectors or actuation module. A central digital computer operates them as pretimed controllers.

[b] The microprocessor data are for the period March, 1977, to May, 1978

Table 13. Frequency of traffic-signal repair by the City of Springfield, Illinois, for the period March, 1976 - February, 1977

Controller Type	No. of Signals	Calls/Signal Per Year
Pretimed	117	2.37
Semi-Actuated	21	3.95
Full-Actuated	6	1.67

1975 when multi-phase full-actuated controllers were purchased and operated semi-actuated in an arterial system.

City of Winston-Salem, North Carolina

Four years of detailed maintenance cost data were obtained for one pretimed and one full-actuated controller (11). These locations were selected by the City as fairly typical. The data, summarized in Table 14, show a very low cost to maintain the controllers. However, the record of the loop-detector maintenance shows 33 trips in four years to retune, replace, and cut new loops.

Washington, D. C.

A total of 497 loop detectors were installed as a part of the UTCS Research Project sponsored by the Federal Highway Administration. The installations were made only after a thorough study by the contractor of the available (crystal) electronics units and the procedures and materials for installing the loop wire and lead-in. In the first year there 33 failures of the electronics units, for a rate of 0.07 failures per detector per year. During that period 26 loops failed because of utility excavations; if these failures are added, the total rate becomes 0.13 failures per detector per year (12).

Conclusions

The foregoing findings provide the basis for conclusions as to the total cost to maintain various types of controllers. Table 15 has been prepared to receive these conclusions as they are determined in this subsection of the report.

It was found that the CALTRANS Maintenance Management System offers the only available data base of total maintenance costs, including both field and bench work, parts and travel. It seems

Table 14. Example costs of traffic-signal maintenance by the City of Winston-Salem, N. C., for the period 1973 - 77

Controller Type	Calls/Year	Maintenance Cost[a] Per Year, $
Pretimed	2.16[b]	17
Full-actuated, 3Ø, solid state, digital	2.05	18
Loop detection for above controller	8.46	340

[a]Project staff increased City costs by 80 percent to account for fringe benefits and overhead. City costs include labor at $5.00/hr., truck, supplies.

[b]Six of the eight calls over 3.7 years were for preventive maintenance.

Table 15. Project-staff conclusions for the total annual cost to maintain various types of traffic-signals.

Controller Type	Cost ($) Per Signal for Various Phasings 2Ø	3-4Ø	5-8Ø	All
ELECTRO-MECHANICAL				
Pretimed	--	--	--	115 (D)
Semi-Actuated	291 (D)	--	--	--
Full-Actuated	508 (D)	753 (C)	1209 (C)	--
Volume-Density	613 (D)	1162 (C)	1506 (C)	--
SOLID-STATE, ANALOG TIMING				
Semi-Actuated	258 (D)	--	--	--
Full-Actuated	532 (D)	657 (C)	1610 (C)	--
SOLID-STATE, DIGITAL TIMING, EXCEPT MICROPROCESSOR				
Full-Actuated	575 (C)	661 (C)	1090 (C)	--
MICROPROCESSOR				
Full-Actuated	--	421 (C)[a]	757 (C)[a]	--

NOTE: The suffix (C) means that this cost was taken directly from the CALTRANS. Maintenance Management System data of Table 1. The suffix (D) means derived as described in the text.

[a] These data are for a few controllers from a single manufacturer. Other microprocessor controllers may have different maintenance requirements. See Charlotte data in Table 12 for additional data on microprocessor maintenance.

appropriate, therefore, to plot the first points from that data. Table 15 shows a suffix (C) for those values determined directly from the CALTRANS data in Table 1.

At this point the data from the other jurisdictions were referenced to fill in the remaining gaps in Table 15. The New York State DOT data (Table 6) were given preference, because man-hours were available only from that source.

For electro-mechanical equipment the coordination point between the CALTRANS and NYSDOT data sets was selected to be the full-actuated controllers of three and four phases. The ratio of California total cost to NYSDOT field cost at that cell in the matrix is 753 ÷ 489 = 1.54. This factor was multiplied by the values in the cells of Table 6 to yield values for the corresponding cells of Table 15.

For solid-state equipment with analog timing the coordination point between CALTRANS and NYSDOT data was again taken at the full-actuated controllers of three and four phases. The ratio of the two cells is 657 ÷ 4.50 = 1.46, which is reassuringly close to the 1.54 calculated for electro-mechanical equipment. This factor of 1.46 was multiplied by the values in the cells of Table 6 to yield values for the corresponding cells of Table 15.

The factors of 1.46 and 1.54 mean essentially that for every dollar spent on the man-hours for field maintenance of actuated equipment, there is an additional fifty cents required for the other items that comprise the total cost as defined by CALTRANS. These items include the truck and its fuel, the parts used in the repair work, and the cost of the bench labor. If these items cost about the same for pretimed equipment as they do for actuated models, then it would be appropriate to derive the total cost of pretimed controller maintenance as 1.50 x $82 (from Table 6) or $123. However, bench-repair labor is certainly less for pretimed equipment than for actuated designs. Therefore the project staff arbitrarily assigned a reduced cost of $115 for entry in Table 15.

This step completed Table 15, which provides the desired estimate of the maintenance cost of pretimed control and the cost of the incremental maintenance requirements associated with the more-sophisticated types of control.

Adequacy of Data

These data were gathered to assist in the future selection of type of control-pretimed, semi-actuated, basic full-actuated, and density full-actuated. Data on microprocessor controllers need to be included. In this context there are two fundamental inadequacies in the available data.

One is that none of the data sets provides the total maintenance costs for each of the four types of control. The CALTRANS data quotes total cost-field and bench labor, travel and materials--but does not include pretimed control or the new Type 170 microprocessor. The New York State DOT data include pretimed equipment, but the cost of only the field man-hours can be obtained; bench labor, travel and parts are not covered. Most of the other sources quote only frequency of repair, not dollar cost.

Another difficulty with these data is that future consideration of actuated control-at least for the future as we can see it now-will focus on the microprocessor controller and the digital loop detector. Almost all of the available maintenance data predate these recent innovations.

Respondents in California, New York State and Charlotte, N.C., for example, make it clear that microprocessor designs of Type 170 (user programmed) and Type 190 (factory programmed) are showing a longer Mean Time Between Failure (MTBF) and a shorter Mean Time to Repair (MTTR) than have the other controllers reported herein. (However, hard data on this superiority are skimpy as of this writing.) Presumably other designs of microprocessors will show similar benefits when their records are tabulated.

Moreover, the digital loop detector is proving to be significantly more effective than its analog counterpart. New York State, for example, has found in 1978 that digital loop electronics are successfully operating loops in such poor condition that the locations had been scheduled for reinstallation of new loops. A number of other respondents indicated that they are extremely impressed with the digital unit's sensitivity and ability to operate under adverse conditions of loop condition, temperature, etc.

The point is that the present research project was conceived at a point in time when some states--particularly those in the northeast and upper mid-west--were experiencing great difficulty in maintaining actuated controllers and loop detectors of conventional design. In 1977 and 1978 the microprocessor and the digital loop detector began to change this situation completely for some agencies. New York State, for example, now is able to look much more positively toward the selection of full-actuated control at individual intersections. It seems clear that this research project has been overtaken by technological breakthroughs that greatly diminish the potential attraction of pretimed or semi-actuated control at individual intersections.

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