Research Report
UKTRP-82-14

SNOW-MELTING SYSTEM, 9th STREET AND I 64, LOUISVILLE

by

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16. Abstract

The 9th Street - I 64 interchange in Louisville was equipped with an automated electrical heating system for snow and ice removal. The system is capable of maintaining a clear and safe passageway. This report summarizes the performance of the heating system and describes the factors that will influence future use of this or other nonconventional methods of snow and ice removal.

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INTRODUCTION

The 9th-Street interchange was originally conceived as a major link in the transportation plan for Jefferson County. The interchange was to provide the primary access to the downtown area via I 264/64 and the proposed Southwest Radial (Figure 1). A combination of grades and superelevations (over 6.5 percent) and exposure conditions compelled planners and designers to analyze hazards that would confront the travelling public during bad weather conditions (more specifically during periods of frost glazing, snow, and/or ice conditions). Conventional snow and ice removal techniques were thought to be inadequate. Therefore, an automated snow and ice removal system was deemed necessary. The specifications, design, construction, and initial operation of the heating system have been documented in earlier research reports *(1, 2, 3, 4)*. This report summarizes the operation, performance, and the factors that influenced operation and performance since the interchange initially opened in the winter of 1976 - 1977.

To the time of its construction, the 9th Street interchange was the largest application of an electrical resistance system to the heating of a highway pavement for the control of ice and snow. The project was experimental and was implemented to evaluate the viability of developing technology.

OPERATION

The heating system has been operated in various modes since its completion. Administrative decisions in response to public pressure has been largely responsible for the method of operation. Initially, to justify the high construction costs of the heating system, high assurance of performance was deemed essential. For the first two years (1976-1977 and 1977-1978) of operation, the bridge decks and ramps were at all times kept warm enough to melt any snow or ice as it formed. A set-point temperature (a predetermined slab temperature used by the Master Controller to adjust the heat input to the slab) of 38°F (3°C) was used for normal operation. In other words, normal operation was to maintain a minimum slab temperature of 38°F (3°C) at all times. Figures 2, 3, and 4 illustrate the results of that approach during 1976-1977 and 1977-1978. Tables 1 and 2 list monthly weather summaries for the same period. In periods of severe weather, heat input was increased to the slab; however, during periods of cold but clear weather, adjustments were not made accordingly. Operation was basically in the automatic mode but manual override persisted during severe weather conditions. The snow- and ice-melting capabilities of the heating system performed beyond expectations. Operating expenses were high but seemed justified as the public grew accustomed to a "clear roads policy" at the interchange. The winter of 1977-1978 was the harshest on record for the Louisville area. Yet, during periods with as much as 10+ inches (280+ mm) of snow cover, the interchange remained clear and safe (Figure 5 and 6).

With increasing demands for governmental frugality and a national effort toward energy conservation, more conservative means were sought for operating the system during the 1978-1979 heating season. The slab set-point was lowered, the pavement was not kept warm enough to melt snow at all times, and more manual override was employed when threatening conditions existed. The prevailing opinion was that there was no need to keep a pavement or bridge deck warm during periods of extreme cold-but-clear weather. When threatening weather conditions were forecast, manual override was employed to raise the level of heat input to ensure a snow-melting condition. Contingency plans for snow removal with chemical abrasives were suggested but were not implemented because of possible corrosive damage to the heating elements. Plots of air and slab temperatures and monthly weather summaries are shown in Figures 7 and 8 and Tables 3 and 4 for the 1978-1979 and 1979-1980 seasons. Again, the heating system was able to keep the interchange free of ice and snow. Indeed, some economy was achieved by modification of operating procedures

In the summer of 1980, officials again questioned the benefits to the public and urged economy in operations. Proposals ranging from total abandonment of the heating system to maintaining the pavement temperature above freezing at all times were proposed and discussed. A summary of the proposals is contained in Appendix A. Some officials argued that conventional snow removal techniques could be employed at a fraction of the cost of heating; others argued that providing a safe passageway for the motoring public under extreme design and climatic conditions required extra-ordinary measures. A decision was made to employ "Method D" as outlined in Appendix A. "Method D" is virtually a continuation of operating procedures employed during the winters of 1978-1979 and 1979-1980. A paradoxical situation developed. Some engineers argued afterward that the heating system was never operated in the most efficient mode. They maintained that the original design strategies called for "total automatic operation" -- a method not yet tested at the interchange. Operation in that mode would allow the slab temperature to go very low (20°F (-7°C)) when cold but clear weather conditions

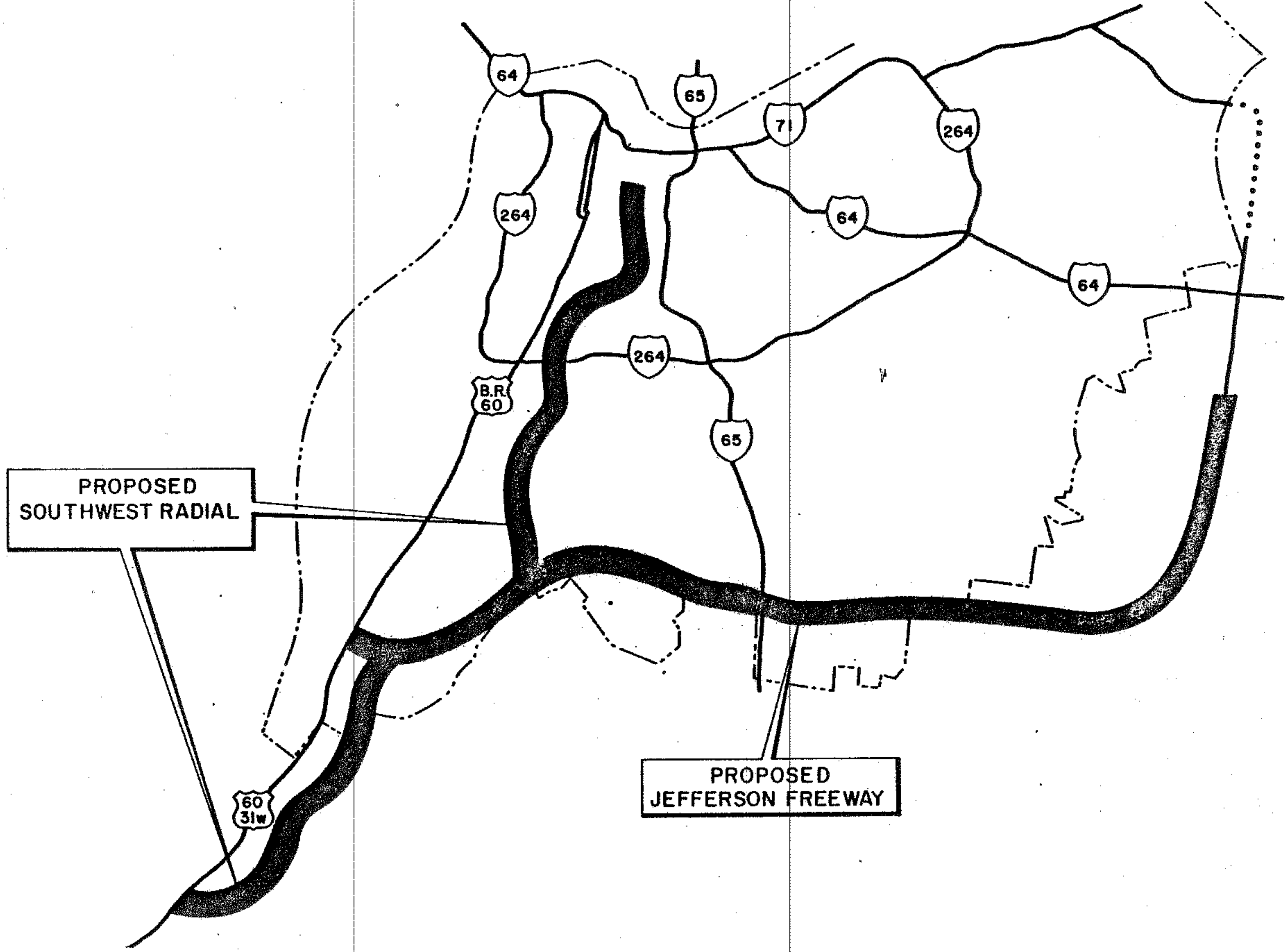

Figure 1. 9th-Street Interchange and Proposed Southwest Radial.

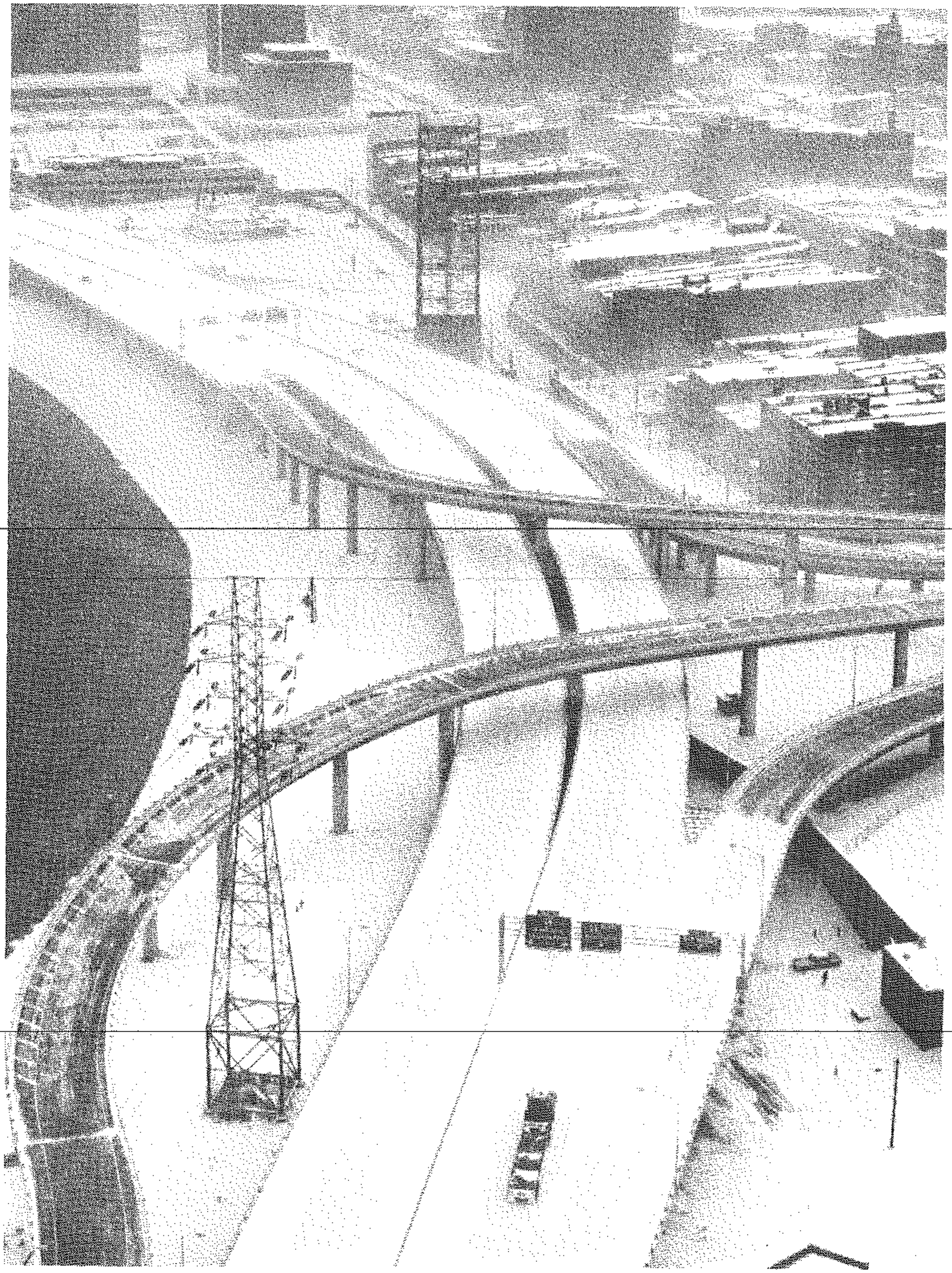

Figure 2. Aerial View of 9th-Street Interchange, January 11, 1977, Showing Distinctive Contrast between Heated and Unheated Sections (Courier-Journal; reprinted with permission).

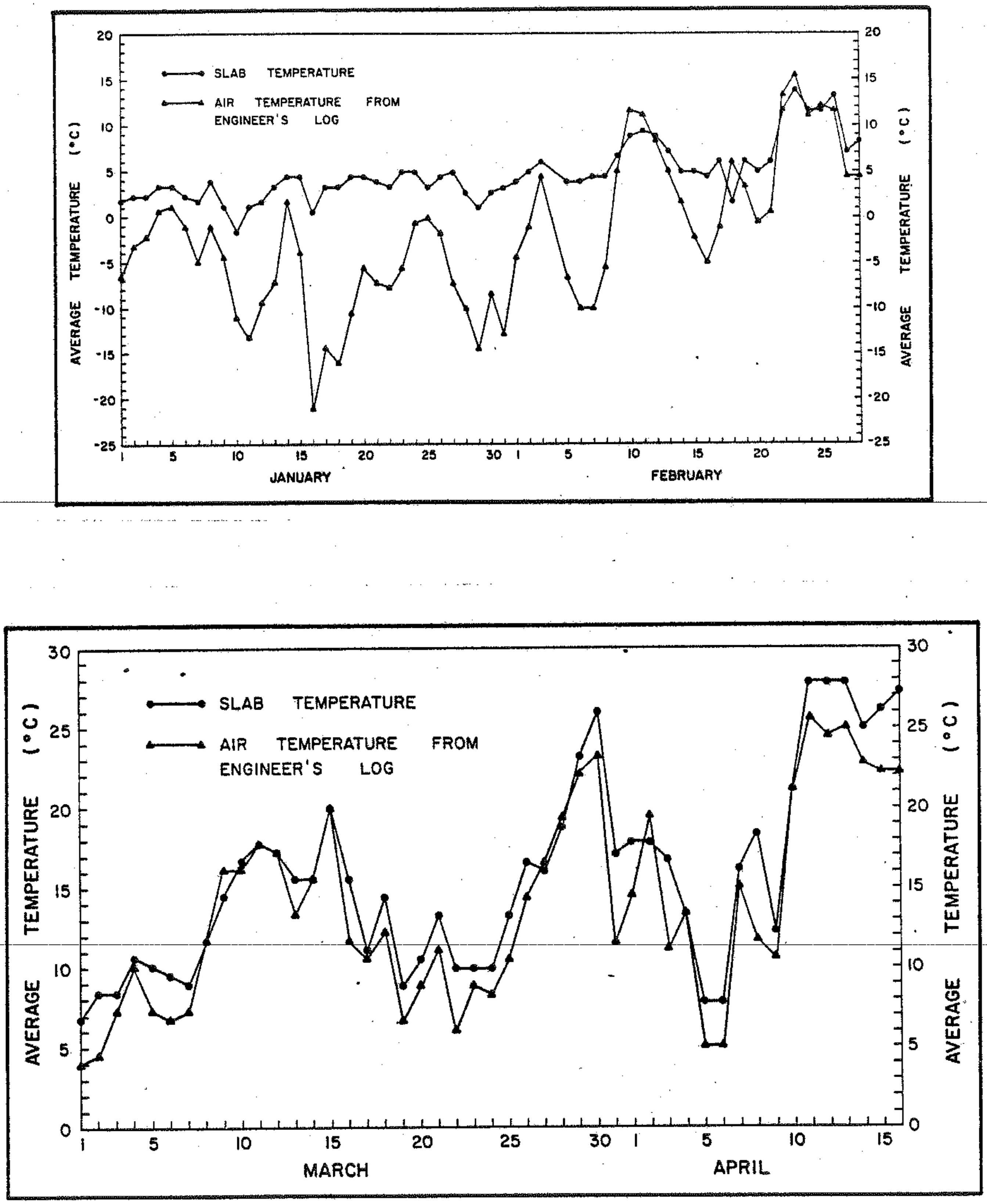

Figure 3. Average Temperatures; January, February, March, and April 1977.

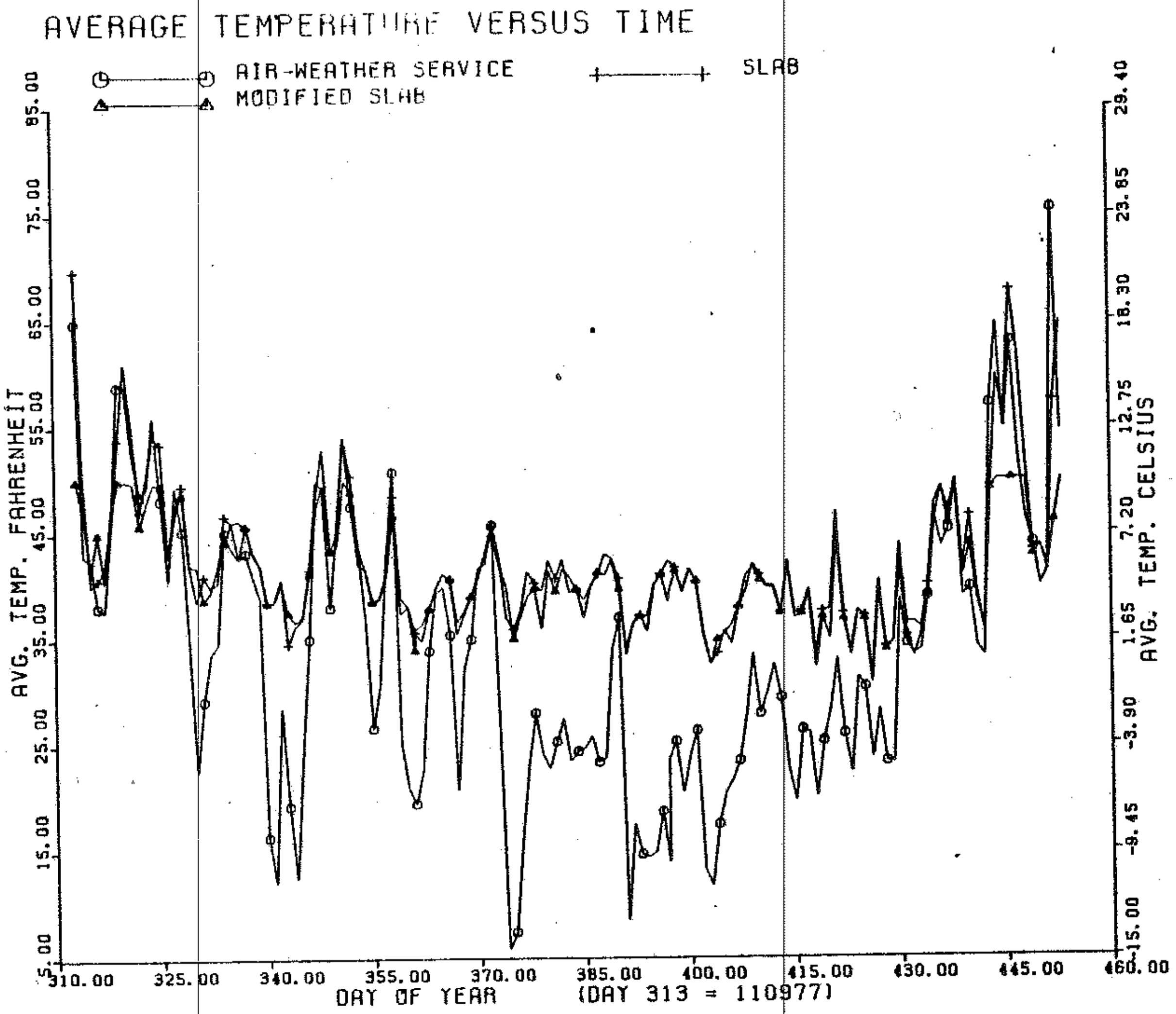

Figure 4. Average Temperatures; 1977-1978.

Figure 5. Snow Melting; March 14, 1978.

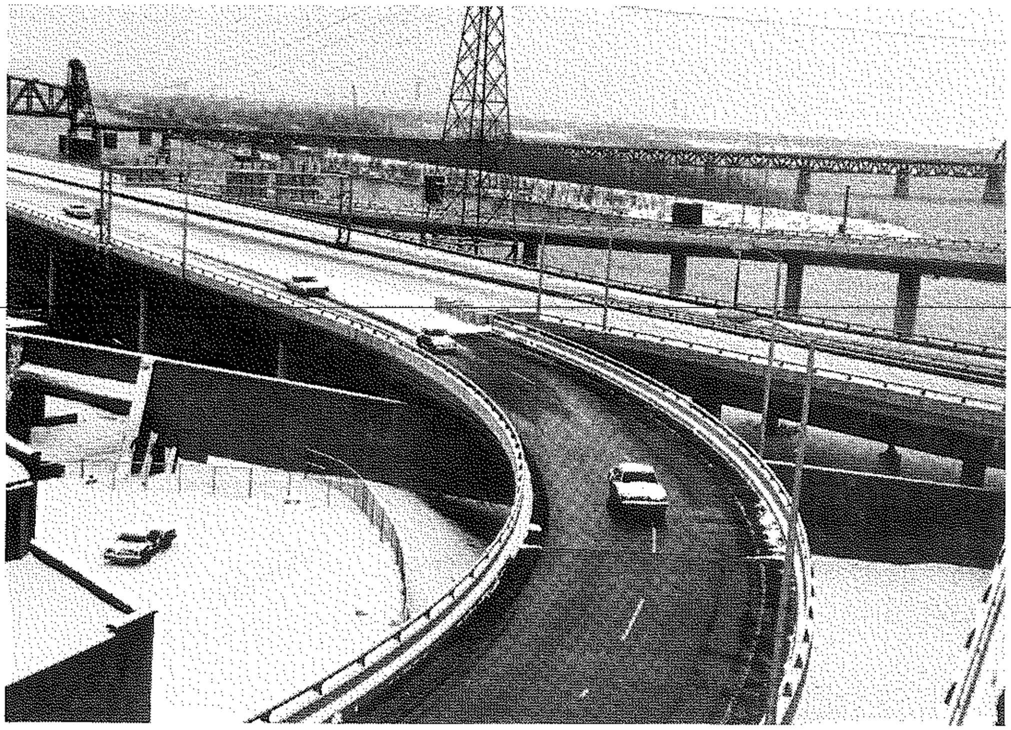

Figure 6. Snow Melting; March 14, 1978.

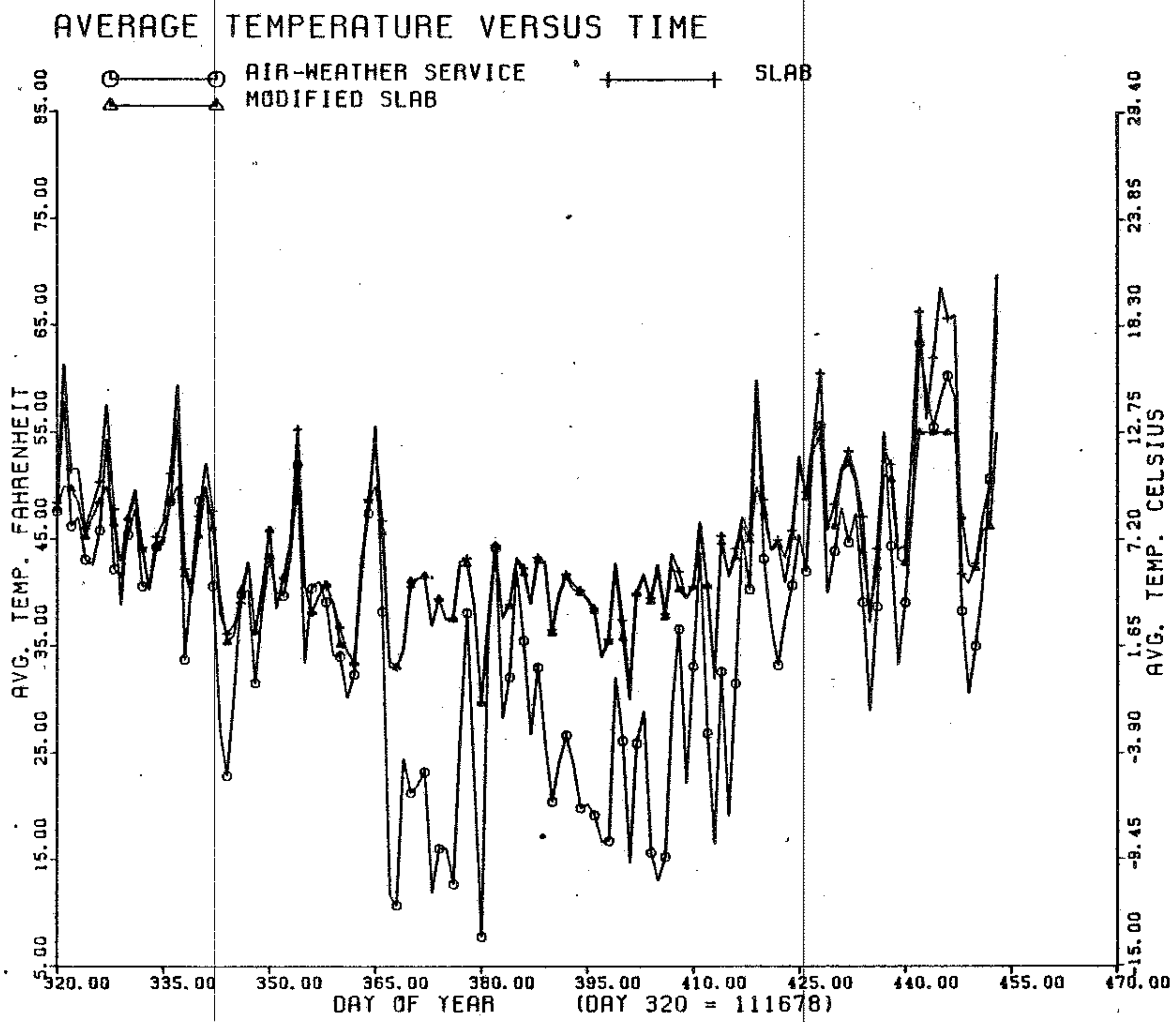

Figure 7. Average Temperatures; 1978-1979.

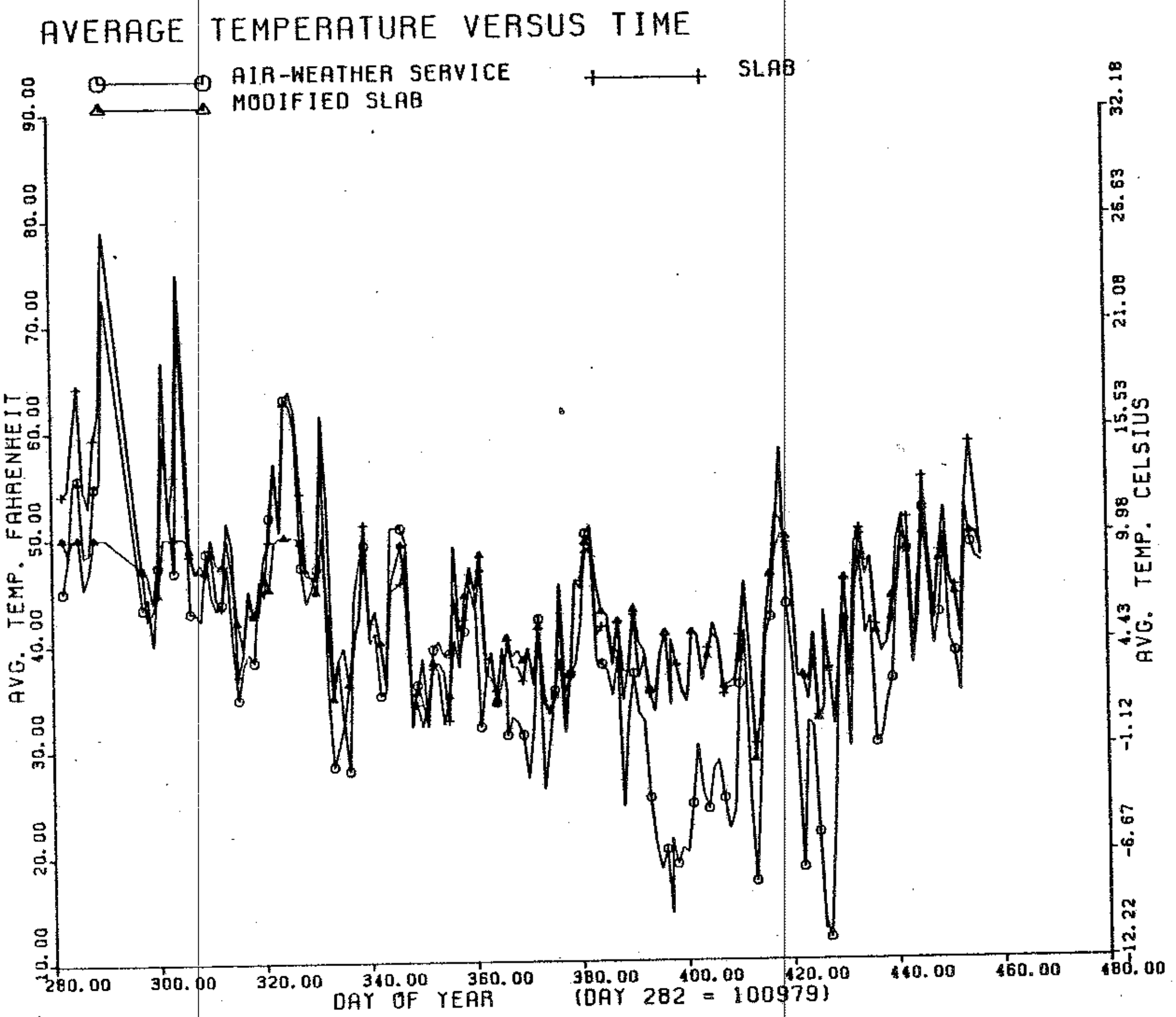

Figure 8. Average Temperatures; 1979-1980.

TABLE 1. WEATHER SUMMARIES, 1976 - 1977

	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL
High Temperature	-	65°F (18°C)	42°f (6°C)	75°F (24°C)	83°F (28°C)	86°F (30°C)
Low Temperature	-	2°F (-17°C)	-13°F (-25°C)	5°F (-15°C)	22°F (-6°C)	33°F (1°C)
Average Temperature	-	33.1°F (1°C)	18.6°F (-7°C)	36.9°F (3°C)	51.7°F (11°C)	60.3°F (16°C)
Largest Snowfall/Date	-	0.9 in. (23 mm) 12-29-76	7.8 in. (198 mm) 1-9, 10-77	0.4 in. (10 mm) 2-19, 20-77	0.1 in. (3 mm) 3-22-77	0.8 in. (20 mm) 4-5, 6-77
Greatest Accumulation/Date	-	1.0 in. (25 mm) 12-29-76	9.0 in. (229 mm) 1-11-77	2.0 in. (51 mm) 2-3-77	Trace 3-22-77	Trace 4-6-77
Total Snowfall	-	1.1 in. (28 mm)	19.6 in. (498 mm)	0.8 in. (20 mm)	0.1 in. (3 mm)	0.8 in. (20 mm)

TABLE 2. WEATHER SUMMARIES, 1977 - 1978

	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL
High Temperature	77°F (21°C)	61°F (16.1°C)	60°F (15.5°C)	40°F (4.4°C)	83°F (28.3°C)	86°F (30.0°C)
Low Temperature	17°F (-8.3°C)	5°F (-15.0°C)	-10°F (-18.3°C)	0°F (-17.8°C)	2°F (-16.7°C)	35°F (1.7°C)
Average Temperature	49.6°F (9.7°C)	34.6°F (1.4°C)	22.9°F (-5.1°C)	23.8°F (-4.6°C)	41.7° F (5.4°C)	58.0°F (14.4°C)
Largest Snowfall/Date	4.8 in. (122 mm) 11-27-77	1.9 in. (48 mm) 12-6-77	14.1 in (358 mm) 1-16, 17-78	1.9 in. (48 mm) 2-18-78	6.4 in. (163 mm) 2-3-78	Trace 3-16-78
Greatest Accumulation/Date	4.0 in. (102 mm) 11-27-77	2.0 in. (51 mm) 12-6-77	19.0 in. (483 mm) 1-20-78	10.0 in. (254 mm) 2-2-78	6.0 in. (152 mm) 2-3-78	Trace 3-16-78
Total Snowfall	4.8 in (122 mm)	2.2 in (56 mm)	28.4 in. (721 mm)	5.3 in. (135 mm)	9.4 in. (239 mm)	Trace 3-16-78

TABLE 3. WEATHER SUMMARIES, 1978 - 1979

	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL
High Temperature	77°F (25.0°C)	66°F (18.9°C)	55°F (12.8°C)	64°F (17.8° F)	76°F (24.4°C)	81°F (27.2°C)
Low Temperature	27°F) (-2.8°C)	17°F (-8.3°C)	0°F (-17.8°C)	3°F (-16.1°C)	18°F (-7.8°C)	30°F (-1.1°C)
Average Temperature	50.0°F (10.0°C)	40.0°F (4.4°C)	24.6°F (-4.1°C)	28.0°F (-2.2°C)	48.3°F (9.1°C)	55.0°F (12.8°C)
Largest Snowfall/Date	0	0	3.0 in. (79 mm) 1-27, 28-79	4.7 in. (119 mm) 2-18-79	0.7 in. (18 mm) 3-24, 25-79	Trace 4-6-79
Greatest Accumulation/Date	0	0	3.0 in. (76 mm) 1-10-79	5.0 in. (127 mm) 2-9-79	1.0 in. (25 mm) 3-25-79	Trace 4-6-79
Total Snowfall	0	0	8.5 in. (216 mm)	10.9 in. (277 mm)	0.9 in. (23 mm)	Trace

TABLE 4. WEATHER SUMMARIES, 1979 - 1980

	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL
High Temperature	74°F (23.3°C)	69°F (20.6°C)	57°F (13.9°C)	64°F (17.8°C)	65°F (18.3°C)	86°F (30°C)
Low Temperature	25°F (-3.9°C)	13°F (-10.6°C)	11°F (-11.7°C)	2°F (-16.7°C)	1°F (-17.2°C)	32°F (0.0°C)
Average Temperature	46.9°F (8.3°C)	39.2°F (4.0°C)	33.5°F (0.8°C)	29.6°F (-1.3°C)	4.8°F (-15.1°C)	53.6°F (12.0°C)
Largest Snowfall/Date	0.1 in. (25 mm) 11-29-79	Trace 12-17-79	6.8 in. (173 mm) 1-30, 31-80	2.0 in. (51 mm) 2-15, 16-80	3.9 in. (99 mm) 3-1-80	Trace 4-15-80
Greatest Accumulation/Date	0.1 in (25 mm) 11-29-79	Trace 12-17-79	7.0 in. (178 mm) 1-7-31	6.0 in. (152 mm) 2-1-80	4.0 in. (102 mm) 3-2-80	Trace 4-15-80
Total Snowfall	Trace	Trace	10.7 in. (272 mm)	3.6 in. (91 mm)	3.9 in. (99 mm)	Trace

existed. The Master Controller, in response to various weather signals, would automatically increase the level of heat to the slab as necessary. Automatic operation, had it performed properly, would have utilized the vast array of logic circuitry designed specifically for this heating system. Other engineers felt that the system would not operate in a fully automatic mode, as installed, because of the early malfunction of various detecting instrumentation. However, it was felt that the system might operate efficiently in a semi-automatic mode. The equipment and strategy were described previously *(2)* as follows:

> *"The Master Controller is provided to obtain as full an automatic control as possible. The basic concept is to operate the heating system at a low level of heat when the slab temperature goes above a certain set point. As the temperature drops, slab temperature sensors cause the voltage regulator to increase the voltage into the system. As the temperature increases, the voltage level is reduced. However, various weather parameters, such as barometric pressure, rain, snow, humidity, and others, are programmed into the system so that the system actually operates on the probability of snow and ice rather than the detection of snow or ice. An illustration is given in Figure A* (Figure 9, here). *The slab temperature establishes a base-line condition. As the temperature drops, more heat input goes into the slab. The basic straight-line situation is then changed by the weather factor signal modifiers, represented by the cross-hatched areas between the curves. If weather conditions remain ideal, even though the temperature goes very low, a minimum of heating would be required, as shown by the lower portion of the cross-hatched area. If weather conditions are unfavorable, more heat would be required as shown by the upper portion of the cross-hatched area."*

Others argued that the system was not capable of total automatic operation as previously described. They maintained that the system was capable of modulation of slab set point by only 2° to 3°F (4° to 5°C) and that the Master Controller would always maintain a slab temperature, within that range, plus or minus, of the set-point. The issue remained unsettled. The design engineering consultant and the electrical subcontractor were questioned, but the issue remained unresolved. Efforts to validate the theory by practical application in both the 1980-1981 and 1981-1982 heating seasons proved fruitless. Mild winters in each year did not provide a period in which "total automatic operation" could be tested.

Some engineers argue that the system will not provide for modulation of the slab temperature outside a range of 2° to 3°F (4° to 5°C) plus or minus of the slab set-point. Rather than the complex logic circuitry employed as the "mechanical brain" of the heating system, a simple thermostat, similar in theory to that employed in a residential home, would have sufficed. Implementation of a thermostat combined with forecasts by the National Weather Service would provide a service virtually identical to that of the Master Controller.

Figures 10 and 11 compare air and slab temperatures and Tables 5 and 6 document weather conditions for the 1980-1981 and 1981-1982 heating seasons.

EQUIPMENT AND INVENTORY

Evaluation of equipment and instrumentation utilized at the interchange tends to be very subjective. The subjective viewpoint stems from the operating engineer's confidence in an individual piece of equipment to perform as an integral part of the total system and if that piece of equipment was of benefit to the operating engineer in optimizing the performance of the heating system at the interchange. An equipment inventory indicating the general condition and an estimated cost of repair is listed in Appendix B. The electrical heating system was maintained from construction through Fiscal Year 1981 by Marine Electric Company of Louisville, the electrical subcontractor during construction. Walter Diecks Electric Company of Louisville was retained for FY 1982. Maintenance costs for the system are listed in Table 7. Of the $114,000 total maintenance cost, approximately $38,000 was for routine maintenance; the remainder was for repair work.

A remote television monitoring system has performed poorly. Repeated efforts to repair and maintain the closed-circuit monitor system have yielded minimal results. According to those charged with the task of providing an operable system, Marine Electric's engineering staff, the system was overdesigned; i.e., the design engineers specified that the monitoring system be a combination of the best parts of several manufacturers. However, some claimed the specified equipment was incompatible and thus yielded poor performance. A total system supplied by one manufacturer might have been preferred and would, perhaps, have given better performance. At the time of writing this report, only three remote TV cameras and four TV monitors are operable. The operating engineer and assistants expressed the need

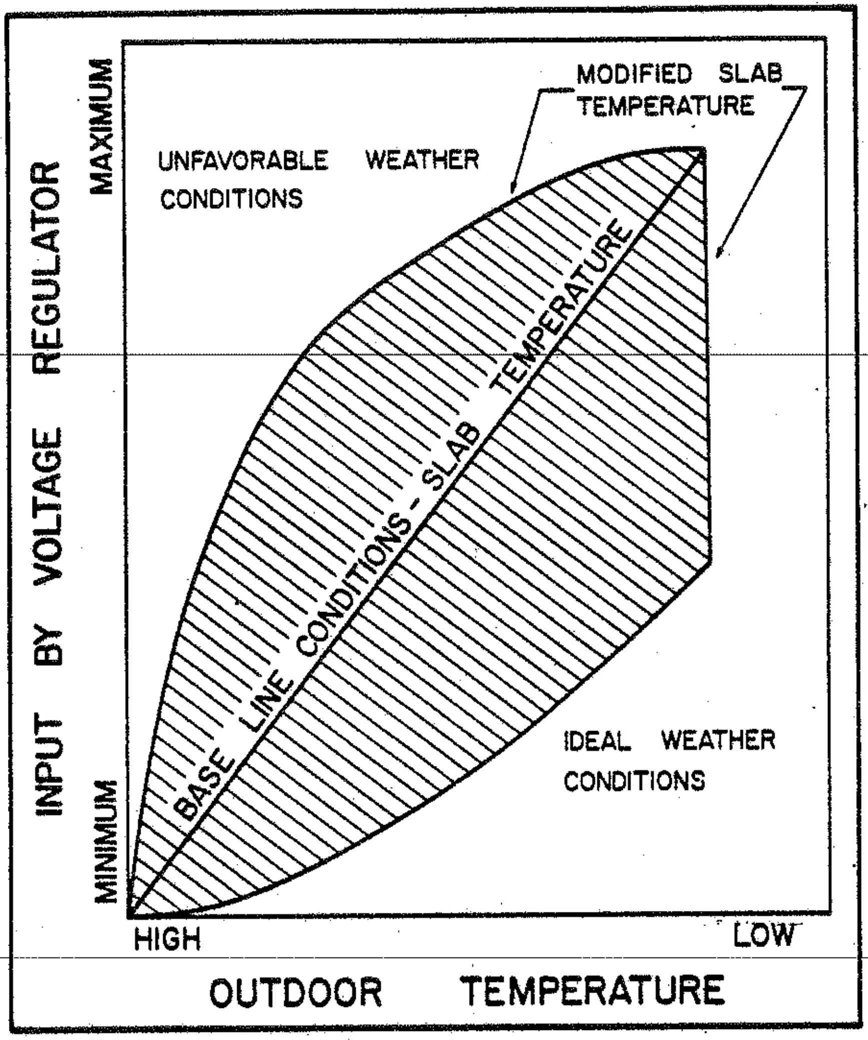

Figure 9. Modified Slab Temperature Conditions (Conceptual).

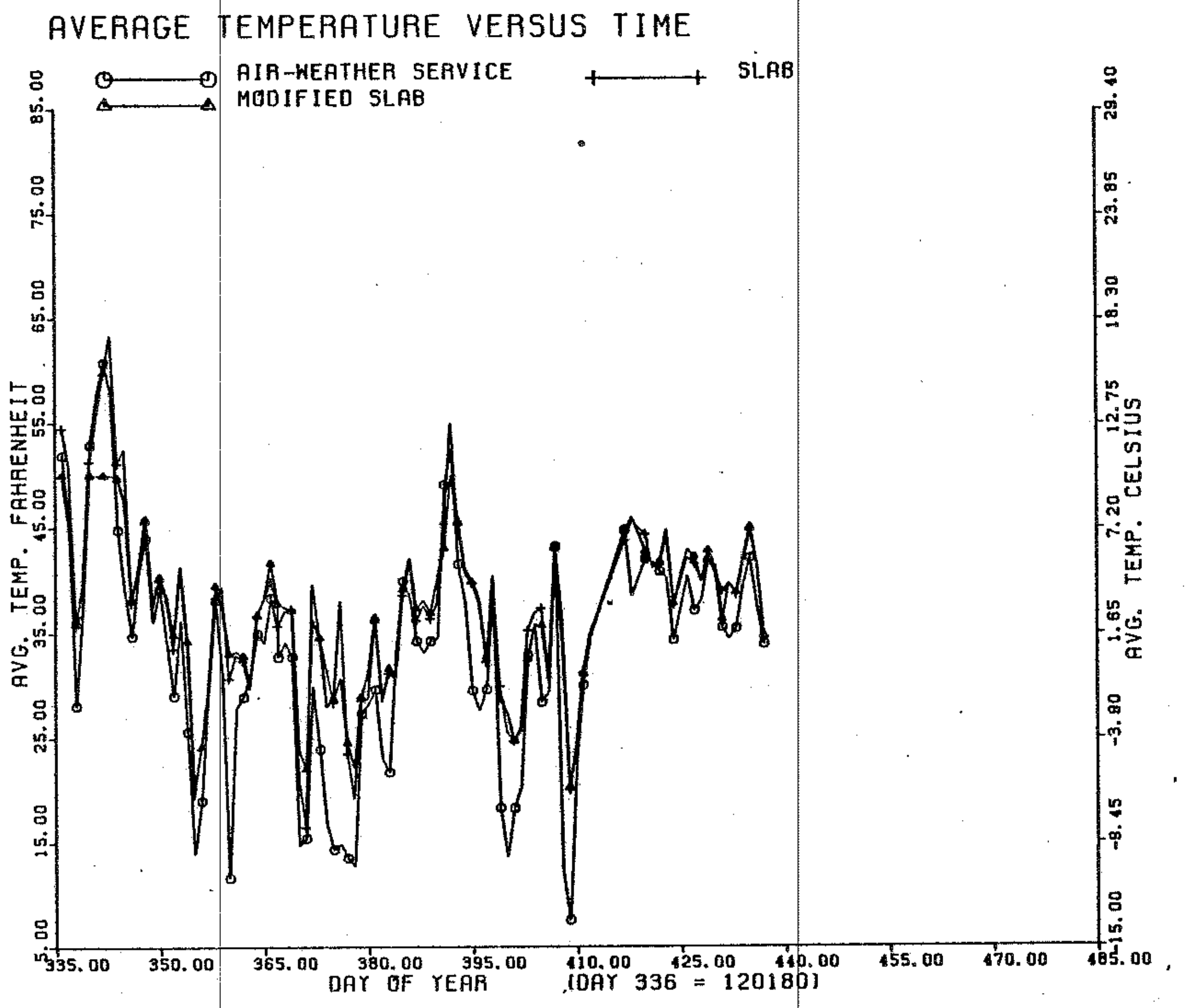

Figure 10. Average Temperatures; 1980-1981.

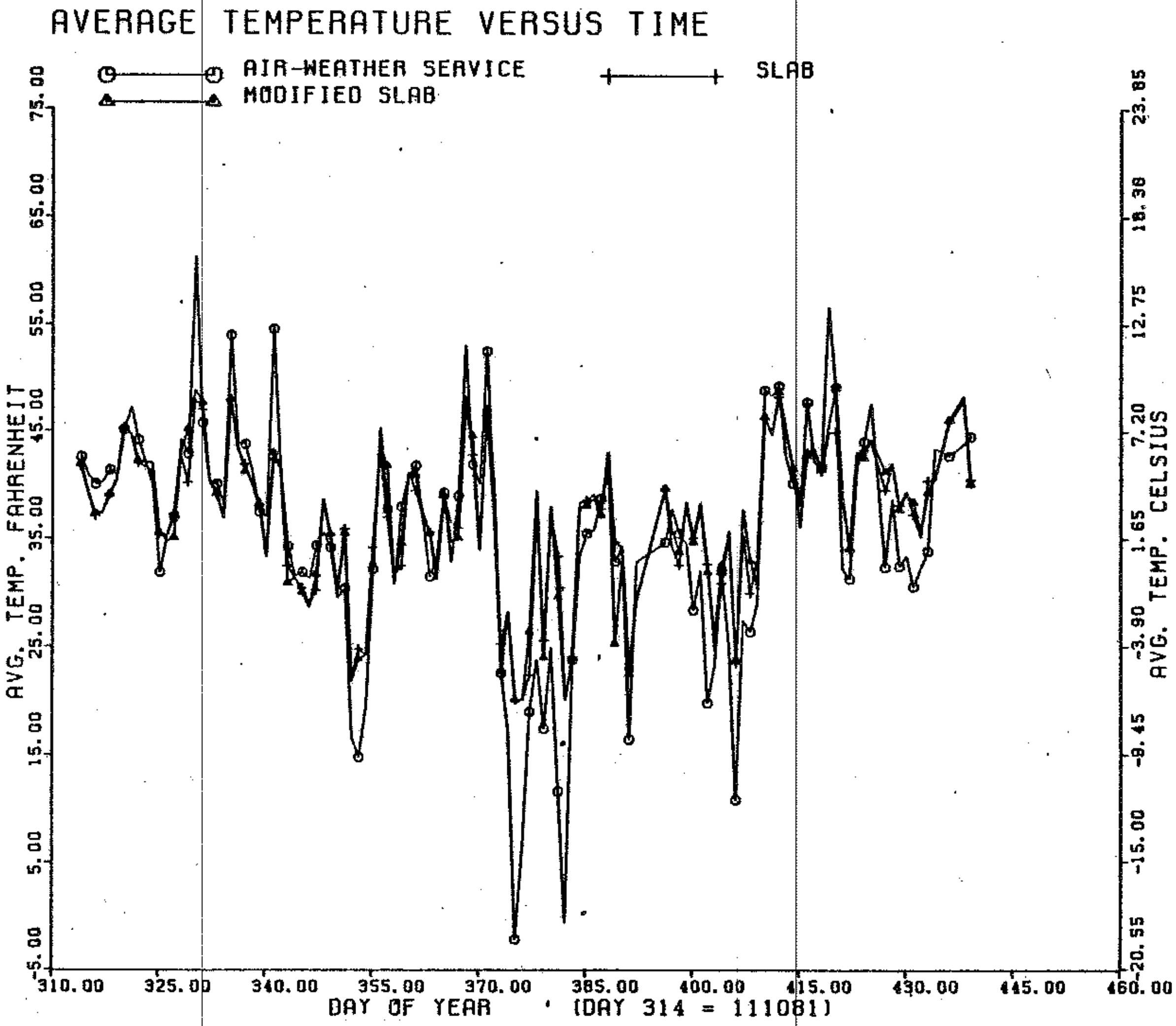

Figure 11. Average Temperatures; 1981-1982.

TABLE 5. WEATHER SUMMARIES, 1980 - 1981

	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL
High Temperature	79°F (26.1°C)	71°F (21.7°C)	66°F (18.9°C)	69°F (20.6°C)	86°F (30.0°C)	87°F (30.6°C)
Low Temperature	24°F (-4.4°C)	9°F (12.8°C)	3°F (-16.1°C)	0°F (-17.8°C)	23°F (-5.0°C)	34°F (1.1°C)
Average Temperature	46.3°F (7.9°C)	38.3°F (3.4°C)	30.4°F (-0.9°C)	38.8°F (3.8°C)	45.7°F (7.6°C)	51.2°F (10.7°C)
Largest Snowfall/Date	Trace 11-29-80	Trace 12-30-80	2.5 in. (64 mm) 1-6, 7-81	0.3 in. (7.6 mm) 2-11-81	0.1 in. (2.5 mm) 3-19-81	0
Greatest Accumulation/Date	Trace 11-29-80	Trace 12-30-80	2.0 in. (51 mm) 1-8-81	Trace 2-13-81	Trace 3-20-81	0
Total Snowfall	Trace	Trace	2.5 in (64 mm)	0.3 in. (7.6 mm)	0.1 in (2.5 mm)	0

TABLE 6. WEATHER SUMMARIES, 1981 - 1982

	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL
High Temperature	76°F (24.4°C)	62°F (16.7°C)	60°F (15.6°C)	75°F (23.9°C)	82°F (27.8°C)	81°F (27.2°C)
Low Temperature	21°F (-6.1°C)	4°F (-15.6°C)	-11°F (-23.9°C)	4°F (-15.6°C)	18°F (-7.8°C)	22°f (-5.6°C)
Average Temperature	47.4°F (8.6°C)	33.8°F (1.0°C)	28.6°F (-1.9°C)	34.9°F (1.6°C)	47.1°F (8.4°C)	51.3°F (10.7°C)
Largest Snowfall/Date	0.1 in. (2.5 mm) 11-20, 21-81	1.7 in. (43 mm) 12-21-81	2.5 in. (64 mm) 1-12, 13-82	2.3 in. (58 mm) 2-12, 13-82	0.3 in. (7.6 mm) 3-6,7-82	1.4 in. (3.6 mm) 4-7, 8-82
Greatest Accumulation/Date	Trace 11-21-81	1.0 in. (25 mm) 12-22-81	2.0 in. (51 mm) 1-15-82	2.0 in. (51 mm) 2-14-82	Trace 3-27-82	1.0 in. (25 mm) 4-8-82
Total Snowfall	0.1 in (2.5 mm)	3.6 in. (91 mm)	2.7 in. (69 mm)	2.9 in. (74 mm)	0.3 in. (7.62 mm)	1.4 in. (36 mm)

TABLE 7. MAINTENANCE COSTS

1976 - 1977	$12,000
1977 - 1978	18,000
1978 - 1979	17,000
1979 - 1980	30,000
1980 - 1981	17,000
1981 - 1982	20,000

for a color TV monitoring system in order to determine the difference between ice and water on the pavement.

Weather stations, more specifically the rain and snow indicators, did not perform as expected. The problem with the rain and snow indicators is apparently inherent to the design and is not correctable. Simply stated, the indicators fail to correctly identify snow or rain at all times. Repeated vibration of both TV cameras and weather stations. mounted on masts rising from bridge ramps is partially accountable for their poor performance.

Of the 201 separate heating circuits, 16 are inoperable due to low resistance. Three circuits have been rewired with two-pole breakers to utilize two of the three circuits which are of sufficient resistance. Five of the 16 inoperable circuits are on on-grade ramps; the remainder are on bridge ramps. Moisture intrusion in or around the heating cables lowers their resistance to ground and renders them inoperable. Figures 12, 13, and 14 show sections where cables have been turned off. Periodic energizing of the system is necessary to minimize intrusion of moisture. A circuit that has become inoperable due to low resistance (moisture intrusion) may be rejuvenated with repeated energizing to "dry out" the circuit.

If a circuit does "blow," repair would be difficult and expensive. Since the heating system is buried in the concrete deck or pavement, it would have to be sawed and removed so as to replace a circuit. However, failures should be minimal if moisture intusion is minimized by use and repeated energizing of the system and if salts that would cause the electrical system to corrode are not applied to the pavement.

DISCUSSION

The heating system at the 9th-Street interchange has been fraught with problems since its inception. It has been both praised and criticized. No one can deny the ability of the system to maintain both a clear and safe passageway.

Problems have been all-pervasive since the system became operational. The design engineering consultant failed to provide operation and maintenance manuals as originally promised and specified. Operating costs have been determined in part by a negotiated contract between Louisville Gas and Electric and the Kentucky Department of Highways (requiring a minimum charge of $5,900 per month regardless of usage). Attempts to operate the heating system in an optimum mode were not successful. However, a degree of efficiency and full effectiveness in melting ice and snow were achieved by operating a semi-automatic mode.

The cost of operating such a system is a major problem. Qualitative economic analysis is difficult because of intangibles to be considered. Installation, operating, and maintenance costs for both heating and conventional snow removal techniques are definable -- road-user benefits to the travelling public and safety of a salt-application crew are rather abstract. Therefore, assigning a value for accident liability, driver safety, travel delays and congestion, salt-crew safety, and service life are subjective. Actual operating costs for the heating system are listed in Table 8. Power usage and costs are listed in Table 9.

One method for cost comparison is to consider an **average annual cost** amortized over a 25-year expected service life:

HEATING SYSTEM

	Cost/ft^2
Initial Cost	$10.79
Replacement Cost	0.00
Operating and Maintenance Cost (Average for first six years)	1.29

$$\text{Average Annual Cost} = [\$10.79 + \$0.00 + 25 \text{ x } \$1.29] \div 25 = \$1.72/\text{yr}/\text{ft}^2$$

CONVENTIONAL SNOW REMOVAL

	Cost/ft^2
Initial Cost	$0.00
Replacement Cost	5.56
Operating and Maintenance Costs (materials, personnel, equipment, advance warning signs)	0.20

$$\text{Average Annual Cost} = [\$0.00 + \$5.56 + 25 \text{ x } \$0.20] \div 25 = \$0.42/\text{yr}/\text{ft}^2$$

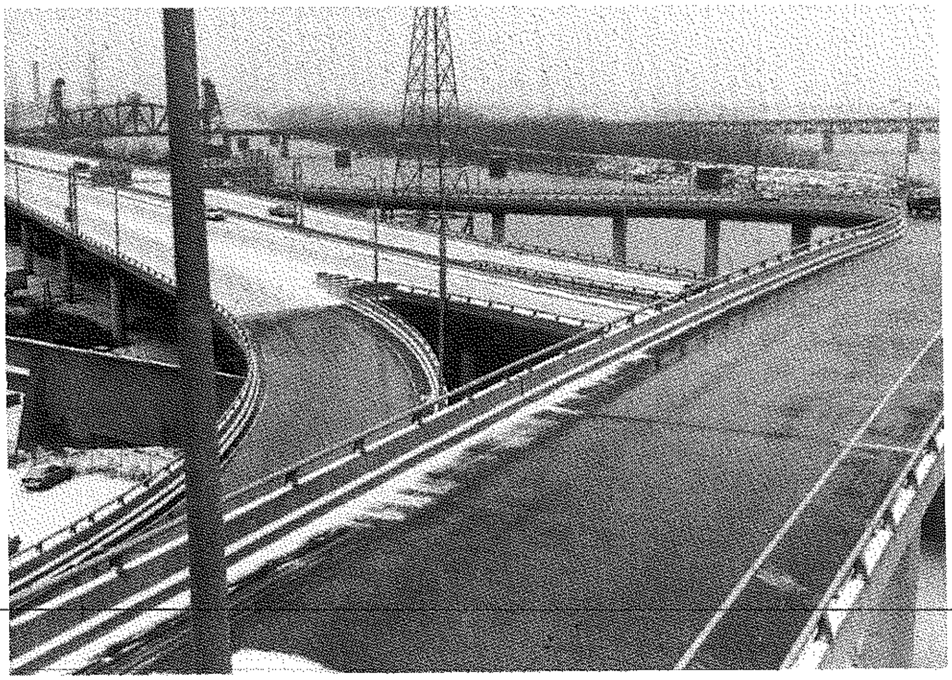

Figure 12. Inoperative Heating Cable (at curb); December 21, 1981.

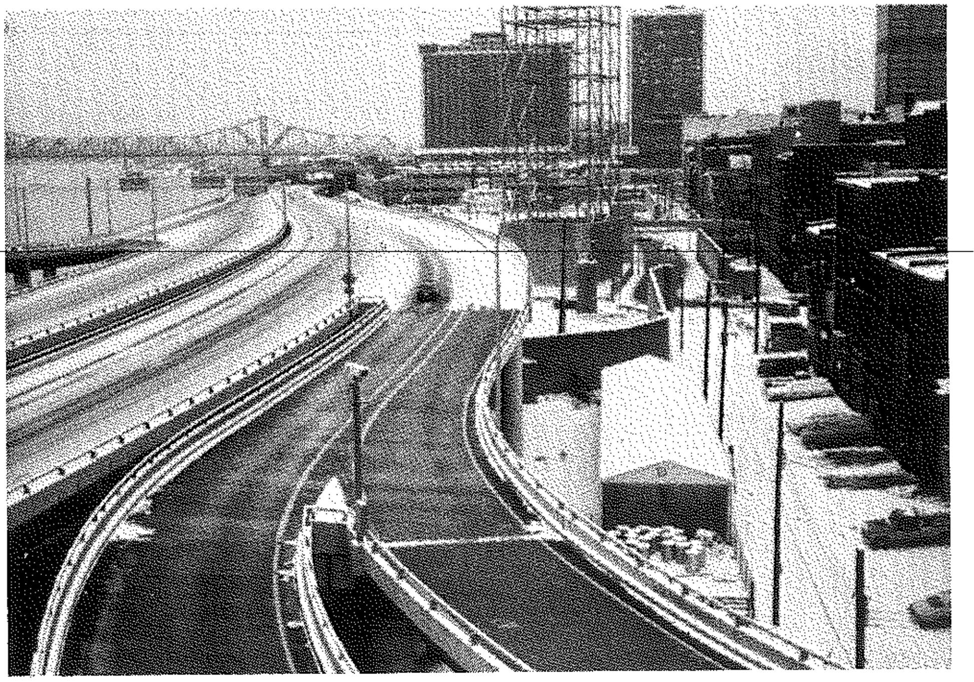

Figure 13. Inoperative Heating Cable (left curb); January 13, 1982.

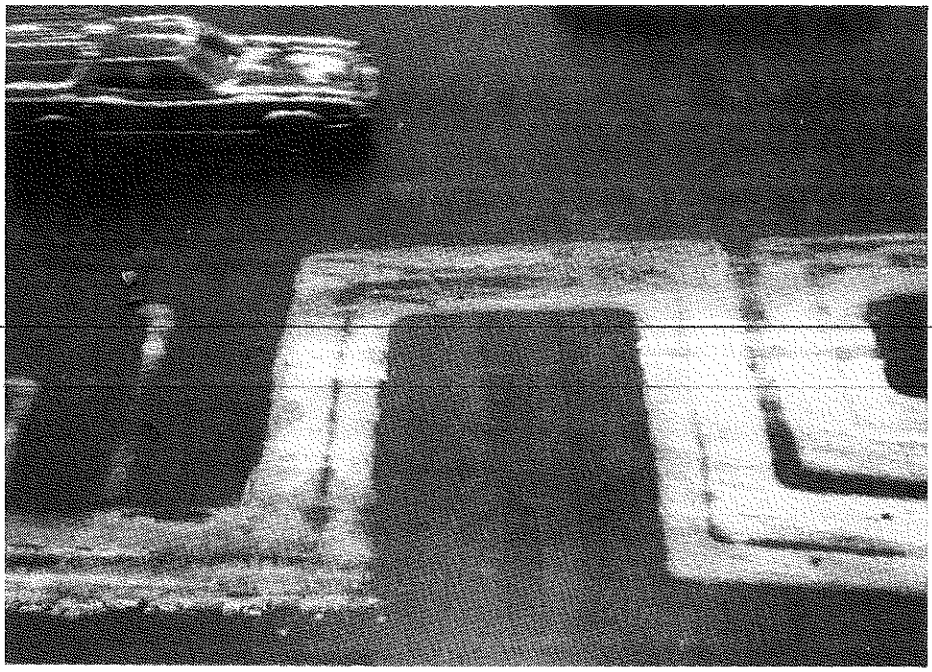

Figure 14. Inoperative Heating Cables; January 13, 1982.

TABLE 8. OPERATING COSTS

	ELECTRIC	PERSONNEL	MAINTENANCE
1976 - 1977	$151,000	$30,000	$12,000
1977 - 1978	202,000	50,000	18,000
1978 - 1979	188,000	50,000	17,000
1979 - 1980	160,000	50,000	30,000
1980 - 1981	102,000	40,000	17,000
1981 - 1982	110,000	35,000	20,000
	$913,000	$255,000	$114,000

TABLE 9. POWER USAGE AND COSTS

PERIOD	NUMBER OF DAYS	KWH	AVERAGE KWH/DAY	COST	AVERAGE COST/DAY
11/9/77 - 12/8/77	30	772,800	25,760	22,887.51	762.91
12/9/77 - 1/11/78	34	1,584,000	46,588	49,388.15	1,452.59
1/12/78 - 2/9(78	29	2,347,200	80,938	77,839.46	2,684.11
2/10/78 - 3/13/78	32	878,400	27,450	31,688.75	990.27
3/14/78 - 4/11/78	29	86,400	2,979	6,663.04	229.76
4/12/78 - 5/11/78	30	28,800	960	1,056.42	35.21
11/9/78 - 12/9/78	31	302,400	9,755	9,888.68	318.98
12/10/78 - 1/10/79	31	1,190,400	38,400	38,671.51	1,247.46
1/11/79 - 2/9/79	29	1,694,400	58,428	55,816.33	1,924.70
2/10/79 - 3/12/79	31	878,400	28,335	29,093.95	938.51
3/13/79 - 4/10/79	29	172,800	5,959	5,920.00	204.14
4/11/79 - 5/10/79	31	28,800	929	958.10	29.94
11/9/79 - 12/10/79	32	350,400	10,950	14,399.60	448.11
12/11/79 - 1/10/80	31	542,400	17,496	22,194.33	715.94
1/11/80 - 2/11/80	32	993,600	31,050	40,732.41	1,272.88
2/12/80 - 3/11/80	29	681,600	23,503	27,895.82	961.92
3/12/80 - 4/10/80	30	129,600	4,320	5,920.00	961.92
4/11/80 - 5/9/80	29	19,200	662	779.38	26.87
11/11/80 - 12/10/80	30	235,200	7,840	11,217.59	373.92
12/11/80 - 1/13/81	34	729,600	21,459	34,340.58	1,010.02
1/14/81 - 2/11/81	29	537,600	18,538	25,369.58	874.81
2/12/81 - 3/12/81	30	254,400	8,480	12,135.39	404.51
11/9/81 - 12/9/81	31	201,600	6,503	9,742.89	314.29
12/10/81 - 1/9/82	32	489,600	15,300	24,092.11	752.88
1/10/82 - 2/9/82	32	782,400	24,450	41,958.86	1,311.22
2/10/82 - 3/9/82	29	345,600	11,917	18,533.94	639.10

Considering the alternatives using a **present-worth** basis with a 10-percent interest rate and a 25-year service life:

HEATING SYSTEM

	Cost/ft^2
Initial Cost	$10.79
Annual Operating & Maintenance Cost $1.29(9.077)* =	11.71
Replacement Cost	0.00
Total	$ 22.50

CONVENTIONAL SNOW REMOVAL

	Cost/ft^2
Initial Cost	$0.00
Annual Operating & Maintenance $0.20(9.077)* =	1.82
Deck Repair & Replacement $5.56(0.092)** =	0.51
Total	$2.33

*Present Worth Factor (Uniform Series)
**Present Worth Factor (Single Amount)

This economic evaluation is based on assumed zero salvage values. Repair and replacement costs were for chemical (salt) damage only. Operating, maintenance, repair, and replacement costs were supplied by the engineering staff of the Department of Highways. No values were assigned to intangibles as described above; however, when a final evaluation is made, consideration must be given to those and to the following:

1. This interchange carries, on the average, 38,000 vehicles per day. On days of inclement weather, fewer vehicles may use the facility.
2. The public has grown accustomed to a "clear roads policy" at the interchange.
3. Provision must be made to close the interchange, if required, thus forcing traffic to use other arterials.
4. A dangerous pavement condition may exist between the time snow accumulates and the time salt crews arrive at the interchange.
5. The societal cost associated with one fatal accident could exceed the annual cost for operating the heating system.
6. Abandonment of the system in a "storage mode" will probably render the system inoperable if needed at a later date.
7. Use of chemical abrasives will create a corrosive atmosphere, causing irreversible damage to the heating system should the system be used on an "on-call" basis for intense snowfalls.
8. Initial costs have not been a moratized to a salvage value of zero where the economic analysis would not be clouded with residuals.

REFERENCES

1. J. H. Havens, *Heating the 9th-Street Interchange, Louisville, Kentucky,* Research Report 400, Kentucky Department of Transportation, September 1974; also **Proceeding,** 23rd Annual Meeting of Southeastern Association of State Highway and Transportation Officials, October 16-19, 1974.
2. W. V. Azevedo, A. S. Rahal, and J. H. Havens, *Heating the 9th-Street Interchange: Construction and Initial Operation,* Research Report 486, Kentucky Department of Transportation, January 1978.
3. J. H. Havens, W. V. Azevedo, A. S. Rahal, and R. C. Deen, *Heating Bridge Decks by Electrical Resistance,* Research Report 494, Kentucky Department of Transportation, February 1978; also **Proceedings,** Second International Symposium on Snow Removal and Ice Control Research, May 15-19, 1978.
4. W. V. Azevedo, R. C. Deen, and J. H. Havens, *The Operation of an Electrical Heating System for Bridge*, Research Report 564, Kentucky Department of Transportation, October 1980.

APPENDIX A

ALTERNATIVES FOR OPERATION OF HEATING SYSTEM

METHOD A
TURN OFF TOTALLY

If this had been done before November 15, 1980, the Department was obligated to pay Louisville Gas and Electric $25,000. After November 15, 1980, there would be no other obligation other than actual use or the minimum monthly charge ($5,920).

Ramps may have to be closed at times.

An estimate of the cost of salt or abrasives and clean up is $15,000 per year. (Note: An estimate by J. W. Spurrier, Assistant State Highway Engineer for Maintenance and Operations in 1969, gave this cost to be in excess of $60,000 per winter season.)

METHOD B
OFF EXCEPT WHEN SNOW GREATER THAN 1 INCH OCCURS

Begin applying cinders, turn on transformers and circuits only after snow begins. Ramps could become hazardous in a heavy snow before heat could catch up. Because of moisture build up on electrical devices, the chances for major breakdowns would be great. An estimated cost breakdown for this method is as follows:

Electricity	40,000
Cinders and Clean-up	10,000
Staff	13,000
Repair and Maintenance	25,000
Total per year	$88,000

METHOD C
IDLE STEP UNTIL SNOW REACHES 1 INCH DEPTH

A staff of 24 would be needed. A cinder truck would be parked at the interchange, and a driver would be called in at the first sign of snow. Start increasing heat at 1 inch snow depth. Using this method, traffic would have problems in about 30 percent of the snows, and only for a few hours. Estimated costs are as follows:

Electricity	90,000
Cinders and Clean-up	8,000
Staff	30,000
Repair and Maintenance	25,000
Supplies and Miscellaneous	3,000
Total per year	$156,000

METHOD D
IDLE STEP, INCREASE HEAT WHEN SNOW IS ANTICIPATED; MANUAL WITH PARTIAL AUTOMATIC OPERATION

This is the method that had been used in the past. The deck would not be warm enough to melt snow all the time, but traffic would have problems in only about 10 percent of the snows, depending upon the accuracy of predictions. Estimated costs are as follows:

Electricity	150,000
Staff	30,000
Repairs and Maintenance	25,000
Supplies and Miscellaneous	3,000
Total per year	$208,000

METHOD E
MOSTLY AUTOMATIC, WARM ENOUGH TO MELT SNOW AT ALL TIMES

This is the optimum method in all respects except energy consumption. Estimated costs are as follows:

Electricity	250,000
Staff	30,000
Repairs and Maintenance	25,000
Supplies and Miscellaneous	3,000
Total per year	$308,000

APPENDIX B

EQUIPMENT INVENTORY

EQUIPMENT INVENTORY

	CONDITION	COST TO REPAIR
1200-amp, 500-MVA, Air-type Circuit Breaker	Good	
Load Meter (Switch Gear Room) (Property of LG & E)	Good	
Main Switch Gear	Good	
Voltage Regulator	Good	
Substations (5)		
Main Busses	Good	
Three Panels	Good	
Three Pal Breakers (12)	Good	
GFI	Good	
TV Cameras (6)	Poor - only three operable	Minimum $20,000
Remote TV Control Console	Fair	$1,000
TV Monitors (6)	Fair - only four operable	$5,000
Weather Stations (2)	Fair	$5,000
Uninterruptable Power Supply	Good	
Power Metering Console		
Total Load Meter	Good	
LG & E Voltage Meter	Good	
Regulated Voltage Meter	Good	
Load Center Voltage Meter	Good	
Load Center Current Meter	Good	
Weather Instrument Console		
Wind Speed Indicator	Excellent	
Wind Direction Indicator	Excellent	
Outdoor Temperature Indicator	Excellent	
Slab Temperature Indicator	Excellent	
Relative Humidity Indicator	Fair	$ 400
Barometric Pressure Indicator	Excellent	
Rain Indicator	Fair	
Snow Indicator	Poor	
Falling Outdoor Temperature Timer	Excellent	
Raising Barometric Pressure Timer	Excellent	
Sunshine Duration and Load Cutback Timer	Never Used	
Voltage Regulator Raise Delay Timer	Excellent - some relay problems, not in timer itself	
Regulator Return Position Timer	Excellent	
Voltage Regulator Raise Delay Snowing Override Timer	Good	
Voltage Regulator Snowing Override Reset Timer	Good	
Voltage Regulator Lower Delay Timer	Excellent - some relay problems, not in timer itself	
Previous Outdoor Temperature Indicator	Excellent	
Previous Barometric Pressure Indicator	Excellent	
Rate of Temperature Drop Indicator	Not Used	
Rate of Barometric Pressure Drop Indicator	Not Used	

Pan-alarm Annunicator	Good	
System Recorder (Honewell)	Good	
Slab Temperature Monitors (2)	Good	
Control Selection Switch	Good	
Thermocouple Patchboard	Good	
Twelve-Point Thermocouple Temperature Recorder (Honeywell)	Good	
System Control		
Manual Loading Stations	Good	
Event Recorder for Preset Weather Conditions (Esterline Angus)	Good	
Slab and Modified Temperature Recorder (Esterline Angus)	Fair	$ 150
Weather Factor Signal Recorder (Esterline Angus)	Fair	$ 150
Voltage Regulator Position Indicator	Good	
Automatic/Manual Override Switch	Excellent	
Summer Lockout Switch	Excellent	
Circuits (201 total circuits)		
Circuits Not in Use	16 circuits inoperable, 3 circuits wired with 2-pole breakers	

Circuits inoperable as of 3/15/82

1A1-3
1A3-1
1A3-6 On Grade Circuits
1A3-8
1A3-9

1B2-4
2A2-3
3A1-10
3A1-11

3B3-7

4A1-8
4A3-1
4B1-9
5B3-2
3B1-8
3B1-4