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IDEA *Innovations Deserving Exploratory Analysis Project*

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Report of Investigation

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AUTOMATED BRIDGE DECK ANTI- AND DEICING SYSTEM

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INNOVATIONS DESERVING EXPLORATORY ANALYSIS (IDEA) PROGRAMS MANAGED BY THE TRANSPORTATION RESEARCH BOARD (TRB)

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AUTOMATED BRIDGE DECK ANTI- AND DEICING SYSTEM

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EXECUTIVE SUMMARY

Winter Maintenance of North American roadways consumes a staggering amount of money; in excess of 1.5 billion dollars annually. Never-the-less, anti- and deicing of bridge decks continues to be one of the most problematic winter maintenance issues. As the air temperatures drop below freezing roadways may remain ice free if the heat of the earth is sufficient to keep the pavement temperature well above freezing. Unfortunately, bridge decks rapidly equilibrate to the ambient air temperature and as a consequence they often freeze before the adjacent roadway. Herein lies a very troublesome operational decision that regularly faces winter maintenance managers. Do you "call out" crews and over-the-road implementry for freezing bridge decks alone or do you wait until both the roadway as well as bridge decks are freezing and then intervene with deicing?

This project investigated the design, installation, and testing of a fixed system, installed permanently on the bridge, so that the bridge deck could be anti- and deiced automatically without calling out traditional snow and ice control crews and implementry. This 'Automated Bridge Deck Anti- and Deicing System' uses accepted liquid freezing point depressants (such as $MgCl_2$), and traditional spray application techniques; coupled with a modern roadway weather information system (RWIS), and novel data communication and process control to perform the task. The system is comprised of a reservoir and attendant pump, and a stationary network of conduit and spray nozzles capable of applying a liquid de-icer on the (often several) lanes of a bridge deck. The processes may be controlled either manually or automatically. Optimally, system status checks and manual operations can be carried out remotely using RF or cellular phone modem commands. Hence, the system may be operated from the cab of a vehicle at the site in question. In addition, operations may be coupled with an expert system that will incorporate knowledge of ambient and pavement temperatures as well as humidity, precipitation type and amount, thus allowing the bridge deck to be anti- and deiced automatically.

Bridge deck snow and ice control systems of this type have been used operationally in Europe. However, prior to this investigation, there were no systems of this type in operation in the US. It was a recommendation of the 1994 Federal Highway Administration (FHwA)/National Cooperative Highway Research Program (NCHRP) International Winter Maintenance Technology Scanning Tour that such systems should be tested, and if shown to be successful, implemented on US highways. This effort addressed exactly that recommendation. The innovation associated with this project was the implementation of a modern winter maintenance technique previously not found in practice in the US. This project verified that fixed bridge deck snow and ice control material broadcast systems can significantly and cost effectively enhance motorist safety during icing conditions relative to the present over-the-road methods of operation. In addition, bridge anti- and deicing systems give winter maintenance managers added flexibility in performing their duties. This project addresses all four previously identified topics (Real-time Bridge Conditions, Incident Data Acquisition and Management, Traffic Safety, and Support of Intelligent Transportation Systems) within the Traffic Operations and Safety area of the IDEA Innovations Needed for Highway Systems.

Under this investigation, a fixed automated snow and ice control material broadcast system was designed, installed, and evaluated on the northbound (test) lanes of the I-215 overpass of the 6200 South Street interchange. This site is in metropolitan Salt Lake City, Utah and is located on a very high traffic density portion of the I-215 belt loop. This interchange/overpass is located in the snowy bench area of southeast Salt Lake valley. In addition the deck section is curved. The net result is that this site is one of the highest loss of friction winter accident sites on the metro Salt Lake freeway system.

The Utah Department of Transportation (UDOT) recognized the intrinsic value of this research and as a result they agreed to partner cooperatively on this project. This cooperation took two forms: cost sharing via matching capital funds from the Research Division of UDOT, and significant site preparation and operational support from Region 2 of UDOT.

The results of the initial evaluation indicate that the *ratio* of snow and ice induced crashes on the northbound, treated test lanes to the southbound, untreated control lanes has, for the previous six winters of record, always been greater than one (1), with the exception of the bridge deck anti- and deicing system evaluation winter of 1997/98, when it was 0.7. In addition, the pavement level-of-service during snow and ice conditions was consistently improved on the treated, test section relative to the adjacent, untreated control section of the bridge. However, under unrelentingly heavy snowfall the bridge deck anti- and deicing system was *not* capable of maintaining bare (wet) pavement and is not a *replacement* for traditional over-the-road snow and ice control techniques under those conditions.

The bridge anti- and deicing system in Salt Lake City will continue to be in operation and under evaluation for the next several winter seasons. These on-going efforts are being undertaken by a consortium of UDOT Divisions (Central Maintenance Planning, and Region 2), and an investigative team from the Winter/Alpine Engineering Laboratory (W/AEL) at the University of Utah.

INTRODUCTION

PROJECT BACKGROUND

The use of fixed snow and ice control material broadcast systems is relatively new to North America. However, in Western Europe systems to spray bridges with liquid snow and ice control materials may be found in operational use at a number of sites [1,2]. Correctly, the European experience points to the fact that these systems will not replace traditional truck mounted implementry for snow and ice control. Automated fixed anti- and deicing systems augment traditional snow and ice control techniques, provide winter maintenance managers with an added degree of flexibility in their snow fighting duties, and enhance public safety.

The intrinsic value of the fixed automated anti-icing systems found in use in Europe was recognized by the touring members of the 1994 FHwA/NCHRP International Winter Maintenance

Technology Scanning Tour. In as much as the Tour was charged to make such recommendations, automated bridge anti-icing technology was one of a suite of technologies recommended for domestic implementation [3]. In addition, the value and domestic need for fixed automated anti- and deicing systems was anticipated as early as 1968, when B. F. Hinrichs' patented a "Pavement Deicier"; an automated fixed snow and ice control material broadcast system [4]. This patent is now in the public domain.

The American Association of State Highway and Transportation Officials (AASHTO), responding in large part to the recommendations of the 1994 International Winter Maintenance Technology Scanning Tour, has taken steps to implement a Snow and Ice Cooperative (SICOP) research program. Fixed automated snow and ice control systems, amongst others, is a technology which has been favorably forwarded to AASHTO's Winter Maintenance Policy Coordinating Committee for additional consideration [5].

In March, 1996 the NCHRP IDEA Program Office funded a Type 1 investigation (NCHRP - IDEA Project #27) with the Winter/Alpine Engineering Laboratory (W/AEL), University of Utah entitled; Automated Bridge Deck Anti- and De-icing Systems [6]. This investigation lead to the design, technology verification, and subsequent installation of a bridge deck anti-icing system on a 465 foot, six lane, curved section Interstate overpass in metropolitan Salt Lake City, Utah. The location of this bridge, relative to the metro Salt Lake City highway system, is depicted in Figure 1. Figure 2 provides a detail of the bridge structure itself. This effort was partnered with the Utah Department of Transportation (UDOT) and Surface Systems, Inc. (SSI). UDOT provided a modest hard match and significant soft matching by way of traffic control, site preparation, and specialized signing for the project. SSI provided in-kind equipment match by way of a complete RWIS node that is used for the atmospheric and pavement condition sensing which may be used to enable the spray process automation.

Mr. Larry Frevert, Deputy Director of Kansas City Public Works was appointed the independent Technical Monitor (TM) for this NCHRP - IDEA project. In that role, Mr. Frevert has been to the site and provided his expert opinion and advice at the time of the project's programmatic review. *At the time of the project's NCHRP - IDEA programmatic review the recommendation was forwarded that any follow-on efforts in the area of automated bridge deck anti-icing systems should address both in-deck nozzling, and single microprocessor operations.* Mr. Frevert was a member of the 1994 International Winter Maintenance Technology Scanning Tour, is presently the American Public Works Association's (APWA) representative to AASHTO's Winter Maintenance Policy Coordinating Committee, and is the past Secretary of the Winter Maintenance Committee (A3C09) of the Transportation Research Board (TRB).

Of primary technical concern in this investigation were the capabilities and reliability of the sub-system hardware and software components of an automated bridge deck anti-icing system. The resulting system was installed and tested, in cooperation with UDOT, on the I-215 overpass of the 6200 South Street interchange. This site in metropolitan Salt Lake City, Utah is located on a very high traffic density (>40,000 ADT) portion of the I-215 belt loop. This interchange/overpass is in the snowy foothill area of southeast Salt Lake valley. In addition the deck section is curved.

The net result is that this site is one of the highest loss of friction winter accident sites on the metro Salt Lake freeway system [7].

The automated bridge deck anti-icing system is comprised of a reservoir, attendant pump and in-line solenoids, and a stationary network of conduit and spray nozzles capable of applying a liquid anti-icing material ($MgCl_2$, in this case) on the three north bound lanes of the bridge deck. The remaining three (south bound) lanes do not presently receive any liquid spray and constitute the control section of the bridge for the purpose of evaluating the effectiveness of the bridge anti-icing system.

The liquid spray is broadcast from the bridge parapet. In addition, the parapet is on the high side of the super elevation of this curved bridge deck and it has been born out that this configuration dramatically enhances the lateral migration of the liquid anti-icing material across the bridge deck. This fact may be used to an advantage when configuring the design of a specific bridge deck anti-icing system.

The anti-icing processes on the I-215 bridge in Salt Lake City may be controlled either manually or automatically. Manual operations and system status checks may be carried out remotely using cellular telephone modem commands. This communications interface is sufficiently generic that this same task could be implemented with a hardwire telephone or radio frequency modem.

The bridge anti-icing system in Salt Lake City will be in operation and under continued evaluation for the next several winter seasons. These efforts are being undertaken by a consortium of UDOT Divisions (Bridge, Central Maintenance Planning, Public Affairs, Region 2, and Research), and a Winter/Alpine Engineering Laboratory (W/AEL) investigation team from the University of Utah.

CONCEPT AND INNOVATION

The bridge deck anti- and deicing system is comprised of traditional hydraulic elements, including; an anti-icing fluid reservoir, attendant pump, and a stationary network of conduit and spray nozzles capable of applying the liquid anti-icing agent on the driving and safety lanes of a bridge deck. Bridge deck snow and ice control systems of this type have been in use operationally in Europe. However, prior to this project, there are no systems of this type in operation in the US. An additional *innovative* element of the system investigated includes the provision for automated process control. The decision to apply anti- and deicing fluid to the bridge may be controlled by a knowledge based algorithm, initialized on a process control computer, located at the bridge, which is coupled to the sensors of a modern roadway weather information system (RWIS). In addition, system status checks and manual operations may be carried out remotely using a cellular phone and voice menu commands. The anti- and deicing process may be initiated from the cab of a vehicle located at the bridge. This project addressed all four previously identified topics (Real-time Bridge Conditions, Incident Data Acquisition and Management, Traffic Safety, and Support of Intelligent Transportation Systems) within the Traffic Operations and Safety area of the IDEA Innovations Needed for Highway Systems.

IDEA PRODUCT

This project addressed the design, installation, and testing of a fixed system, installed permanently on a bridge, so that the bridge deck may be anti- or deiced automatically without calling out traditional snow and ice control crews and implementry. This 'Automated Bridge Deck Anti- and Deicing System' uses accepted liquid freezing point depressants, such as NaCl brine or liquid MgCl2, and traditional spray application techniques; coupled with a modern roadway weather information system (RWIS), and novel data communication and process control to perform the task. The prototype system was installed on the Interstate I-215 overpass/interchange at 6200 South Street in metropolitan Salt Lake City. This curved bridge deck has six lanes, in total, and is over four hundred feet in length.

WORKPLAN

The workplan for this investigation was divided into the following three concurrent tasks:

- Analog/digital data and process control algorithm development, coupled with the development of manual, remote (land line/cellular telecommunication) operating capabilities, including cold weather reliability testing. These efforts were undertaken on the process control bench and in the cold room, both of which are located in the Winter/Alpine Engineering Laboratory (W/AEL) at the University of Utah.
- Reservoir/pump/pipe/nozzle system assembly and testing, including spray extent, pattern, and volume checks. This design/test element of the project was undertaken at the UDOT Cottonwood Maintenance District yard and onsite at the I-215/6200 South interchange bridge site.
- Subsequent evaluation of the bridge deck anti/de-icing system installation at the I-215/6200 South interchange bridge site.

This above suite of requisite tasks consume the first nine months of the initial year of investigation. As a follow on to these initial tasks, the various measures of success associated with the implementations of this new winter maintenance technique were assessed.

Results from this proof-of-concept demonstration of an automated bridge deck anti/de-icing system was reported at a variety of appropriate forums, including the TRB Annual Meeting (Winter Maintenance Committee), the AASHTO and WASTO Maintenance Committee meetings, various FHwA/APWA Annual Winter Maintenance Conferences, and various regional and local StateDOT sponsored events. The purpose of disseminating the project results in this fashion, to these specific bodies of Federal, State and local winter maintenance leaders, was to assure the best possible opportunity for this new technology to reach widespread implementation into practice.

INVESTIGATION

SYSTEM DESIGN

Hydraulic Components

The hydraulic components of the fixed bridge anti- and deicing spray systems were laid out in such a fashion that all 465 feet of the three northbound driving lanes plus outside safety lanes of the test section would receive ~35 gallons/lane mile of liquid snow and ice control material coverage from nozzles mounted on the east side bridge parapet. The east side parapet is on the elevated side of the bridge deck super elevation. These liquid snow and ice control material coverages are within the limits established for effective snow and ice control using liquid anti-icing agents [8]. These coverages were achieved using alternating spray cone patterns of 15 and 80 degrees. The 15 degree nozzle produced a coherent stream of material that reached into the second and third driving lanes, while the 80 degree cone nozzles provided adequate coverage for the first safety and driving lanes, nearest the parapet.

In order to maintain the design pressure condition at each nozzles (~45 psi), it was necessary to install seven (7) separate spray "manifolds", with seven (7) nozzles per manifold. Each spray manifold was connected to a mainline with an electronically controlled valve. This configuration is depicted schematically in Figure 3, 4, and 5. Each manifold is opened and spraying liquid snow and ice control materials for ~30 seconds.

Due to the fact that this test bridge is relatively new and pristine, the use of nozzle systems in the bridge deck itself was not contemplated for this initial investigation.

The hydraulic line diameters and pump size were developed using standard engineering analysis techniques (analysis of hydraulic energy, including pipe and fitting losses) for hydraulic systems. Other hydraulic system design criteria included storage capacity for liquid anti-icing material onsite, capability to store and broadcast corrosive (chloride brine) materials, and operation of the manifold control values (dual polarity, double throw ball values) for each of the seven (7) separate spray "zone" manifolds along the length of the bridge. Specific hydraulic elements and material specifications and quantities for the systems are tabulated below. Though not an endorsement of any given equipment supplier, for completeness, the vendor for certain hydraulic elements of the installed system are presented.

Hydraulic Components

- 49 Spray Tech stainless steel nozzles (25 fan and 24 stream spray) - ~70 gpm at 45 psi.
- 7 Tee-jet dual polarity, 12 volt, double throw ball values - ~1 second response time.
- 550' of 2" Pacific Echo-Spiralite helical wound, flexible (at or below freezing), UV stabilized PVC tubing - 70 psi max operating pressure.
- 300' of 1" PVC tubing.
- 1 32 mesh in-line anti-icing material filter.

- 2100 gallon UV stabilized plastic anti-icing material storage tank.
- 1 Vertiflo stainless steel pump and 3-phase electric motor - 75 gpm at 225' of head, 15 HP.
- 1 Rotary Dynamics 220 volt 3-phase power converter.

Process Control

The anti- and deicing processes may be controlled either manually or automatically. System status checks and manual operations may be carried out remotely using radio frequency (RF), cellular or hardline phone modem commands. These operations could be initiated from the cab of a vehicle at the site in question. The Process Control Sequence flowchart is depicted in Figure 6. This sequence may be initiated manually or by way of system automation. The first action in the sequence is the lighting of the flashers of a motorist information sign ~1/4 mile prior to the bridge. The sign message states; DE - ICING SPRAY BEING APPLIED WHEN FLASHING 45 MPH. The purpose of this sign is to provide motorist with some for-knowledge of the spray process that is on-going on the bridge ahead. This sign is shown in Figure 7. The process control sequencing is managed by the application; LabView, a product of National Instruments, running on a Pentium class PC supported by MicroSoft Windows NT. LabView is has an object oriented process control development environment that supports LabView's input/output (I/O) data acquisition and (low voltage side) relay cards. The latter are installed in the expansion slots of the PC microprocessor's mother board. Figure 8 shows the object oriented LabView process control program.

The process control sequence may be coupled with an expert systems algorithm that incorporates knowledge of ambient and pavement temperatures as well as humidity, precipitation type and amount, thus allowing the bridge deck to be anti- and deiced automatically. The knowledge base for the expert system may be generated by an onsite Roadway Weather Information Systems (RWIS). Table 1. is an inventory of the RWIS components and associated costs that were used to verify RWIS based spray process control algorithms. Figure 9 shows the flowchart logic for RWIS base process control.

Alternatively, the anti- and deicing system process may be controlled with an expert system algorithm that incorporates knowledge derive from relatively inexpensive, analog pavement and atmospheric sensing systems. Figure 10 shows the flowchart logic for Analog sensor based process control. Analog process control sensors include, at a minimum; pavement and ambient temperature sensors, and a heated agricultural "wet-leaf" sensor that determines whether or not there is incipient or on-going precipitation. The capital cost of the hardware systems for analog process control are ~1/10 that of RWIS based process control.

SYSTEM EVALUATION

During the winter of 1997/98 an evaluation procedure was implemented in an effort to determine the effectiveness of the bridge anti- and deicing system at the 6200 South overpass of I-215. Liquid snow and ice control materials were sprayed on the northbound test lanes of I-215 using the system developed and installed under this investigation. The southbound control lanes of I-215 did *not* receive liquid snow and ice control materials from the fixed bridge anti- and deicing systems. Both test and control lanes received their usual winter maintenance treatments (plowing and salting with dry granular NaCl from over-the-road vehicles) from UtahDOT's winter maintenance patrols. The details of this bridge deck anti- and deicing system evaluation may be found elsewhere [9].

The evaluation plan for this effort included collection of various onsite data, including; ambient and pavement temperatures, precipitation conditions, anti- and deicing spray actions taken, and the resulting bridge deck pavement conditions of the northbound (test) lanes and the southbound (control) lanes of the Interstate. In total, eighteen (18) separate storm events were treated with the bridge's fixed spray anti- and deicing system during the evaluation winter of 1997/98. The tabulated results of these efforts are provided as Table 2. A review of these data indicates that the bridge deck pavement level-of-service for the test lanes were, in all cases, improved relative to the control lanes. However, it should also be noted that in certain cases (typically those with unrelenting heavy snowfall) the bridge's fixed liquid snow and ice control material spray system was *not* able to maintain clear (wet) pavement through-out the storm.

In addition and if daylight permitted, photo documentation of the resulting test and control bridge deck pavement conditions were made. Figures 11 through 16 show test, test approach, and control pavement conditions for the storm of 2/8/98 and storm impulses 1 and 2 of 2/22/98. Please be informed that "Knudsen's" is the local Salt Lake City description for the 6200 South overpass of the I-215. Note that in those cases where the bridge deck pavements have been treated with the fixed liquid snow and ice control material spray system, the pavement condition is of a higher level-of-service than the control section, and also its own approach section for that matter.

Lastly, an effort was made to compare total numbers and ratio of crashes due to snow and ice on both the northbound test lanes and southbound control lanes of the 6200 South overpass/I-215 bridge for the evaluation winter of 1997/98, and for the previous five (5) winters. The resulting data are presented as Table 3. Also present on Table 3 is an annual Winter Index for each of the six (6) winter seasons leading up to and including the evaluation winter of 1997/98. This winter index is a measure of the severity of a given winter season, accounting for snowfall, average minimum and maximum daily temperatures, and the mean daily number of days below freezing [10]. It is valuable to note that the *ratio* of snow and ice induced crashes on the northbound test lanes to the southbound control lanes has always been greater than one (1), with the exception of the bridge deck anti- and deicing systems evaluation winter of 1997/98, when it was 0.7. Note too, that the winter index for the evaluation winter of 1997/98 was a nominal -14.0, indicating that the winter of 1997/98 was "average" or nominal in severity.

IMPLEMENTATION GUIDE

CRITERIA FOR SITE SELECTION

There are various criteria that, if met, would indicate whether or not a given site is appropriate for a fixed, automated anti- and deicing system. Implicit, but otherwise very important to the site selection process and subsequent ranking of sites, is the reminder that fixed, automated snow and ice control material broadcast systems *do not replace* traditional over-the-road winter maintenance activities at a given site. Fixed, automated snow and ice control material broadcast systems find their greatest value in augmenting existing over-the-road winter maintenance practices. Their benefit is in increasing motorist safety, and also increasing the flexibility winter maintenance managers have in their decision making duties [1,2]. In addition, there are other potentially beneficial attributes to fixed, automated snow and ice control material broadcast systems that are not linked to motorist safety or winter maintenance flexibility, including; decreasing the corrosion potential on a given structure through the use of low corrosion snow and ice control materials, and decreasing the deleterious effects of winter maintenance activities on surface and ground water quality through the use of alternative snow and ice control materials. Lastly, not all sites that are appropriate for fixed, automated snow and ice control material broadcast systems are bridges. Other appropriate sites might include tunnel entrances and exits, snow (avalanche) sheds, troublesome intersections, etc.

The following is a list of criteria that should be considered in the selection and ranking of sites under consideration for potential fixed, automated snow and ice control material broadcast systems:

- Is the bridge (site) a known icing trouble site?
- Is there a proportionally higher number of snow and ice accidents at this site?
- What is the average, peak (and time of peak) traffic, and fleet mix at the site?
- How far removed from the nearest winter maintenance facility (shed) is the site?
- How far removed from the nearest emergency services is the site?
- What is under the bridge (rail, rail yard, commercial, pedestrian, roadway, river, lake, etc.)?
- What, if any, is the existing structural drainage system?
- Are there surface and ground water quality issues at the site that will be impacted (positively or negatively) by the potential installation?
- Are there any corrosion, design life, repair/rehab structural issues at the site?
- What is the size of the structure?
- What, if any, utility service (electricity/phone) or other winter maintenance infrastructure (RWIS) is close at hand to the site?
- Are there any special issues (environmental, archeological, historic preservation,...) at the site that will impact site preparation and/or onsite installation efforts (extreme heights, hazardous winds or surf,...)?

SAMPLE PROCUREMENT SPECIFICATION

The following is a generic, sample procurement specification for fixed, automated snow and ice control material broadcast systems for bridges. It is anticipated that specific site conditions and agency procurement procedures will result in significant modifications prior to any use.

Sample:

This specification describes components for a fixed, automated snow and ice control material broadcast system to be mounted on bridge decks for the purpose of applying liquid anti- and deicing chemicals to the traffic and safety lanes of the bridge. The installed systems will be required to meet or exceed the specifications below. Any variances from these requirements shall be proven successful and adequate for the designed purposes by the selected vendor. Variances will be granted at the sole discretion of the requesting agency.

General:

The fixed, automated snow and ice control material broadcast system shall be designed to address the specific needs of the site. An assessment of these needs may require a pre-design, onsite inspection of traffic conditions, environmental concerns, construction and installation issues, and any other site-specific needs that will require consideration during system design. The system shall be permanently mounted on the structure and be capably of utilizing any acceptable liquid anti-and deicing agent. Upon completion of installation, adequate documentation and training shall be provided to the agency regarding operation, preventative maintenance, and repair of the system. The vendor shall be capable of providing, on demand of the requesting agency, a technician to the site within 48 hours. All system components shall be aesthetically located to minimize the visual impact, and be easily accessible during the winter maintenance season. The successful vendor shall provide "as built" construction drawings of the installed system and a complete list of sub-system components and replacement parts sources.

Hydraulic Components:

Pump:

- The pump shall be adequately sized to maintain a minimum application rate of ~30 gallons per lane mile and up to a maximum of ~70 gallons per lane mile of liquid snow and ice control materials to all driving and safety lanes of the bridge. The material may weight up to ~12 pounds per gallon. The pump shall be constructed of materials suitable for any acceptable liquid anti- and deicing agent, including corrosives. The pump and motor shall be housed in a weatherproof enclosure. The pump shall be capably of providing the above cited application rates within an ambient and material temperature range of +40 to -25 degrees Fahrenheit.

Tank:

- The tank shall be constructed of a UV stabilized polyethylene material capable of containing a sufficient quantity of liquid anti- and deicing agent without
- rupture. The tank capacity shall be adequate for operations for an entire winter season. The tank shall be equipped with an internal agitation device.

Nozzles:

- The nozzles shall be constructed of stainless steel or ceramic and produce a resulting spray pattern capable of maintaining adequate material coverages of the driving and safety lanes at the specified application rates. All nozzles shall be self cleaning.

In-Deck Nozzles:

- In addition to the above requirements, in-deck nozzles that are installed in and/or pass through the bridge deck shall be installed and operate flush or slightly recessed with respect to the bridge deck surface, be impact resistant, shall be easily removable for repairs and replacement, and shall not operate with a spray loft (maximum vertical extent) greater than 18 inches. All in-deck nozzle locations shall be adequately sealed to prevent the intrusion of snow and ice control materials into the bridge deck structure.

Piping:

- All piping shall be resistant to the liquid snow and ice control materials being used, and UV stabilized. Piping shall be routed to minimize the potential for auxiliary damage, ease of all-season repair, and bridge aesthetics.

Controls and Communications:

All control equipment shall be contained in a NEMA 4 weatherproof enclosure. The fixed, automated snow and ice control material broadcast system process controller shall include a tank level sensor, manual and automated operations capability, event logging, system status, and modem access. Using both pavement and atmospheric condition information, the system controller shall be capable of automatically applying or re-applying a pre-determined amount of liquid anti- and deicing material to the traffic and safety lanes of the bridge.

RWIS Based System Controller:

When requesting by the agency, a Roadway Weather Information System (RWIS) system shall be installed which is compatible with existing RWIS technology.

Non-RWIS Based System Controller:

When requested by the agency, an analog system controller capable of monitoring pavement and precipitation condition shall be provided.

Options:

Other system capabilities that may be required by the requesting agency include:

- Traffic Logging
- Bridge Deck Inspection

- Remote Power Capability
- Water Quality Monitoring
- System Implementation and Evaluation Plans
- Long Term Maintenance and Repair Agreements

Warranty:

The successful vendor shall warranty the hydraulic elements for a period of !!! (!) years under normal operating conditions. All components shall be warranted for a period !!! (!) years from the date of completion and acceptance of the system installation.

Propriety:

This specification meets the claims and elements of *US Patent # 3,540,655, Hinrichs, B.F. 1968 filed/1970 issued,* now in the public domain.

VENDORS

The following is a list of vendors that are now active in providing variaous public and private sector organizations with fixed, automated snow and ice control material broadcast systems for bridges, as well as other structures and sites.

- Boschung Company, P.O. Box 1160, Brainerd, MN 56401
- Maintenance Specialties, Inc. (MSI), 363 Edith Avenue, Salt Lake City, UT 84111
- Odin Systems, 620 Sea Island Road, St. Simons Island, GA 31522

CONCLUSIONS

Winter Maintenance of roadways will continue to be a costly and difficult highway maintenance task. However, widespread domestic implementation of fixed automated snow and ice material broadcast systems to anti- and deice bridge decks has the potential to reduce snow and ice related crashes and increase the decision making flexibility of winter maintenance managers.

Bridge deck snow and ice control systems of this type have been used operationally in Europe. However, prior to this investigation, there were no systems of this type in operation in the US. This project verified that fixed bridge deck snow and ice control material broadcast systems can significantly and cost effectively enhance motorist safety during icing conditions relative to the present over-the-road methods of operation. In addition, bridge anti- and deicing systems give winter maintenance managers added flexibility in performing their duties.

At the installed bridge anti- and deicing system in Salt Lake City, results of the initial evaluation indicate that the *ratio* of snow and ice induced crashes on the northbound, treated test lanes to the southbound, untreated control lanes has, for the previous six winters of record, always been greater than one (1), with the exception of the bridge deck anti- and deicing system evaluation winter of 1997/98, when it was 0.7. In addition, the pavement level-of-service during snow and ice conditions was consistently improved on the treated, test section relative to the adjacent, untreated control section of the bridge. However, under unrelentingly heavy snowfall the bridge deck anti- and deicing system was *not* capable of maintaining bare (wet) pavement and is not a *replacement* for traditional over-the-road snow and ice control techniques under those conditions.

The bridge anti- and deicing system in Salt Lake City will continue to be in operation and under evaluation for the next several winter seasons. In addition, there are now a suite of vendors actively engaged in providing variaous public and private sector organizations with fixed, automated snow and ice control material broadcast systems for bridges, as well as other structures and sites.

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8.) Manual of Practice for an Effective Anti-icing Program, Publication No. FHwA-RD-95-202, June, 1996.

9.) Evaluating the Anti-Icing Spray System at the Interstate 215 Overpass/Exchange at 6200 South Street, Salt Lake City, TRB Annual Meeting Paper/Presentation, Friar, S., and R. Decker, January, 1999.

10.) Roadway Weather Information Systems, Vol. 1: Research Report, SHRP, Boselly, S.E III, J.E. Thornes, and C. Ulberg, 1993.

Table 1 RWIS Process Control Components.

Quantity	Description	Unit Price	Total Price
	System Components:		
2	FP 2000 pavement sensors	3,996.00	7,992.00
1000 feet	Estimated amount of Type V sensor extension cable	0.75/ft.	750.00
1	Sub-surface temperature probe	$1,088.00	$1,088.00
1	RPU software license, full size card rack, interface card for 4 surface sensors, expandable to 8 surface sensors, Hennessey NEMA 4 aluminum RPU enclosure	15,984.00	15,984.00
1	Optical Weather Identifier Precipitation sensor	8,997.00	8,997.00
1	Air Temperature/Relative Humidity sensor	1,856.00	1,856.00
1	Wind Speed/Direction Sensor	672.00	672.00
1	Autodial/answer telephone modem, US Robotics 14.4 Kbaud modem	179.00	179.00
1	ESP-RPU tower (30' max. height) if required	2,013	2,013
	Total System Components		$39,531.00
	Services:		
	Initial hookup of system		1,186.00
	System commissioning at bridge site		1,977.00
	Special Engineering for developing communications interface		Dependent on development required
	TOTAL SSI CONTRIBUTION		$42,694.00

Table 2
Pavement Condition of Test and Control Sections

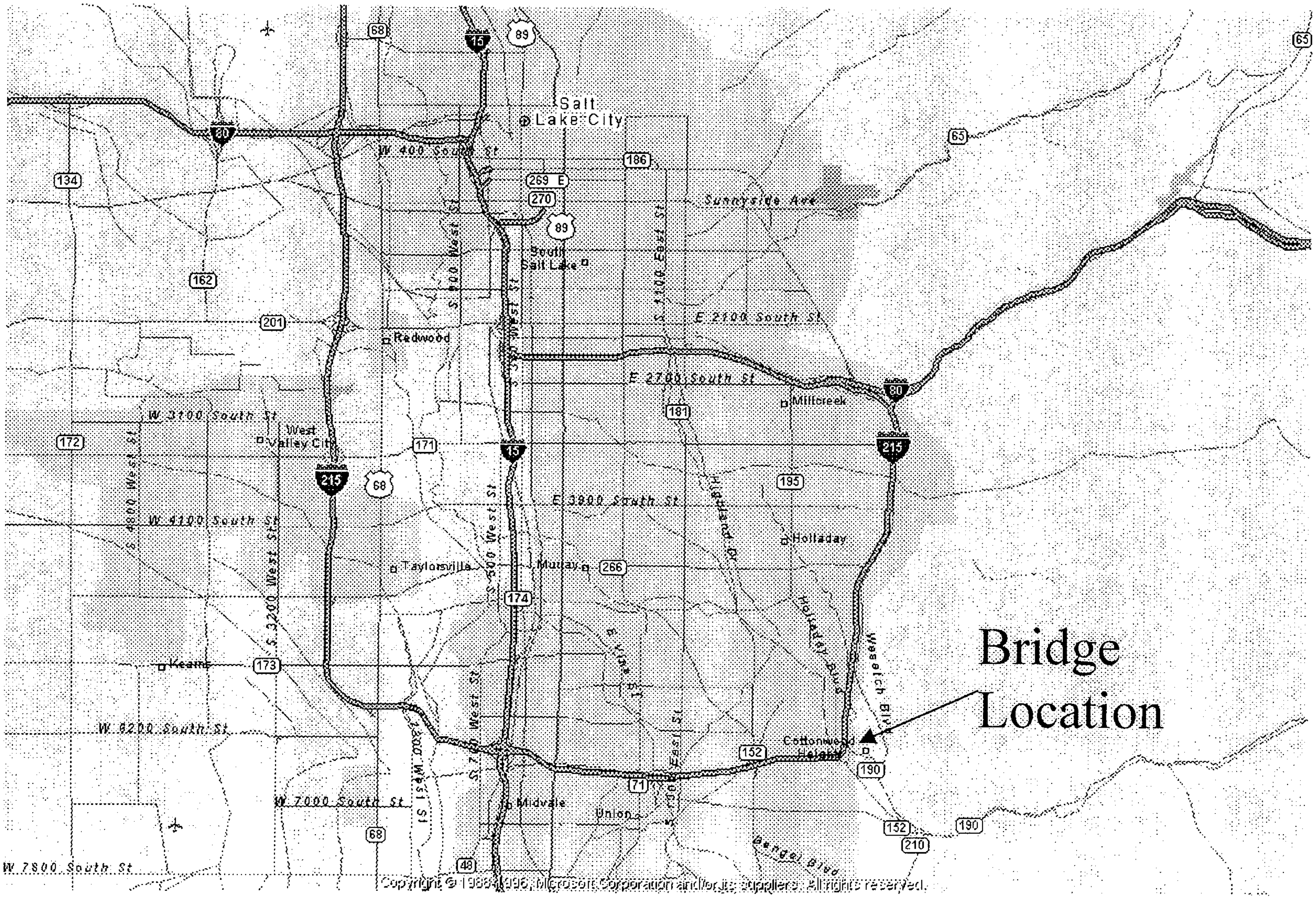
		Spray Time	Pavement T	Air T		Control Lane			Test Lane	Test Lane			
Date	**Time**	**(Seconds)**	**Deg C**	**Deg C**	**Picture**	**Inside**	**Middle**	**Outside**	**Approach**	**Inside**	**Middle**	**Outside**	**Reason**
7-Dec	9:00 PM	90	none	5	None	CW	CW	CW	CW	CW	CW	CW	Predicted Snow
8-Dec	7:00 AM	90	none	1	None	SCT	SC	SC	SC	MCS	CW	SCT	Snow
18-Dec	8:42 AM	90	none	0	None	LSL	LSL	LSL	LSL	CW	CW	CW	Snow
21-Dec	9:00 PM	90	none	-3	None	LSN	SCT	LSN	LSL	SOL	CW	CW	Snow
23-Dec	8:30 PM	110	none	-5	None	LSN	MCS	MCS	MCS	CW	CW	CW	Snow
24-Dec	4:15 AM	120	-14	6	Night	LSN	MCS	SC	SC	CWT	MCS	SC	Snow
29-Dec	4:30 PM	90	none	1	Night	CD	CD	CD	CD	CD	CD	CD	Predicted Snow
5-Jan	1:30 AM	120	-7	-3	Night	SC	SC	SC	SC	SC	SOL	SOL	Snow
19-Jan	8:00 AM	120	-5	-1	Fig 6	CWT	CW	CW	SCT	CWT	MCS	MCS	Snow
19-Jan	6:00 PM	120	-3	0.5	Fig 7	SC	CWT	SIT	SC	SOL	MCS	SOL	Snow
8-Feb	12:00 PM	90	-6	1	Fig 8	TSI	MCS	MCS	SC	CW	CW	CW	Snow
22-Feb	7:00 AM	90	-7	-1.5	Fig 9	TSI	CW	CW	SIT	CW	CW	CW	Snow
22-Feb	12:15 PM	90	-2	-1	Fig 10	SC	TSI	TSI	MCS	CW	CW	CW	Snow
3-Mar	8:00 PM	90	-6	1	Night	LSN	CW	CW	LSN	CW	CW	CW	Snow
5-Mar	11:30 PM	90	-8	0	Night	CD	CD	CD	CD	CD	CD	CD	Predicted Snow
6-Mar	6:30 AM	90	-7	-1.5	Fig 11	SI	TSI	TSI	TSI	CW	CW	CW	Snow
6-Mar	9:00 AM	90	-4	-2	Fig 12	SI	TSI	SIT	MCS	CW	CW	CW	Snow
6-Mar	3:00 PM	120	-2	1	Fig 13	CWT	TSI	TSI	SIT	MCS	MCS	MCS	Snow

CW	Clear and Wet
LSL	Light Slush
LSN	Light Snow
CD	Clear and Dry
SC	Snow Covered
CWT	Clear and Wet with some Tracking
TSI	Thin Layer of Slush and Ice
SI	Slush and Ice Covered
SCT	Snow Covered with tracks
MCS	Mostly Clear with some Slush/Ice
SIT	Slush and Ice Tracks
SOL	Snow Covered with Solution Tracks Running Across

Table 3
Accident Data at Knudsen's Bridge, Salt Lake City, Utah

	1997/1998	1996/1997	1995/1996	1994/1995	1993/1994	1992/1993
Northbound	5	15	21	10	10	16
Southbound	7	14	6	8	7	10
Total	12	29	27	18	17	26
Ratio	0.7	1.1	3.5	1.25	1.4	1.6
WI	-14.0	-10.3	-16.3	-18.5	-7.3	-26.3

Figure 1
Salt Lake Area Map



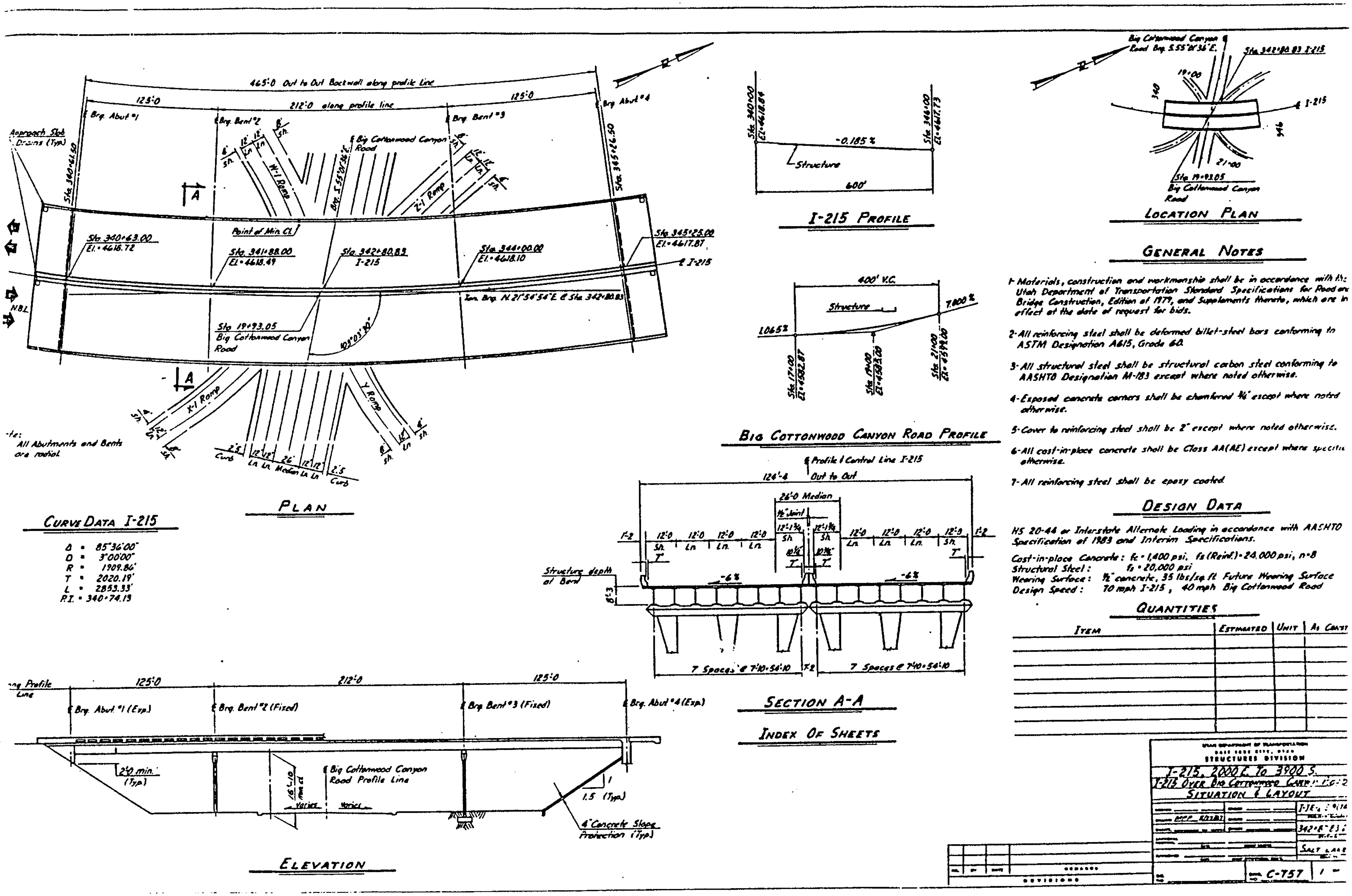
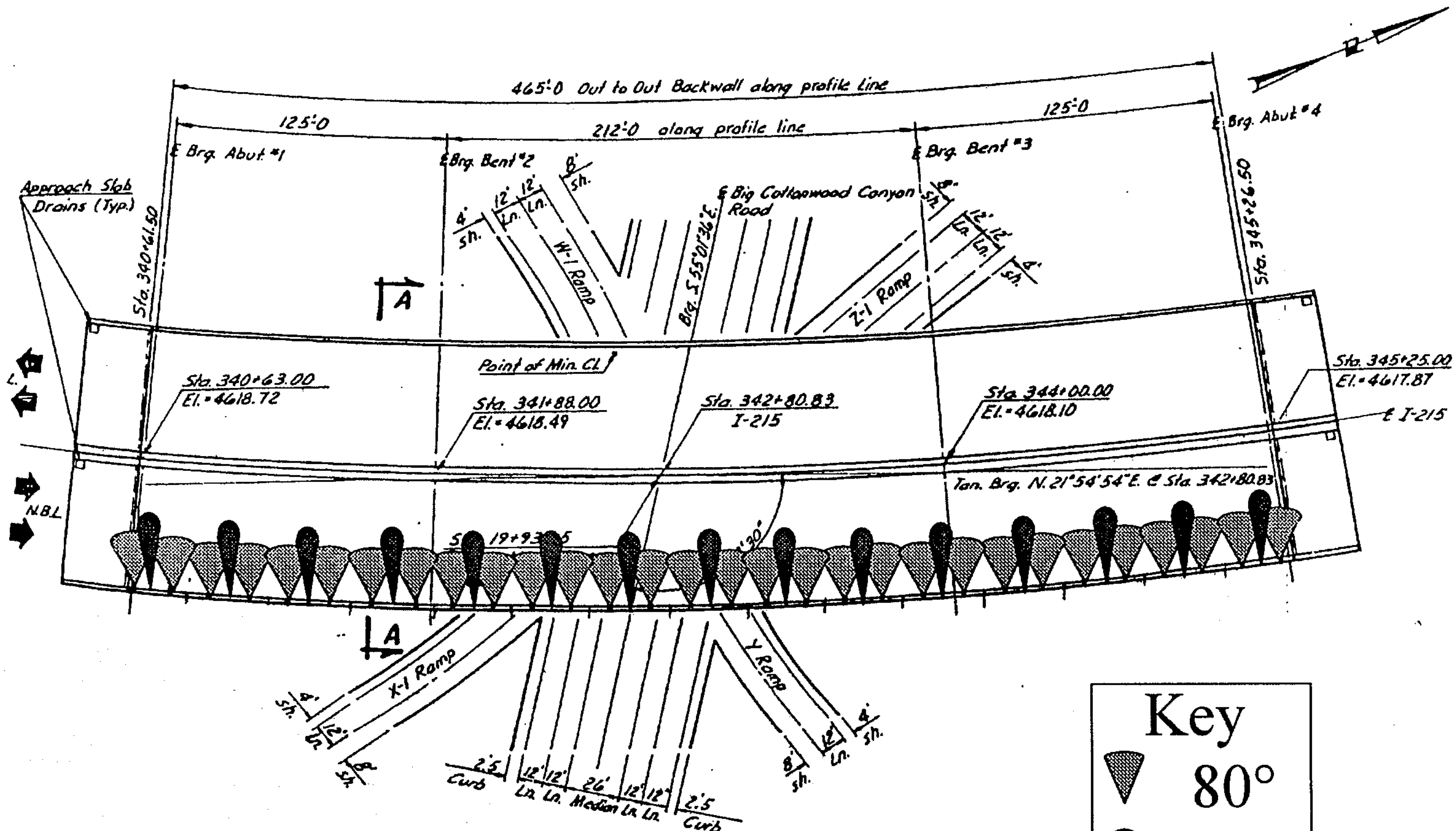


Figure 2. The I - 215/6200 South Overpass Bridge Deck (sections)

Figure 3
6200 South Overpass at I-215



Key
80°
15°

Figure 4
System Layout at Knudsen's Bridge, Salt Lake City, Utah

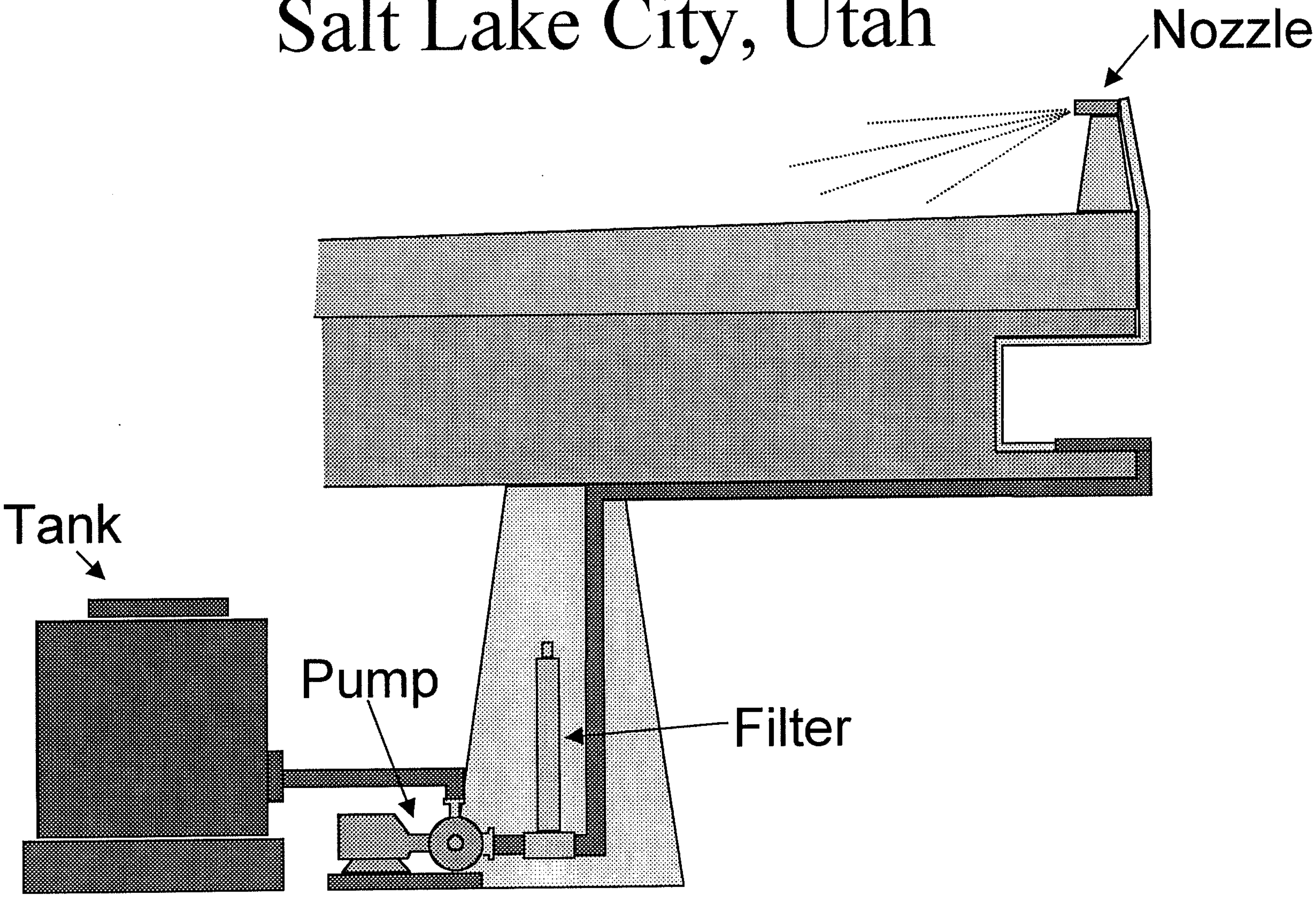


Figure 5
Piping Network at Knudsen's Bridge, Salt Lake City, Utah

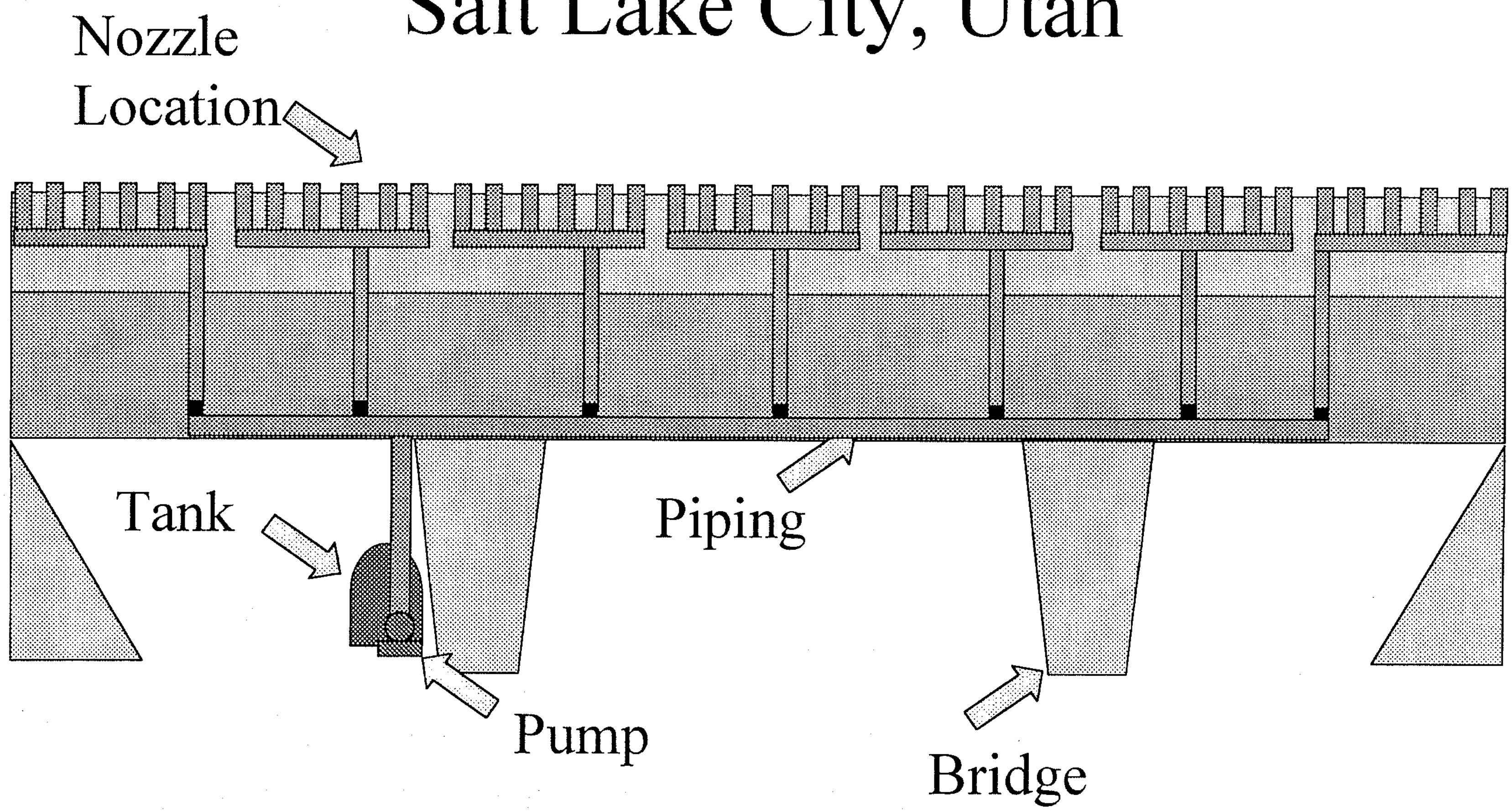
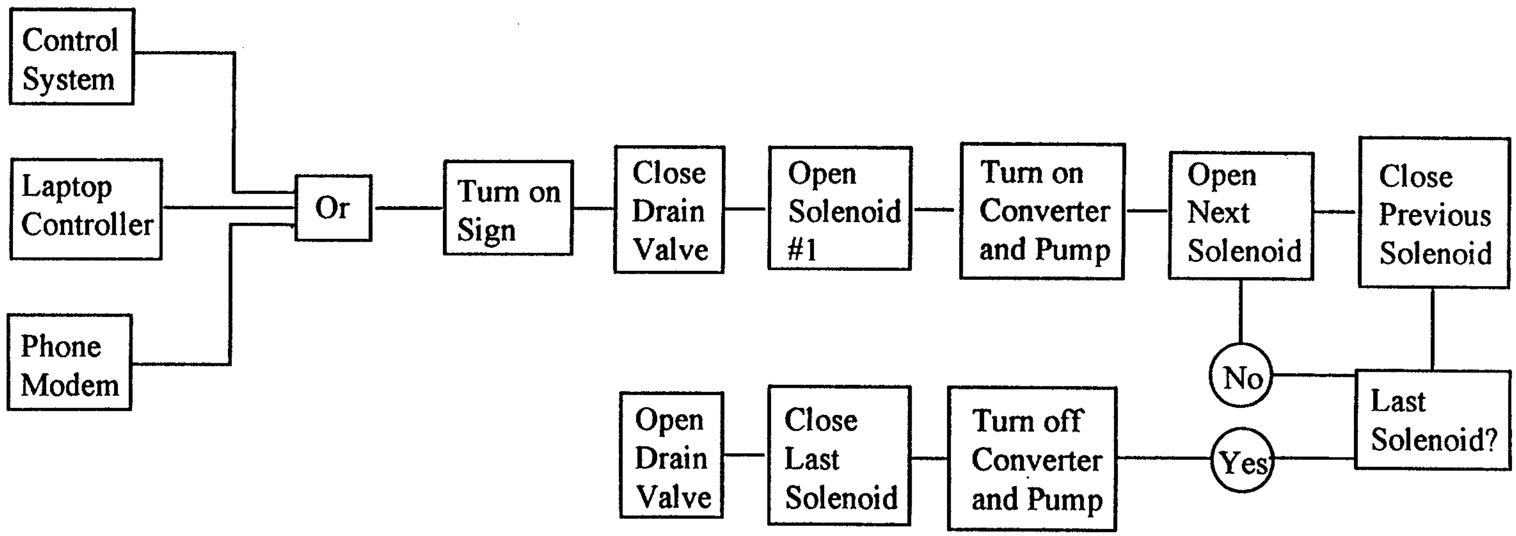


Figure 6

Process Sequencing



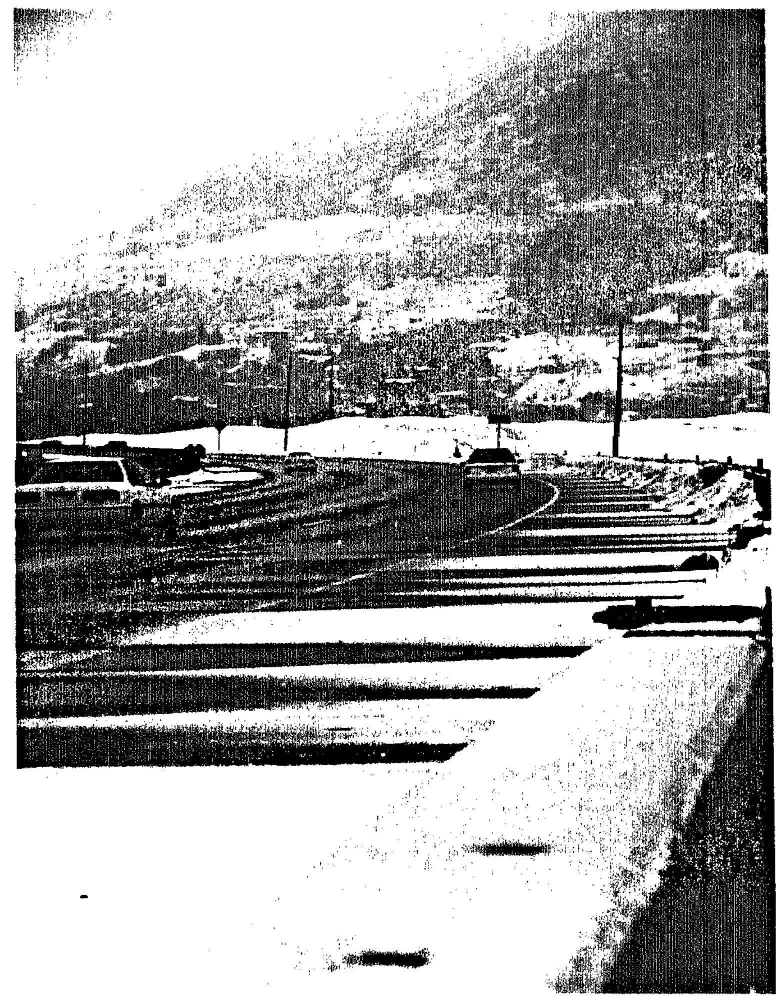


Figure 7
Motorist Information Sign at I-215
and 6200 South, Salt Lake City, Utah

Figure 8
Automated Control Criteria

- Is Ice Content Greater Than 25%
- Is There a Frosting Situation and Pavement Temp is Below the Calculated Freezing Point
- Is There Precipitation and Pavement Temp is Below the Calculated Freezing Point

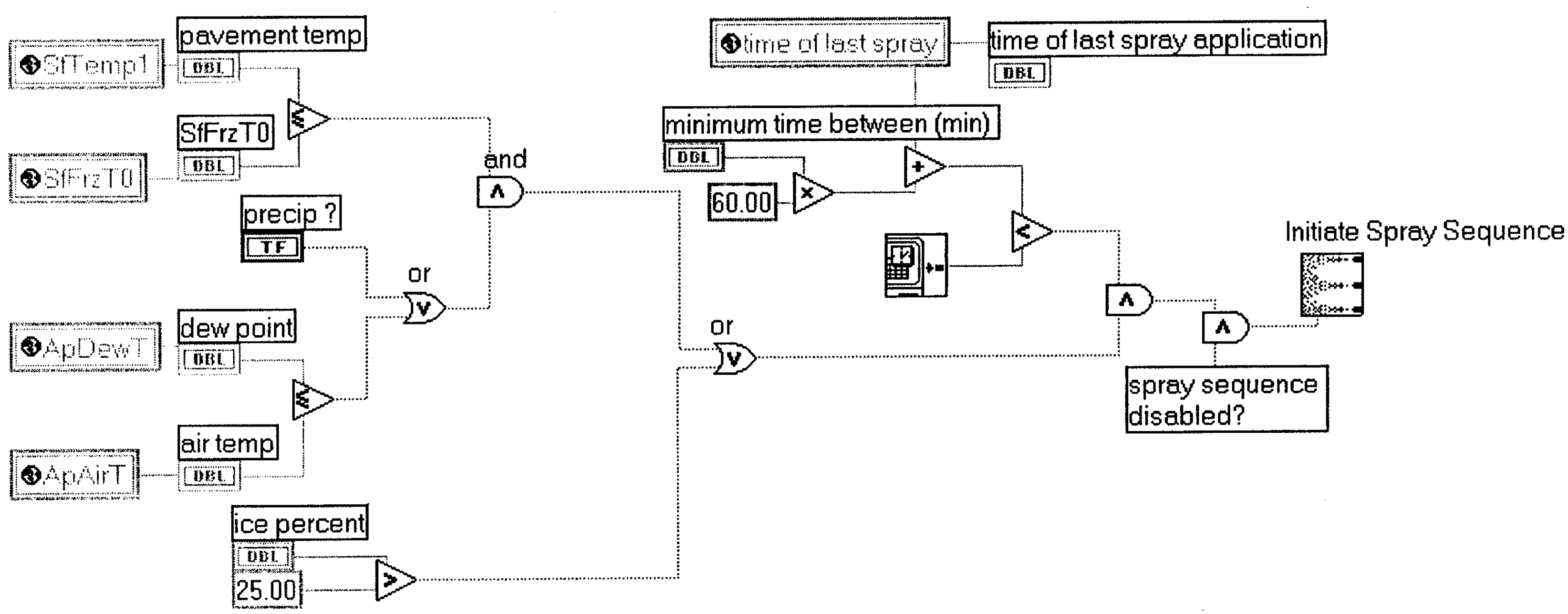


Figure 9

Process Control Logic

Option 1: RWIS Sensors

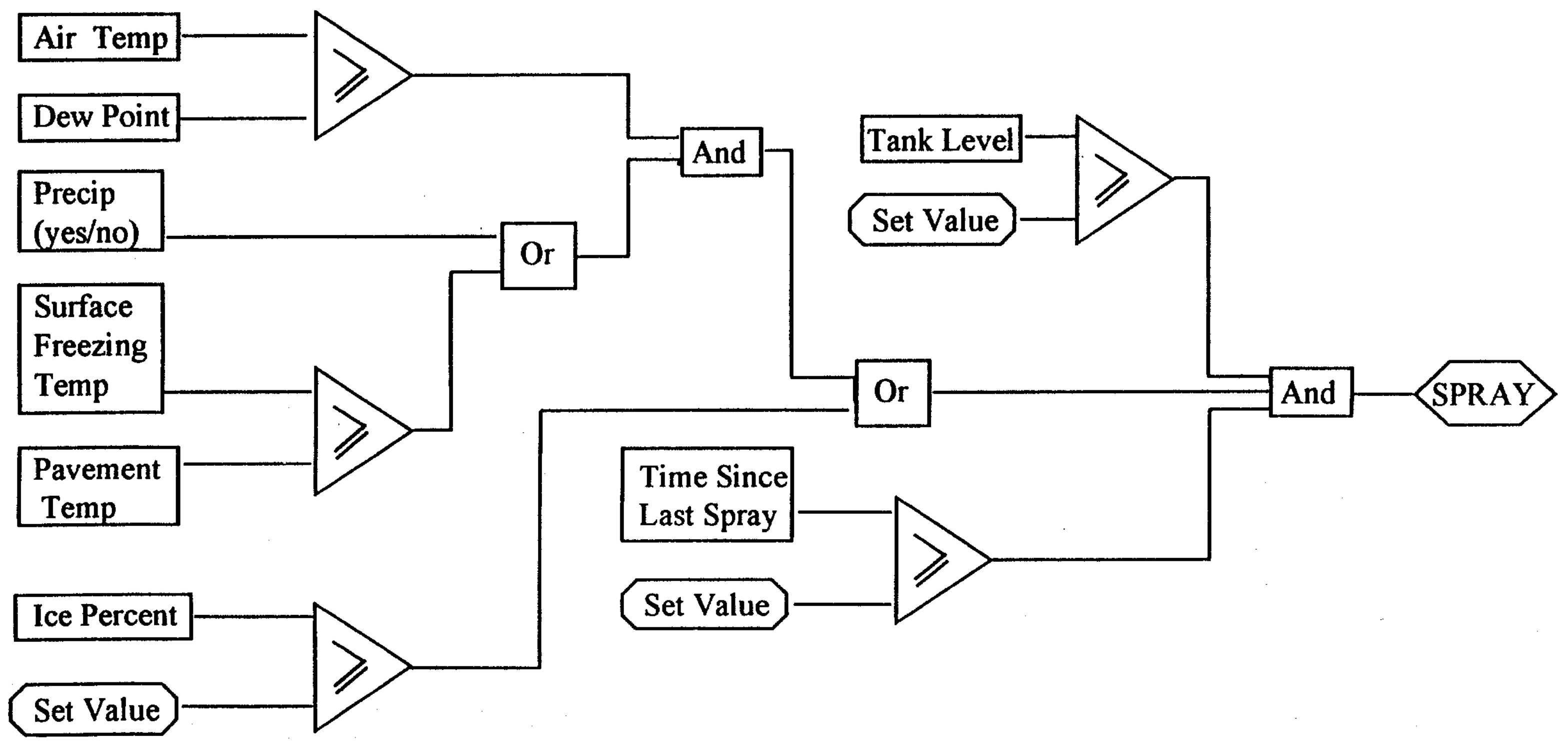
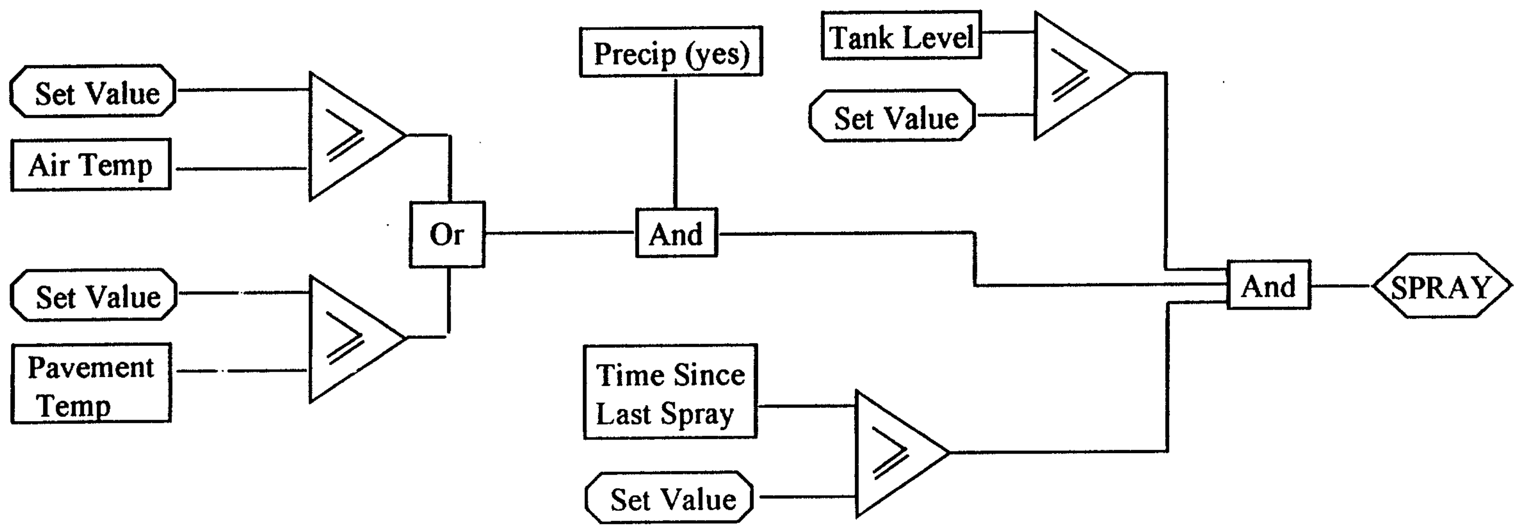


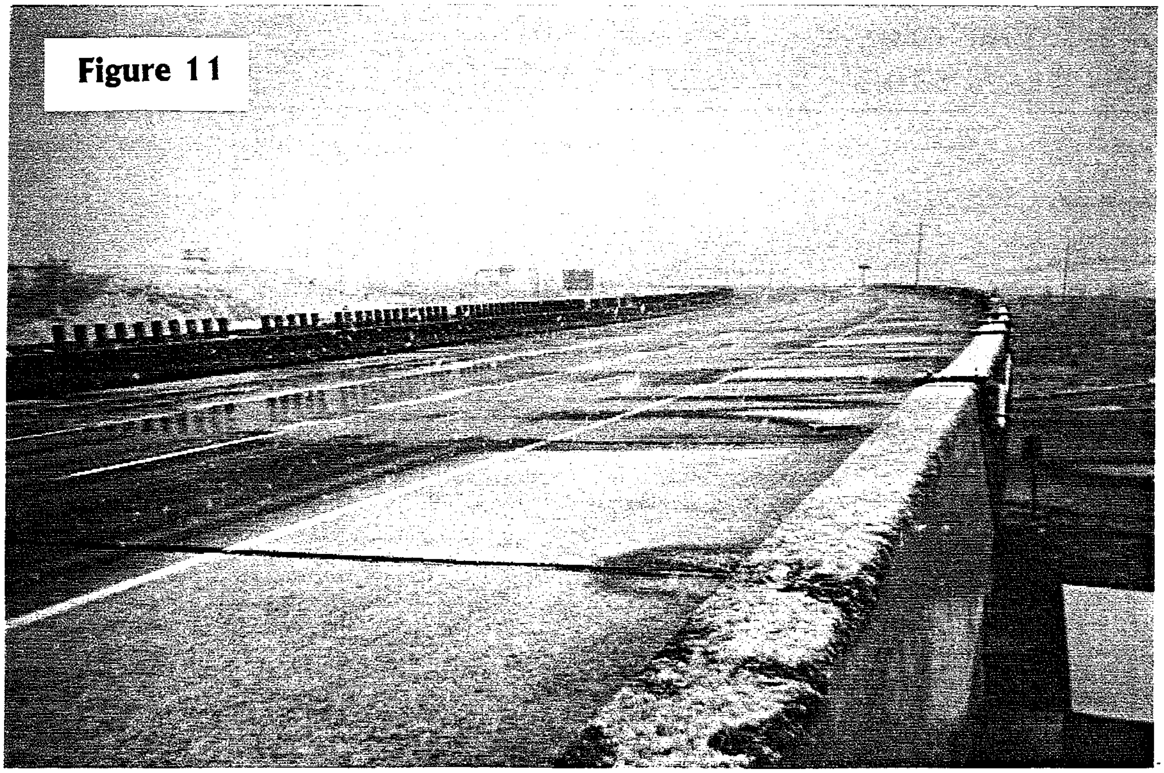
Figure 10

Process Control Logic

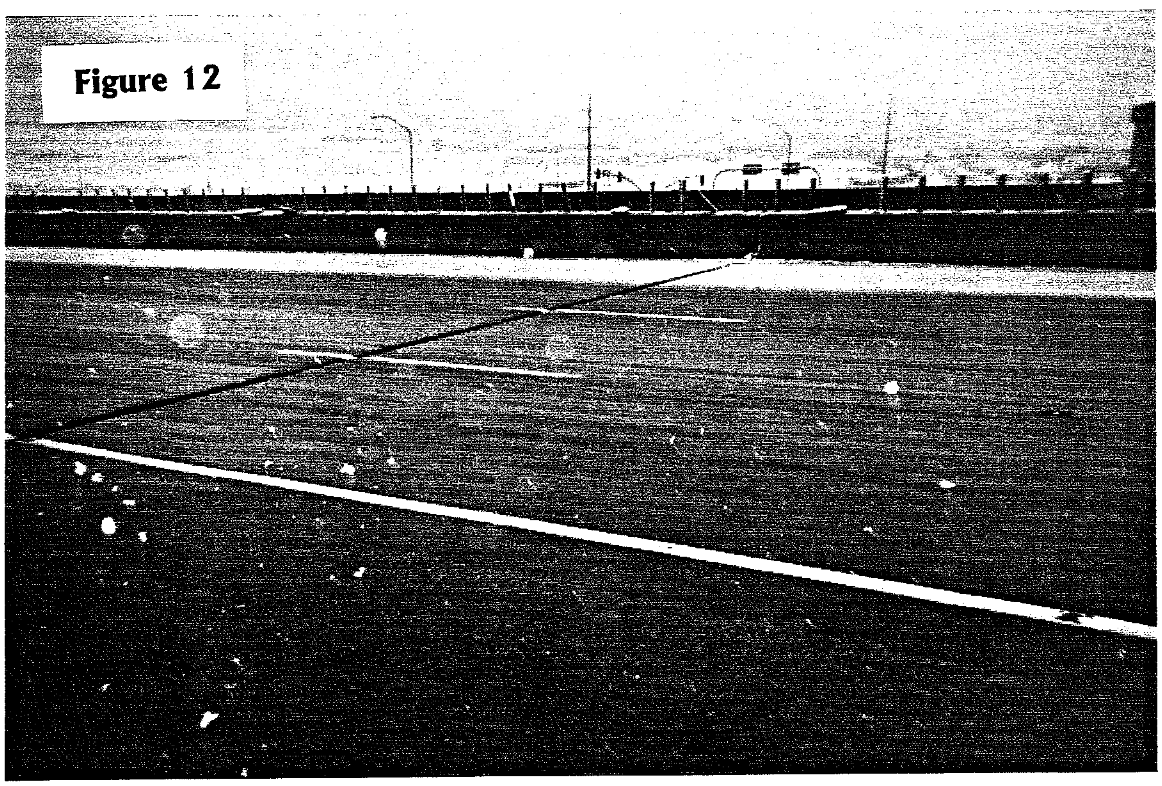
Option 2: Analog Sensors



Figures 11 through 16
Test and Control Sections for bridge anti- and deicing.

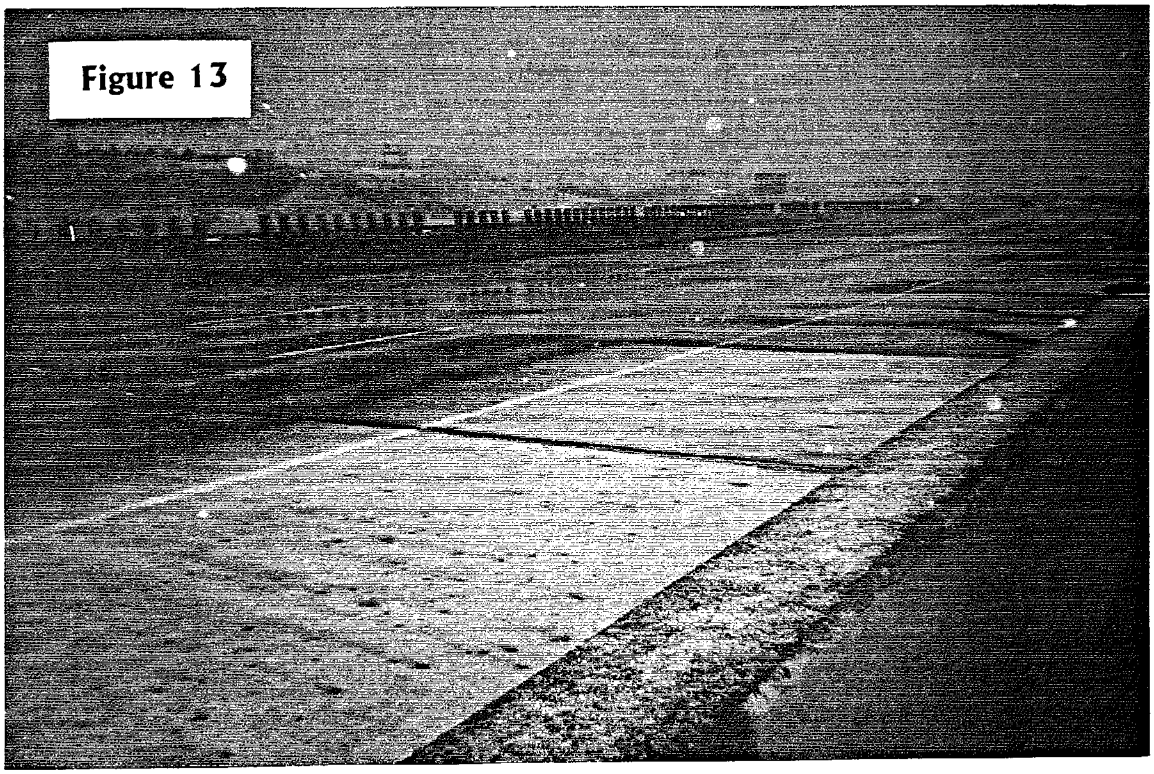


Salt Lake City: Knudsen's 2/8/98 *TEST SIDE*



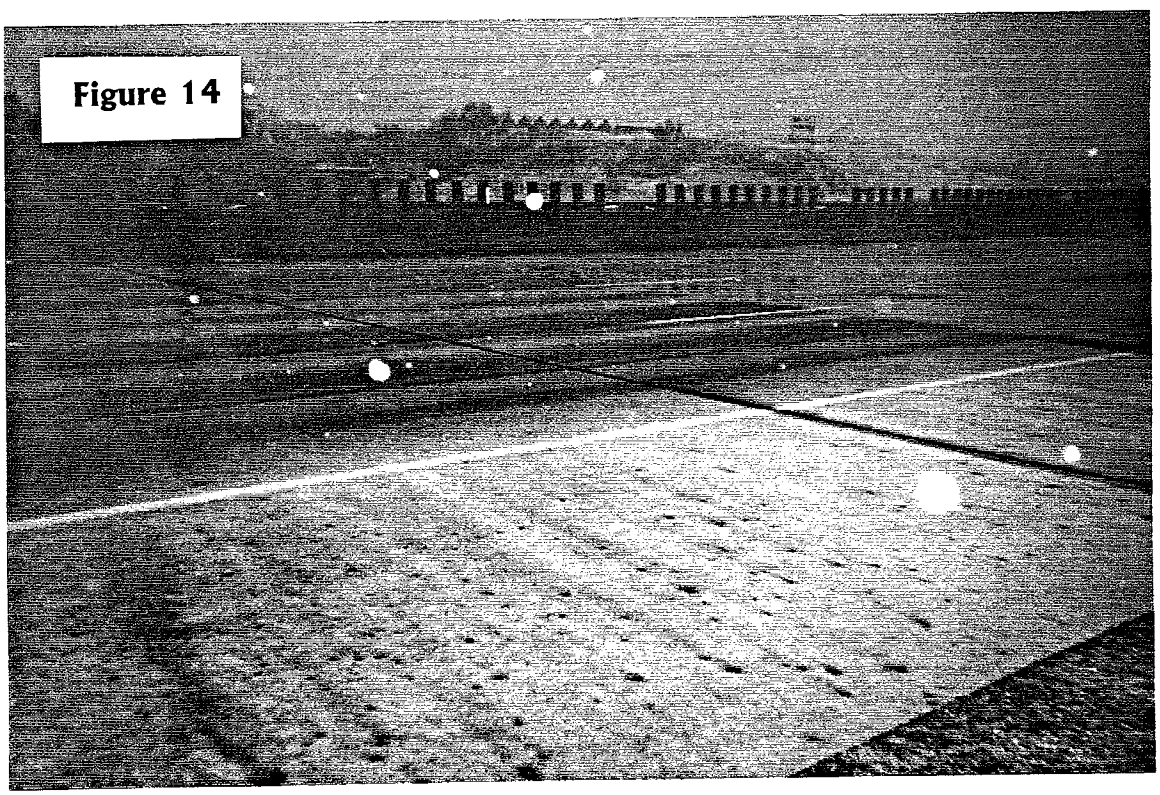
Salt Lake City: Knudsen's 2/8/98 *CONTROL SIDE*

Figure 13

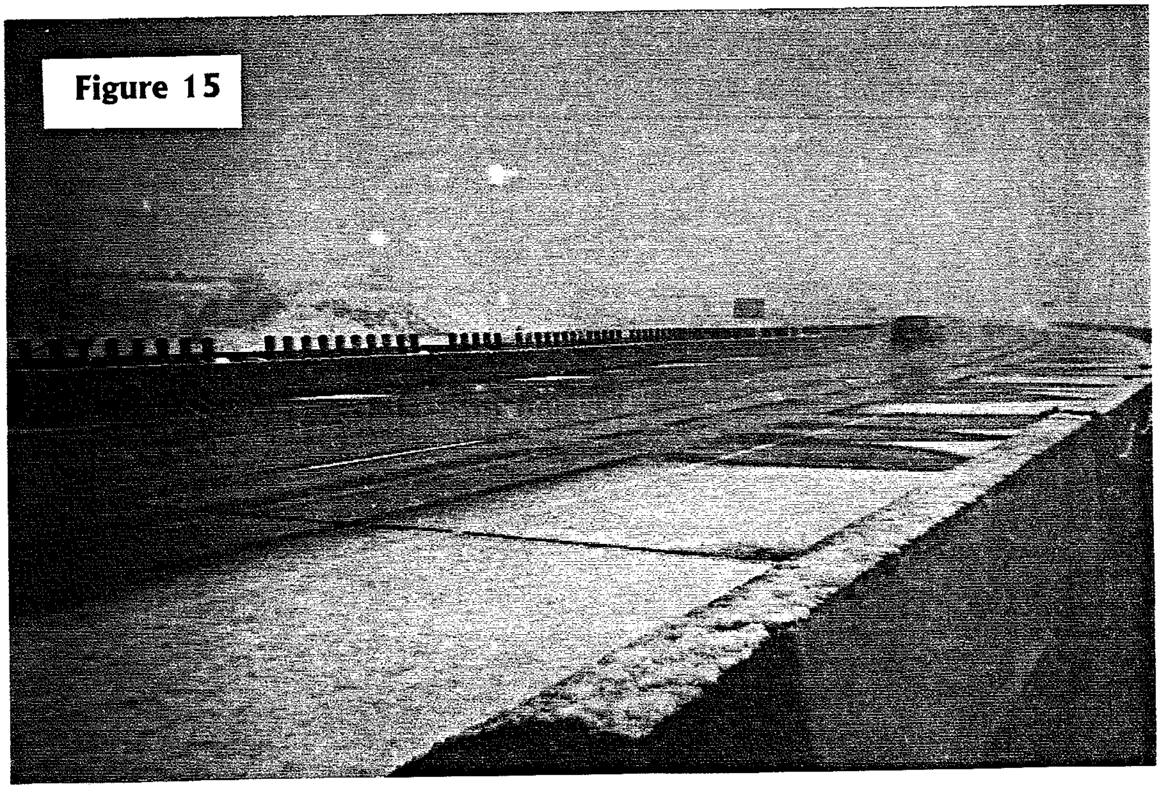


Salt Lake City: Knudsen's 2/22/98 Storm #1 *TEST SIDE*

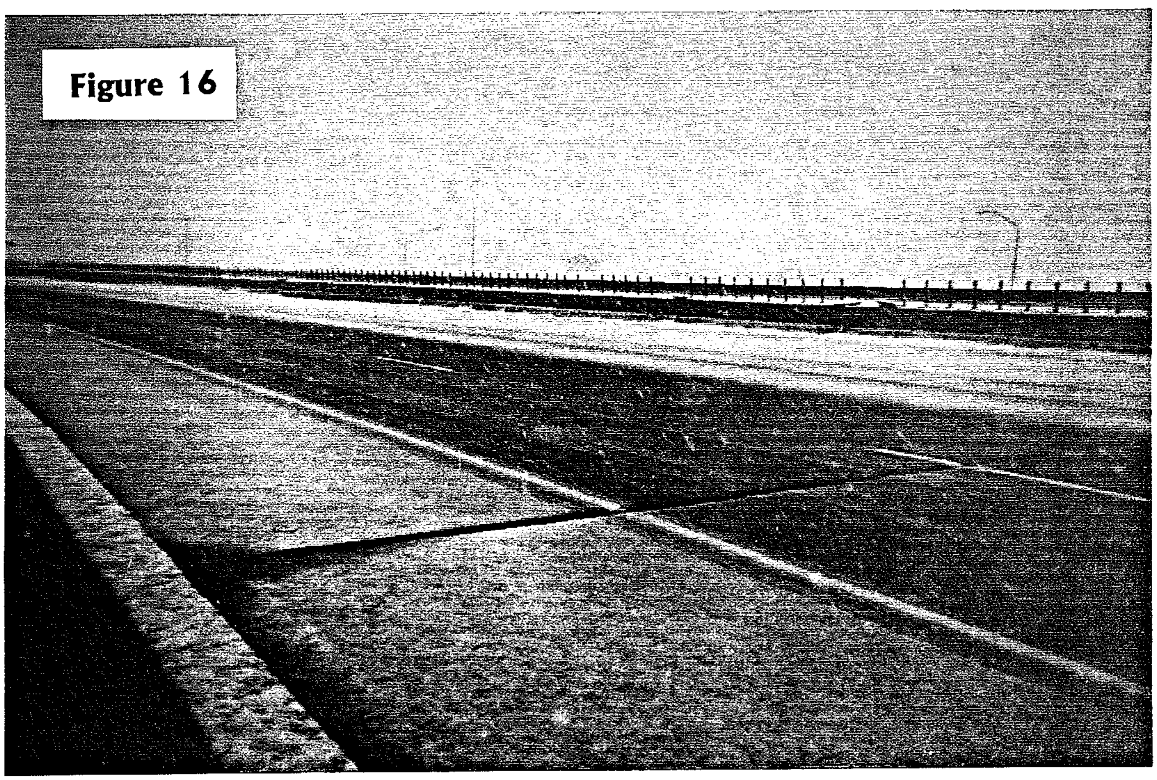
Figure 14



Salt Lake City: Knudsen's 2/22/98 Storm #1 *APPROACH*



Salt Lake City: Knudsen's 2/22/98 Storm #2 *TEST SIDE*



Salt Lake City: Knudsen's 2/22/98 Storm #2 *CONTROL SIDE*