Alaska Department of Transportation & Public Facilities

Research & Technology Transfer

Electrical Deicing Utilizing Carbon Fiber Tape for Asphalt Approach and Crosswalk

Phase I – Literature Review

Prepared by:
Zhaohui "Joey" Yang, Ph.D.
CFT Solutions, LLC
PO Box 141273
Anchorage, AK 99508

Date: June 30, 2016

Prepared for:
Alaska Department of Transportation & Public Facilities
Statewide Research Office
3132 Channel Drive
Juneau, AK 99801-7898

FHWA-AK-RD-4000(133)-LitDeic

REPORT DOCUMENTATION PAGE			Form approved OMB No.
Public reporting for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestion for reducing this burden to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-1833), Washington, DC 20503			
1. AGENCY USE ONLY (LEAVE BLANK) FHWA-AK-RD-4000(133)-LitDeic	2. REPORT DATE June 30, 2016	3. REPORT TYPE AND DATES COVERED Literature Review, up to Dec. 2015	
4. TITLE AND SUBTITLE Electrical Deicing Utilizing Carbon Fiber Tape for Asphalt Approach and Crosswalk Phase I – Literature Review			5. FUNDING NUMBERS Project No. 64006 4000(133)
6. AUTHOR(S) Zhaohui "Joey" Yang, Ph.D.			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) CFT Solutions, LLC PO Box 141273 Anchorage, AK 99508			8. PERFORMING ORGANIZATION REPORT NUMBER N/A
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) State of Alaska, Alaska Dept. of Transportation and Public Facilities Research and Technology Transfer 3132 Channel Drive Juneau, AK 99801-7898			10. SPONSORING/MONITORING AGENCY REPORT NUMBER FHWA-AK-RD-4000(133)-LitDeic
11. SUPPLENMENTARY NOTES Performed in cooperation with State of Alaska, Alaska Dept. of Transportation and Public Facilities and Federal Highway Administration			
12a. DISTRIBUTION / AVAILABILITY STATEMENT No restrictions			12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

The purpose of this study is to provide a comprehensive literature review of electrical deicing technology for possible application in asphalt approach and crosswalks. A thorough review of existing and emerging deicing technology for snow/ice melting was conducted. Particularly, the carbon fiber tape (CFT) deicing technology and its recent applications was summarized. The operation cost of such system was reviewed and compared with that of a hydronic system. Finally, current state of the practice of intersection/crosswalk winter maintenance was surveyed among state DOT's. The intersection/crosswalk winter maintenance procedure adopted by the Central Region Maintenance & Operation (M&O) of the State of Alaska Department of Transportation and Public Facilities (AK DOT&PF) was described, and the annual winter M&O cost per intersection was estimated. It was found that the annual energy cost of the CFT deicing technology is about the average annual M&O cost of current practice. In addition, an automatic electrical deicing system will bring the benefits such as minimized delay time and improved safety for pedestrian and vehicular traffic in an urban application. As AK DOT&PF maintains a quite large inventory of intersections/ crosswalks within Anchorage, we think an electrical deicing system such as the CFT system is well worthy of consideration and the investment, and would recommend such technology be tested in Asphalt pavement to verify its suitability for application in intersection/crosswalk winter maintenance.

14- KEYWORDS : winter maintenance; intersections; crosswalks; electric heating; asphalt pavements;			15. NUMBER OF PAGES 60
			16. PRICE CODE N/A
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT N/A

NSN 7540-01-280-5500

STANDARD FORM 298 (Rev. 2-98)
Prescribed by ANSI Std. 239-18 298-1

METRIC (SI*) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4		mm
ft	feet	0.3048		m
yd	yards	0.914		m
mi	Miles (statute)	1.61		km
		AREA		
in^2	square inches	645.2	millimeters squared	cm^2
ft^2	square feet	0.0929	meters squared	m^2
yd^2	square yards	0.836	meters squared	m^2
mi^2	square miles	2.59	kilometers squared	km^2
ac	acres	0.4046	hectares	ha
		MASS (weight)		
oz	Ounces (avdp)	28.35	grams	g
lb	Pounds (avdp)	0.454	kilograms	kg
T	Short tons (2000 lb)	0.907	megagrams	mg
		VOLUME		
fl oz	fluid ounces (US)	29.57	milliliters	mL
gal	Gallons (liq)	3.785	liters	liters
ft^3	cubic feet	0.0283	meters cubed	m^3
yd^3	cubic yards	0.765	meters cubed	m^3

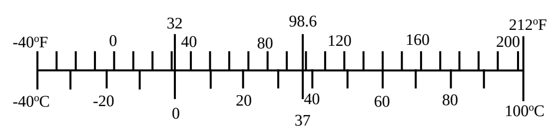
Note: Volumes greater than 1000 L shall be shown in m^3

Symbol	When You Know	Multiply By	To Find	Symbol
		TEMPERATURE (exact)		
ºF	Fahrenheit temperature	5/9 (ºF-32)	Celsius temperature	ºC
		ILLUMINATION		
fc	Foot-candles	10.76	lux	lx
fl	foot-lamberts	3.426	candela/m^2	cd/cm^2
		FORCE and PRESSURE or STRESS		
lbf	pound-force	4.45	newtons	N
psi	pound-force per square inch	6.89	kilopascals	kPa

These factors conform to the requirement of FHWA Order 5190.1A *SI is the symbol for the International System of Measurements

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	Miles (statute)	mi
		AREA		
mm^2	millimeters squared	0.0016	square inches	in^2
m^2	meters squared	10.764	square feet	ft^2
km^2	kilometers squared	0.39	square miles	mi^2
ha	hectares (10,000 m^2)	2.471	acres	ac
		MASS (weight)		
g	grams	0.0353	Ounces (avdp)	oz
kg	kilograms	2.205	Pounds (avdp)	lb
mg	megagrams (1000 kg)	1.103	short tons	T
		VOLUME		
mL	milliliters	0.034	fluid ounces (US)	fl oz
liters	liters	0.264	Gallons (liq)	gal
m^3	meters cubed	35.315	cubic feet	ft^3
m^3	meters cubed	1.308	cubic yards	yd^3
		TEMPERATURE (exact)		
ºC	Celsius temperature	9/5 ºC+32	Fahrenheit temperature	ºF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/cm^2	candela/m^2	0.2919	foot-lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	pound-force	lbf
kPa	kilopascals	0.145	pound-force per square inch	psi



Project No. 64006

Electrical Deicing Utilizing Carbon Fiber Tape for Asphalt Approach and Crosswalk

Phase I – Literature Review

Final Report

Prepared for

State of Alaska Department of Transportation and Public Facilities
And
Federal Highway Administration

Zhaohui "Joey" Yang, Ph.D.
Co-Founder and Principal Investigator

CFT Solutions, LLC
PO Box 141273
Anchorage, AK 99508

June 30, 2016

Table of Contents

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGMENTS

The research reported herein was supported by the State of Alaska Department of Transportation and Public Facilities (AK DOT&PF) (Project #64006) and Federal Highway Administration (FHWA). Dr. Zhaohui (Joey) Yang, Co-Founder of CFT Solutions, LLC, was the Principal Investigator. The author would like to express his appreciation to Ms. Anna Bosin, P.E., Research Engineer, Research Development and Technology Transfer of AK DOT&PF, for her continuous support during the entire course of the study including drafting research needs, reviewing the survey questions, administering the survey, compiling the survey results, and critical review of the draft report.

ABSTRACT

The purpose of this study is to provide a comprehensive literature review of electrical deicing technology for possible application in asphalt approach and crosswalks. A thorough review of existing and emerging deicing technology for snow/ice melting was conducted. Particularly, the carbon fiber tape (CFT) deicing technology and its recent applications was summarized. The operation cost of such system was reviewed and compared with that of a hydronic system. Finally, current state of the practice of intersection/crosswalk winter maintenance was surveyed among state DOT's. The intersection/crosswalk winter maintenance procedure adopted by the Central Region Maintenance & Operation (M&O) of the State of Alaska Department of Transportation and Public Facilities (AK DOT&PF) was described, and the annual winter M&O cost per intersection was estimated. It was found that the annual energy cost of the CFT deicing technology is about the average annual M&O cost of current practice. In addition, an automatic electrical deicing system will bring the benefits such as minimized delay time and improved safety for pedestrian and vehicular traffic in an urban application. As AK DOT&PF maintains a quite large inventory of intersections/ crosswalks within Anchorage, we think an electrical deicing system such as the CFT system is well worthy of consideration and the

investment, and would recommend such technology be tested in Asphalt pavement to verify its suitability for application in intersection/crosswalk winter maintenance.

Keywords: winter maintenance; intersections; crosswalks; electric heating; asphalt pavements;

EXECUTIVE SUMMARY

This report provides a comprehensive review of existing and emerging deicing technologies including the newly developed carbon fiber tape (CFT) deicing technology, and the current state of the practice of intersection/crosswalk winter maintenance. The main findings from this project are summarized below:

1. Most DOT’s do not have responsibility on intersection/crosswalk winter maintenance, or do not treat it differently than a highway. Only Alaska and British Columbia, Canada treat crosswalk differently, and maintain a certain standard for crosswalks winter maintenance.

2. A typical snow/ice treatment procedure for intersection/crosswalk would include plow, and sand/brine mixture application depending on weather conditions and temperatures. Anti-icing treatment is used pre-storm or during freeze-thaw events.

3. While mechanical/chemical method is the most cost-effective method, heated pavement, particularly the electrical resistance heated pavement methods, offer many promising benefits such as being environment friendly, and great potential for innovation.

4. The operation cost may prohibit application of electrical resistance heating method in very large areas; however, it offers a great alternative snow/ice melting

technology for small areas with concentrated traffic such as urban crosswalks, sidewalks, bus stops, and bridge decks.

5. Compared with other field-tested electrical resistance heating methods, CFT deicing technology has certain advantages in terms of being easy to install, no need to modify AC mix ratio, durable, safe, and satisfactory performance.

6. The energy cost of the CFT deicing system is about the average annual M&O cost of current practice regarding intersection/crosswalk winter maintenance. In addition, an automatic electrical deicing system will bring the benefits such as minimized delay time and improved safety for pedestrian and vehicular traffic.

7. As Central Region M&O of AK DOT&PF maintains a quite large inventory of intersection/crosswalks, we think an electrical deicing system such as the CFT system is well worthy of consideration and the investment, and would recommend such technology be tested in asphalt pavement for potential application in areas with concentrated traffic including intersections/crosswalks.

CHAPTER 1: REVIEW OF EXISTING AND EMERGING DEICING METHODS

1.1 Mechanical and Chemical Deicing Methods

In mechanical ice removal, large equipment and vehicles are used to plow and scrape snow and ice from pavement. The expense of employing equipment operators is a major factor contributing to the high cost of mechanical deicing. Removing compacted snow and ice with shovels or snow blowers is not always an easy task due to the strong bond between ice and pavement. Chemical treatment helps break the bond by melting the ice (Henderson 1963). Deicing of roads has traditionally been done by a combination of mechanical and chemical methods. Salt, often mixed with sand and gravel, is spread by snowplows or dump trucks on slick roads, and the ice loosened by salting is plowed from roadways. Chloride-based salts including sodium chloride, magnesium chloride, and calcium chloride are the most common chemicals used for ice and snow control since they are inexpensive and effective (Menzies 1991). These salts, however, can corrode vehicles and reinforcing steel in the concrete and pollute the environment (Jones 1992; Williams et al. 2000; Shi et al. 2009b).

To reduce damage to concrete structures, some complex chemical solutions have been applied (Kuemmel 1994; Zenewitz 1977). In recent years, acetate-based deicers such as potassium acetate, calcium magnesium acetate, or calcium-magnesium-potassium acetate have been given preference as deicers, since they tend to decompose faster and do not contain chloride. However, acetates pose a risk to the durability of concrete and asphalt pavements and are costly (Hassan et al. 2002; Fay et al. 2008; Pan et al. 2008; Shi et al. 2009a; Shi et al. 2011). Calcium magnesium acetate (CMA) is noncorrosive to steel reinforcement, but it requires large trucks for transport, is less effective than salts, that is, it performs slower than salts, and its application temperature range is smaller (Slick 1988; Fay et al. 2008).

More recently, organic compounds generated as by-products of agricultural operations, such as sugar beet refining or the distillation process that produces ethanol, have been applied for ice and snow control. When mixed with other chloride, such as magnesium chloride, these organic compounds have longer residual effects when spread on roadways. Additionally, mixing common rock salt with some of the organic compounds and magnesium chloride results in spreadable materials that are effective at colder temperatures (-30°F/-34°C) and require lower overall rates of spreading per unit area (http://www.magicsalt.info/Magic%20Salt.htm). Nevertheless, organic compounds mixed with chloride can harm the environment and are costly. It is worth mentioning that urea, a soluble nitrogen compound, is commonly used for airport pavement deicing because of its low corrosiveness.

1.2 Thermal Methods

A number of alternative thermal methods have been developed to control snow and ice formation on ramps and bridge decks. Yehia and Tuan (1999) have provided a comprehensive literature survey of road deicing/anti-icing methods used over the past 30 years. A brief review of thermal methods is presented here.

1.2.1 Pavement Deicing with Internal Heating Elements

1.2.1.1 Ground-Source Heat Pipe

Initial experimental testing of ground heat pipes was conducted in 1970 by Dynatherm Corporation at the FHWA Fairbanks Highway Research Station (Bienert et al. 1974). In 1975, Long and Baldwin (1980) conducted experiments using a heating system that had 1,213 ground heat pipes extending 60 ft into the ground on a highway ramp in Oak Hill, West Virginia. This system was successfully used to prevent snow and ice accumulation, except when snow drifting occurred. The far-field ground temperature in this case averaged around 13°C. A gravity-operated heating pipe system that used a manifold ground heat exchanger was implemented in a bridge deck in 1981 in Laramie, Wyoming (Lee et al. 1984). This system used field-assembled heat pipes to transfer energy from 100 ft vertical evaporators in the ground. The results show that the heated surface was approximately 2–14°C warmer than the unheated portion of the bridge during operation, which was sufficient to prevent preferential freezing of the bridge deck surface and provided some snow-melting function. The main disadvantage was that the assembly of the heat pipes was complicated and 40% of the total cost was for drilling and grouting the pipes. Zenewitz (1977) described another example of using a geothermal source in snow and ice control in Oregon. In this case, a hot-water heating system with copper pipes containing antifreeze heated by a geothermal source was installed in reinforced concrete pavement approximately 122 m long on the deck of a canal bridge to keep the deck free of ice.

1.2.1.2 Hot Fluid Heat Pipe

In 1993, rubber hoses containing antifreeze heated by a gas boiler were embedded in a concrete pedestrian overpass in Lincoln, Nebraska (Cress 1995). This heating system was not in service due to a leak in the PVC supply and return lines. The installation cost of the system was \$161/m^2, and the operating cost per storm was about \$250 to melt 76 mm thick snow. A heating system that consisted of steel pipes and carried Freon heated to 149°C by a propane-fired boiler was installed in the Buffalo River Bridge at Amherst, Virginia, in 1996 (ASCE 1998). This system used the latent heat released during condensation of the evaporated Freon for deicing, and the estimated annual operating cost was approximately \$1,000. Similar hydronic systems have been installed in Ohio, Oregon, Pennsylvania, South Dakota, and Texas. Nowadays, a hydronic system consisting of plastic pipes embedded in Portland cement concrete (PCC) pavement and glycol heated by gas or oil burning boilers is commonly used in Anchorage, AK (e.g. Downtown Anchorage intersections and sidewalks) and other cold regions for deicing and anti-icing purposes (Wheeler et al. 2012).

1.2.1.3 Solar-Source Heat Pipes

Zhao et al. (2010) reported a deicing system in Japan that uses solar energy. The solar energy is collected from the road surface by a water pump when the temperature is high in summer, and is stored underground by horizontal and vertical pipes embedded in pavement. In winter, the water pump brings warm water through the pipes to the pavement for deicing. Only the water pump consumes electric energy in this system. The energy used for deicing came from solar radiation and a geothermal heat source.

Wu et el. (2009) and Chen et al. (2011a&b) described a similar system called asphalt solar collector based on thermally conductive asphalt concrete. The idea was to add thermally conductive fillers such as Graphite powders (Wu et al. 2005) to asphalt concrete mixture to improve its thermal conductivity, which facilitates harvesting of the solar radiation energy through water circulated copper tubes embedded in asphalt during summer. The heated water is stored underground for ice/snow melting in winter. The circulating fluid can also help cool the asphalt concrete, hence reduce its risk of permanent deformation due to high temperature in summer months.

Such system is essentially a hydronic system that is used to harvest solar energy in summer and melt snow/ice in winter. This type of system utilizes renewable energy and is environment friendly. However, the melting process is quite slow if not coupled with other energy source such as geothermal heat as the temperature of the stored water is not very high. It also inherits all the disadvantages of a hydronic system such as high maintenance cost, vulnerable to cracks/deformation in pavement, requirement of a large underground water storage, etc.

1.2.1.4 Electric Heating Cable

Electric heating cables were installed on the approach and the deck of a highway drawbridge to remove snow/ice in Newark, New Jersey, in 1961 (Henderson 1963). Power density was 378 W/m^2 for the bridge deck and 430 W/m^2 for the road pavement. The heat generated by electric current was sufficient to melt 25 mm thick snow per hour. However, the installation was later abandoned because the electric cables pulled out of the asphalt concrete (AC) overlay due to traffic load on the pavement. A similar system was installed in two ramps and a bridge deck in Teterboro, New Jersey, in 1964 (Zenewitz 1977). This system was reported to work well for deicing. The power density was about 375 W/m^2, and the annual operating cost was approximately \$5/m^2. Installation of similar systems can be found in Nebraska, Ohio, Oregon, Pennsylvania, South Dakota, Texas, and West Virginia.

1.2.1.5 Carbon Fiber Heating Wire

Carbon fiber wires have been used as a heating element for deicing. Zhao et al. (2010, 2011) reported a field experiment where carbon fiber heating wires were embedded in a PCC slab for pavement deicing study. The slab of 1 × 2 × 0.25 m (L×W×T) was cast by using C40 PCC concrete. Carbon fiber heating wires were wound around the reinforcing mesh longitudinally, and the interval between the reinforcing bars was 100 mm. The power density was in the range of 500–800 W/m^2, and the annual operating cost was in the range of \$0.375–\$2.8/m^2-storm.

Xiang (2014) was granted a patent on using carbon heating wires for deicing of AC sidewalk. The carbon fiber heating wires are embedded in AC layer to generate heat for snow/ice melting. No field studies were found in AC pavement.

Lai et al. (2014) and Liu et al. (2015) reported a larger scale field experiment to study the snow melting performance of carbon fiber heating wires. In this experiment, 4.6 m × 4.6 m × 0.4 m PCC slabs was built and the carbon fiber grille (or mesh) assembled with reinforcing steel mesh and 48k carbon fiber heating wires were buried 5 cm below pavement surface. The heating wires were spaced at 10 cm and the power density was 350 W/m^2.

This method has the advantage of easy installation as it can be combined with the reinforcing mesh. The key issue is that the heat power is not uniformly distributed on the pavement, creating a temperature gradient and thermal stress, which could lead to thermal cracking. In addition, the effects of the insulated carbon heating wire wound around reinforcing steel bars on steel-PCC pavement bondage and structural function of the pavement are not clear. If installed by itself in the AC pavement, the heating wires could be pulled out of the AC overlay due to traffic load on the pavement, as did for metal heating wires (Henderson 1963).

1.2.1.6 Magnetic Snowmelt Device

Zhang et al. (2011) described a quite interesting snowmelt method that utilizes a magnetic heating device embedded in pavement for highway pavement deicing. The magnetic heating device takes advantage of the so-called magneto-caloric effect, which causes temperature change of certain ferromagnetism or ferrimagnetism material when it is exposed to a changing magnetic field. This method was presented as being fast, easy to operate, and energy efficient. The field experiment indicated the segment with the heating device melted the snow much sooner than the segments without snow melting device. However, the snow fallen the first day did not completely melt until the third day.

1.2.1.7 Carbon nano-fiber polymer sheet (CNFP) and graphite-PET sheet deicing methods

Li et el. (2013) reported a novel deicing system consisting of carbon nano-fiber polymer thermal source and multiwall carbon nanotube (MWCNT) cement based thermal conductive composite. This system utilized a thermally insulated substrate made of AlN-ceramic wafer to improve the energy efficiency. The power density used in the limited scale field experiment was 600 W/m^2 to 1800 W/m^2, and the snow melting performance was very impressive. However the heating source, i.e. carbon nano-fiber polymer, is very expensive and has poor mechanical properties. This system is quite complex and still far from large-scale field application. Recently, Zhang et al. (2016) developed a thin flexible sandwiched graphite-PET sheet heating element for deicing. A water proof membrane was used to protect the heating element. Such heating element has improved mechanical property. However, its long-term durability remains to be verified by field application.

1.2.2 Pavement Deicing with External Heating Elements

1.2.2.1 Microwave

Hopstock (2003) conceived the idea of testing magnetite-bearing taconite aggregate and microwave technology for two potential road-use applications: (1) all-season hot-mix pothole patching and curing, and 2) chemical-free deicing of surfaces paved with AC, including highways, bridge decks, pedestrian walkways, and airport runways. Results from a preliminary bench-scale assessment of this idea using a conventional microwave oven show that magnetite-bearing taconite aggregate is indeed an excellent microwave absorber (Hopstock 2003; Hopstock and Zanko 2005). When a truck-mounted microwave generator is driven over an ice-covered roadway constructed with crushed taconite as the aggregate, the microwaves should pass through the ice and be absorbed as heat at the road/ice interface, allowing the ice to be easily detached and scraped away. However, these findings have not been validated in a full-scale, practical testing program (Hopstock 2005).

1.2.2.2 Infrared Heat Lamp

An infrared heat lamp was used as an external heating element in an ice prevention system installed on the Mississippi Avenue Bridge in Denver, Colorado (Zenewitz 1977). The infrared lamps were used to heat the underside of the bridge deck with a power density of 75 W/m^2. It was found that the heat lamp system was insufficient to prevent ice formation on the road surface due to excessive lag time and inadequate power density.

1.2.3 Electrically Conductive Portland Cement Concrete

Conventional PCC is not electrically conductive. In electrically conductive concrete, a certain amount of electronically conductive components is used to replace a certain portion of the fine and coarse aggregates to attain stable and relatively high electrical conductivity.

Electrically conductive concrete (ECC) is a patented technology developed at the National Research Council of Canada (Xie et al. 1995, U.S. Patent No. 5,447,564; Pye et al. 2003, U.S. Patent No. 6,503,318 B2).

Conductive concrete can be classified into two types: fiber-reinforced conductive concrete with higher mechanical strength and lower conductivity (100 Ω-cm), and aggregate-containing conductive concrete with lower compressive strength and higher conductivity (10 to 30 Ω-cm) (Xie and Beaudoin 1995; Xie et al. 1996). Conductive concrete cement-based composites with both high conductivity and mechanical strength were applied to melt snow/ice in the laboratory and in the field (Xie and Beaudoin 1995; Xie et al. 1996). A composite concrete slab consisting of a base ECC layer and a PCC overlay was used to melt snow. The overlay had a w/c ratio of 0.325 and a mix design of cement/fine aggregate/coarse aggregate of 1:2:2. The dimensions of the experiment slab were 0.24 × 0.31 × 0.05 m (L×W×T). For typical applications, voltages were always less than 15 V, and the primary current through the ECC layer was less than 30 A (Pye et al. 2003). The current through the overlay was extremely small (0.012 mA). Alternately, the thickness of the overlay can be increased to reduce the current through the overlay. However, the energy efficiency for snow melting will be compromised with a very thick overlay (Tumidajski et al. 2003).

Yehia and Tuan (1998) developed a conductive concrete mix with steel fibers and steel shavings specifically for bridge deck deicing. Over 50 trial mixes of conductive concrete were prepared using steel fibers and steel shavings. The heat generated by the conductive concrete was stable and uniform, using 15–20% conductive material (i.e., steel fibers and shavings) by volume. Experiments using small-scale slabs showed that the average power density of approximately 520 W/m^2 was generated by the conductive concrete, and it took 30 min to raise the slab temperature from -1.1° to 15.6°C (Yehia and Tuan 1998; Yehia and Tuan 1999). In 1998, Yehia and Tuan conducted several groups of laboratory deicing and anti-icing experiments. They found that steel shavings of 20% per volume and steel fibers of 1.5% per volume were the upper bound; higher amount of shavings or steel fibers result in poor workability and surface finishability (Yehia et al. 2000; Yehia and Tuan 2000).

Two 9-cm thick conductive concrete overlays, 2 m× 2 m and 1.2 m × 3.6 m, were cast on top of 15-cm thick conventional concrete slabs for conducting deicing experiments in the natural environment. Deicing and anti-icing experiments were conducted in five snowstorms in 1998. An average power density of about 590 W/m^2 was generated by the conductive concrete overlays to prevent snow and ice accumulation (Yehia and Tuan 2000). The average unit energy cost was about \$0.8/m^2 for each storm, with an assumed electricity cost of \$0.08/kWh (Yehia and Tuan 2000; Tuan 2004).

In spring 2001, carbon products were used to replace the steel shavings in the conductive concrete. Based on the findings from laboratory tests, the conductive concrete with carbon products was applied on a bridge deck at Roca, Nebraska (referred to as Roca Spur Bridge) for deicing (Tuan and Yehia 2004). A 36 m long and 8.5 m wide conductive concrete inlay was built and instrumented with temperature and current sensors for heating-performance monitoring during winter storms. The inlay was divided into 52 isolated 1.2 × 4.1 m slabs (Tuan 2008). Three-phase 208 V, 600 A AC power was supplied to the conductive concrete slabs for deicing. All mixes contained 1.5% steel fibers and 25% carbon products per volume of the conductive concrete. Operation of this deicing system in four winter seasons shows that power density was in the range of 203~431 W/m^2, and the unit energy cost was about \$250 per snowstorm, or about \$0.8/m^2 (Tuan 2008).

Heymsfield et al. (2014) reported a Federal Aviation Administration (FAA) sponsored pilot study using conductive concrete overlay panel and renewable energy to develop anti-icing airfield runway. Ten 4'x10' overlay panels were constructed by electrically conductive concrete in Arkansas to conduct anti-icing test with photovoltaic panels and battery storage system. It was concluded that the energy warranted to sustain the thermal mass of ten large overlay panels at an above-freezing temperature is difficult to attain by a solar based renewable energy system. The authors further proposed to attach heat wires such as copper wires to concrete pavement surface and power it by solar energy to develop an anti-icing system. However, practical issues of installing and protecting wires under vehicular loads exists.

In summary, the electrically conductive concrete overlay approach shows promise for deicing and anti-icing application. However, it has not been widely used for deicing/snow melting to date because of issues such as high resistivity, low electro-thermal efficiency, and steel fiber corrosion. In addition, practical issues such as thermal (transverse) and longitudinal cracking, deterioration of electrical properties, and rutting of the overlay will significantly impact the reliability and life-span cost of electrically conductive concrete overlay method.

1.2.4 Electrically Conductive Asphalt Concrete

Electrically conductive AC can be used to generate heat and hence provide another method for snow melting and deicing. Pan et al. (2014) provided a review on the structure design, performance and engineering applications of conductive AC. Conventional AC contains coarse and fine aggregates, asphalt binder and mineral filler. It behaves as an electrical insulator with a resistivity value between 10^8 and 10^{12} Ω.m. Electrically conductive materials have to be added to AC mixture to make it conductive and these materials includes: 1) powders including graphite, carbon black, and aluminum chips (Huang et al. 2009; Wen and Chung 2004); 2) fibers including carbon fiber, steel fiber, steel wool, and carbon nanofiber (Garcıa et al. 2009); and 3) solid particles such as steel slag substituting for the coarse and fine aggregates (Ahmedzade and Sengoz 2009).

Devin et al. (2003) reported a field application of electrically conductive AC pavement system (with the commercial name Snowfree®) for snow melting at O'Hare International Airport. The Snowfree® electrically conductive AC pavement consists a blend of graphite and asphalt; copper buses, alternating between live and ground were placed at intervals of 16 ft and cast within a 2 in layer of the graphite infused AC. In collaboration with the Federal Aviation Administration (FAA), such system was installed on 7,500 ft^2 of a taxiway in November 1994. The installation costs were at $15/$ft^2$ (no inflation adjustment). During the three and a half years of operation, the conductive AC system consistently produced a power density of 484 W/m^2 (153 $BTU/(hr \cdot ft^2)$) while in operation, and satisfactorily cleared snow and ice. Throughout the evaluation period, 200,000 aircrafts travelled on the graphite infused AC and no significant cracking was observed. However, the FAA deemed that the operating cost was high, and no other airport has utilized this technology (Lopez 2012).

However, the addition of conductive materials will require a substantial change of the mixing procedure and will also impact the mechanical performance of the pavement. Furthermore, asphalt as a typical viscoelastic material is extremely sensitive to temperature; thermal cracking will deteriorate the conductive network, hence resulting in increased resistivity over time. In addition, cold regions pavement are subjected to intense loading by climatic and environmental factors, which intensify the damaging effect of heavy loads acting on the pavement structure, leading to accelerated deterioration, and hence more frequent maintenance and even replacement of the pavement (Dore and Zubeck 2009). These factors will render the conductive AC approach unreliable and expensive.

1.3 Summary

Deicing has traditionally been accomplished by mechanical, chemical, and thermal methods. These methods have drawbacks in that some of them damage the pavement, pollute the environment, and corrode vehicles and reinforcing steel in concrete, and some require complicated installation or are too expensive to install and operate.

Table 1-1 presents an evaluation of the advantages of combined chemical/mechanical, and various electrical resistance heating deicing methods. While mechanical/chemical method remains the most cost-effective method for winter road maintenance, heated pavement, particularly the electrical resistance heated pavement methods offer many promising benefits such as being environment friendly, and potential for innovation. In addition, heated pavement can reach areas outside the plow track/brine application such as curb to curb. It could also expose crosswalk striping more consistently throughout winter than the plow/brine applications to further define the crosswalk for all users. While the operation cost may prohibit application of electrical resistance heating method in very large areas such as highways, it offers a great alternative snow/ice melting technology for small areas with concentrated traffic such as urban crosswalk, sidewalks, bus stops, and bridge decks prone to icing.

Table 1-1 Evaluation of advantages between mechanical/chemical, and various heated pavement snowmelt methods in PCC

Snowmelt Technology	**Initial Cost**	**Operation and Maintenance Cost**	**Construct-ability**	**Dura-bi lity**	**Safety**	**Potential for Innovation**	**Environment Friendly/ Green Energy**
Mechanical/ chemical o✓	✓	✓	N/A				
Hydronic heated pavement					✓		✓
Electrical resistance heated pavement			TBD	✓	✓	✓	✓

CHAPTER 2: CARBON FIBER TAPE-BASED DEICING METHOD: REVIEW AND APPLICATIONS

2.1 Review of Carbon Fiber Tape Deicing Method

Carbon fiber tape (CFT)-based deicing method was invented by a team from the University of Alaska Anchorage and University of Houston and non-provisional patent is pending (Yang et al. 2012; Singla et al. 2014; Yang et al. 2012). This method takes advantage of CFT's unique properties including low resistivity, high strength and light weight, assemble commercially available CFT into heating panels with CFT strips connected by two bus bars in parallel. The heating panels can be of rectangular or other shapes to suit deicing needs of areas with different geometry. The CFT panel bus bars are then connected to a low-voltage (less than 36 V) AC power source to resistively heat the pavement for anti-icing or deicing purposes. The heating panels are embedded about two inches below the pavement surface so it is protected against pavement surface damages, and can be reused even if the surface pavement has to be milled and replaced.

The advantage of CFT-based deicing can be summarized as being *safe, durable, easy to maintain, and efficient,* and have received favorable reviews from recent studies (e.g. Shi et al. 2014; Ceylan et al. 2014). As low voltage (less than 36 V) is supplied to power the system and the heating panels are embedded in the pavement, it poses minimum risk for pedestrians. The carbon fiber material is light weight, strong and durable, and free of corrosion. As the carbon fiber tape can distribute the heat more uniformly than the wires in a carbon fiber or metal wire mesh, or the pipes in a hydronic system, CFT heating panels induces minimal thermal stress in the pavement. All these features lead to a very durable system. As there is no fluid or moving parts, the CFT deicing system requires minimal amount of maintenance. The heat can be uniformly distributed on the pavement surface to melt the snow/ice. Coupled with a snow/ice detection sensor and automatic controller, this system is quite efficient in operation. This will be evidenced in the operation cost comparison with hydronic systems presented hereafter.

2.2 Structural and Functional Performance

During the pilot testing, three major questions were brought to our attention and they need to be resolved before this technology is readily applicable in the field. These questions are: 1) the impact of heating panel embedment to structural integrity of pavement/bridge decks, 2) the reliability of the CFT heating panel including the impact of coupled thermal cycling (i.e. heating-cooling from deicing operation) and freeze-thaw cycling (due to ambient temperature fluctuations) on the electrical properties of the heating panels and the survivability of the heating panel to potential pavement cracking, and 3) the impact of electromagnetic field generated by the deicing operation on the corrosion of steel reinforcement in the pavement/bridge deck. Yang et al. (2012)

conducted a comprehensive study including comprehensive laboratory structural testing of PCC concrete beams, analyses and observation of the performance of PCC test sidewalks slabs during consecutive winters including the snowiest winter in Anchorage, Alaska to address these questions and the major findings include:

1. The expected induced current in the steel rebar mesh is at the level of nano Amps and its impact on corrosion is negligible.

2. Embedment of the CFT can provide higher strength to the PCC slab while being used as heating elements for deicing application. However use of the CFT alone for the reinforcement purpose is not recommended as the CFT can only provide limited ductility as compared to steel rebar.

3. The uncoated CFT can survive ¼ in. wide crack in PCC test beams without sacrificing its heating capacity. It is envisioned that the CFT coated with flexible electrically insulating epoxy can survive even large cracks in PCC slabs.

4. The CFT heating panel deicing system demonstrates excellent deicing/anti-icing capability and quite stable electrical resistance during the two and a half year-long field experiment in PCC test sidewalk slabs and this shows its promising long-term reliability and stability.

These findings further confirmed the suitability of field applications of this technology, as evidenced by the field installations presented next.

2.3 Recent Applications

CFT-based deicing has been installed in PCC pavement at three locations. Figure 2-1, Figure 2-2, and Figure 2-3 present snapshots of and snow melting performance of the various installations, respectively. Table 2-1 summarizes the three field applications of the CFT deicing technology including installation date, coverage area, controller type, UL field certification status, and intended usage. In short, UL field certification indicates a field installed electrical system passes the safety code requirements, and the Municipality of Anchorage inspectors require UL certification before allowing public access to the installed electrical system. As one can see, two of these installations have been UL-certified and the third one did not require one as it was only for snow melting in a private snow storage yard. All the heating panels at these three sites have been performing satisfactorily, with the longest operating for three winters.

Table 2-1 Summary of CFT Deicing field applications as of April 2016

Installation site	Date	Area (ft^2)	Controller type	UL certification	Intended usage
Pathway to ULB Annex, UAA	Sept. 4, 2013	230	Automatic with snow/ice sensor	Yes	Anti-icing
Entrance to EIB, UAA	May 21, 2015	750	Automatic with snow/ice sensor	Yes	Anti-icing
Snow storage yard, Cook Inlet Housing Authority	Nov. 19, 2015	120	Manual	Not required	Snow melting

Figure 2-1 CFT-based deicing installed at the pathway to north entrance of ULB Annex on UAA campus. Left: Installation; right: CFT snowmelt system at work.

Figure 2-2 CFT-based deicing installed at the main entrance of EIB on UAA campus. Left: Installation; right: CFT snowmelt system at work.

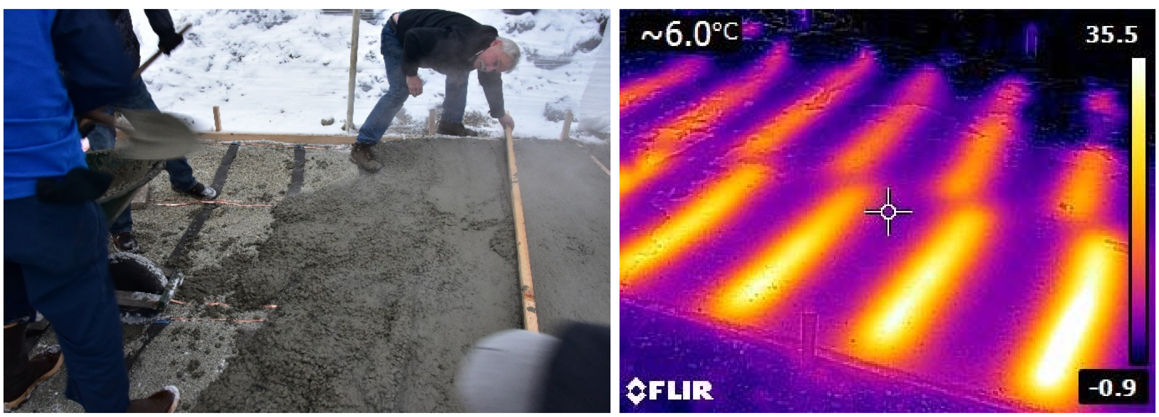


Figure 2-3 CFT-based deicing installed for snow melting at Cook Inlet Housing Authority. Left: Installation; right: CFT snowmelt system at work (IR image).

2.4 Energy Cost Comparison with a Hydronic System

Cook Inlet Housing Authority sponsored a study on the energy use of two separate large-scale hydronic snowmelt systems from September 2011 to September 2012

(Wheeler et al. 2012). One snowmelt area ranges from 3,750 ft^2 to 11,850 ft^2. Note this was a record setting year with about 134.5" snow fallen on Anchorage. Table 2-2 show the range of energy costs observed for hydronic snowmelt system. The costs were based on the assumption of 86% efficiency for the gas-burning heating system, and 83% efficiency for the oil-burning heating system. The gas price was assumed at $0.73/CCF, and the heating oil price was assumed at $4.0/gallon. The duration of snowmelt season was assumed to be 3650 hours long (5 months). This provides a great case for comparison with CFT deicing system. The power consumption data obtained from the CFT snowmelt system installed at the north entrance pathway of University Lake Building Annex on UAA campus was monitored from Jan. 1, 2014 to March 31, 2014, when the total snowfall in Anchorage was about average. The snowmelt area of the pathway is 230 ft^2. The price of electricity was assumed at $0.08/kW.hr. The monthly cost obtained from the monitoring data was used to estimate the annual cost assuming five (5) month snowmelt season. Note that both systems use automatic control with the use of a snow sensor. No idle feature is available for the CFT system in this application. The variation of energy costs of hydronic systems is due to the use of the idle feature, which refers to the action of keeping the glycol at a certain warm temperature so that the system can be activated and melt snow as soon as snow is detected. Such system is not used in the CFT system. From Table 2-2, one can observe the energy cost when idle feature was not used is significantly less than the CFT system, whereas the cost when the idle feature is used is higher than that of the CFT system.

Table 2-2 Comparison of snowmelt system annual energy costs in Anchorage, AK

	Natural gas heat ($0.73/CCF)	Oil Heat ($4.00/gallon)	Electricity ($0.08/(kW.hr))
Hydronic system	$0.88-2.85	$3.89-12.59	N/A
CFT System	N/A	N/A	$0.94

2.5 COST Comparison with Other Electrical Deicing Systems

Cost-effectiveness has always been an important factor affecting the applicability of a deicing system. The present system is compared with other systems that have been reported in the literature in terms of costs, including both installation cost and operation cost, and power density. As discussed in the previous section, the deicing cost is very sensitive to air temperature. The experiments conducted in the present study had air temperatures that varied from 0–36°F (-17.7–2.2°C), while the data of other deicing systems reported in the literature were for a narrower air temperature range. To make a reasonable cost comparison, it is necessary to select an air temperature range, say from 21–27°F (-6–3°C), for comparing average unit energy cost with other systems.

Table 2-3 compares the various reported deicing systems with the current system in terms of installation cost, annual operating costs, power density, and unit energy cost. The operating cost per storm is defined as the average cost for operating a deicing system to melt snow on a unit surface area (m^2) during each deicing/anti-icing experiment. The annual operating cost indicates the average operating cost of all deicing and anti-icing experiments conducted during one year. Note that the electricity cost was assumed to be \$0.08/kWh in order to compare all systems reported in the literature on the same basis.

The installation cost for the present system was calculated based on the sum of the costs of the heating panels, electrical and control equipment, and insulation boards used in the three 6 × 4 ft test sidewalk blocks. It did not include the labor cost and the cost of the sidewalk materials. For the electric heating cable system (Henderson 1963), the cost of the installation was calculated in such a manner as to integrate the cost of laying the cable, installing electrical and control equipment including transformers, and electric service facilities. For the conductive concrete heating system (Tuan 2008), the installation cost includes the cost of building and installing control facilities, and the cost of integrating and programming the deicing operation controller. For the hot water deicing system reported by Cress (1995) and the conductive concrete deicing system reported by Yehia and Tuan (1999), the installation costs were quoted directly from the literature. The installation cost of the carbon fiber heating wire system reported by Zhao et al. (2010) was not available and was not considered in the cost analysis.

Table 2-3 Cost comparison of different deicing systems

Deicing System and Built Year	Installation Cost ($/m^2)	Annual Operating Cost ($/m^2)	Power Density (W/m^2)	Unit Energy Cost at -6 – -3℃ air temp. ($/[m^2-cm])
Electric heating cable, 1961 (Henderson 1963)	[b] $23.6/m^2	[b] $2.8/m^2	[b] 323–430	[b] 0.368
Hot Water, 1993 (Cress 1995)	[a] $161/m^2	[a] $250/storm	[a] 473	N/A
Conductive concrete mixing with steel shaving and steel fiber, 1998 (Yehia and Tuan 1999)	[a] $48/m^2	[a] $0.8/m^2/storm	[a] 590	[b] 0.075
Conductive concrete mixing with Steel Fibers and Carbon Particles, 2003-2007 (Tuan and Yehia 2004; Tuan 2008)	[b] $205/m^2	[b] $0.74/m^2/storm	[a] 350	[b] 0.033
Carbon Fiber Heating Wire, 2008 (Zhao et al. 2010)	N/A	[b]$0.38–$2.8/m^2 /storm	[a] 500–800	[b] 0.025
Carbon Fiber Tape Heating Panel, 2010-2011 (Yang et al. 2012)	$145/m^2	$0.27/m^2/storm	~300	0.030

Note:

1) [a] Cost value and power density were quoted directly from the literature.
2) [b] Cost value and power density were converted into uniform unit.
3) Energy cost was assumed at $0.08/kWh for comparison.

It can be seen in Table 2-3 that the present system has the lowest power density and unit energy cost, and a relatively lower installation cost among the systems compared. The high efficiency of the present system is likely due to the use of an insulation layer, and the system's rather uniform heating coupled with its low power density. For applications in Alaska, the average air temperature will be lower than -6°C, and the unit energy cost will be higher. The data show that the CFT-based deicing system has the potential to become a quite cost-effective deicing technology in the future.

2.6 Summary

Various resistive heating deicing systems have been reviewed. To help understand the advantages and disadvantages of these systems, Table 2-4 presents an evaluation of different electrical heating deicing methods that have been field-tested including heating wire method using metal or carbon fiber wires, electrically conductive (EC) PCC or AC pavement methods, magnetic snowmelt device and CFT heating panel method. Different aspects including constructability, durability, safety, field performance and application examples are addressed. Compared with other field-tested electrical resistance heating methods, CFT has certain advantages in terms of being easy to install, no need to change AC mix, durable, safe, and satisfactory performance. However, its performance in AC pavement is yet to be verified.

Table 2-4 Evaluation of different electrical resistance heating deicing methods

Electrical Heating Deicing Method	**Construct-ability**	**Durability**	**Safety**	**Field performance**	**Application examples**
Heating wire method	Easy	Fair	Safe	Poor	AC pavement in Newark, New Jersey; abandoned due to cable pulled out of pavement by traffic load
EC PCC/AC pavement method	Change of pavement mix formula	Good	Safe	Good	Bridge deck (Roc Spur bridge), Snowfree® technology at O'Hare Inter. Airport (demolished)
Magnetic heating device method	Easy	N/A	N/A	Poor	Unknown
CFT heating panel method	Easy	Good	Safe	Good	Multiple applications in PCC pathways; not yet applied in AC pavement

CHAPTER 3: INTERSECTION/CROSSWALK MAINTENANCE: THE STATE OF THE PRACTICE

3.1 Introduction

Winter maintenance operations are crucial for pedestrian and motorist safety and public mobility on urban street crosswalks and highways in cold regions, especially during winter storms. Hansen et al. (2014) predict global warming will cause warmer and wetter winters and more icing events in the arctic, which would likely result in increased winter maintenance and operation burden for the broad cold regions including Alaska. Shi et al. (2014) conducted a review of highway winter maintenance operations at extremely low temperatures. There is very limited study on urban crosswalk maintenance in winter. For example, Anastasio (2016) reported issues with crosswalks and sidewalks in New York City as being a persistent problem, as one comment reads, “This is a truly disgusting problem – one that makes NYC look like a third world country whenever it snows.” This chapter presents a survey designed to find out the state-of-the-practice on crosswalk maintenance at state DOTs levels. Note that municipalities were not surveyed since their practices and road inventory vary too greatly from traditional DOT roads and responsibilities.

3.2 Survey of State DOTs on Crosswalk Maintenance

This survey was designed to gather information regarding the state of the practice on how state DOTs are dealing with crosswalk winter maintenance. The following questions were drafted and reviewed by Ms. Anna Bosin, Research Engineer of Research Development and Technology Transfer, State of Alaska Department of Transportation & Public Facilities (AK DOT&PF), and sent out to all state DOTs for survey on Jan. 29, 2016 via the American Association of State Highway and Transportation Officials (AASHTO) Research Survey Advisory Committee List Serv. The following questions were included in this survey:

1) *Does your state need to clear ice and snow for crosswalks? If No. You are done with survey. If Yes, go to question 2.*
2) *What are the procedures to be applied after snowfall in terms of response time, equipment used, personnel, material spread, etc.?*
3) *Is salt often used for snow/ice melting at crosswalks? Is sanding used for crosswalk winter maintenance? Is salting or anti-icing agent used pre-storm?*
4) *Are there methods other than salting/sanding applied to maintain some heavily used crosswalks or strategical locations such as bridge ramps, steep graded approaches to crosswalks, and busy bus stops? (Examples and photos about application and technology used would be appreciated)*

5) *Is there any application of heating method for snow/ice management?*
6) *What kind of heating methods are used currently or are being considered for future applications? Electrical heating or hydronic system such as heated glycol circulating in buried tubes?*
7) *Please provide a name and contact information of the best person(s) in your agency to contact regarding this topic.*

3.3 Survey Results

17 states or provinces responded to the survey and they are summarized in Table A-1 to A-5 in Appendix A. Among these states, six (6) states indicate they do not need to clear crosswalks as these are left to municipalities or towns, nine (9) indicate that they do not treat crosswalks, if any, differently from highway itself in their states. Only two states/provinces, i.e. Alaska and BC, Canada, indicate they treat crosswalk differently, and maintain a certain standard for crosswalks during winter season. A typical snow/ice treatment procedure for crosswalk would include plowing, salt and sand applications depending on weather conditions and temperatures. In some states, anti-icing is used pre-storm in the form of MgChl and Salt brine. Some states (for example, MT) indicated that it has been used in sidewalks to melt snow and ice. Hydronic system has been used in some occasion. In at least some location, the heat generated from computer servers has been used to heat the sidewalks around the building. It is interesting to note that no

electrical resistive heating method has been applied by any state DOT in maintaining crosswalks/ intersections.

3.4 Current State-of-the-Practice in Alaska and Cost Estimation

The survey results from the Central Region Maintenance and Operations of AK DOT&PF is shown in Appendix B. For Alaska, the CR M&O maintains a quite large number of crosswalks on Seward and Minnesota Freeway, and major arterials throughout Anchorage, Alaska. Priority is given to freeways (same day), then major arterials (1 day), and then other streets (2+ days) maintained by AK DOT&PF. There is a specific procedure for intersection/ crosswalk maintenance. For fresh snow, a nose plow with belly blade are used to plow a 100' approach and the intersection, and cast sand/brine mixture. This takes one employee and one truck to operate. If there is ice pack on the intersection, it would take another employee and a grader to treat the surface first. Brine solution is applied at crosswalks and intersection approaches pre-storm or during freeze/thaw events. No other method is used currently for snow/ice management. The personnel time estimation for intersection winter maintenance can be found from Appendix C. The time estimation ranges from about 10 min travel time for a two-lane intersection to 25 min. for a five-lane intersection. For comparison, a two-lane intersection was assumed. Table 3-1 lists the FUR and IFUR rates for the equipment used in winter M&O.

Table 3-1 FUR and IFUR rates for the equipment used for winter M&O

FUR Class	**Class Description**	**FUR Rate**	**IFUR Rate**
S359T	40,000 lb grader	117.25/hr	49.15/hr
S217T	6x4 8CY plow truck	91.63/hr	20.44/hr
S773T	De-icer 1000/2000 gal	16.07/hr of use	1.04/hr of use

Table 3-2 summarizes the personnel, equipment and amount of materials used for each two-lane intersection for the central region. Depending on the nature of snow/ice event, the cost of intersection maintenance is estimated to be in the range of \$46.77 to \$88.41 per storm. Assuming three (3) events per month and 5 winter months per year, the cost of winter maintenance is in the range of \$701.55-\$1,326 per year.

If a CFT deicing system is used, for a two-lane intersection, the area of the intersection itself plus pedestrian walk is about 1,152 ft^2 (Area = 24' x 12' x 4= 1,152 ft^2, assume no approach is covered), the annual operation cost due to electricity consumption would be around \$0.94 x 1,152 ft^2 = \$1,080, which is about the average annual M&O cost of current practice. The manageable operation cost and the benefits of an automatic deicing system such as the minimized delay time and improved safety for pedestrian and vehicular traffic show that an electrical deicing system such as the CFT system might be well worthy of consideration and the initial investment in future intersection/crosswalk design.

Table 3-2 Personnel, equipment and amount of materials for winter maintenance of a two-lane intersection with crosswalk per storm

Winter Events	**Avg. Wage with FHWA Overhead Rate**[1] ($69.01/hr)	**Equipment**			**Materials** (Sand w/ brine = $14.14/ton; brine = $0.17/gal)	**Cost**
		Plow Truck ($91.63 /hr)	Grader ($117.25 /hr)	Brine Tank (16.07 /hr)		
Fresh snow	One employee $11.50	$15.27	N/A	N/A	sand/brine mixture, one yard/intersection, $20 ($14.14/ton x 1.45 ton/yard x 1 yard/intersection = $20)	$46.77
Ice pack	Two employees $23.00	$15.27	$19.54	N/A	N/A	$57.81
Pre-storm or freeze/thaw event	One employee $11.50	$15.27	N/A	$2.68	40 gal/lane-mile, $1.15/intersection (224 ft x 0.000189 mile/ft x 4 lane x 40 gal/lane-mile *$0.17/gal = $1.15)	$30.60

Note: [1] Average wage is 36.71/hr, FHWA overhead rate is 88%, and the total rate is $69.01/hr. No overtime is considered.

3.5 Summary

The survey results of current state of the practice of DOT's intersection/crosswalk winter maintenance show that most DOT's do not have responsibility on intersection/

crosswalk winter maintenance, or do not treat intersection/crosswalk differently than a highway. Only Alaska and British Columbia, Canada treat crosswalk differently, and maintain a certain standard for crosswalks during winter season. A typical snow/ice treatment procedure for crosswalk would include plow, and sand/brine mixture applications depending on weather conditions and temperatures. Anti-icing treatment is used pre-storm or during freeze-thaw events. The energy cost of an electrical resistance heating technology such as the CFT deicing system is about the average annual M&O cost of current practice. In addition, an automatic electrical deicing system will have the benefits such as minimized delay time and improved safety for pedestrian and vehicular traffic. As AK DOT&PF maintains a quite large inventory of intersection/crosswalks throughout Anchorage, AK, we think an electrical deicing system such as the CFT system might be well worthy of consideration and the investment in future intersection/crosswalk design.

CHAPTER 4: CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

The purpose of this study is to provide a comprehensive literature review of electrical deicing technology for possible application in asphalt approach and crosswalks. A comprehensive review of existing and emerging deicing technology for snow/ice melting was conducted. In particular, the carbon fiber tape (CFT) deicing technology and its recent applications in Alaska was summarized. The operation cost of such system was reviewed and compared with that of a hydronic system. Finally, current state of the practice of intersection/crosswalk maintenance was surveyed among state DOT's and the results were summarized. The intersection/crosswalk winter maintenance procedure adopted by the Central Region Maintenance & Operation of AK DOT&PF was described and the cost of annual winter maintenance was estimated and compared with that of a CFT deicing system. The following conclusions can be drawn:

1. Deicing has traditionally been accomplished by mechanical, chemical, and thermal methods. While mechanical/chemical method is the most cost-effective method, heated pavement, particularly the electrical resistance heated pavement methods offer many promising benefits such as being environment friendly, and potential for innovation.

2. While the operation cost may prohibit application of an electrical resistance heating method in very large areas, it offers a great alternative snow/ice melting technology for small areas with concentrated traffic such as urban crosswalks, sidewalks, bus stops, and bridge decks.

3. Compared with other field-tested electrical resistance heating methods, CFT has certain advantages in terms of being easy to install, no need to modify AC mix ratio, durable, safe, and satisfactory performance. However, its performance in AC pavement is yet to be verified.

4. The survey results show that most DOT's do not have responsibility on intersection/crosswalk winter maintenance, or do not treat intersection/crosswalk differently than a highway. Only Alaska and British Columbia, Canada treat crosswalk differently, and maintain a certain standard for winter maintenance of intersections/crosswalks.

5. A typical snow/ice treatment procedure for intersection/crosswalk would include plow, and sand/brine mixture application depending on weather conditions and temperatures. Anti-icing treatment is used pre-storm or during freeze-thaw events.

6. The energy cost of the CFT deicing system is about the average annual M&O cost of current practice. In addition, an automatic electrical deicing system will bring

the benefits such as minimized delay time and improved safety for pedestrian and vehicular traffic.

4.2 Recommendations

As AK DOT&PF maintains a quite large inventory of intersection/crosswalks, and global warming might bring warmer and wetter winters to and increase the winter maintenance burden in the arctic including Alaska, we think an electrical deicing system such as the CFT system is well worthy of consideration and the investment in future intersection/crosswalk design. We would recommend such technology be tested in Asphalt pavement to verify its suitability for applications in intersection/crosswalk winter maintenance.

REFERENCES

Ahmedzade, P. and Sengoz, B. (2009). “Evaluation of steel slag coarse aggregate in hot mix asphalt concrete.” Journal of Hazardous Materials 165(1–3): 300–305.

Anastasio, J. (2016). “Let’s fix NYC’s snow-filled crosswalk problem.” http://ltvsquad.com/2016/01/26/lets-fix-nycs-snow-filled-crosswalk-problem/. Accessed Apr. 19, 2016.

ASCE. (1998). “Heated pipes keep deck ice free.” Civ. Eng. (N.Y.), 68 (1), 19–20.

Bienert, W. B., Pravda, M. F., Suelau, H. H. and Wolf, D. A. (1974). “Snow and Ice Removal from Pavements Using Stored Earth Energy.” Report FHWA-RD-75-6. FHWA, U. S. Department of Transportation.

Ceylan, H., Gopalakrishnan, K., Kim, S., and Cord, W. (2014). "Heated Transportation Infrastructure Systems: Existing and Emerging Technologies" (2014). Civil, Construction and Environmental Engineering Conference Presentations and Proceedings. Paper 23.

Chang, C., Ho, M., Song, G., Mo, Y.L. and Li, H. (2009). “A feasibility study of self-heating concrete utilizing carbon nanofiber heating elements.” Smart Materials and Structures, 18, doi: 10.1088/0964-1726/18/12/127001.

Chen, M., Wu, S., Wang, H., and Zhang, J. (2011a). “Study of ice and snow melting process on conductive asphalt solar collector.” *Solar Energy Materials & Solar Cells*. 95:3241-3250.

Chen, M., Wu, S., Zhang, J., and Pan, P. (2011b). “Design and performance of an asphalt pavement snow melting system.” *Key Engineering Materials*, 467-469: 1550-1555.

Cress, M. D. (1995). “Heated bridge deck construction and operation in Lincoln, Nebraska.” IABSE Symposium, International Association for Bridge and Structure Engineering, San Francisco, 449–454.

Derwin, D., Booth, P., Zaleski, P., Marsey, W., and Flood Jr., W. (2003). “Snowfree, Heated pavement system to eliminate icy runways.” SAE Technical Paper Series. Report No. 2003-01-2145. Warrendale, PA.

Dore, G. and Zubeck, H. K. (2009). Cold Regions Pavement Engineering. ASCE Press.

Fay, L., Volkening, K., Gallaway, C. and Shi, X. (2008). “Performance and impacts of current deicing and anti-icing products: user perspective versus experimental data.”

Proc. 87th Annual Meeting of Transportation Research Board, TRB, Washington, D.C., 08-1382.

Fibre Glast Developments Corporation. (2011). Carbon Fiber Tape. <http://www.fibreglast.com/product/Carbon_Fiber_Tape_597/>.

Garcıa, A., Schlangen, E., van de Ven, M., and Liu, Q. (2009). “Electrical conductivity of asphalt mortar containing conductive fibers and fillers.” Construction and Building Materials, 23(10): 3175–3181.

Hansen, B. B., Isaksen, K., Benestad, R.E., Kohler, J., Pedersen, Å. Ø., Loe, L.E., Coulson, S.J., Larsen, J.O., Varpe, Ø. (2014). “Warmer and wetter winters: Characteristics and implications of an extreme weather event in the High Arctic.” Environmental Research Letters, 9(11): 1-10

Hassan, Y., Abd El Halim, A. O., Razaqpur, A. G., Bekheet, W. and Farha, M. H. (2002). “Effects of runway deicers on pavement materials and mixes: Comparison with road salt.” Journal of Transportation Engineering, 128(4), 385–391.

Heymsfield, E., Osweiler, A., Selvam, P., and Kuss, M. (2014). “Developing Anti-Icing Airfield Runways Using Conductive Concrete with Renewable Energy.” *J. of Cold Regions Engineering*, 28(2): 04014001

Henderson, D. J. (1963). “Experimental roadway heating project on a bridge approach,” Highway Research Records, 111(14), 14–23.

Hopstock, D. M. (2003). “Microwave-absorbing road construction and repair material.” Final Report to NRRI on Idea Evaluation Subcontract, June 11.

Hopstock, D. M. and Zanko, L. M. (2005). “Minnesota Taconite as a Microwave-Absorbing Road Aggregate Material for Deicing and Pothole Patching Applications.” Final Report, August 2005.

Huang, B.S., Chen, X.W. and Shu, X. (2009). “Effects of electrically conductive additives laboratory-measured properties of asphalt mixtures.” Journal of Materials in Civil Engineering, 21(10): 612–617.

Jones, P. H. Jeffrey, B. A., Watler, P. K. and Hutchon, H. (1992). “Environmental impact of road salting.” Chemical deicers and the environment, F.M. D″Itri, eds., Lewis Publishers, Chelsea, MI.

Khattak, M.J., Khattab, A., Rizvi, H.R., and Zhang, P. (2013). “The impact of carbon nano-fiber modification on asphalt binder rheology.” Construction and Building Materials, 30: 257–264.

Kuemmel, D. E. (1994). “Managing roadway snow and ice control operations.” Transportation Research Record 207, No. NCHRP. Transportation Research Board, Washington, D.C.

Lee, R. C., Sackos, J. T., Nydahl, J. E. and Pell, K. M. (1984). “Bridge heating using ground-source heat pipes.” Transportation Research Record. 962, Transportation Research Board, Washington, D.C., 51–57.

Li, H., Zhang, Q., and Xiao, H. (2013). Self-deicing road system with a CNFP high-efficiency thermal source and MWCNT/cement-based high-thermal conductive composites. Cold Regions Science and Technology, 86:22-35.

Liu, Y., Lai, Y., and Ma, D. (2015). “Research of carbon fiber grille reinforced composites in airport pavement snowmelt.” Materials Research Innovations, 19(10): S10-49-S10-54

Long, D. C. and Baldwin, J. S. (1980). “Snow and Ice Removal from Pavement Using Stored Earth Energy.” Report FHWA-TS-80-227. FHWA, U. S. Department of Transportation.

Lopez, R. 2012. "Interest Warms up in Heated Runway Systems: The FAA's Funding of Two Heated Runway Concept Trials has Reawakened Interest in This De-icing Technology." Jane's Airport Review: 14-16.

Menzies, T. R. (1991). “National cost of damage to infrastructure from highway deicing.” Corrosion forms and control for infrastructure, ASTM STP 1137, V. Chaker, ed., American Society for Testing and Materials, Philadelphia, PA, 30–46.

MWH (2003). “Anchorage street deicer and snow disposal 2003 best management practices guidance.” Prepared for Municipality of Anchorage Watershed Management Services, Document No. WMS CPg03001.

Pan, P., Wu, S., Xiao, F., Pang, L., and Xiao, Y. (2015). “Conductive asphalt concrete: A review on structure design, performance, and practical applications.” *Journal of Intelligent Material Systems and Structures*, 26(7): 755-769

Pan, T., He, X. and Shi, X. (2008). “Laboratory investigation of acetate-based deicing/anti-icing agents deteriorating airfield asphalt concrete.” Journal of the Association of Asphalt Paving Technologists (AAPT), 77, 773–793.

Pye, G., Myers, R., Arnott, M., Beaudoin, J. and Tumidajski, P. J. (2003). Conductive concrete compositions, U.S. Patent Number 6,503,318 B2.

Singla, M., Chang, C., Song, G., Yang, Z., and Ge, X. (2014). "Automatic Controls for the Carbon Fiber Tape-Based Deicing Technology." J. Cold Reg. Eng., 28(1): 04013001

Shi, X., Akin, M., Pan., T., Fay, L., Liu, Y. and Yang, Z. (2009a). “Deicer impacts on pavement materials: Introduction and recent developments.” Open Civil Engineering Journal, 3, 16–27.

Shi, X., Fay, L., Yang, Z., Nguyen, T. A. and Liu, Y. (2009b). “Corrosion of deicers to metals in transportation infrastructure: Introduction and recent developments.” Corrosion reviews, 27(1–2), 23–52.

Shi, X., Fay, L., Peterson, M. M., Berry, M. and Mooney, M. (2011). “A FESEM/EDX investigation into how continuous deicer exposure affects the chemistry of Portland cement concrete,” Construction and Building Materials, 25(2), 957–966.

Shi, X., Huang, J., Williams, D., Akin, M., and Veneziano, D. (2014). “Highway winter maintenance operations at extremely cold temperatures.” Climatic Effects on Pavement and Geotechnical Infrastructure - Proceedings of the International Symposium of Climatic Effects on Pavement and Geotechnical Infrastructure 2013, p 52-65.

Slick, D. S. (1988) “Effects of calcium magnesium acetate on pavements and motor vehicles.” Transportation Research Record, 1157, 27–30.

Sun, M., Mu, X., Wang, X., Hou, Z. and Li, Z. (2008). “Experimental studies on the indoor electrical floor heating system with carbon black mortar slabs.” Energy and Buildings, 40(6), 1094–1100.

TRB (Transportation Research Board). (1992). “Highway Deicing: Comparing Salt and Calcium Magnesium Acetate.” National Research Council, Special Report 235.

Tuan, C. Y. (2004). “Electrical resistance heating of conductive concrete containing steel fibers and shavings.” American Concrete Institute Materials Journal, 101(1), 65–71.

Tuan, C. Y. (2008). “Roca spur bridge: The implementation of an innovative deicing technology.” Journal of Cold Regions Engineering, 22(1), 1–15.

Tuan, C. Y. and Yehia, S. (2004). “Evaluation of electrically conductive concrete containing carbon products for deicing.” ACI Materials Journal, 101(4), 287–293.

Tumidajski, P. J., Xie, P., Arnott. M. and Beaudoin, J. J. (2003). “Overlay current in a conductive concrete snow melting system.” Cement and Concrete Research, 33, 1807–1809

Wheeler, M., Mitchell, A., and Kaluza, P. (2012). *Salamatof Heights Sidewalk Snowmelt Energy Use Study*. Final report prepared for Cook Inlet Housing Authority.

Williams, D., Williams, N. and Cao, Y. (2000). “Road salt contamination of ground water in major metropolitan area and development of a biological index to monitor its impact.” Water Research, 34(1), 127–138.

Wen, S. and Chung, D.D.L. (2004). “Effects of carbon black on the thermal, mechanical and electrical properties of pitch-matrix composites.” Carbon, 42(12–13): 2393–2397.

Wu, S., Chen, M., Wang, H., and Zhang, Y. (2009). “Laboratory study on solar collector of thermal conductive asphalt.” Inter. J. Pavement Research and Technology, 2(4): 130-136

Wu, S., Mo, L., Shui, Z., Chen, Z. (2005) Investigation of the conductivity of asphalt concrete containing conductive fillers. Carbon, 43(7): 1358–1363.

Xiang, D. (2014). “Carbon fiber heating system for snow melting and deicing of sidewalk asphalt road.” Chinese Patent #CN203700906U.

Xie, P. and Beaudoin, J. J. (1995). “Electrically conductive concrete and its application in deicing.” Proc., 2nd CANMET/ACI Int. Symp., Advances in Concrete Technology, SP-154, V. M. Malhotra, ed., American Concrete Institute, Farmington Hills, Mich., 399–417.

Xie, P., Gu, P., Fu, Y. and Beaudoin, J. (September 5, 1995). Cement based conductive compositions, U.S. Patent Number 5,447,564.

Xie, P., Gu, P. and Beaudonin, J. J. (1996). “Electrical percolation phenomena in cement composites containing conductive fibres.” J. Mater. Sci., 31(15), 4093–4097.

Yang, T., Yang, Z., Singla, M., Song, G., and Li, Q. (2012). "Experimental Study on Carbon Fiber Tape–Based Deicing Technology." J. Cold Reg. Eng., 26(2): 55-70

Yang, Z., Yang, T., Song, G., Singla, M., and Chang, C. (2012). Designs and Methods for Self-Heating Concrete. Provisional patent (US 61/699,372); Non-provisional Patent filed Sept.

Yang, Z, Zhang, X, Song, G., Singla, M., and Patil, D. (2012). *Impact of the Embedded Carbon Fiber Heating Panel on the Structural/ Mechanical Performance of Roadway Pavement*. Final Report (Report No. INE/AUTC 12.39), Alaska University Transportation Center, Fairbanks, Alaska. December.

Yehia, S. and Tuan, C. (1998). “Bridge Deck Deicing.” Transportation Conference Proceedings.

Yehia, S. and Tuan, C. (1999). “Conductive concrete overlay for bridge deck deicing.” American Concrete Institute Materials Journal, 96(3), 382–390.

Yehia, S. A. and Tuan, C. Y. (2000). “Thin conductive concrete overlay for bridge deck deicing and anti-icing.” Transportation Research Record 1698, Transportation Research Board, Washington, D.C., 45–53.

Yehia, S., Tuan, C., Ferndon, D. and Chen, B. (2000). “Conductive concrete overlay for bridge deck deicing: Mixture proportioning, optimization, and properties.” American Concrete Institute Materials Journal, 97(2), 172–181.

Zenewitz, J. A. (1977). “Survey of alternatives to the use of chlorides for highway deicing.” Rep. No. FHWA-RD-77-52, U.S. Dept. of Transportation, Federal Highway Administration, Offices of Research and Development, Washington, D.C.

Zhang, D., Yue, W., and Xu, X. (2011). “The application of magnetic energy snowmelt technology in urban transport.” ICCTP 2011: Towards Sustainable Transportation Systems - Proceedings of the 11th International Conference of Chinese Transportation Professionals. 3693-3700

Zhang, J., Das, D. K., Peterson, R. and Goering, D. (2007). “Comprehensive evaluation of bridge anti-icing technology.” Final report prepared for Alaska Dept. of Transportation and Public Facilities, Report No. INE/AUTC 07.06, January

Zhang, J., Das, D. K. and Peterson, R. (2009). "Selection of effective and efficient snow removal and ice control technologies for cold-region bridges." Journal of Civil, Environmental, and Architectural Engineering, 3 (1)

Zhang, Q., Yu, Y., Chen, W., Chen, T., Zhou, Y., and Li, H. (2016). Outdoor experiment of flexible sandwiched graphite-PET sheets based self-snow-thawing pavement. Cold Regions Science and Technology, 122: 10-17.

Zhao, H., Wang, S., Wu, Z. and Che, G. (2010). "Concrete slab installed with carbon fiber heating wire for bridge deck deicing." Journal of Transportation Engineering, 136(6), 500–509.

Zhao, H., Wu, Z., Wang, S., Zheng, J., and Che, G. (2011). *Concrete pavement deicing with carbon fiber heating wires.* Cold Regions Science and Engineering. 65:413-420.

Zhou, X., Yang, Z., Chang, C. and Song, G. (2011). "Numerical assessment of electric roadway deicing system utilizing emerging carbon nanofiber paper." Journal of Cold Regions Engineering, 26(1), 1-15.

APPENDIX A SURVEY RESULTS

Table A-0-1 Response from state/province DOTs regarding Survey Question 1

States	1) Does your state need to clear ice and snow for crosswalks?
Vancouver-British Columbia	In the Province of British Columbia, we clear snow and ice from crosswalks on our provincial highways both during and after a snow event. Most crosswalks reside within municipalities and as such, are the responsibility of the applicable municipal department.
MN	Yes
MO	We would offer an overall response, that we don't treat crosswalks separately they would be part of that route maintenance when it comes to snow and ice removal. We do not have any heated crosswalks. Crosswalks would get the anti-icing treatment for the storm for the particular route, some would also receive the same salt and sand treatment applied during the storm.
MT	Yes, although in many of our urban areas the local communities have an ordinance where the adjacent landowner is responsible to clear the snow. The local ordinance typically has a timeframe for when the sidewalks need to be cleared of snow.
NY	Yes
TX-Amarillo District (AMA) TX-LBB District TX- Childress District (CHS)	We don't specifically clear crosswalks, but some crosswalks are in the roads we clear, therefore they get cleared as we plow the roads. We sand busy intersections which coincidently have high pedestrian traffic.

Table A-0-2 Response from state/province DOTs regarding Survey Question 2

States	2) What are the procedures to be applied after snowfall in terms of response time, equipment used, personnel, material spread, etc.?
Vancouver-British Columbia	We have maintenance specifications. (please see attached link to the spec for response times, in particular Chapter 3, Winter Maintenance). We have end product performance specs, so it is left to the contractor to determine how they want to achieve them. Typically use a single or tandem axle truck for application of salt and/or sand as part of their normal highway maintenance procedures. Some pre-wet sand with MgChl when applying abrasives which reduces blow off effect from traffic, and greater adhesion to the compact ice to facilitate quicker slushing of ice. http://www2.gov.bc.ca/gov/content/transportation/transportation-infrastructure/contracting-to-transportation/highway-bridge-maintenance/highway-maintenance/agreement/specifications
MN	There is not a specific response time for crosswalks as they are cleared as part of our snow and ice standard procedures.
MO	Crosswalks would get the anti-icing treatment for the storm for the particular route, some would also receive the same salt and sand treatment applied during the storm.
MT	We do not have a specific timeframe for clearing the sidewalks/paths that we maintain but we try and perform the work as soon as the roadways are cleared. The manpower is our same employees that we have for plowing the highways. The equipment that is used is either a Toolcat (UTV) or ATV with attachments such as a plow, broom or snow blowers. In terms of materials we typically do not apply any materials such as sand or salt to the sidewalks or paths.
NY	Cross walks are cleared as part of the highway snow and ice control, with plows and anti-icing material (normally NaCl).
TX-Amarillo District (AMA), TX-LBB District, TX-Childress District (CHS)	Our response begins when the storm begins & continues until the road is cleaned up. As mentioned we don't specifically target crosswalks, but plow them simultaneously w/ the road.

Table A-0-3 Response from state/province DOTs regarding Survey Question 3

States	3. Is salt often used for snow/ice melting at crosswalks? Is sanding used for crosswalk winter maintenance? Is salting or anti-icing agent used pre-storm?
Vancouver-British Columbia	Both salt and sand applications can be used depending on weather conditions and temperatures. In some locations, anti-icing is used pre-storm in the form of MgChl and Salt brine.
MN	The same chemicals are used for crosswalks that are used for the traveled roadway. Chemicals could salt, sand, salt brine etc.
MO	Crosswalks would get the anti-icing treatment for the storm for the particular route, some would also receive the same salt and sand treatment applied during the storm.
MT	In terms of materials we typically do not apply any materials such as sand or salt to the sidewalks or paths.
NY	Q: Is salt often used for snow/ice melting at crosswalks? A:Yes Q: Is sanding used for crosswalk winter maintenance? A: Not usually Q: salting or anti-icing agent used pre-storm? A: Yes, normally NaCl is applied.
TX-Amarillo District (AMA), TX-LBB District, TX- Childress District (CHS)	We pretreat our higher volume roads prior to storms w/ brine, then de-ice during the storm w/ either brine or salt and use sand to improve traction.

Table A-0-4 Response from state/province DOTs regarding Survey Question 4

States	4. Are there methods other than salting/sanding applied to maintain some heavily used crosswalks or strategical locations such as bridge ramps, steep graded approaches to crosswalks, and busy bus stops? Examples and photos about application and technology used would be appreciated.
Vancouver-British Columbia	Conventional methods are used, again end product specs so we rely on performance time frames.
MN	Standard methods and chemicals are used.
MO	No
MT	No
NY	No
TX-Amarillo District (AMA), TX-LBB District, TX- Childress District (CHS)	We actually avoid plowing in urban settings as much as possible due to the problems of impeding traffic with snow piles. Our storms tend to be fairly short-lived, so there is very little need to address crosswalks individually. Our larger towns are responsible for snow control within their city limits, and that is where most of the district's crosswalks are found.

Table A-0-5 Response from state/province DOTs regarding Survey Question 5 and 6

States	**5. Is there any application of heating method for snow/ice management?**	**6. What kind of heating methods are used currently or are being considered for future applications? Electrical heating or hydronic system such as heated glycol circulating in buried tubes?**
Vancouver-British Columbia	NO	N/A
MN	No	N/A
MO	No	
MT	We do not maintain any sidewalks that are heated but I do know that a couple developers put in heated sidewalks in order to melt the snow and ice.	I don’t know for sure but I believe some are using the hydronic system and at least one location is using the heat generated from computer servers to heat the sidewalks around the building.
NY	No	
TX-Amarillo District (AMA), TX-LBB District, TX- Childress District (CHS)	No	N/A

APPENDIX B SURVEY RESULTS FROM CR M&O OF AK DOT&PF

State of Alaska
DEPARTMENT OF TRANSPORTATION
& PUBLIC FACILITIES

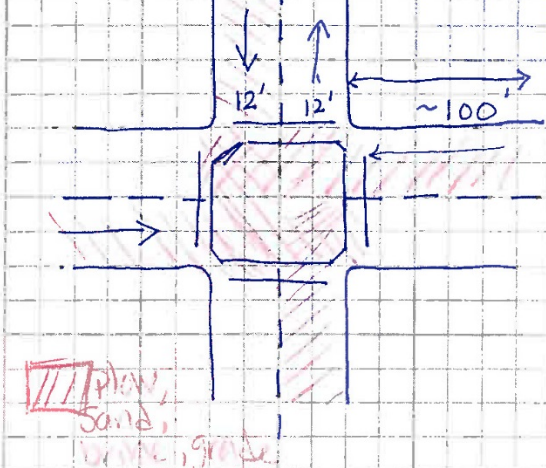
COMPUTATIONS

Item No.______

Date ______
Project No. ______
Project Name ______
Calc. By ______
Checked By ______

FOR AKDOT&PF CR M&O INT WINTER ACT.

2-lane INT



RAC AASHTO Q&A:

① YES

② IF FRESH SNOW:
NOSE PLOW w/ belly blade
= 1 truck, 1 employee
plows & casts sand/brine combination
1 YD sand/intersection
1 pass/lane
~ 100' approach + through intersection
1 truck holds 8 YDS sand
Sand mixture w/brine = $14.14/ton
IF Ice pack:
= 1 grader, 1 employee

③ no salt. yes pre-storm or during freeze/thaw events a pre-application of brine solution is applied @ rate of 40 gal/lan-mile
cost of brine is $0.17/gal

Response times:	Priority	During/after a Storm
Same day	1	Glenn Freeway (no crosswalks) Seward & Minnesota Freeways
1-day	2	Major Arterials, includes X-walks
2+ days	3	see website

④ NO

⑤ NO

⑥ NONE

Sheet ____ of ____ Sheets

APPENDIX C WINTER M&O TIME ESTIMATION

Fresh snow or Pre-storm treatment

Cost assumptions: SMALL INT:

- Assume intersection is signalized on all 4 approaches.
- Assume 2 lane wide + (2) 10' wide sidewalks + (2) 6' wide shoulders
- 100' LF treated prior to intersection on all 4 approaches.
- int is 56' wide + 100' approach × 4 = 624 LF traveled & treated/per int.
- assume waits @ signal each approach for 2 min.
- Travels @ 25 MPH

≈ 8.5 min travel/int.

MAJOR ARTERIAL INT:

- Assume 5 lanes wide + (2) 10' wide sidewalks + (2) 6' wide shoulders. = 96' wide int + 100' approach × 12 = 2352 LF/int on all 12 approaches (2 thru lanes + 1 turn lane)
- assume waits @ signal each approach (12) for 2 min
- travels @ 25 mpH

≈ 25.0 min travel/int.

36