2010

Snow and Ice Removal and Anti-Icing Synthesis Study

Bob McCullouch
Purdue University

Snow and Ice Removal and Anti-Icing Synthesis Study

SPR-2454

Summary Report

Bob McCullouch

July 19, 2010

Table of Contents

Introduction

This study started in 2000 with the original purpose to assist INDOT Snow and Ice Operations by collecting information on practices, equipment, and materials used for snow and ice removal and anti-icing strategies, materials and costs. Research and studies performed by states and federal groups have been plentiful in this area. SHRP and AASHTO have published reports as well as other states in the Midwest area. Also, associated costs will be collected for these various methods and activities. Indiana has a wide range of snow and ice potential between Laporte, Seymour and Vincennes Districts.

Over a period of 10 years the study was extended in scope to include other topics relative to these operations. All these additional activities were directed by the Winter Operations Team (WOT) group at INDOT. This report describes these activities.

Activities

The initial scope was to:

1. Perform a literature search and accumulate information on this topic area. Emphasis will be on past research and studies performed by FHWA, SHRP, and other state DOTs. Additionally, contacts will be made with various DOTs to determine their success with new methods and technology and the status of their current operations.

2. Comparison studies will be performed using various materials during the winter season. Side-by-side comparisons will be performed under similar conditions at various locations around the state. District comparisons and methods will be recorded and analyzed. Associated costs will be collected for these various methods and activities.

3. The study will produce a report of findings with specific recommendations on implementing potential improvements. Findings and results will be shared with the WOT. Through this group the information will be distributed throughout INDOT.

As the project proceeded the WOT asked for assistance with other activities so the scope expanded and numerous time extensions were granted. Other activities that occurred were the following:

1. Review and recommendations on the TAPER logs
2. Analysis of de-icing chemicals used in the Districts
3. Analysis of the product Ice Ban
4. Analysis of Caliber and Geomelt
5. Review of Weather Services
6. Y-Chute Analysis
7. Develop a Winter Severity Index
8. Develop the Total Storm Management Manual
9. Revision of the Total Storm Management Manual

The following is a summary of these activities.

Literature Review

The initial literature review performed in 2000 consisted of reviewing the following publications.

Winter Maintenance Exchange: Activities by Topic: Equipment
http://www.ota.fhwa.dot.gov/winter/exchange/topics/equipment.html

Winter Maintenance Exchange: Activities by Topic: Anti-Icing
http://www.ota.fhwa.dot.gov/winter/exchange/topics/anti_icing.html

Advance Cutting Edge Clears More Ice in New Hampshire
http://www.ota.fhwa.dot.gov/roadsvr/CS014.htm

Snow and Ice Control: The New Generation
http://www.ota.fhwa.dot.gov/roadsvr/CS027.htm

Anti-Icing Saves Time and Money
http://www.ota.fhwa.dot.gov/roadsvr/CS024.htm

Making Snow-Covered Roads Easier to Open
http://www.ota.fhwa.dot.gov/roadsvr/CS009.htm

"Summary of SHRP Research and Economic Benefits of Snow and Ice Control"
Road Savers, Dec. 1997, U.S. Department of Transportation, Federal Highway of Administration.

"Economic Evaluation of Advanced Winter Highway Maintenance Strategies"
D.E. Smith and J.A. Zogg. 1998 Transportation Conference Proceedings.

New Technologies Improve Cost-Effectiveness of CMA
http://www.tfhrc.gov/pubrds/novdec99/cmaupdate.htm

A Revolution in Winter Maintenance
http://www.thrc.gov/pubrds/winter96/p96w2.htm

FHWA - annual of Practice for an Effective Anti-Icing Program
http://www.fhwa.dot.gov///////reports/mopeap/mop0296a.htm

New Strategies Can Improve Winter Road Maintenance Operations
http://www.tfhrc.gov/pubrds/spring95/p95sp16.htm

http://www.tfhrc.gov/trnsptr/may99/contents.htm

Research & Technology Transporter (November 1997) – Highway Operations
http://www.tfhrc.gov/trnsptr/rttnov97/tr1997p5.htm

Research & Technology Transporter Online (August 1996) – Pavements
http://www.tfhrc.gov/trnsptr/rttaug96/rd960801.htm

District Anti-Icing/De-Icing Comparisons - October 10, 2000

District	Materials Used	Application Info	Comparison Analysis
Crawfordsville	• Mg chloride (27-30% solution) • Ice ban • Brine (23% solution) • Caliber	• Application rates are: 1. Mg Chloride: 30 gal/ lane mile 2. Salt brine: 40 gal/ lane mile 3. Ice ban: 30 gal/ lane mile 4. Caliber: 30 gal/ lane mile	Anti-Icing comparison with various materials.
Fort Wayne	• Mg Chloride • Caliber		• 16 unit centers use Mg chloride as pre-wet, and two unit centers use caliber as pre-wet. • Fort Wayne Unit 1 will compare caliber with Mg chloride on I-469. • Goshen will compare unit 1's caliber with pretreated Mg chloride from unit 2 (New Paris) on US20.
Greenfield	• 9000 gallons of caliber (for		• Caliber used in Fortville will be

	pre-wetting) • Ca chloride (used with corrosion inhibitor for pre-wetting)		compared with Ca chloride used in Anderson. • End-to-end comparisons
LaPorte	• Caliber (two tankers at Logansport, and 25,000 gallons at South Bend Unit)		• In Logansport, study is carried out at US35 and US24. • Caliber pre-wetted salt and straight salt will be compared under various temperature conditions. • Fewer treated salt will be placed in the study areas compared to a control section. • In South Bend, US20 and US31 are targeted for study and M-50 as control section. • Caliber liquid is compared to caliber pre-wetted salt through truck-mounted systems. • Less caliber will be placed compared to the control section. • Also, caliber liquid in South Bend will be compared to salt pre-treated with brine or magnesium chloride in Logansport. • For all the study areas in LaPorte, various rates will be observed and pavement temperatures

			documented.
Vincennes	• Rock Salt (39700 tons) • Liquid Mg chloride (10400 gal) • Liquid Ca chloride (6000 gal) • Salt brine (800 gal)		• Pre-wet @ spinner and compare to untreated salt. • Pre-treat salt and compare to untreated salt
Seymour	• 16,000 gal of Caliber M2000 (used to pre-treat Na chloride)	10 gal of Caliber M 2000 per ton of Na chloride	• De-icier will be loaded on the routes leading to and leaving the Seymour site by four different maintenance units. Comparison between treated pile and untreated salt. • Treated pile with 1:1 mix salt and abrasives. • Visible results to the various applications will be recorded.

Ice Ban Testing

Performed by Highway Innovation Technology Evaluation Center (HITEC), a service center of the civil engineering research foundation, this report dates September 1999.

There were four objectives in the evaluation:

1. To characterize the fundamental chemical and physio-chemical properties of Ice Ban Magic.
2. To determine the effects of the Ice Ban Magic on highway structures and appurtenances, including their influence on:
    - Corrosion of metal,
    - Scaling of concrete, and
    - Stripping of asphalt pavement.
3. To determine the effectiveness of Ice Ban Magic melting snow and ice.
4. To resolve operational performance issues, including:
    - Ease of use of Ice Ban product,
    - Required frequency and rate of application,

- Usage limitations based on temperature or type of precipitation,
- Ability to provide a residual deicing capability,
- Refreeze characteristics, and
- Cost-effectiveness relative to other snow and ice control agents.

A laboratory testing program was developed and performed. It consisted of tests designed to determine the physio-chemical properties of Ice Ban Magic; its effectiveness in melting snow and ice; corrosive effects; and other effects on adjacent structures.

Results from the laboratory testing program include the following:

- Minimum freezing point is –40°F.
- Minimum freezing point lower than that for sodium and magnesium chloride (-6°F and –28°F) but higher than that calcium chloride (-60°F)
- Ice melting capacity
    - At each test temperature, Ice Ban Magic consistently melted more ice than did the magnesium chloride solution.
    - As expected, the amount of ice melted by each product decreased with temperature. In the case of the magnesium chloride solution, the effect of temperature was profound: the product was completely ineffective at a test temperature of 5°F (no brine generated) and it performed only marginally better at a test temperature of 10°F.
    - As a rough rule-of-thumb, Ice Ban Magic appears to melt as much as more ice than does magnesium chloride solution at a 10°F higher temperature. For example, at a test temperature of 10°F, each gram of Ice Ban Magic melted more ice than did an equal weight of the magnesium chloride solution at a test temperature of 20°F. Similarly, at a test temperature of 5°F, Ice Ban Magic melted about the same unit quantity of ice as the magnesium chloride did at a temperature of 15°F.
- Ice melting rate:
    - At each test temperature, Ice Ban Magic consistently melted ice at a significantly faster rate than did the magnesium chloride solution.
    - The two products displayed distinctly different patterns of ice melting. In case of Ice Ban Magic, the ice melting performance was characterized by an initial period of very rapid ice melting, which took place within 10 minutes of application, followed by continued melting at a much more gradual rate throughout the duration of the test. In contrast, the magnesium chloride solution displayed no early, rapid ice-melting ability.
    - Like the quantity of ice melted, the rate of melting also decreased for lower test temperatures. Again, the effect of temperature was more pronounced for the magnesium chloride solution than for Ice Ban Magic. At each test temperature, Ice Ban Magic continued to melt ice throughout the duration of the test albeit at a reduced rate for lower temperatures. In contrast, for the magnesium chloride, the melting continued at a significant rate only for the test conducted at 20°F.
- Ice penetration:

    - At each test temperature, Ice Ban Magic consistently penetrated ice to a greater depth and at a faster date than did the magnesium chloride solution.
    - As in the ice melting tests, the depth of the ice penetration and the rate of penetration decreased for lower test temperatures. For example, as in the 5°F ice melting test, the magnesium chloride solution was completely ineffective at the lowest test temperature: no observable ice penetration took place.
    - For both products, the most significant ice penetration took place during the 20°F test. At that temperature, Ice Ban Magic penetrated the ice to a depth of about 1/8 inch (3.175mm) within about 15minutes, and to ¼ inch by the end of the test. In comparison, the magnesium chloride solution penetrated to a depth slightly less that 1/8-inch after an hour.
    - At lower test temperatures, for both products, almost all of the ice penetration took place within 15 minutes of application. From that point on until the end of the test, the incremental penetration was relatively minor. For Ice Ban Magic, the maximum depth of the penetration in the tests at the three lowest temperatures ranged from about 1/16-inch (1.5 mm) to about 3/32-inch (2.4mm). For the magnesium chloride solution, the maximum depth of penetration in the latter tests ranged from zero to about 1/16 inch.
- Corrosion of bare metals
    - According to the MCP data, Ice Ban products are less corrosive to steel than three commonly used deicing chemicals----salt, magnesium chloride, and corrosion-inhibited magnesium chloride. They were also slightly less corrosive than distilled water.
- Effects on non-metals
    - Transparent Plastics. Neither product crazed, stained or discolored acrylic or polycarbonate plastics, when tested in accordance with ASTM F484.
    - Painted Surfaces. Neither product softened the paint film on produced any streaking, discoloration or blistering of the paint film, when tested in accordance with ASTM F502.
    - Unpainted Surfaces. Neither product produced streaking or left any stains that required polishing to remove, when tested in accordance with ASTM F485.
- Concrete scaling
    - Concrete exhibited a negligible amount of scaling, less than that induced by other ice control agents or distilled water.
- Asphalt stripping
    - Asphalt pavement exposed to Ice Ban does not adversely affect its corrosive or adhesive strength.
- Friction tests
    - Skid resistance of both pavement types immediately after the application of Ice Ban Magic at the rate of 42 gallons per lane-mile was almost identical to the wet pavement skid resistance.
    - Skid resistance of both pavement types with Ice Ban Magic dried on the pavement surfaces comparable to the respective untreated (bare pavement) surfaces, with the exception of the test on concrete pavement.

- Finally, the test results with dried Ice Ban Magic on concrete without water applied to the pavement surface is somewhat less, but within an acceptable safety margin.

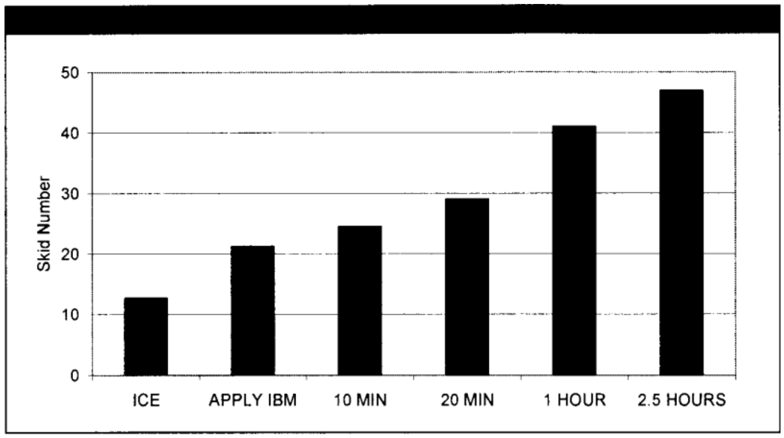

Figure 2.15 Results of Nebraska Skid Tests on Portland Cement Concrete Pavement

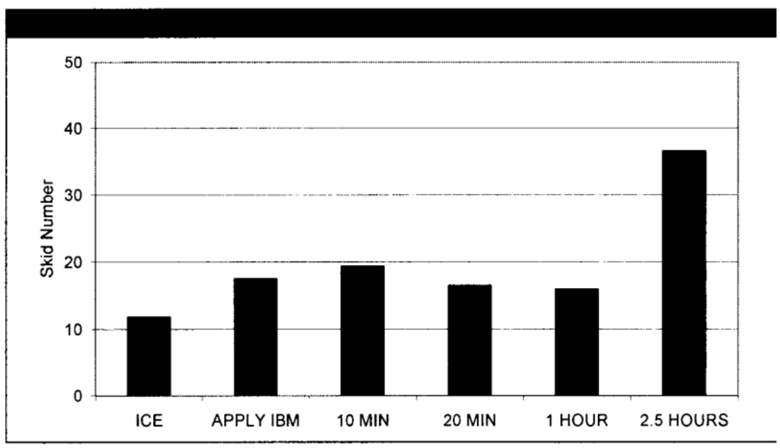

Figure 2.16 Results of Nebraska Skid Tests on a Concrete Bridge Deck

Figure 1 – Nebraska Tests

Field Tests

A field-testing program was designed and conducted by eight volunteer highway agencies, with INDOT being one.

Lessons learned in Indiana were:

Storm Event	Test strategy	Technique	Results
Light Snow 30°F	Deicing (Stockpile Pre-wet)	Salt pre-wet with 8 gal/ton of Magic applied at 231 lbs/lane-mile in first pass and at 250 lbs/lane-mile in second pass.	No hard pack. Kept pavement wet.

Heavy Snow 18°F to 28°F	Deicing (Onboard Wetting)	225 lbs/lane-mile of salt pre-wetted with 8 gal/ton of Magic applied on snow-covered roadways at 5 sites.	Magic worked fast, giving excellent anti-bonding effect.

Lessons learned from New York were:

Storm Event	Test Strategy	Techniques		Results
Heavy Snow 31°F		225 lbs/lane-mile of salt pre-wetted with 4 gal/ton of Magic applied to snow covered road; subsequent applications were made periodically throughout storm at 115 lbs/lane-mile		Ten to 12" snowfall. No hard pack, lanes quickly became bare. After storm ended, easier clean up.
Freezing Rain 29°F	Deicing (Onboard Wetting)	225 lbs/lane-mile of salt pre-wetted with 4 gal/ton of Magic applied to ice covered road; 2nd application made 10 hours later at 115 lbs/lane-mile.		Magic worked very fast, stayed on the traffic lanes, and kept roadway predominantly wet throughout storm.
Heavy Snow 0°F to 26°F		225 lbs/lane-mile of salt pre-wetted with 6 gal/ton of Magic applied at each site. On Route 104, a 2nd application was made at 150 lbs/lane-mile.		Snow/ice pack showed bare pavement with 15 minutes of application.
		Control	Test	
Light Snow 24°F	Deicing (Stockpile pre-wet)	2 salt passes at 290 lb/lane-mile on Route 53.	229 lbs/lane-mile of salt pre-wetted with 8 gal/ton of Magic applied on both routes; 2nd pass at 176 lbs/lane-mile on Rt. 53.	Magic started working on 1st pass, road surface seemed to be drying on 2nd pass. Control displayed 15---20% wet pavement in spotty patches; Test had 90 to 95% wet pavement with much more consistent pattern.

Summary and Conclusions

1. Performance:
    a. General

Ice Ban products provided equivalent or better performance than the control materials in every case studied, with two isolated exceptions that occurred during testing in

Nebraska. There, a sprayed application of Ice Ban Magic during a freezing rain at 28°F was ineffective due to a refreeze. The lack of success under those circumstances is not unexpected: because of the large quantity of deicer required to retain an effective concentration during either a freezing rain or sleet storm, the use of any liquid ice control agent is not typically recommended for those conditions.

b. Direct Liquid Applications

Direct comparisons between the field performance of magnesium chloride solution and Ice Ban Magic performed in Colorado and Indiana confirm the findings of a carefully controlled program of laboratory testing: Ice Ban Magic melts snow and ice faster and at lower temperatures than magnesium chloride solution. Field personnel from INDOT and WSDOT also have observed that Ice Ban Magic provides a more consistent, longer lasting residual effect (i.e., ability to reactivate between storms) than magnesium chloride.

Controlled field trials performed in New York indicate that when applied in an anti-icing strategy, sprayed applications of Ice Ban Magic can significantly reduce the amount of salt needed in follow-up applications during the course of a snowstorm.

c. Pre-wet Salt

Controlled field comparisons conducted by NYSDOT indicate that salt pre-wet with 8 gallons per ton of Ice Ban Magic can provide better performance than straight salt, even when applied to the roadway at significantly lower rates.

Wisconsin reported similar results. There, based on a total of more than 100 applications of the Ice Ban products at pavement temperatures ranging from 20°F to 33°F, it was concluded that salt pre-wet with Ice Ban equal or better deicing performance than untreated salt or salt pre-wet with calcium chloride, even when applied to the road at significantly lower rates than standard practice (i.e., 150 to 200 pounds per lane-mile versus 250 to 300 pounds per lane-mile).

d. Pre-wet Abrasive

Colorado uses dust-free, sand-sized winter abrasives. There, an abrasives stockpile pre-wet with Ice Ban Magic provided a mix that appeared to adhere better to the road surface than either plain sand or sand pre-wet with magnesium chloride, and thus was effective in providing traction and melting ice.

2. <u>Effects on Infrastructure:</u>

a. Corrosion of Steel

Informal (visual) evaluations of truck bodies, augers, and other winter maintenance equipment in New York and Wisconsin confirm the results of the laboratory tests, indicating less equipment corrosion for salt pre-wet with Ice Ban Magic than for straight salt or salt pre-wet with calcium chloride.

b. Concrete Scaling

The relative effects of Ice Ban Magic and six other ice control agents on the scaling of concrete were determined in a comprehensive program of testing by the FHWA. The other deicers tested included sodium, magnesium, and calcium chlorides and sodium, potassium, and calcium magnesium acetates.

The performance of Ice Ban Magic was outstanding. The concrete to which Ice Ban Magic was applied exhibited a negligible amount of scaling, less than that induced by any of the other ice control agents or the distilled water control.

c. Asphalt Stripping

Test performed on thin films of asphalt and on compacted bituminous mixtures indicate that exposure to Ice Ban solutions does not have an adverse effect on either (a) the cohesive or adhesive strength of asphalt or (b) the moisture sensitivity of finished bituminous mixtures.

3. Ease of Use:
    a. Many user agencies initially experienced difficulties in handling Ice Ban products, notably due to clogged nozzles in liquid applicators. In some cases, these problems were caused by operator inexperience (the failure to re-circulate the product in the storage vessel using existing pumps); others were due to characteristics of the product itself (viscosity); still others were caused by problems of quality control (the presence of oversized solids).

4. Cost Effectiveness

The following generalizations regarding the relative costs and benefits of Ice Ban products based on their observed performance in the two major types of applications---as a pre-wetting agent and as a direct spray--- can be made:

a. Pre-wetting of Salt

Salt pre-wet at a typical 10 gallons per ton and applied at up to 300 pounds per lane-mile requires only about 1.5 gallons of liquid deicing agent per lane-mile. Considering that reductions in salt usage of as much as 30 percent were sometimes achieved for salt pre-wet with Ice Ban Magic as compared to straight salt or salt pre-wet with calcium chloride (e.g., in New York and Wisconsin), one would generally expect pre-wetting with Ice Ban Magic to be cost-effective based on materials costs alone, let alone improved performance.

b. Direct Spray Applications

One of the most significant developments in this study was the establishment of quantitative measures of the respective ice melting capacity of Ice Ban Magic and magnesium chloride solution over a wide range of temperatures. It is expected that these quantitative data, which permit the unit material cost per ton of ice control agents, should assist DOT maintenance managers in making more informed decisions regarding the cost-effectiveness of the two products.

Caliber Analysis

The following are responses from users of Caliber. These contacts were provided by Steve Bytnar of Minnesota Corn Processors.

Mike Hern - Colorado Dept. of Trans. 303-442-4382
Bruce Juelfs - City of Fort Collins, CO 970-221-6883
Greg Goldman - City of LaVista, NE 402-331-8927

Pat Kerr - City of Minnetonka, MN 612-988-8400
Mark Cornwell - University of Michigan 734-764-8031
Phillip Anderle- Colorado Dept. of Transportation 970-947-9361

Responses

Greg Goldman- City of LaVista, NE

They used caliber in winter 2000 for De-icing. No anti-icing tried. One particular event, 1/8" ice, 10-15 F, they sprayed and had wet pavement. The product works well in colder temperatures. They were pleased with its performance. The product is clear, doesn't smell, doesn't track, and doesn't clog equipment. Solids are less than 1%. Much improved over Ice ban in these areas. Performance is similar to Ice Ban.

Pat Kerr – City of Minnetonka, MN

A cleaner product!

One event, -15 F, salt/sand mixture pretreated , and the roads were wet on the second pass. The pile is easier to work with after adding caliber.

A second event, snow ½-1", temps in the 20s. Pavement stayed wet and there was residual for the next event. So anti-icing was present for the next storm. Pretreated the salt with 10 gal./ton. They are now looking into having pretreated salt delivered. Their experience is that less salt is needed.

Phillip Anderle – Colorado Department of Transportation

They used caliber M1000. Due to the mild winter they did not get to use it often. They wanted to compare caliber with mag chloride. They saw no differences until the temps drop below 20 F. One event, freezing drizzle with the temp. dropped to 12, They sprayed at 80 gal./mile and prevented any freezing. It keeps pavement wet below 20F. Cost difference is too much above 20, to use caliber. No complaints from the public.

Mike Hern – Colorado DOT

Received caliber in March 2000 and did not have an opportunity to use it. This winter he plans to use it as a de-icer. He may use it as a pretreatment in a colder storm.

	Events	**Method**	**Product**	**Summary**
1	Light Snow	Plow and Spread Dry Salt/ Plow and Spread Pre-Wetted Salt	Salt + Caliber w/ or w/o Spinner	Results are similar for spread dry salt or pre-wetted salt.
2	Light	Plow only	Salt or Previously Treated	No results were recorded

	Snow		Caliber	
3	Light Snow	Anti-ice with Liquids	M-1000	Anti-Ice w/ Liquids appear to work well
4	Light Snow	De-Ice with Liquids	M-1000	De-Ice appear to work well when temperature is not below 20^0
5	Light Snow	Other	1:1 Mix with Caliber/ Caliber/ M-1000/ Salt	Straight salt mix does not appear to work well in roads with compacted snow. 1:1 Mix with Caliber may have better results.
6	Light Snow & Drifting	Plow and Spread Dry Salt/ Other	Salt/ Caliber	Results are similar with salt and salt + caliber mix.
7	Moderate Snow	Spread Pre-Wetted Salt (Without Plowing)	Salt/ Salt + Caliber/ Salt + Caliber & Spinner	Salt + caliber mix works better than straight salt. Reduced amounts provide similar results (400# - 250#)
8	Moderate Snow	Plow and Spread Dry Salt/ Plow and Spread Pre-Wetted Salt	Salt	Plow and Spread Dry Salt versus Plow and Spread Pre-Wetted Salt, results are similar
9	Moderate Snow	Coating of Accumulation	Salt/ Salt + Caliber Mix	Results are similar with salt and with salt + caliber mix.
10	Heavy Snow	Plow and Spread Dry Salt/ Plow and Spread Pre-Wetted Salt/ Spread Pre-Wetted Salt (Without Plowing)	Salt/ Salt + Caliber/ Salt + Caliber & Spinner/ Pre-Treated Salt + Caliber	Salt + caliber mix appear to have better results over straight salt, 250# and 8 gallons of caliber.
11	Heavy Snow	Anti-ice with Liquids	Salt + Caliber	Anti-Ice w/ chemicals appear to have no effect
12	Ice	Spread Pre-Wetted Salt (Without Plowing)	Salt + Caliber/ Pre-wetted Salt Pile	Salt + caliber mix appears to work well on ice

Winter 2002 Analysis

Comparisons

1. Crawfordsville District, January 6, 2002, Light Snow Event, Road Temperature 27-29 °. 25 gal/mile application rate. U.S. 40.

   Applied caliber three times during the event. Each time the surface was either bare or had wheel tracks. The results were similar road conditions.

MGCL

When pavement was partially bare or covered, MGCL worked well. When the surface is ice covered or compacted snow, it wasn't very effective. Took longer to clean up a section than a caliber section.

2. Crawfordsville District, January 19, 2002, Light to moderate snow, road temps in the 20s. U.S. 40.

   Anti-iced two hours before the storm event.

   It snowed less than 1". The pavement started bare or wet. The result was ice or compacted snow. Caliber did not produce the desired result as the other chemicals.

   Salt Brine – 40 gal/LM

   The roadway had been pretreated. Multiple applications during the event. At the end of the storm, salt was spread. Good results when the road temperature is above 20°. Below 20° the road surface had compacted snow and ice.

   CACL – 25 gal/LM

   Pretreated before the storm event. Snow covered at 2:30 AM when first application made. Second application at 4:00 AM with salt added. Third application with salt added at 5:00 AM, 2-1/2 hours after the initial treatment. Starting to work at this time.

   MGCL – 25 gal/LM

   Pretreated before storm. Two applications of MgCl and two applications of salt. Results appeared four hours after initial application.

   Ice Ban – 25 gal/LM

   Pretreated before storm. When the event started an application was performed. Two other applications of dry salt made. Three hours after the start of the event compacted snow started to break up.

   Caliber – 25 gal/LM

   Pretreated before storm.. Caliber applied 5 times over 2 hours. Plow and spread salt 4 times over the next two hours. Results appeared after the salt was applied.

   Ice Ban – 25 gal/LM

Pretreated before the storm. Treated 5 times with Ice Ban during the event. Plow and spread salt 4 times. Road surface goes from bare to covered back to bare and wet. Results occurred after two salt applications.

3. Vincennes District, U.S. 41, event date 1-19-02. Event type – light to moderate snow. Road temperature - 28°.

   Salt/caliber mix applied – 400#/LM, 18 gal/ton.

   Results were good.

   Plain Salt - 400#/LM

   Results were the same as the salt/caliber mix.

4. Toll Road – Mainly used it on bridge decks for frost prevention.

   Results-

   a. Good results on tire ice in light snow events.
   b. Good results against frost.
   c. Used in anti and de-icing applications.
   d. Works good in light snow events when temps are low, below 20.
   e. Road surface seems to stay wetter longer in light snow events.
   f. Pre-treatment seems to help delay road freezing. This gives time to respond during a heavy snow event.

   Summary-

   The toll road reported good results with their use of caliber. The other two districts appeared to have mixed results from use.

<u>Geomelt Analysis</u>

Comments

- There was tire ice, had to spread salt to get it to go away.
- The road was dry when we put it on and dry when we finished.
- The product does not seem to spread out in the lane very well.
- Tire ice, had to spread salt.
- Tire icing was reappearing 2 ½ hours after application.
- Tire icing appeared after 3 hours, geomelt works well when spread but doesn't seem to last long enough.
- There was some slush but was mostly wet during event of snowfall.
- Plugged the filters.

- Does not seem to track out as well as M-1000, also it is not as visible when sprayed on pavement.
- Does not seem to track as well from lane to lane but seems to last longer on pavement.
- Works good on frost, do not have to spread salt, it is liked.
- When you get snow it gives you a grace period before you have to spread salt, will melt about ¾ to 1 inch of snow.
- It did a good job melting the snow before we had to spread salt. You can tell the difference.
- Most of the time the driving lane was wet but not slippery, the spray is working, and the snow is not sticking. However it is hard to read what it’s doing because it looks black most of the time.
- Made a mix of salt, sand, and geomelt and it works great.
- Snow was intermittent, was hard to track results, results were favorable from what was seen.
- Sticking to docks and under overhead.
- Some tire icing at first. The product works but slowly.
- This product is good it will work, on tire icing in the single digits.
- Road slippery in spots due to light snow.
- No tire icing over several hours.
- The road tire iced and they had to re-spray the area.
- Sprayed the road for snow but it was so heavy it didn’t do much good.

Conclusions

- Some experience tire icing and had to spread salt.
- It does not seem to spread out in the lane very well for some.
- Hard to see and therefore tell if it is working.
- Some liked it a lot, said it would work well.
- Works well on frost.

Weather Services Analysis

In 2001 a weather services analysis was performed and the various options are described in the below table.

Company Name	Service	Description
AccuWeather	AccuWarn™ Warning Services	AccuWeather's staff of 85 professional meteorologists constantly monitors your weather and notifies you before you are hit by lightning, strong winds, severe thunderstorms, snow, ice, hurricanes, extreme temperatures, flooding or any other weather hazards that can adversely effect your operation. Our expert meteorologists provide pinpoint local forecasts and warnings and up-to-the-minute weather information anytime you want. We give you the specific details you need to make key decisions when you need them. **Cost: A starting fee of $1300 per year and up.**
	Hurricane Warning Service	AccuWeather's meteorologists are expert in the prediction of hurricanes and tropical storms and have predicted accurate and timely warnings for major hurricanes from Agnes to Floyd. Warnings are customized to the specific needs of emergency management agencies, oil companies, shipping companies, port authorities and other subscribers and are available via fax, PC, email or Internet. **Cost: A location fee of $2150 and up per season (depending on locations)**
	NEXRAD Doppler Radar	Complete real-time Doppler radar. **Cost: $49 per month**
	Road Weather Information System (RWIS)	AccuWeather's heat-balance equation model, powered by weather forecasts from AccuWeather meteorologists, provides the most accurate surface forecasts for roads and runways.
	Satellite Imagery	AccuWeather provides full-color graphic satellite images for the entire world.

	Snow Warning Service™	AccuWeather provides precise, detailed advance warnings of snow and ice to highway departments, schools and businesses. Forecasts are geared to the exact location of each individual client and are customized to each client's specific work schedules. Included with the service is 24-hour a day consultation with AccuWeather meteorologists **Cost: From $1500 to $2800 per season depending on location.**
	Transportation	AccuWeather is the leading supplier of weather forecasts and data for trucking companies and railroads. Products include maps showing forecasts of disruptive weather - with precise locations and timing, terminal forecasts, highway forecasts and much more, available by fax, email or on the Internet. **Cost: $350 and up per month.**
	Premium Service	Hour-by-Hour Forecasts To 10 Days (240 Hours) For All International Locations Temperature, RealFeel™ Temperature, Precipitation, Cloud Cover, Dewpoint, Humidity, Wind Direction, Wind Speed, Wind Gust, 1-hour Precipitation, 1-hour Rainfall, 1-hour Icefall, I-hour snow fall, visibility, wet bulb temperature Most Current Local Radar – 21 Types Base Reflectivity Tilt 1,2,3,4, Composite Reflectivity, Extended Base Reflectivity, Low-Level, Mid-Level, High-Level Layered Reflectivity, Base Velocity Tilt 1,2,3,4, Relative Mean Radial Velocity Tilt 1,2 One-Hour Precipitation Three-Hour Precipitation, Storm-Total Precipitation, Vertically Integrated Liquid, Echo Tops **Cost: $199 per year**

DTN	Transportation Weather	DTN Transportation Weather is a satellite weather information service designed especially for the transportation industry. Whether you're responsible for road maintenance or your business depends on road conditions, you can have instant access to comprehensive local, regional and national weather forecasts and information . . . at an affordable price, with no online, access or other phone charges. It's not a computer. DTN Transportation Weather is a"stand-alone" information system, with all the equipment (hardware and software) provided by DTN. The satellite delivery technology of DTN Transportation Weather allows you unlimited usage of the most current weather data available 24 hours a day, seven days a week - for one low monthly fee. **Cost: $93.00 per month** **Shipping & Handling: $69.00**
	Broadcast Weather	DTN Broadcast Weather is a satellite-delivered weather and news information service designed for the broadcast industry. The service provides instant access to comprehensive local, regional and national weather forecasts and information, along with NOAA Warnings & Alerts and Learfield World & National News Summary . . . at an affordable price, with no online, access or other phone charges. It's not a computer. DTN Broadcast Weather is a "stand-alone" information system, with all the equipment (hardware and software) provided by DTN. The satellite delivery technology of DTN Broadcast Weather allows you unlimited usage of the most current weather data available 24 hours a day, seven days a week - for one low monthly fee. Cost: $103.00 per month based on quarterly payment. Shipping & Handling: $69.00

	Satellite Programming Reception	Cost: $330 for one time reception (must be purchased if either one of the above services is purchased; however, the fee can be waived if either one of the above services is "purchased" before January 1st 2001.
WSI	WeatherProducer	Powerful, versatile, dependable, and fast, WSI's WeatherProducer is the meteorological workstation and automated weather graphics production system that can most effectively help you meet the challenges you face in today's broadcast market. Valid forecast data and imagery, 3D animations, special effects, detailed local maps, event-driven storm tracking, interactive local weather report, and automated severe weather alerts are all at your command with the WeatherProducer.
	SkyAlert	A severe weather alerting and data streaming system, SkyAlert gets you on air fast with severe weather graphics that seamlessly blend with the rest of your weather shows. When networked to the WeatherProducer, this turnkey system combines up-to-the-second updates from the NOAA Weather Wire with live, 24-bit weather imagery for the most comprehensive coverage of severe weather available today.
	Skycast	Skycast shows viewers the weather the way it will actually look. Based on each local forecast, a video clip of future weather is overlaid onto a local skyline or landmark that your station selects. It's easy for you to use, easy for your viewers to understand, and provides on-air promotion opportunities for your station.

	SkyTracker	A dynamic, interactive weather tracking tool with access to many different types of weather data, SkyTracker empowers you to tell compelling weather stories as they unfold every day. With SkyTracker, you can broadcast stunning graphics, live weather updates, and interactive analysis, especially when severe weather threatens the local viewing area. SkyTracker can create dynamic, interactive graphics even when the most compelling weather is outside your immediate viewing area. Therefore, it can be used and promoted every day.
	Predictor	Featuring 10 km grid resolution at 30-minute time steps, Predictor provides the detail you need to generate the most local weather forecasts with smooth on-air animations. Predictor is a turnkey, remotely monitored, local atmospheric modeling service for broadcasters. Its model data is automatically converted by the WeatherProducer into ready-to-air visualizations showing the forecast for your specific viewing area.
	Precisioncast	Based on the Meso-Eta model with 20 km grid resolution, Precisioncast delivers temperature, wind, humidity, cloud cover and precipitation forecasts via satellite to the WeatherProducer. The system then uses this information to automatically produce easy-to-understand, broadcast-ready graphics which show local weather variations over changing terrain.
	Showfx	Showfx enables you to clearly illustrate the effects of severe weather with a continuously updated library of professional, ready-to-use, 3D animations. Integrated with the latest weather data, they enable you to create eye-catching 3D weather animations. Later, they can be recalled, automatically updated with new forecast data, and dropped into your WeatherProducer show. Then, you're ready to go on the air.

	True 3D	WSI's 3D Real Earth Model works with Showfx enabling you to wrap weather imagery around the globe and navigate it. You can create exciting real earth animation sequences for any geographic location, and create attention-getting special effects for your weathercast
	Programming Services	From still images and text forecasts to broadcasting complete weather shows, WSI can provide a variety of weather programming services. WSI has extensive experience creating animated weather graphics, developing forecasts, and presenting weathercasts to local television viewers and cable network audiences. Whether you prefer a complete weathercasting service, weekend assistance, or eye-catching graphics, WSI can reliably meet your weather programming needs.
	Radar	WSI's mosaicked radar imagery is scrutinized by meteorologists around the clock to eliminate false echoes and ground clutter. This quality control results in highly accurate NOWrad mosaics, national and regional radar summary graphics, PRECIP rainfall accumulation mosaics and winter storm mosaics which can be used for aviation, broadcast, energy, government, and consumers. Local, regional, and national radar images are frequently updated and can be animated and zoomed.
	Satellite	Domestic and international high-resolution satellite imagery is available 24 hours a day from WSI. NOAA's Geostationary (GOES) and Polar Orbiters, Japan's GMS and Europe's Meteosat satellites provide infrared, visible and water vapor data for a full suite of thresholded and full spectrum satellite snapshots processed by WSI. You can loop or zoom in on all satellite imagery. Delivery is via Internet or WSI's high capacity satellite network.

	Charts	Operational weather charts for current and forecast surface conditions for a wide variety of parameters are frequently updated, colorful and easy to understand. For aviation professionals, WSI AVcharts include both surface and upper level conditions, Weather Progs, Wind and Temperature Progs, U.S. Surface Analyses and more. WSI also offers international charts for significant weather worldwide.
	Forecast Visualizations	WSI provides a suite of forecast models in both gridded format and graphical images. Smooth, eye-catching, intuitive graphics that clearly depict the forecasted weather are available on the Internet for consumers and professionals. Visualizations can be global, regional or very local in scale and are based on a wide assortment of models. These include the AVN, Eta, Ruc, and Meso-Eta from the NWS, ECMWF from the European Centre and MM5 processed locally at WSI.
EarthSatellite	Custom	Has been providing services to INDOT

<u>Y-Chute Analysis</u>

In 2007, analysis of a Y chute was performed in the Seymour District. Modifications were made to improve their performance. A summary of evaluation comments follows.

Advantages

- Puts salt right where needed.
- Does not bounce off road.
- Would work great on 31 passing lane since our boxes throw to left and we could drop it on the centerline with y-chute.
- Good job on the curves.
- Puts salt on centerline on roads that have reflectors for easy cleanup.
- Work great on blow in’s.
- Can spread at a higher speed without salt bouncing off road.

Disadvantages

- Cannot pre-wet salt because it plugs the down chutes.
- Chutes will plug from the snow.
- Salt freezes and it will not switch from one side to the other.

Comments

- The drivers really like it. They think it does a lot better job.
- A little snow on the white line.
- Where Y-chute was used the center cleaned up easier.
- Put on the center out the left chute and it cleaned it up well.
- At first the center and left track were melting after six hours the center line was fairly clean.
- Within the first two hours the center was covered and after about five hours there was still build-up in center line.
- Center still had snow and for three hours and wheel tracks appeared after one hour.
- Center was slushy within the first hour, center and left track were slushy within the next two hours. In another event there was snow on the white line.
- Ice on bridges.
- Used spinner-cover lanes good.
- Used spinner-spread material good.
- Good pattern- just continuous snow. Used center shoot excellent coverage.
- Good pattern-used spinner.
- Plow only-materials not doing any good.
- Spreader worked fine.
- Spreader worked really well, won't freeze up as longs as spinner stays spinning.
- Spreader worked fine, clogged up once but wasn't real bad.
- Spinner kept getting clogged, chute seemed to work ok.
- Spinner kept getting plugged up.
- Cleaned roads.
- Melted Ice from road did not need to plow anything from road surface.
- Liquid need to be dispensed closer to road for better coverage.

Indiana Winter Severity Index

INTRODUCTION

INDOT created a committee named the Winter Operations Team(WOT) to address issues associated with winter activities. Some of the WOT's past activities have included developing a Total Storm Management Manual (TSM) and studying the effectiveness of several chemicals used by INDOT.

The WOT determined that a Winter Severity Index (WSI) would be helpful for several reasons. A WSI could be used to compare the efforts of snow and ice removal between the different climatic zones in Indiana. Another is the ability to compare and analyze mild and severe winters. It will also provide a quantitative method for determining what relationships exist between different weather events and snow and ice removal. A subcommittee of the WOT was put together to study existing indices and determine if one or a combination of indices could be used for INDOT. It was recommended that if other Winter Severity indices did not work that an index for INDOT be developed. During development, the intent was to derive an index that did not require cumbersome and time-consuming data collection. This paper explains the INDOT WSI and describes how it was developed.

EXISTING INDICES

One of the first actions was to look at previous developed winter severity indices. Several indices have been created by different organizations and are summarized.

Wisconsin

The Wisconsin Index uses the weather factors:

SE - Snow events
FR - Freezing rain events
AMT - Snow amount
DUR - Storm duration
INC - Incidents(drifting, cleanup, and frost runs)

The winter index(WI) is:

$$WI = 10 \times \frac{SE}{63} + 5.9 \times \frac{FR}{21} + 8.5 \times \frac{AMT}{314} + 9.4 \times \frac{DUR}{1125} + 9.2 \times \frac{INC}{50}$$

Wisconsin uses the WI to measure the type of winter in Wisconsin. Since the counties perform the snow and ice removal it will be used to evaluate their performances and expenditures. A value is calculated for each county. This requires that the above weather data be recorded in each county. One future plan for the WI is to incorporate it into a Level of Service model that will be used to allocate operations funding and could be used to distribute winter reserve funding. Wisconsin has developed reports to show the correlation between the severity index and salt use and a graph showing the relationship between WI and cost per lane mile(1 & 3).

Washington State

Washington DOT (WSDOT) developed a frost index(FI), which is a severity index less the snowfall factor. WSDOT found the FI relates directly to performance measurement in the winter activities. It plans to use the FI when an overrun occurs in the snow and ice budget and a supplemental funding request is made to the state legislature(4).

Modified Hulme

This index has been used by some international organizations. It uses three weather factors and the equation is:

$WI = 10T - F - (18.5S)^{1/3} \pm C$

T - Mean maximum air temperature
F - Total number of ground frosts
S - Number of days with snow cover at 9:00 AM
C - Constant

SHRP Index

The SHRP(Strategic Highway Research Program)(2) index uses the weather factors:

TI - The average daily temperature index
S - Mean daily snowfall
N - Proportion of days with air frosts
R - Temperature range

Temperature Index(TI)
TI =0, if minimum air temperature is above 32; TI = 1 if maximum air temperature is above 32 while minimum air temperature is at or below 32; TI = 2 if the maximum air temperature is at or below 32.

Number of air frosts(N): Number of days with minimum air temperature at or below 32.
Temperature Range(R): The mean monthly maximum minus the mean monthly minimum.

$$WI = a(TI)^{0.5} + b \ln\left[\frac{S}{10} + 1\right] + c\left[\frac{N}{R + 10}\right]^{0.5} + d$$

a, b, c are constants.

Kansas and Minnesota DOTs have adopted the SHRP index. Minnesota calculates by location and month.

The Ontario Province, Canada modified the SHRP equation to include freezing rain. The equation is:

$$WI = -a(TI)^{0.5} - b \ln\left[\frac{S}{10} + 1\right] - c\left[\ frz\ \right]^{0.5} + 50$$

frz – number of freezing rain days

The SHRP index was tried with weather data from South Bend for four winters (Figure 2). The figure is a plot of the SHRP index and the cost/mile for the South Bend, Indiana maintenance unit. The cost/mile is the total labor, equipment, and material cost divided by the lane miles, within the unit. The figure shows no correlation between the two.

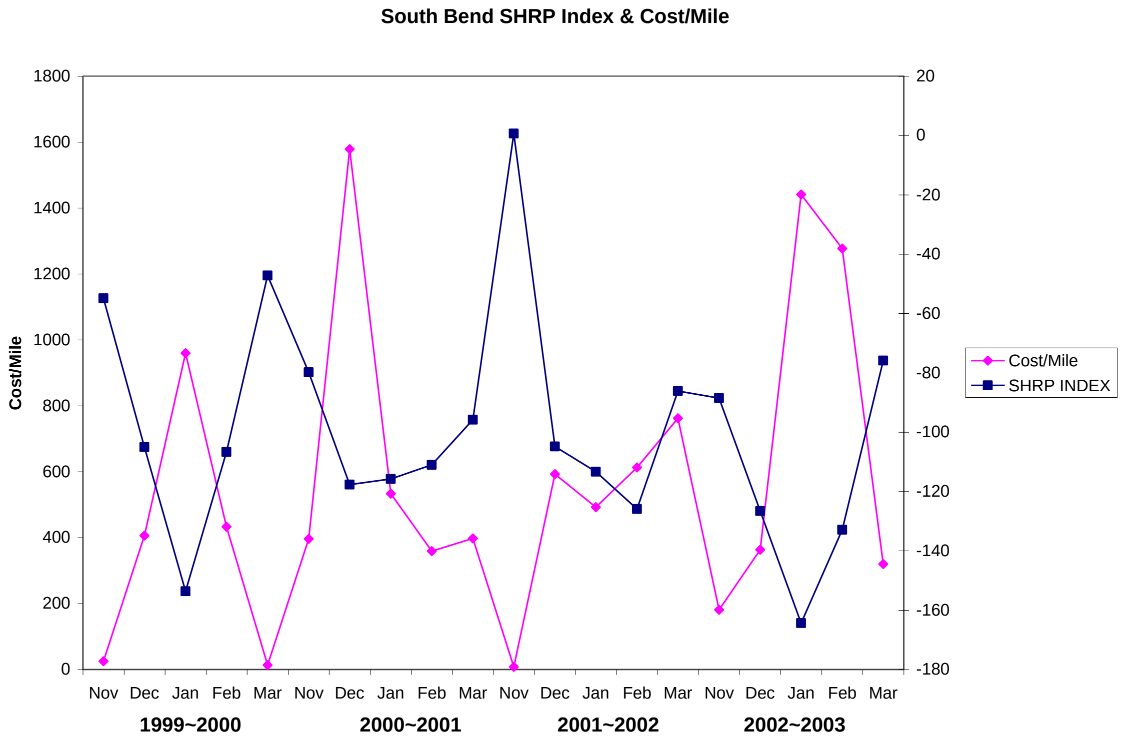

Figure 2 – SHRP Index for South Bend

Not feeling comfortable with this result and looking at the other indices and their missing weather influences, INDOT decided to develop its own by using the total costs/mile as the dependent function in the equation. Weather data for Indiana had to be found and evaluated first.

WEATHER DATA

Indiana has basically four different winter climatic zones. See Figure 3. The southern zone has milder winter weather and a considerably shorter winter season. The central zone is somewhat colder and experiences more snow. The northern zone is noticeably harsher in temperature and receives greater snowfall. Also, the northern zone can be further divided into two distinct regions; one being the northwest corner that typically receives Lake Michigan effect snows that drive up the average to twice the snowfall as the rest of the northern region. Because these four zones are different, winter weather data was collected for each of these areas.

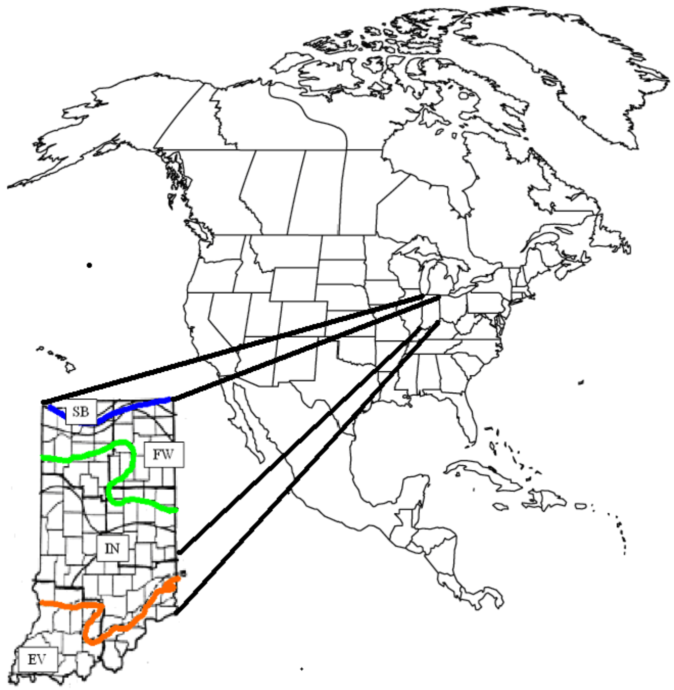

Figure 3 – Indiana Map

The National Oceanic and Atmospheric Administration(NOAA) records weather conditions at various locations in the United States. A website has an on-line store where weather data can be purchased. The addresss is http://www.ncdc.noaa.gov/oa/ncdc.html. There are four Indiana locations available and they are Evansville, Fort Wayne, Indianapolis, and South Bend. Each one represents one of the four climate zones. Evansville for the southern zone; Indianapolis for the central zone; Fort Wayne for northeast Indiana; and South Bend for northwest with lake effect snow.

The cost for the on-line weather data is $3/month at each location. Weather data was obtained for four winters (months - November through March, for the winter seasons of 2002-2003, 2001-2002, 2000-2001, 1999- 2000). The data can be downloaded in either a text or pdf file. Figure 4 shows the first page of monthly weather data available at these locations.

DECEMBER 2001
LOCAL CLIMATOLOGICAL DATA
NOAA, National Climatic Data Center

EVANSVILLE, IN
DRESS REGIONAL AIRPORT (EVV)
Lat: 38°02' N Long: 87°32' W Elev (Ground): 418 Feet
Time Zone: CENTRAL WBAN: 93817 ISSN #:0198−1951

DATE	TEMPERATURE °F MAXIMUM	MINIMUM	AVERAGE	DEP FROM NORMAL	AVERAGE DEW PT	AVERAGE WET BULB	DEG DAYS BASE 65° HEATING	COOLING	WEATHER	SNOW/ICE ON GND (IN) 0600 LST DEPTH	1200 LST WATER EQUIV	PRECIPITATION (INCHES) 2400 LST SNOW-FALL	2400 LST WATER EQUIV	PRESSURE (INCHES OF HG) AVERAGE STATION	AVERAGE SEA LEVEL	WIND RESULTANT SPEED	RES DIR	AVERAGE SPEED	MAXIMUM 5-SEC SPEED	5-SEC DIR	2-MIN SPEED	2-MIN DIR	DATE
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
01	53	36	45	5	38	41	20	0	BR				0.00	29.81	30.23	2.2	26	3.8	12	36	9	33	01
02	58	34	46	6	40	43	19	0	BR				0.00	29.86	30.29	1.8	16	2.7	13	15	10	15	02
03	64	36	50	11	40	46	15	0	RA BR				T	29.80	30.22	4.3	21	4.7	17	21	15	23	03
04	69	50	60	21	48	54	5	0	RA				T	29.81	30.22	7.0	20	7.6	21	25	16	23	04
05	70*	54	62*	23	47	54	3	0					0.00	29.79	30.21	10.2	21	10.5	26	23	22	23	05
06	62	46	54	16	51	52	11	0	RA FG+ BR				0.64	29.70	30.12	1.0	17	5.7	26	34	20	35	06
07	55	42	49	11	47	48	16	0	RA FG+ BR				0.09	29.65	30.07	2.9	09	3.8	12	04	10	04	07
08	49	39	44	6	44	45	21	0	RA BR				0.09	29.62	30.03	7.1	36	8.3	18	02	15	35	08
09	47	29	38	1	30	34	27	0	BR				0.00	29.84	30.27	2.9	03	4.1	13	35	10	36	09
10	46	26	36	-1	31	33	29	0	TS BR				0.00	29.77	30.20	0.9	06	1.6	13	02	9	03	10
11	53	26	40	4	35	38	25	0	BR HZ				0.00	29.82	30.25	2.5	12	2.9	13	17	9	16	11
12	53	44	49	13	49	49	16	0	RA BR				0.88	29.64	30.06	4.2	15	4.6	12	15	10	15	12
13	58	47	53	17	51	52	12	0	RA BR				0.20	29.55	29.96	3.8	33	7.1	20	28	15	30	13
14	48	42	45	9	42	43	20	0	RA BR				0.50	29.50	29.92	5.3	32	9.7	37*	33	29*	32	14
15	49	33	41	6	40	42	24	0	RA FG+ BR				T	29.87	30.30	4.3	11	4.8	15	15	13	15	15
16	52	45	49	14	47	48	16	0	RA BR				2.30	29.69	30.11	4.2	12	5.2	17	14	13	15	16
17	54	43	49	14	48	49	16	0	RA BR				1.95	29.36	29.77	6.7	35	8.3	23	32	18	33	17
18	49	33	41	7	35	38	24	0	BR HZ				0.00	29.55	29.97	2.4	28	4.2	17	32	15	31	18
19	46	33	40	6	32	36	25	0	RA BR				T	29.54	29.97	7.3	31	8.7	32	33	25	32	19
20	47	27	37	3	23	32	28	0					0.00	29.85	30.28	7.2	26	8.1	22	23	20	23	20
21	52	26	39	6			26	0					0.00	29.88		2.3	19	3.6	10	16	8	15	21
22	58	36	47	14	36	42	18	0	RA BR				0.42	29.62	30.04	9.5	19	10.1	28	16	21	20	22
23	51	29	40	7	25	33	25	0	RA BR				0.08	29.57	30.00	12.0	29	13.4	30	27	26	27	23
24	35	24	30	-3	15	25	35	0					0.00	29.66	30.09	10.6	30	10.6	28	31	24	31	24
25	30	20	25	-8	15	22	40	0					0.00	29.69	30.13	5.0	29	5.8	14	29	12	28	25
26	29	17	23	-9	16	22	42	0	SN BR				T	29.54	29.97	6.6	28	6.9	22	30	17	27	26
27	38	24	31	-1	19	27	34	0					0.00	29.41	29.84	9.8	25	10.4	21	25	16	25	27
28	44	27	36	4	23	31	29	0	SN				T	29.35	29.78	7.9	28	9.9	25	29	20	27	28
29	31	14	23	-9	13	20	42	0	SN BR				0.01	29.71	30.14	7.9	33	8.1	29	34	23	32	29
30	25	13	19*	-12	11	17	46	0					0.00	29.89	30.33	4.4	30	4.6	21	29	15	29	30
31	27	13*	20	-11	12	18	45	0					0.00	29.87	30.31	5.1	32	5.6			12	30	31
	48.5	32.5	40.5				24.3	0.0	< MONTHLY AVERAGES	TOTALS-->			7.16	29.68		2.5	28	6.6	<= MONTHLY AVERAGES				
	4.9	5.8	5.3		<-------------DEPARTURE FROM NORMAL--------------->								3.49	SUNSHINE, CLOUD, & VISIBILITY TABLES ON PAGE 3									

DEGREE DAYS

	MONTHLY TOTAL	MONTHLY DEPARTURE	SEASON TO DATE TOTAL	SEASON TO DATE DEPARTURE
HEATING:	754	-170	1509	-278
COOLING:	0	0	1377	1

GREATEST 24-HR PRECIPITATION: 3.43 DATE: 16-17
GREATEST 24-HR SNOWFALL: DATE:
GREATEST SNOW DEPTH: DATE:

SEA LEVEL PRESSURE DATE TIME
MAXIMUM : 30.40 15 0954
MINIMUM : 29.60 14 0554

NUMBER OF DAYS WITH →
MAXIMUM TEMP ≥ 90: 0
MAXIMUM TEMP ≤ 32 : 5
THUNDERSTORMS : 1
MINIMUM TEMP ≤ 32 : 14
MINIMUM TEMP ≤ 0 : 0
HEAVY FOG : 3
PRECIPITATION ≥ 0.01 INCH : 11
PRECIPITATION ≥ 0.10 INCH : 7
SNOWFALL ≥ 1.0 INCH :

DECEMBER 2001
EVANSVILLE, IN

Figure 4 – NOAA Monthly Weather Data

Weather factors that can be obtained from this data are:

1. Number of freezing rain events
2. Number of snow events
3. Amount of snow
4. Average maximum temperature
5. Average minimum temperature
6. Storm duration
7. Average wind velocity
8. Number of frost days
9. Number of days w/ snow cover

Weather data in text file format can be imported into an excel spreadsheet and macros written with these parameters defined to automatically calculate the number of certain weather events. Some of these events are counted manually by scanning the weather data. For each month and location seven weather events were tabulated. They were:

1. Frost day
2. Freezing Rain
3. Drifting

4. Snow
5. Snow Depth
6. Storm Intensity
7. Average Temperature

FORMULATING THE EQUATION

Field Factors

The first equation developed was based on input from field operations. This came through surveying field crews and talking with employees involved in the snow and ice removal effort. This group identified four weather factors with the most influence. So the first equation basic form was:

WI = a(Frost Day) + b(Freezing Rain) + c(Snow Event) + d(Drift day)

A snow event is affected by the amount of snow, the duration of the event, and the temperature during the event. These factors were used to define the snow event. The coefficients a,b,c, and d are weight values. These values were arrived by surveying field operations. The survey asked to distribute 100 points between the four weather events. Based on the survey results the values became:

a = 0.06
b = 0.29
c = 0.38
d = 0.27

This relationship is now shown in equation format with a mathematical description of each factor.

Events	Symbols	Definitions
Frost	FrD	Number of days with minimum temperature $\leq$ to 32 F and a minimum dew point $\leq$ 32 ° F.
Freezing Rain	RfD	Number of days with freezing rain and/or drizzle and minimum temperature $\leq$ 32 ° F.
Drifting	DrD	Number of days with wind speeds > 15 mph and snow on ground or a snow event.
Snow	(SnD)*In/AvT	Number of days with minimum temperature less than or equal to 32 ° F times the snowfall intensity divided by the average temperature during the event.

The original equation looked like this:

WI = 100*(.06(FrD) + 0.29*(RfD) + 0.38*(DrD) + 0.27*(SnD)*In/AvT)

The next step was to validate the equation. The equation uses weather data to calculate a severity index value. This was done for the various locations and months. Initial analyses looked at index values by locations. Figure 5 shows index values by location for three winters. Some of the values look acceptable while others don't. For example in winter 2000-2001 Indianapolis had a higher index than Fort Wayne.

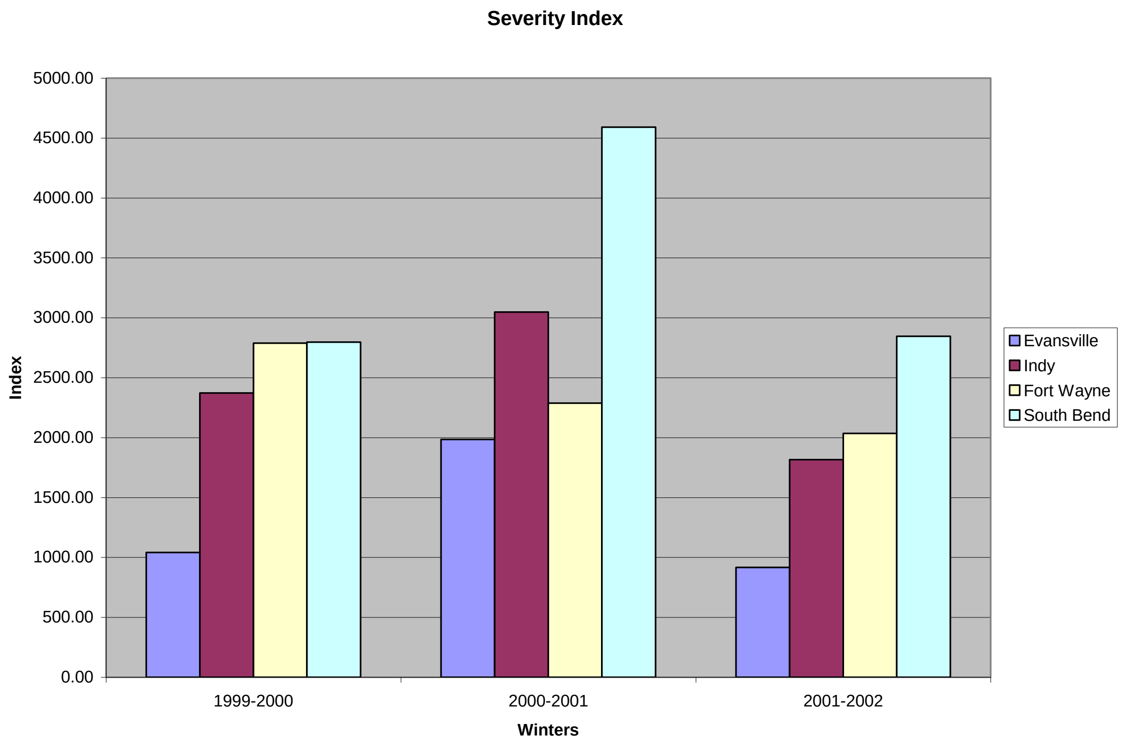

Figure 5 – Original WI for three years

One possible validation is to graph WI values with lane mile snow removal costs. Figure 6 and 7 show these plots. Looking at Figures 6 and 7, the line graphs do not correlate well between WI and cost per lane mile. Using these results it is difficult to validate the equation.

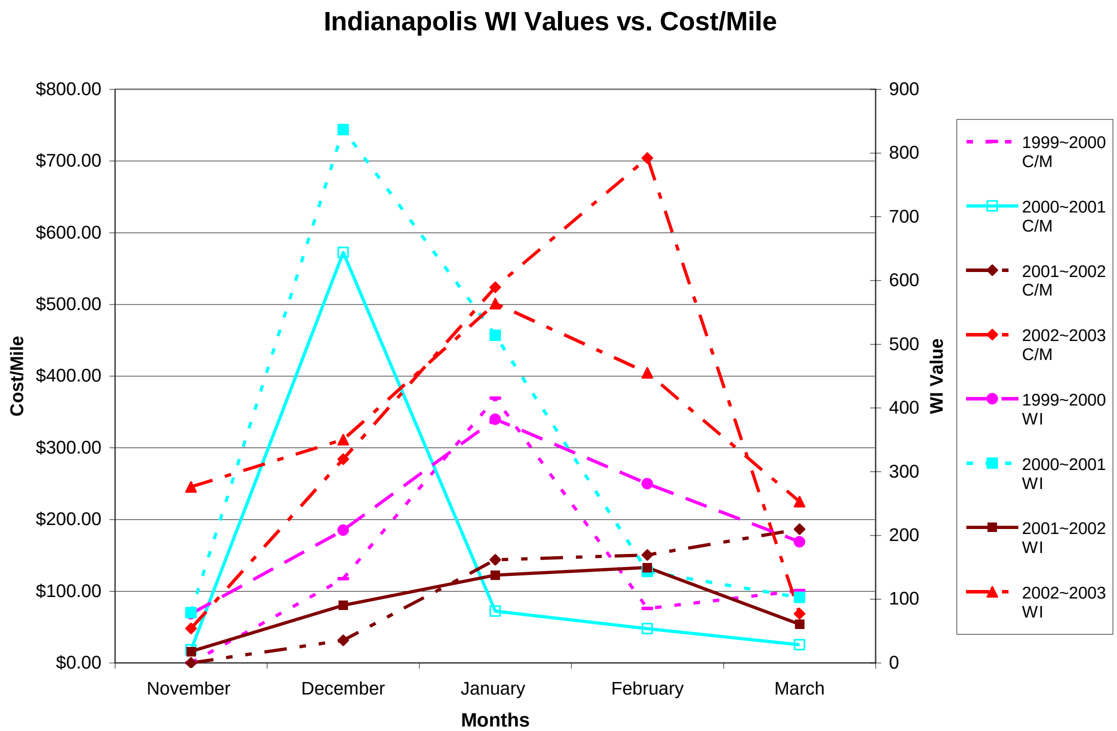

Figure 6 – Original WI Values

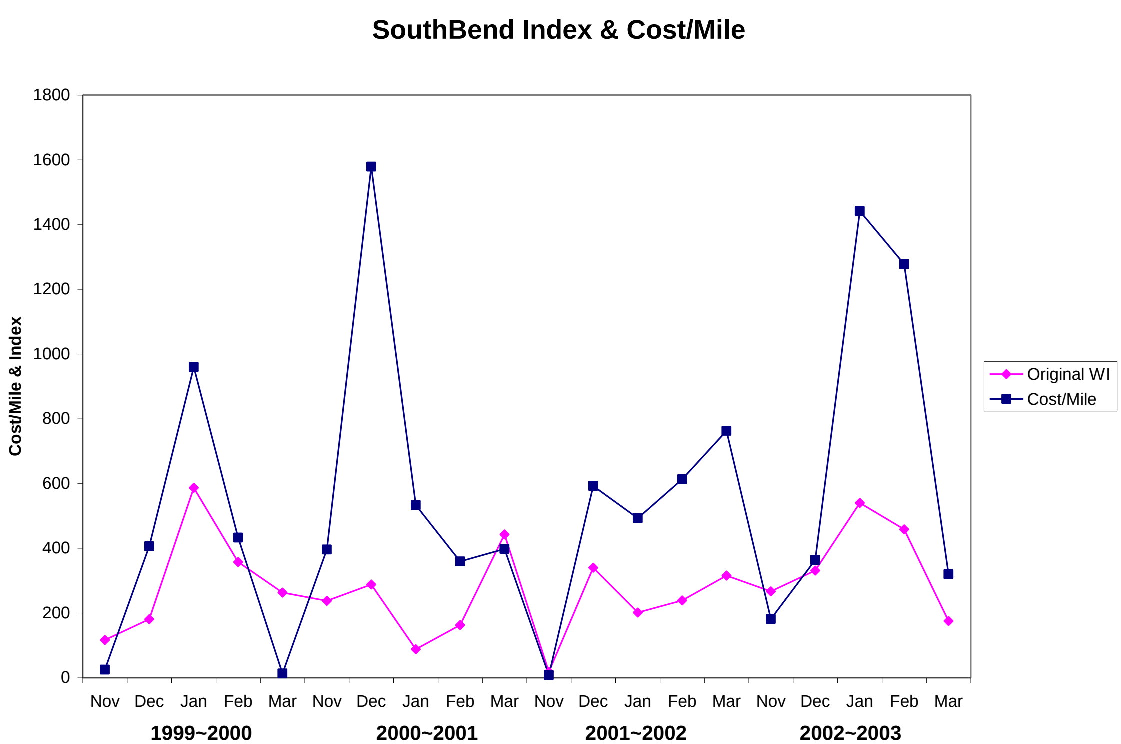

Figure 7 – Original WI Equation

The coefficients used were established by the number of survey responses. After reviewing them, it was felt that that there may have been too much bias and the results were skewed. For example, some locations use anti-icing to prevent frost and do not consider it as an important factor in the effort. While other locations respond to frost callouts in the middle of the night, giving it a high priority. Therefore a more scientific statistical approach was taken, similar to what some of the other indices took.

Statistical Approach

With a multiple factor relationships and using lane mile costs as the controlling(or forecast) variable, this problem is best solved using regression analysis. Since there are multiple weather(or explanatory) variables, a multiple regression analysis is needed.

The tool used to perform the multiple regression analysis was SAS. It is an interactive and batch programming environment that provides modules for basic data analysis, statistics, and report writing. The software is easy to use and making modifications to variable data is easy. The software allowed for multiple equations to be produced with validation.

Because of SAS it was decided to start with the original WI equation four weather factors. Figure 8 shows this equation. Notice it correlates significantly better than the original equation shown in Figure 7. Additional weather factors were analyzed with SAS and compared with the controlling variable. As more factors were included in the analysis the two line graphs moved closer to each other. Figure 9 shows the five weather factor index(original factors + snow depth) graph. This is an improvement over Figure 8. The final SAS analysis included all seven main weather events experienced in Indiana, listed previously. The seven factors are: Frost day, Freezing Rain, Drifting, Snow, Snow Depth, Storm Intensity, and Average Temperature. From SAS the following equations were generated and validated with the lane mile costs. Figure 10 shows the graph for Indianapolis. Figure 11 a comparison of WI for the four locations using the statewide equation.

The below equations were created from the multiple regression analysis based on regional weather data. Also, a statewide equation was generated.

South Bend

WI = -5.98483 * Frost + 13.73518 * Freezing_Rain + 12.57288 * Drifting + -25.18103 * Snow + 28.78145 * Snow_Depth + 4.29121 * Hour + 6.77877 * Average_Temperature

Fort Wayne

WI = 7.05832 * Frost – 16.21024 * Freezing_Rain + 6.31394 * Drifting + 31.24970 * Snow + 25.36240 * Snow_Depth + 1.23828 * Hour – 6.95440 * Average_Temperature

Indianapolis

WI = 3.42152 * Frost + 7.96888 * Freezing_Rain + 7.24260 * Drifting + 14.044284 * Snow + 16.63333 * Snow_Depth + 1.50251 * Hour – 3.90486 * Average_Temperature

Evansville

WI = 0.01116 * Frost + 23.68383 * Freezing_Rain + 43.46891 * Drifting – 18.77938 * Snow + 63.02214 * Snow_Depth + 0.23399 * Hour – 0.32291 * Average_Temperature

Statewide

WI = 0.71839* Frost + 16.87634 * Freezing_Rain + 12.90112 * Drifting – 0.32281 * Snow + 25.72981 * Snow_Depth + 3.23541 * Hour – 2.80668 * Average_Temperature

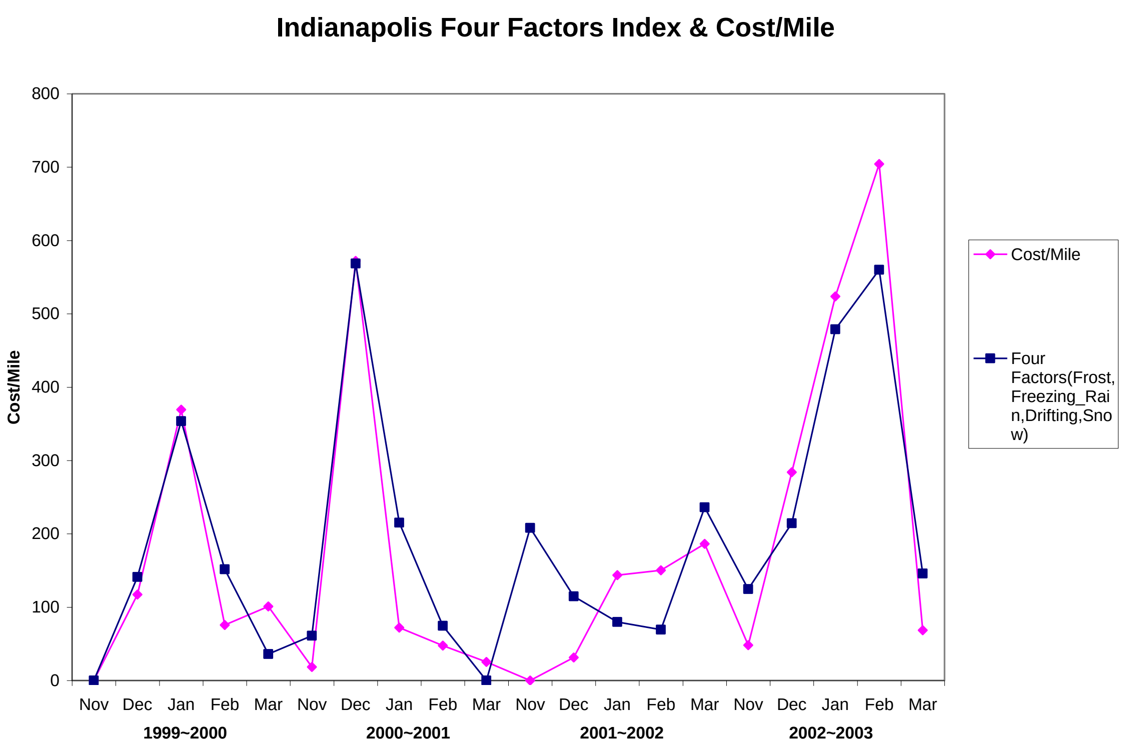

Figure 8 – Four Factor Index

Indianapolis Five Factor Index & Cost/Mile

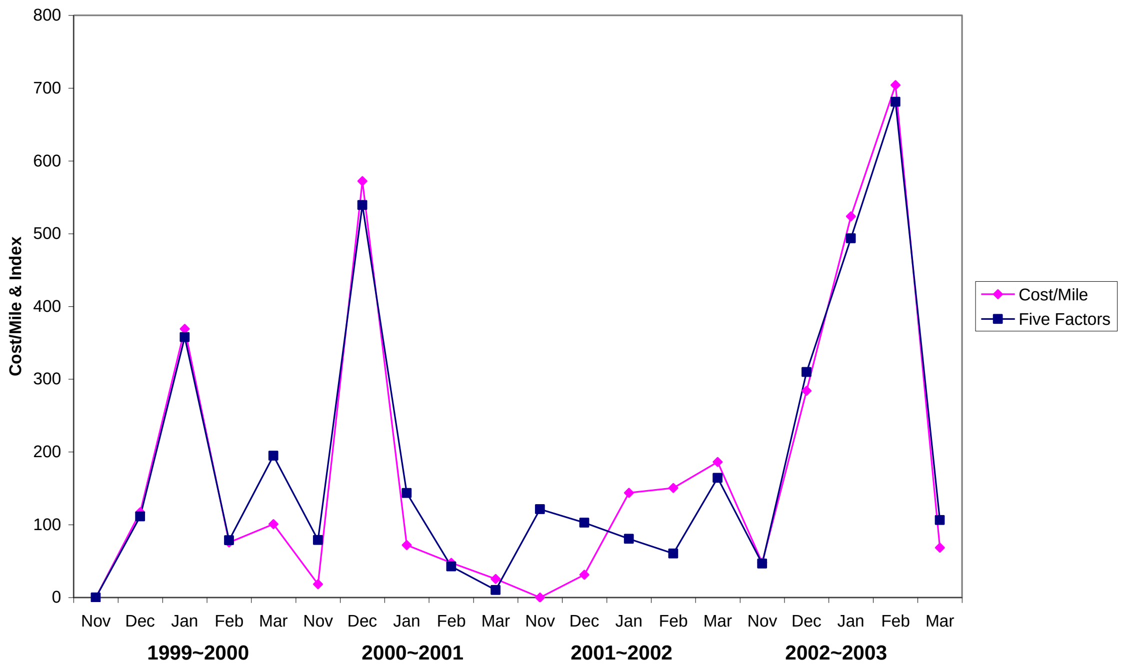

Figure 9 – Five Factor Index

Indianapolis Seven Factor Index & Cost/Mile

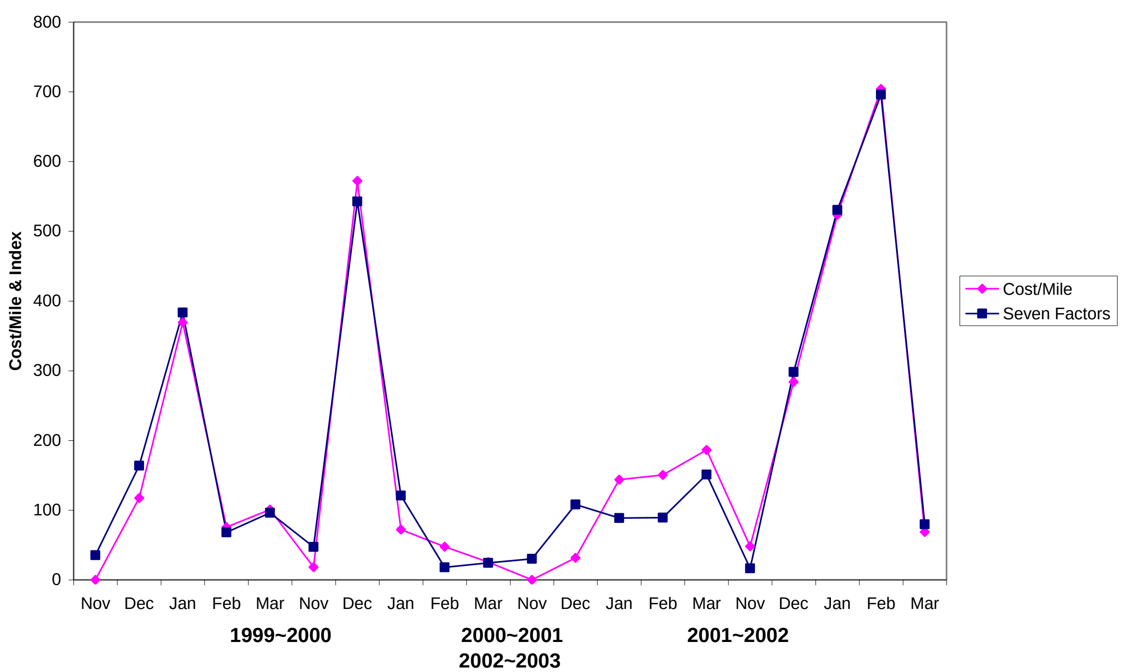

Figure 10 – Indianapolis Seven Factor

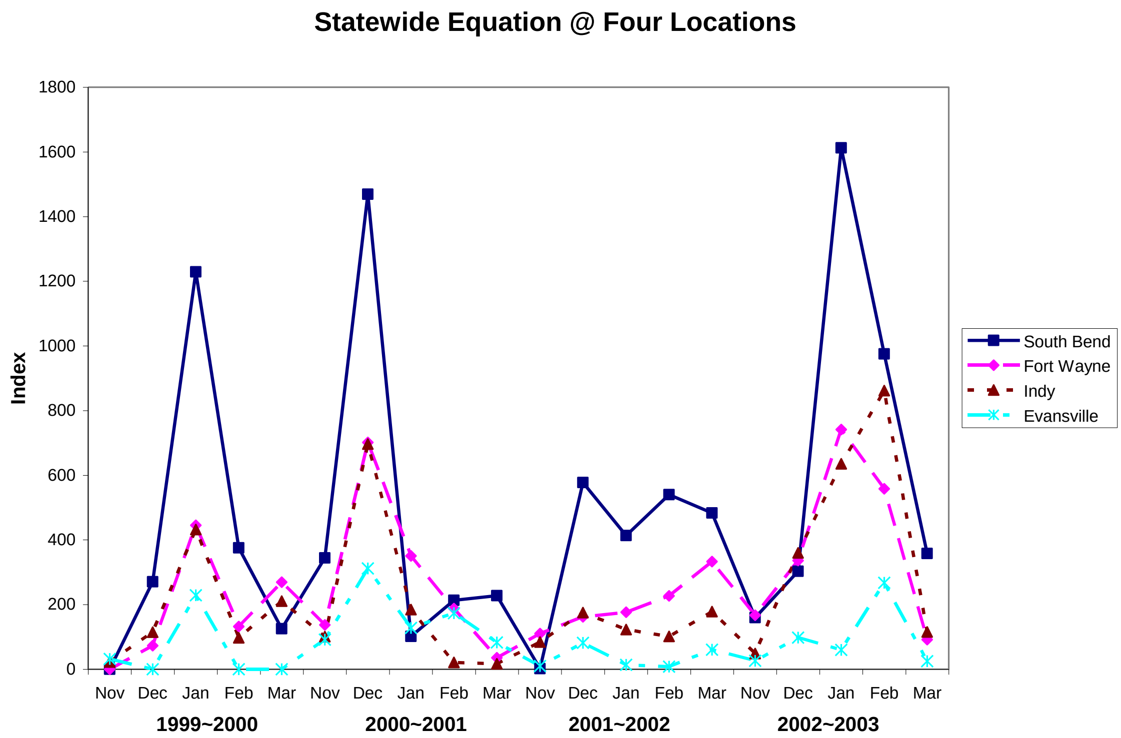

Figure 11 – Statewide Index

CONCLUSION

The equations derived from SAS correlate well with the lane mile cost. Only one is shown in this paper.

What can be done with the Winter Severity Index? One possibility is to use it to verify snow and ice removal expenditures. It may answer questions such as are new technologies reducing costs? The new technologies may include proactive snow fighting measures, additional higher-tech training, improved weather service information and a higher overall winter priority.

Another possibility is to use it for resource allocation. Are funds being spent where they are needed? Comparisons may be made between the WI and expenditures by climatic zones. Materials are easy to quantify, but do some zones need more money for manpower and equipment to provide comparable levels of service? The WI may also be used to justify expenditures or the need for additional funding.

There are several things that need to be looked at in further detail as a result of this research. How do the removal costs of heavy snowfalls compare with small snowfall events and freezing rain? Does the severity index capture these effects accurately? As the index is implemented other similar issues will be scrutinized by using the WI.

By obtaining and analyzing future winter data, the equations can be further refined and validated and will become more trusted and useful.

Total Storm Management Manual

The initial Total Storm Management (TSM) Manual was released on August 1, 2003. It was developed through a WOT subcommittee chaired by Rusty Fowler. Copies were distributed to all the Districts and it was available on-line at the INDOT intranet and at the JTRP website(www.purdue.edu/jtrp). This version consisted of 169 pages divided into the following nine chapters with an appendix that contains operating procedures, forms, reports, checklists, etc.

1. Purpose and Principles of Winter Maintenance Program
2. Administration and Management
3. Environmental Issues
4. Personnel Issues
5. Equipment
6. Snow and Ice Control Materials
7. Weather Information Systems
8. Storm Operations
9. Special Considerations

In 2009 a major revision to the TSM was performed. It was completed on October 19, 2009 and officially approved and released June 2010. It consists of 167 pages with revisions to all chapters and a new chapter added, Chapter 10 – Winter Operations Research.

Conclusion

Many different activities were performed through this project and are described in this report. It started as a Synthesis Study and the scope evolved over the years. The two major products were the development and use of the Winter Severity Index and the Total Storm Management Manual.

REFERENCES

1. Adams, Michael J., “Winter Severity Index,” Wisconsin DOT internal document, 2001.

2. Andrey, Li and Mills, “A Winter Index for Benchmarking Winter Road Maintenance Operations on Ontario Highways,” 80 th Annual Meeting Preprint CD-ROM, proceedings of the Transportation Research Board annual meeting, January 7-11, 2001, Washington, D.C.

3. Martinelli, Tom, Wisconsin DOT, personal interview, 2001.

4. Perry, A.H. and Symons, L.J., “SHRP H-350 Report, Road Weather Information Systems,” Vol. I, Highway Climatology.