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A Benefit/Cost Analysis of Intelligent Transportation System Applications for Winter Maintenance

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ABSTRACT

The primary purpose of winter highway maintenance is to provide vehicular traffic with a roadway surface that can be safely traveled. Roadway geometrics and an icy surface may create specific locations that are particularly susceptible to snow and ice related accidents. Revisions to roadway geometrics are very expensive, so problem areas typically become the responsibility of highway maintenance to mitigate the hazard by winter maintenance operations.

This paper explores the feasibility of incorporating an intelligent transportation system (ITS) method to assist maintenance operations at a high accident location on Interstate 90 in Washington State. The section of I-90 is located near Vantage, Washington just east of the Columbia River and is under the jurisdiction of the Washington State Department of Transportation (WSDOT), North Central Region. A portion of this corridor is highly prone to ice and snow related accidents. Only that portion is addressed in this paper.

It is proposed to address ice and snow related accidents by preventing the formation of ice on the roadway surface. The process explored by this paper is with anti-icing chemicals applied to the roadway surface by an automatic anti-icing system. This paper identifies the system costs, cost savings due to accident prevention and calculates a benefit cost ratio.

INTRODUCTION

The primary purpose of winter highway maintenance is to provide vehicular traffic with a roadway surface that can be safely traveled. Locations exist in most maintenance areas where roadway geometrics and an icy surface create hazardous driving conditions resulting in many snow and ice related accidents. Revisions to roadway geometrics are very expensive, so problem areas typically become the responsibility of highway maintenance to mitigate the hazard by winter maintenance operations.

One such area is located on Interstate 90 in Washington State. The section of Interstate 90 is located near Vantage, Washington, just east of the Columbia River and is under the jurisdiction of the Washington State Department of Transportation (WSDOT), North Central Region. A portion of this corridor is highly prone to ice and snow related accidents and is designated a high accident corridor (HAC).

Traditional winter maintenance methods of plowing and applying abrasives have not been effective at reducing the accident hazard. Anti-icing methods were implemented in 1998 with some positive benefit. However, maintenance crews have many lane miles to cover and are not able to effectively monitor weather and surface conditions within the HAC. To resolve this problem, it is proposed to install an automatic anti-icing system to apply anti-icing chemicals to the roadway surface when conditions warrant.

PROBLEM DESCRIPTION

Accidents

The HAC from SR 90 milepost 137.67 (east pavement seat of the Columbia River Bridge) to SR 90 milepost 138.49 is within the SR 26 Interchange area. Nineteen vehicle accidents occurred in this section in a three-year period from 3/1/94 to 2/28/97 (Table 1). Of the total accidents, ten (52%) occurred during the winter months from 11/1 through 2/28. One of the nine non-winter period accidents occurred on wet pavement. Accident history suggests that poor roadway surface conditions are a contributor to 42% of the total accidents and 70% of accidents during the winter period. Average daily traffic volume is 10,000 vehicles per day with 26% trucks (1). Truck accidents at this location commonly result in spilled loads that block and close both directions of SR 90 for several hours.

Geometrics

The alignment and profile of SR 90 through the study area consists of a 955 foot radius horizontal curve and a vertical alignment transition from 3% to 5% within the limits of the horizontal curve. The roadway cross section is two 12-foot lanes with a 10-foot shoulder in each direction. A 16-foot median is divided by barrier. A bridge overpass for an SR 26 ramp is also within the limits of the horizontal curve. Steep grades and short radius horizontal curvature are likely contributors to the accident problem in this area, particularly for westbound (down hill) traffic.

Topography

The Columbia River defines the topography of the site. The river flows in a channel approximately two miles wide. The walls of the channel are near vertical basalt formations rising over 500 feet above the river. SR 90 from the west dips into the river channel, crosses the river then turns north to climb out of the channel on the east side of the river. It is the curve to the north and part of the grade climbing out of the channel that make up the problem area.

Weather

Typical winter weather patterns are temperatures near freezing and moisture present from the river and weather systems passing through. Historically, in November, December, January, and February, the average high temperature is 40 degrees F., the average low temperature is 23 degrees F., average mean temperature is 31 degrees F., and the lowest temperature is 5 to 10 degrees F. below zero. Typical winter weather causing slippery roadway conditions is freezing rain or drizzle. The area normally receives two snow storms per winter. These storms generally deposit one to two inches of snow. Snow fall of four to six inches occur infrequently. The freezing rain is by far the most prevalent winter weather problem within the problem area. Average precipitation amounts are approximately 0.25 inches per week through the winter (2, 3).

Operations

Winter maintenance and operations procedures for the section are currently performed by the North Central Region crew based at George. A single plow/sander is deployed from the George shed each day and night shift to patrol approximately 210 lane miles of roadway. Up to three additional plows are called out to assist on an as needed basis. When freezing precipitation occurs, the winter maintenance emphasis is placed on the 5% grade described above (also known as Vantage Hill) and another steep grade section on SR 28 near Trinidad. Liquid chemical anti-icing products are used for pre-treatment prior to freezing weather events.

This method of winter maintenance is changing and evolving into a more proactive approach. During the winter of 1999-2000, the George maintenance crew experimented with an approach that depended on weather information, crew scheduling, and anti-icing chemicals. The frequency of road patrols was reduced to only when freezing precipitation was forecast or occurring. Results from proactive methods are encouraging, however areas such as the HAC described in this paper continue to cause problems for traffic and the maintenance crew.

SOLUTION

Anti-Icing System

The proposed solution for the snow and ice related accidents is an automatic anti-icing system from milepost 137.69 to 138.29. The limits include the 955 foot radius horizontal curve where most of the wintertime accidents occurred. An automatic anti-icing system would address snow and ice accidents by treating the roadway surface with a liquid chemical designed to lower the freezing point of water. The chemical prevents the bonding of ice to the roadway surface, prevents the formation of frost and black ice, and reduces the impact of freezing rain. In conjunction with the anti-icing system, a roadway weather information station (RWIS) would be installed. The RWIS monitors weather conditions, the roadway surface temperature, and the presence and concentration of chemical on the surface. The RWIS sends information to a computer controlling the anti-icing system. The system can be activated automatically to dispense liquid chemical when predetermined conditions are detected by the RWIS. The system can also be activated manually from a computer. The liquid chemical is dispensed through a network of nozzles mounted on the barrier and imbedded in the roadway. An alert is sent by the system to a dispatcher who can notify a maintenance supervisor that the system has dispensed chemicals. A camera, linked to the WSDOT computer network, would be installed in a location to view the performance of the anti-icing system remotely.

The total cost of installing the anti-icing system, RWIS, and camera is estimated to be $599,500. This cost includes design and construction engineering. Annual operations and maintenance costs are estimated at $32,800 (Table 2).

Problems

There are potential problems with the proposed solution. Liquid water on the roadway can refreeze due to dilution of the chemical and/or cold temperatures. Dilution could occur during heavy snowfall or heavy freezing rain events. Frequent applications of chemical from the system would be required to maintain chemical concentration levels high enough to prevent refreeze. Plowing and applying abrasives would help remedy the refreeze problem by removing excess snow and temporarily improving friction on the ice surface. Refreeze due to extreme cold temperatures that can occur in the area can be mitigated somewhat by applying abrasives. There is a potential for adverse reaction from motorists alarmed by an application as they pass through the area and motorists are concerned over corrosion from the chemical. Motorists reactions can be monitored by the video images recorded by the camera. The concern may be unfounded. Effects of corrosion on the SR 26 structure, which will received direct applications of chemical, could be a problem and should be monitored. Non-corrosive chemicals should be used. System malfunctions such as nozzles plugging from external debris or solids in the chemical could allow a refreeze condition.

ANALYSIS

Benefit Cost

The anti-icing system approach to solving the snow and ice related accidents is analyzed by the benefit cost ratio, where the present worth of benefits (PWOB) divided by the present worth of costs (PWOC) equals the b/c ratio. The PWOB, PWOC, and benefit cost ratio are calculated using the WSDOT Benefit/Cost Worksheet for Collision Reduction (Table 3). This worksheet was developed by WSDOT for user benefit analysis of highway safety improvements. Using this worksheet, a benefit cost ratio of 2.36 and a net benefit of $1,179,274 was calculated. This b/c ratio is very good and validates the viability of the proposed solution.

The following elements are determined and entered on the worksheet:

Project Cost

Project Cost is the estimated total cost to develop and construct the system. It includes the anti-icing system (control system, chemical storage tank, distribution lines, pump, and nozzles), RWIS, camera, connection to power and communications, Washington State sales tax, and design and construction engineering.

Operations and Maintenance Costs
Annual Operations and Maintenance Costs are the sum of materials, power, communications, weather forecast, training, and system maintenance (Table 3). The material is the liquid chemical. The amount needed per year was estimated by calculating the amount of chemical required to melt the expected freezing precipitation. The expected freezing precipitation was estimated to be half the weekly average winter precipitation, assuming that over a four-month period half the precipitation would occur during periods when air and surface temperatures were above 32 degrees F. It was determined, by using this method, that approximately 12,000 gallons of liquid chemical was needed to treat the 2.4 lane miles of roadway for a 16-week winter period.

Safety Benefits
Annual Safety Benefits are the estimated benefits of accident reduction. Only the snow or ice related accidents occurring during the winter time period over the three years were considered. The annual rate of collisions over a three-year period, categorized by collision type (fatality, disabling injury, property damage only, etc.), was determined and the expected rate of collisions after implementing the safety improvement was estimated. The after rate is determined by multiplying the annual collision rate by the resultant factor, which is the estimated percentage of collisions expected after the improvement is implemented. There is no history in Washington of the resultant rate of collision reduction accountable to an automatic anti-icing system. Therefore, a mid range resultant factor of 0.40 was initially used based on the assumption that most snow or ice accidents (60%) would be eliminated but not wet roadway accidents. Information from maintenance managers at Pennsylvania DOT, who have observed systems in place, indicates that accident reduction due to automatic anti-icing systems was closer to 100%. Given that information, further consideration was warranted. Allowing for wet pavement accidents and the possibility of ice related accidents during a refreeze or heavy snow conditions, a higher resultant factor of 0.20 was used. Thus it was presumed that 80% of the snow and ice related accidents would be eliminated.

Collision Costs
Costs Per Collision is the product of the cost of collisions, by type, and the annual safety benefit. The total of all category of collisions is the cost of collisions. The cost per collision type was determined by WSDOT.

Service Life and Salvage Value
Service Life and Salvage Value are derived from discussions with representatives of the private sector marketing automatic anti-icing systems.

Methodology
PWOC and PWOB are calculated by the spreadsheet using the present worth factor of a uniform series. The calculated benefit cost ratio and net benefit are the result of the worksheet (4).

IMPLEMENTING THE SOLUTION

Operational Changes

Incorporating an automatic anti-icing system in the region's winter maintenance program would require operational changes. Winter maintenance in the region is moving toward a proactive approach, using chemical anti-icing as a pretreatment for frost and winter storms. The automatic anti-icing system would be expected to assist with the mitigation of any freezing precipitation, needing assistance only in the form of snow plowing and applying abrasives during heavy freezing rain or snow events and extreme cold temperatures. Monitoring of the system and roadway conditions would occur at the area maintenance office or at the region dispatch office, who could alert the George maintenance crew if necessary. Weather conditions, pavement temperature, and chemical concentration would be monitored and appropriate action taken if conditions are moving toward a refreeze situation. Anti-icing of roads and ramps adjacent to the area covered by the anti-icing system would be accomplished by the maintenance section using their anti-icing trucks.

It is management's expectation that the use of abrasives will be significantly reduced resulting in less costs for materials cleanup from the roadway and drainage structures. Also, there should be a corresponding reduction in accidents in the area served by the anti-icing system as well as other region roadways where proactive winter maintenance practices are implemented. This is consistent with expectations from management that proactive winter maintenance results in an overall improved level of service by enhancing safety, mobility, and efficiency.

Training

All maintenance staff will need training on operation and monitoring of the system. Training on properties of the chemical used and the limitations of the chemical under various weather conditions is recommended. Supervisors should receive training on decision making with respect to a proactive winter maintenance program. Initial system training is provided by the anti-icing system and RWIS vendors.

Public Information

Public communication processes should be used to educate and inform the public of the anti-icing system and its benefits. A demonstration video should be available on the WSDOT internet site that shows the system in operation. Camera views from the site should be available on the internet site as are other camera images of the mountain passes and select roadways. Advisory signs warning of the potential for liquid spray should be erected on both sides of the area covered by the anti-icing system.

SUMMARY

The analysis indicates that the proposed automatic anti-icing system is a viable and cost effective method of reducing the snow and ice related accidents in the Interstate 90 HAC under evaluation. Benefit cost ratio is greater than two (2.36) and the net benefit is over one million dollars ($1,179,274). ITS solutions to winter maintenance and operations problems are considered experimental in Washington State. This project could be considered a model to evaluate for other areas on the state highway system prone to snow and ice accidents. Overall, this ITS solution has the potential to significantly reduce accidents within this high accident corridor and should be considered more practical than high cost alignment revisions.

REFERENCES

I. WSDOT Annual Traffic Report, 1999

II. Washington Climate for Grant, Kittitas, Klickitat, and Yakima Counties - Cooperative Extension Service, School of Agriculture, Washington State University, Pullman, WA, Publication EM4422, May 1979

III. Western Regional Climate Center, http://www.wrcc.dri.edu/

IV. A Manual on User Benefit Analysis of Highway and Bus-Transit Improvements - 1977, American Association of State Highway and Transportation Officials

TABLES

TABLE 1 Accident Data

<<< SR 26 Interchange Vicinity >>>

SR	CURR SRMP	DATE MM/DD/YY	TIME	MSEV	#INJ	#FAT	#VEH	VT #1	EH YPE #2	JUNCT RELAT	RDWY SURF	LIGHT COND	ACCIDENT DESCRIPTION
90	137.67	10/9/1995	23:40	1	0	0	1	6		NON INT	DRY	ST.LT	GUARDRAIL, SURFACE
90	137.68	4/21/1994	23:25	1	0	0	1	6		NON INT	DRY	DARK	LARGE DOMESTIC ANIMAL
90	137.71	4/1/1994	2:55	6	1	0	1	1		NON INT	DRY	DARK	CONCRETE BARRIER,SURFACE
90	137.71	7/7/1995	0:40	7	2	0	2	2	2	NON INT	DRY	ST.LT	SM DIR-ALL OTHERS
90	137.74	5/26/1995	20:35	1	0	0	2	1	0	NON INT	DRY	DUSK	SM DIR-B STR-B MOV-SDSWP
90	137.81	8/14/1994	0:30	1	0	0	1	6		NON INT	DRY	ST.LT	GUARDRAIL, SURFACE
90	137.87	3/14/1995	3:00	6	1	0	1	6		NON INT	WET	ST.LT	CONCRETE BARRIER,SURFACE
90	137.96	3/21/1995	9:05	1	0	0	1	1		NON INT	DRY	DAYLT	GUARDRAIL, SURFACE
90	138.27	9/22/1996	16:45	1	0	0	2	2	1	NON INT	DRY	DAYLT	SM DIR-B STR-B MOV-REND
										Winter Accidents			
90	137.69	12/29/1995	10:30	1	0	0	1	6		NON INT	SNOW	DAYLT	GUARDRAIL, SURFACE
90	137.81	11/7/1994	15:55	5	1	0	2	2	7	NON INT	DRY	DAYLT	OP DIR-B STR-B MOV-SDSWP
90	137.81	1/28/1997	3:05	5							* *SNOW*		HITS APPURTENANCE
90	137.91	12/29/1996	21:30	1	0	0	1	1		NON INT	SNOW	DARK	CONCRETE BARRIER,SURFACE
90	137.93	1/7/1995	17:25	6	1	0	1	2		AT INT	ICE	ST.LT	CONCRETE BARRIER,SURFACE
90	137.98	1/5/1995	6:01	6	1	0	2	6	6	NON INT	DRY	DARK	SM DIR-ALL OTHERS
90	137.98	1/5/1995	6:00	6	1	0	1	6		NON INT	DRY	DARK	CONCRETE BARRIER,SURFACE
90	138.11	12/24/1996	16:00	7	1	0	1	1		NON INT	ICE	DAYLT	CONCRETE BARRIER,SURFACE
90	138.3	11/20/1996	15:54	7	1	0	2	2	1	NON INT	SNOW	DAYLT	SM DIR-B STR-B MOV-REND
90	138.41	1/5/1996	21:35	1	0	0	1	2		NON INT	SNOW	DARK	GUARDRAIL, SURFACE

Severity Code:
- 1 Property Damage Only
- 5 Disabling Injury
- 6 Evident Injury
- 7 Possible Injury

* Data not recorded. Maintenance records indicate the roadway surface was compact snow and ice at this location at the time and date of the collision.

TABLE 2 Cost Estimates

Project Cost

1	**Automatic Anti-Icing System** (Control system, storage tank, pump, distribution lines, nozzles, training)		$450,000
2	**Roadway Weather Information System** (CPU, instrumentation, tower, training)		$50,000
		Subtotal	$500,000
3	**Washington State Sales Tax (8%)**		$40,000
4	**Power and Communications hookup**		$5,000
		Subtotal	$545,000
5	**Design and Construction Engineering (10%)**		$54,500
	Total Project Cost		**$599,500**

Annual Operations and Maintenance Costs

1	**Materials**	$28,000
2	**Power and Communications**	$400
3	**System Maintenance**	$1,500
4	**Weather Forecast**	$1,000
5	**Training**	$1,900
	Total	**$32,800**

TABLE 3 Benefit Cost Worksheet

BENEFIT / COST WORKSHEET
for Collision Reduction

Safety Improvement Location: SR: 90 MP 137.69 MP 138.29

Safety Improvement Description: Automatic Anti-Icing System

Evaluator: Date: 11/8/1999

1. **Initial Project Cost, I:** $599,500.00
2. **Net Annual Operations & Maintenace Costs, K:** 32,800
3. Annual Safety Benefits in Number of Collisions:

Collision Type	Before (historic) No.	Yrs.		Rate	- After (Estimated) Resultant Factor	Rate	=	Annual Benefit
a) Fatality	0.00	3	=	0.00	0.20	0.00	=	0.00
b) Disabling Injury	1.00	3	=	0.33	0.20	0.07	=	0.27
c) Evident Injury	1.00	3	=	0.33	0.20	0.07	=	0.27
d) Possible Injury	2.00	3	=	0.67	0.20	0.13	=	0.53
e) Property Damage Only	3.00	3	=	1.00	0.20	0.20	=	0.80

4. Costs Per Collision:

Collision Type	Cost
a) Fatality	$ 800,000
b) Disabling Injury	$ 800,000
c) Evident Injury	$ 62,000
d) Possible Injury	$ 33,000
e) Property Damage Onl	$ 5,800

5. Annual Safety Benefits by Costs of Collision:

a) (3a)(4a)	=	0
b) (3b)(4b)	=	213,333
c) (3c)(4c)	=	16,533
d) (3d)(4d)	=	17,600
e) (3e)(4e)	=	4,640
f) Total, B	=	252,107

6. Service Life, n = 10 7. Salvage Value, T = 20000 8 Interest Rate, i = 0.04

9. Present Worth of Costs, PWOC:

   b) Present Worth Factorof a uniform series, SPWin 8.11

   c) PWOC= I + K(SPWin)-T(PWni) 865,538

10. Present Worth of Benefits, PWOB=B(SPWin) 2,044,812

11. **Benefit Cost Ratio, B/C=PWOB/PWOC** **2.36**

12. **Net Benefit = PWOB-PWOC** 1,179,274