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Accident Analysis of Ice Control Operations

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The Salt Institute
Alexandria, Virginia

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Introduction

Highway maintenance involves all work necessary to assure that the highway system is kept safe, open to traffic, and in proper working order. During winter, the removal of snow and ice from streets, roads, and highways is a major maintenance operation. With more than 135 million motor vehicles registered in the United States and roughly four million miles of roads and streets, local governments must be prepared to deal with the removal of snow and ice to insure public safety, and to reduce the adverse impact on the affected area's economy.

Snow and ice covered roads can paralyze the functioning of the community and pose a considerable threat to the public safety. They produce hazardous driving conditions which increase traffic deaths, injuries, and property damage. The general assumption has always been that snow and ice on highways causes accidents. There are a number of reasons for this assumption. Snow and ice reduce the coefficient of friction between the pavement and vehicle tires, making maneuvering of the vehicle very difficult and occasionally impossible. Ice is not always apparent to the motorist and is not uniform, so that the driver is not always prepared when he encounters an icy section on the roadway. Vehicle mobility is reduced, causing possible severe disruption of important public emergency services, such as fire, police, and ambulance operations.

Without close attention to the effective removal of snow and ice from roads, the economy of the region involved will suffer, and traffic accidents will escalate. Most activities of individuals, industries, utilities, schools, and government activities are handicapped in social and economic ways during the duration of snow and ice conditions on roads and streets.

Prior to this research project there was not extensive or mathematically sound accident research on the effects of snow and ice control [1].

During the late 1980's the Technical University of Darmstadt in Germany completed an extensive research project [2] documenting the accident experience before and after winter road maintenance operations, and following a bare road pavement policy. The analysis of Horst Hanke and Christoph Levin covered over 4700 accidents including less than 1900 casualties, on about 650 Kilometers (400 miles) of roads outside built-up areas in four representative highway maintenance centers. The cost of property damage was about DM^6 55 million ($35 million). Salt was the only de-icing material used on these roads. The time was determined at which salt spreading took place, then an hourly accident analysis were conducted for 12 hours before and 12 hours after.

The result of their accident analysis is shown in Figure 1. Marquette University was approached in the Fall of 1990 by the Salt Institute to undertake a similar study, utilizing the same methodology of the German Study, but for one winter season, the winter of 1990-91 instead of for four years as was the German Study.

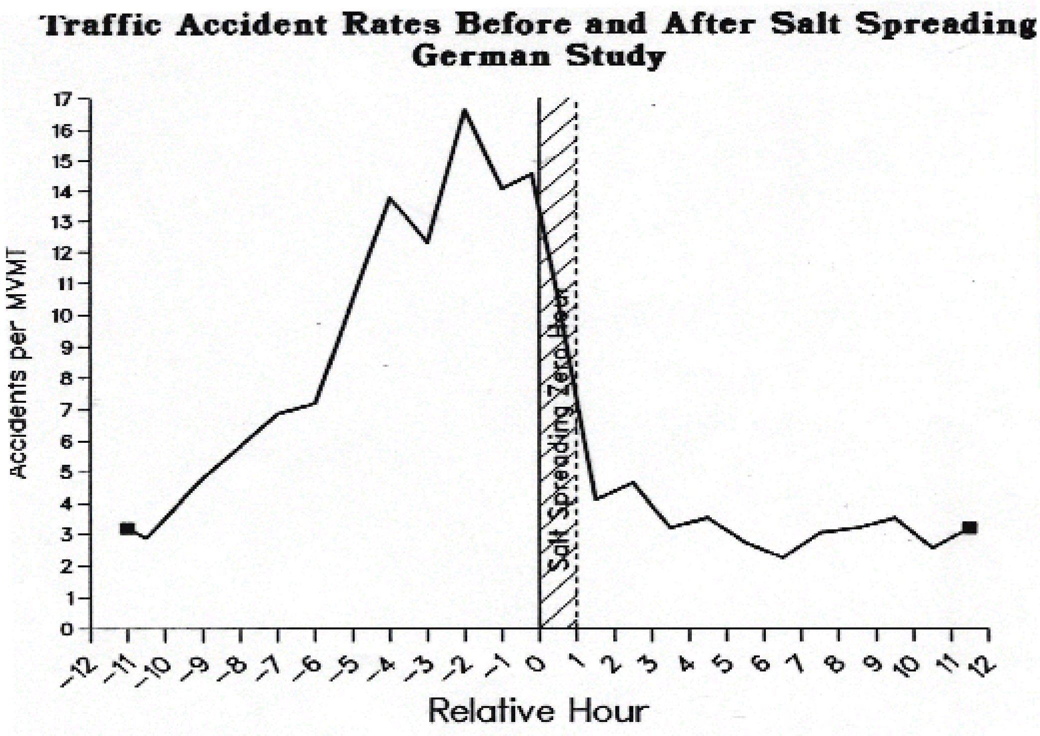

Traffic Accident Rates Before and After Salt Spreading
German Study
Accidents per MVMT
Salt Spreading Zero Hour
Relative Hour

Figure 1

METHODOLOGY

A. Highway Testing Sections:

A network of two-lane undivided and divided highways of approximately 520 and 50 miles respectively were selected randomly with the cooperation of authorities in New York (Wayne, Tompkins, Cortland, and Monroe Counties), Illinois (Ogle and Lee counties), Minnesota (Rochester and Stewartville Sub-areas), and Wisconsin (Walworth County).

1. Characteristics:

The 570 miles of highway networks consist of a total of 24 divided multi-lane and 102 undivided two-lane highway sections. The highway testing sections selected for analysis were primarily rural or suburban in character and had traffic volumes form 1000 Annual Average Daily Traffic (AADT) to approximately 30,000 AADT. Wherever a test section contained a variation in volumes, that was considered multiple sections.

a) Two-lane sections: The low number of weaving areas on these sections reduced any additional variables that would affect accident occurrences. Average lane width was 11 ft., average shoulder width was 4 ft., mostly level terrain, and few restrictions to through traffic by control devices. This eliminated any question about in which lane an accident occurred and whether the lanes were salted.

b) Freeway sections: Average lane width was 12 ft., divided highways, with 2 or 3 lanes/direction, and average shoulder width was 10 ft.

The highway test sections in each state are shown in Appendix 1.

2. Traffic Volumes:

Hourly traffic volume = AADT $\times$ M $\times$ D $\times$ H

Where

M	=	Monthly conversion factor
D	=	Daily conversion factor
H	=	Hourly index

In this project the 1990 AADT were provided from New York and Wisconsin and were calculated for Illinois and Minnesota. Monthly conversion factors were provided by all states.

-- 24-hour counts with hourly volumes for each testing section were provided by authorities in each respective area (New York, Illinois and Minnesota).

-- In Minnesota, 24-hour counts without hourly volumes were available for all testing sections. Hourly counts for 24 hours at similar nearby Automatic Traffic Recorder (ATR) Stations were provided. These counts were used as the base to calculate hourly indices for the testing sections , and these indices applied to AADTs to obtain hourly volumes.

Information needed to derive the monthly conversion factors for the traffic volumes in the testing areas was also provided by authorities in each respective area. Based on this information monthly conversion factors were obtained or calculated.

1) Day of the Week Conversion Factor:

All 24-hour traffic volume counts provided by highway authorities in the four states were based on Monday through Thursday counts. These counts were used as the average day of the week (Monday-Thursday) traffic counts. A simple approach was taken to decide if the day of the week conversion factors, were required for weekend traffic volumes. An analysis was made based on the following relationship

$$\text{Traffic Accident Rate} = \frac{\text{accident frequency}}{\text{traffic volume} \times \text{highway length}}$$

and the following generated cases:

1. 24 hour count between noon Thursday and noon Friday
2. 24 hour count between noon Friday and noon Saturday
3. 24 hour count between noon Saturday and noon Sunday
4. 24 hour count between noon Sunday and noon Monday

A comparison was made between the above generated cases and the provided traffic volume. The following four results were likely for each of the preceding cases:

1. Under estimation of ADT and over calculation of accident rate.
2. Under estimation of ADT and over calculation of accident rate.
3. Over estimation of ADT and under calculation of accident rate.
4. Over estimation of ADT and under calculation of accident rate.

The number of over estimation cases was 43 for two-lane highways and 34 for freeways. The number of underestimation cases was 41 for two-lane highways and 39 for freeways. Since the numbers were nearly the same, there was minimal effect from not using day of the week conversion factors.

2) Hour of the Day:

Hourly factors were generated from the hourly volumes provided or from ATR data nearby, as follows:

$$\text{Hourly index}_{(K)} = \frac{\text{Volume of Hour } K}{\text{Total Volume for 24-hour period}}$$

b) Snow Traffic Volumes:

For every snowstorm, the hourly traffic volume was measured at the ATR and compared to the normal hourly traffic volume for the same location during a similar day, and at the same hour, month and year. From the comparison, hourly reduction factors were derived for the testing sections in that area during the snow storm, in order to estimate vehicle miles of travel.

In Tompkins County, NY ATR stations were not available. Traffic volume reduction factors were derived based on similar weather conditions existing at nearby ATR locations. These factors were used in calculating the hourly traffic volume during similar snowstorms in Tompkins County, NY.

Reduction factors ranged from 0.80 to 1.0 with snow fall amounts less than three inches. Factors of from 0.71 to 0.95 were used for snow falls of three inches or more.

B. Time of Salt Application

Participating areas in New York, Illinois, and Wisconsin have been using salt as the common deicing material. At temperatures below 25^{o} participating areas in

1. New York has been using mainly a mixture of Salt - $CaCl_2$ or in some cases abrasives-salt mixture when necessary.
2. Wisconsin and Illinois have been using $CaCl_2$ to prewet salt.

The participating highway agencies in Minnesota have been using abrasive-salt mixtures independent of temperature range. In New York, a few events were selected in which salt and abrasives were mixed (a ratio of from 10 to 30% salt to total mix).

For almost all two-lane highways, salt or salt/abrasive mixtures are usually applied to the middle third of the two-lane pavement and the high side of super-elevated curves in all participating areas. In most cases the trucks spread salt one way and plowed on return or the reverse of this procedure depending on snow fall. The numbers of applications vary by condition. In all participating test areas the average number of applications per average storm was 2.6.

In New York State, keeping a record of each snow and ice control field operation is part of the participating highway maintenance work activities. A copy of the snow and ice control records, which contain information such as route number, section code, start and end time of the snow and ice field operation, section length, type of action, and quantity of deicing material used, was provided for each snowstorm. Records containing date of the snowstorm, start and end of the snowstorm, start and end time of work, temperature range, type of snow and depth of snow were also provided for each snowstorm by the authorities in each participating area in New York State.

In other participating areas a simple form was designed to serve the purpose of this research project. Route number, section code, start and end time of the snow and ice field operation, section length, and type of action were requested by the designed form to be reported. Records containing date of the snowstorm, start and end of the snowstorm and end time of work temperature range, type of snow, and depth of snow were provided on a separate form for each month of the researched period . An events calendar is contained in Appendix 2.

The resultant combination of test sections (each with a uniform volume) and events (winter maintenance activity periods) resulted in sub-events which totaled approximately 4600 and are broken down by jurisdiction in Table 1.

Test Sections, Events, Sub-Events by State and Location

	New York				Illinois		Wisc.	Minn	Total
County	Tompkins	Wayne	Monroe	Cortland	Ogle	Lee	Walworth	Rochester & Stewartville	All
Test Sections									
2 Lane	35	31			7	3	16	10	102
Freeway			14	4	2		2	2	24
Events	63	46	24	60	8	6	14	5	226
Sub-Events									
2 Lane	2205	1426			56	18	224	50	3979
Freeway			336	240	16		28	10	620

Table 1

C. **Compilation of Accident Rates:**

The methodology was as follows:

1. For each testing section, the last salt spreading time was determined during each snowstorm (zero hour).

2. For each testing section, hourly intervals were taken backwards and forwards (up to 12 hours) from the spreading time (zero hour).

3. For each testing section, traffic volume and accidents were compiled separately for each hourly interval. Total accidents are shown in Table 2.

4. For each testing section, vehicle miles of travel (VMT) were calculated for each hourly interval.

5. For all testing section the VMT and accidents of the same relative hourly interval were totaled and traffic accident rates calculated.

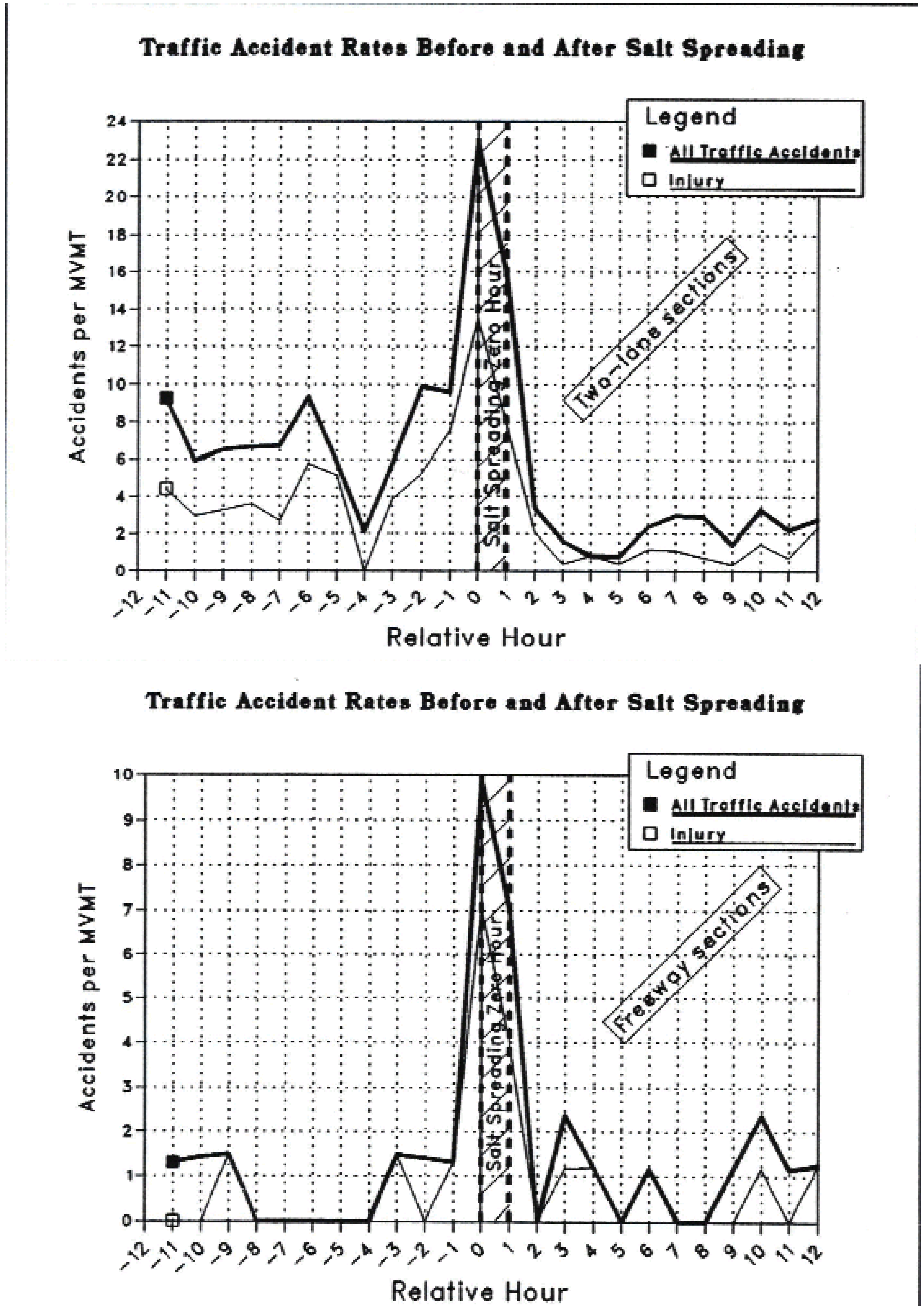
Accident Frequency on Test Sections		
Participating Areas	Traffic Accidents on	
	Two-Lane Testing Sections	Freeway Testing Sections
Walworth County, WI	24	2
Wayne County, NY	75	--
Tompkins County, NY	136	--
Cortland County, NY	--	4
Monroe County, NY	--	12
Ogle County, IL	17	2
Lee County, IL	2	--
Stewartville Sub-Area, MN	4	6
Rochester Sub-Area, MN	4	--
Total	262	26

Table 2

D. **Before and After Accident Analysis:**

The before and after accident rates are shown graphically in Figure 2 for two-lane and freeway test sections.

An analysis of before and after accident rates was conducted to determine the significance of difference using sound statistical methods. The "Poison" method the "Paired t" test and a more recent and conservative statistical significance test referred to as the "Revised Decision Criteria" (Weed) [3] were conducted. All three tests showed significant difference for the before and after accident rates for each hourly period "after" selected (from 1 to 12 hours) when compared to the equivalent hourly period (one to 12 hours) "before" on TWO LANE HIGHWAYS at the 99% confidence level. A summary of statistical significance is shown in appendix 3. Because the sample size and hence accident frequency was smaller on Freeways, the same hourly comparison showed a significant difference only for the first four hours, and only at the 95% confidence level, still significant however. Details of the statistical analysis are contained in the dissertation for the degree of Doctor of Philosophy for one of the co-authors [4].



Traffic Accident Rates Before and After Salt Spreading
Legend
All Traffic Accidents
Injury
Accidents per MVMT
Salt Spreading Zero Hour
Two-lane sections
Relative Hour
Traffic Accident Rates Before and After Salt Spreading
Legend
All Traffic Accidents
Injury
Accidents per MVMT
Salt Spreading Zero Hour
Freeway sections
Relative Hour

Figure 2

A limited amount of data was gathered in a similar fashion on the use of abrasive/salt mixtures and is shown in Figure 3. Because the data was insufficient (in number of incidents) no further analysis was made and they were not included in the accident analysis benefit/cost calculations.

E. Benefit Cost Analysis

A benefit/cost analysis of snow and ice control operations using salt only as a deicer was performed. The analysis used only direct benefits of accident reduction and savings in vehicle operating costs and travel time and direct costs.

The time period selected for benefit cost analysis was done very conservatively, and for the period of greatest accident significance. Hence for two-lane highways, only the four hours before/after reduction was utilized, although from Figure 2 it can be seen that added benefit accrued through accident reduction beyond four hours. For Freeways only the two hours before/after reduction was used, but extension beyond two hours is not much different.

Table 3 shows the before and after accident rates for two-lane highways and freewayss.

Rate (Per MVMT)	Salt Spreading		Reduction in (%)
	Before	After	
All Accidents	12.72	1.65	87
Fatal	--	--	--
Injury	7.98	0.93	88
Property Damage	4.74	0.72	85
Accident Costs	$625,000	$74,000	88
Average ($/Accident)	$49,000	$44,000	10

Two Lane Highways (4 Hours Before and After Only)

Rate (Per MVMT)	Salt Spreading		Reduction in (%)
	Before	After	
All Accidents	5.47	1.21	78
Fatal	--	--	--
Injury	4.10	0.61	85
Property Damage	1.37	0.60	56
Accident Costs	$316,000	$49,000	85
Average ($/Accident)	$57, 500	$45,500	30

Freeways (2 Hours Before and After Only)

Table 3

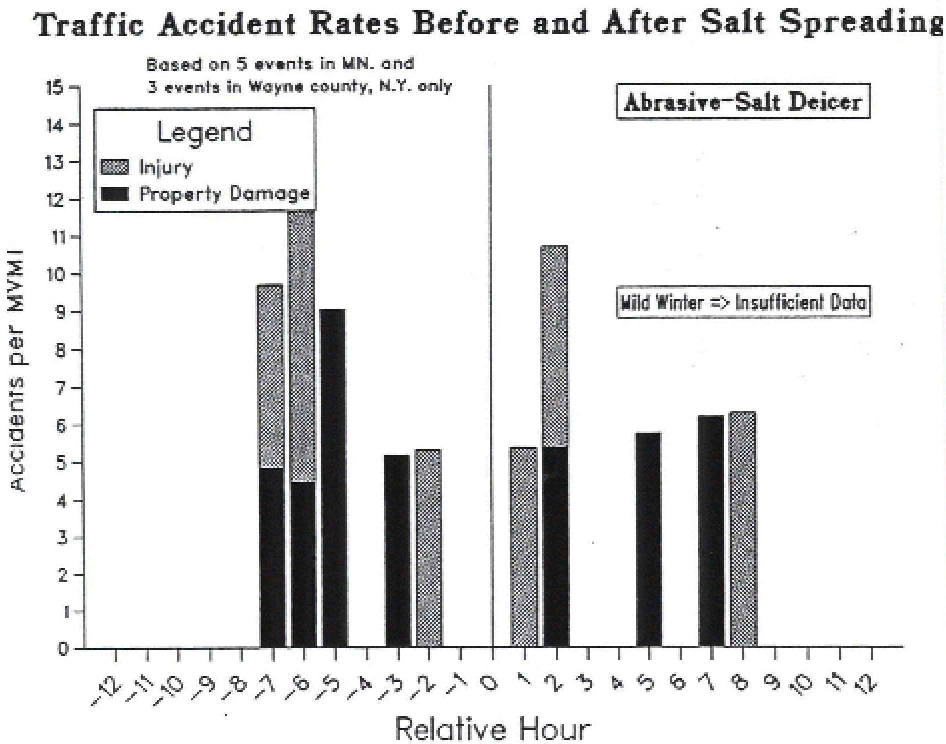


Figure 3

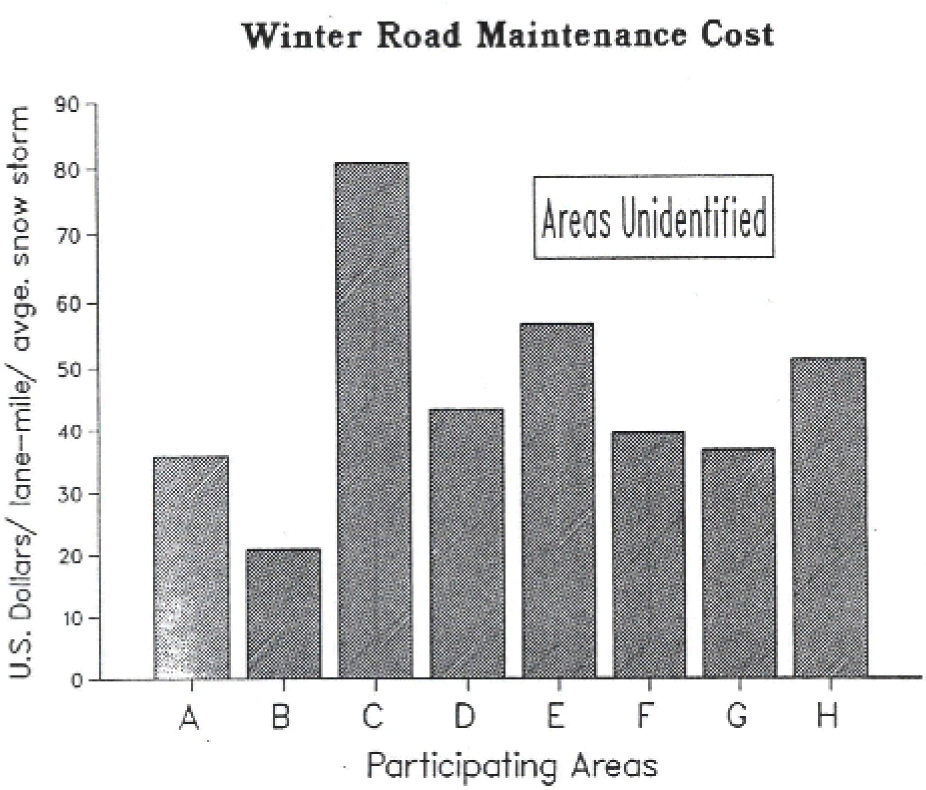


Figure 4

Direct benefits measured in this study were those of accident reductions. A recent FHWA study [5] was used for the cost of accidents. The 1991 Federal Highway Administration study used accident cots which include medical expense, emergency services, workplace costs, travel delay, property damage and administration and legal out of pocket expenses. It also included the cost of wages and household production, the cost of pain, suffering and lost quality of life.

Estimates used by the National Safety Council [6] are substantially lower for injuries and fatalities, but the more recent estimates were used because of the apparent thoroughness and currentness of the FHWA study and the fact that a conservative approach was used in limiting the cost benefit period to only four hours for freeways when discussing results in the conclusion.

Other direct user benefits of travel time and operating cost savings were calculated using established AASHTO Procedures [7] but were not directly measured in this study. For the savings due to snow and ice control operating costs, Claffey's work in 1976 [8] was used. The differences in gasoline consumed between snow covered or icy pavements and bare pavement in gallons per mile traveled, adjusted for travel speed and multiplied by vehicle miles of travel, were used to calculate excess fuel consumption. The average price of gasoline by geographic region for that time period was also used to arrive at the savings in operating costs. Other vehicular operating and fixed costs were not considered.

The other user benefit calculated but not measured was travel time. Time savings were estimated using a conservative speed reduction assumption of 10 MPH on two-lane highways (25% of their average normal speed) and 10 MPH on freeways (15% of their average normal speed). This was more conservative than the speed reductions measured in prior work [9]. The value of travel time of $3.00 in 1975 [7] was inflated by using the Gross National Product (GNP) index rather than the Consumer Price Index (CPI) since this resulted in a more conservative estimate of travel time savings of $6.65 per hour for 1990.

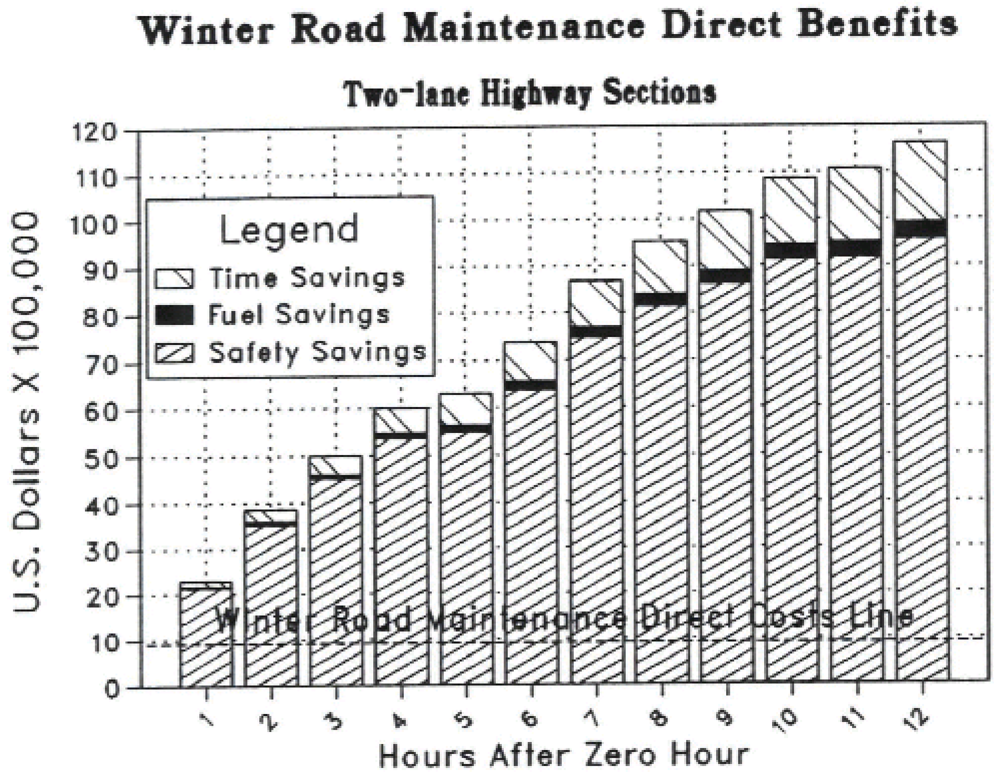
The direct cost of winter maintenance operations, includes direct labor, fringe benefits, material, equipment operation and amortization, and any other cost included as a direct cost by the states, including in some cases supervision, dispatching etc., but excluding any indirect costs. The data was gathered for the entire winter in each maintenance district along with total lane miles of highway and total number of events involved in each district and is shown in Figure 4. This was averaged for the districts utilized and an average unit cost in $ per lane mile per operation calculated. This unit cost was then applied towards the number of events and lane miles of test sections used in each district to arrive at a cost figure for all operations. This was a conservative estimate for purposes of this research since it was the cost of an "average" storm. Major storms impacted this average cost (increasing the average cost) but the major storms were not used for this research. So the costs are somewhat overstated (conservative) for that reason.

The results of the total (cumulative) benefits in U.S. dollars are shown in Figure 5 for both two-lane highways and freeways. The results are also shown in Table 4.

TOTAL OPERATING COSTS BEFORE AND AFTER						
Cost Category	Two-Lane Highways[1]			Freeways[2]		
	Cost (Cents per Vehicle Mile)			Cost (Cents per Vehicle Mile)		
	Icy	De-iced	Variation	Icy	De-Iced	Variation
Accident	62.5	7.4	-55.1	31.6	4.9	-26.7
Time	22.2	16.66	-5.6	13.3	11.1	-2.2
Operational	73	6.1	-1.2	8.6	7.8	-0.8
Total	92.0	30.1	-61.9	53.5	23.8	-29.7

[1]Four hours before and after
[2]Two hours before and after

Table 4


Winter Road Maintenance Direct Benefits
Two-lane Highway Sections
Legend
Time Savings
Fuel Savings
Safety Savings
Winter Road Maintenance Direct Costs Line
U.S. Dollars X 100,000
Hours After Zero Hour

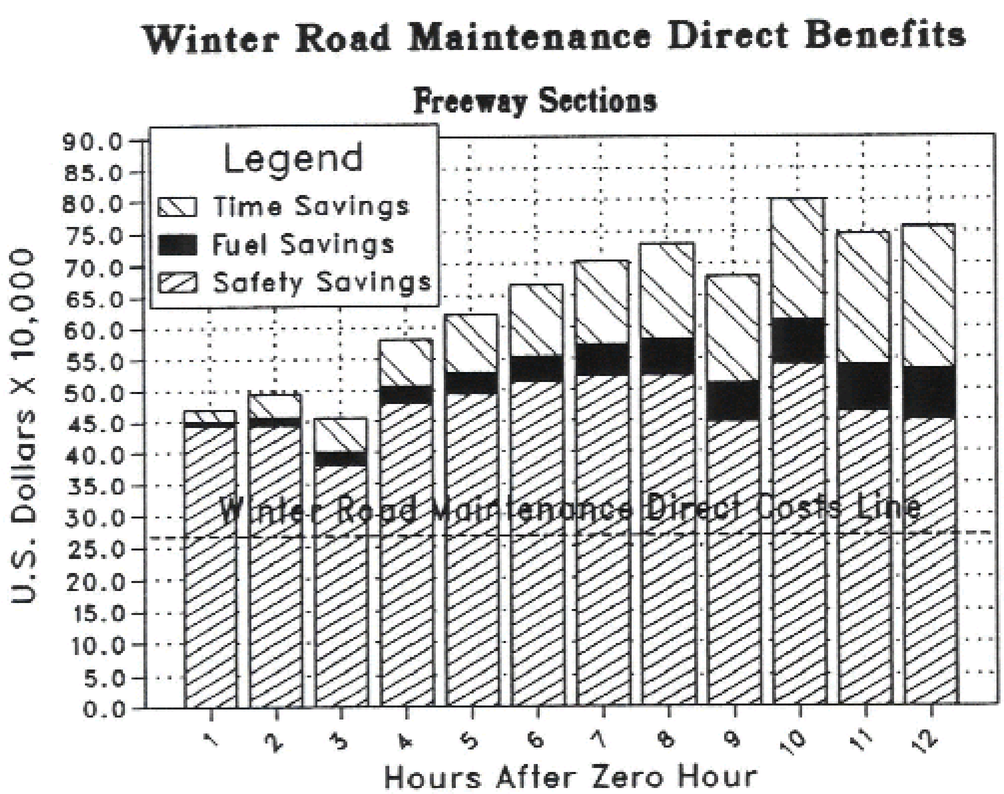

Winter Road Maintenance Direct Benefits
Freeway Sections
Legend
Time Savings
Fuel Savings
Safety Savings
Winter Road Maintenance Direct Costs Line
U.S. Dollars X 10,000
Hours After Zero Hour

Figure 5

CONCLUSIONS

Results very similar to those in Germany occurred in this study. Differences between the highway network utilized in Germany and in the USA resulted in differences in the shape of the hourly accident rate curve. The reason for the difference is that in Germany the maintenance districts analyzed had responsibility for all roads including local roads. Hence there was a longer time period involved from the beginning of snowfall to completion of the entire operation - local roads priority followed arterials. In this research study most two-lane highways (except approximately one-third of the test sections in Walworth County, Wisconsin which were County Trunk Highways) were state highways. Hence they had a higher priority. From observations made by the researchers the time of applications closely followed the time of the ice conditions on the highway, since all the test sections were major or minor arterials (or in the case of Walworth County, Wisconsin, some collectors) and none were local roads.

The conclusions are summarized under the appropriate highway type. All rates are in accidents or injuries per million vehicle miles of travel (MVMT). No fatalities occurred before or after.

TWO-LANE HIGHWAYS

1. Winter maintenance using salt or salt and $CaCl_2$ only as deicers, reduced accidents as follows (comparing only 4 hours before and after, which were most significant).

    a) The rate for all traffic accidents before salt spreading is about eight times higher than that after (12.72 accidents/MVMT before and 1.65 accidents/MVMT after);

    b) The rate for injury traffic accidents is about nine times higher than that after (7.98 injury accidents/MVMT before and 0.93 injury accidents/MVMT after);

    c) The rate for property damage (PD) traffic accidents is about seven times higher than that after. (4.74 PD accidents/MVMT before to 0.72 PD accidents/MVMT after);

    d) The severity of traffic accidents is reduced. The ratio of injury to property damage accident rates before (7.98/4.74 or 1.68) is about 30% higher than the same ratio after (.92/.72 or 1.29).

2. Winter maintenance reduced traffic accident costs from "before" to "after" by 88% and reduced the average cost of an accident by 10%.

    a) Traffic accident costs rate before was $635,000/MVMT (62.5 cents/VMT) and the cost rate after was $74,000/MVMT (7.4 cents/VMT).

    b) The average cost of an accident before was $49,000 and after $44,000.

3. Travel time costs were reduced from 22.2 cents to 16.6 cents/VMT and operational costs reduced from 7.3 to 6.1 cents/VMT. Total direct operating costs were reduced from 92 cents/VMT to 30.1 cents/VMT.

4. Winter maintenance resulted in direct user benefits much greater than the direct maintenance cost.

    a) During the first four hours after zero hour, (only the most significant) the direct road user benefits were $6.50 for every $1.00 spent on direct maintenance costs for the operation.

    b) The average direct costs are offset by direct benefits as soon as 71 vehicles have driven over the highway.

    c) The winter road maintenance service pays for itself within the first 25 minutes of the first one hour after salt spreading zero hour.

MULTI-LANE DIVIDED FREEWAYS

5. All rates are in accidents or injuries per million vehicle miles of travel (MVMT). Winter maintenance using salt or salt and CaCl only as deicer reduced accidents as follows (comparing only two hours before and after, which were most significant.

    a) The rate for all traffic accidents before salt spreading is about 4.5 times higher than that after (5.47 accidents/MVMT before and 1.21 accidents/MVMT after);

    b) The rate for injury traffic accidents is about seven times higher than that after (4.10 injury accidents/MVMT before and 0.61 injury accidents/MVMT after);

    c) The rate for property damage (PD) traffic accidents is about two times higher than that after. (1.37 PD accidents/MVMT before to 0.60 PD accidents/MVMT after);

    d) The severity of traffic accidents is reduced. The ratio of injury to property damage accident rates before (4.10/1.37 or 3.0) is about 200% higher than the same ratio after (.61/.60 or 1.0);

6. Winter maintenance reduced traffic accident costs from “before” to “after” by 85% and reduced the average cost of an accident by 30%.

    a) Traffic accident cost rates before were $316,000/MVMT (31.6 cents/VMT) and the cost rate after was $49,000/MVMT (4.9 cents/VMT).

    b) The average cost of an accident before was $57,500 and after $45,500.

7. Travel time costs were reduced from 13.3 to 11.1 cents/MVT and operational costs reduced from 8.6 to 7.8 cents/VMT. Total direct operating costs were reduced from 53.5 to 23.8 cents/VMT.

8. Winter maintenance resulted in direct user benefits much greater than the direct maintenance cost.

    a) During the first two hours (only the most significant) after zero hour, the direct road user benefits were $3.50 for every $1.00 spent on direct maintenance costs.

    b) The average direct costs are offset by direct benefits as soon as 280 vehicles have driven over the roadway.

    c) The winter road maintenance service pays for itself within the first 35 minutes of the first one hour after salt spreading zero hour.

9. Inconclusive results from salt and abrasive mixtures were obtained due to limited experience. The results are shown in Figure 10. Major effort on the scale of this test is recommended for further research.

10. This methodology is suggested ass a state-of-the-art for cost benefit analysis of deicing efforts.

11. Research on the indirect benefits of winter maintenance is noticeably lacking and should be addressed with a substantial study like that of the indirect costs of ice control [10].

This report is based on a doctoral dissertation submitted to Marquette University (Milwaukee, WI) Graduate School by Rashad M. Hanbali [4]. For a more thorough discussion of the methodology, readers are referred to the 305 page dissertation.

REFERENCES

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(4) Hanbali, Rashad M., (1992), "Influence of Winter Road Maintenance on Traffic Accident Rates," Doctoral Dissertation, Department of Civil and Environmental Engineering, Marquette University, Milwaukee, WI, 1992.

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(9) Welch, Robert H., Etal, "Economic Impact of Highway Snow and Ice Control, "National Pooled Fund Study, FHWA Report RD-77-20, Washington, D.C., 1976.

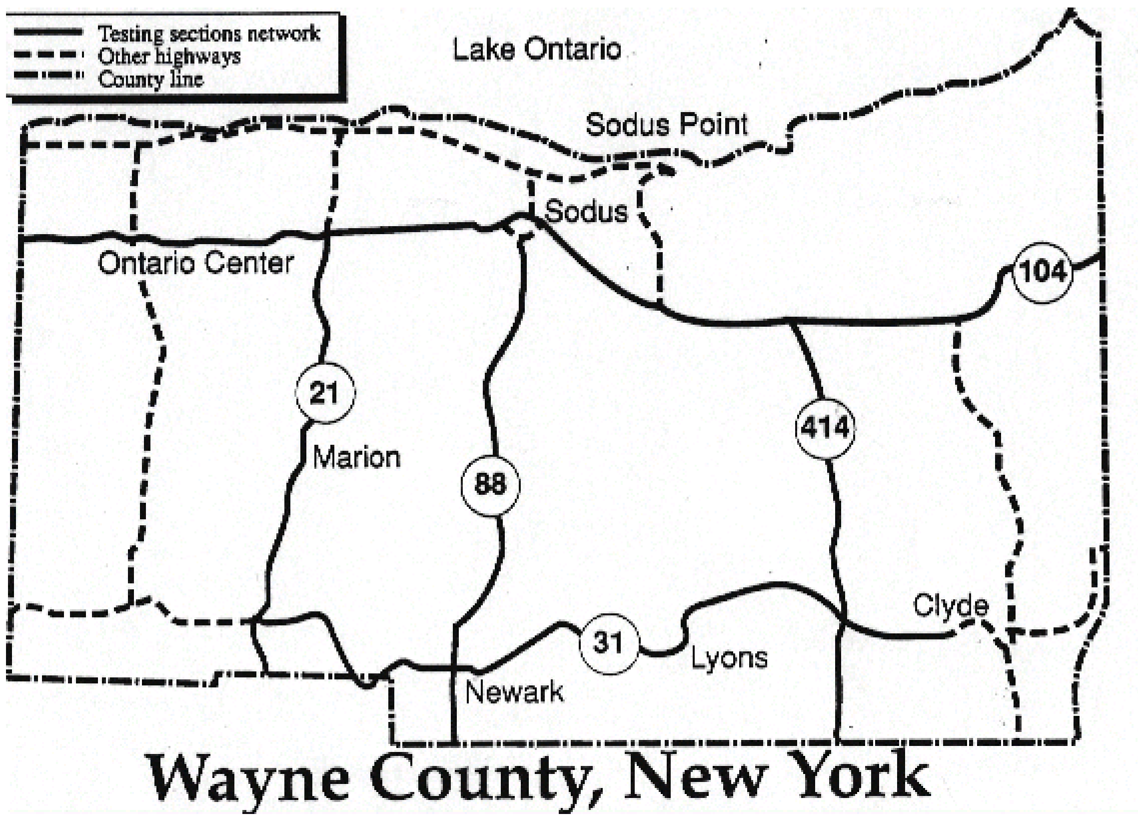
(10) Transportation Research Board, "Highway Deicing," Special Report 235, Washington, D.C., (1991).

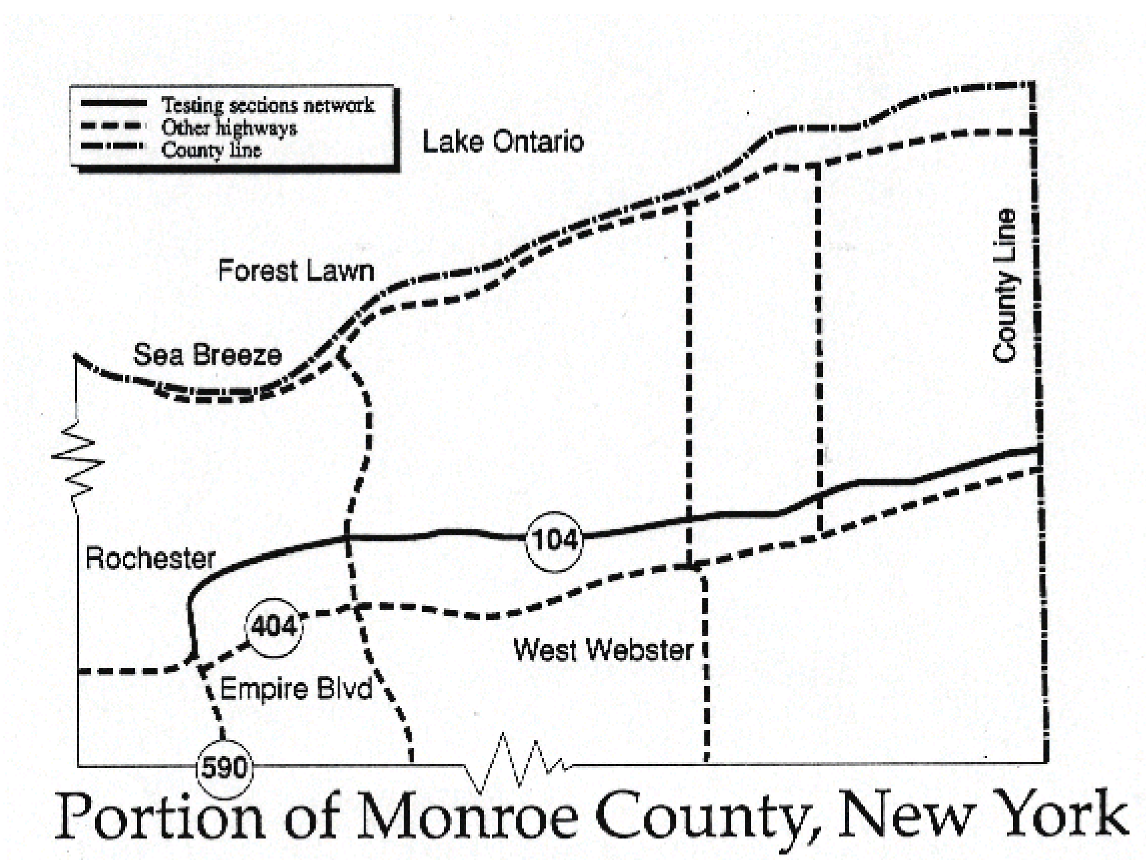
Appendices

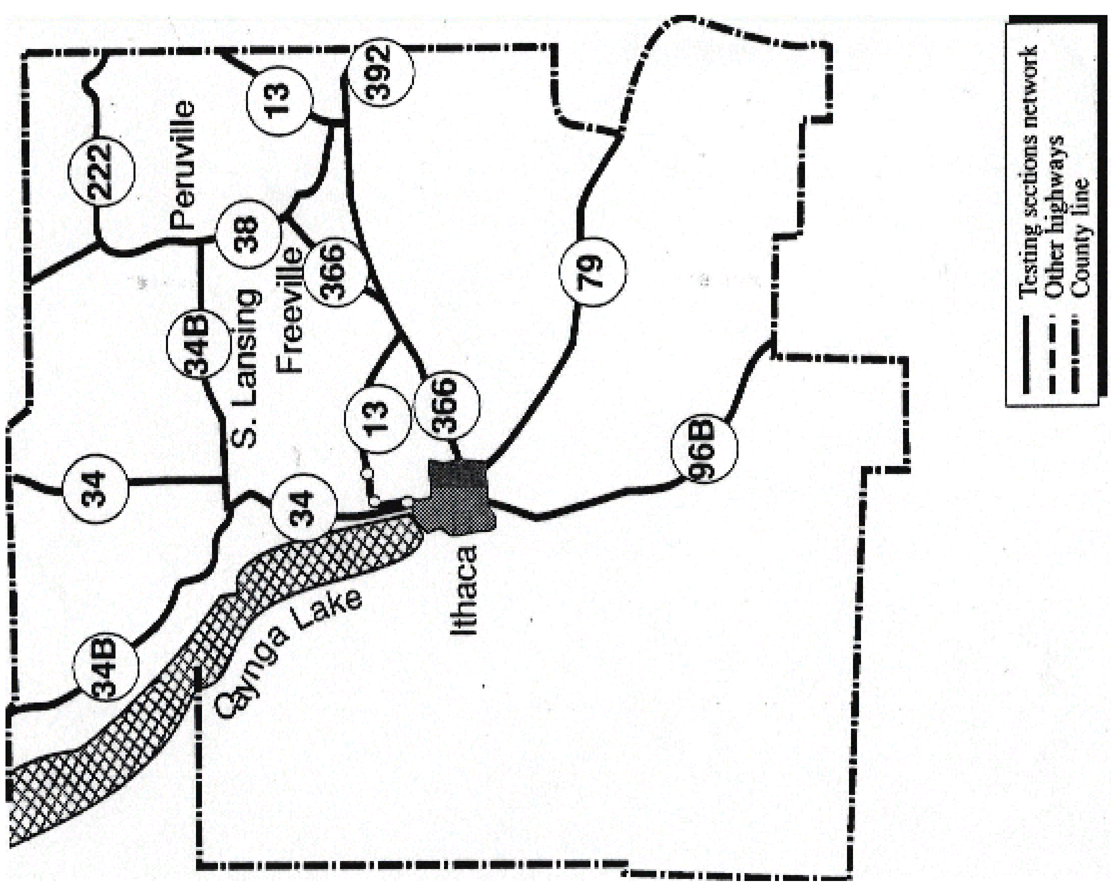
1. Test Section Maps (4)
2. Events Calendars (4)
3. Summary of Statistical Significance (4)

Appendix 1

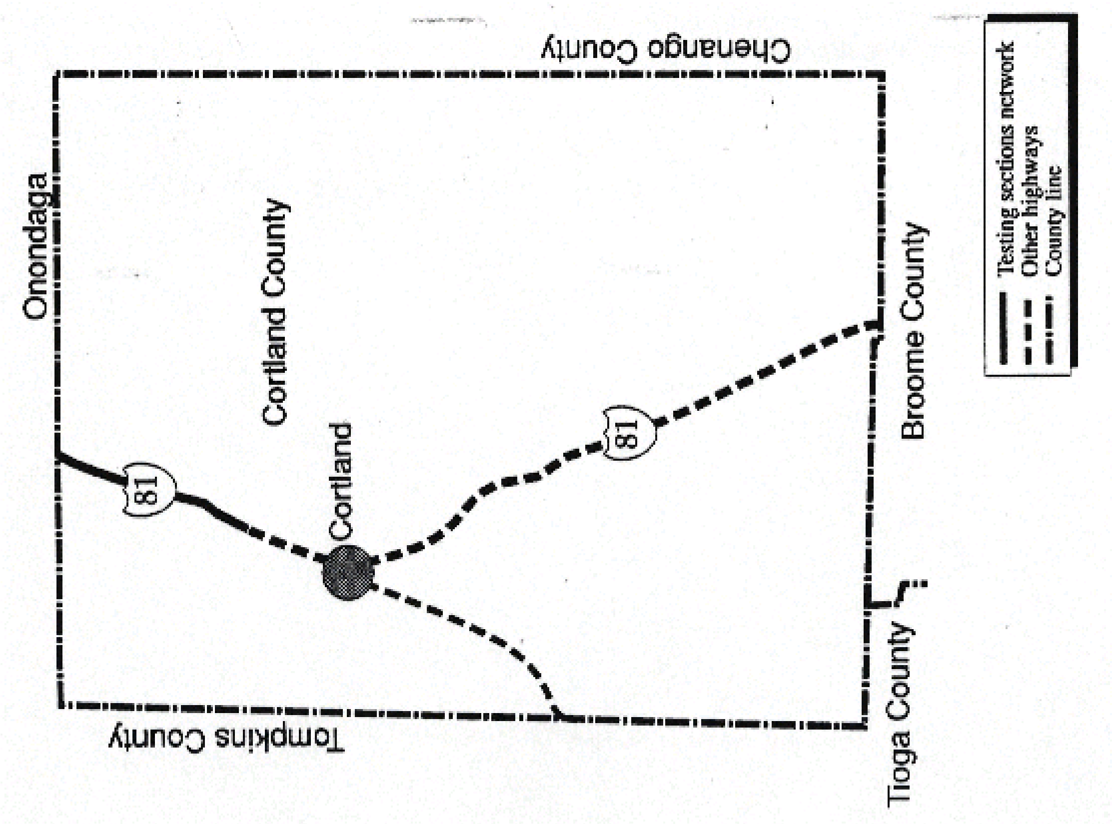
Test Section Maps



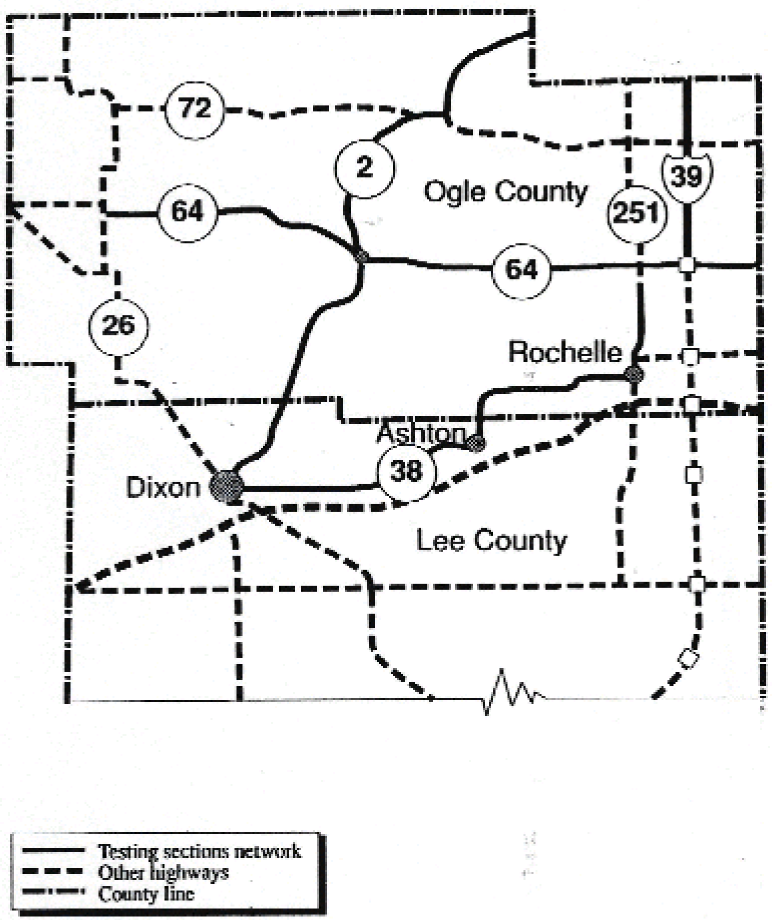




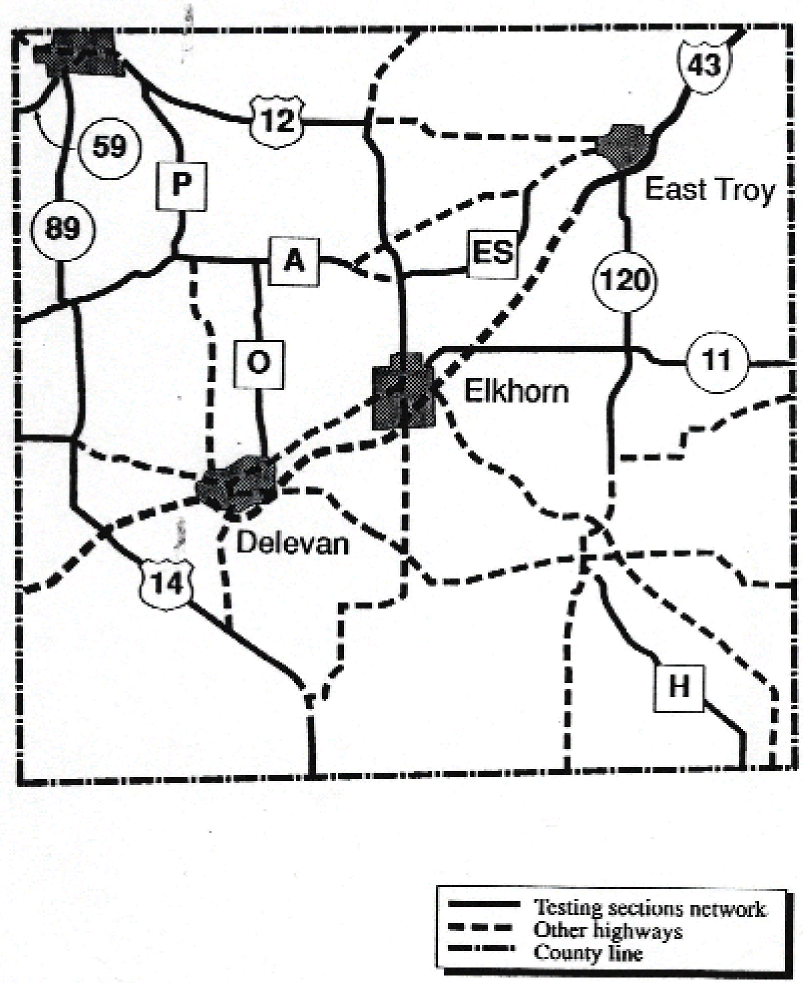
Tompkins County, New York



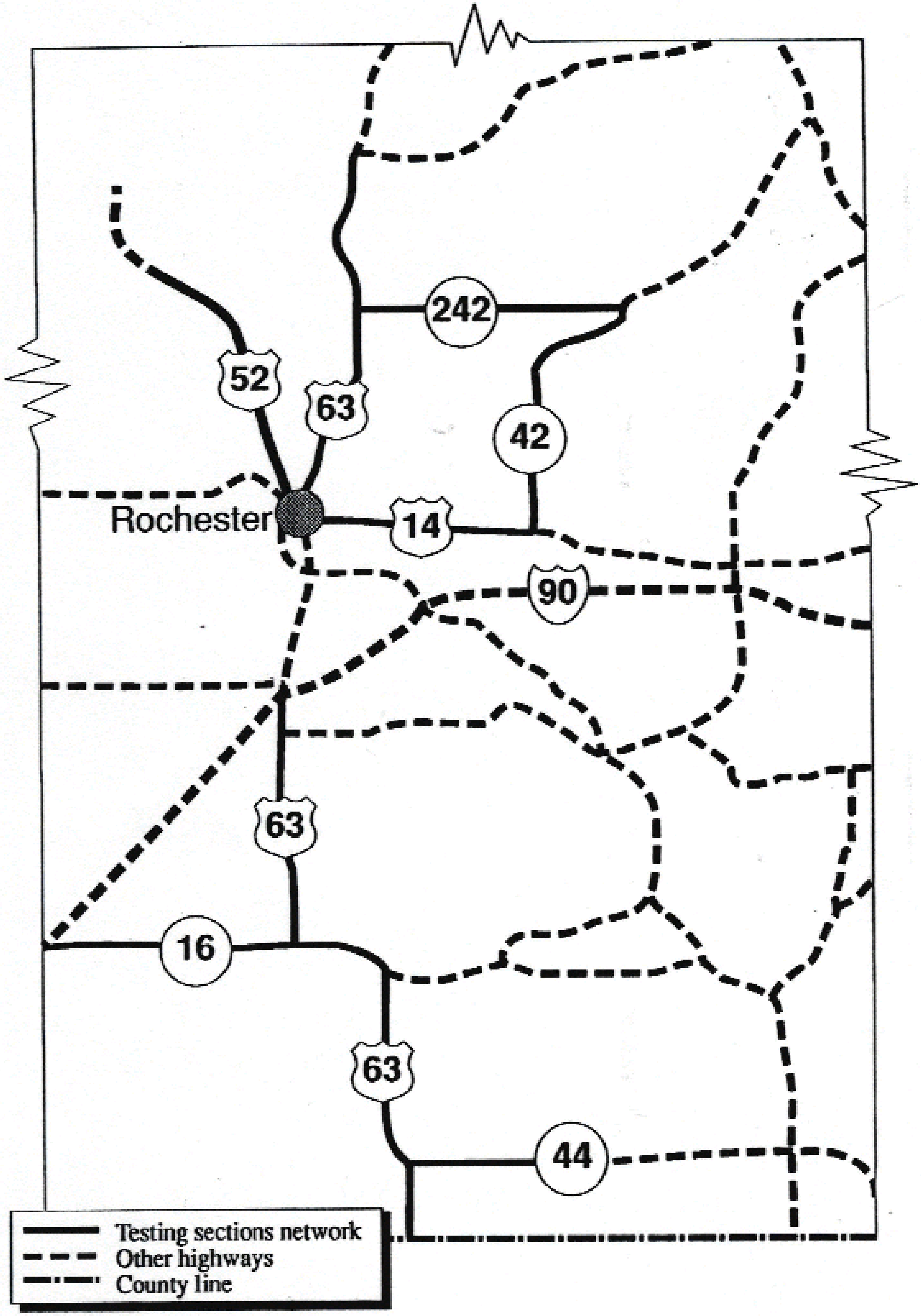
Cortland County, New York



Ogle and Lee Counties, Illinois



Walworth County, Wisconsin



Rochester and Stewartville Sub-areas, Minnesota

Appendix 2

Events Calendars

INFLUENCE OF WINTER ROAD MAINTENANCE ON TRAFFIC ACCIDENT RATES STUDY

EVENTS CALENDAR OF SNOW STORMS USED AT (Wayne, Tompkins, and Cortland Counties) NEW YORK STATE
1989 - 1990

	DECEMBER					JANUARY					FEBRUARY				MARCH			
SUN		3 NW NT NC	10 NW	17 NC	24	31 NW NT	7 NC	14 NW NT NC	21 NW NT	28 NC	4 NT NC	11	18	25 NW NT	4 NW	11	18	25 NW
MON		4 NW NT NC	11 NW NT	18	25 NW NT	1 NW NT	8	15 NT NC	22 NW NT NC	29 NW NT NC	5 NT NC	12	19	26 NT	5 NW NT	12	19 NW	26 NW
TUE		5 NW	12 NW NT NC	19 NW NT NC	26 NW NT	2 NW NT	9	16	23 NT NC	30 NW NT	6	13	20	27 NW	6 NT	13	20 NW NT	27
WEN		6 NT NC	13 NW NC	20 NW NT NC	27 NW NT	3 NT	10 NT	17	24 NT NC	31	7	14 NW	21	28 NW NC	7	14	21 NT	28
THU	30 NT NC	7 NT NC	14 NW NC	21 NT	28 NT	4	11 NT NC	18 NW NC	25 NT NC	1 NC	8	15 NW	22	1 NW NC	8	15	22 NW NT	29
FRI	1 NT NC	8 NT NC	15 NC	22 NT	29 NT	5	12 NT NC	19 NW NC	26 NT NC	2 NT NC	9	16 NW NT	23 NW NT	2 NW	9	16	23 NW	30
SAT	2 NW NT	9	16 NC	23 NT	30 NW NT	6 NC	13 NW NT NC	20 NT	27	3 NT	10	17 NW NT	24 NW NT	3	10	17	24	31

* NC = Cortland County, New York. - Total number of events = 22

* NT = Tompkins County, New York. - Total number of events = 32

* NW = Wayne County, New York. - Total number of events = 24

** An event covers 12 hours before and 12 hours after the salt spreading applications during any one snow storm.

INFLUENCE OF WINTER ROAD MAINTENANCE ON TRAFFIC ACCIDENT RATES STUDY

EVENTS CALENDAR OF SNOW STORMS USED AT (Wayne, Tompkins, Cortland and Monroe Counties) NEW YORK STATE

1990 - 1991

	DECEMBER				JANUARY					FEBRUARY				MARCH				
SUN	2	9	16 NT NC	23 NW NT	30 NT	6 NW NT NC NM	13 NW NT NC NM	20 NC	27 NW NC NM	3	10 NC	17 NW NM	24 NW NC NM	3 NW NM	10	17 NC	24	31
MON	3 NW NT	10	17 NT NC	24 NW NT NC	31 NT NC	7 NT NM	14 NW NT NC NM	21 NC NM	28 NW NC NM	4	11 NT NC NM	18 NT NC	25	4 NW NT NC NM	11	18 NC	25	
TUE	4 NW NT	11 NW NT NC	18	25 NW NT NC	1 NC	8 NW NT NM	15 NC	22 NC NM	29 NC NM	5	12 NW NT NC NM	19 NT NC	26 NT NC	5 NW NT NC NM	12	19 NC	26	
WED	5 NW NC	12 NW NT NC	19	26 NW NT NC	2 NW NT NC NM	9 NW NT NC NM	16 NC	23 NM	30 NT NC NM	6	13 NW NT	20	27 NT NC NM	6	13 NC	20	27	
THU	6 NC	13 NT NC	20	27 NW NT	3 NW NT NC NM	10 NT NC	17 NT NC NM	24 NT NC NM	31 NT NC NM	7	14 NW NT NC	21	28 NW NT NC NM	7 NW NC NM	14 NW NT NC	21	28	
FRI	7	14 NT NC	21	28 NW NT	4	11 NW NT NC NM	18 NW NT NC NM	25 NT NC NM	1 NT NC	8	15 NC	22 NT	1 NW NC	8 NW NC NM	15 NW NT	22	29 NC	
SAT	8	15 NT NC	22	29	5 NW NT NC NM	12 NW NT NC NM	19 NW NC NM	26 NC	2	9	16 NW NM	23 NW NT NC NM	2	9	16	23	30 NC	

* NW = WAYNE COUNTY (22 events), * NT = TOMPKINS COUNTY (31 events), * NC = CORTLAND COUNTY (38 events), * NM = MONROE COUNTY (24 events).

INFLUENCE OF WINTER ROAD MAINTENANCE ON TRAFFIC ACCIDENT RATES STUDY

EVENTS CALENDAR OF SNOW STORMS USED AT THE PARTICIPATING AREAS IN ILLINOIS, MINNESOTA, AND WISCONSIN STATES

1990 - 1991

	DECEMBER				JANUARY					FEBRUARY				MARCH				
SUN	2	9	16	23	30	6	13 MN	20	27	3	10	17	24	3	10	17	24	31
MON	3	10	17	24	31	7	14 MN	21	28	4	11	18 MN	25	4	11 WW	18	25	
TUE	4	11	18	25	1	8 WW IL	15 WW IL	22	29	5	12	19 MN	26 WW IL	5	12 WW IL MN	19	26	
WED	5	12	19	26	2	9 WW IL	16 WW IL	23	30	6	13 WW IL	20 WW	27 WW IL	6	13 IL MN	20	27	
THU	6	13	20	27	3	10 WW IL	17	24	31	7	14 WW IL MN	21 WW	28	7	14	21	28	
FRI	7	14 WW	21 WW	28 WW	4 IL MN	11 WW IL	18 WW	25	1	8	15 MN	22	1	8 WW	15	22	29	
SAT	8	15 WW	22 WW	29 WW	5 IL MN	12 WW	19 WW	26	2	9	16	23	2	9 WW	16	23	30	

* IL = OGLE & LEE COUNTIES, IL. (7 events), * MN = ROCHESTER & STEWARTVILLE SUB-AREAS, MN. (5 events), * WW = WALWORTH COUNTY, WI. (14 events).

** An event covers 12 hours before and 12 hours after the salt spreading applications on all the testing sections during any one snow storm.

Appendix 3

Summary of Statistical Significance

INFLUENCE OF WINTER ROAD MAINTENANCE ON TRAFFIC ACCIDENT RATES STUDY Statistical analysis results of accident rate reductions occurring on two-lane highway test sections								
(Z) Hours in comparison	Traffic Accidents Before	**Level of Confidence = 99% (Level of Significant = 0.01)**						Overall Y/N or Partial
		Poisson test		**Paired t-test**		**Revised Decision**		
		Rate Reduction (%)	Y/N	$P_{calculated}$	Y/N	$Change_{Critical}$ (%)	Y/N	
1	49	85.3	Y	----	----#	44.9	Y	Y
2	68	84.9	Y	0.0004	Y	38.2	Y	Y
3	85	86.7	Y	0.0000	Y	34.7	Y	Y
4*	94	87.1	Y	0.0002	Y	33.0	Y	Y
5	97	83.7	Y	0.0000	Y	32.0	Y	Y
6	105	80.6	Y	0.0000	Y	30.5	Y	Y
7	118	79.0	Y	0.0000	Y	29.7	Y	Y
8	128	79.1	Y	0.0000	Y	28.1	Y	Y
9	139	76.8	Y	0.0000	Y	27.3	Y	Y
10	151	75.9	Y	0.0000	Y	25.8	Y	Y
11	163	74.4	Y	0.0000	Y	25.2	Y	Y
12	184	73.9	Y	0.0000	Y	23.4	Y	Y
Y = significant, N = Not Significant, # = Not a reliable result high variance (see Appendix C), * = Most Significant								

INFLUENCE OF WINTER ROAD MAINTENANCE ON TRAFFIC ACCIDENT RATES STUDY Statistical analysis results of accident rate reductions occurring on freeway test sections							
(Z) Hours in comparison	Traffic Accidents Before	**Level of Confidence = 95% (Level of Significant = 0.05)**					Overall Y/N or Partial
		Poisson test		**Paired t-test**	**Revised Decision**		
		Rate Reduction (%)	Y/N		$Change_{Critical}$ (%)	Y/N	
1	7	100.0	Y	NOT APPLICABLE BECAUSE OF THE LOW NUMBER OF ACCIDENTS OCCURRED IN THE BEFORE PERIOD ON THE FREEWAYS TESTING SECTIONS	70.0	Y	Y
2*	8	78.0	Y		70.0	Y	Y
3	9	71.0	Y		70.0	Y	Y
4*	10	74.4	Y		70.0	Y	Y
5	10	66.8	Y		70.0	N	P
6	10	67.8	Y		70.0	N	P
7	10	68.3	Y		70.0	N	P
8	10	60.7	Y		70.0	N	P
9	10	45.3	N		70.0	N	N
10	11	43.2	N		72.7	N	N
11	12	40.8	N		66.7	N	N
12	13	38.2	N		61.5	N	N
Y = Significant, N = Not Significant, * = Most Significant							