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Weather in the Infostructure

prepared for

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February 4, 2003

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■ Introduction

The Federal Highway Administration (FHWA) Office of Operations is currently investigating the overall information data requirements necessary to support a minimum level of management and operation of the transportation system in real time. This proposed network of data collection and dissemination for system management is known as the Infostructure. To date, the FHWA has identified three primary areas where the Infostructure is relevant: 1) Congestion Management; 2) Security Management; and 3) Weather Response. Providing traveler information to system users is considered a cross-cutting function that supports the other three.

All road users and operators are affected by weather and its impacts on road conditions, and hence have a need for weather and road condition information (also known as road weather information). A recent analysis of weather impacts by Mitretek shows that an average of 6,500 fatalities and 450,000 injury accidents occurred annually during adverse weather between 1995 and 2001. Adverse weather also has significant costs in terms of delay and travel time, particularly in major metropolitan transportation networks that are already operating at or near capacity. Speed reductions of 10 to 25 percent are experienced in wet pavement conditions and 30 to 40 percent reductions are experienced on snowy or slushy pavements. These reductions translate into significant reductions in roadway capacity and increases in travel delay of up to 50 percent. The economic impacts of weather events are significant in terms of both public expenditures (24 percent of all road operating costs are for winter maintenance) and economic impacts. Both the general public and transportation operating agencies have indicated a desire for better information on the impacts of weather on travel conditions.

Specific information needs vary considerably by user and by weather event. The complexity behind the generation of timely and accurate road weather information means there are many steps in the processing of the data, as well as numerous sources of data that support these processes. There also may be more than one way to provide the end users with their road weather information needs. There are two primary reasons for collecting weather-related data: 1) for real-time response to observed weather conditions; and 2) to feed traffic-related models for prediction purposes. For the purpose of this paper, the basic system design consists of the traditional approach of installing fixed sensors along the roadway with limited connectivity to the meteorological community. Clearly this approach is changing rapidly in the real world, and future studies will incorporate these changes.

This paper addresses the Weather Response component of the Infostructure. Its primary purpose is to discuss the fundamental data needs of the weather Infostructure component, and to estimate an aggregate cost for national deployment of road weather data collection systems. It does this by first documenting a methodology for determining the number of Road Weather Information System (RWIS) sensors (sometimes called "environmental sensing stations," or ESS) needed across the country to support basic road weather needs, and then documenting a methodology for determining the cost. The paper does not address the information systems needed to convert the sensor data into timely, accurate, and relevant road weather information for specific users. It is also important to note that RWIS represents only one method of collecting information on weather and roadway conditions; it is important that transportation agencies have a wide range of sources available.

The national focus of the Infostructure covers the following areas:

- Metropolitan areas with populations greater than one million;
- Critical military routes and infrastructure;
- Critical evacuation routes; and
- Rural and statewide coverage.

This paper concentrates on metropolitan areas with populations greater than one million, of which there are 61 according to the latest census information.[1]

Weather Data Needs and Requirements

In building a methodology, it is important to understand who uses or, more importantly, who could use weather data and why. Currently, weather information is available from both the National Weather Service and numerous private vendors. Many transportation agencies also have their own weather sensors used primarily to support snow removal and winter maintenance activities. None of these sources is considered adequate to fully address the weather information needs of transportation operators. Forecasts and information obtained from outside sources are generally not of high enough resolution for transportation agencies to actively manage and operate their transportation systems, or they are not tailored into a format that is readily useable by road users and operators.

A variety of weather events impact the surface transportation system, including snow, ice, wind, heavy rain, and fog. Events such as snow, ice, and flooding require immediate

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[1] Information on critical military routes and infrastructure was unavailable to the authors. Coverage across rural and statewide areas is well documented and underway. There are approximately 1,200 environmental sensor stations deployed along the roadside nationwide, primarily in rural areas.

mobilization of weather and/or emergency response crews. Advance information on these as well as other events, such as heavy fog, can aid motorists in avoiding potentially catastrophic crashes. Accurate, reliable, and timely weather information, presented in a readily useable format, is key to realizing the significant benefits that come from an agency's ability to respond more proactively (e.g., anti-icing) and more effectively.

Road weather information typically requires three major components: 1) environmental sensor stations that collect field data; 2) processing equipment and software at a traffic management center; and 3) the communications infrastructure between them. These components are part of the overall ESS infostructure that would be integrated with other sources of meteorological forecasts and traffic management center operations. Costs of environmental sensor stations vary with the number and nature of data elements being collected. Areas experiencing harsh winter weather will have different, and probably more expensive, requirements than warm-weather areas because harsh weather requires more data. The cost of communications infrastructure will vary depending on proximity to the center and the availability of existing infrastructure.

Weather information is extremely valuable to many constituencies, including maintenance managers, weather response managers, traffic operations managers, emergency responders, the traveling public, and private enterprise. Table 1 provides a partial list of specific weather data elements and their potential users. [More information on weather data elements can be found in the report titled Surface Transportation Weather Decision Support Requirements, found at: http://www.its.dot.gov/welcome.htm EDL# 12143.]

Table 1 Weather Information and Data Needed by Users

Data Needed	Maintenance Managers	Travelers/ Commercial Users	Traffic Managers	Emergency Responders
Current pavement temperature	•	•	•	•
Forecasted pavement temperature	•		•	
Current pavement condition	•	•	•	•
Forecasted pavement condition	•	•	•	•
Current precipitation	•	•	•	
Forecasted precipitation	•	•	•	•
Wind speed	•	•	•	•
Forecasted wind speed	•	•	•	•
Ambient temperature	•	•	•	•
Camera snapshot of current conditions	•	•	•	•
Visibility	•	•	•	•
Relative humidity	•			•

The relative importance of specific data elements and the required level of detail and accuracy varies significantly between different users. When these differing levels of detail in the data are considered, the problem of collecting and disseminating quickly becomes complex. Maintenance managers, for example, need very specific information about existing and forecast pavement temperature, particularly if the ambient temperature is near freezing and relative humidity is high or precipitation is expected. Both the timing and nature of road surface treatments will be determined by this information. Traffic managers need less specific information – adequate to tell them of high probability of surface freezing on the roadway, sufficient to inform the public. Traffic managers might also disseminate information over the Internet, the media, or post warnings on dynamic message signs to lower speed limits, for example. Emergency responders need a similar level of information in order to mobilize resources to prepare for a likely increase in crashes and incidents.

Improved weather information can also help address increased concerns over homeland security. For example, additional RWIS can be helpful in planning and implementing evacuation routes, identifying the impacts of Hazmat releases, and determining routes for safe movement of military convoys.

■ Methodology

The main focus of this paper is to estimate the cost of deploying a suggested number of surface-based road weather sensors in the 61 metropolitan areas with populations of more than one million. The majority of the country's travel congestion and delay is experienced in these areas, and weather events can aggravate these conditions significantly in networks that are at or near capacity. Coverage across rural and statewide areas is well documented and underway. There are approximately 1,200 environmental sensor stations deployed along the roadside nationwide, primarily in rural areas. Obviously the number of sensors will vary depending on local weather conditions and traffic patterns. Therefore, the development of the methodology requires a step-by-step process in order to normalize and aggregate the 61 areas across the nation. That process includes:

- Identifying the key weather-related variables that might impact sensor requirements;
- Identifying the key transportation-related variables that might affect weather-related impacts on the transportation system;
- Establishing an overall index to estimate the relative need for weather sensors in different metropolitan areas; and
- Establishing a way to estimate sensor density and cost for each metropolitan area.

Weather-Related Variables

A wide range of weather data is available for metropolitan areas. For this analysis, summary data were taken from the Places Rated Almanac.[2] The need for sensor installations will vary based on both the severity of weather events and their impacts on the transportation system. Snow and freezing precipitation are weather events that are strongly associated with dangerous driving conditions and decreased mobility. Transportation managers have noted, however, that motorists tend to be more cautious in snow and ice but do not always recognize the danger that wet pavements can represent in rainy conditions. As a result, heavy rain and fog also can have significant impacts on the transportation system, particularly in regions such as the Southeast where severe thunderstorms and hurricanes occur during summer and fall months. Specific factors affecting visibility, such as fog, are usually highly localized and can dramatically affect safe transportation operations.

The analysis involved stratifying the 61 metropolitan areas based on weather severity and threat. Initial results pointed to a clear difference between summer and winter weather threats. Therefore both seasons were classified based on the most applicable weather variables and, from that, both summer and winter indices were derived.

A number of weather variables were evaluated for this study. Table 2 describes each variable considered, the name used in the ranking algorithm, and whether the variable was used in the final analysis.

Factor analysis and data review were used to drive the classification of the metropolitan areas based on road weather threats. The factor analysis was used to determine the groupings that best explained the variance across all the weather variables. The factor analysis technique was also used to guide the weighting given to each of the weather variables as they were combined to generate the summer and winter indices. These indices were then used to group the metropolitan areas. Because of the highly localized nature of fog and other factors affecting visibility, the factor analysis used to develop the indices did not incorporate the visibility data in a meaningful way. Regions that do experience frequent events of dense fog, or other localized phenomena, may want to increase the deployment density of RWIS in specific problem areas. Increased density of sensors may also be considered on roadways that are heavily impacted by weather events such as heavy thunderstorms and ice storms. In addition to contributing to regional weather and traffic information systems, sensors in these areas can be linked to local traffic warning systems that provide information to travelers entering the area.

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[2] "Places Rated Almanac," Richard Boyer and David Savageau, MacMillan General Reference, 1999.

Table 2 Weather Variables

Variable	Abbreviation	Used	Description
Freezing Temperatures (winter)	Temp32	Yes	The average number of days per year (based on 30 years of record) that the daily temperature falls to or below freezing.
Snow (winter)	Snow	Yes	The average amount of snow (in inches) per year (based on 30 years of record). The greatest amounts were found to be in the lee of the Great Lakes.
Ice (winter)	Ice	Yes	The average number of hours that ice (in the form of freezing rain) occurred per year (based on 30 years of record). Freezing rain can occur anywhere from the northern tier to the deep south. However, the mid-Atlantic region to the east of the Appalachians from North Carolina to Pennsylvania is most susceptible.
Winter Index (winter)	Wm	No	The Places Rated Almanac compiled this index based on the average wind chill temperature, the average number of months where temperatures reach freezing or less, and the average daily temperature of the coldest month.
Precipitation Days (winter)	Precip_W	Yes	The average number of days where measurable precipitation (accumulations of >= 0.01 inches) occur during the winter half of the year from October through March (based on 30 years of data). These values were biased toward the Pacific Northwest and the northern tier in the lee of the Lakes.
Precipitation Days (summer)	Precip_S	Yes	The average number of days where measurable precipitation (accumulations of >= 0.01 inches) occur during the summer half of the year from April through September (based on 30 years of data). These values displayed the convective nature of storms over the Gulf Coast and central Plains.
Thunder (summer)	Tstm	Yes	The average number of days per year that thunder is heard (based on 30 years of data). These values showed maximums over the Gulf Coast/Florida and the central Plains.
Heavy Rain (summer)	Hrain	Yes	The average number of days per year where rainfall of two inches or more occurred (based on 30 years of record). While heavy rain can occur at any time of the year, tropical summer storms produced the greatest frequency of events.
Hail (summer)	Hail	Yes	The average number of days per year with large hail (diameter > ¾ inch) (based on 30 years of data). The greatest frequency of large hail extended from the central Plains, northeast toward the Ohio River Valley.
Tropical Storms (summer)	Tropic	Yes	The probability (in percent) of any named tropical cyclone (hurricane or tropical storm) striking a location within a tropical season (June to November). This value was highest along the coastal region from the Outer Banks of North Carolina to south Texas.
Summer Mildness Index	Sm	No	The Places Rated Almanac compiled this index to measure the mildness of the summer season. It consists of the humidity, the average 24-hour temperature of the warmest month and the number of months where temperatures reach or exceed 90°F.
Fog (annual)	Fog	No	The average number of days per year that surface visibility falls to one-half mile or less (at the observation site) (based on 30 years of record). Fog can occur at any time of the year. However, surface transportation is usually not affected until visibility falls to below one-quarter mile.
Precipitation Amount (annual)	Pamt	Yes	The average amount of liquid precipitation (rain and melted snow/ice) per year (based on 30 years of record).
Wind (annual)	Wind	Yes	The average number of times per year that peak wind speeds were greater than 50 mph. These events can occur during the summer with severe storms or during winter during blizzards.

Summer Index

After several iterations, the best summer index was determined to be:

Summer Index = Precip_S + Tstm + Pamt + Tropic + Hrain + Hail

All six of the variables were weighted equally. The formula gives the highest scores to areas that experience frequent summer storms with heavy amounts of rainfall. Use of the "Tropic" variable results in slightly higher scores for southeastern and Gulf Coast areas that experience tropical storms. Metropolitan areas were sorted in descending order by summer index score and divided into six categories. These categories were based on natural breakpoints in the data and then adjusted so that they were grouped logically from a meteorological perspective. Appendix A contains all of the data for the 61 metropolitan areas that went into the summer analysis. Figure 1 maps the results of the summer index analysis, with Group 1 having the highest summer index and Group 6 the lowest.

Winter Index

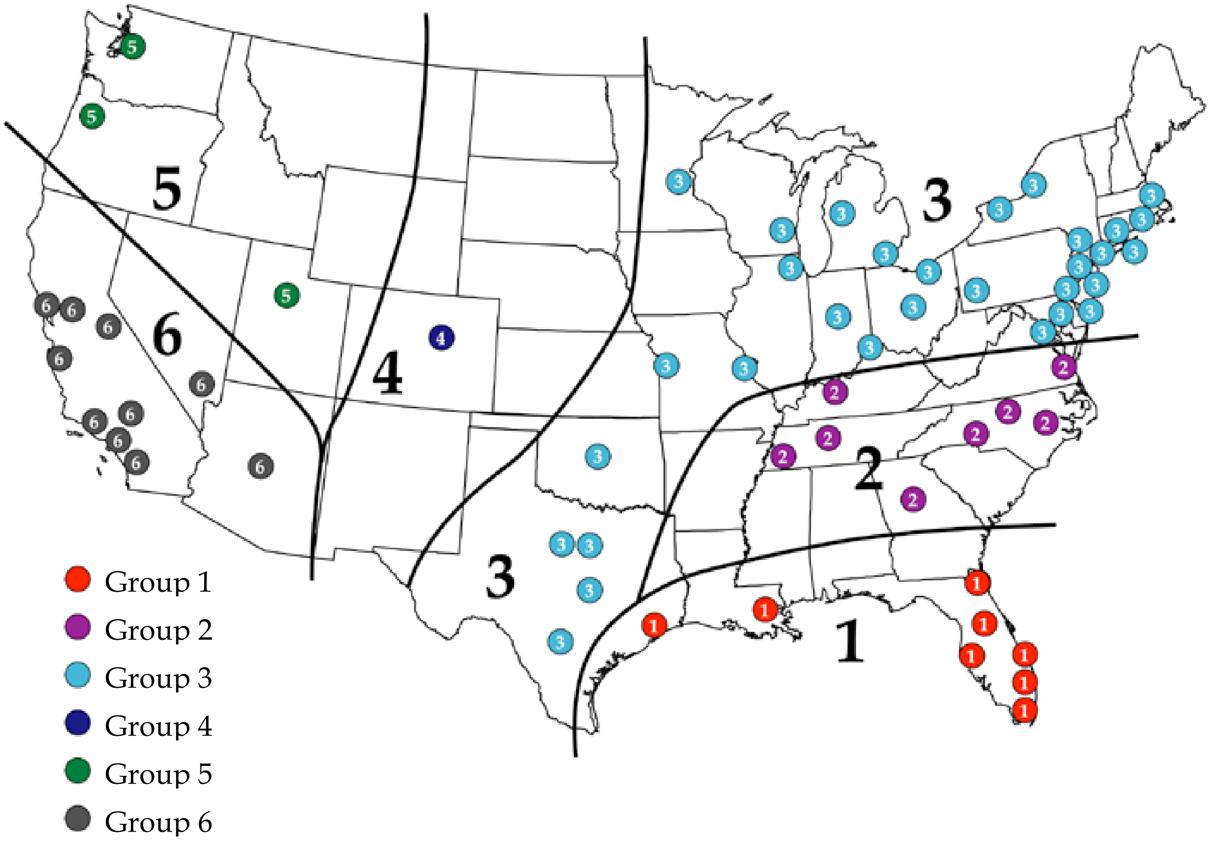
For the winter index, standard scores were developed for each of the identified weather variables. Different weightings were tested because of the perceived importance of ice and snow in weather-related incidents. The length of the winter (based on the number of days that the temperature fell to freezing) was also considered an important variable. Several different composite indices were developed and tested, and the best winter index was determined to be:

Winter Index = (Temp32 * 9) + Precip_W + (Snow * 10) + Wind + (Ice * 4)

Unlike the summer index, the winter index was calculated using "normalized" scores. The average value for all metropolitan areas was subtracted from the value of each metropolitan area and then divided by the standard deviation. For example, the Washington, D.C., area averages 16.6 inches of snow per year; the average of the 61 metropolitan areas is 19.6 inches, with a standard deviation of 23.0. Therefore, for Washington, D.C., the formula to determine the normalized average snowfall score is:

Normalized Score = (16.6 – 19.6) / 23 = -0.13

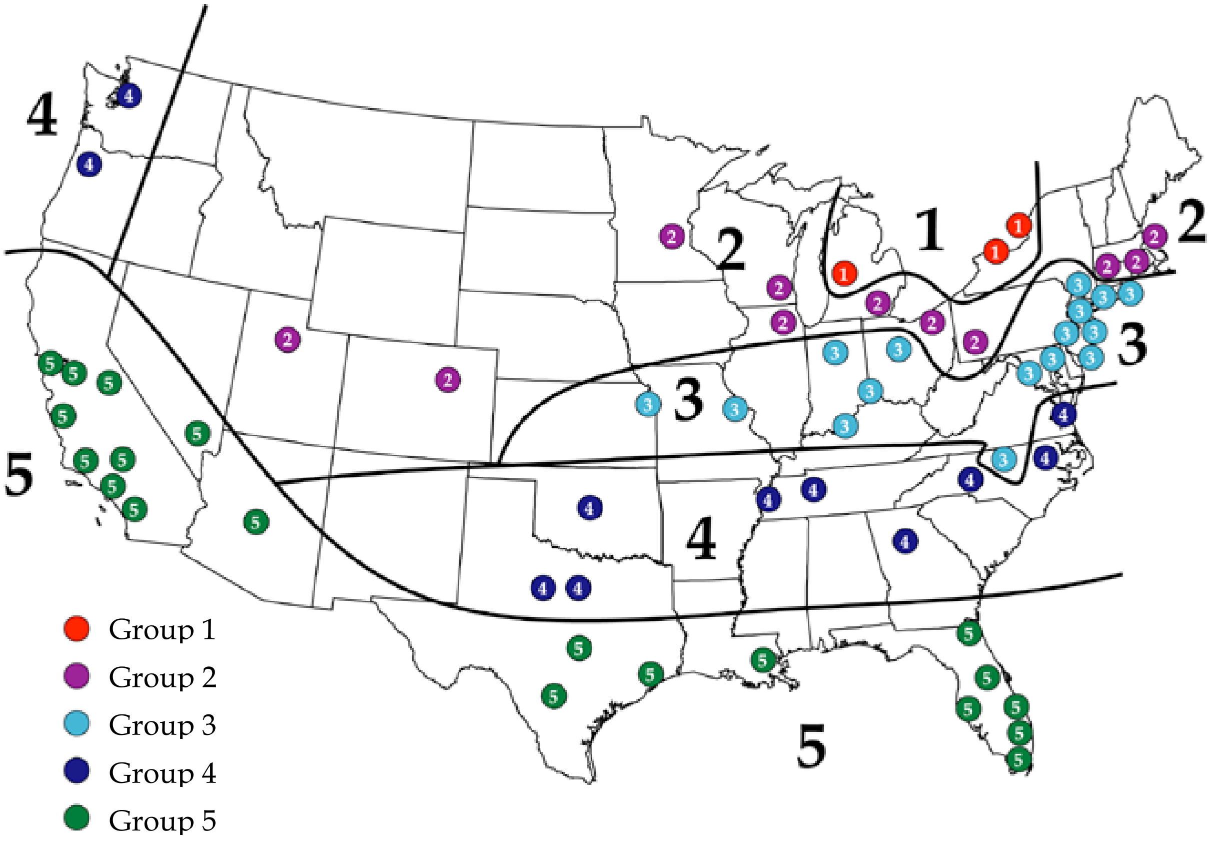
Figure 1 **Metropolitan Areas by Summer Index**



This procedure produces a normal distribution of the data, and helps account for different orders of magnitude in the raw data. For example, the Temp32 variable ranges from zero to 158, while the Wind variable ranges from one to nine. Normalization adjusts for these differences and makes the weighting process easier.

As with the summer index, the metropolitan areas were sorted by the winter index score in descending order and split into categories. These categories were based on natural breakpoints in the data and then adjusted so that they were grouped logically from a meteorological perspective. Appendix B contains all of the data for the 61 metropolitan areas that went into the winter analysis. Figure 2 maps the results of the winter index analysis, with Group 1 having the highest winter index and Group 5 the lowest.

Figure 2 Metropolitan Areas by Winter Index



Traffic and Roadway Variables

Transportation system and geographic characteristics are also important measures in assessing road weather information requirements. A number of variables were hypothesized as having an effect in these areas; some of the variables considered in the analysis included:

- **Geographic area (square miles).** Weather sensor density is generally a function of geographic area. However, the size of various metropolitan areas varied greatly with some including vast undeveloped areas. This did not permit an effective comparison between metropolitan areas.

- **Road miles**. A greater number of roadway miles implies a greater demand for maintenance and thus a need for more intensive road weather data. Total mileage for Interstate, non-Interstate expressway, and principal arterial roadways in each metropolitan area was summed from GIS data. Major roadway categories were used because they carry the largest volumes of traffic and are the most likely locations for environmental sensor stations.

- **Traffic congestion measures**. A higher level of congestion in a metropolitan area can increase the severity and secondary consequences of weather-related incidents. Crashes are more likely to occur, particularly those involving multiple vehicles. Additional capacity is usually not available to absorb the reduction that comes with heavy rain, ice, or snow. Several measures from the FHWA Mobility Monitoring program were considered including travel time index, travel rate index, and hours of delays per capita. They all produced similar results. The **Travel Time Index** was selected because it measures both recurring and non-recurring congestion. The index measures the ratio of total travel time in a region to free-flow travel time.

- **Road miles per capita**. This was tested as a potential measure of congestion; a low ratio of roadway mileage to population might reflect a higher level of congestion. It did not correlate well with other congestion measures and was therefore omitted.

- **Bridge data**. The number and length of bridges have an impact on the need for environmental sensor stations because bridges freeze before roadways. Wind conditions can also have an impact on the safety of bridge operation. Consideration of bridge data as a method of siting additional stations was beyond the scope of this analysis.

- **Topographic data**. The topography of an area will also determine the severity of impacts from weather-related events and the degree of variability of weather across a region. Additional thought is needed on how to use topography in the analysis. Consideration of topography was beyond the scope of this analysis.

In the end, only **Road Miles** and the **Travel Time Index** were used in this analysis to help calculate RWIS needs. Like the weather indices, they were sorted and divided into categories (numbered 1 through 5) based on logical breaks in the data. Detailed data on roadway and congestion measures can be found in Appendix C.

Calculation of RWIS Sensor Needs

Weather data was considered more significant than transportation data in estimating RWIS needs, therefore a composite score representing RWIS sensor needs was based on the following weighted formula:

Composite Score = (winter index category * 6) + (summer index category * 2) +
Road Mile Category + (Travel Time Index * 1.5)

Both the winter and summer index categories were converted so that the highest number (5 or 6) represented the greatest road weather information need and the lowest number (1) represented the lowest need (see Appendices A and B for detailed data). It was assumed that metropolitan areas with high composite scores would need a greater density of environmental sensor stations and those with low scores fewer.

Before a calculation of RWIS sensor needs could be made, sensor densities had to be estimated. The starting point for this analysis was a proposed density of one sensor per 30-km grid square (900 square km). This is taken from the paper "The RWIS Network Design

Strategy and Decision Support Tool ROADS – (**R**WIS **O**bjective **A**utomated **D**ecision **S**upport)" Tool Monitoring and Technologies Strategies Division, Environment Canada, by Gary Grieco, March 5, 1997. According to the paper, the "30-km grid...was selected since it is consistent with current meteorological forecasting model grids. It represents the coverage range used for RWIS sensors in other locations." The 30-km grid spacing for environmental sensing stations was also proposed in the RWIS Implementation Guide, SHRP-H-351, 1993. Other Canadian work suggests deployment of one RWIS sensor for every 60 linear km. However this estimate was developed primarily for long stretches of rural highway.

The grid suggested by Grieco translates into one sensor per 346 square miles. In order to obtain an initial estimate of magnitude of RWIS sensor requirements, the total square mileage of each metropolitan area was divided by 346, resulting in the need for 984 sensors nationwide. This estimate, however, is distorted because some of the metropolitan areas, particularly those in the western United States, include large stretches of unpopulated land. Because this approach was not reasonable, the next step involved dividing land area by the total number of road miles. Road Miles combines mileage from Interstates, non-Interstate expressways, and principal arterials. This approach yielded a median of one sensor per 70 linear miles. The median was used in the next step, rather than the average, in order to reduce the distorting impacts of the large geographic areas.

The methodology assumes that metropolitan areas with high composite scores need a greater density of environmental sensor stations than do those with lower scores. By applying the median of one sensor per 70 linear miles to the composite score for all 61 metropolitan areas, the areas were then divided into five groups accordingly from their average composite score of 30, with a standard deviation of eight.

Starting with the middle group at a density of one environmental sensor station per 70 linear miles, higher and lower sensor densities were applied to the metropolitan areas relative to their composite scores. In other words, groups with the most severe weather were assigned higher densities, and groups with the least severe, lower densities. In descending order, the densities applied were one environmental sensor station per 50, 60, 70, 100, and 150 linear miles. Appendix D contains the details of the analysis and shows the total number of estimated environmental sensor stations for the Infostructure at 832.

Cost Estimate

Cost assumptions were derived from the FHWA Intelligent Transportation Systems unit cost database, and include costs for RWIS processing units (equipment and software) in traffic management centers, or TMCs. These costs assume that, on average, two processing units would be needed in each metropolitan area based on an average of two TMCs per area. Costs for the RWIS sensor stations range from $10,000 to $50,000 depending on the type and amount of data collected, as well as need for communications. An average value of $30,000 was selected. A summary of costs associated with identified sensor needs is shown in Table 3.

Table 3 Summary of RWIS Sensor Needs

	Based on Composite Scoring and Road Miles	Based on Land Area Only
Number of RWIS Sensors	832	984
RWIS TMC Units at $25,000/TMC (Assume average two units per metro area)	$3,050,000	$3,050,000
RWIS Field Sensor cost median $30,000 each (range $10,000 to $50,000)	$24,960,000	$29,520,000
Development and Engineering (10%)	$2,801,000	$3,257,000
Total Up-Front Cost	**$30,811,000**	**$35,827,000**

The methodology results in an estimated 832 RWIS sensors totaling $30.8 million. This estimate is approximately 14 percent lower than the calculation based solely on density per overall land area (one sensor per 346 square miles). Neither estimate includes annual operating costs.

Table 4 shows the composite scores and the estimated number of RWIS sensors required for each of the 61 metropolitan areas. The table is sorted from highest score to lowest and reflects a strong weighting toward the winter weather index. Some cities with more moderate winter weather but a high summer index and heavy congestion are also relatively high on the list. Examples include Washington, Denver, and New York. It is important to note that these estimates represent a minimum coverage requirement. Local conditions may dictate that a greater density of RWIS sensors is appropriate. In cases where a sensor network already exists, additional analysis may identify opportunities to expand functionality and extend the benefits to a broader user base.

Table 4 Composite Score and RWIS Requirements for 61 Largest Metropolitan Areas

Metropolitan Area	State	Score	# RWIS
Chicago, Illinois	IL	45.5	53
Boston, Massachusetts-New Hampshire	MA	43.5	27
Detroit, Michigan	MI	42.0	26
Minneapolis-St. Paul, Minnesota-Wisconsin	MN	42.0	23
Buffalo-Niagara Falls, New York	NY	41.5	10
Rochester, New York	NY	41.5	12
Grand Rapids-Muskegon, Michigan	MI	40.5	8
Milwaukee, Wisconsin	WI	39.5	13
Cleveland-Lorain-Elyria, Ohio	OH	39.0	18
Denver, Colorado	CO	39.0	16
Washington, D.C.-Maryland-Virginia-West Virginia	DC	38.5	29
New York, New York	NY	38.5	27
Pittsburgh, Pennsylvania	PA	38.5	26
Providence, Rhode Island	RI	37.0	12
Philadelphia, Pennsylvania-New Jersey	PA	36.5	35
Long Island, New York (Nassau-Suffolk)	NY	35.5	12
Newark, New Jersey	NJ	35.5	11
Hartford, Connecticut	CT	35.5	10
St. Louis, Missouri-Illinois	MO	35.5	29
Baltimore, Maryland	MD	34.5	17
Bergen-Passaic, New Jersey	NJ	34.5	6
Greensboro-Winston Salem, North Carolina	NC	34.5	12
Middlesex-Somerset-Hunterdon, New Jersey	NJ	34.5	7
Monmouth-Ocean, New Jersey	NJ	34.5	7
Cincinnati, Ohio-Kentucky-Indiana	OH	33.5	13
Indianapolis, Indiana	IN	33.5	11
Louisville, Kentucky-Indiana	KY	33.5	7
Atlanta, Georgia	GA	33.0	26
Kansas City, Missouri-Kansas	MO	33.0	20
Columbus, Ohio	OH	32.5	9
Salt Lake City-Ogden, Utah	UT	32.0	6
Dallas, Texas	TX	29.5	23
Houston, Texas	TX	29.0	24
Seattle, Washington	WA	29.0	15
Charlotte-Gastonia-Rock Hill, North Carolina-South Carolina	NC	28.5	10
Raleigh-Durham, North Carolina	NC	28.5	9
Nashville, Tennessee	TN	28.0	11
Memphis, Tennessee-Arkansas-Mississippi	TN	27.0	8

Table 4 Composite Score and RWIS Requirements for 61 Largest Metropolitan Areas (continued)

Metropolitan Area	State	Score	# RWIS
Norfolk-Virginia Beach, Virginia	VA	27.0	9
Ft. Worth-Arlington, Texas	TX	26.0	14
Tampa-St. Petersburg-Clearwater, Florida	FL	25.5	8
Orlando, Florida	FL	25.5	8
Portland-Vancouver, Oregon-Washington	OR	25.0	8
Miami, Florida	FL	25.0	4
Oklahoma City, Oklahoma	OK	25.0	7
Fort Lauderdale, Florida	FL	23.5	4
West Palm Beach, Florida	FL	23.5	4
Los Angeles-Long Beach, California	CA	23.0	27
Jacksonville, Florida	FL	23.0	6
New Orleans, Louisiana	LA	22.0	5
Orange County, California	CA	20.0	9
Riverside-San Bernardino, California	CA	20.0	21
Austin-San Marcos, Texas	TX	19.5	5
Oakland, California	CA	19.0	7
San Antonio, Texas	TX	19.0	6
Phoenix-Mesa, Arizona	AZ	18.0	13
Las Vegas, Nevada-Arizona	NV	18.0	10
San Francisco, California	CA	18.0	4
Sacramento, California	CA	17.0	6
San Jose, California	CA	16.0	4
San Diego, California	CA	16.0	5
Total			**832**

Conclusions and Recommendations for Further Research

Specific numbers of sensors for a given metropolitan area should not be construed as cast in stone. Rather, they provide a general estimate or order of magnitude for nationwide deployment. The methodology developed and applied in this paper produced what appears to be a reasonable first estimate of RWIS sensor needs in the 61 metropolitan areas considered. The results generally appear logical and place the greatest level of resources where weather threats and potential benefits of RWIS sensor deployment would be the greatest. There are some anomalies in the data, however, particularly in some of the Southern California areas. The large geographic areas and length of road mileage, combined with heavy congestion, result in a relatively large estimate of RWIS sensors there. Future adjustments to reduce these numbers may be appropriate because weather-related events are rare in these areas. It is also important to emphasize that the benefits from sensor deployments are only as good as the information that is generated from them.

Overall there are a number of areas where additional research is needed to refine the results. There are also indications about other types of research that may be appropriate. These include:

- This paper could be refined to take into account bridge and topographical data in the analysis. These factors could meaningfully impact the results. The information exists in various forms; however, additional time and effort would be required to assemble it, and develop and incorporate a methodology into the analysis.

- The scope of this paper could be expanded to take into account critical military routes and infrastructure, as well as rural and statewide RWIS sensor coverage needs.

- Additional research on security issues may be appropriate. This paper does not take into account RWIS sensor deployment necessary to perform predictive atmospheric modeling relating to surface transportation. Modeling capability may be useful to predict the impacts of chemical or biological threats released into the atmosphere in a metropolitan area, and the resulting impacts on evacuation strategies and the transportation system.

- Additional research on RWIS sensor placement in metropolitan areas should be examined in more detail. The level of confidence in data derived from placement, including the need for accuracy, relevance, and timeliness needs to be better understood with a goal of developing guidelines for different deployment scenarios.

- FHWA may want to consider the development of standards for RWIS equipment, and make them available for use by state DOTs, local agencies, and private companies. Issues that should be addressed under a standards development effort include location and density of sensors within the overall network and specific site characteristics that will impact performance. For example, sites should be level, not shaded by buildings or trees, and have power supply and communications available. Physical performance requirements, maintenance standards, and training requirements should be specified because of the harsh, outdoor environment. This effort must recognize that desired equipment features will vary based on weather characteristics but a basic set of sensor capabilities would include measurement of:

- Ambient air temperature;
- Relative humidity;
- Wind speed and direction;
- Precipitation amount and type;
- Visibility;
- Solar radiation;
- Road surface temperature; and
- Road surface condition.

- Additional work is needed to estimate transportation-related benefits derived from RWIS sensor deployment. Additional research may be appropriate in areas where RWIS has been deployed so that estimates of benefits, such as travel time reduction, crash reduction, and air quality benefits, can be refined.

- An analysis of the overall "bang-for-the-buck" could be conducted to determine the optimal sensor densities for given areas in order to determine the point of diminishing return for sensor deployment. A comparison to other countries would also be worthwhile in this regard.

- This paper addresses urban RWIS sensor needs, but not rural. This work could be expanded to include a nationwide estimate, possibly based on more rigorous meteorological analysis.

- The stratification and grouping of metropolitan areas give useful indications as to how the FHWA could best target a program delivery strategy around RWIS. In other words, the data can help drive strategies for delivering training, technical tools, and technical assistance to metropolitan areas aimed at advancing the state of the practice across the country.

Appendix A

Summer Weather Index

Appendix A – Summer Weather Index

Metropolitan Area	State	Precip_S	Tstm	Pamt	Tropic	Hrain	Hail	Summer Index
West Palm Beach FL	FL	80	79	60.8	50	5	1	276
Miami FL	FL	81	74	55.9	50	5	2	268
Fort Lauderdale FL	FL	80	75	56	50	5	1	267
Tampa-St. Petersburg-Clearwater FL	FL	69	87	43.9	50	4.5	3	257
Orlando FL	FL	74	80	48.1	45	5	2	254
New Orleans LA	LA	63	69	61.9	45	4.5	2	245
Jacksonville FL	FL	70	65	51.3	45	5	2	238
Houston TX	TX	53	62	50.8	35	4	3	208
Memphis TN-AR-MS	TN	52	59	52.1	15	3	3	184
Atlanta GA	GA	57	48	50.8	20	3	4	183
Nashville TN	TN	58	54	47.3	15	3	3	180
Greensboro-Winston Salem NC	NC	62	43	42.6	25	2.5	3	178
Charlotte-Gastonia-Rock Hill NC-SC	NC	57	41	43.1	20	2.5	5	169
Norfolk-Virginia Beach VA	VA	59	37	44.6	25	2	1	169
Raleigh-Durham NC	NC	58	42	41.4	20	2.5	3	167
Louisville KY-IN	KY	60	45	44.4	10	1.5	3	164
Kansas City MO-KS	MO	56	51	37.6	0	2.5	7	154
New York NY	NY	58	24	47.3	20	2	1	152
Columbus OH	OH	64	40	38.1	5	1	3	151
Hartford CT	CT	64	20	44.1	20	2	1	151
Long Island NY (Nassau-Suffolk)	NY	60	24	44.7	20	2	0	151
Cincinnati OH-KY-IN	OH	62	39	41.3	5	1	2	150
Providence RI	RI	60	21	45.5	20	2	1	150
Bergen-Passaic NJ	NJ	59	24	47.3	15	2	2	149
St. Louis MO-IL	MO	56	46	37.5	0	2.5	7	149
Pittsburgh PA	PA	67	35	36.9	5	1	4	149
Newark NJ	NJ	60	31	43.5	10	2	2	149
Monmouth-Ocean NJ	NJ	54	26	40.3	25	2	1	148
Dallas TX	TX	40	47	36.1	15	2	7	147
Ft. Worth-Arlington TX	TX	40	47	36.1	15	2	7	147
Baltimore MD	MD	58	27	42.4	15	1.5	3	147
Indianapolis IN	IN	59	43	39.9	0	1	4	147
Washington DC-MD-VA-WV	DC	58	30	38.6	15	1.5	3	146
Philadelphia PA-NJ	PA	59	27	41.4	15	1.5	2	146
Middlesex-Somerset-Hunterdon NJ	NJ	56	24	46.4	15	2	2	145
Oklahoma City OK	OK	48	50	33.4	5	2	7	145
Cleveland-Lorain-Elyria OH	OH	69	34	36.6	0	1	4	145
Chicago IL	IL	62	38	37.4	0	1	4	142
Buffalo-Niagara Falls NY	NY	69	30	38.6	0	2	1	141
Boston MA-NH	MA	60	21	41.5	15	2	0	140
Austin-San Marcos TX	TX	39	41	31.9	20	2	5	139
San Antonio TX	TX	39	36	31	25	2	5	138
Grand Rapids-Muskegon MI	MI	63	34	36	0	1	3	137
Minneapolis-St. Paul MN-WI	MN	63	37	28.3	0	1.5	5	135
Milwaukee WI	WI	62	35	32.9	0	1	3	134
Detroit MI	MI	63	32	32.6	0	1	3	132
Rochester NY	NY	64	27	32	0	2	2	127
Denver CO	CO	52	39	15.4	0	0	7	113
Seattle WA	WA	54	8	38	0	2	0	102
Portland-Vancouver OR-WA	OR	52	8	36.3	0	1	0	97
Salt Lake City-Ogden UT	UT	38	38	16.2	0	0	2	94
Phoenix-Mesa AZ	AZ	15	23	7.7	0	0	1	47
Sacramento CA	CA	12	2	17.5	0	4	0	36
Oakland CA	CA	11	1	18.03	0	1	0	31
San Francisco CA	CA	10	0	19.7	0	1	0	31
Las Vegas NV-AZ	NV	11	13	4.1	0	0	0	28
San Jose CA	CA	9	2	14.49	0	1	0	26
Riverside-San Bernardino CA	CA	12	2	9.6	0	0.5	0	24
Los Angeles-Long Beach CA	CA	7	1	12	0	0.5	0	21
Orange County CA	CA	7	1	11	0	0.5	0	20
San Diego CA	CA	9	0	9.9	0	0.5	0	19

Appendix B

Winter Weather Index

Appendix B – Winter Weather Index

Metropolitan Area	State	Temp32	Precip_W	Snow	Wind	Ice	Winter Index
Rochester NY	NY	135	93	89.9	8	15	54.86
Buffalo-Niagara Falls NY	NY	131	100	91.1	5	12	50.85
Grand Rapids-Muskegon MI	MI	146	81	71.6	4	15	45.91
Hartford CT	CT	135	63	47.3	4	15	32.47
Minneapolis-St. Paul MN-WI	MN	158	51	49.5	7	6	31.01
Cleveland-Lorain-Elyria OH	OH	123	87	55.4	5	9	30.75
Denver CO	CO	155	36	60.4	9	0	30.54
Detroit MI	MI	136	71	41.4	4	12	28.01
Salt Lake City-Ogden UT	UT	134	51	57.9	6	1	25.71
Milwaukee WI	WI	141	62	46.5	4	6	25.62
Pittsburgh PA	PA	124	86	43.1	4	9	24.96
Chicago IL	IL	132	64	38.2	5	6	21.11
Providence RI	RI	117	64	35.6	4	9	19.29
Boston MA-NH	MA	99	67	40.9	5	9	19.17
Middlesex-Somerset-Hunterdon NJ	NJ	128	58	26.7	4	9	17.03
Columbus OH	OH	118	72	27.6	3	9	15.85
Newark NJ	NJ	123	61	31.3	4	6	15.81
Indianapolis IN	IN	119	65	22.7	3	9	13.52
Cincinnati OH-KY-IN	OH	107	67	23.2	2	9	11.18
St. Louis MO-IL	MO	107	54	19.8	4	9	10.14
Kansas City MO-KS	MO	105	46	20.2	4	9	9.53
Bergen-Passaic NJ	NJ	81	58	28.1	4	9	9.40
Baltimore MD	MD	97	55	20.8	3	9	8.31
Philadelphia PA-NJ	PA	94	58	20.8	3	9	7.94
Greensboro-Winston Salem NC	NC	85	56	8.6	2	15	5.39
Long Island NY (Nassau-Suffolk)	NY	85	60	26.7	4	3	4.60
New York NY	NY	81	59	28.1	4	3	4.46
Washington DC-MD-VA-WV	DC	71	54	16.6	3	12	4.38
Monmouth-Ocean NJ	NJ	108	58	16.1	4	3	3.92
Louisville KY-IN	KY	90	64	16.2	2	6	2.50
Raleigh-Durham NC	NC	77	54	7	2	12	0.69
Oklahoma City OK	OK	79	34	9.1	5	6	-2.42
Charlotte-Gastonia-Rock Hill NC-SC	NC	65	55	5.5	2	9	-4.51
Nashville TN	TN	76	61	10.2	2	3	-5.22
Memphis TN-AR-MS	TN	59	54	5.1	2	6	-8.29
Portland-Vancouver OR-WA	OR	44	102	6.5	5	3	-8.51
Atlanta GA	GA	49	58	2	2	9	-8.67
Norfolk-Virginia Beach VA	VA	54	56	7.4	2	3	-10.56
Seattle WA	WA	32	104	11.8	2	1	-11.58
Dallas TX	TX	40	38	2.7	4	3	-14.88
Ft. Worth-Arlington TX	TX	40	38	2.7	4	3	-14.88
Las Vegas NV-AZ	NV	37	15	1.3	5	0	-19.19
Austin-San Marcos TX	TX	21	43	0.9	3	3	-19.29
Houston TX	TX	24	51	0.4	2	1	-20.79
San Antonio TX	TX	22	42	0.7	2	1	-21.50
Sacramento CA	CA	21	46	0	2	0	-22.59
Jacksonville FL	FL	12	46	0	2	1	-23.33
New Orleans LA	LA	13	50	0.2	1	0	-24.26
San Francisco CA	CA	6	52	0	2	0	-24.89
Riverside-San Bernardino CA	CA	14	31	0	1	0	-25.20
Phoenix-Mesa AZ	AZ	10	20	0	3	0	-25.35
Oakland CA	CA	0	50	0	2	0	-26.05
Tampa-St. Petersburg-Clearwater FL	FL	3	38	0	2	0	-26.18
West Palm Beach FL	FL	1	51	0	1	0	-26.39
Orlando FL	FL	3	41	0	1	0	-26.58
Fort Lauderdale FL	FL	0	50	0	1	0	-26.62
Miami FL	FL	0	48	0	1	0	-26.73
San Jose CA	CA	0	42	0	1	0	-27.06
San Diego CA	CA	0	33	0	1	0	-27.54
Los Angeles-Long Beach CA	CA	0	28	0	1	0	-27.81
Orange County CA	CA	0	24	0	1	0	-28.03

Appendix C

Roadway Mileage and Congestion Index

Appendix C – Roadway Mileage and Congestion Index

Metropolitan Area	State	Pop_2000	Int_Mi	Expy_Mi	PrArt_Mi	Total_Mi	TTI Index
Orange County CA	CA	2,778,415	77.94	85.5	705.25	868.69	2.06
Los Angeles-Long Beach CA	CA	9,220,312	348.85	218.93	2,169.96	2,737.74	2.06
Seattle WA	WA	2,356,143	186.48	114.59	748.66	1,049.73	1.81
San Francisco CA	CA	1,675,039	46.29	101.78	238.88	386.94	1.77
Oakland CA	CA	2,347,638	182.64	60.28	438.13	681.04	1.77
Washington DC-MD-VA-WV	DC	4,745,302	378.2	176.04	1,171.07	1,725.3	1.71
Boston MA-NH	MA	3,296,878	250.28	92.94	1,006.07	1,349.29	1.71
New York NY	NY	8,603,992	217.58	2.59	1,424.11	1,644.28	1.70
Long Island NY (Nassau-Suffolk)	NY	2,671,294	72.26	0	659.85	732.12	1.70
Bergen-Passaic NJ	NJ	1,337,377	50.84	50.2	284.69	385.74	1.70
Monmouth-Ocean NJ	NJ	1,105,377	33.58	60.33	310.19	404.09	1.70
Newark NJ	NJ	1,944,061	156.46	51.57	458	666.03	1.70
Middlesex-Somerset-Hunterdon NJ	NJ	1,128,973	112.64	25.67	256.17	394.48	1.70
Chicago IL	IL	7,864,846	549.81	82.78	2,012.85	2,645.44	1.69
Portland-Vancouver OR-WA	OR	1,888,819	153.04	48.13	611.48	812.66	1.65
San Diego CA	CA	2,859,202	242.18	155.52	332.35	730.04	1.64
Atlanta GA	GA	3,807,451	430.04	55.32	1,342.65	1,828.01	1.63
Houston TX	TX	4,008,119	238.66	334.33	1,100.93	1,673.92	1.61
Denver CO	CO	1,993,142	222.14	110.85	615.39	948.37	1.61
Detroit MI	MI	4,505,455	415.7	92.36	793.26	1,301.32	1.59
Miami FL	FL	2,089,376	29.61	58.84	344.28	432.72	1.58
Minneapolis-St. Paul MN-WI	MN	2,909,888	379.54	0	794.6	1,174.14	1.58
Las Vegas NV-AZ	NV	1,384,481	285.54	42.32	720.37	1,048.23	1.57
San Jose CA	CA	1,646,595	48.25	167.83	363.56	579.64	1.56
Sacramento CA	CA	1,584,266	135.41	91.67	646.51	873.58	1.55
Riverside-San Bernardino CA	CA	3,234,161	739.4	101.94	1,232.82	2,074.16	1.50
Phoenix-Mesa AZ	AZ	3,034,464	347.95	49.34	863.42	1,260.72	1.50
Dallas TX	TX	3,277,816	369.72	296.93	944.34	1,610.98	1.47
Austin-San Marcos TX	TX	1,149,201	88.08	73	375.3	536.38	1.47
Cincinnati OH-KY-IN	OH	1,641,098	303.2	36.64	559.87	899.71	1.47
St. Louis MO-IL	MO	2,584,538	444.23	86.16	1,182.5	1,712.89	1.46
Baltimore MD	MD	2,528,739	224.67	135.93	656.52	1,017.12	1.45
West Palm Beach FL	FL	1,084,445	46.86	41.48	318.42	406.76	1.44
Fort Lauderdale FL	FL	1,533,988	90.15	59.44	200.73	350.32	1.44
Philadelphia PA-NJ	PA	4,966,257	308.23	68.75	1,717.82	2,094.8	1.44
Indianapolis IN	IN	1,545,986	325.95	5.91	455.84	787.7	1.43
Louisville KY-IN	KY	1,010,464	226.35	15.42	234.9	476.68	1.42
Charlotte-Gastonia-Rock Hill NC-SC	NC	1,413,215	142.41	52.78	524.52	719.71	1.42
Raleigh-Durham NC	NC	1,114,141	178.32	66.27	415.38	659.97	1.42
Greensboro-Winston Salem NC	NC	1,187,143	205.3	161.92	379.2	746.42	1.42
Orlando FL	FL	1,574,284	48.77	27.8	758.26	834.83	1.41
Milwaukee WI	WI	1,467,865	137.31	43.73	597.94	778.98	1.40
Tampa-St. Petersburg-Clearwater FL	FL	2,308,247	144.16	28.18	646.71	819.05	1.38
Columbus OH	OH	1,502,584	237.52	57.06	366	660.59	1.37
Ft. Worth-Arlington TX	TX	1,637,606	205.27	141.76	606.02	953.05	1.34
Salt Lake City-Ogden UT	UT	1,324,187	156.39	9.36	220.43	386.18	1.34
Providence RI	RI	1,088,433	113.12	89.17	492.88	695.17	1.33
Norfolk-Virginia Beach VA	VA	1,585,776	123.61	111.91	373.75	609.27	1.33
Nashville TN	TN	1,186,108	266.57	50.29	475.75	792.61	1.32
San Antonio TX	TX	1,597,810	240.11	82.6	312.62	635.32	1.32
Cleveland-Lorain-Elyria OH	OH	2,228,317	340	94.5	656.74	1,091.24	1.31
New Orleans LA	LA	1,325,345	177.64	30.47	321.07	529.19	1.31
Memphis TN-AR-MS	TN	1,116,341	163.49	18.08	394.33	575.9	1.29
Jacksonville FL	FL	1,086,690	151.16	73.87	384.21	609.24	1.28
Oklahoma City OK	OK	1,050,216	270.08	35.71	383.44	689.23	1.21
Kansas City MO-KS	MO	1,759,224	379.26	212.82	781.11	1,373.18	1.20
Hartford CT	CT	1,149,141	120.73	75.91	379.78	576.43	1.19
Pittsburgh PA	PA	2,361,710	324.02	0	1,220.6	1,544.63	1.16
Buffalo-Niagara Falls NY	NY	1,166,581	110.62	0.07	480.94	591.64	1.11
Grand Rapids-Muskegon MI	MI	1,059,044	143.2	38.36	285.54	467.1	1.11
Rochester NY	NY	1,095,210	219.18	1.36	472.56	693.11	1.11

Appendix C – Roadway Mileage and Congestion Index (continued)

Notes:

Pop_2000 = Metropolitan Area Census Population 2000
Int_Mi = Total Interstate Highway Mileage in Metropolitan Area
Expy_Mi = Total non-Interstate Expressway Mileage in Metropolitan Area
PrArt_Mi = Total Principal Arterial Mileage in Metropolitan Area
Total_Mi = Sum of Mileage of Three roadway categories
TTIndex = Travel Time Index; ratio of total region travel time to free flow travel time

Appendix D

RWIS Needs Data

Appendix D – RWIS Needs Data

Metropolitan Area	State	Winter Index	W Category	Summer Index	S Category	Total_Mi	Rd Mile Category	TTIndex	TTI Category	Score	Mi/ RWIS	# RWIS
Chicago IL	IL	21.11	4	142.40	4	2645.44	6	1.69	5	**45.5**	50	**53**
Boston MA-NH	MA	19.17	4	139.50	4	1349.29	4	1.71	5	**43.5**	50	**27**
Detroit MI	MI	28.01	4	131.60	4	1301.32	4	1.59	4	**42.0**	50	**26**
Minneapolis-St. Paul MN-WI	MN	31.01	4	134.80	4	1174.14	4	1.58	4	**42.0**	50	**23**
Buffalo-Niagara Falls NY	NY	50.85	5	140.60	4	591.64	2	1.11	1	**41.5**	60	**10**
Rochester NY	NY	54.86	5	127.00	4	693.11	2	1.11	1	**41.5**	60	**12**
Grand Rapids-Muskegon MI	MI	45.91	5	137.00	4	467.1	1	1.11	1	**40.5**	60	**8**
Milwaukee WI	WI	25.62	4	133.90	4	778.98	3	1.4	3	**39.5**	60	**13**
Cleveland-Lorain-Elyria OH	OH	30.75	4	144.60	4	1091.24	4	1.31	2	**39.0**	60	**18**
Denver CO	CO	30.54	4	113.40	3	948.37	3	1.61	4	**39.0**	60	**16**
Washington DC-MD-VA-WV	DC	4.38	3	146.10	4	1725.3	5	1.71	5	**38.5**	60	**29**
New York NY	NY	4.46	3	152.30	4	1644.28	5	1.7	5	**38.5**	60	**27**
Pittsburgh PA	PA	24.96	4	148.90	4	1544.63	5	1.16	1	**38.5**	60	**26**
Providence RI	RI	19.29	4	149.50	4	695.17	2	1.33	2	**37.0**	60	**12**
Philadelphia PA-NJ	PA	7.94	3	145.90	4	2094.8	6	1.44	3	**36.5**	60	**35**
Long Island NY (Nassau-Suffolk)	NY	4.60	3	150.70	4	732.12	2	1.7	5	**35.5**	60	**12**
Newark NJ	NJ	15.81	3	148.50	4	666.03	2	1.7	5	**35.5**	60	**11**
Hartford CT	CT	32.47	4	151.10	4	576.43	2	1.19	1	**35.5**	60	**10**
St. Louis MO-IL	MO	10.14	3	149.00	4	1712.89	5	1.46	3	**35.5**	60	**29**
Baltimore MD	MD	8.31	3	146.90	4	1017.12	4	1.45	3	**34.5**	60	**17**
Bergen-Passaic NJ	NJ	9.40	3	149.30	4	385.74	1	1.7	5	**34.5**	60	**6**
Greensboro-Winston Salem NC	NC	5.39	3	178.10	5	746.42	2	1.42	3	**34.5**	60	**12**
Middlesex-Somerset-Hunterdon NJ	NJ	17.03	3	145.40	4	394.48	1	1.7	5	**34.5**	60	**7**
Monmouth-Ocean NJ	NJ	3.92	3	148.30	4	404.09	1	1.7	5	**34.5**	60	**7**
Cincinnati OH-KY-IN	OH	11.18	3	150.30	4	899.71	3	1.47	3	**33.5**	70	**13**
Indianapolis IN	IN	13.52	3	146.90	4	787.7	3	1.43	3	**33.5**	70	**11**
Louisville KY-IN	KY	2.50	3	163.90	5	476.68	1	1.42	3	**33.5**	70	**7**
Atlanta GA	GA	-8.67	2	182.80	5	1828.01	5	1.63	4	**33.0**	70	**26**
Kansas City MO-KS	MO	9.53	3	154.10	4	1373.18	4	1.2	2	**33.0**	70	**20**
Columbus OH	OH	15.85	3	151.10	4	660.59	2	1.37	3	**32.5**	70	**9**
Salt Lake City-Ogden UT	UT	25.71	4	94.20	2	386.18	1	1.34	2	**32.0**	70	**6**
Dallas TX	TX	-14.88	2	147.10	4	1610.98	5	1.47	3	**29.5**	70	**23**
Houston TX	TX	-20.79	1	207.80	6	1673.92	5	1.61	4	**29.0**	70	**24**
Seattle WA	WA	-11.58	2	102.00	2	1049.73	4	1.81	6	**29.0**	70	**15**
Charlotte-Gastonia-Rock Hill NC-SC	NC	-4.51	2	168.60	5	719.71	2	1.42	3	**28.5**	70	**10**
Raleigh-Durham NC	NC	0.69	2	166.90	5	659.97	2	1.42	3	**28.5**	70	**9**
Nashville TN	TN	-5.22	2	180.30	5	792.61	3	1.32	2	**28.0**	70	**11**
Memphis TN-AR-MS	TN	-8.29	2	184.10	5	575.9	2	1.29	2	**27.0**	70	**8**
Norfolk-Virginia Beach VA	VA	-10.56	2	168.60	5	609.27	2	1.33	2	**27.0**	70	**9**
Ft. Worth-Arlington TX	TX	-14.88	2	147.10	4	953.05	3	1.34	2	**26.0**	70	**14**
Tampa-St. Petersburg-Clearwater FL	FL	-26.18	1	257.40	6	819.05	3	1.38	3	**25.5**	100	**8**
Orlando FL	FL	-26.58	1	254.10	6	834.83	3	1.41	3	**25.5**	100	**8**
Portland-Vancouver OR-WA	OR	-8.51	2	97.30	2	812.66	3	1.65	4	**25.0**	100	**8**
Miami FL	FL	-26.73	1	267.90	6	432.72	1	1.58	4	**25.0**	100	**4**
Oklahoma City OK	OK	-2.42	2	145.40	4	689.23	2	1.21	2	**25.0**	100	**7**
Fort Lauderdale FL	FL	-26.62	1	267.00	6	350.32	1	1.44	3	**23.5**	100	**4**
West Palm Beach FL	FL	-26.39	1	275.80	6	406.76	1	1.44	3	**23.5**	100	**4**
Los Angeles-Long Beach CA	CA	-27.81	1	20.50	1	2737.74	6	2.06	6	**23.0**	100	**27**
Jacksonville FL	FL	-23.33	1	238.30	6	609.24	2	1.28	2	**23.0**	100	**6**
New Orleans LA	LA	-24.26	1	245.40	6	529.19	1	1.31	2	**22.0**	100	**5**
Orange County CA	CA	-28.03	1	19.50	1	868.69	3	2.06	6	**20.0**	100	**9**
Riverside-San Bernardino CA	CA	-25.20	1	24.10	1	2074.16	6	1.5	4	**20.0**	100	**21**
Austin-San Marcos TX	TX	-19.29	1	138.90	4	536.38	1	1.47	3	**19.5**	100	**5**
Oakland CA	CA	-26.05	1	31.03	1	681.04	2	1.77	6	**19.0**	100	**7**
San Antonio TX	TX	-21.50	1	138.00	4	635.32	2	1.32	2	**19.0**	100	**6**
Phoenix-Mesa AZ	AZ	-25.35	1	46.70	1	1260.72	4	1.5	4	**18.0**	100	**13**
Las Vegas NV-AZ	NV	-19.19	1	28.10	1	1048.23	4	1.57	4	**18.0**	100	**10**
San Francisco CA	CA	-24.89	1	30.70	1	386.94	1	1.77	6	**18.0**	100	**4**
Sacramento CA	CA	-22.59	1	35.50	1	873.58	3	1.55	4	**17.0**	150	**6**
San Jose CA	CA	-27.06	1	26.49	1	579.64	2	1.56	4	**16.0**	150	**4**
San Diego CA	CA	-27.54	1	19.40	1	730.04	2	1.64	4	**16.0**	150	**5**
Total RWIS Sensor Needs												**832**