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The Use of Weather Data to Predict Non-recurring Traffic Congestion

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16. ABSTRACT

This project will demonstrate the quantitative relationship between weather patterns and surface traffic conditions. The aviation and maritime industries use weather measurements and predictions as a normal part of operations and this can be extended to surface transportation. While it is generally asserted that there is a causal relationship between weather and transportation systems delays, this relationship has not been quantified in a way that allows the effect on surface transportation systems to be predicted. This research has the potential to accomplish two very important things: (1) prediction of non-recurring traffic congestion and (2) prediction of conditions under which incidents or accidents can have a significant impact on the freeway system. This linkage of weather to traffic may be one of the only non-recurring congestion phenomena that can be accurately predicted. This work will create algorithms and implementations to correlate weather with traffic-congestion. Further, it may provide a means for traffic management to place resources proactively to clear incidents.

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Executive Summary

This project demonstrates the quantitative relationship between weather patterns and surface traffic conditions. The aviation and maritime industries use weather measurements and predictions as a normal part of operations, and this can be extended to surface transportation.

Data from two data mines on the University of Washington campus are combined to evaluate the quantitative relationship between freeway speed reduction and rain fall rate as measure by Doppler radar. The Atmospheric Science department maintains an archive of Nexrad radar data and the Electrical Engineering department maintains a data mine of 20 second averaged inductance loop data. The radar data is converted into rainfall rate and the speed data from the inductance loop speed traps is converted into a deviation from normal performance measure. The deviation from normal and the rainfall rate are used to construct an impulse response function that can be applied to radar measurements to predict traffic speed reduction.

This research has the potential to accomplish two very important things: (1) prediction of non-recurring traffic congestion and (2) prediction of conditions under which incidents or accidents can have a significant impact on the freeway system. This linkage of weather to traffic may be one of the only non-recurring congestion phenomena that can be accurately predicted. This project creates algorithms and implementations to correlate weather with traffic congestion. Furthermore, it may provide a means for traffic management to proactively place resources to clear incidents.

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CHAPTER 1

Introduction

The goal of this project is to demonstrate the quantitative relationship between weather patterns and surface traffic conditions. The aviation and maritime industries use weather measurements and predictions as a normal part of operations, and this can be extended to surface transportation [1, 2, 3]. While it is generally asserted that there is a causal relationship between weather and transportation system delays, this relationship has not been quantified in a way that allows the effects on surface transportation systems to be predicted. This research has the potential to accomplish two very important things: (1) prediction of non-recurring traffic congestion and (2) prediction of conditions under which incidents or accidents can have a significant impact on the freeway system. This linkage of weather to traffic may be one of the only non-recurring congestion phenomena that can be accurately predicted. If the research is successful, it will create a report that describes an algorithm and implementation to correlate weather and traffic congestion. Furthermore, it may provide a means for traffic management to proactively place resources to clear incidents.

CHAPTER 2

Background

While it is widely accepted on an anecdotal basis that weather phenomena affect traffic congestion, little quantitative work actually provides a statistical causal link [4, 5, 6]. For example, weather radar can follow moving weather cells across a large region and even predict, with some accuracy, the expected track. If there were an accurate statistical correlation between the properties of the cell (e.g., precipitation intensity) and observed traffic disruption (e.g., non-recurring reductions in speed due to visibility or surface wetness), a traffic condition forecast (and a confidence interval for the forecast) could be calculated in advance of this type of non-recurring event. However, to accomplish this, researchers from two different fields, Atmospheric Sciences and Electrical Engineering, would need to cooperate to address both the prediction of weather cell motion and then the prediction of non-recurring congestion. This may be one of the only forms of non-recurring congestion that can be predicted accurately. Two data mines are on the UW campus that can be used to correlate weather and traffic phenomena. The TDAD data mine in EE and the Doppler radar data mine in Atmospheric Sciences (AS) contain the raw data to undertake such a correlation. In collaboration, EE and AS investigators undertake creation of a mechanism to correlate non-recurring congestion, caused by weather, with Doppler radar data. This can be expanded to create a mechanism to use the real-time radar data to provide traffic managers with a warning of the time and location for a probable incident. An example of a low-resolution Doppler radar data map is shown in Figure 2.1.

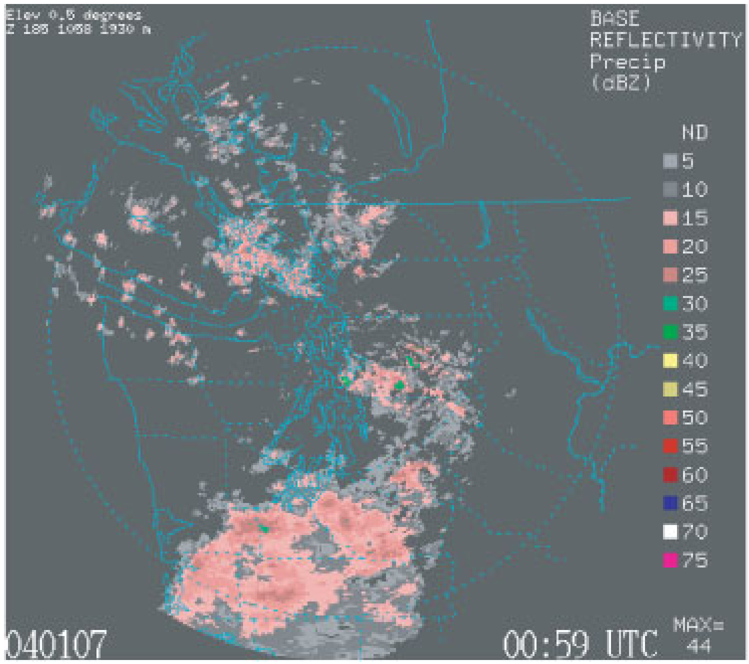

Figure 2.1: Example of low resolution radar image.

Past work has created tools to correlate traffic behavior over long portions of I-5 and over the course of a whole day. For example, the speed data from sensors along I-5 north for the course of a Monday are shown in Figure 2.2. The morning recurring commute congestion appears as a valley on the plot around 7:00-8:00 am. The work presented here identifies days on which there are significant weather events that would likely have the effect of creating non-recurring congestion. Data for several months of traffic flow and radar data are extracted from the two data mines. These two sets of data are cross-correlated in time and space to estimate the probabilities of when and where the two data sets are correlated. This type of data fusion between disciplines may be one of the few ways that non-recurring freeway congestion can be accurately predicted. Weather is one of the few types of impact on traffic congestion that can be predicted.

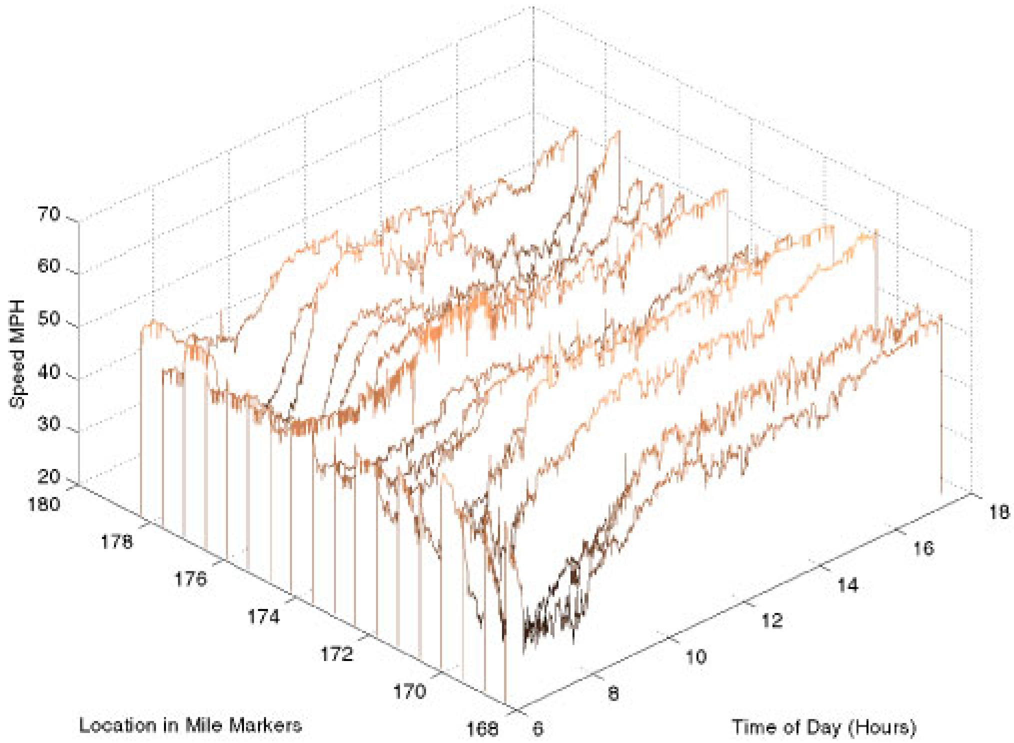

Figure 2.2: Speed at sequential locations along the I-5 corridor over the course of a Monday.

CHAPTER 3

Radar and Inductance Loop Data

The Nexrad radar used in this work is located on Camano Island, Washington. The latitude is 48 degrees 11 minutes 40 seconds and the longitude is -122 degrees 29 minutes 45 seconds, and it is mounted 494 ft above sea level. A full sweep of data for every range bin and angle is available every six minutes. The sweep is quantized into one degree of angle and one kilometer in range. A scaled representation of the location of the equipment cabinets and inductance loops in the sweep pattern is shown in Figure 3.1.

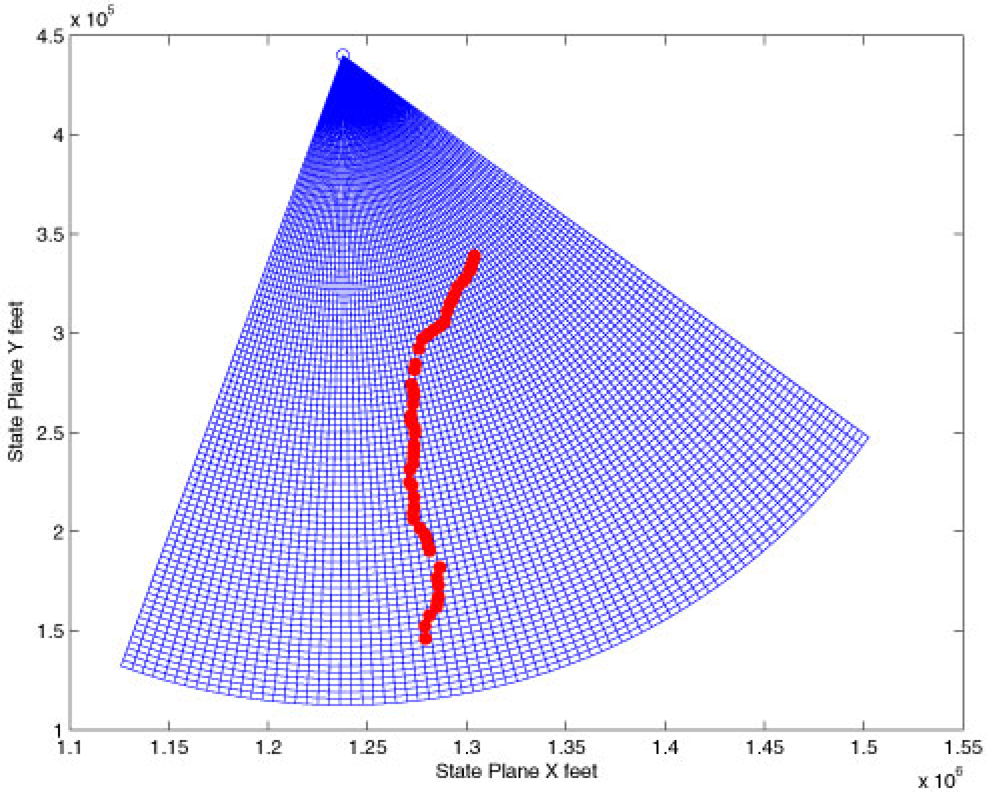

Figure 3.1: Location of I-5 inductance loop sensors in the radar scan.

There are a number of products/data available from the radar. The one used here is the "base reflectivity." This is measured at an elevation angle of 0.5 degrees and the full range is approximately 230km. It is quantized into integers from 0 to 15 representing the reflectivity or the power returned to the radar per unit of volume when precipitation or water vapor scatter the radar electromagnetic signal. These measurements are on a logarithmic scale in decibels(dB) over a range from 10 to 55 dB, and represent rainfall rates ranging from 0.1 millimeters per hour (mmh^{-1}) to over 100 mmh^{-1}.

The data from the radar is stored in a partially compressed format that is decoded using custom software. The code that performs the decompression is part of the Unix operating system and this means that the decompression must be done under Unix. The data files, as received from Atmospheric Sciences, are arranged with one file per radar sweep that takes six minutes to complete. The radar operates in one of three modes: maintenance, clear air, and precipitation, and only data from the precipitation mode is used in this effort.

For the work presented here inductance loop speed trap locations were chosen in north Seattle where there is a "convergence zone" that experiences increased rainfall over other areas of Seattle. Only a limited number of speed traps are available in this area, and the speed traps used in the effort are shown in Table 3.1 along with the location both in geodetic and state plane coordinates. The SensorID field is the name used in the WSDOT TMS where the first three numbers indicate where along the highway the equipment cabinet is located, the "MS" indicated mainline south bound and the T2 or T3 indicate it is a speed trap in lanes 2 or 3.

Using the location from Table 3.1, the range and angle to the radar is computed for each of the cabinets. Each six minute duration sweep of the radar begins at a slightly different angle and each sweep must be examined to identify the indices in the radar data that are related to the location of the loop sensors. Once this is done the data for the seven locations from the Table 3.1 can be identified for that sweep.

The data associated with the locations of the speed traps is collected into a time series for the entire duration of a day. It should be noted that the radar operates on UTC time and thus the "day" begins at 16:00 PST. And the loop data for the same day period is extracted from the TDAD data base. These two time series, loop and radar, are the basis for the quantitative comparison of the weather and the traffic. The next section provides a theoretical basis to do that comparison.

Talbe 3.1: Speed Trap Names and Locations

SensorID	Lat	Lon	X	Y	Location
145D_MS_T2	47.68109514	122.321248	1273922	251986	Lake City Way
145D_MS_T3	47.68109514	122.321248	1273922	251986	Lake City Way
152D_MS_T2	47.69235547	122.329574	1271951	256132	NE 88th St
167D_MS_T2	47.73350293	122.3248357	1273409	271116	NE 145th St
167D_MS_T3	47.73350293	122.3248357	1273409	271116	NE 145th St
186D_MS_T2	47.79183058	122.3160626	1275977	292347	228th St SW
186D_MS_T3	47.79183058	122.3160626	1275977	292347	228th St SW

Theory

The goal of this project was to demonstrate the quantitative relationship between weather patterns and surface traffic conditions. While it is generally asserted that there is a causal relationship between weather and transportation systems delays, this relationship has not been quantified in a way that allows the effect on surface transportation systems to be predicted. We have obtained several years of NexRad radar data from Atmospheric Sciences, and we have obtained matching roadway data for many stations in North Seattle from the TDAD data mine.

A theoretical framework has been developed to quantitatively compare these data. The measured traffic speed, $\hat{y}$ (t), where t is time, is modeled as the output of linear system as shown in Figure 4.1. It is the sum of three input components: (1) the "normal" traffic pattern, $\overline{y}(t)$, where examples for the loops under consideration are found in Figure 4.2, (2) the contribution to slowing from the rain fall rate, $r(t)$, and (3) all other contributions, $z(t)$

$$\hat{y}(t) = \overline{y}(t) + z(t) - \int h(\tau) r(t-\tau) d\tau. \qquad (1)$$

where τ is a placeholder variable of integration and h is the "impulse response function" in linear systems theory. This is a standard text book linear systems relationship [8]; and can be thought of as a "Black Box" model for the response of traffic to rainfall rate. While this is an approximation it provides a mechanism to quantitatively relate the rainfall rate to traffic slowing. The impulse response function, h, is convolved with the rainfall rate r (the integral in equation (1)) to estimate the contribution of rainfall to slowing. While h is not known a priori it is the purpose of this section to create a framework to estimate this function and then use it to predict the effect of weather on traffic.

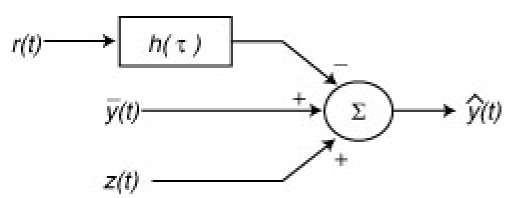

Figure 4.1 System Model for identifying impulse response function for traffic slowing.

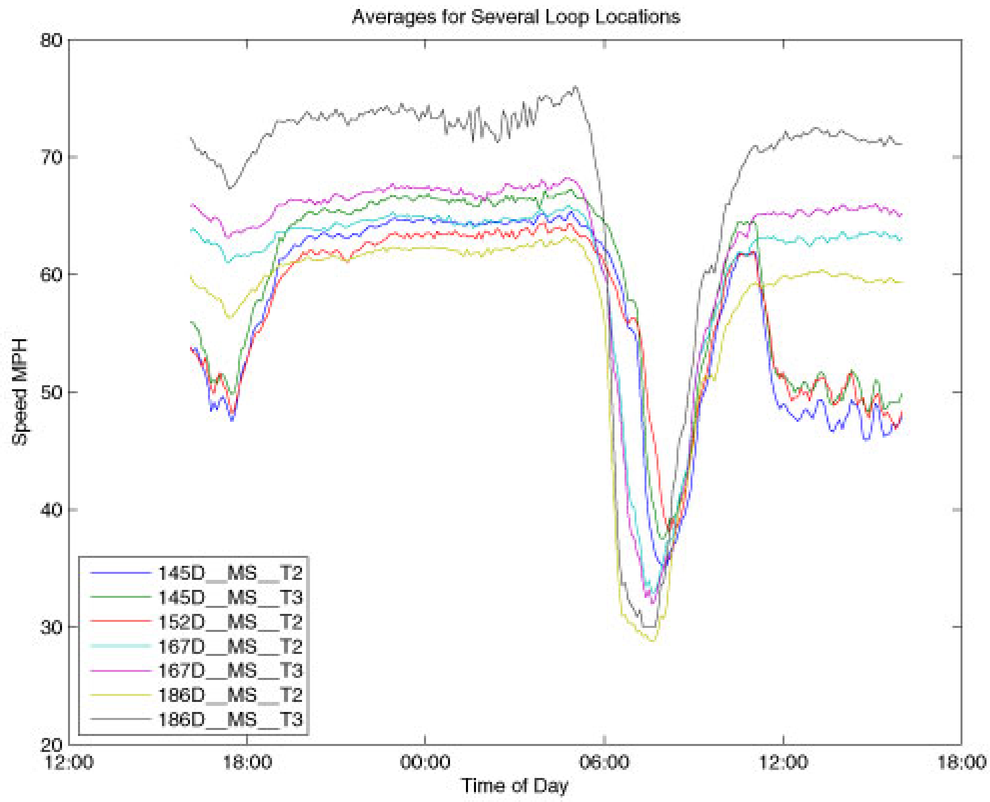

Figure 4.2. One year average, or normal speed, as a function of time of day for the loops used for comparison with radar data.

The radar reflectivity in dB, not rainfall rate, is the actual measurement available from the radar. These measurements are converted to rainfall rates at the inductance loop sensor locations. The rain fall rate is estimated from the Doppler radar reflectivity using

$$r = \frac{1}{a}\left(10^{\frac{dB}{10}}\right)^{\frac{1}{b}}, \qquad (2)$$

where a and b are site specific and dB is the measured radar reflectivity index. These parameters are taken as $a = 200$ and $b = 1.6$ from page 25 of [7]. This relationship is non-linear, as shown in Figure 4.3.

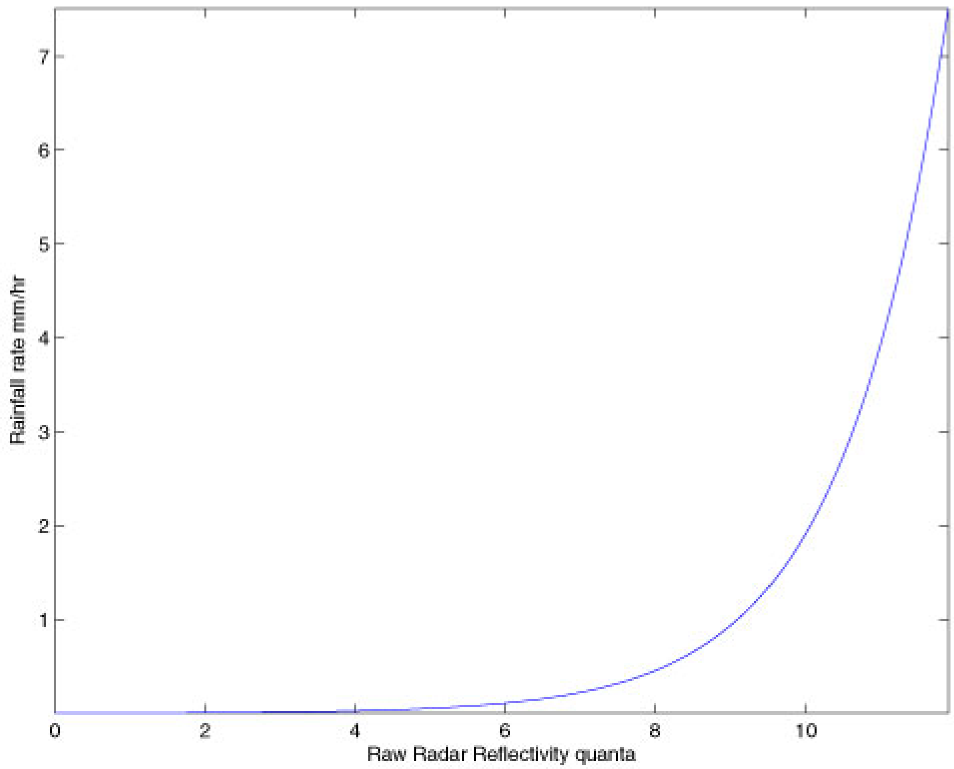

Figure 4.3: Relationship between rainfall rate and radar raw data.

To estimate the speed deviation, $\delta(t)$, from normal, subtract $\overline{y}(t)$ from both sides of equation (1) to get,

$$\delta(t) = \hat{y}(t) - \overline{y}(t) = z(t) - \int h(\tau) r(t-\tau) d\tau. \qquad (3)$$

The rainfall rate is related quantitatively to the speed deviation by means of an impulse response function, h. To obtain an estimate of h, we Fourier transform equation (3)

$$\Delta(f) = Z(f) - H(f)R(f), \qquad (4)$$

where f is frequency, Δ if the Fourier transform of the speed deviation δ, R is the Fourier transform of the rainfall rate r and H is the Fourier transform of h also known as the transfer function. We post multiply by the complex conjugate value of $R(f)$, $R^*(f)$ to get

$$\Delta R^* = ZR^* - HRR^*, \tag{5}$$

that can be rewritten in terms of the power spectrum as

$$G_{\Delta R} = G_{ZR} - HG_{RR} \tag{6}$$

Assume that the "other" contributions and the rainfall are uncorrelated, $G_{ZR} = ZR^* \approx 0$, to get

$$G_{\Delta R} \approx HG_{RR} \qquad \text{implying,} \qquad H \approx \frac{G_{\Delta R}}{G_{RR}}. \tag{7}$$

Therefore, h is approximately the inverse Fourier transform of

$$\frac{G_{\Delta R}}{G_{RR}}. \tag{8}$$

This provides an estimate of the impulse response function, h, and allows for the estimation of the impact of rainfall on traffic using equation (3).

In order to construct h, observations where rainfall is impacting traffic need to be identified. We use the coherence function between the observed speed deviation and the rainfall,

$$\gamma^2 = \frac{|G_{\Delta R}|^2}{G_{\Delta\Delta} G_{RR}}. \tag{9}$$

The coherence function can be interpreted as the portion of the output which is linearly related to the input [8]. We select days where the coherence is greater than 0.7 as the days to be used in estimating the impulse response function h from equation (8).

The experiment to determine an impulse response function was done using one year of radar and freeway data. The location of the freeway loops was chosen based on (1) a known convergence zone in north Seattle that is expected to have an above average number of rain events, and (2) locations where paired inductance loops are available to measure speed. The "average" speed as a function of time of day for various loops in north Seattle is shown in Figure 4.2. The date and inductance loops used to compile the estimate of h are found in Table 4.1.

Table 4.1: Speed Trap Names and Dates

Name	Year	Month	Day
145D_MS_T2	2004	1	28
145D_MS_T2	2004	1	29
145D_MS_T2	2004	2	29
145D_MS_T2	2004	3	4
145D_MS_T2	2004	5	8
145D_MS_T2	2004	5	28
145D_MS_T3	2004	1	7
145D_MS_T3	2004	1	29
145D_MS_T3	2004	2	29
145D_MS_T3	2004	3	4
145D_MS_T3	2004	5	27
145D_MS_T3	2004	5	28
145D_MS_T3	2004	5	29
145D_MS_T3	2004	7	10
145D_MS_T3	2004	8	4
145D_MS_T3	2004	9	11
145D_MS_T3	2004	10	6
145D_MS_T3	2004	11	2
152D_MS_T2	2004	1	8
152D_MS_T2	2004	1	29
152D_MS_T2	2004	3	5
152D_MS_T2	2004	4	20
152D_MS_T2	2004	8	4
152D_MS_T2	2004	8	6
152D_MS_T2	2004	9	11
152D_MS_T2	2004	10	6
152D_MS_T2	2004	11	27
152D_MS_T2	2004	2	27
152D_MS_T2	2004	3	5
152D_MS_T2	2004	3	26
152D_MS_T2	2004	4	14
167D_MS_T2	2004	5	27
167D_MS_T2	2004	8	6
167D_MS_T2	2004	8	22
167D_MS_T2	2004	9	11
167D_MS_T2	2004	10	6
167D_MS_T2	2004	11	27
167D_MS_T3	2004	1	7
167D_MS_T3	2004	1	30
167D_MS_T3	2004	2	27
167D_MS_T3	2004	3	5
167D_MS_T3	2004	3	25
167D_MS_T3	2004	3	26

167D_MS_T3	2004	5	27
167D_MS_T3	2004	8	6
167D_MS_T3	2004	8	22
167D_MS_T3	2004	9	11
167D_MS_T3	2004	10	6
167D_MS_T3	2004	11	18
167D_MS_T3	2004	11	27
186D_MS_T2	2004	1	7
186D_MS_T2	2004	1	30
186D_MS_T2	2004	2	27
186D_MS_T2	2004	3	24
186D_MS_T2	2004	3	26
186D_MS_T2	2004	8	22
186D_MS_T2	2004	9	1
186D_MS_T2	2004	11	27
186D_MS_T3	2004	1	7
186D_MS_T3	2004	1	8
186D_MS_T3	2004	2	27
186D_MS_T3	2004	5	27
186D_MS_T3	2004	8	22
186D_MS_T3	2004	9	1
186D_MS_T3	2004	11	18

The impulse response function, determined using data from the year 2004, is shown in Figure 4.4. The peak at approximately one hour indicates that the decrease in traffic speed is most likely to occur about one hour after the radar identifies large reflectivity values. This suggests the prediction horizon for the impulse response function technique, based on radar observations, is on the order of one hour.

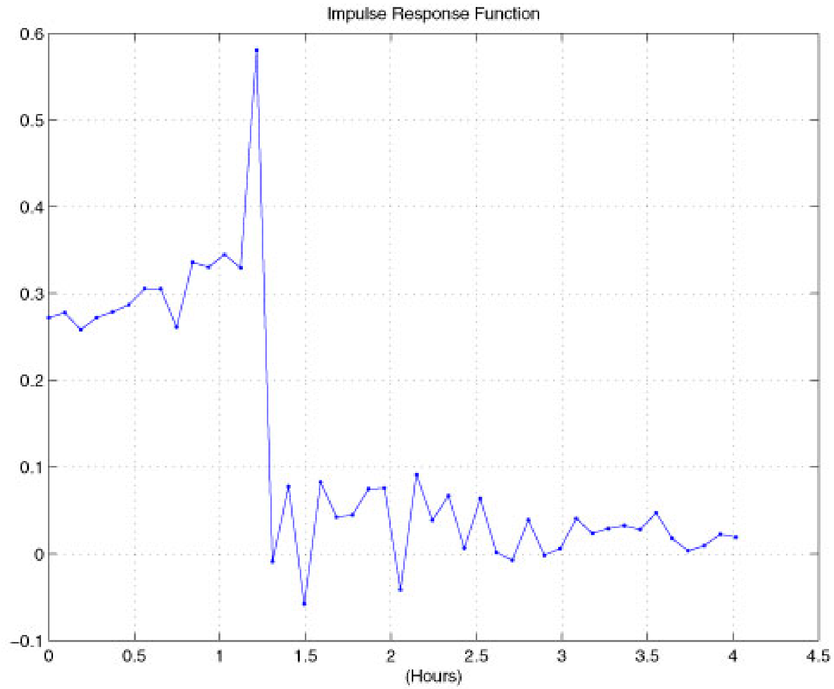

Figure 4.4: Impulse response function from 2004.

In support of the notion that the maximum impact of the rainfall rate on traffic is on the order of one hour we constructed the cross-correlations function between the deviation from normal speed and the rainfall rate,

$$\hat{R}_{\delta r}(\tau) = \frac{1}{T}\int_0^T \delta(t) r(t+\tau) dt \,, \tag{10}$$

where T is 24 hours, whose peak value is located at the delay (τ) necessary to align the two time series. Figure 4.5 is a histogram of the location of the largest peak found in the cross-correlation function for the data set found in Table 4.1. The largest number of delay peaks is at approximately one hour.

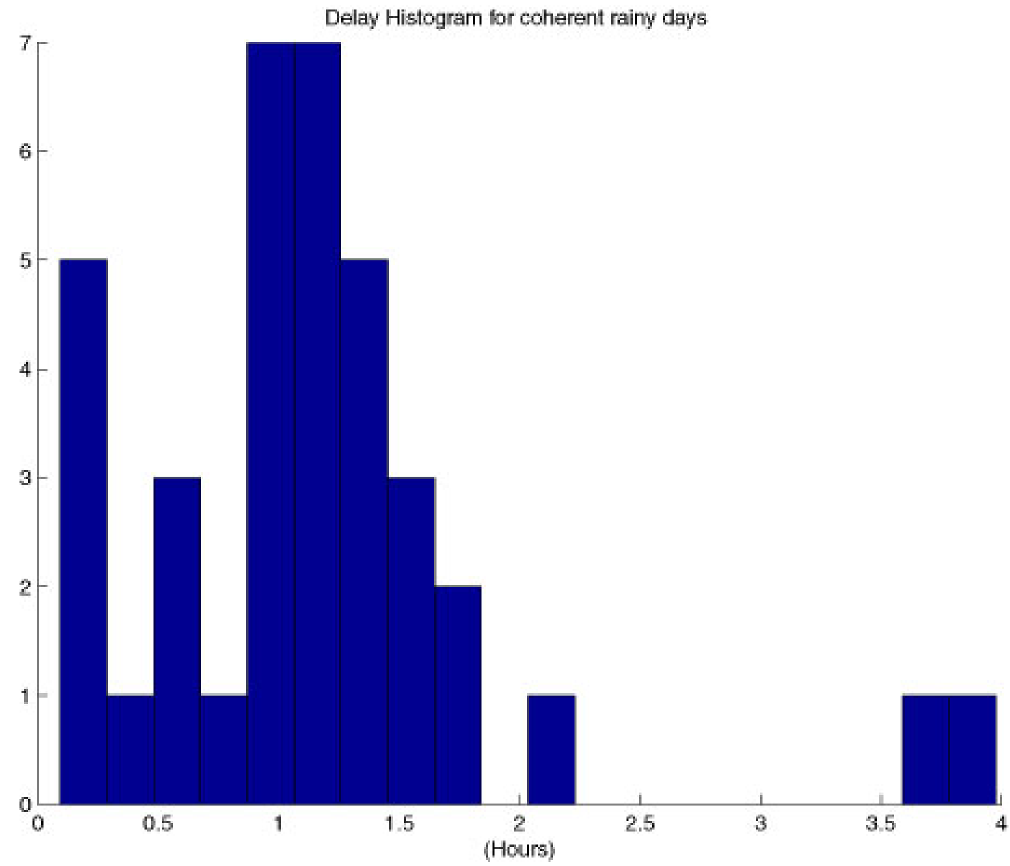

Figure 4.5: Histogram of delay peak location for the coherent rainy days in Table 4.1.

Equation (3) can be used with h to predict the slowdown of traffic due to weather conditions. The data taken from the radar is convolved with the impulse response function h to produce a prediction of slowing of traffic. A comparison of predicted and actual speed deviation are shown in Figures 4.6 to 4.9 for four locations ordered from south to north. At three of the four locations there were two operational inductance loop speed traps. In Figures 4.6, 4.8, and 4.9 the predictions and the observed speed deviation for two speed traps are shown for I-5 at Lake City Way, 145th Street, and 228th Street SW respectively. In Figure 4.6 there are recurring delays shown at the evening and morning rush hours that are not predicted by the rainfall rate and there is a period of slowing from 21:00 to 3:00 that is predicted by the rainfall rate. This shows that while rainfall does effect the slowing other congestion causes may outweigh the effect of weather. Figures 4.6. 4.8, and 4.9 are all from the same day September 1, 2004, and all show the prediction from the rainfall rate leading the observed nonrecurring slowing taking place at night when there were no other external effects acting on the traffic.

In Figure 4.7 is the single operational loop on I-5 at 88th Street with the prediction using the methodology presented. Again the predicted slowing leads the actual slowing temporally.

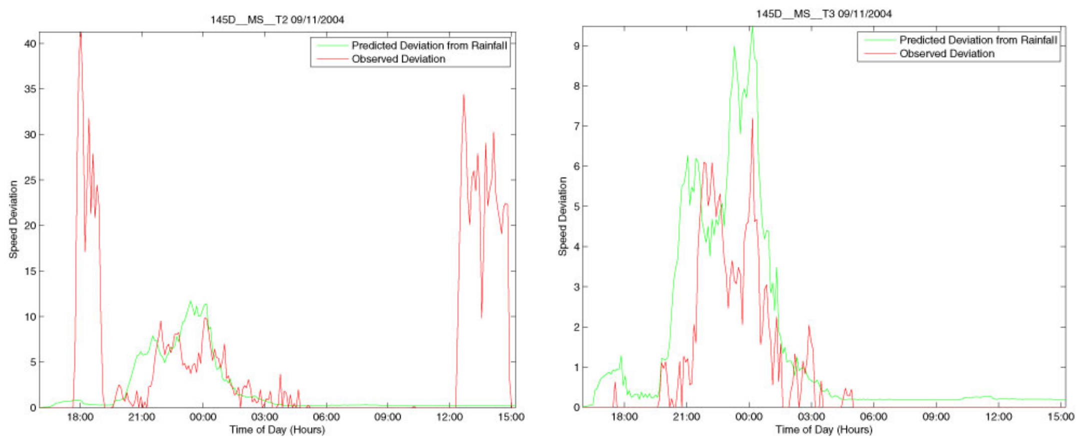

Figure 4.6: Prediction and measurement of speed deviation at Lake City Way on I-5.

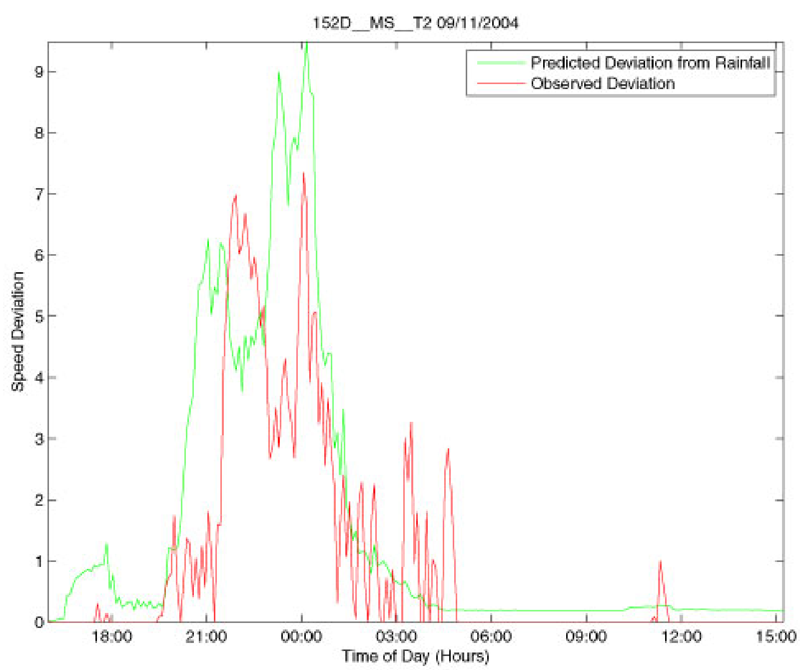

Figure 4.7: Prediction and measurement of speed deviation at 88th street on I-5.

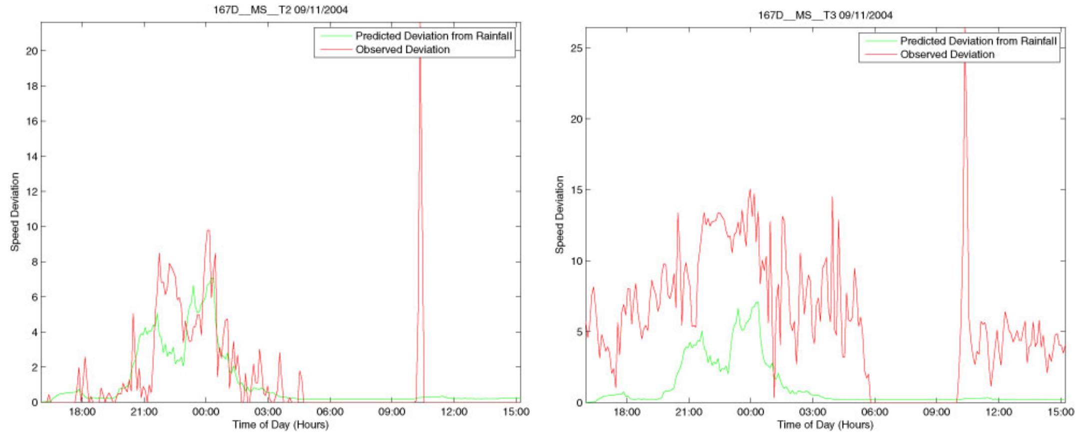

Figure 4.8: Prediction and measurement of speed deviation at 145th street on I-5.

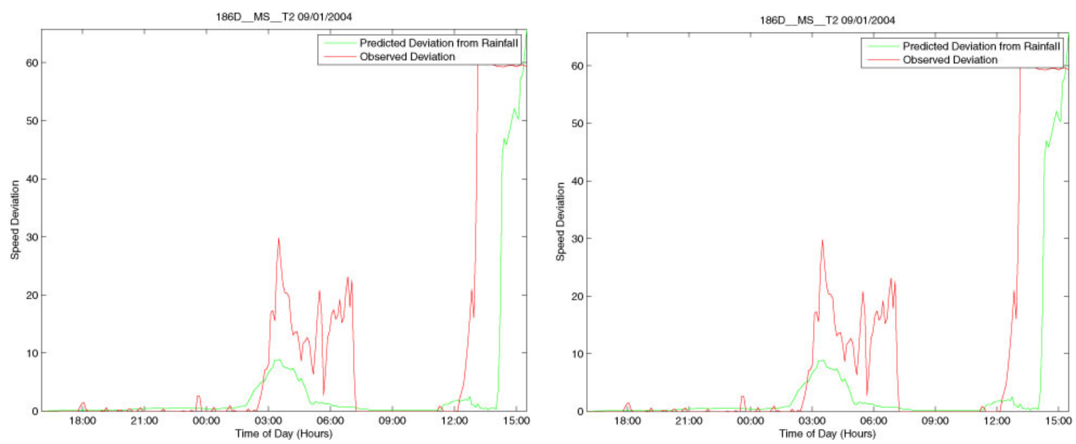

Figure 4.9: Prediction and measurement of speed deviation at 228th St SW on I-5.

Conclusion

This project demonstrates the quantitative relationship between weather patterns and surface traffic conditions. The aviation and maritime industries use weather measurements and predictions as a normal part of operations, and this can be extended to surface transportation.

Data from two data mines on the University of Washington campus are combined to evaluate the quantitative relationship between freeway speed reduction and rain fall rate as measure by Doppler radar. The Atmospheric Science department maintains an archive of Nexrad radar data and the Electrical Engineering department maintains a data mine of 20 second averaged inductance loop data. The radar data is converted into rainfall rate and the speed data from the inductance loop speed traps is converted into a deviation from normal performance measure. The deviation from normal and the rainfall rate are used to construct an impulse response function that can be applied to radar measurements to predict traffic speed reduction. The days to be used to construct the impulse response function are identified using the coherence function. The shape of the impulse response function predicts that the largest effect on traffic we be approximately one hour after radar reflections of a significant scale begin.

Examples that show the relationship between the predicted slowing and the observed slowing are presented and compare favorably. However, a larger data set will provide a better evaluation. A real-time connection to the radar data should be setup and data plus predictions should be recorded over a longer period.

This research has the potential to accomplish two very important things: (1) prediction of non-recurring traffic congestion and (2) prediction of conditions under which incidents or accidents can have a significant impact on the freeway system. This linkage of weather to traffic may be one of the only non-recurring congestion phenomena that can be accurately predicted. This project creates algorithms and implementations to correlate weather with traffic congestion. Furthermore, it may provide a means for traffic management to proactively place resources to clear incidents.

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