Predicting Fatigue Lifetime from Strain Histograms in an Abbreviated Time Window

Andrew T. Metzger & Arthur Huckelbridge

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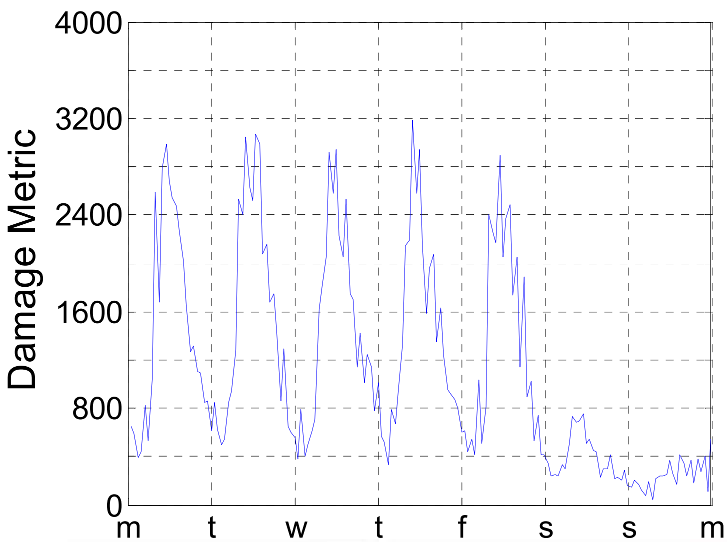

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16. Abstract

This work presents the development of a methodology for estimating the year in which AASHTO-prescribed fatigue lifetime expectations will be reached for a structural detail on a steel highway bridge. The methodology is based upon a year-round strain monitoring program of an ensemble of 24 bridge structures, located on Ohio highways of 8 different functional classes. The data from the strain monitoring program was processed into a normalized temporal representation of the expected accumulation of fatigue damage for the 8 different highway functional classes studied. An algorithm is presented to estimate the annual damage for a particular detail from a site-specific strain histogram, collected over an abbreviated time window. The extrapolation of the short-term histogram to an annual fatigue damage estimate is carried out utilizing the normalized temporal damage accumulation model for the appropriate highway functional class. Sample statistics and probability theory are used to construct confidence intervals associated with the estimate of annual damage. Projected growth rates of traffic volume and/or truck weights can be readily incorporated into the lifetime projection.

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Authored by:

Arthur Huckelbridge, D. Eng., P.E.
Andrew T. Metzger, P.E.
Department of Civil Engineering
Case Western Reserve University
Cleveland, Ohio 44106

Prepared in Cooperation with the Ohio Department of Transportation and the U.S. Department of Transportation, Federal Highway Administration

Disclaimer:

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Ohio Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification or regulation.

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1 INTRODUCTION

It is known that the details comprising the structural steel elements of highway bridges are susceptible to fatigue failure. For this reason, consideration of fatigue is code-required in the design of such elements. The *AASHTO LRFD Bridge Design Specifications* (AASHTO, 2004) [1] (hereinafter referred to as the *Code*) of the American Association of State Highway and Transportation Officials (AASHTO) contain provisions for fatigue design. These provisions provide requirements for the (vehicle) loads to be used in fatigue design. The *Guide Manual for Condition Evaluation and Load and Resistance Factor Rating (LRFR)* [2] and *Guide Specifications for Fatigue Evaluation of Existing Steel Bridges* [3] outlines procedures for estimating the temporal response produced by a particular fatigue load event as well as an analytical model for predicting fatigue lifetime under conditions of constant amplitude stress cycles (AASHTO, 2003; AASHTO, 1990 respectively).

Major assumptions of this codified methodology include the concept of a "Design Truck" with prescribed axle weights and spacing. Other assumptions inherent to the present standard of practice include lane assignments, load distribution among structural elements, the anticipated number of passages of the Design Truck, damping characteristics of the structure (i.e. the number of stress cycles per vehicle passage) and the contributions to fatigue damage by vehicles other than the Design Truck.

In reality, one may expect the variability of vehicle passage frequency, vehicle weight, secondary vibration and possibly strains resulting from changes in temperature to more closely represent what may be defined as random process (hereinafter referred to as the Strain Cycle Process or SCP). Including the temporal characteristics of the SCP into a fatigue damage assessment methodology will contribute to a more meaningful representation of fatigue damage and more appropriate estimation of fatigue life. Herein it is proposed that short-term monitoring of a site-specific SCP, coupled with a database of temporal multipliers derived from long-term monitoring of multiple bridges on similar highway functional classes, facilitates an estimate of remaining fatigue life. Using such a method to represent a particular fatigue damage accumulation process should overcome most of the drawbacks associated with the inherent assumptions of the traditional codified analytical fatigue evaluation procedures.

Furthermore, for the proposed method to be of practical use, it must be readily implemented by personnel familiar with fatigue-prone details in bridges. The partnering agency, Richland Engineering Limited (Mansfield, Ohio), provides bridge inspection and design services and was employed to collect a portion of the long-term data utilized for this project. It will also be shown that with the SCP temporal factors, the estimation of fatigue life is mathematically straight forward.

2 RESEARCH OBJECTIVES

The objectives of this research are to 1) demonstrate the feasibility of application of the field monitoring system by existing bridge inspection personnel with minimal training in the use of strain monitoring hardware and software and 2) develop an effective database that characterizes the SCP for different highway functional classes. The database is derived from data collected during long-term monitoring of multiple structures on an ensemble of highway functional classes and facilities the extrapolation of remaining fatigue life.

The bridge inspection personnel trained in the application of the system was provided by the partnering agency, Richland Engineering Limited (REL). REL, the P.I. for this project and a graduate student from Case Western Reserve University collected the long-term data for this project from an ensemble of in-service highway bridges. The bridges monitored for this project are along those highways of functional classes (FCs) that appear to be most prone to fatigue damage based on historical truck volume data. (See Appendix 8.1)

The long-term data was processed into temporal factors that characterize the SCP for the various functional classes studied in this project. The temporal factors facilitate estimation of the remaining bridge fatigue life using the algorithm proposed herein.

The final product of this work is an extrapolation algorithm that may be calibrated to a specific detail or structure situated along a fatigue-prone roadway type with the included temporal factors derived from long-term monitoring.

3 GENERAL DESCRIPTION OF RESEARCH

To develop the proposed fatigue lifetime estimation methodology, the following objectives must be accomplished:

- Gather histogram data over an adequate time period to represent the SCP for in-service bridges of different FC's
- Develop a temporal model of the fatigue damage for respective functional classifications
- Develop a methodology to determine the expected time at which Code prescribed fatigue limits will be achieved (i.e. the time at which expected fatigue lifetime has ended)

3.1 Ensemble of Bridges

Prior to data collection, it was necessary to identify subject bridges, from which data was to be collected. Preliminary calculations indicated that the traffic volumes for most roadways classified as "Local" or "Collector" are not as likely to produce fatigue concerns as the "Arterial" roadways. For this reason the subject bridges were confined to ODOT FC 1, 2, 6, 7, 11, 12, 14 and 16. The bridges used in this study are listed in Table 3.1.1. Maps is Appendix 9.2 show the locations of the bridges.

SUBJECT BRIDGE LIST				
Functional Classification	Roadway Served by Bridge	Location	ODOT District	County
1	I 71	I 71 over Gridder Road	3	Richland
1	I 76	I 76 over Ryan Road	3	Medina
1	I 80	I 80 over I 271	4	Summit
2	SR 18	US 18 over CSXT RR	3	Medina
2	SR 224	SR 224 over E. Fork Cr.	3	Medina
2	US 30	US 30 over Koogle Road	3	Richland
6	SR 3	SR 3 over I 71	3	Medina
6	SR 39	SR 39 over CSXT Railway	3	Richland
6	SR 83	SR83 over SR 224	3	Medina
7	SR 303	SR 303 over I 271	4	Summit
7	SR 42	SR 42 over SR 224	3	Medina
7	SR 603	SR 603 over CSXT Railway	3	Richland
11	I 271	I 271 over Solon Road	12	Cuyahoga
11	I 480	I 480 over Lee Road	12	Cuyahoga
11	I 77	I 77 over Hillside Road	12	Cuyahoga
12	SR 176	SR 176 over Valley Road	12	Cuyahoga
12	SR 422	SR 422 over Miles Road	12	Cuyahoga
12	SR 8	SR 8 over I 80	4	Summit
14	SR 14	SR 14 over I 490	12	Cuyahoga
14	SR 82	SR 82 over IR 71	12	Cuyahoga
14	SR 87	SR 87 over IR 271	12	Cuyahoga
16	SR 17	SR 17 over CSX Railway	12	Cuyahoga
16	SR 21	SR 21 over CSX Railway	12	Cuyahoga
16	Turney Road	Turney Road over I 480	12	Cuyahoga

Table 3.1.1: Subject Bridges used for Long-Term Monitoring

3.2 Data Collection

It is well known that truck traffic volumes and hence expected fatigue damage rates exhibit substantial variation with time for given highway categories. These temporal variations consist of short term hourly fluctuations over the course of a given day, daily variations over the course of a given week and longer term monthly or seasonal variations over the course of a given year. There are also even longer term trends attributable to gradual growth in truck volume and/or truck weights.

To develop a model of the strain cycle processes, it is necessary to collect data that characterizes the behavior of the process over time. The data collection scheme used for this study has been developed to record variations in the strain cycle process by hour-of-day, day-of-week and month-of-year.

The dataloggers used to collect data for this project were deployed to run continuously for one week. Strain readings on girder flanges at interior piers were taken at a sampling rate of 50Hz, and the measured strain cycles categorized into bin counts by rainflow counting. (See reference [4] for additional information concerning rainflow counting) Updated bin counts were recorded each hour during active monitoring.

Dataloggers were redeployed each week of each month. The assumption was made that a week of data collected in a particular month is indicative of all days within that month. This allows one data logger to collect “monthly” data from four bridges per month. (For the purposes of this article, “monthly” data will represent all the data collected during an entire week within a particular month – 168 hours of data).

The monitoring scheme allowed for monthly data to be collected from twelve bridges over the course of a year, employing three dataloggers. A “year” of data consists of 168 hours of data (1 week) for each month of the year monitored (total of 2016 hours per subject bridge monitored). The first-year data set consists of two year-long data records for each Urban FC in the study and one year-long data record for each Rural FC in the study. (An unfunded follow-on study completed an ensemble of three year-long data records for each FC included in the investigation.) Refer to Table 9.1.1 for the distinction between "Rural" and "Urban" Functional Classes. Additional information concerning Functional Classification may be found in reference [5].

The first year-long data collection commenced in December of 2004 and concluded in February of 2006 (the second "unfunded" year of data collection began in March of 2006 and was completed in April of 2007). Data was collected utilizing full-bridge "clamp-on" strain transducers, mounted on girder flanges at interior piers, and connected to a computerized datalogger unit. The strain transducers were mounted only during active data collection and "travelled" with the datalogger during redeployment, each week. Figure 3.2.1 illustrates the datalogger configuration and a typical clamp-on strain transducer mounting example.

The datalogger software contains an intrinsic rainflow counting algorithm that is being used in this project. The entire strain range measured by the datalogger is divided into subranges or "bins". The rainflow counting algorithm counts the cycles for each strain subrange as they are completed and increments the corresponding bin accordingly. The result is a set of histogram data representing the number of cycles in each subrange during the monitoring interval.

The overall measurable strain range arbitrarily chosen for the project is 400με (live load strains from-200 με to +200 με). No "over-strains" beyond this range have been observed in the monitoring period. The cycles are divided into bins at intervals of 10με (0-10με, 10-20με, …, 390-400με). The first bin (0-10με) is disregarded as electronic "noise" inherent to the data acquisition system. A typical histogram that has been collected for this project is shown in Figure 3.2.2. The assumption is made that the collected strain data represents bridge response within the linear elastic range, and can thus be converted directly to stress quantities for fatigue analysis.

Figure 3.2.1: Data Logger and Clamp-on Strain Transducer Configuration

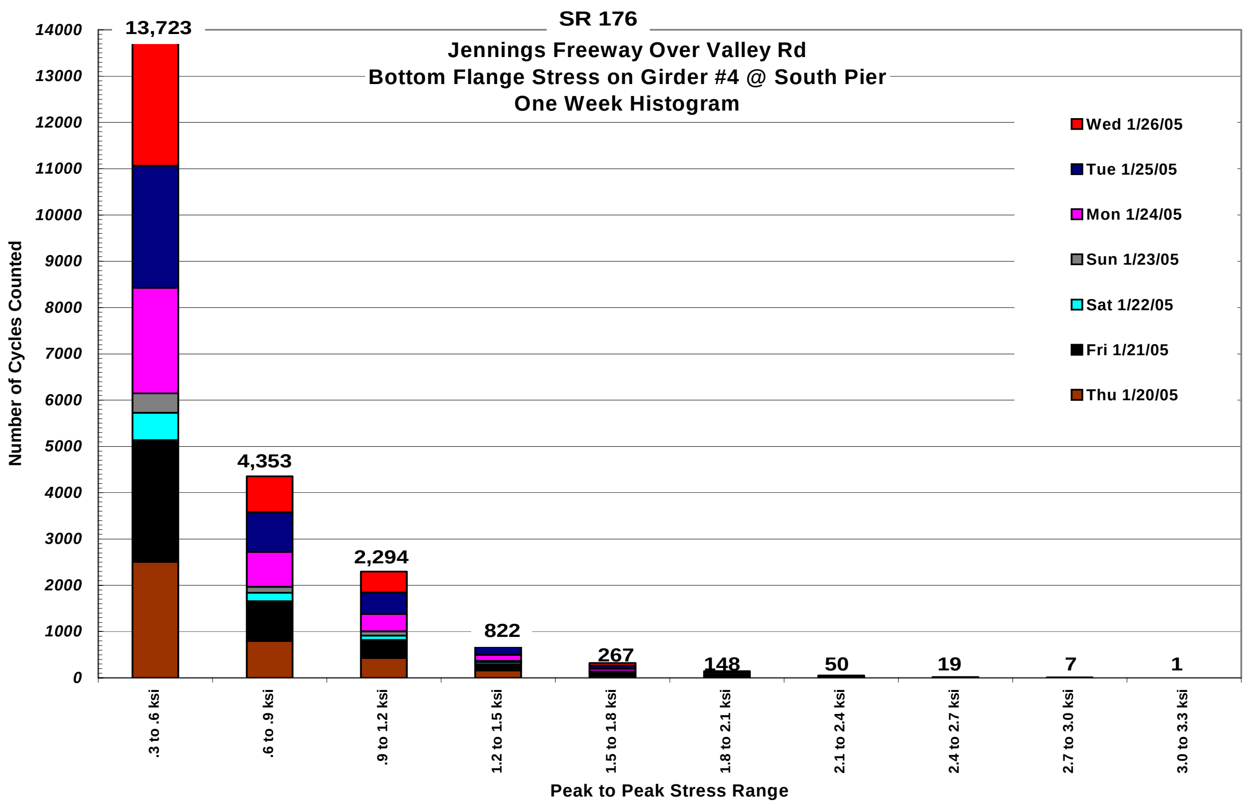


Figure 3.2.2: Typical Weekly Stress Histogram

As a featured aspect of this investigation, Case Western Reserve University (CWRU) partnered with a consultant to help execute the project. Richland Engineering Ltd. (REL) was employed to assist in the collection of long-term data. This partnership was also an opportunity to assess the implementation potential of the method developed during this project. Specifically, the feasibility of having experienced bridge inspection personnel extend their duties to collecting the data needed for fatigue life calculations through field monitoring of bridge response.

CWRU assembled the data acquisition system and associated accessories and delivered them to REL. After an initial meeting to discuss the project and how to use the equipment, CWRU personnel accompanied REL personnel to the field for the first few deployments. CWRUs role in these first few deployments was to assist REL as required. Cooperative deployments were continued until REL felt comfortable independently deploying the system and collecting data. After the initial few deployments, REL successfully collected the long term data independently for the rural functional class bridges studied in the first year of this project.

3.3 Summary of Data

As was stated previously, each bridge in the study was monitored for one week of each month during the collection year. This effort resulted in 2016 hourly bin counts for each bridge in the study. Figure 3.3.1 is an example of a set of bin counts collected during a day of data collection.

date/ time	0-10 μin/in	>10-20	>20-30	>30-40	>40-50	>50-60	>60-70	>70-80	>80-90	>90-100
8/21/2006 0:00	3	1	0	0	0	1	1	0	0	0
8/21/2006 1:00	1	0	1	0	0	0	0	0	0	0
8/21/2006 2:00	0	0	0	0	0	0	0	0	0	0
8/21/2006 3:00	2	1	2	0	0	0	1	0	0	0
8/21/2006 4:00	6	1	2	1	0	0	2	0	0	0
8/21/2006 5:00	2	1	2	1	0	0	2	0	0	0
8/21/2006 6:00	7	2	2	0	0	0	2	0	0	0
8/21/2006 7:00	11	0	3	2	0	1	1	0	0	0
8/21/2006 8:00	25	6	2	1	2	1	3	0	0	0
8/21/2006 9:00	16	5	7	2	1	0	0	0	0	0
8/21/2006 10:00	43	12	11	2	2	5	2	0	0	0
8/21/2006 11:00	32	13	12	4	1	3	3	0	0	0
8/21/2006 12:00	30	5	10	1	1	1	2	0	0	0
8/21/2006 13:00	24	5	7	1	0	1	1	0	0	0
8/21/2006 14:00	45	12	11	0	3	3	1	1	0	0
8/21/2006 15:00	14	5	3	0	2	0	0	0	0	0
8/21/2006 16:00	38	8	6	0	2	3	1	0	0	0
8/21/2006 17:00	70	6	8	3	1	2	0	1	0	0
8/21/2006 18:00	17	4	6	0	0	2	1	0	0	0
8/21/2006 19:00	17	5	1	3	0	1	0	0	0	0
8/21/2006 20:00	8	1	1	0	0	0	1	0	0	0
8/21/2006 21:00	9	3	3	1	0	2	1	1	0	0
8/21/2006 22:00	2	1	0	0	1	0	0	0	0	0
8/21/2006 23:00	2	0	0	0	1	1	0	1	0	0

Figure 3.3.1: Example of Bin Count Data

3.4 The Damage Metric Concept and Definition of Fatigue Life

Fundamentally, the aim of this project is to characterize traffic-induced fatigue damage over time. To do this, one needs an appropriate standard of measure or "metric" for an increment of damage. For the purposes of this investigation the "damage metric" for a given stress range magnitude shall be defined as:

$$\mathcal{D} = nS_R^3 \tag{1}$$

where: n = the number of stress cycles at stress range S_R

S_R = the stress range magnitude corresponding to n

The damage metric for the hour of data '*h*' collected during this project can be readily calculated from the collected strain data using the constitutive relation:

$$S_R = \varepsilon_R E_s \tag{2}$$

and the following expression:

$$\mathcal{D}_h = \sum_i n_i S_{Ri}^3 \tag{3}$$

where: ε_R = the strain corresponding to bin range *R* of the bin count data

E_s = Modulus of Elasticity for steel

i = denotes bin number

Henceforth, the hourly damage metric is the sum of damage metrics for each bin count during hour '*h*'. More generally, the damage metric for a particular segment in time is the sum of damage metrics for all non-overlapping time periods within that segment of time. (i.e., the 'monthly' damage metric is the sum of damage metrics for all non-overlapping time periods within the month.)

Noting that the AASHTO S-N relationship for stress levels above the fatigue threshold can be written in terms of fatigue life (See reference [1], equation: 6.6.1.2.5-1):

$$N = \left(\frac{A}{S_R^3} \right) \tag{4}$$

where: A = a fatigue category detail constant

Substituting this expression into the Palmgren-Miner Rule (See reference [4] for information on the Palmgren-Miner Rule) yields:

$$\sum_j \frac{n_j}{\left[\frac{A}{S_R^3} \right]_j} = 1 \tag{5}$$

Noting that 'A' is a constant in the above expression yields:

$$\sum_j n_j S_{Rj}^3 = A \tag{6}$$

Equation (6) will serve as the definition of fatigue life for this investigation. This is to say that, fatigue life is assumed to end (for the detail under consideration) when the cumulative damage metric corresponding to the detail equates to the AASHTO detail constant appropriate for said detail. The fatigue threshold for a particular fatigue category can also readily incorporated into this approach, if desired, by only including strain (stress) cycle bin counts for bins which are above the assumed fatigue threshold in the damage metric calculation.

3.5 Temporal Characteristics of the Normalized Fatigue Damage Metric

As was stated earlier, the focus of the data collection scheme was to characterize the occurrence of fatigue damage over time. Appendix 9.3 contains plots of the damage metric data calculated from the bin count data collected during this project. Upon inspection of the plots in Appendix 9.3, the following conclusion may be inferred:

When considered over time, the occurrence of vehicle induced mechanical fatigue damage in steel components of highway bridges exhibits a general and consistent temporal structure.

A few characteristics that are apparent from the plots in Appendix 9.3 are:

- The magnitude of the damage metric for a Monday through Friday "work day" is greatest during business hours
- The magnitudes of damage metrics on Saturdays, Sundays and holidays is appreciably less than work days
- The general weekly temporal structure is preserved throughout the data collected (with the exception of weeks affected by holidays)
- There is apparent month-of-year (or seasonal affects) within the damage metric representation of the data – i.e., the total damage that occurs within a given week is dependent upon where that week occurs during a calendar year.

The first two points above are intuitively reasonable. The apparent "structure" within the data will be exploited to characterize the SCP for the various functional classes studied in this work.

It appears, from Appendix 9.3, that the amount of damage that occurs in a given hour of the year may be dependent upon the hour of day in which that hour occurs; the day of the week in which that hour occurs; and the month of the year in which that hour occurs. For these reasons the SCP will be characterized with *temporal factors* describing the fraction of the total damage that occurs within a given time period. However, an underlying assumption of this approach is that there is no appreciable temporal interaction within the data.

3.5.1 Analysis of Variance of the Damage Metric Data

To evaluate the existence (or lack) of temporal interaction within the SCP data, an Analysis of Variance (ANOVA) calculation was performed on the data. Specifically, "Analysis of Variance" calculations were performed to test the validity of the assumption of "no interaction" between "hour-of-day" effects and "day-of-week" effects and also between "day-of-week" effects and "month-of-year" effects in the SCP.

An ANOVA calculation was performed for the "hour-of-day" versus "day-of-week" condition. When considering the entire seven day week, the calculation showed significant temporal interaction. Intuitively, this is sensible because of the difference in traffic patterns on Saturday and Sunday compared to the Monday through Friday. In this case, the "hour-of-day" fraction DOES depend on the "day of week" when considering the entire seven day week. For this reason, weekday fractions will be considered separately from weekend-day fractions.

The results of ANOVA calculations on weekday data alone indicate no appreciable temporal interaction between "hour-of-day" effects and "day-of-week" effects. The results of this analysis on the FC11 data are summarized in Table 3.5.1. An ANOVA calculation for "month-of-year" versus "day-of-week" was also performed. The analysis indicates no appreciable interaction for this condition as well. The results of the ANOVA for the FC11 data are also summarized in Table 3.5.1. ANOVA calculation for data from the other functional classes yielded similar results.

FC11 Data ANOVA

Day-of-Week versus Hour-of-Day			Month-of-Year versus Day-of-Week	
Month	F Ratio	Conf. Level	F Ratio	Conf. Level
January	0.4850	0.9998	0.3738	0.9997
February	0.5901	0.9957		
March	0.6722	0.9767		
April	0.4766	0.9999		
May	0.6062	0.9938		
June	0.6291	0.9897		
July	0.7650	0.9107		
August	0.6068	0.9937		
September	0.2951	1.0000		
October	0.2937	1.0000		
November	0.5843	0.9963		
December	0.3711	1.0000		

Table 3.5.1: ANOVA Results for FC11 Data

Based on the above discussion, it does not seem unreasonable to use the temporal factor approach to characterize the SCP.

3.5.2 Comparison of Truck Count Data with Hourly Damage Metric Fractions

The "hour-of-day" factors (explained in Section 3.6) represent the fraction of total daily damage that occurs in a particular hour of the day. This data has been compared to the corresponding data from truck-count observations published by ODOT [6]. The comparison is illustrated in the plots of Appendix 9.4. The truck count data used for this plot has been resolved into hourly fractions of the total daily truck traffic volume. The comparison between the two sets of data is not unfavourable.

3.6 Temporal Factors

In order to develop a robust algorithm for extrapolating short-term histogram observations to expected fatigue lifetime predictions, it is convenient to utilize normalized fatigue damage metrics to represent those histograms. For example, to investigate the hour-by-hour fatigue damage rate variations, it is convenient to look at the compiled hour-by-hour fatigue damage metrics, normalized by the average hourly damage metric for the entire day of observation. The statistical average of those normalized hour-by-hour variations form the basis for extrapolating an observation over only a portion of a day to the expected damage incurred during the entire day.

In a similar vein, observed daily damage metrics could be normalized by the average daily damage metric for a given week of observation to form a basis for extrapolating an observation over a portion of a week to the expected damage incurred during the entire week. Monthly damage metrics could also be normalized by the average monthly damage metric for an entire year, providing the basis for extrapolating a monthly fatigue damage estimate to the expected annual fatigue damage. Historical growth rates of truck traffic volume and/or truck weights since the construction of the bridge, but prior to the damage rate observation, coupled with projected growth in the future, subsequent to the damage rate observation, would then allow a lifetime projection, based upon the short-term damage rate observation.

The temporal factors will be derived from the hourly damage metrics calculated from the data collected during this project. Data from bridges that occur along roadways of the same functional classification will be normalized and combined to calculate the temporal factors for that particular highway classification.

3.6.1 Month-of-Year Factors

To calculate the monthly factors, it is first necessary to normalize the data collected from each bridge for a particular FC. After normalization, the data may be combined to formulate the month-of-year factors for the fatigue life estimation. For month-of-year factors, the data is normalized by dividing the hourly damage metrics by the corresponding yearly mean damage metric.

For each set of data corresponding to the FC for which factors are being calculated, the sum of the normalized hourly damage metrics for each month is divided by the sum of all damage metrics for the year. This results in a set of quotients that represent the fraction of yearly damage that occurred in a particular month. The month-of-year factors are calculated by averaging the monthly factors from each set of long term data. (i.e., the March factor for a particular FC is the average of all March factors for that FC from the long term data collection.)

Table 3.6.1 summarizes the Month-of-Year factors based on the data collected during this project.

Month-of-Year Temproal Factors

FC	Jan.	Feb.	March	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
1	0.086	0.089	0.064	0.073	0.084	0.091	0.083	0.107	0.102	0.075	0.077	0.068
2	0.056	0.059	0.090	0.095	0.101	0.090	0.088	0.085	0.094	0.095	0.080	0.067
6	0.112	0.065	0.060	0.077	0.086	0.073	0.082	0.080	0.102	0.115	0.100	0.048
7	0.057	0.045	0.062	0.074	0.075	0.124	0.133	0.094	0.068	0.101	0.093	0.075
11	0.059	0.076	0.098	0.091	0.071	0.078	0.093	0.088	0.112	0.097	0.070	0.067
12	0.051	0.069	0.065	0.104	0.104	0.101	0.093	0.095	0.086	0.100	0.070	0.063
14	0.056	0.036	0.048	0.088	0.114	0.130	0.111	0.089	0.080	0.090	0.091	0.066
16	0.044	0.056	0.066	0.103	0.106	0.107	0.101	0.102	0.093	0.071	0.080	0.071

Table 3.6.1: Month-of-Year Temporal Factors

3.6.2 Day-of-Week Factors

In a fashion similar to the monthly factors, the long term weekly data was normalized. However, in the case of day-of-week factors, the hourly metrics for each week are divided by the average hourly metric value for that week. This operation results in twelve sets of hourly damage metrics for each bridge, normalized by their respective weekly means.

The factors for day-of-week fractions are calculated by dividing the sum of all hourly metrics for a particular day by the sum of the metrics for the corresponding week. This results in seven values that represent the fraction of total weekly damage that occurred in a particular day of the week. The result of this operation is that each long term set of data for each bridge will have twelve factors (one from each month of observation) for each day of the week. The daily factors are calculated by averaging the daily fractions from all the long term data collected in each FC. i.e., To calculate the Tuesday factor, average of all Tuesday fractions from each week of data from each set of long term data in the particular FC. Table 3.6.2 summarizes the day-of-week temporal factors derived from the data collected during this project.

	Day-of-Week Temporal Factors					
FC	Mon.	Tue.	Wed.	Thu.	Fri.	Sat.
1	0.146	0.187	0.191	0.180	0.140	0.077
2	0.167	0.189	0.190	0.181	0.154	0.058
6	0.174	0.194	0.194	0.186	0.188	0.041
7	0.166	0.180	0.193	0.210	0.160	0.057
11	0.170	0.186	0.198	0.188	0.179	0.051
12	0.170	0.198	0.207	0.187	0.169	0.044
14	0.185	0.189	0.193	0.186	0.174	0.056
16	0.171	0.193	0.178	0.188	0.183	0.055

Table 3.6.2: Day-of-Week Temporal Factors

3.6.3 Hour-of-Day Factors

To normalize the data for hour-of-day factor calculation, each hourly metric is divided by its corresponding daily average metric. This operation is applied to each calendar day of the long term data. After initial data analysis, it was decided to utilize one set of hour-of-day factors for non-holiday weekdays (Monday through Friday) and a separate set of hour-of-day factors for weekends and holidays.

The hourly metrics are determined by dividing the hourly damage metrics by the total damage metric for the day. Respective hourly metrics for a given FC are then averaged over all the data collected. These operations result in 24 hourly factors corresponding to weekday hour-of-the-day and 24 hourly factors corresponding to weekend/holiday hour-of-the-day. The hour-of-day factors represent the fraction of total daily damage that occurred in a particular hour. Appendix 9.5 summarizes the hour-of-day factors for the data collected during this project.

3.7 Extrapolation of the Yearly Fatigue Damage Metric

With the availability of the temporal factors, the yearly damage metric may be estimated by a step-wise calculation. To do this is it first necessary to collect some short term, or *temporal* strain cycle histogram data from a specific structure and fatigue detail under scrutiny. The temporal data may be collected in the form of hourly histograms from one or more time windows of varying duration.

Fundamentally, the calculation begins at the lowest level of ‘hours’ and progressively extrapolates to the next higher level (‘days’ to ‘weeks’, etc.) until the estimated yearly damage is determined. Described in general terms:

Step 1:

Accumulate the daily damage metrics for full days within the time interval of collection, [a, b], and extrapolate the estimated full day damage metrics for any partial days within the time interval of collection, [a, b], resulting in a set of daily damage metrics for all days within the time interval [a, b]. The extrapolation of partial days is achieved by dividing the sum of observed hourly damage metrics over the observed partial day by the sum of the corresponding hourly factors for the same time period.

Step 2:

Accumulate the daily damage metrics for any full weeks within the time interval of collection, [a, b], and extrapolate the estimated daily damage metrics for any partial weeks within the time interval of collection, [a, b], resulting in a set of observed/extrapolated weekly damage metrics for all weeks within the time interval [a, b]. The extrapolation of partial weeks is achieved by dividing the sum of observed daily temporal damage metrics over the observed partial week by the sum of the corresponding daily factors for the same time period.

In the event that the short term data is collected for a duration greater than one week (168 hours) within a particular month, the overlapping damage metric data shall be averaged. i.e., If [a, b] begins at 10am on Monday, September 1 and continues until 4pm on Wednesday, September 10, it will be necessary to average the observed damage metrics for Monday and Tuesday. It will also be necessary to average the data for 0:00 hours to 16:00 hours on Wednesday. The extrapolation procedure will proceed as described above.

Step 3:

Recalling that the temporal factors were derived from data collected one week out of each month, an estimated 'monthly' damage metric may be calculated by multiplying the damage metric for a single week by 4.348, the average number of weeks per month in a solar year.

Step 4:

Similar to steps 1) and 2), the estimated 'yearly' damage metric may be calculated by dividing the sum of monthly damage metric(s) by the sum of the corresponding monthly factor(s). If the observation interval should happen to extend more than one month, a average procedure similar to that described for step 2 could be carried out.

The following notation will be used for the temporal factors:

M_m = factor that represents the fraction of total yearly damage that occurs in a particular month of the year; m = 1 - 12

D_d = factor that represents the fraction of total weekly damage that occurs in a particular day of the week; d = 1 - 7

H_h = factor that represents the fraction of total daily damage that occurs in a particular hour of the day; h = 1 - 24 (recall there are separate hourly factors for weekday days and weekend/holiday days)

The process is illustrated with the following hypothetical example:

Temporal damage metrics have been calculated for time interval [a, b] occurring within a single calendar day. Estimation of the yearly damage metric would proceed as follows:

$$\mathcal{D}_{day_{[a,b]}} = \frac{\sum_{[a,b]} \mathcal{D}_h}{\sum_{[a,b]} H_h} \Rightarrow \mathcal{D}_{week_{[a,b]}} = \frac{\mathcal{D}_{day_{[a,b]}}}{D_{d_{[a,b]}}} \Rightarrow \mathcal{D}_{month_{[a,b]}} = \mathcal{D}_{week_{[a,b]}} * 4.348 \Rightarrow \mathcal{D}_{Y_{[a,b]}} = \frac{\mathcal{D}_{month_{[a,b]}}}{M_{m_{[a,b]}}}$$

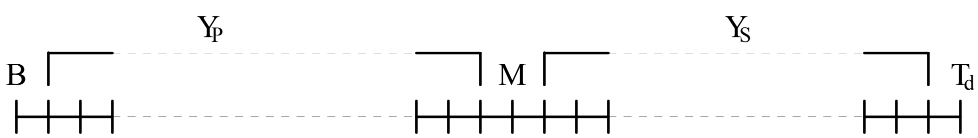
where:

$\mathcal{D}_{Y_{[a,b]}}$ = estimated yearly damage metric extrapolated from observation interval [a, b]

3.8 Estimating Residual Fatigue Life

The $\mathcal{D}_{Y_{[a,b]}}$ will be used to estimate the year in which the Code-prescribed fatigue limits are expected to be achieved. This will be accomplished in the following manner:

Consider a steel bridge with a finite fatigue lifespan characterized by a "birth" and a "death". Birth will be defined as the time at which the accumulation of fatigue damage begins – the bridge is opened to traffic. Death will be defined as the year in which the Code fatigue requirements have been achieved. At some point between birth and death, the bridge will be instrumented to gather SCP data. The years during the fatigue life of the bridge can be represented by the following timeline schematic:



where:

B = year of "Birth" – bridge is open to traffic

T_d = expected year of "Death" – year in which code prescribed fatigue requirements are expected to be achieved (i.e. fatigue *life* has ended)

M = year in which bridge was monitored for short term SCP data and $\mathcal{D}_Y$ was estimated

Y_P = Years prior to the year of monitoring

Y_S = Years subsequent to the year of monitoring

The fatigue damage timeline can be represented by the following relation:

$$F_D \Delta_s(y_D)\mathcal{D}_Y + \sum_{y=B+1}^{M-1} \Delta_p(y)\mathcal{D}_Y + \mathcal{D}_Y + \sum_{y=M+1}^{T_d} \Delta_s(y)\mathcal{D}_Y + F_B \Delta_p(y_B)\mathcal{D}_Y = A \qquad (7)$$

where:

$\mathcal{D}_Y$ = Expected yearly damage - fatigue damage incurred during the year "M" that the bridge was monitored

A = AASHTO fatigue detail constant for the monitored fatigue detail

F_B = Fraction of Year of Birth, B, that bridge was open to traffic

F_D = Fraction of Year of Death, D, that bridge will be serviceable

$\Delta_p(y)$ = function to account for growth in annual fatigue damage rates with respect to year of monitoring, for years prior to the year of monitoring

$\Delta_s(y)$ = function to account for growth in annual fatigue damage rates with respect to year of monitoring, for years subsequent to the year of monitoring

$F_B \Delta_p(y_B)\mathcal{D}_Y$ = fatigue damage that occurred during the fraction of the year that the bridge was first opened to traffic

$F_D \Delta_s(y_D)\mathcal{D}_Y$ = fatigue damage that occurred during the fraction of the final year that the bridge is expected to be serviceable

$\sum_{y=B+1}^{M-1} \Delta_p(y)\mathcal{D}_Y$ = fatigue damage for years $B+1$ to $M-1$

$\sum_{y=M+1}^{T_d} \Delta_s(y)\mathcal{D}_Y$ = fatigue damage for years $M+1$ to T_d

To facilitate the calculation of residual fatigue life, Equation [6] may be rearranged as follows:

$$F_D \Delta_s(y_D) + \sum_{y=M+1}^{T_d} \Delta_s(y) = \frac{A}{\mathcal{D}_Y} - F_B \Delta_p(y_B) - \sum_{y=B+1}^{M-1} \Delta_p(y) - 1 \qquad (8)$$

T_d may be determined from equation [7] by iteration. In cases where $\Delta_p(y)$ and $\Delta_s(y)$ may be represented by constant annual growth rates, a closed form solution for the expected residual fatigue lifetime is possible.

4 RESULTS

The fundamental result of this investigation is the identification of a general temporal structure of vehicle induced fatigue damage. This structure is obvious from inspection of the damage metric data in Appendix 9.2. The lack of interaction observed in the ANOVA calculations strengthens this argument.

The presence of this general temporal structure has been exploited to develop an algorithm for estimating the year in which code-prescribed fatigue limits may be achieved.

The bridges monitored in this investigation do not represent an irrefutably robust sample of bridges when considering the total number of bridges in the State of Ohio. However, the comparison with published truck-count data (Appendix 9.4) is an indication that the information contained herein may well have inventory-wide relevance.

5 CONCLUSIONS

Based on the data and analyses acquired during this project, it appears that the occurrence of vehicle induced mechanical fatigue damage exhibits a general temporal structure. The general characteristics of this temporal structure have been characterized using long term data collection. This characterization encompasses the Functional Classes studied in this project. In light of the comparison made between hourly data collected during this project and published hourly truck count data, the results of this work may have state wide applicability.

Short-term site-specific SCP data combined with long-term Functional-Class-specific data will advocate a reasonable estimate residual fatigue life. The method proposed herein may be applied to a broad class of bridges within the inventory as opposed to monitoring schemes that target a specific structure.

The method of short-term data collection utilized in the proposed method may be implemented by existing bridge inspection professionals with little additional training.

6 RECOMMENDATIONS

It is recommended that the proposed methodology is further verified through additional long-term monitoring of in-service bridges. This may be accomplished by collecting a year-long continuous set of hourly damage metric data. Such information will yield the true yearly damage metric. The methods described in this work may be verified by applying “windows” of the continuous data set to the fatigue life estimation procedure and comparing the results to the true yearly damage metric.

It is also recommended that an Implementation Manual be developed prior to implementation of the fatigue life estimation methodology. Such a manual would outline data collection procedures, fatigue calculation procedures and trouble-shooting. The document would also facilitate training of personnel. The manual can serve as a platform to provide recommendations on how to best utilize the fatigue life assessment method for the purposes of strategic planning and budget justification.

7 IMPLEMENTATION PLAN

The methods of data acquisition and fatigue life estimation presented in this project have been developed to be easily implemented with minimal additional training of either State or private bridge inspection professionals.

It was shown in this project that bridge inspection personal, with no previous data collection experience (as required by this project), were readily trained to perform the tasks necessary for this project. The consultant used in this project successfully collected the long term data for the bridges along rural functional classes.

The long-term data collection operations for this project provide insight into the field effort required for implementation. The duration of the typical equipment setup procedure was approximately 20 to 30 minutes. The download/ breakdown procedure was generally of similar duration. Based on the experience gained in this project, incorporating the collection of short term data for fatigue life estimation will add approximately 1 crew-hour of field time to a bridge-maintenance inspection. These estimates as based on monitoring bridge components that are readily accessible via ladder and do not require special traffic control. For certain fatigue details, as well, clamp-on type strain transducers may not be practical. In such instances, strain gauge installation time would then have to be added to the above time estimates.

The fatigue life estimation calculation may be implemented using commercially available spreadsheet or other mathematical software packages. The estimation procedure may also be incorporated into a self contained software package. It is estimated that processing of the short term data and performing the calculation will require, at most, one hour of office time for an individual.

The estimates for both data collection, processing and lifetime calculation provided above are based on trained, competent personal that have experience with the procedures involved. During data collection for this project, there was an initial “break-in” period that required additional time. The break-in period lasted for the first 3 to 4 cycles of deployment and collection.

Based on the above discussion and experience gained during this project, the proposed fatigue life estimation methodology has the potential of immediate implementation. The execution of an “Implementation Plan” would require the development of an Implementation Manual, and the subsequent training of personnel, as needed, to obtain the objectives set forth by the State.

8 BIBLIOGRAPHY

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[2] AASHTO, Guide Manual for Condition Evaluation and Load and Resistance Factor Rating (LRFR) of Highway Bridges, 2003

[3] AASHTO, Guide Specifications for Fatigue Evaluation of Existing Steel Bridges, 1st ed., 1990

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[5] Ohio Department of Transportation Highway Classification data. Available on line at the ODOT Systems Planning and Program Management website: http://www.dot.state.oh.us/planning/default.htm

[6] Ohio Department of Transportation Traffic Survey data. Available on line at ODOT Office of Technical Services webpage: http://www.dot.state.oh.us/techservsite/default.htm

[7] Huckelbridge et al., Implementation of Field Measurements for Fatigue Lifetime Evaluations, Report No.: FHWA/OH-2002/025

9 APPENDIX

9.1 Fatigue Life Calculations based on Historical Truck Data

The table below is the estimated number of truck load cycles incurred by bridges of various Functional Classifications in the year of 2002. The data used in the calculations was taken from "Hourly Percent by Vehicle Type" data found on the ODOT website. It is assumed that this data may represent the Average Daily Truck Traffic for use in fatigue life calculations.

The following equation was used to calculate the number of load cycles from trucks:

$$N_T = n\frac{C_T}{C} \times 365 \times 75 \qquad (9.1)$$

Where:

n = number of cycles per truck passage (conservatively estimated at 2.0 – see reference [1] (table 6.6.1.2.5-2) for additional information)

C_T = number of trucks from published data (see Note below)

C = number of locations monitored for each FC from published data

$\frac{C_T}{C}$ = Average number of trucks per roadway that was "counted"

The number of load cycles from trucks, N_f, was compared to the corresponding stress range. Judgment was used to decide which Functional Classifications were most likely to experience unacceptable levels of fatigue damage within the lifetime of a bridge. The allowable stress range "S" is calculated using equation (6.6.1.2.5-1) from reference [1]. A detail category "E" was used in the calculations. Category E is a common detail and is relatively prone to fatigue damage. The endurance limit for category E is between 3 and 4 ksi (See ref. 1, Fig.

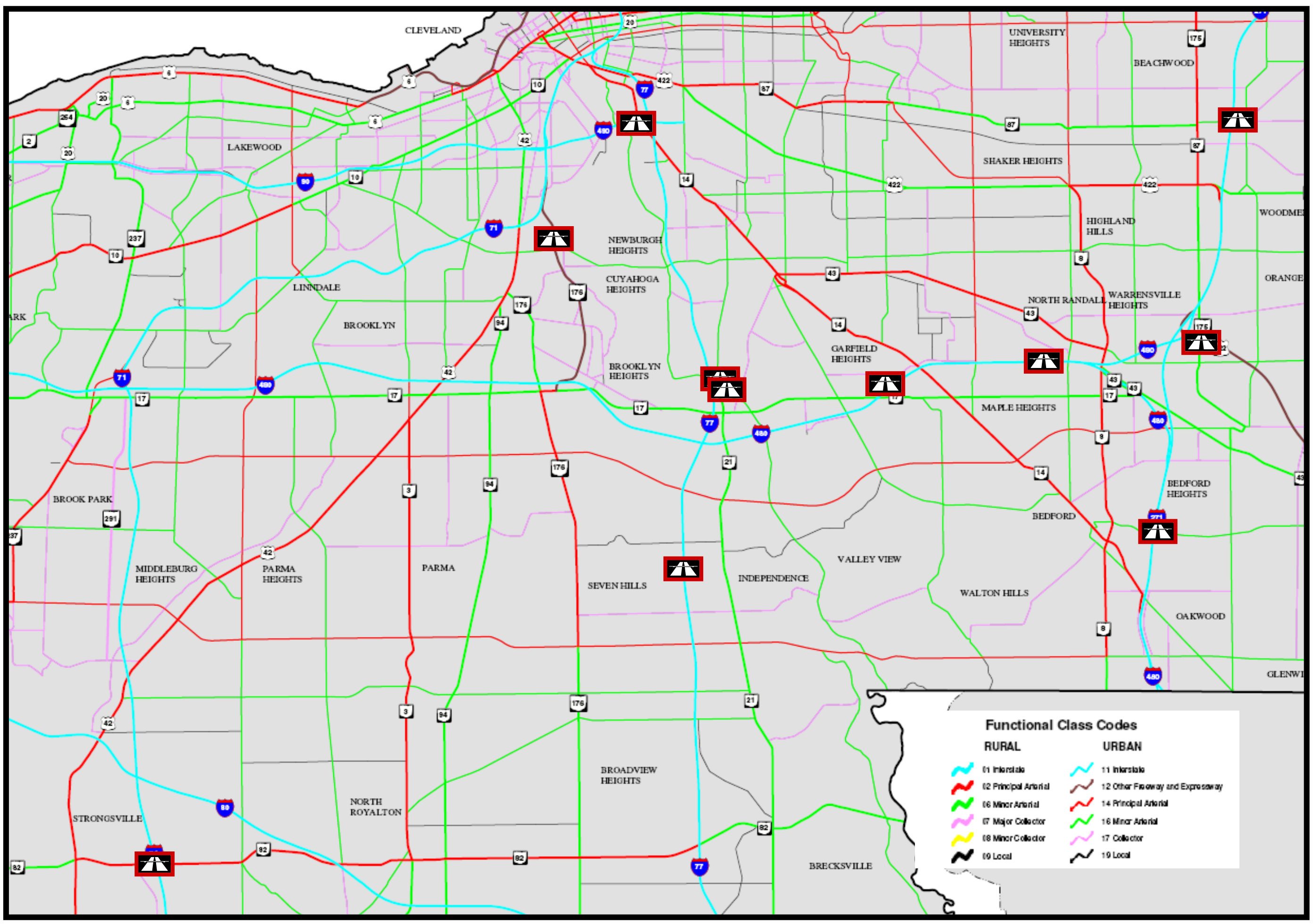
C6.6.1.2.5-1). Based on Table 9.1.1, those FCs with a number of load cycles corresponding to an allowable stress range of approximately 4 ksi or less were selected for this project. With no better information available, Table 9.1.1 was used as an indicator as to which FCs are most likely to experience unacceptable levels of fatigue damage within the design service life of the bridge.

FC	FC Description	C_T	C	n	N_f	S (ksi)
1	Rural Interstate	344,414	28	2	673,452,375	1.18
2	Rural Principal Arterial	537,255	194	2	151,622,223	1.94
6	Rural Minor Arterial	175,138	207	2	46,322,732	2.88
7	Rural Major Collector	166,190	475	2	19,155,584	3.86
8	Rural Minor Collector	9,937	38	2	14,317,125	4.26
9	Rural Local	234	2	2	6,405,750	5.56
11	Urban Interstate	94,688	49	2	105,799,347	2.19
12	Urban Freeway	166,066	75	2	121,228,180	2.09
14	Urban Principal Arterial	279,747	217	2	70,581,328	2.50
16	Urban Minor Arterial	153,888	265	2	31,793,842	3.26
17	Urban Collector	30,907	115	2	14,714,420	4.22
19	Urban Local	2,282	5	2	24,987,900	3.54

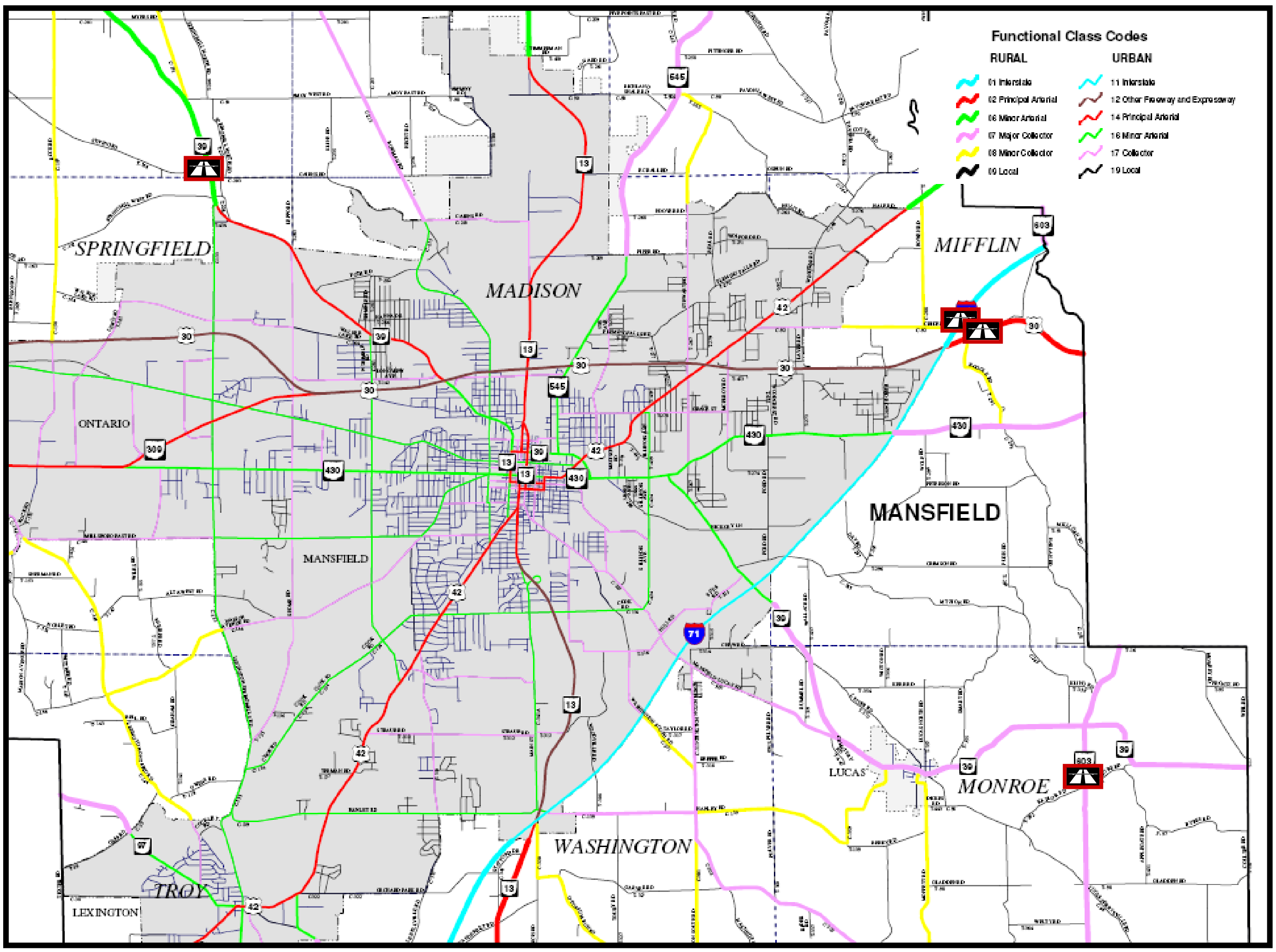
Table 9.1.1 – Allowable Stress Range Calculations

9.2 Subject Bridge Locations

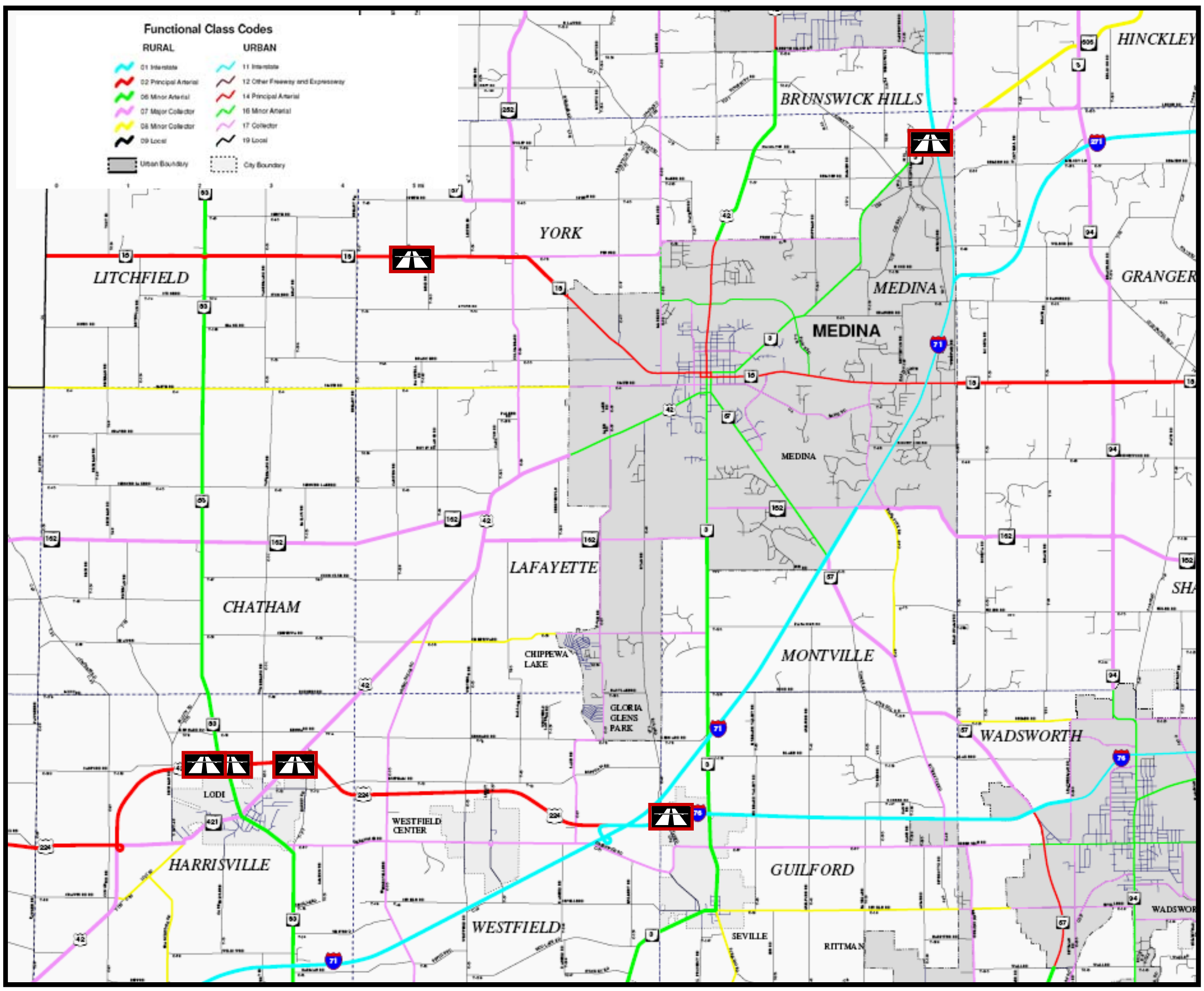
Bridge	FC	County	ODOT District
IR 271 over Solon Rd.	11	CUY	12
IR 77 over Hillside Rd.	11	CUY	12
SR 176 over Valley Rd.	12	CUY	12
SR422 over Miles Rd.	12	CUY	12
SR 87 over IR 271	14	CUY	12
SR 82 over IR 71	14	CUY	12
SR 17 over CSX Railway	16	CUY	12
SR 21 over CSX Railway	16	CUY	12
IR 480 over Lee Rd,	11	CUY	12
SR 14 over IR 490	14	CUY	12
Turney Road over IR 480	16	CUY	12



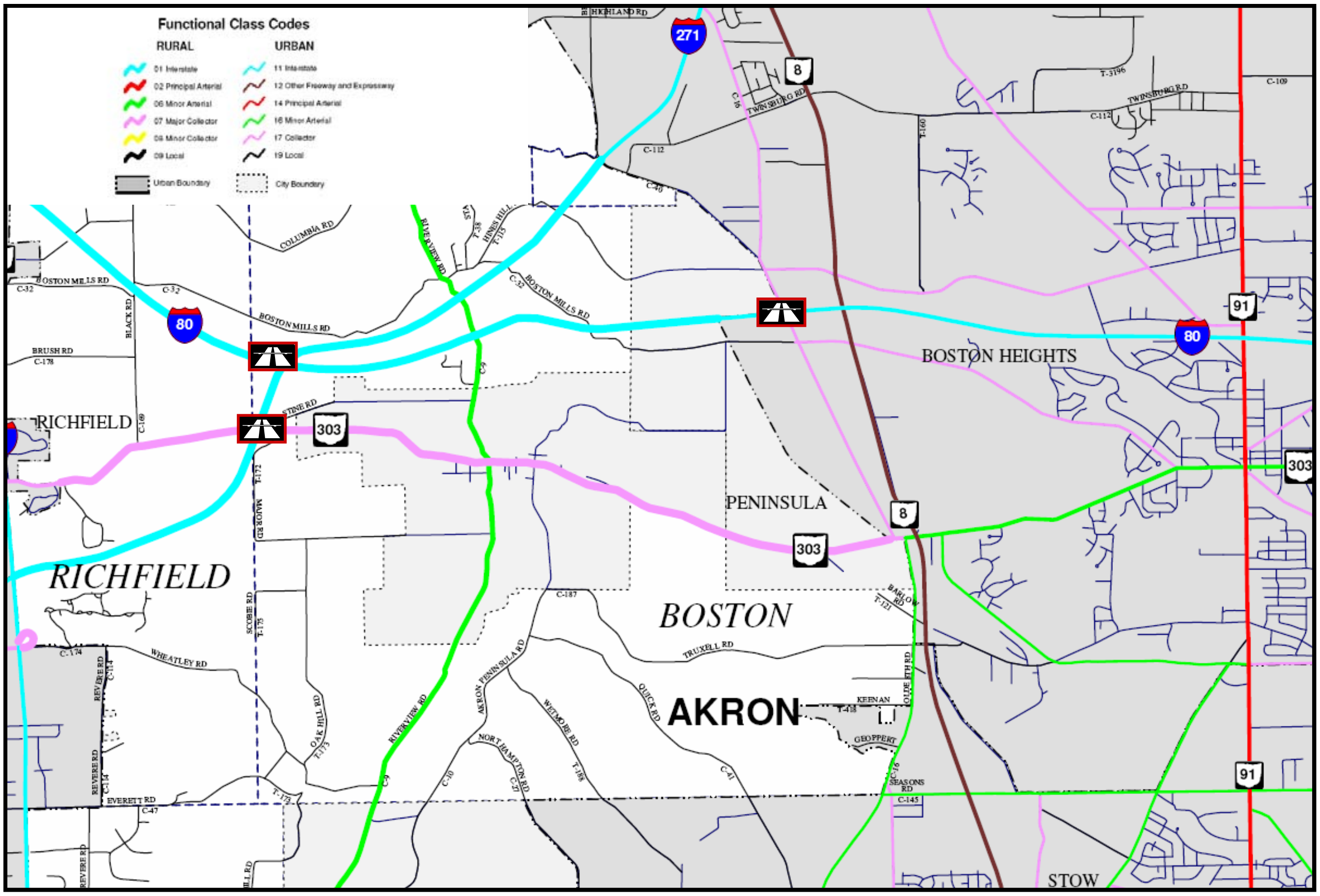
Bridge	FC	County	ODOT District
IR 71 over Grider Rd.	1	RICH	3
US 30 over Koogle Rd.	2	RICH	3
SR 39 over CSX Railway	6	RICH	3
SR603 over CSX Railway	7	RICH	3



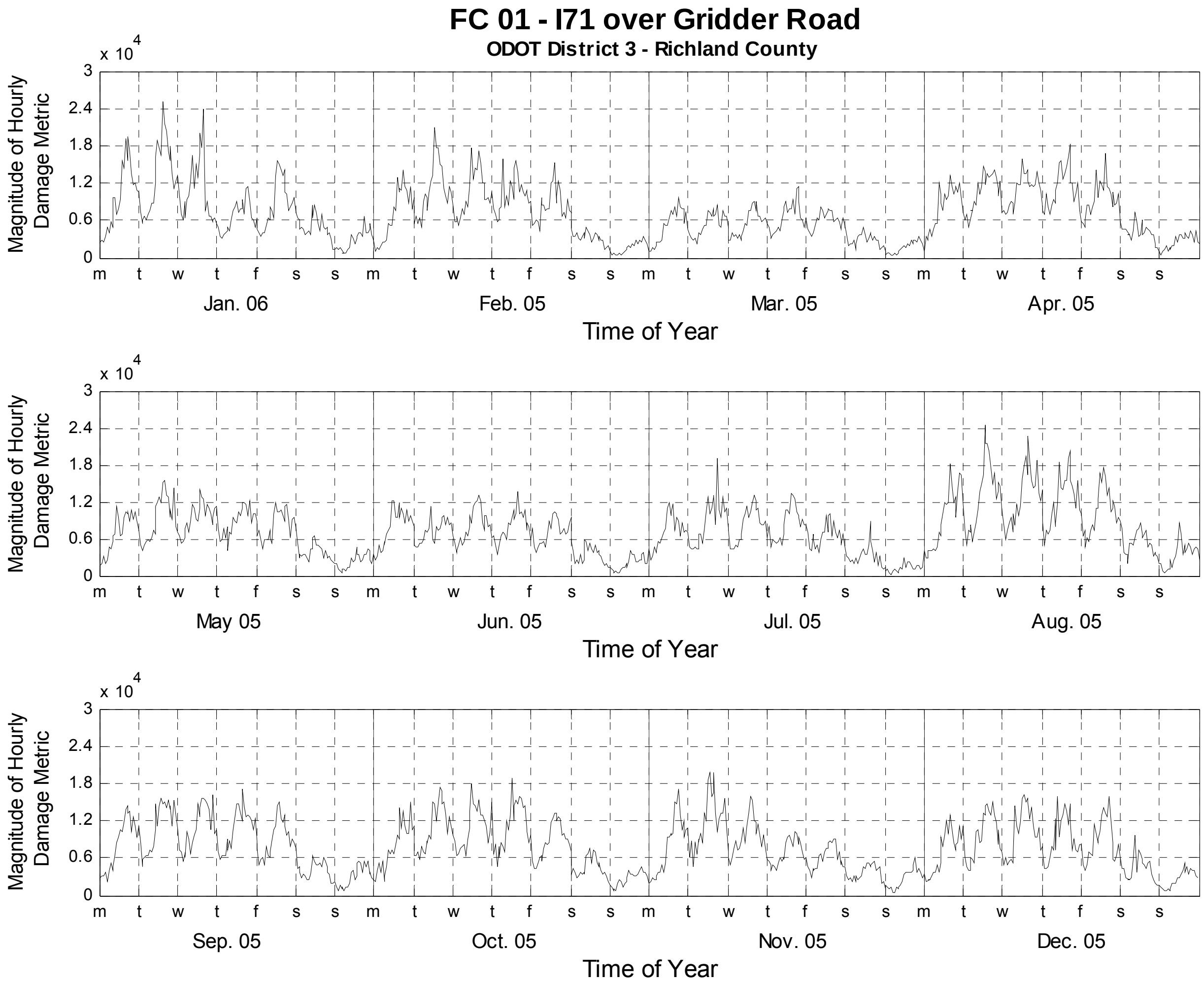
Bridge	FC	County	ODOT District
IR 76 over Ryan Rd.	1	MED	3
US 18 over CSX RR.	2	MED	3
SR 224 over E. Fork Cr.	2	MED	3
SR 3 over IR 71	6	MED	3
SR 83 over SR 224	6	MED	3
SR 42 over SR 224	7	MED	3



Bridge	FC	County	ODOT District
IR 80 over IR 271	1	SUM	4
SR 303 over IR 271	7	SUM	4
SR 8 over IR 80	12	SUM	4

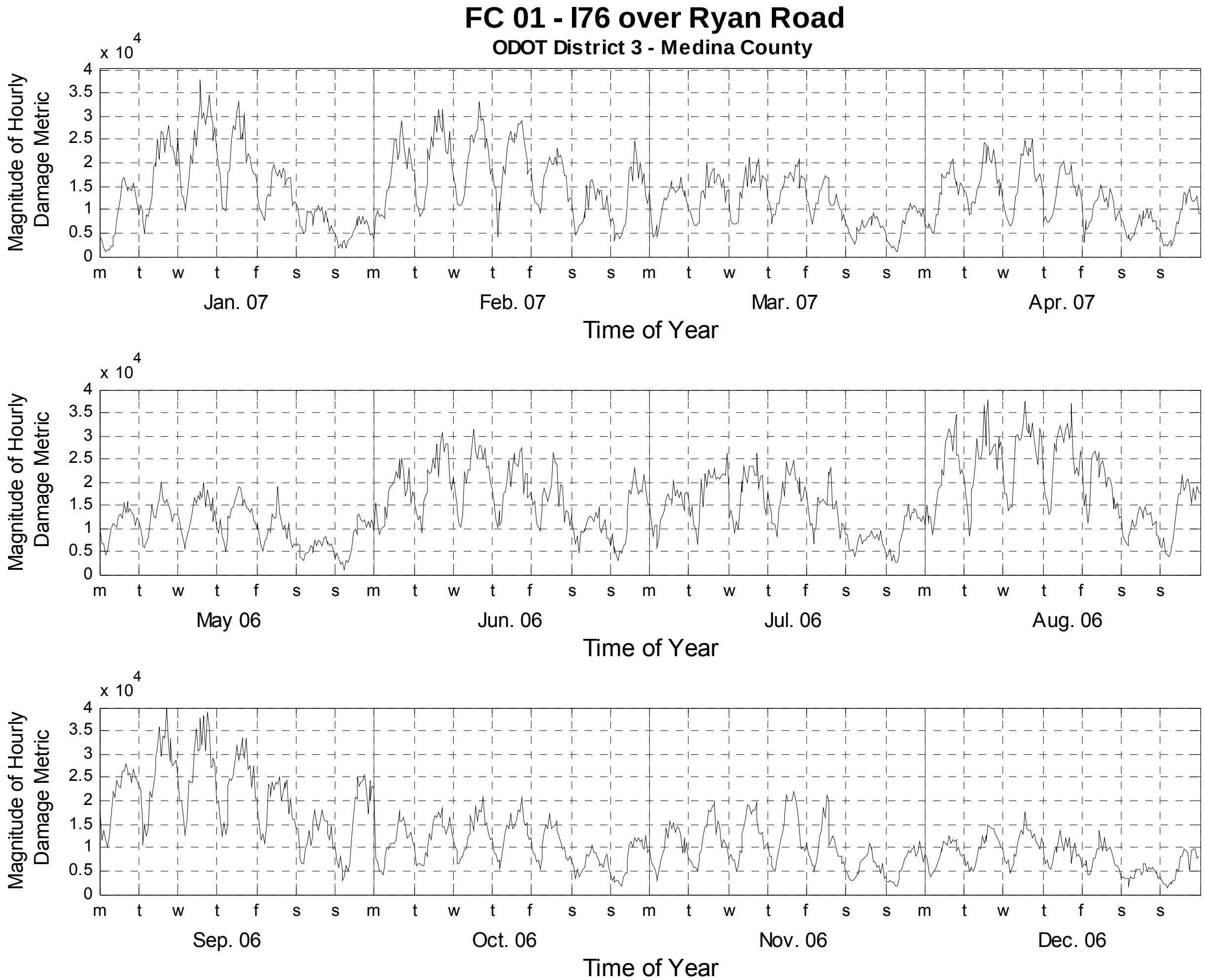


9.3 Damage Metric Data



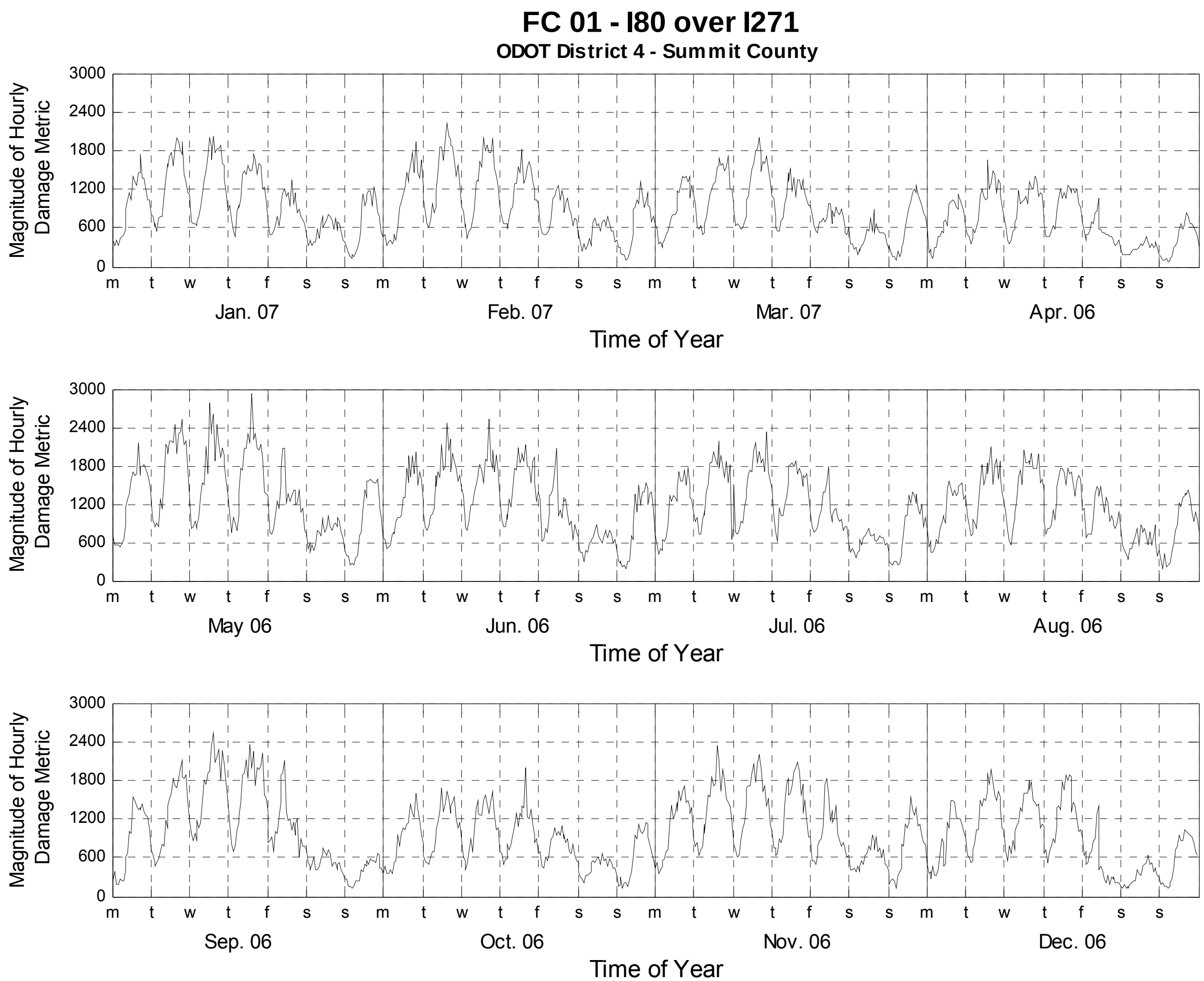
I 71 Damage Metric Plot

COMMENTS: none



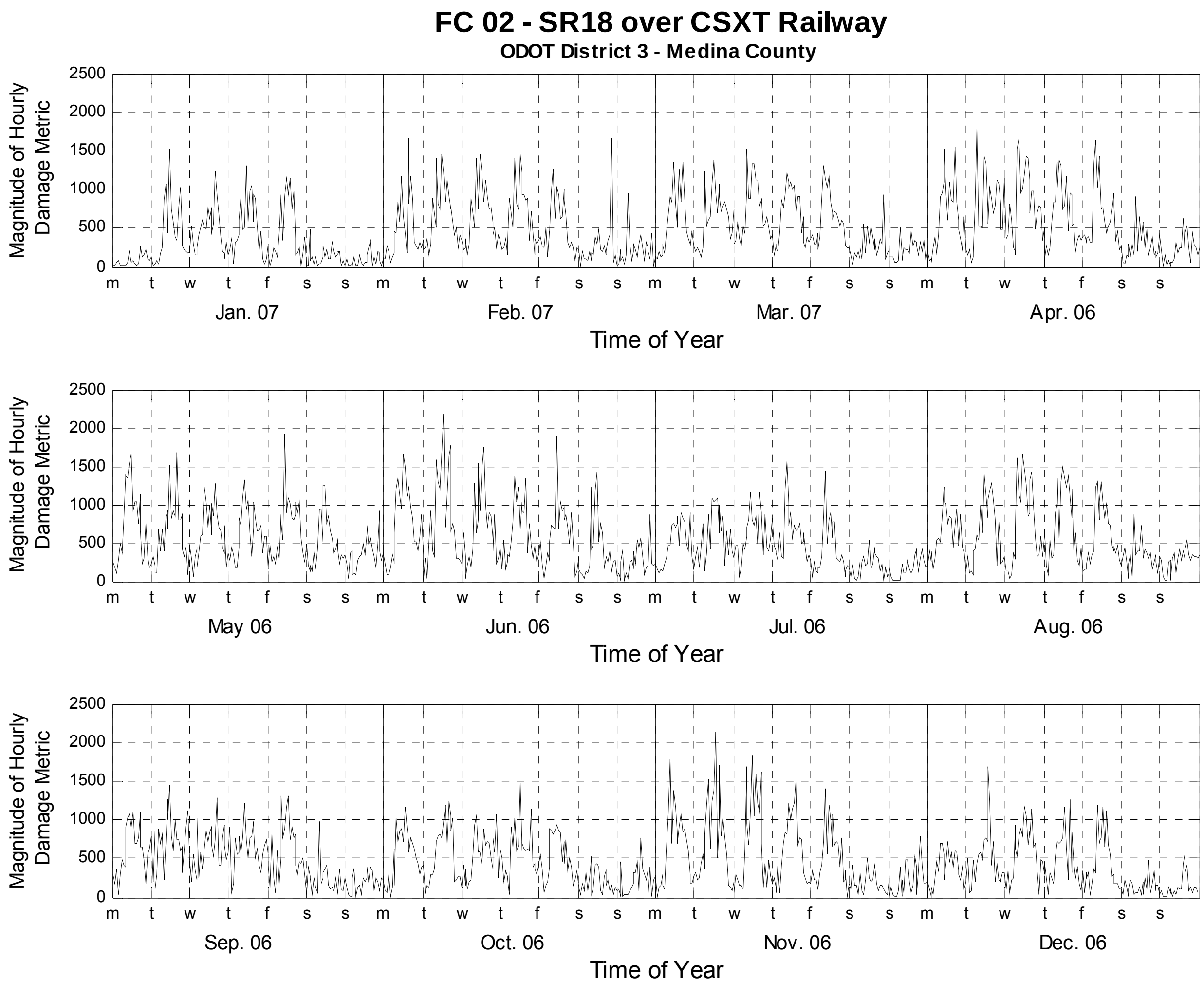
I 76 Damage Metric Plot

COMMENTS: none



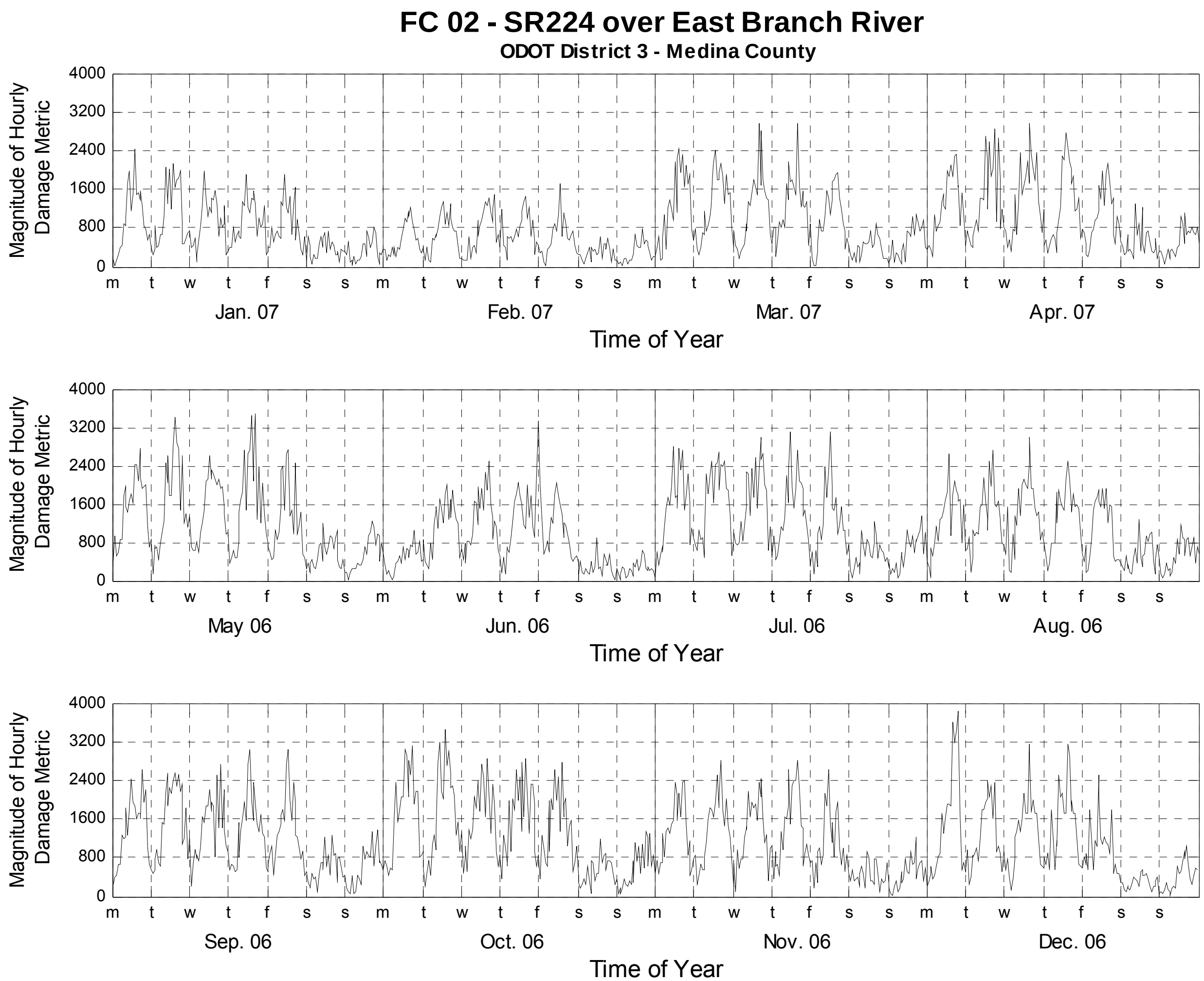
I 80 Damage Metric Plot

COMMENTS: none



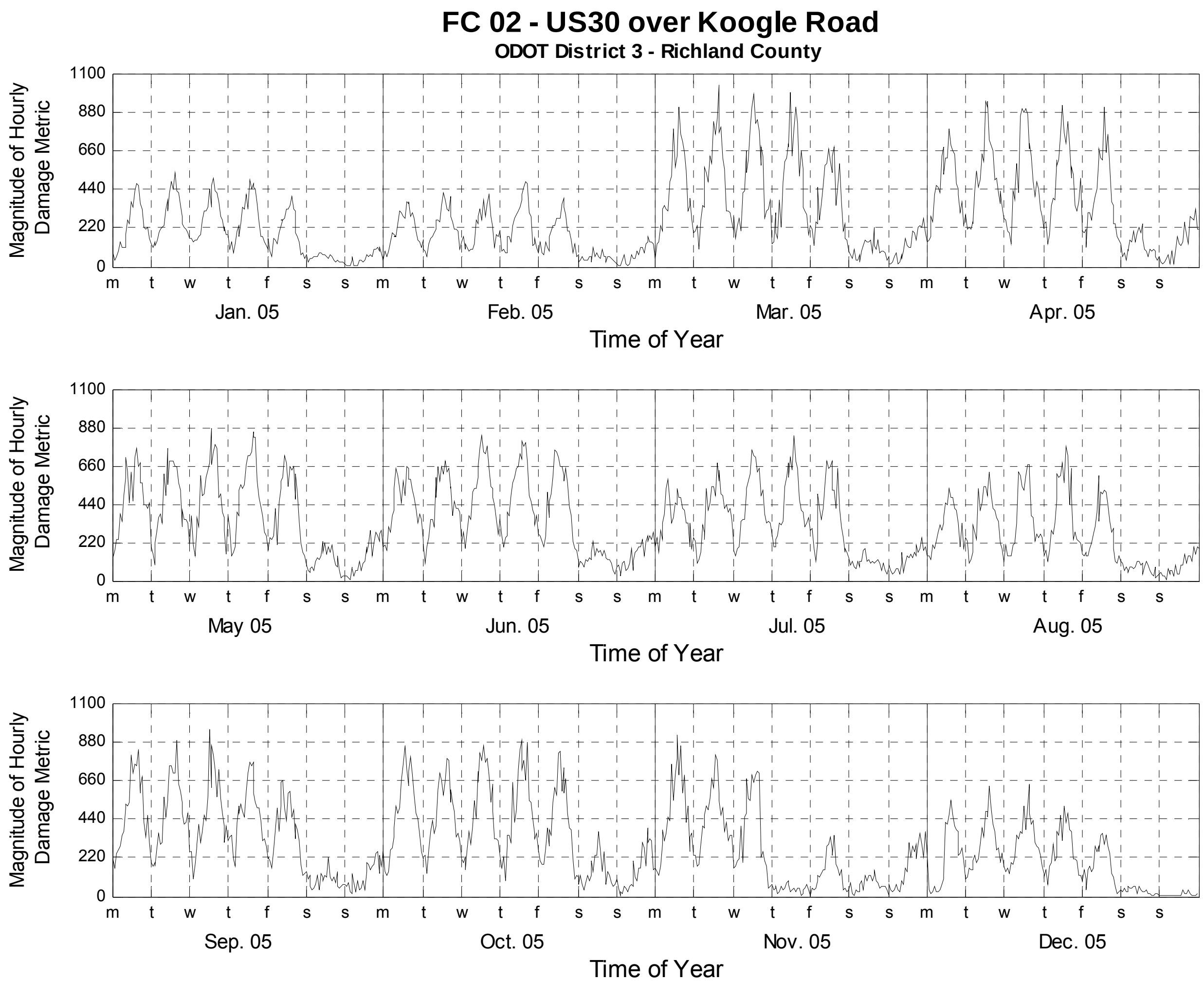
SR 18 Damage Metric Plot

COMMENTS: Monday in January was the New Year's Day Holiday



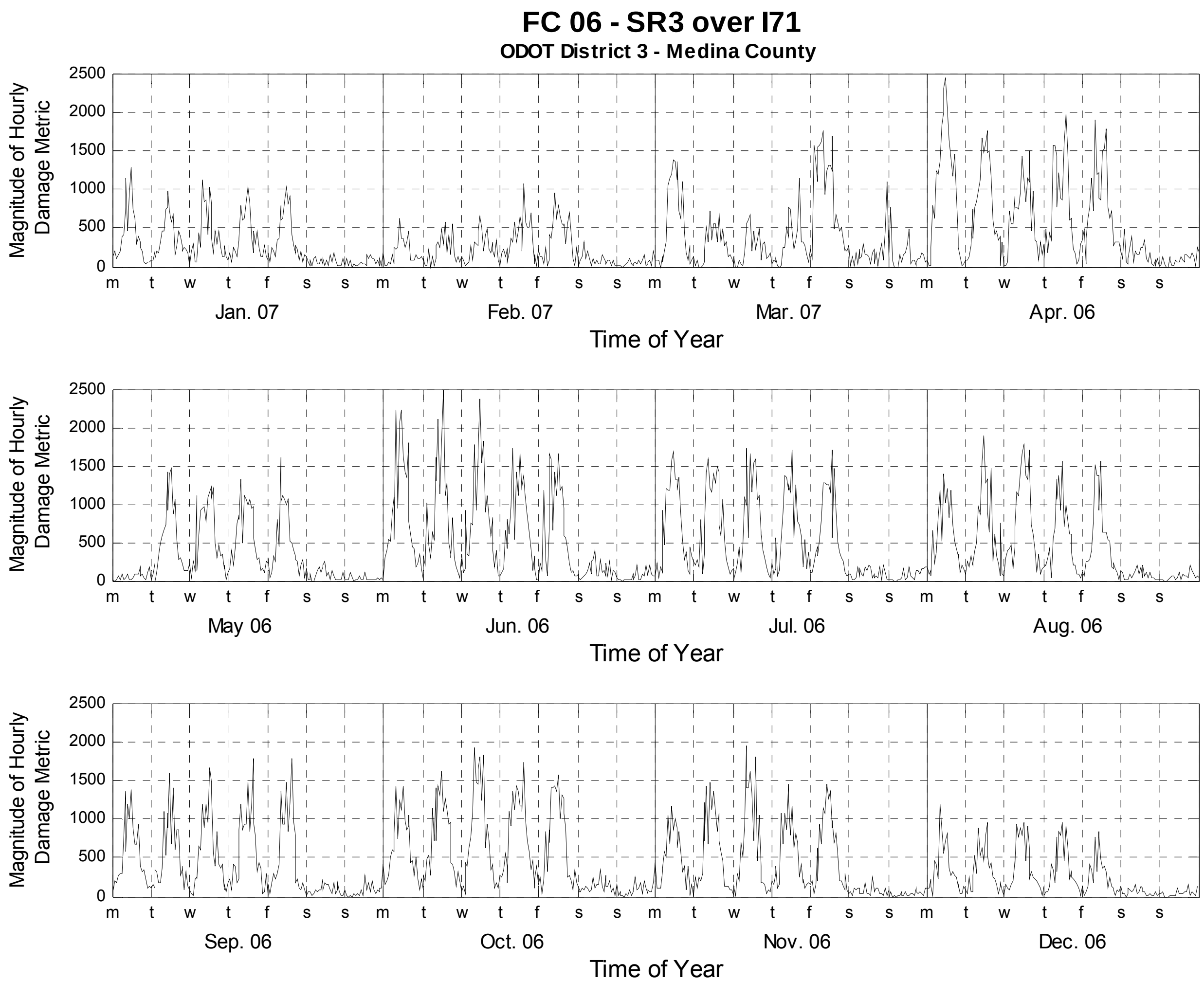
SR 224 Damage Metric Plot

COMMENTS: Monday of the June data was Memorial Day; monitoring began in May and concluded in June



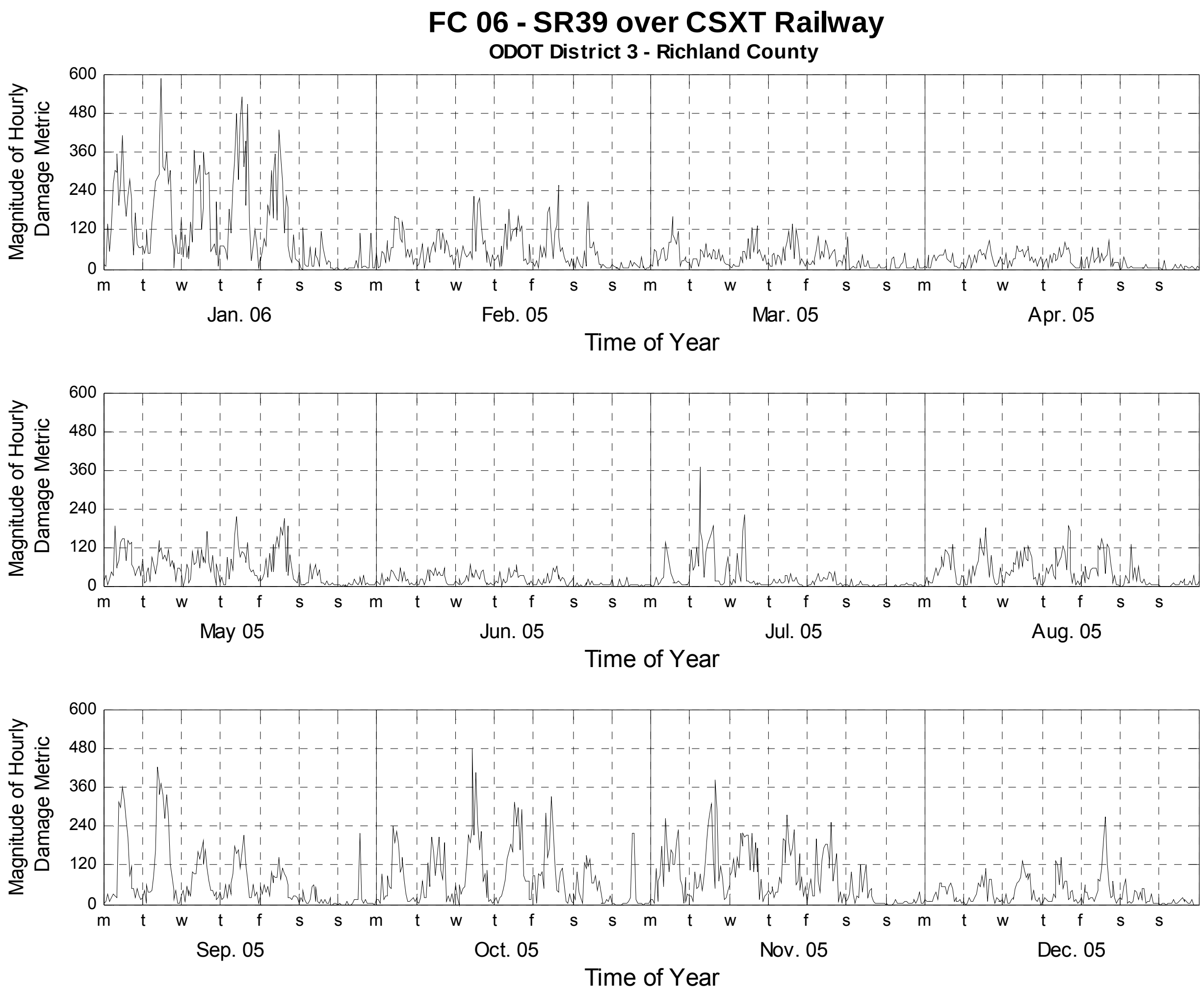
US 30 Damage Metric Plot

COMMENTS: November data was collected over the Thanksgiving holiday



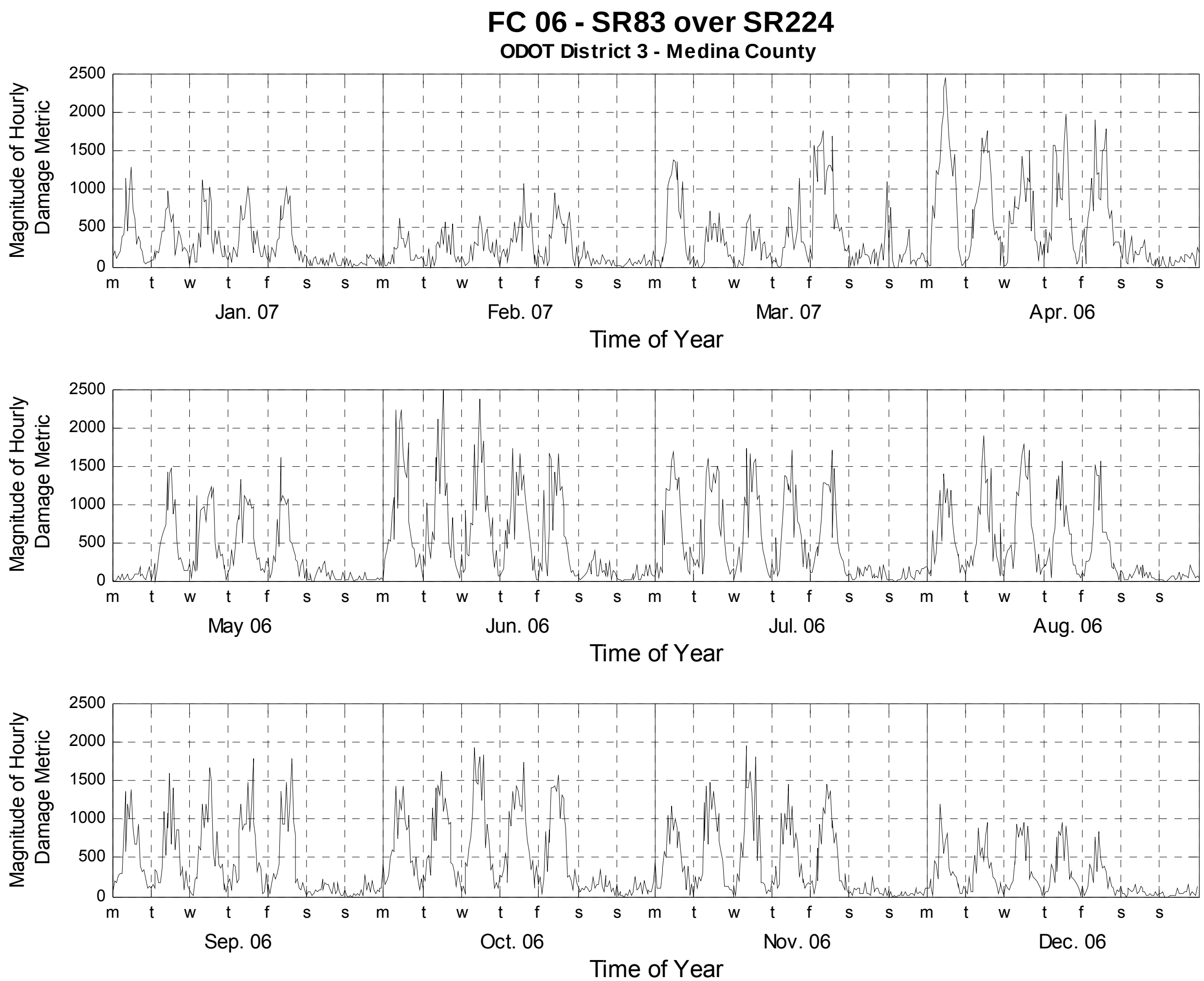
SR 3 Damage Metric Plot

COMMENTS: Monday in May was the Memorial Day Holiday



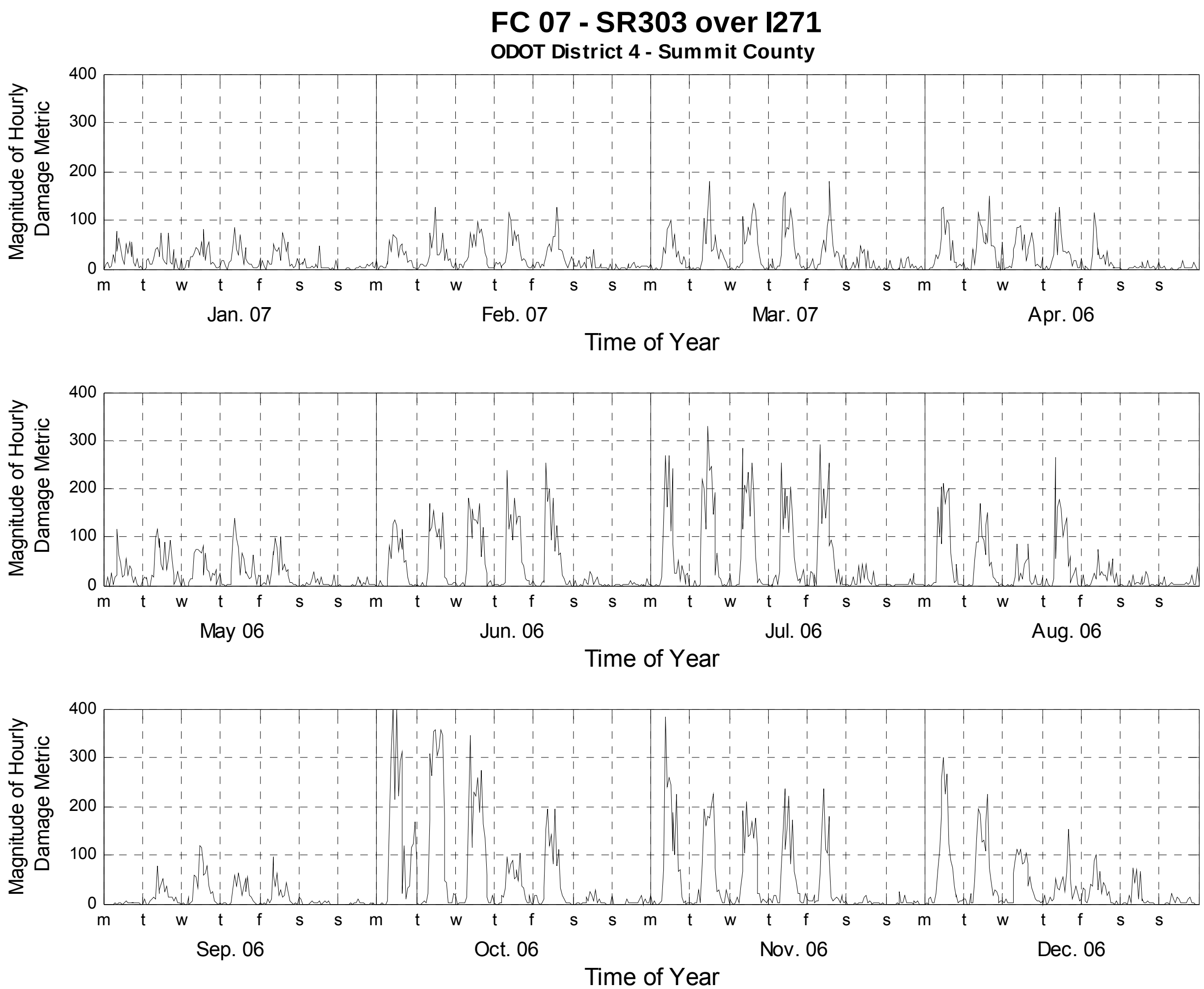
SR 39 Damage Metric Plot

COMMENTS: none



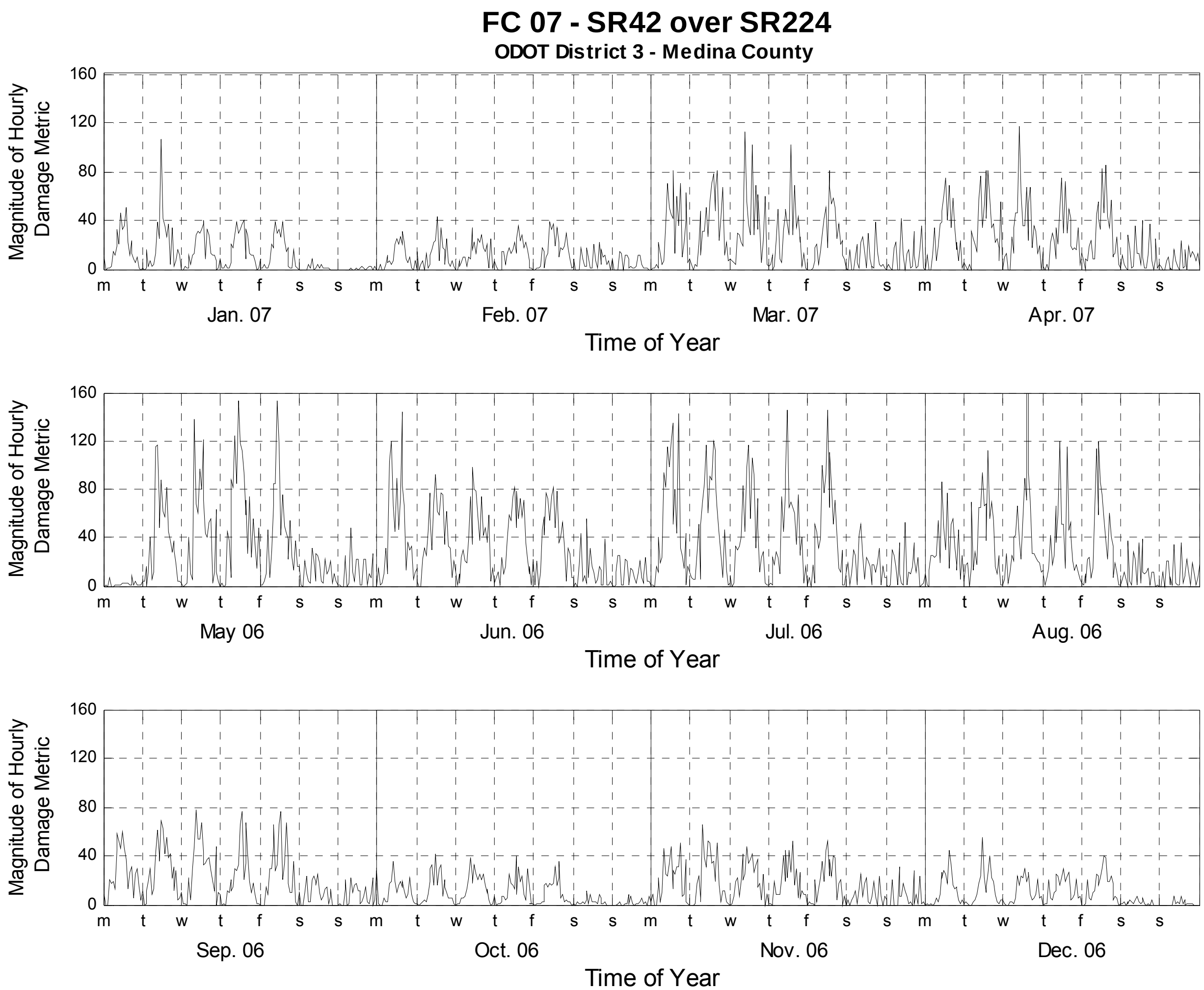
SR 83 Damage Metric Plot

COMMENTS: Monday in May was the Memorial Day holiday



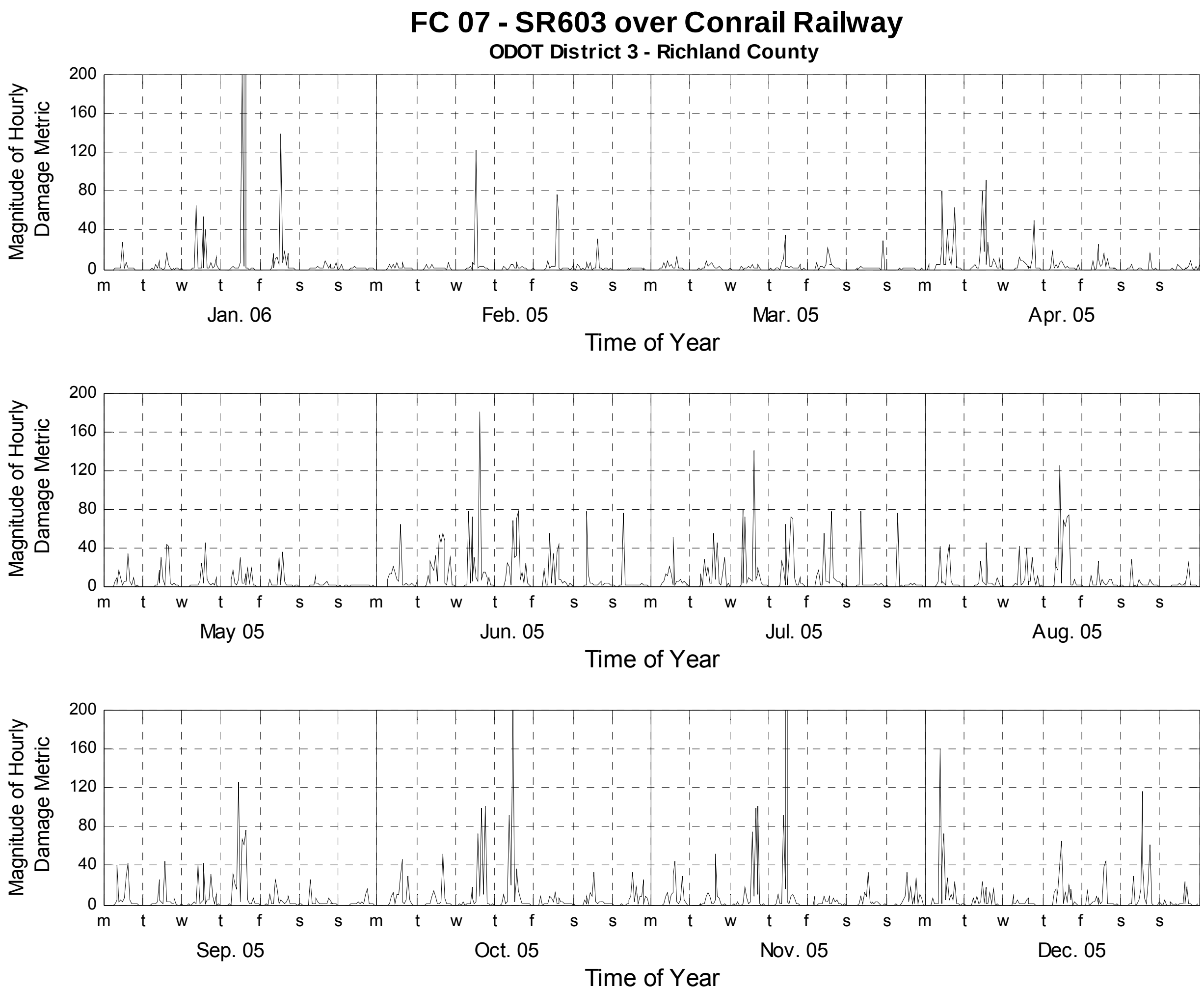
SR 303 Damage Metric Plot

COMMENTS: Monday in September was the Labor Day Holiday



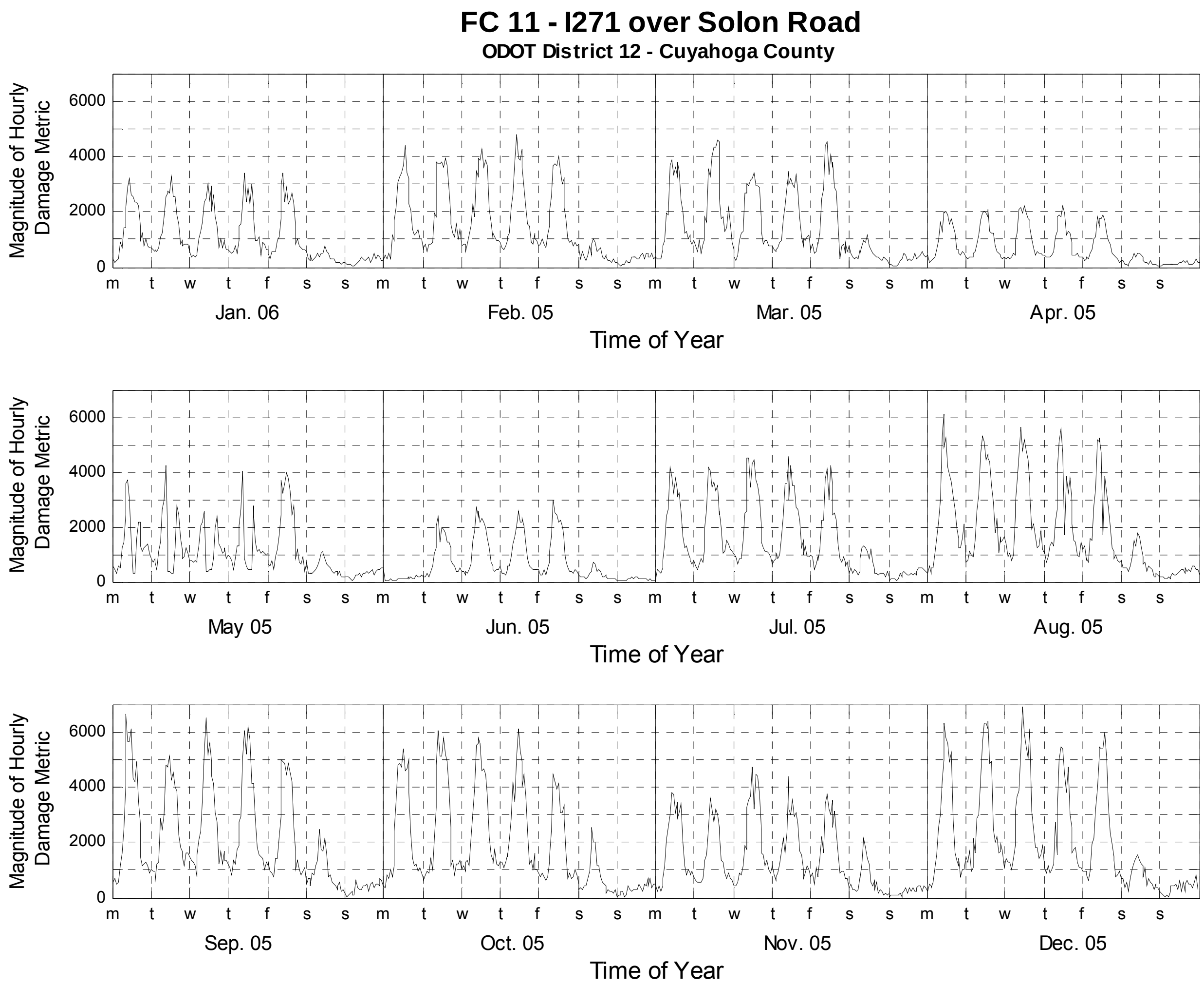
SR 42 Damage Metric Plot

COMMENTS: Monday in May was the Memorial Day Holiday



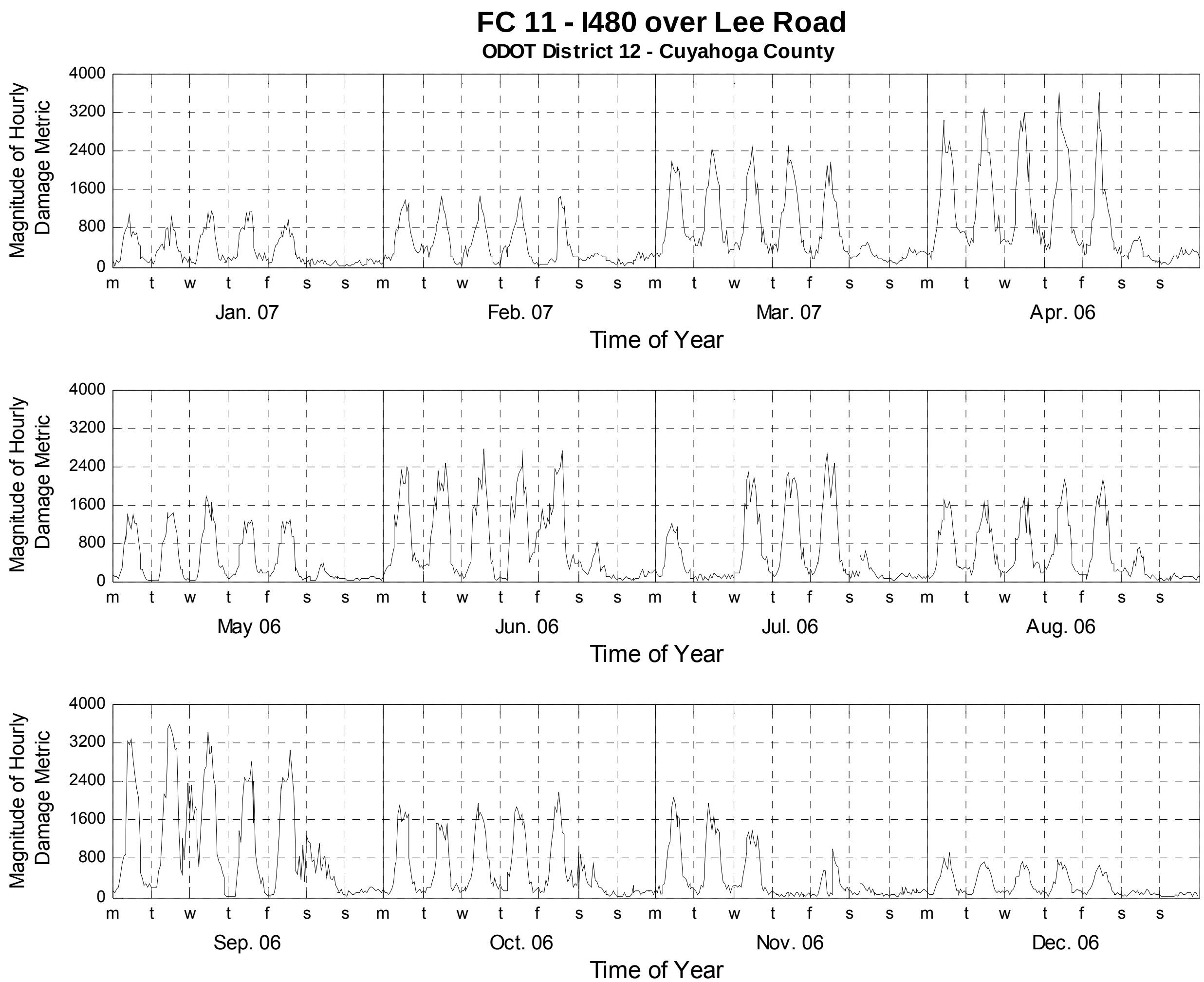
SR 603 Damage Metric Plot

COMMENTS: none



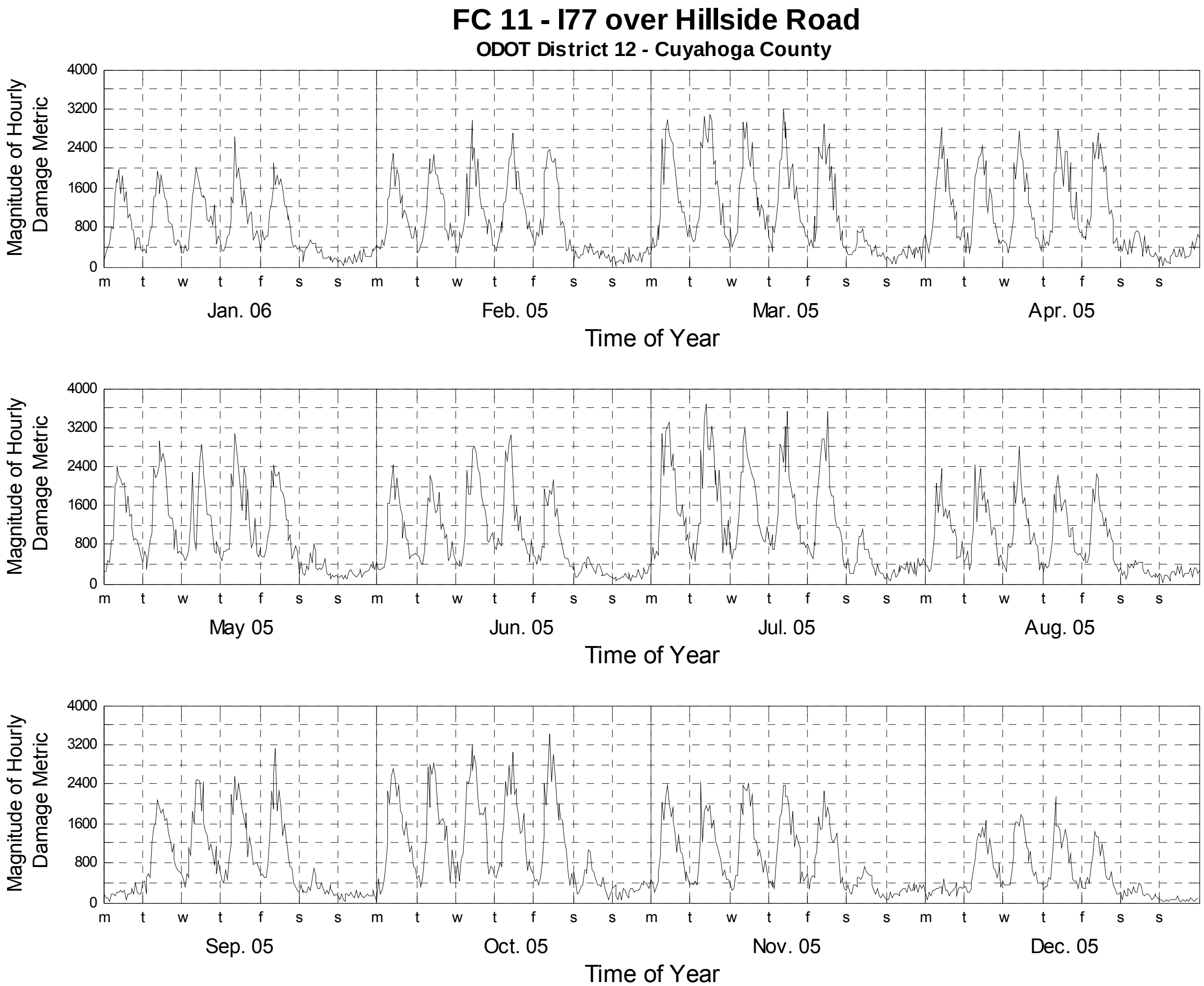
I 271 Damage Metric Plot

COMMENTS: Monday of the June data was Memorial Day; monitoring began in May and concluded in June



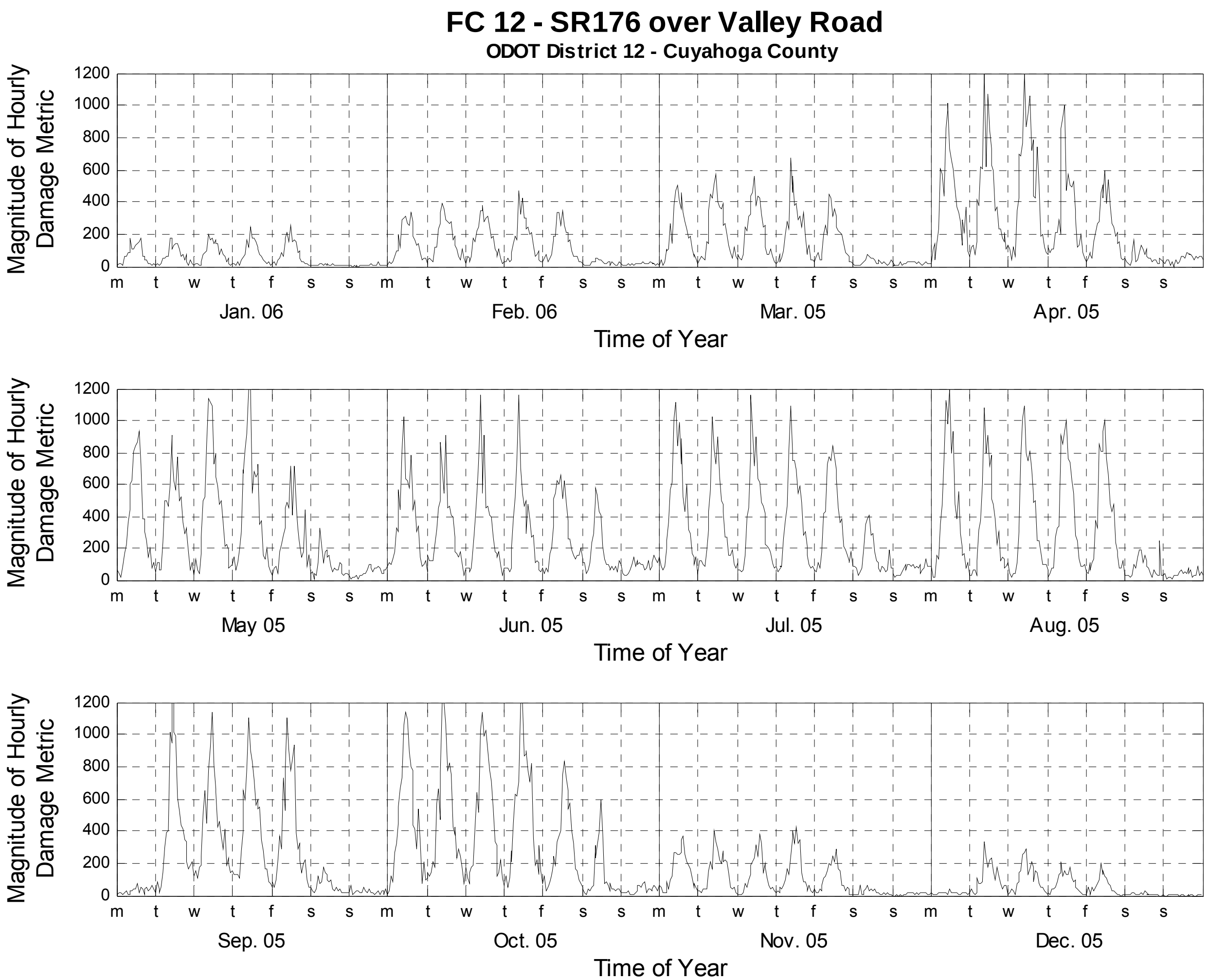
I 480 Damage Metric Plot

COMMENTS: Tuesday in July was the July 4th holiday; November data was collected over the Thanksgiving holiday



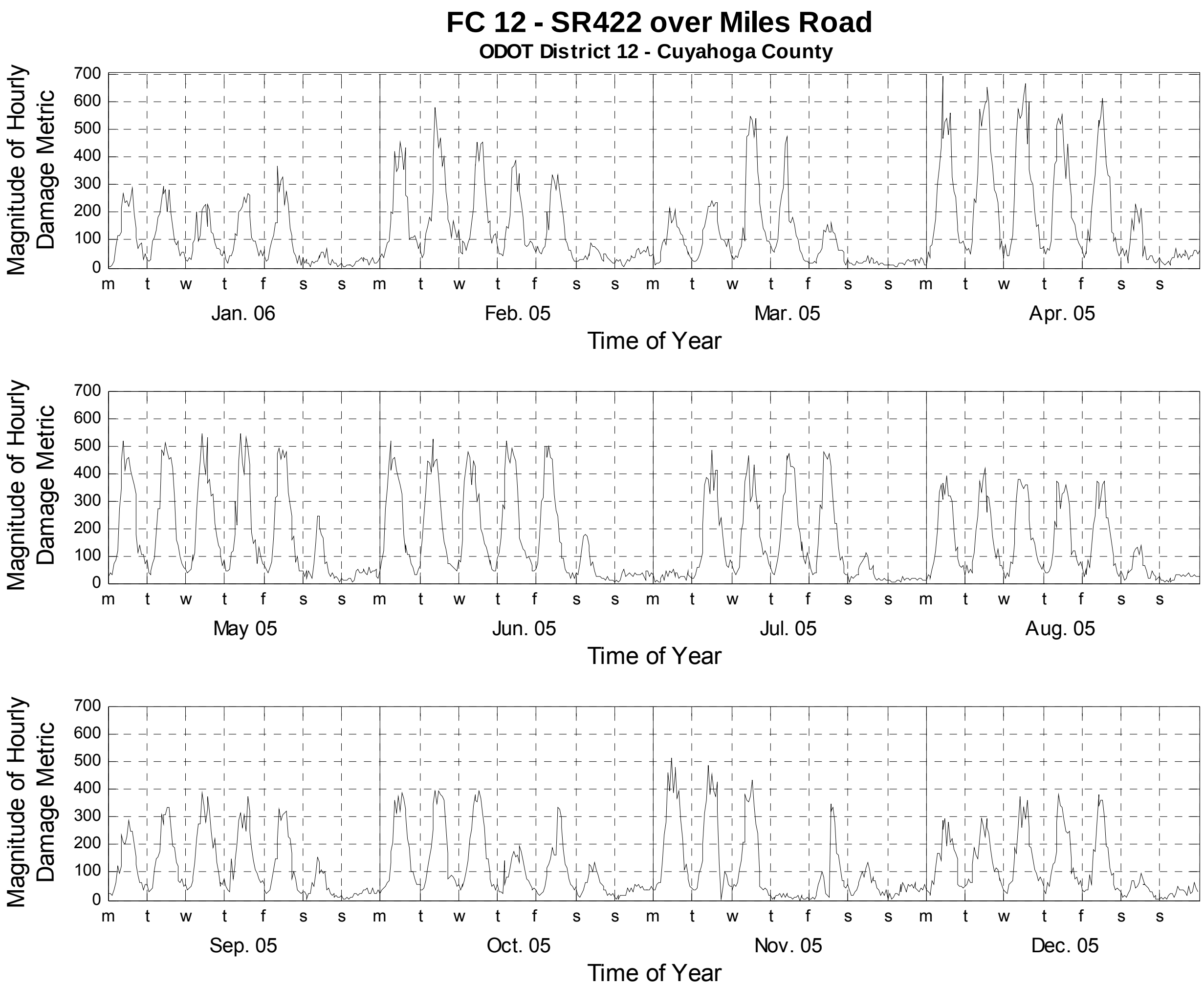
I 77 Damage Metric Plot

COMMENTS: Monday in September was the Labor Day holiday; Monday in December was the Christmas holiday



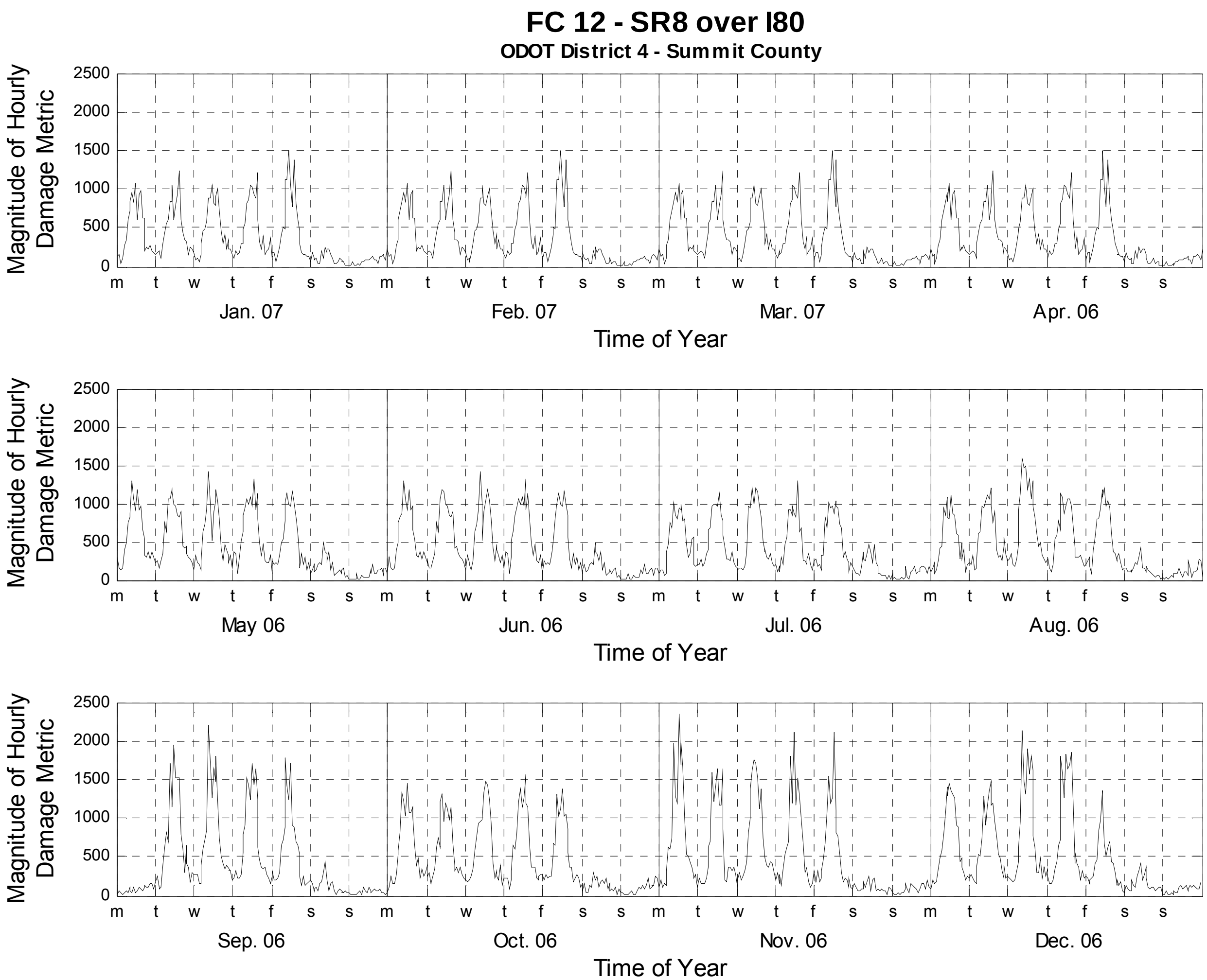
SR 176 Damage Metric Plot

COMMENTS: Monday in September was the Labor Day holiday; Monday in December was the Christmas holiday



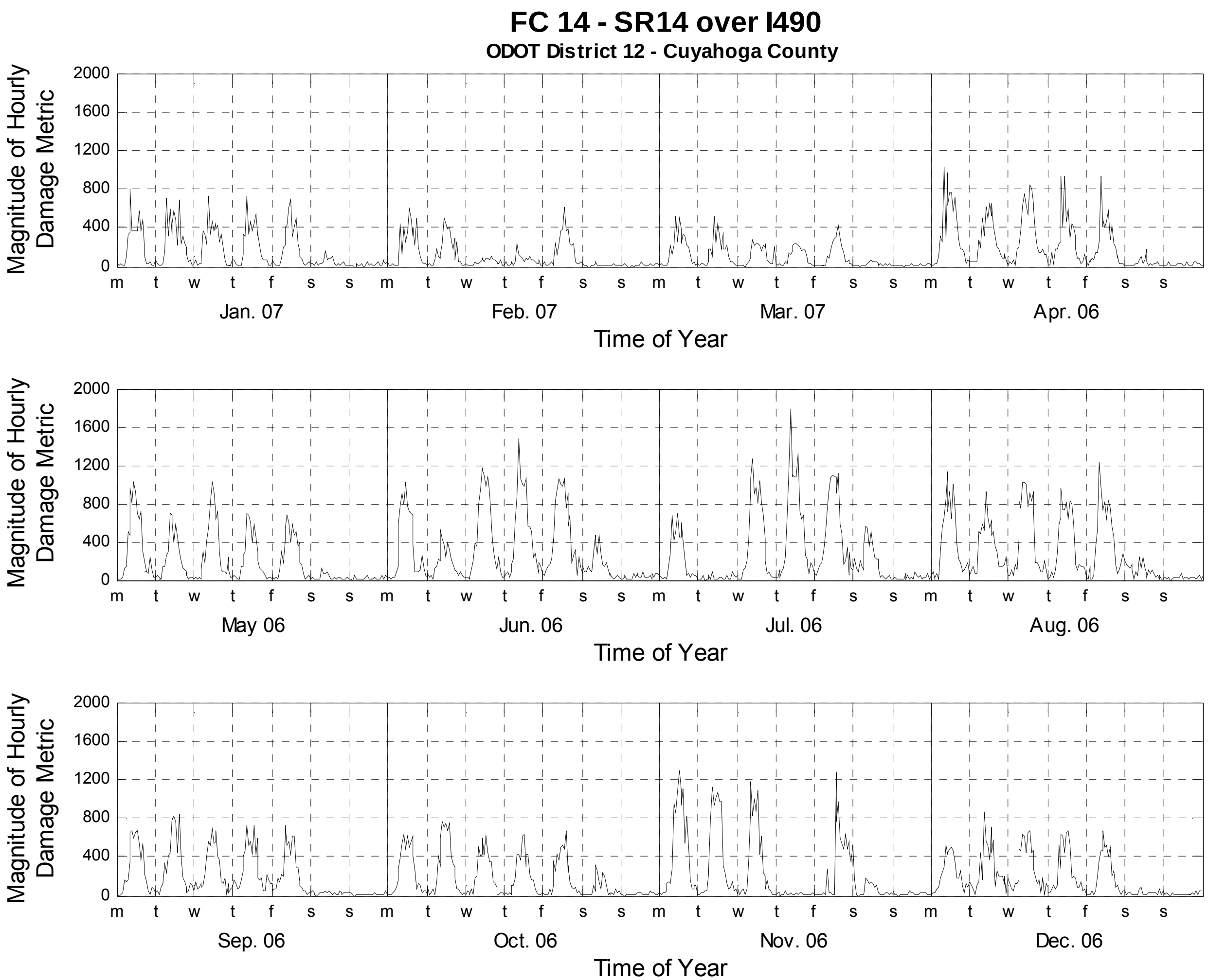
SR 422 Damage Metric Plot

COMMENTS: Monday in July was the July 4th Holiday; November data was collected over the Thanksgiving holiday



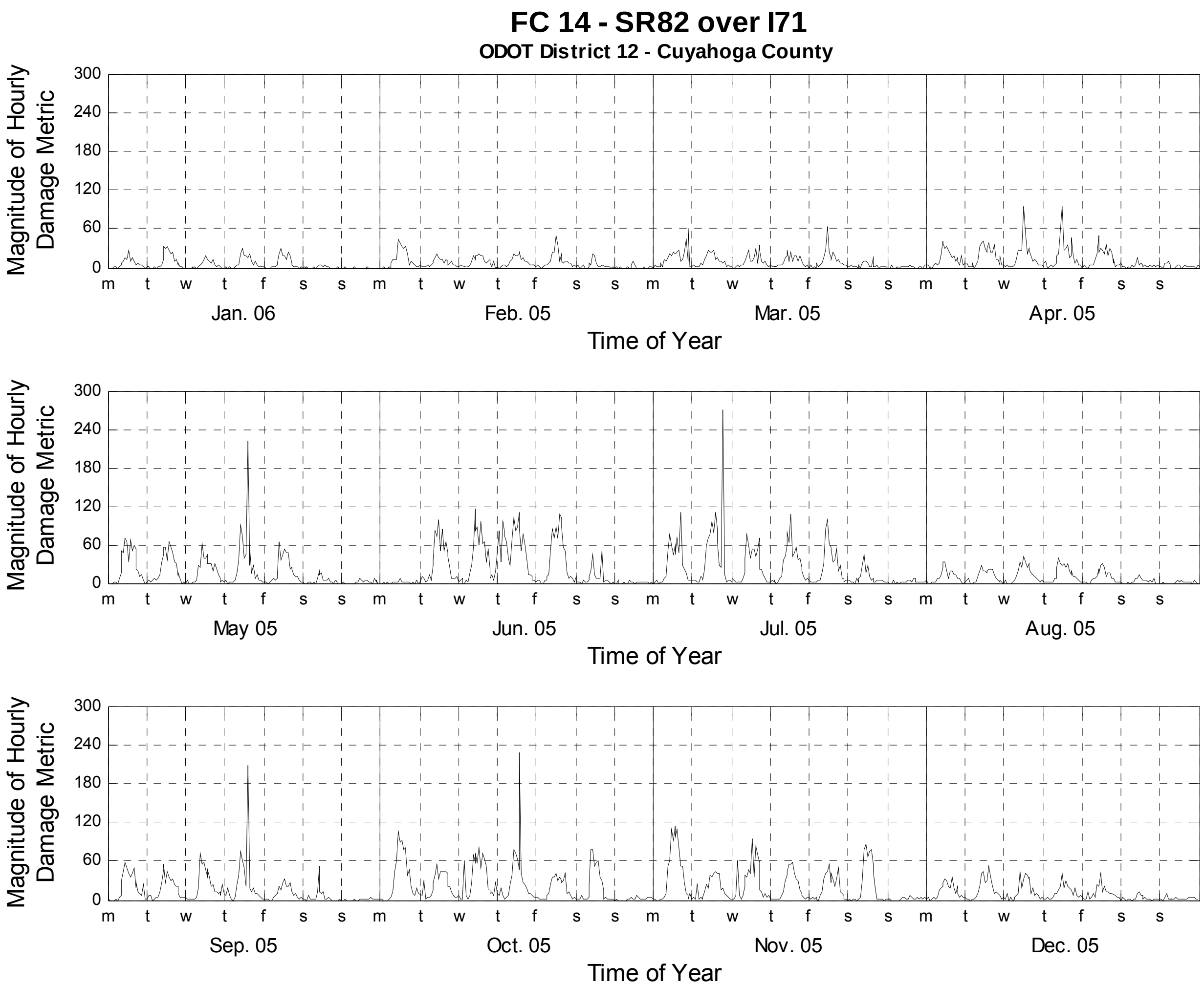
SR 8 Damage Metric Plot

COMMENTS: Data in February, March and April was suspicious – replaced with January data; Monday in September was the Labor Day holiday



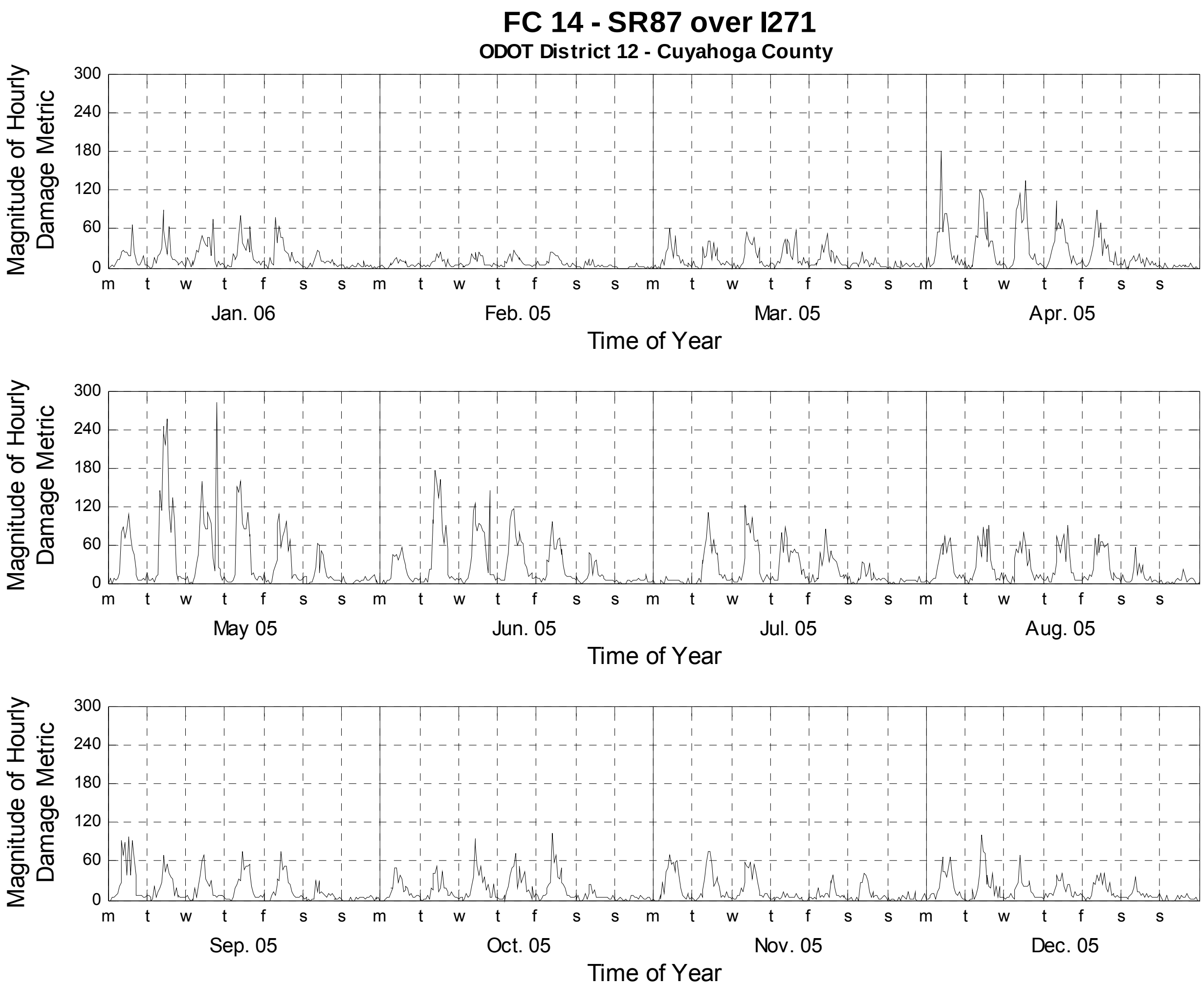
SR 14 Damage Metric Plot

COMMENTS: Tuesday in July was the July 4th holiday; November data was collected over the Thanksgiving holiday



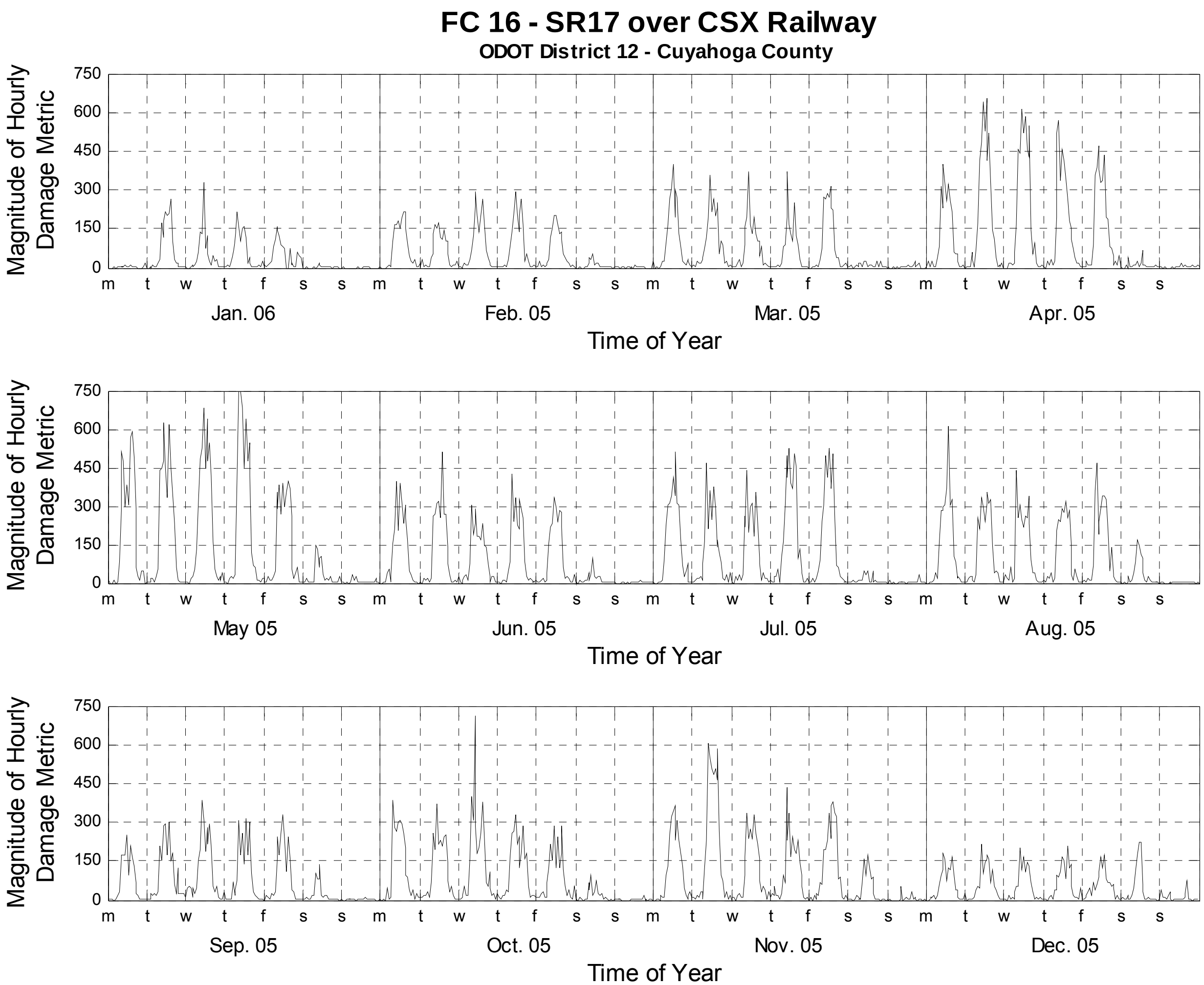
SR 82 Damage Metric Plot

COMMENTS: Monday of the June data was Memorial Day; monitoring began in May and concluded in June



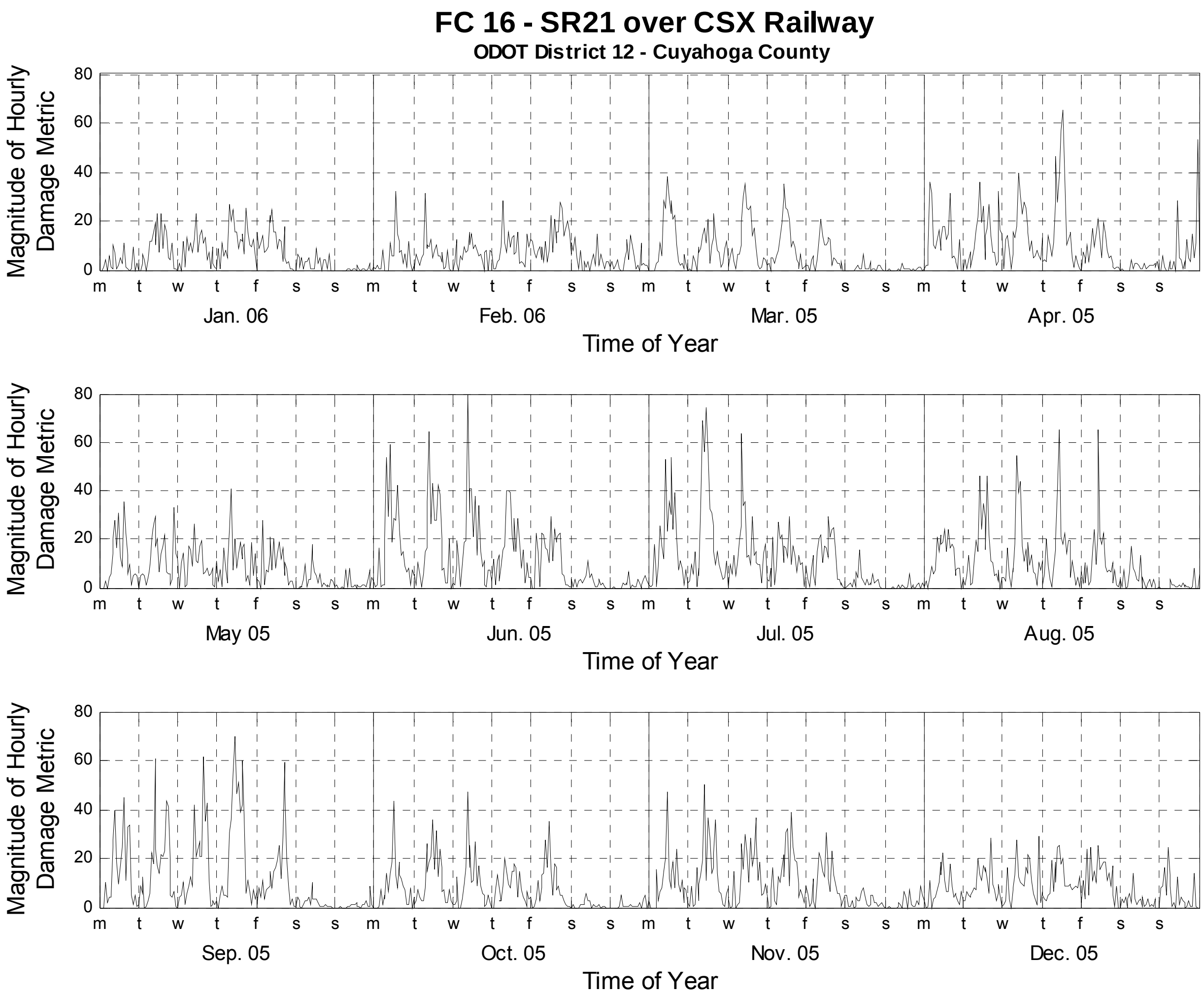
SR 87 Damage Metric Plot

COMMENTS: Monday in July was the July 4th Holiday; November data was collected over the Thanksgiving Holiday



SR 17 Damage Metric Plot

COMMENTS: Monday in January was the New Year's Day holiday



SR 21 Damage Metric Plot

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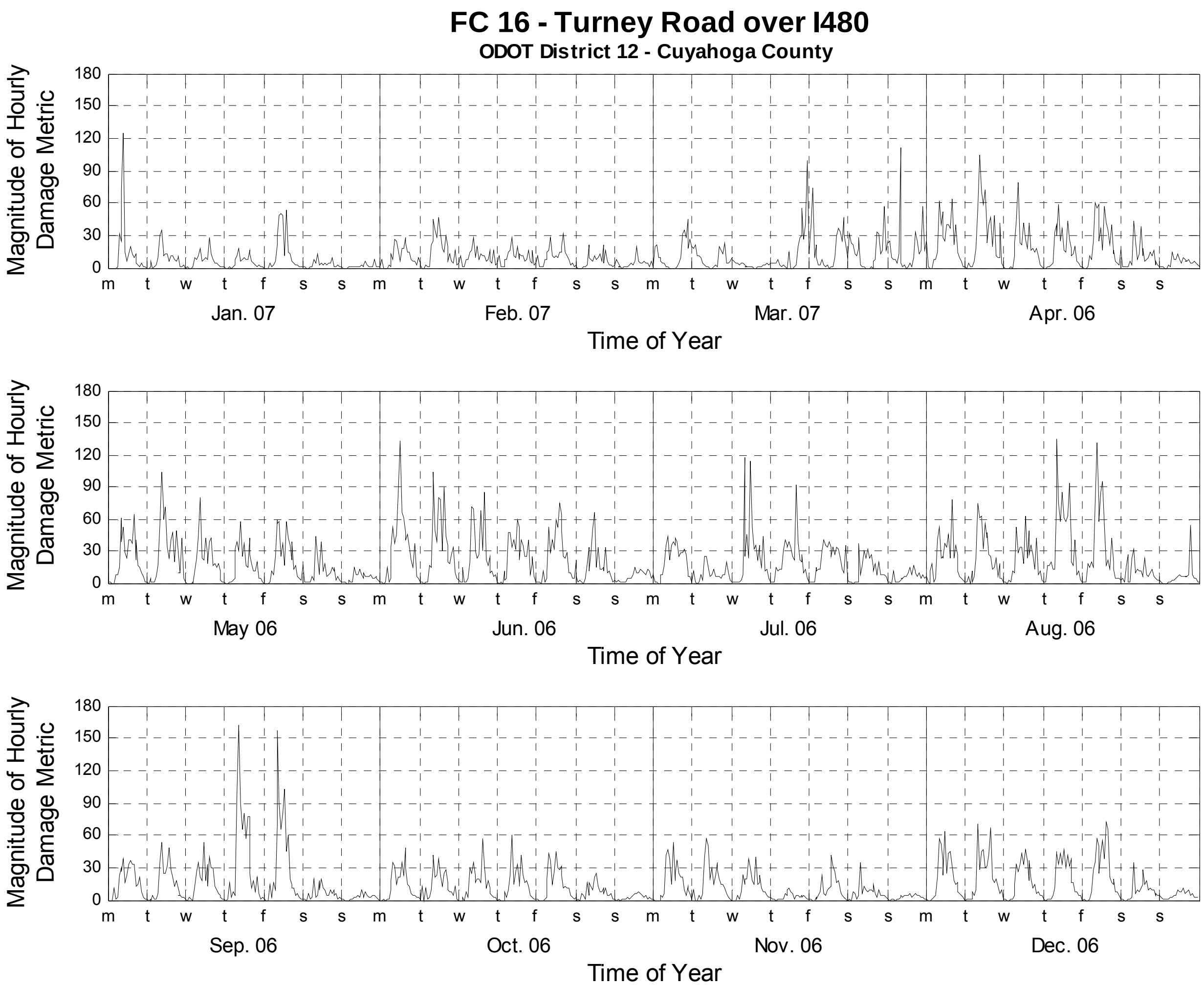
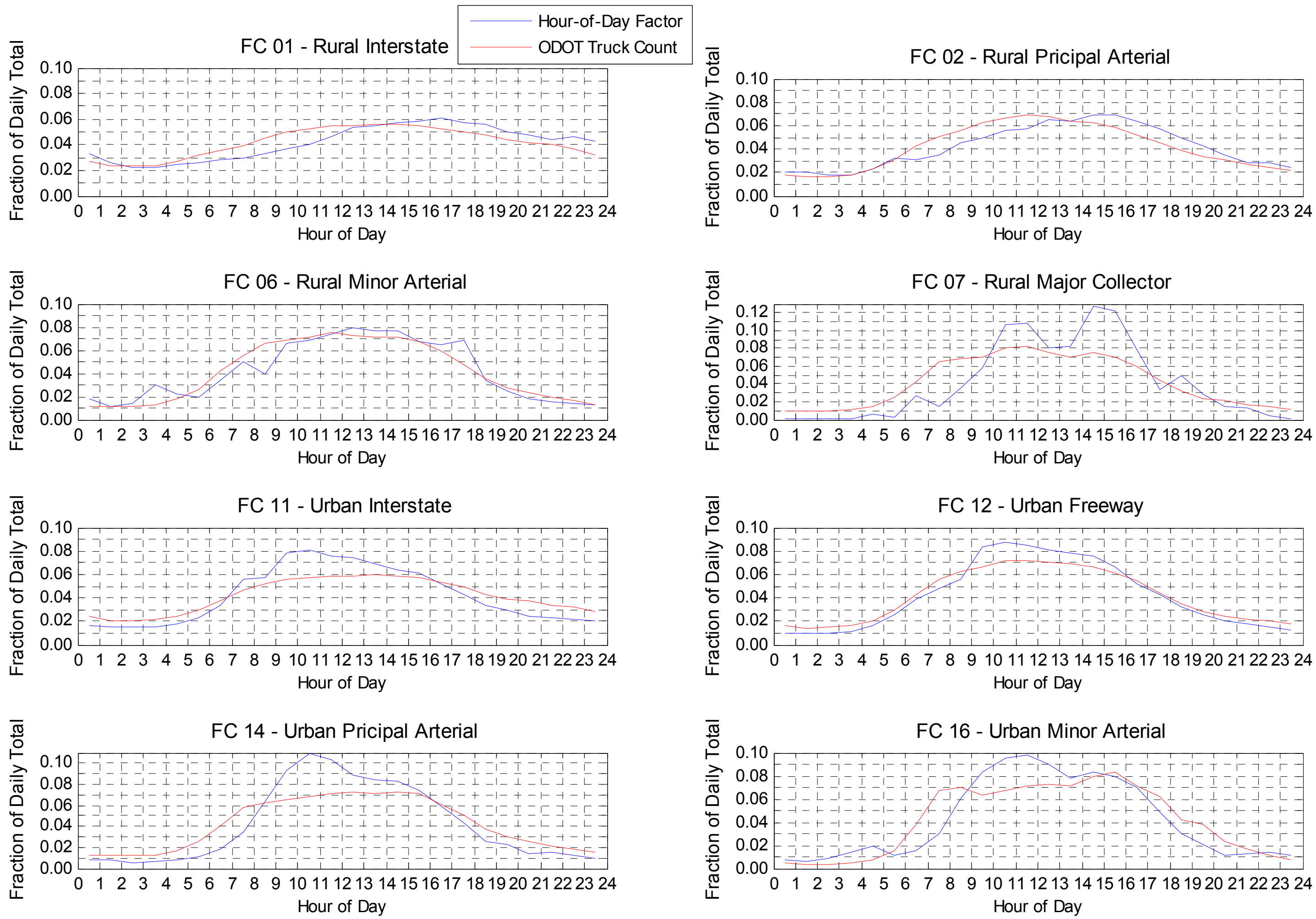


Turney Road Damage Metric Plot

COMMENTS: Tuesday in July was the July 4th holiday; November data was collected over the Thanksgiving holiday

9.4 Comparison between ODOT Truck Count Data and Weekday Hour-of-Day Factors



9.5 Hour-of-Day Temporal Factors

Hour-of-Day Temporal Factors

Weekday Factors

FC	0:00-1:00 hours	1:00-2:00	2:00-3:00	3:00-4:00	4:00-5:00	5:00-6:00	6:00-7:00	7:00-8:00	8:00-9:00	9:00-10:00	10:00-11:00	11:00-12:00
1	0.030	0.026	0.023	0.023	0.023	0.027	0.033	0.037	0.041	0.045	0.049	0.053
2	0.019	0.017	0.016	0.019	0.025	0.029	0.038	0.052	0.063	0.056	0.067	0.069
6	0.009	0.011	0.021	0.017	0.018	0.029	0.041	0.042	0.071	0.085	0.087	0.087
7	0.004	0.003	0.003	0.015	0.019	0.024	0.022	0.046	0.066	0.084	0.085	0.085
11	0.015	0.014	0.015	0.017	0.022	0.031	0.052	0.056	0.078	0.082	0.077	0.076
12	0.010	0.010	0.012	0.018	0.025	0.038	0.048	0.056	0.080	0.086	0.082	0.080
14	0.008	0.006	0.005	0.008	0.012	0.018	0.030	0.055	0.080	0.108	0.101	0.090
16	0.007	0.010	0.017	0.023	0.012	0.018	0.034	0.059	0.081	0.093	0.093	0.085
	Saturday Factors											
1	0.042	0.035	0.029	0.028	0.028	0.031	0.035	0.038	0.044	0.051	0.052	0.054
2	0.029	0.034	0.027	0.023	0.030	0.033	0.033	0.051	0.053	0.048	0.066	0.066
6	0.035	0.028	0.056	0.030	0.022	0.027	0.051	0.041	0.068	0.095	0.077	0.074
7	0.015	0.011	0.008	0.022	0.028	0.024	0.051	0.060	0.117	0.058	0.084	0.070
11	0.039	0.037	0.031	0.033	0.033	0.042	0.058	0.072	0.078	0.083	0.079	0.067
12	0.031	0.024	0.018	0.029	0.034	0.050	0.060	0.069	0.091	0.089	0.075	0.085
14	0.027	0.021	0.012	0.013	0.015	0.017	0.032	0.057	0.110	0.128	0.110	0.088
16	0.020	0.019	0.021	0.014	0.017	0.027	0.052	0.087	0.072	0.111	0.106	0.088
	Sunday/ Holiday Factors											
1	0.019	0.016	0.015	0.013	0.014	0.015	0.016	0.020	0.027	0.037	0.044	0.056
2	0.019	0.012	0.014	0.016	0.022	0.017	0.020	0.024	0.029	0.026	0.042	0.046
6	0.011	0.022	0.020	0.006	0.021	0.016	0.016	0.025	0.035	0.033	0.028	0.055
7	0.005	0.012	0.018	0.018	0.024	0.012	0.051	0.041	0.050	0.040	0.038	0.086
11	0.022	0.020	0.017	0.018	0.018	0.020	0.034	0.037	0.042	0.041	0.047	0.042
12	0.016	0.015	0.015	0.014	0.021	0.020	0.023	0.031	0.039	0.045	0.048	0.052
14	0.034	0.029	0.029	0.023	0.017	0.014	0.008	0.030	0.036	0.050	0.061	0.063
16	0.034	0.012	0.009	0.006	0.014	0.012	0.030	0.041	0.049	0.031	0.055	0.056

Hour-of-Day Temporal Factors

Weekday Factors

FC	0:00-1:00 hours	1:00-2:00	2:00-3:00	3:00-4:00	4:00-5:00	5:00-6:00	6:00-7:00	7:00-8:00	8:00-9:00	9:00-10:00	10:00-11:00	11:00-12:00
1	0.030	0.026	0.023	0.023	0.023	0.027	0.033	0.037	0.041	0.045	0.049	0.053
2	0.019	0.017	0.016	0.019	0.025	0.029	0.038	0.052	0.063	0.056	0.067	0.069
6	0.009	0.011	0.021	0.017	0.018	0.029	0.041	0.042	0.071	0.085	0.087	0.087
7	0.004	0.003	0.003	0.015	0.019	0.024	0.022	0.046	0.066	0.084	0.085	0.085
11	0.015	0.014	0.015	0.017	0.022	0.031	0.052	0.056	0.078	0.082	0.077	0.076
12	0.010	0.010	0.012	0.018	0.025	0.038	0.048	0.056	0.080	0.086	0.082	0.080
14	0.008	0.006	0.005	0.008	0.012	0.018	0.030	0.055	0.080	0.108	0.101	0.090
16	0.007	0.010	0.017	0.023	0.012	0.018	0.034	0.059	0.081	0.093	0.093	0.085
	Saturday Factors											
1	0.042	0.035	0.029	0.028	0.028	0.031	0.035	0.038	0.044	0.051	0.052	0.054
2	0.029	0.034	0.027	0.023	0.030	0.033	0.033	0.051	0.053	0.048	0.066	0.066
6	0.035	0.028	0.056	0.030	0.022	0.027	0.051	0.041	0.068	0.095	0.077	0.074
7	0.015	0.011	0.008	0.022	0.028	0.024	0.051	0.060	0.117	0.058	0.084	0.070
11	0.039	0.037	0.031	0.033	0.033	0.042	0.058	0.072	0.078	0.083	0.079	0.067
12	0.031	0.024	0.018	0.029	0.034	0.050	0.060	0.069	0.091	0.089	0.075	0.085
14	0.027	0.021	0.012	0.013	0.015	0.017	0.032	0.057	0.110	0.128	0.110	0.088
16	0.020	0.019	0.021	0.014	0.017	0.027	0.052	0.087	0.072	0.111	0.106	0.088
	Sunday/ Holiday Factors											
1	0.019	0.016	0.015	0.013	0.014	0.015	0.016	0.020	0.027	0.037	0.044	0.056
2	0.019	0.012	0.014	0.016	0.022	0.017	0.020	0.024	0.029	0.026	0.042	0.046
6	0.011	0.022	0.020	0.006	0.021	0.016	0.016	0.025	0.035	0.033	0.028	0.055
7	0.005	0.012	0.018	0.018	0.024	0.012	0.051	0.041	0.050	0.040	0.038	0.086
11	0.022	0.020	0.017	0.018	0.018	0.020	0.034	0.037	0.042	0.041	0.047	0.042
12	0.016	0.015	0.015	0.014	0.021	0.020	0.023	0.031	0.039	0.045	0.048	0.052
14	0.034	0.029	0.029	0.023	0.017	0.014	0.008	0.030	0.036	0.050	0.061	0.063
16	0.034	0.012	0.009	0.006	0.014	0.012	0.030	0.041	0.049	0.031	0.055	0.056