Improvement of Michigan Climatic Files in Pavement ME Design

FINAL REPORT

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16. Abstract: Climatic inputs have a great influence on Mechanistic-Empirical design results of flexible and rigid pavements. Currently the state of Michigan has 24 climatic files embedded in Pavement ME Design (PMED), but several limitations have been identified. First, five of the climatic files cannot be directly utilized because of an entire month of missing data. These missing data should be filled properly. Second, the 24 weather stations in Michigan are not uniformly distributed geographically, with some regions poorly represented. It is desirable to add new weather stations for these gap regions. Third, existing climatic files for Michigan have not been updated since 2006. A longer climatic data length can better represent the long-term climatic conditions, so it is recommended that the data length of existing climatic files be extended. This study aims to improve the climatic files in Michigan for PMED. To achieve this goal, quantity and quality checks of the existing 24 climatic files were conducted to find out the potential missing data and erroneous data. Procedures for filling the missing data and correcting the erroneous data were proposed as well. The sensitivity of PMED design performance to weather station variation in Michigan, the five individual climatic variables, and the depth to ground water table was investigated. Two traffic levels (heavy and medium) and two pavement types (flexible and rigid) were used for the sensitivity analysis. Typical traffic load spectra, pavement structures and materials in Michigan were incorporated as well. Additional weather data from the Automated Surface Observation Systems (ASOS) and Michigan Road Weather Information System (RWIS) were investigated as potential sources to add new weather stations in gap regions and to extend the existing climatic files. Quantity and quality checks on both data sources were conducted to evaluate the feasibility of application in PMED. It was found the ASOS data and the existing climatic data are from the same historical data records. Fifteen additional weather stations were added to fill the gap regions using the ASOS data. In addition, all the existing climatic files have been extended from Feb. 2006 to Dec. 2014. Finally, climatic zones based on pavement design results and multiple climatic variables for Michigan were preliminarily investigated. Fifteen climate zones were established for Michigan based on pavement surface temperatures and distress predictions.

17. Key Words
Climatic files; Pavement ME Design; quantity check; quality check; sensitivity; climate zone

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TABLE OF CONTENTS

TABLE OF FIGURES

LIST OF TABLES

CHAPTER 1: BACKGROUND AND RESEARCH STATEMENT

1.1 Background

Historically, pavement designs using the AASHTO Guide for Design of Pavement Structures (1993) have not directly accounted for site-specific climatic effects and their impact on performance. These environmental effects have been shown to have a significant impact on pavement responses for flexible, rigid, and composite pavement structures. The development and release of the AASHTOWare® Pavement ME Design (PMED) software is the national-level attempt at incorporating climatic impacts in the prediction of pavement performance. To provide site-specific climate data in this software, weather data from the National Climate Data Center (NCDC) for stations throughout the country have been collected and formatted for use in this software. The software uses the climate data in the Enhanced Integrated Climatic Model (EICM) to predict the temperature and moisture throughout the pavement structure that affect response and characteristic changes of pavement materials during the service life. Site-specific climate data can have a great impact on the prediction results of pavement performance in the PMED[1].

PMED is new pavement design software built on the Mechanistic-Empirical Pavement Design Guide (MEPDG). It uses the same temperature and moisture prediction program, EICM, as the MEPDG. In addition, it has several advantages as compared to MEPDG, such as the ability to run multiple analyses simultaneously, the ability to easily edit climate data and significantly reduce analysis time [2]. On the other hand, while the MEPDG has been updated to PMED, the climatic files have not been significantly updated since 2006. While there is no nationwide attempt to improve the climatic files currently embedded, some state DOTs have been improving the climatic files for the weather stations within their own states. In addition, other states have evaluated the sensitivity of climate condition on the design results. A summary of the activities from other agencies that have started or completed these investigations to date is shown in Table 1-1.

Table 1-1: Climatic data evaluation of other states

States	Activities or studies	Status
North Carolina	Improve Climatic Data for Mechanistic-Empirical Pavement Design[3]	Complete
Louisiana	Evaluation of Current Flexible Pavement Structures Using PMS Data and New Mechanistic- Empirical Pavement Design Guide[4]	Complete
Arkansas	Sensitivity Analysis of Climatic Influence on MEPDG Flexible Pavement Performance Predictions[5]	Complete
Mississippi	Developing MEPDG Climate Data Input Files for Mississippi[6]	Complete
Indiana	MEPD Implementation (Validation/Model Calibration/Acceptable Distress Target/IRI Failure Trigger/Thermal Selection/Binder Selection) and Climate Data Generation[7]	Active
South Dakota	Climate and Groundwater Data to Support Mechanistic-Empirical Pavement Design in South Dakota[8]	Complete
NCHRP	Sensitivity Evaluation of MEPDG Performance Prediction[9]	Complete

1.2 Research statement

The Michigan Department of Transportation (MDOT) initiated this study with the overall goal of improving the weather data in the PMED for Michigan. There are currently 24 Michigan weather stations in PMED, but five of them cannot be utilized directly because of an entire month of missing data. The data from these stations could be used if an appropriate method were determined for filling the missing month of data. In addition, there may be other missing data or erroneous data in the existing 24 climatic files. Therefore, an objective of this study is to improve the quantity and quality of the existing weather data embedded in the PMED. Another limitation of the existing data is that most of the weather stations in the PMED are concentrated in the lower half of the Lower Peninsula in Michigan, which potentially leads to underrepresentation of other areas of the state. Thus, to apply PMED reliably throughout the state, another objective of this study is to determine whether this limited data availability has significant influence on performance prediction and if additional weather stations are needed for sufficient climate data coverage. If the existing data from NCDC weather stations is found to be insufficient, this study investigates additional sources of weather data. In addition, this study aims to find a reliable approach to obtain equivalent weather data for gap regions based on neighboring weather stations, or demonstrate that a climatic region approach is appropriate for pavement design [10].

CHAPTER 2: LITERATURE REVIEW

2.1 Climatic data sensitivity analysis and quantity/quality check

The climate data required in the Enhanced Integrated Climatic Model (EICM) are air temperature, wind speed, percent sunshine, precipitation and relative humidity. All of this weather information is required on an hourly basis for at least one entire year to run the EICM. Most climate records currently available in the PMED software range from 5-10 years in length. For project designs longer than this period, the same weather data is repeated until the analysis period is completed. The quantity and quality of the climatic data may have a great influence on the design results.

Several previous studies conducted evaluations on the sensitivity of the MEPDG or PMED results. A study aiming to investigate the effect of the climatic factors in the recently developed Canadian climate database on the pavement performance prediction in the MEPDG found that asphalt pavement performance is sensitive to projected climate changes [11]. Tighe et al. [12] conducted a study to quantify the impacts of climatic changes on pavement performance using MEPDG, and found that the longitudinal and alligator cracking are sensitive to climatic changes in flexible pavements. A sensitivity analysis of climatic influence on the MEPDG flexible pavement performance predictions for the state of Arkansas was conducted and noted that climatic factors are influential to the predicted distress levels, with temperature being the most influential climate parameter [5]. However, temperature variation throughout that state of Arkansas is not high, so climatic influence is not a primary factor for road design in Arkansas. Qiao et al. [13] conducted a general study and found that the pavement performance predicted by the MEPDG is sensitive to the climatic factors such as the change of average annual temperature and the seasonal temperature variation. In terms of the quantity and quality check of climate files for the EICM, Heitzman and Timm [6]developed MEPDG climate data files for the Mississippi DOT and provided some criteria to check the quality of existing climate data, such as maximum and minimum values of each variable.

2.2 Additional weather information resources

The current weather data used in MEPDG and PMED are from the National Climate Data Center (NCDC) database. It contains more than 800 weather stations throughout the United States with hourly weather-related data required in the EICM. There are 24 weather stations in the state of Michigan, but these stations are not uniformly distributed geographically. The majority of these stations are located in the lower half of the Lower Peninsula. In addition, two of the four stations in the Upper Peninsula are near the borders with Ontario and Wisconsin. This makes a large area in Upper Peninsula and middle part of Lower Peninsula poorly represented geographically. Thus, the existing weather data from NCDC may be not sufficient for reliable climate data input in these gap areas.

To supplement the NCDC station, there are other weather information resources that are potentially useful for the gap areas in Michigan, such as the automated weather/surface observation system (AWOS/ASOS) and Michigan Road Weather Information System (RWIS). AWOS is mostly operated and controlled by the Federal Aviation Administration (FAA), as well as state or local governments. ASOS is a weather information collection system designed to serve meteorological and aviation observing needs. It is operated and controlled cooperatively by the National Weather Service (NWS), FAA and Department of Defense (DOD). There are more than 900 ASOS sites in the United States. Generally, ASOS reports weather data every hour, but it also reports special observations if rapid changes occur for the weather conditions [14]. For Michigan, ASOS/AWOS stations cover most of the areas throughout the state except for the western Upper Peninsula. Compared to the current weather database, the ASOS/AWOS has a much wider coverage than the current climate database in PMED. ASOS/AWOS can provide hourly weather information of ten parameters including wind speed, visualization, weather, sky condition, temperature, relative humidity, wind chill, heat index, pressure, and precipitation. All of the five parameters in the EICM except the percent sunshine can be directly read from the ASOS/AWOS weather records. In the ASOS/AWOS weather records, a similar parameter named sky condition can be adopted to calculate the percent sunshine. The sky condition is graded as either CLR (clear, no cloud coverage), FEW (few, 1/8 to 2/8 cloud coverage), SCT (scattered, 3/8 to 4/8 cloud coverage), BKN (broken, 5/8 to 7/8 coverage), or OVC (overcast, 8/8 coverage). Thus, an estimated percent sunshine value can be provided from these sky condition grades, as shown in Table 2-1. The historical ASOS data can be publically downloaded through the Iowa Environmental Mesonet (IEM), which provides the ASOS data for all the states of the United States and several other countries [15].

Table 2-1: The conversion from sky condition grade to percent sunshine

Sky condition grades	Percent sunshine
CLR	100
FEW	75
SCT	50
BKN	25
OVC	0
VV	0

The Michigan RWIS is a weather information system to monitor atmospheric and road surface conditions for managing winter maintenance activities and providing better travel information for drivers. The RWIS collects road weather information including air temperature, wind speed, wind gust, precipitation, and relative humidity. Thus, it includes all the required climate variables of PMED except the percent sunshine. To date, MDOT has installed and monitored more than 50 RWIS weather stations covering a wide range of the Upper Peninsula and the Northern Lower Peninsula of Michigan.

2.3 Generation of virtual weather stations

For a gap region where there is no nearby climate station in the MEPDG, the EICM can create virtual weather stations (VWS) through interpolations based on the weather data from up to six nearby stations. The user needs to input the longitude, latitude, elevation and depth to water table for the specific location into the model. It is recommended that a virtual climate station have an elevation similar to the actual stations, although the temperature difference can be adjusted for locations with different elevations [16]. For states with highly diverse climate conditions, it is recommended that the state can be divided into several small regions whose climate data will be collected separately [16]. Li et al. [17] verified the virtual climate data in MEPDG using the Long Term Pavement Performance (LTPP) database and found that most climatic data from VWS can estimate the actual data reasonably well, but some significant differences were also observed. Li et al. also recommended that using all applicable nearby weather stations can provide more accurate results compared to using only the closest weather station [17]. Another study investigating the environmental impacts on the MEPDG predictions found that VWS generated from different nearby actual stations can result in significantly different pavement performance predictions [18]. Similarly, Saha et al.[11] conducted a study in Canada and found that climate data of different quality and duration (i.e. data accuracy and quantity) for nearby stations can result in significantly different performance predictions using VWS. A study conducted in Minnesota showed that missing or outlier data in a certain weather station may have great influence on the design output based on VWS, especially when the VWS is close to that weather station [19]. In the study by Breakah et al. [20], the weather data generated from the IEM and the data from the interpolated MEPDG default climatic files were compared, and the results showed that the designs using the default climatic data predicted higher rutting, lower thermal cracking and lower international roughness index as compared to the design using the IEM files. Furthermore, the use of VWS has been shown to be troublesome for areas with localized micro-climates due to mountains and large bodies of water, such as in California and Illinois [10, 21].

2.4 Climatic zones

The use of climatic regions, where climates in given areas predict similar temperature and moisture profiles and result in insignificant performance prediction differences, has been used in previous studies. Climatic zones are typically defined based on the landform, average temperature, precipitation, and other climate variables. Other fields have used this approach for design. The Department of Energy defines eight general climatic zones for United States—hot-humid, mixed-humid, hot-dry, mixed-dry, cold, very-cold, subarctic and marine [22]. For building codes, California is divided into 16 climate zones [23]. Harvey et al. [24] also used climatic zones for pavement designs using the MEPDG in California. Wang et al. [25] studied the impact of climatic condition on asphalt pavement preservation effectiveness and found that the effectiveness varied significantly in different climatic zones. Li et al. [26] developed climatic zones using the climate data from the NCDC in Oklahoma and found the climatic zones can improve the data accuracy, but it turned out that the data accuracy improvement was insignificant due to the state’s flat geography.

CHAPTER 3: QUANTITY AND QUALITY CHECK OF EXISTING CLIMATIC FILES IN PMED

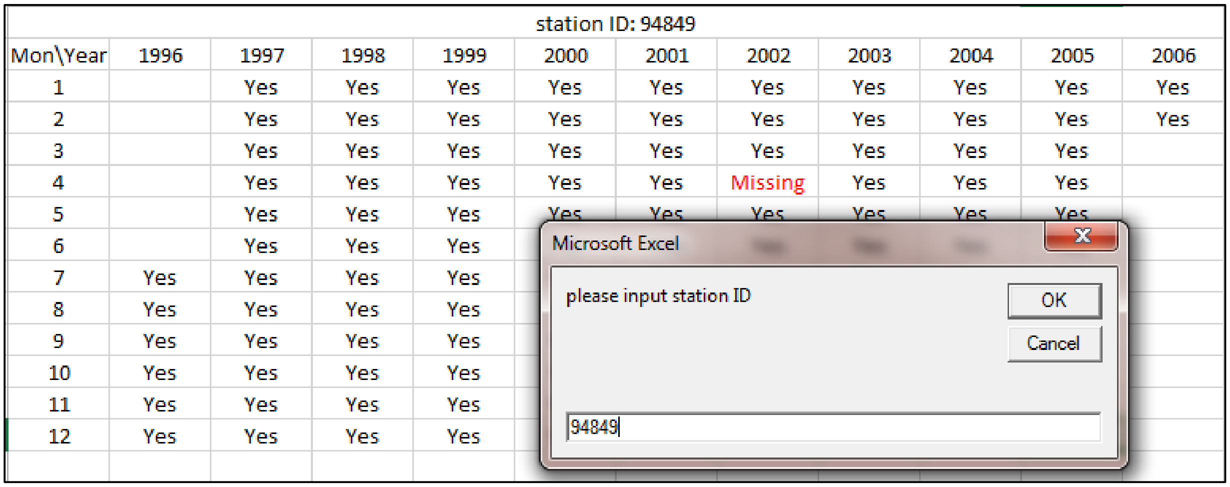
Each climatic file in the PMED has at least several years of hourly data. It is possible that there are some missing data or erroneous data in the climatic files. For instance, five climatic files for Michigan have an entire month of missing data. Missing or bad data may have an influence on the pavement performance predictions using PMED. Hence, a comprehensive data check was conducted in this study to ensure the data quantity and quality. After the data check, the missing data were filled and the erroneous data were corrected. Currently there are 24 climatic data files that are embedded in the PMED software for Michigan. Each file consists of roughly 400,000 data values. Therefore, about ten million data values needed to be scanned to perform the quantity and quality check. To effectively process such a large amount of data by hand, Visual Basic for Application (VBA) codes were written for this project.

3.1 Quantity check

As previously mentioned, the climate data in the EICM are required on an hourly basis for at least one whole year to enable the software to run. Thus, the quantity check of the climatic data files is based on the following criteria:

1) All of the climatic data files should contain the five parameters required (temperature, wind speed, percent sunshine, precipitation, and relative humidity)
2) All of the data should be hourly based.
3) There should be no missing data for each year, month, date and hour.

A user-written VBA program (as shown in Appendix C, Code 1) was used to check the missing months of the 24 existing climatic files, count the data length, and output the results in the Microsoft (MS) Excel sheets, as illustrated in Figure 3-1. Based on the data check results, the data length in terms of entire years or months can also be obtained. A button was created in the Excel sheets to make a direct operation for the user to check the data length and missing months. To conduct the missing month check, the user needs to click the button “check missing month”, and input the ID of the stations to be checked, as shown in Figure 3-1. Then, the missing months are shown in the spreadsheet and marked in red. The quantity check results showed that all of the 24 data files currently embedded in PMED for Michigan contain hourly records of the five required climate parameters. At least five entire years of data during the period 1996 to 2006 were observed for all the 24 stations, as shown in Figure 3-1 and Figure 3-2. While it is unknown whether five years of data can represent the long term climatic condition, longer periods of data would likely result in more reliable design results. Therefore, it would be advantageous to extend the data length of these climatic files. Missing months were found in five climatic files, as shown in Table 3-1. In addition to the entire month, the quantity check was also conducted for possible missing days or hours. A VBA program was also written to achieve this. The program is shown in Appendix C, Code 2. It turned out that there were no missing days or hours in any of the 24 climatic files besides the missing month in five files.



station ID: 94849

Mon\Year	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
1		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
3		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
4		Yes	Yes	Yes	Yes	Yes	Missing	Yes	Yes	Yes	
5		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
6		Yes	Yes	Yes							
7	Yes	Yes	Yes	Yes							
8	Yes	Yes	Yes	Yes							
9	Yes	Yes	Yes	Yes							
10	Yes	Yes	Yes	Yes							
11	Yes	Yes	Yes	Yes							
12	Yes	Yes	Yes	Yes							

Figure 3-1: Results of data missing month check for weather station 94849 using VBA

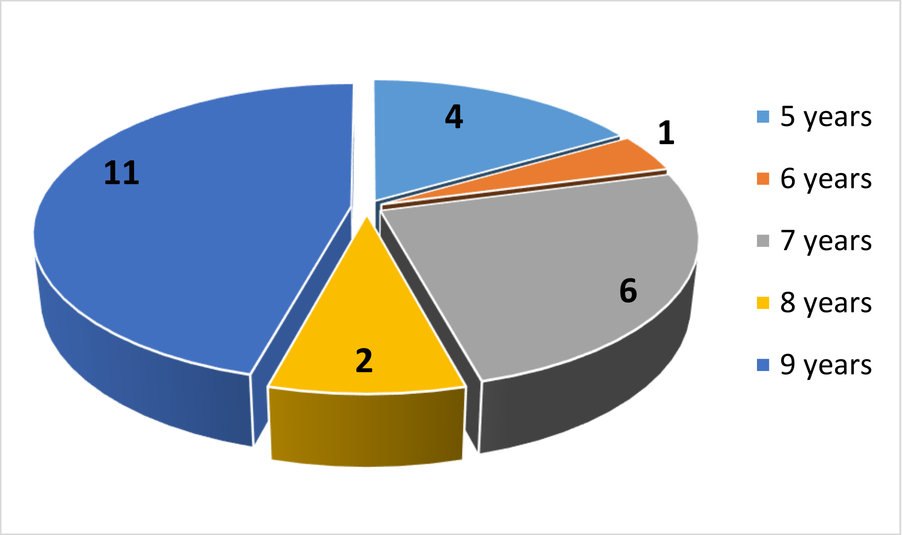


Figure 3-2: Climatic data length of the 24 stations embedded in PMED for Michigan

Table 3-1: The missing months in the current climate files for Michigan

Station ID	City	Missing months
04839	Allegan, MI	Jan. 1997
14833	Jackson, MI	Nov. 2000
14845	Saginaw, MI	Oct. 2004
14847	Sault Ste. Marie, MI	Apr. 1998
94849	Alpena, MI	Apr. 2002

3.2 Quality check

The weather data in the climatic files were checked for outliers and errors. Some criteria used in the quality check are as follows:

1) The recorded highest and lowest air temperature for Michigan is 112˚F and -51˚F, respectively [27, 28], so the temperature value should be within this range.
2) The value of wind speed should be positive and not higher than 50-70 mph (typical value of thunderstorm).
3) The percent sunshine should be between 0 and 100. In fact, since the percent sunshine is an estimated value, it should be 0, 25, 50, 75 or 100.
4) The relative humidity should be between 0 and 100%. Due to the realistic ambient conditions, the relative humidity should not be too low. According to the study by Heitzman and Timm [6], a minimum relative humidity of 12% was used. In this study, this minimum value will also be adopted.
5) The value of precipitation should be positive or zero. The PMED set 10 inches as the maximum acceptable limit of daily precipitation. Thus, the daily precipitation should be lower than this value.
6) The hourly temperature change should be consistent so that the temperature change curve should be fairly smooth. The PMED software set 30˚F as the warning limit for the hourly temperature change. Thus, any hourly temperature change of more than 30˚F was flagged as suspicious data, and a manual determination of data accuracy was made.

Similarly, a user-written VBA program (as shown in Appendix C, Code 3) was applied to check the data quality for all of the 24 climatic files. The erroneous data and the suspicious data were identified and shown in the spreadsheets. Table 3-2 shows an example of the quality check results of the weather station in Allegan (ID: 04839). The left part of the table lists the outliers and null data of the five climatic variables according to criteria 1 to 5, and the right part shows the suspicious temperature data based on criterion 6. It was observed that some temperature data are null and that some relative humidity values were higher than 100 or lower than 12, which are considered outliers. Some non-numerical data were also identified, such as "M" and "***" in the climatic files with station ID of 04847 and 14836, as shown in Appendix B.

In addition to the outliers that can be easily recognized, some suspicious data requires manual inspection to make a final decision. As mentioned above, if the hourly temperature change is higher than 30˚F, it will be listed as suspicious data requiring a manual check. For instance, some suspicious temperature data was observed in the night of 09/06/2004 and the early morning of 09/07/2004. In particular, there was temperature drop from 68˚F to 15˚F at 8pm, and after two hours, the temperature went up from 15˚F to 61˚F. It is interesting that a similar phenomenon occurred for some other climatic files during that time, as shown in Appendix B. Normally, if a rapid temperature change occurs, some accompanying weather conditions may be identified, such as a sharp change of percent sunshine due to cloud coverage changes, a significant change of wind speed, or precipitation. After manually checking other variables during that night, no other visible changes were found. Furthermore, the historical data from another weather resource was checked, and it was found that there was no such temperature fluctuation during that night [29]. Thus, it is safe to regard the data values during that night as erroneous. A correction is needed for these erroneous data.

Table 3-2: Data quality check results of the weather station 04839

Station ID: 04839							
Time	Erroneous data and outliers				Relative humidity	Suspicious data	
	Temperature	Wind speed	Percent sunshine	Precipitation		Time	Temperature
1997020209					1	2003110418	64
1997020422					104	2003110419	38
1997020423					3	2004090620	68
1997020821					104	2004090621	15
1997020822					105	2004090622	15
1997022002					127	2004090623	61
1997061222					103	2004090705	61
1997061504					103	2004090706	18
1997061805					103	2004090707	18
1997081902					103		
1997082500					104		
1997090702					103		
1997091421					104		
1997091703					104		
1998040205	Null						
1998040216	Null						
1998082023					1		
1999021205	Null						
1999021216	Null						
1999101009					0		
1999101015					0		
1999101016					6.3		

3.3 Missing data filling

After the data quantity and quality check, the missing data should be filled and the erroneous data should be corrected. As shown in the quantity check results above, five weather stations have an entire month of missing data. No other missing daily or hourly data were found. Therefore, only the missing monthly data needs to be filled. Two approaches were proposed in this study to fill the missing month of data. The first approach is to utilize the data of the same month in other years at the same weather station. The second approach is to utilize the data of the same month and year from neighboring weather stations. The detailed descriptions of the two approaches are given below.

In the first approach, it is assumed that the missing data at each hour is close to the average data of the same hour in other years at the same location. For instance, if the missing data is at hour 2000010100 (hour 00 on the date of 01/01/2000), it is assumed that this missing data is close to the average data of the same hour (hour 00 of the date 01/01) in other years. Therefore, each weather data set within the missing month is filled with the average data at this specific hour in all other years at the same station. To evaluate the reliability of the filled data, one month of data was manually extracted from the original data files and compared with predicted data for the same period. The manually extracted month was the same month but in the next year of the missing month. For instance, the missing month in Jackson is November 2000, and the month extracted for testing is November 2001. The average values of the climate data in November of all other years are calculated and compared with the extracted data in November 2001. Detailed information on the extracted data for each weather station is shown in Table 3-3.

In the second approach, it is assumed that the weather at a certain station is similar to that at its neighboring stations. At least one neighboring station was found for each of the five stations with a missing month, as shown in Figure 3-3. The blue marks represent the stations with a missing month, while the red marks represent their selected neighbors. For the three stations in the Lower Peninsula, close neighbors can be found. For the station in the middle part of the state, two neighboring stations were found. For the station in the Upper Peninsula, a station from Ontario, Canada was selected as the neighboring station. Two months of data were extracted from the original data to compare with that from neighboring stations. If the missing month is November 2000, the two extracted months are November 1999 and 2001. The correlation between the extracted data and data from neighboring stations was evaluated for these months to determine if neighboring data can be a good alternative for filling missing data in the PMED climate files.

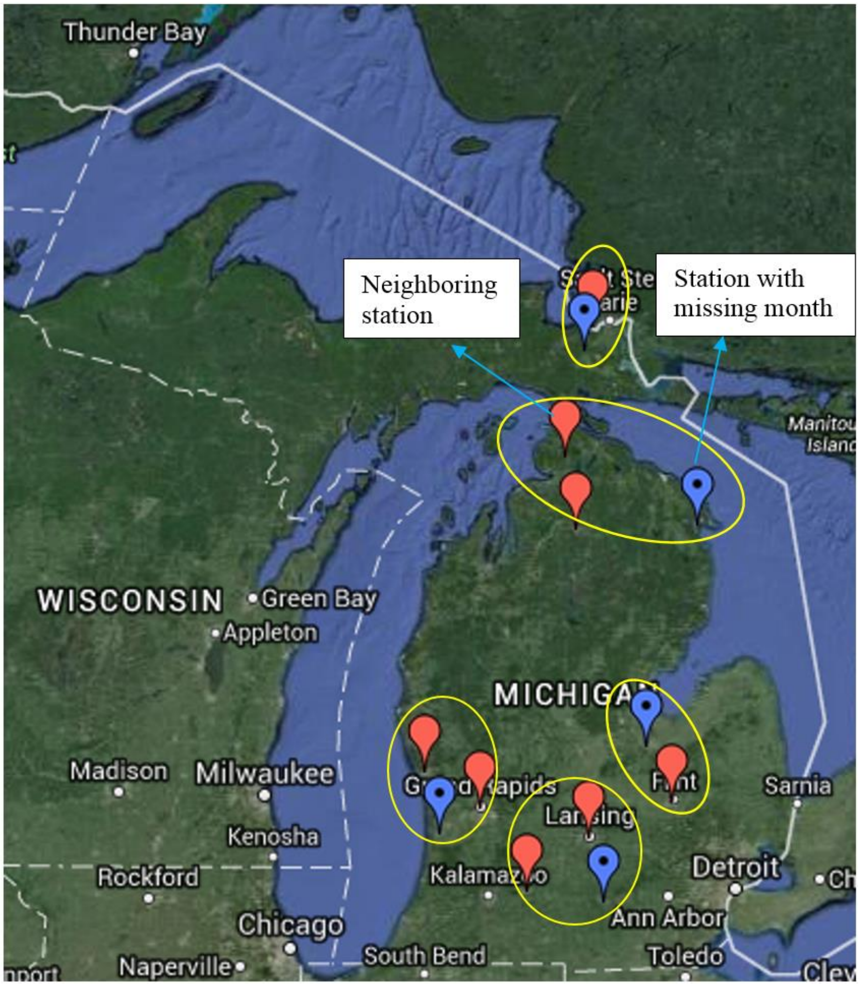


Figure 3-3: Location of stations with a missing month and their neighboring stations

Table 3-3: Data information of the stations with a missing month and their neighboring stations

Station	ID	Missing Month	Data range	Replacement month	Neighboring station ID
Holland	04839	01/1997	07/96-02/06	01/98*	14840 & 94860
Jackson	14833	11/2000	10/00-02/06	11/01*	14815 & 14836
Saginaw	14845	10/2004	09/98-02/06	10/03 & 10/05	14826
Sault Ste. Marie	14847	04/1998	01/97-02/06	04/97 &04/99	94842
Alpena	94849	04/2002	07/96-02/06	01/01 & 04/03	04854 & 14841
*Note: The month in the previous year does not exist, so only the month in the next year is selected					

The two approaches were evaluated using the Statistical Analysis System (SAS) software. The correlation coefficient (*r* value) between the extracted data and predicted data is a measure of the reliability of the filling approaches. The absolute value of *r* is between 0 and 1. If the two variables have a strong correlation, the absolute value of *r* is close to 1; if the two variables have a weak correlation, the *r* value is close to 0. Dancey and Reidy [30] categorized the strength of correlation and recommended a strong correlation if *r* is between 0.7 and 0.9, a moderate correlation if *r* is between 0.4 and 0.6, and a weak correlation if *r* is between 0.1 and 0.3. The r values between the extracted data and predicted data using the first approach (average data of other years) is shown in Table 3-4. It was found that most of the *r* values were low. Only the temperatures of Sault Ste. Marie and Saginaw have *r* values higher than 0.5. Figure 3-4 directly displays the comparison between the predicted and extracted temperatures for Saginaw using the first approach. This also shows that the correlation between the predicted and extracted data is relatively low, even at the best station. This indicates that the first approach using the average data of other years is not a reliable method for filling missing data. This also indicates that the data from a certain year cannot be well predicted by data from other years. The reason of this is that the weather data may vary significantly from one year to another.

Table 3-4: Correlation coefficients between the extracted and predicted data using the first filling approach (average value of other years)

Stations	Correlation coefficients (*r* values)				
	Temp.	Wind Speed	Percent Sunshine	Precip.	Relative Humidity
Jackson	0.10647	0.1319	0.07924	0.4058	0.46436
Sault Ste. Marie	0.5477	0.1778	-0.0311	0.2945	0.2293
Alpena	0.4622	0.3413	0.3193	0.5238	0.3053
Holland	0.2662	0.1641	0.1568	-0.0652	0.2203
Saginaw	0.6058	0.1925	0.0801	0.6343	0.2434

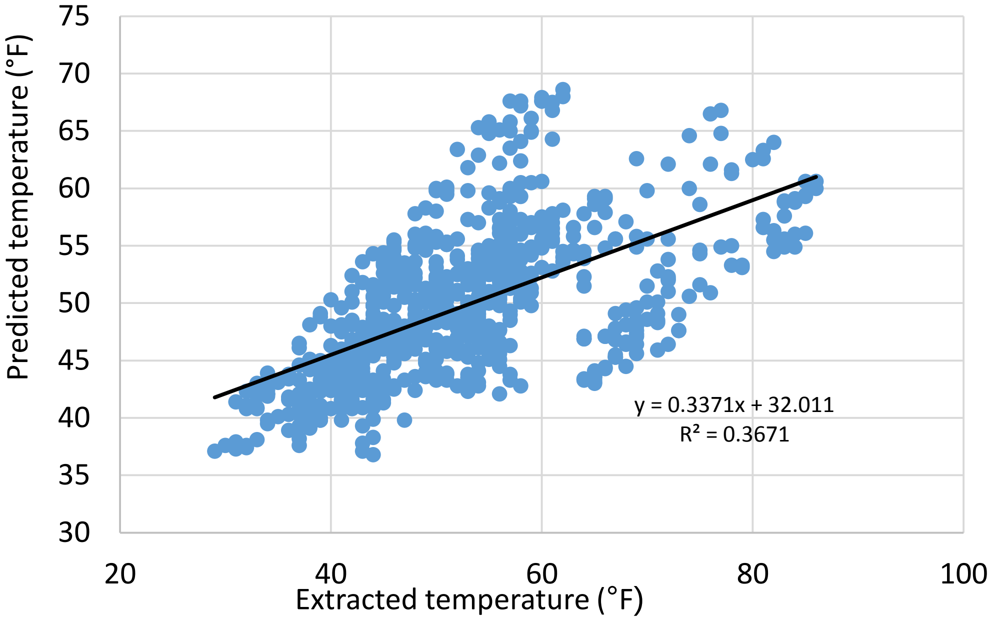


Figure 3-4: Comparison of the predicted and extracted data for the Saginaw weather station

The reliability of the second approach was also evaluated using neighboring stations at the same specific time as the missing data. The *r* values between the extracted data and neighboring data are much higher using this method, as shown in Table 3-5. All of the correlation coefficients are higher than 0.6, except for one station's precipitation (Sault Ste. Marie). All correlation coefficients for temperature are higher than 0.95. Temperature is regarded as the most sensitive variable in the PMED program. Thus, the correlation coefficient for temperature is especially important. Figure 3-5 gives an example of the comparison of the extracted temperature and the temperature from neighboring stations. Based on the strong correlation, a linear equation can be used to predict the extracted data using neighboring data.

To evaluate the impact of this prediction on the PMED results, two climatic files were used for a comparison study. The first file is the original climatic file embedded in the software. The second file was generated by replacing one or two months with the predicted data from neighboring data, as shown in Table 3-3. When there are two neighboring stations, the average value of the two neighbors were used to fill the missing month data. The flexible and rigid pavements for heavy traffic and medium traffic levels with typical Michigan pavement structures were used for the analysis. The distress prediction results using the original file and using the file with months filled using neighboring data are shown in Table 3-6 and Table 3-7. It was found that differences between the two predictions were marginal, and many distress predictions were exactly the same. This indicates that it is sufficient to use data predicted from neighboring stations to fill the missing month.

Table 3-5: Correlation coefficients between the existing data and the neighboring data

Stations	**Correlation coefficients**				
	Temp.	Wind Speed	Percent Sunshine	Precip.	Relative Humidity
Jackson (two neighbors)	0.9735	0.8542	0.7949	0.9300	0.8108
Sault Ste. Marie (one neighbor)	0.9519	0.7792	0.6814	-0.063	0.8508
Alpena (two neighbors)	0.9627	0.7651	0.8411	0.9130	0.8924
Holland (two neighbors)	0.9852	0.8675	0.6163	0.8238	0.8760
Saginaw (one neighbor)	0.9755	0.6654	0.6566	0.8791	0.7600

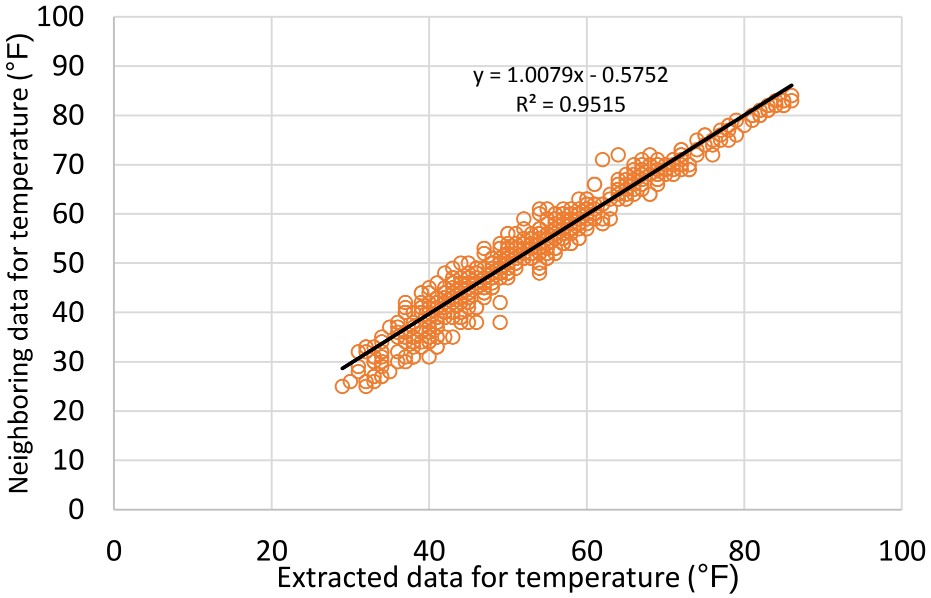


Figure 3-5: Comparison of the extracted data for temperature and the temperature from neighboring weather stations

Table 3-6: Distress prediction comparison of flexible pavement design using the original files and the modified files

Stations	IRI (in./mi)	Total Rut (in.)	Bottom-up Crack (percent)	Thermal Crack (ft/mi)	Top-down Crack (ft/mi)	AC Rut (in)
Holland_0	161.60	0.96	5.34	83.42	323.35	0.33
Holland_1	161.61	0.96	5.34	83.42	323.45	0.33
Jackson_0	163.46	0.98	5.38	176.97	328.58	0.34
Jackson_1	163.46	0.98	5.38	176.94	328.58	0.34
Chipwa_0	175.50	0.90	5.03	2452.34	335.50	0.26
Chipwa_1	175.48	0.90	5.02	2452.19	335.40	0.26
Alpena_0	175.48	0.90	5.02	2452.19	335.40	0.26
Alpena_1	175.48	0.90	5.02	2452.19	335.40	0.26
Saginaw_0	162.09	0.91	5.06	557.44	309.03	0.29
Saginaw_1	162.10	0.91	5.06	557.57	309.06	0.29
Note: “_0” represents the original file; “_1” represents the original file with one or two months replaced using neighboring data						

Table 3-7: Distress prediction comparison of rigid pavement design using the original files and the modified files

Stations	IRI (in.)	Faulting (in.)	Trans. Cracking (per.)
Holland_0	153.15	0.09	3.83
Holland_1	153.27	0.09	3.83
Jackson_0	162.66	0.1	3.83
Jackson_1	162.65	0.1	3.83
Sault Ste. Marie_0	152.61	0.06	3.83
Sault Ste. Marie_1	152.62	0.06	3.83
Alpena_0	152.62	0.06	3.83
Alpena_1	152.62	0.06	3.83
Saginaw_0	156.11	0.09	3.83
Saginaw_1	156.11	0.09	3.83
Note: “_0” and “_1” represent the original and revised files, respectively.			

3.4 Erroneous data correction

The erroneous data in existing climatic files includes the data identified from the VBA macros (data outliers, unrecognized strings, and nulls) and the suspicious data manually confirmed as erroneous. For the data outliers, different correction approaches can be used for different parameters. Under normal circumstances, ambient temperature changes smoothly on an hourly basis. Thus, the average value of the neighboring data (before and after) was used to replace the temperature outliers. For the percent sunshine, since it is an estimated value, only 0, 25, 50, 75 and 100 should be used in the climatic files, and all of the data other than these five values should be corrected. The correction approach is shown in Table 3-8. For the relative humidity, although the theoretical lower limit value is 0, a value of 12% is used according to a previous study in Mississippi [6]. Therefore, if the data value is higher than the upper limit or lower than the lower limit, 100% and 12% were used, respectively, to replace the original data. For the precipitation, a lower limit of zero and an upper limit of 10 in/day were set for the quality check. Thus, 0 will be used if the precipitation values are negative. For the wind speed, if the data value is beyond the extreme range, an upper or lower limit will be used. If it is erroneous data, an average value of the neighboring data values (before and after) is used to replace the erroneous data. The data correction procedure was implemented through a user-written VBA program, as shown in Appendix C, Code 5. The suspicious data were checked manually, one by one. If it was confirmed as erroneous data, it was corrected manually using the same approach as that mentioned above.

Table 3-8: The data correction for the percent sunshine

Initial values	**Value after correction**
Lower than 12.5	0
12.5 ~ 37.5	25
37.5 ~ 62.5	50
62.5 ~ 87.5	75
Higher than 87.5	100

3.5 Impact of missing month data and erroneous data on design results

After the quantity and quality check, the impact of the missing data and erroneous data in the existing database on the design results in PMED should be evaluated. The impact of the missing data on the PMED is obvious. If one month data of a certain weather station is missing, this station cannot be used alone but can be used as a virtual weather station. This is the reason why only 19 weather stations for Michigan can be directly used in the PMED, although 24 climatic files are included in the software. The impact of the erroneous data can be evaluated by comparing the distress predictions using the original and corrected climatic files.

To assess the effect of corrected climate files, a new flexible pavement and a new rigid pavement under a medium traffic level were designed using the PMED. Six weather stations throughout the state of Michigan were selected for this analysis. These six stations were Adrian, Gaylord, Hancock, Lansing, Iron Mountain, and Muskegon. Please refer to section 4.4 for the reason why these six stations were selected for the analysis. To make the design results comparable, the pavement structures and all the input parameters were the same except for the weather data. Typical pavement structures and materials used in Michigan were adopted in this study. Detailed information on the traffic inputs, pavement structure and material inputs is shown in Table 4-1 to Table 4-3. The reasons we put these two tables in the Chapter 4 is that all the details of structural and material inputs are described there. Based on the initial and corrected climatic data, Table 3-9 and Table 3-10 show the distress predictions for typical Michigan flexible and rigid pavements, respectively. It can be found that the distress predictions using the corrected climatic files were very close to those using the original climatic files. This indicates that the erroneous data in the climatic files do not have much impact on the pavement design results. The reason for this is that the amount of the erroneous data in existing climatic files is very low in comparison to the total hours in the pavement design life. Nevertheless, it is better to correct these data to ensure more reliable pavement designs.

Table 3-9: Distress prediction comparison between using the original and corrected climatic files for typical Michigan flexible pavement

Distresses		Adrian	Gaylord	Hancock	Lansing	Iron Mount.	Muskegon
Thermal Cracking	original	124.1200	1786.2020	1180.4920	83.3711	2267.2520	2419.6420
	corrected	124.4700	1786.5460	1180.3140	83.3711	2267.7750	2424.9410
AC Rut	original	0.3701	0.2774	0.2720	0.3060	0.2622	0.3018
	corrected	0.3702	0.2774	0.2720	0.3059	0.2622	0.3018
Total Rut	original	1.0024	0.9099	0.9004	0.9362	0.9036	0.9387
	corrected	1.0025	0.9099	0.9003	0.9362	0.9036	0.9386
Top-down Cracking	original	331.5000	325.1630	305.4949	316.0323	341.6772	336.5617
	corrected	331.7000	325.1630	305.4949	316.0323	341.6772	336.6818
Bottom-up Cracking	original	5.4280	5.0882	5.0982	5.2482	4.8682	5.0982
	corrected	5.4280	5.0882	5.0982	5.2382	4.8782	5.1082
IRI	original	164.1700	171.1462	166.0566	160.1787	173.8955	176.9601
	corrected	164.1800	171.1487	166.0492	160.1733	173.9043	176.9961

Table 3-10: Distress prediction comparison between using the original and corrected climatic files for typical Michigan rigid pavement

Distresses		Adrian	Gaylord	Hancock	Lansing	Iron Mount.	Muskegon
Faulting	original	0.0961	0.0620	0.0702	0.0641	0.0798	0.0877
	corrected	0.0961	0.0619	0.0702	0.0641	0.0798	0.0877
Transverse Cracking	original	3.8318	3.8318	3.8318	3.8318	3.8318	3.8318
	corrected	3.8318	3.8318	3.8318	3.8318	3.8318	3.8318
IRI	original	160.2240	155.9194	157.1267	162.8712	152.8523	150.3318
	corrected	160.2098	155.8300	157.1267	162.8712	152.8523	150.3318

3.6 Climatic file update

After filling the missing data and correcting erroneous data, the new climatic files should be updated and embedded into the PMED software. All the data editing in this study was conducted in MS Excel, so the .hcd files should be opened in MS Excel and then saved as .hcd files. To achieve this, the original climatic files are opened with MS Excel first and then saved as an .xlsx file. Because there are commas between the weather data in the '.hcd' files, comma separators were used when opening the '.hcd' files so that only numbers existed in the newly opened Excel files. Then the missing data is filled and the erroneous data is corrected using the user-written VBA program. Next, the Excel file is saved as a .csv file with comma separators. Finally, the file is renamed as an .hcd file. The flow chart of this procedure for opening, editing, and saving climatic data files is shown in Figure 3-6. The file format conversion from .xlsx to .hcd was achieved by a user-written VBA code, as shown in APPENDIX C, Code 6.

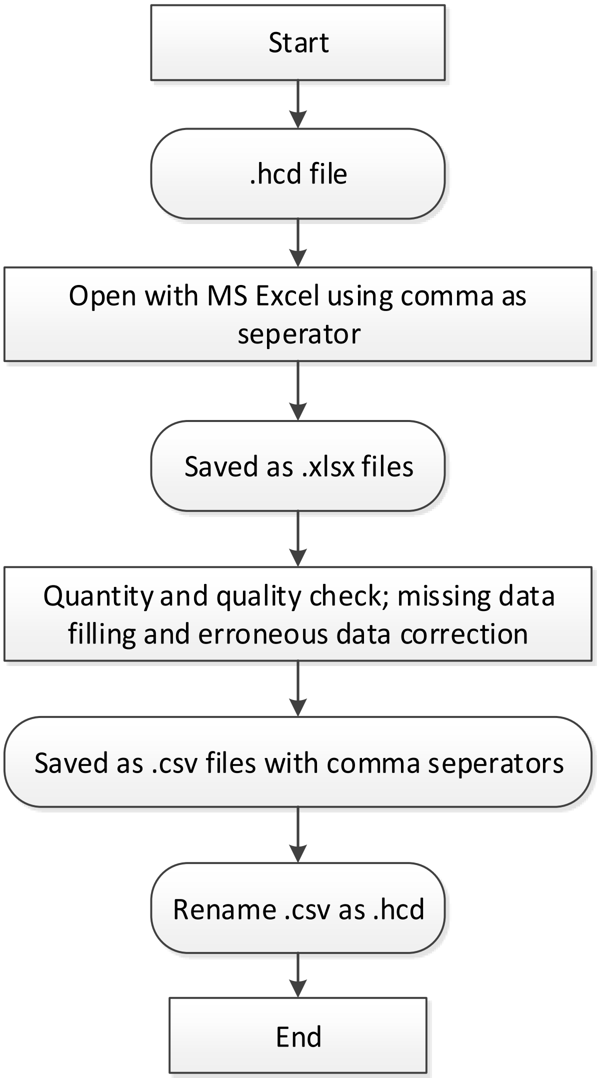


Figure 3-6: Flow chart of the procedure for reading, editing and saving climatic file

CHAPTER 4: SENSITIVITY OF DISTRESS PREDICTIONS TO CLIMATIC INPUTS

4.1 General design inputs

4.1.1 Traffic Inputs

Traffic inputs have a great influence on the design results, as climate and traffic have cumulative effects on predicted pavement responses and subsequent distress development. To make the designs suitable for Michigan, the traffic inputs for this project were in accordance with realistic traffic conditions in Michigan. According to the traffic count maps in Michigan [31], the annual average daily truck traffic (AADTT) varies from 500 to about 12,000 for state-owned roads. Considering that the influence of weather data on the design results may be different at different traffic levels, a medium traffic level and a heavy traffic level were used for the pavement designs in this study. Initial AADTT values of 2,000 and 9,000 were selected to represent the medium and heavy traffic level, respectively. Other traffic inputs such as load spectra, vehicle class distribution, axle spacing, etc. were referenced from a previous study on characterization of the truck traffic in Michigan [32]. For the traffic inputs that could not be estimated, the default values from the PMED software were used. The detailed traffic inputs of this study are shown in Table 4-1.

4.1.2 Structure and Material Inputs

The pavement structures used in this study were based on the typical freeway structures in Michigan. The typical pavement cross-sections of the flexible and rigid pavement are shown in Table 4-1. A typical asphalt pavement consists of three asphalt concrete courses, one base layer, one subbase layer and the subgrade. The asphalt mix type and aggregate gradation were selected according to the MDOT specification of construction [33]. A typical jointed plain concrete pavement (JPCP) consists of a jointed plain concrete layer, an open graded drainage course (OGDC) base, a sand subbase and the subgrade. The material type and gradation were also selected based on the MDOT specification of construction [33]. Design thicknesses were selected to be representative of typical sections in use in the state as designed with the AASHTO 1993 procedure, which is MDOT's official design procedure at the time of this study.

Table 4-1: Traffic inputs used in this study (Additional inputs are given in Appendix D.)

Input parameters	**Medium traffic level**	**Heavy traffic level**
Initial-way AADTT	2,000	9,000
Design life (years)	20	
Number of lanes	2	3
Percent trucks in design direction	51%	
Percent trucks in design lane	92%	65%
Operational speed	60	
Average axle width	8.5	
Dual tire spacing	12	
Tire pressure	120	
Tandem axle spacing	51.6	
Tridem axle spacing	49.2	
Quad axle spacing	49.2	
Mean wheel location	18	
Traffic wander standard deviation	10	
Percent trucks with short axle spacing	17	
Percent trucks with medium axle spacing	22	
Percent trucks with long axle spacing	61	
Traffic growth rate	2% compounded	
Vehicle class distribution	See Table D1	
Monthly adjustment factors	See Table D2	
Axles per truck	See Table D3	
Axle load distributions	See Tables D4, D5, D6 and D7	

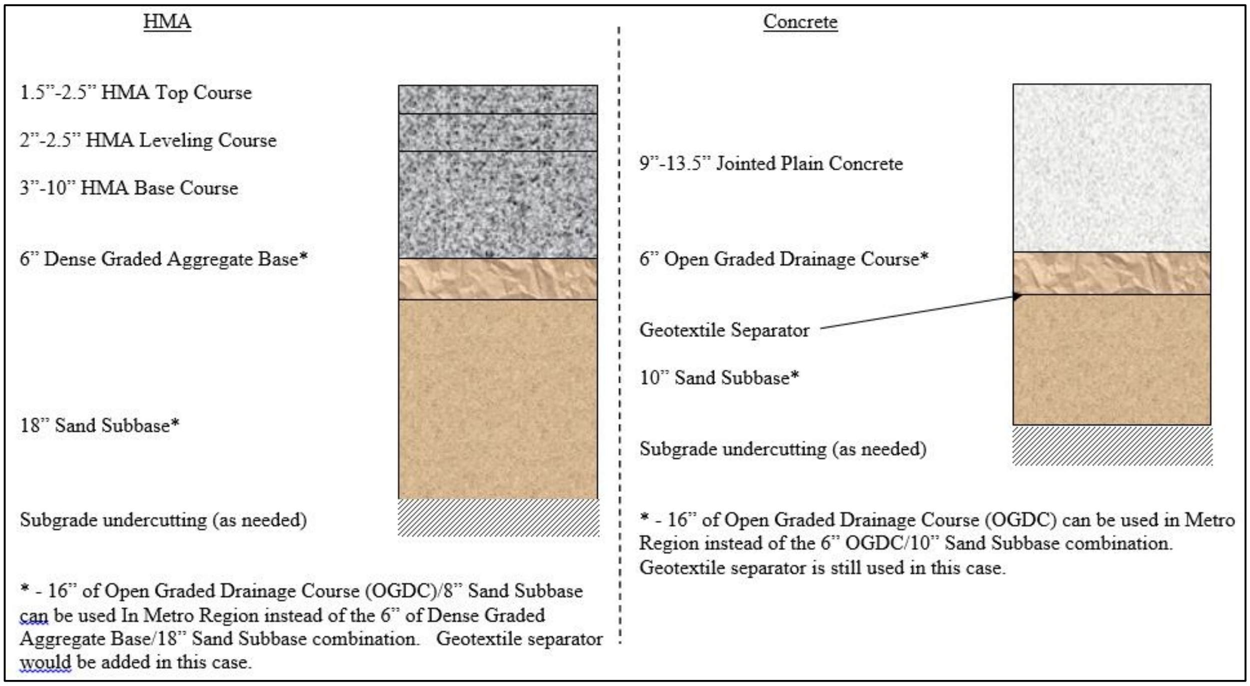
1) Flexible pavement

Based on the traffic inputs above, the cumulative equivalent single axle loads (ESAL) of the designs for flexible pavement at the medium and heavy traffic levels were calculated by the PMED as 8.43 and 29.56 million, respectively. It should be noted here, ESALs calculated by the PMED can be different from that calculated by AASHTO 93, which is currently used by the

MDOT in pavement design. This is because the PMED takes account into load spectra and the traffic hourly, daily, and monthly adjustments. Therefore, according to the MDOT specification of construction, the HMA layer mix type of the two designs should be E10 and E30, respectively [33]. On the basis of the HMA selection guidelines of Michigan [34], the HMA types for the freeway designs of the two traffic levels are shown in Table 4-2. Gap graded Superpave (GGSP) mixtures were used as the top course for the heavy traffic level design as required by MDOT standards. The material property inputs were selected according to tested results in Michigan, including the dynamic modulus (|E*|) and creep compliance of asphalt mixture, as well as the dynamic shear modulus (|G*|) of asphalt binder. A total of six types of HMA mixtures were used in this study. For the design under the medium traffic level, the asphalt mixes 5E10, 4E10 and 2E10 were used for the top course, leveling course and base course, respectively. Since the |E*| data of the 2E10 mix was not available, the properties of 3E10 mix was used as the base course for the design under the medium traffic level. For the design under the heavy traffic level, the asphalt mixes GGSP, 4E30 and 3E30 were used for the top course, leveling course and base course, respectively. Five temperatures (14, 40, 70, 100 and 130 ℉) and four frequencies (0.1, 1, 10 and 25 Hz) were selected for the |E*| inputs. Three temperatures (-4, 14 and 32 ℉) were selected for the creep compliance inputs. Five temperatures (40, 70, 100, 130 and 168) were selected for the |G*| input at the frequency of 1.59 Hz (10 rad/s). The software default values were used for other required inputs. The detailed inputs of the HMA properties are shown in Appendix E.

Table 4-2: Structure and materials in the asphalt pavement

Structure	Material type	
	AADTT = 2000	AADTT = 9000
Top course	2.0” HMA 5E10	2.0” HMA GGSP
Leveling course	2.5” HMA 4E10	2.5” HMA 4E30
Base course	5.0” HMA 2E10	7.0” HMA 3E30
Aggregate base	6” Non-stabilized aggregate base, Mr = 33,000 psi	
Sand subbase	18” Non-stabilized sand subbase, Mr = 20,000 psi	
subgrade	Sandy clay subgrade, Mr = 5,000 psi	



* - 16” of Open Graded Drainage Course (OGDC)/8” Sand Subbase can be used In Metro Region instead of the 6” of Dense Graded Aggregate Base/18” Sand Subbase combination. Geotextile separator would be added in this case.

* - 16” of Open Graded Drainage Course (OGDC) can be used in Metro Region instead of the 6” OGDC/10” Sand Subbase combination. Geotextile separator is still used in this case.

Figure 4-1: Typical Michigan freeway cross-sections

2) Rigid pavement

Based on the traffic inputs above, the cumulative ESALs of the designs for rigid pavement at the two traffic levels were calculated by the PMED as 10.04 and 29.54 million, respectively. Similar to the flexible pavement ESAL calculation, the ESALs of rigid pavement calculated by the PMED can also be different from that calculated by AASHTO 93. The structure of the JPCP is shown in Table 4-3. The structure consists of four layers: the Portland cement concrete (PCC), open graded drainage course (OGDC), sand subbase, and subgrade. The PCC layer thicknesses are 10.0” and 11.5” for the medium and heavy traffic levels, respectively. In addition, the dowel diameters are 1.5” and 1.25” for the high and medium traffic levels, respectively.

Table 4-3: Structure and materials in the concrete pavement

Structure	Material type	
	AADT = 2000	AADT = 9000
PCC thickness	10.0”	11.5”
6” OGDC base	Mr = 33,000 psi	
10” sand subbase	Mr = 20,000 psi	
Subgrade	Sandy clay subgrade, Mr = 5,000 psi	

4.1.3 *Local calibration factors*

The distress prediction equations embedded in the PMED have several coefficients, which have a great influence on the resulting predictions. The default coefficient values in the PMED are representative of nationwide conditions, and thus it is preferred to use the coefficients after local calibration for Michigan. Local calibration of these coefficients for Michigan were provided by the MDOT. The values after local calibration are shown in Table 4-4 and Table 4-5. It should be noted that the calibration factors listed here were obtained when the local calibration research was still ongoing. So it is possible that they are different from the final numbers used by MDOT.

Table 4-4: Model coefficients for flexible pavement after Michigan’s calibration

Distresses		Coefficients	Values in Michigan
Bottom-up cracking		C1	2.97
		C2	1.2
Top-down cracking		C1	0.5
		C2	0.56
Rutting	HMA	BR1	0.9453
		BR3	1.3
		BR3	0.7
	Base/subgrade	BS1 (coarse)	0.0985
		BSG1 (fine)	0.0367
Thermal cracking		K (level 1)	0.75
		K (level 3)	4
IRI		C1	50.372
		C2	0.4102
		C3	0.0066
		C4	0.0068

Table 4-5: Model coefficients for rigid pavement after Michigan's calibration

Distresses	Coefficients	Values in Michigan
Transverse cracking	C4	0.23
	C5	-1.8
Joint faulting	C1	0.4
	C2	1.1
	C3	0.001725
	C4	0.0008
	C5	250
	C6	0.4
	C7	1.2
IRI	C1	1.2347
	C2	3.545
	C3	1.4929
	C4	52.4964

4.2 Sensitivity analysis method

In a previous study by Schwartz et al. [35], a normalized sensitivity index (NSI) was used to quantitatively evaluate the sensitivity of MEPDG design results to variable inputs. The NSI was defined as the ratio of the percentage change of the output distress value (relative to the distress value limit) to the percentage change of a certain input [35]. NSI values of 0.1, 1 and 5 were selected as the thresholds of sensitive, very sensitive and hypersensitive levels. The expression of NSI is shown in Equation (1).

$$NSI = \frac{\Delta Y}{DL} \bigg/ \frac{\Delta X}{X} = \frac{\Delta Y}{\Delta X}\frac{X}{DL} \tag{1}$$

where X is the initial value of the variable; ΔX is the change in the value of the variable; ΔY is the change in predicted distress corresponding to ΔX; and DL is the design limit for that distress.

Equation (1) can be used to analyze the sensitivity for most climatic inputs. However, some climatic inputs are changed discretely (or categorically), not continuously. For instance, the weather station change is from one location to another, which is not continuous. In this case, a modified NSI is used. The expression of the modified NSI is shown in Equation (2).

$$\text{NSI}= \frac{\Delta Y}{DL}\bigg|_{\Delta X=1\ category} \tag{2}$$

Where ΔX is the category change of the climatic variable; ΔY is the change in predicted distress corresponding to the change of the climatic inputs; and DL is the design limit for a certain distress.

NSI for IRI is regarded as a special case because the lower limit of IRI is non-zero. The distress change is in fact the difference between the distress limit and the initial distress. The expression of NSI for IRI is shown in Equation (3).

$$NSI = \frac{\Delta Y}{(DL-DI)} \Big/ \frac{\Delta X}{X} = \frac{\Delta Y}{\Delta X}\frac{X}{(DL-DI)} \tag{3}$$

where X is the initial value of the climatic variable; ΔX is the change in the value of the climatic variable; ΔY is the change IRI corresponding to ΔX; DL is the design limit for IRI; and DI is the initial distress of IRI.

4.3 Sensitivity to weather station change

There are 24 climatic files currently embedded in the PMED software. Since these weather stations are located throughout the state, it is necessary to understand how sensitive the design results are to the weather station so that it is known whether more weather stations are needed in the gap regions. All 19 stations are utilized for the sensitivity analysis. Six stations from Indiana, Wisconsin and Ohio are also taken account, as shown in Figure 4-2.

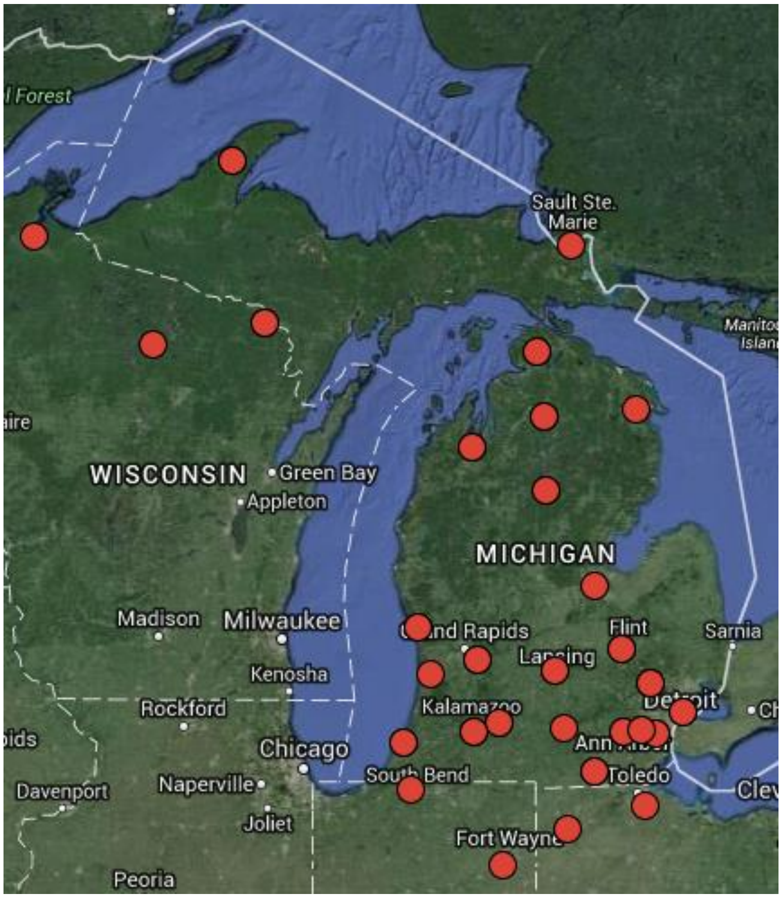


Figure 4-2: Weather stations of Michigan and neighboring states in the PMED

Two types of pavements (flexible and rigid) and two traffic levels (heavy and medium traffic levels) were applied for the sensitivity analysis. For the flexible pavement design, the traffic inputs and pavement structures are shown in Table 4-1 to Table 4-3. To make the design results comparable from station to station, all of the input parameters were held constant except for the weather station selection.

Figure 4-3 and Figure 4-4 show the design results of the flexible pavement for the weather stations under the heavy and medium traffic conditions, respectively. It was observed that some of the distresses under different climatic conditions were very close (e.g. the IRI), while some others varied significantly when the climate condition changes (e.g. the thermal cracking). Most of the thermal cracking predictions under the heavy traffic level were similar, while the thermal cracking predictions under the medium traffic level varied significantly from each other. The main reason for this is that the pavement under the heavy traffic level has thicker asphalt concrete layers and better low temperature material performance to resist thermal crack initiation. As seen in Table

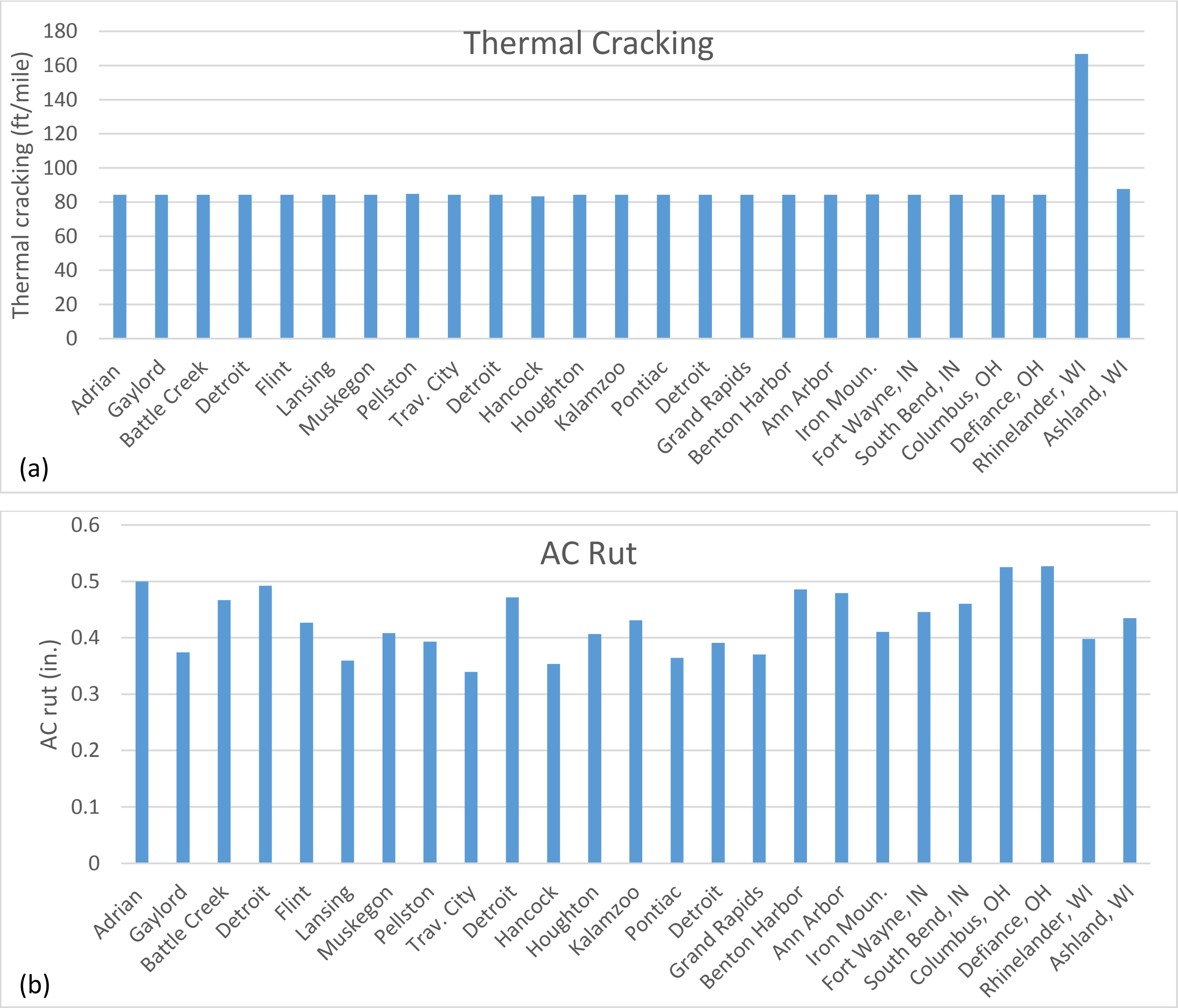
4-2, the HMA base courses under the high and medium traffic levels are 7.0” and 5.0”, respectively. The increased HMA layer thickness helps resist thermal cracking. In addition, the creep compliance of the GGSP layer is higher than that of the 5E10 layer, as seen in Table E7 and E10. This indicates the GGSP layer resists thermal cracking better than the 5E10 mix under low temperatures. For all other distress values, noticeable variations were observed from station to station for both the high and medium traffic levels. Based on Equations (1) - (3), Equation (2) was selected to analyze the sensitivity of design results to a weather station change. The NSI of IRI was analyzed using Equation (3). The NSI results of the distress indexes are shown in Figure 4-7. In the heavy traffic level design, the NSIs of AC rutting and total rutting were higher than 0.1, while the NSIs of all other distresses were lower than 0.1. This indicates that, under the heavy traffic level design, the AC rutting and total rutting are sensitive to weather station change while other types of distress are not. In the medium traffic level design, the NSI of thermal cracking was 2.34, which is higher than the threshold of “very sensitive”. The NSIs of AC rutting, total rutting and IRI were between the thresholds of “very sensitive” and “sensitive”. The top-down cracking and bottom-up cracking were not sensitive to weather station change.

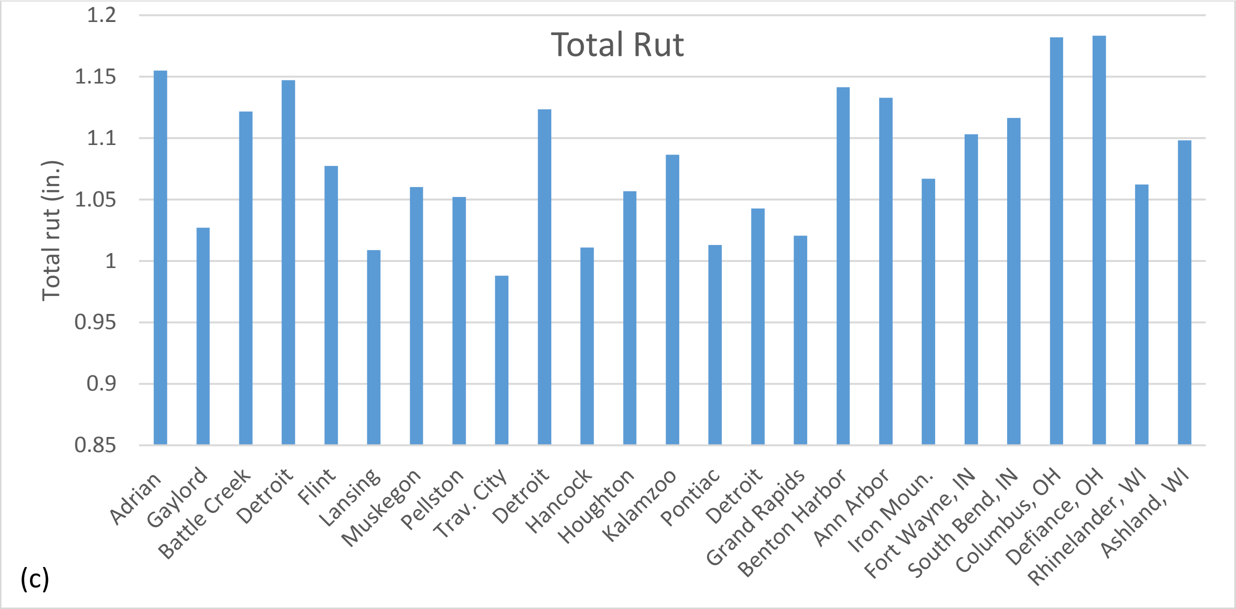
Figure 4-5 and Figure 4-6 show the distress predictions of rigid pavement under high and medium traffic levels, respectively. It was observed that the transverse cracking does not vary from station to station under both the high and medium traffic level designs. However, the faulting and IRI exhibit visible differences from one station to another. The NSIs were calculated and shown in Figure 4-8. Both faulting and IRI were sensitive to the weather station change as the NSIs are between 0.1 and 1.

The sensitivity of distress prediction to weather station variation can be summed up as follows:

1) For flexible pavement with typical Michigan pavement structures and material inputs, the sensitivities of distress prediction to weather station variation are different under high and medium traffic level designs. For the heavy traffic level design, AC rutting and total rutting are sensitive to weather station change, while thermal cracking, top-down cracking, bottom-up cracking and IRI are not sensitive to weather station change. For the medium traffic level design, thermal cracking is very sensitive to weather station variation; AC rutting, total rutting and IRI are sensitive to weather station variation; while top-down cracking and bottom-up cracking are not sensitive.

2) For rigid pavement with typical Michigan pavement structures and material inputs, the sensitivities of distress prediction to weather station variation are similar under high and medium traffic level designs. Faulting and IRI are sensitive to weather station change, while thermal cracking is not sensitive to weather station change.




Total Rut
Total rut (in.)
1.2
1.15
1.1
1.05
1
0.95
0.9
0.85
Adrian
Gaylord
Battle Creek
Detroit
Flint
Lansing
Muskegon
Pellston
Trav. City
Detroit
Hancock
Houghton
Kalamzoo
Pontiac
Detroit
Grand Rapids
Benton Harbor
Ann Arbor
Iron Moun.
Fort Wayne, IN
South Bend, IN
Columbus, OH
Defiance, OH
Rhinelander, WI
Ashland, WI
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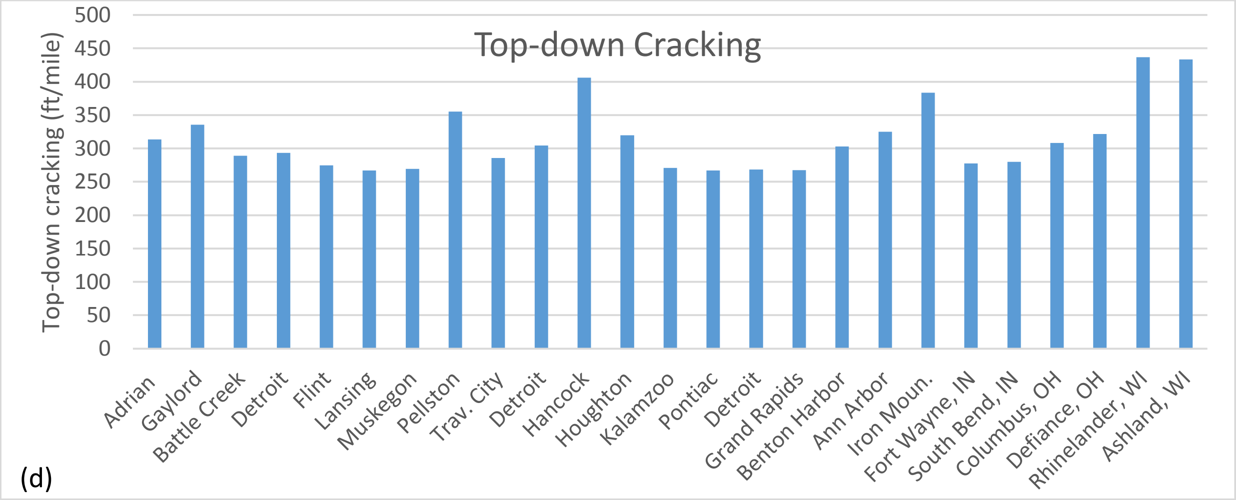
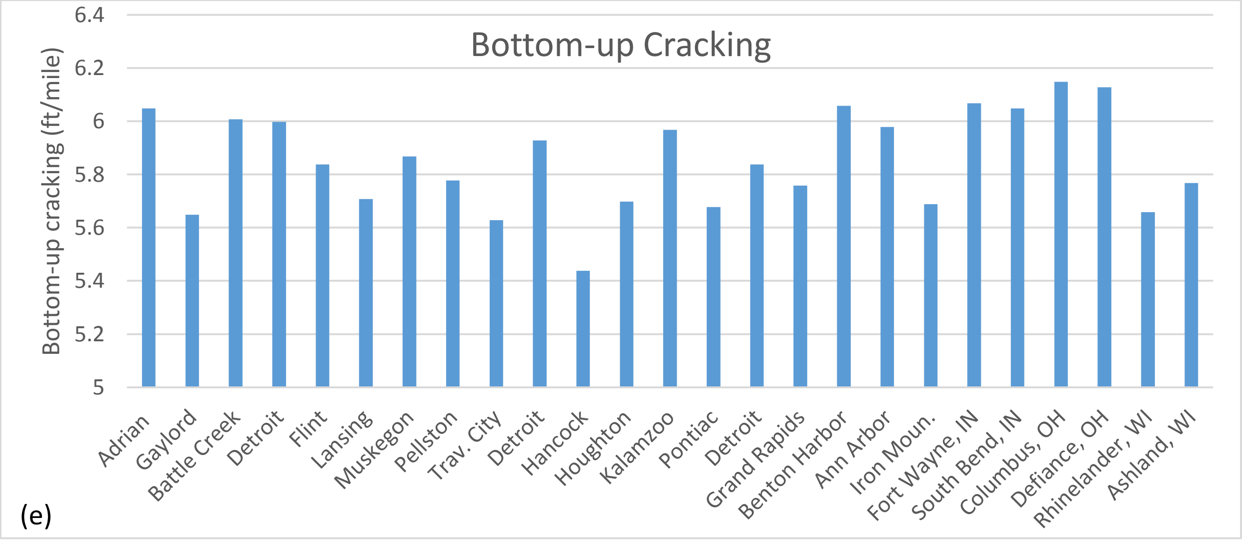

Top-down Cracking
Top-down cracking (ft/mile)
500
450
400
350
300
250
200
150
100
50
0
Adrian
Gaylord
Battle Creek
Detroit
Flint
Lansing
Muskegon
Pellston
Trav. City
Detroit
Hancock
Houghton
Kalamzoo
Pontiac
Detroit
Grand Rapids
Benton Harbor
Ann Arbor
Iron Moun.
Fort Wayne, IN
South Bend, IN
Columbus, OH
Defiance, OH
Rhinelander, WI
Ashland, WI
(d)


Bottom-up Cracking
Bottom-up cracking (ft/mile)
6.4
6.2
6
5.8
5.6
5.4
5.2
5
Adrian
Gaylord
Battle Creek
Detroit
Flint
Lansing
Muskegon
Pellston
Trav. City
Detroit
Hancock
Houghton
Kalamzoo
Pontiac
Detroit
Grand Rapids
Benton Harbor
Ann Arbor
Iron Moun.
Fort Wayne, IN
South Bend, IN
Columbus, OH
Defiance, OH
Rhinelander, WI
Ashland, WI
(e)

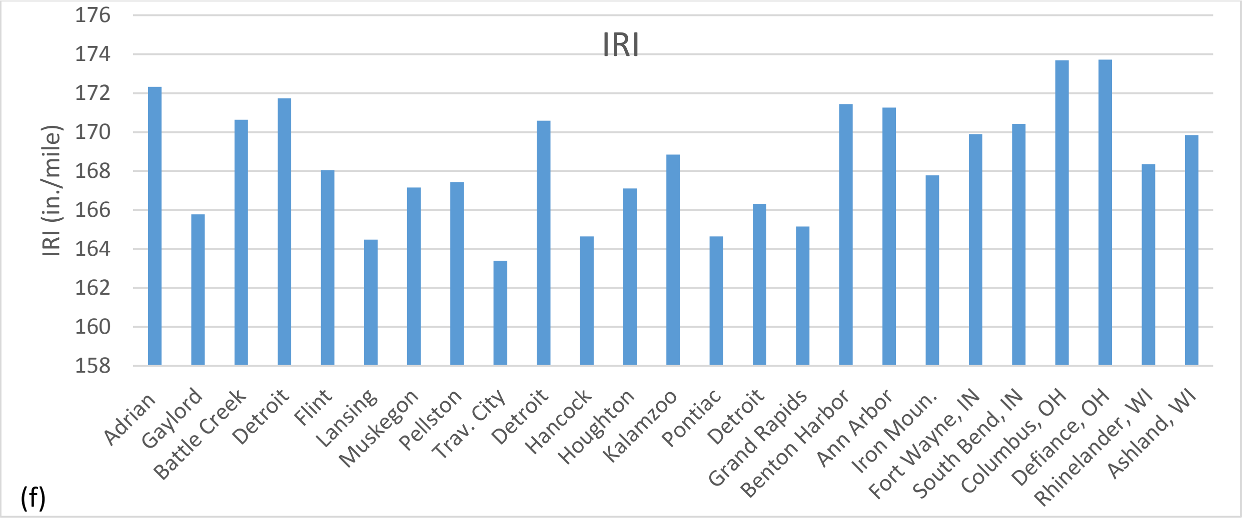
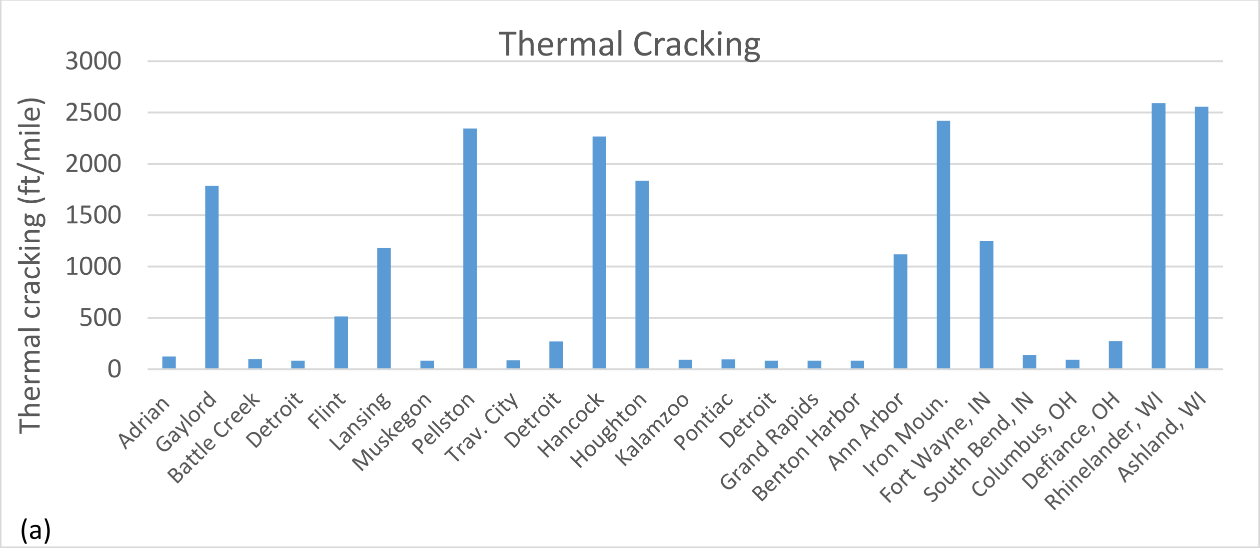
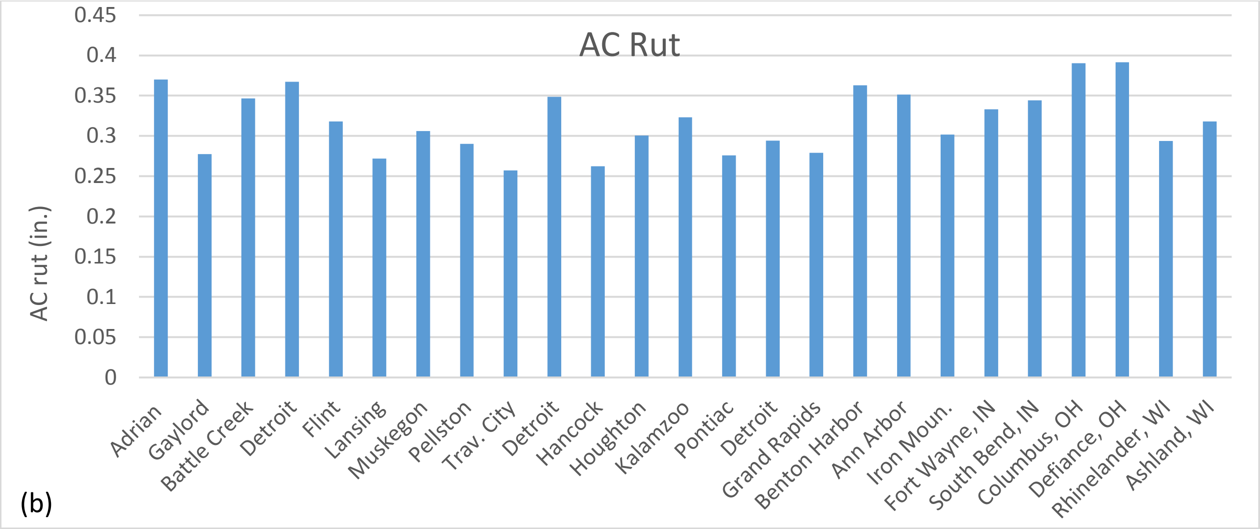
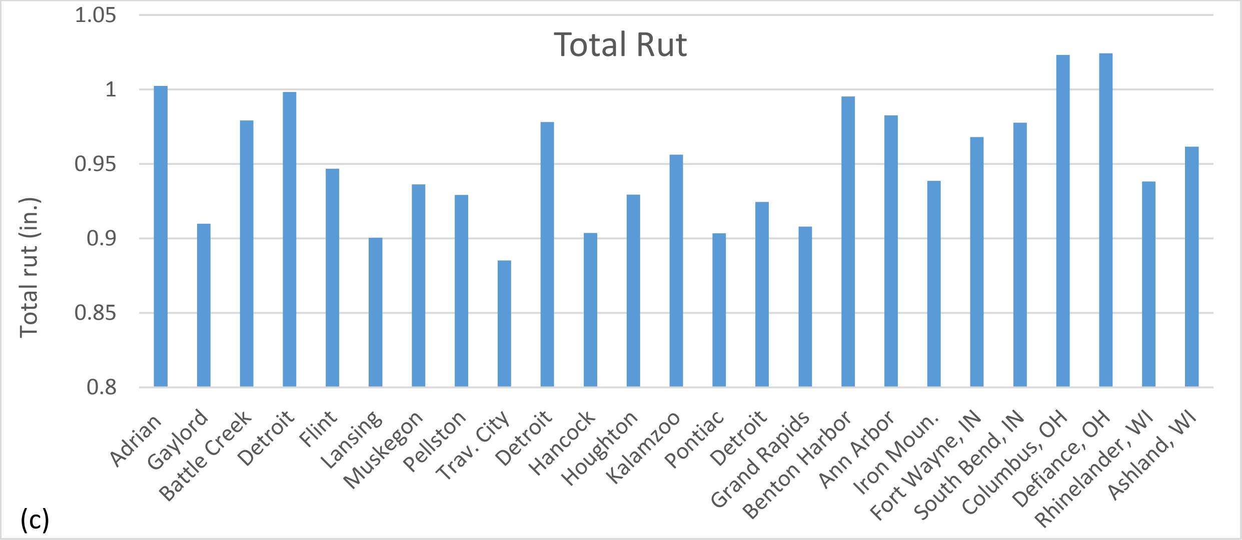


Figure 4-3: Flexible pavement distress prediction results under the heavy traffic level: (a) thermal cracking comparisons; (b) AC rutting comparisons; (c) total rutting comparisons; (d) top-down cracking comparisons; (e) bottom-up cracking comparisons; and (f) IRI comparisons

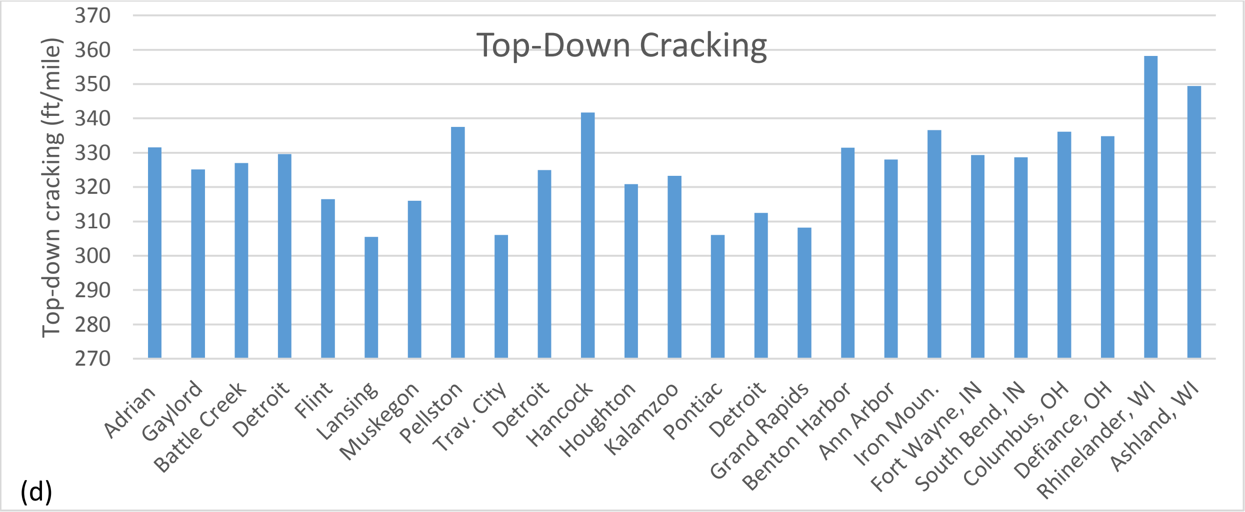



AC Rut
AC rut (in.)
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Adrian
Gaylord
Battle Creek
Detroit
Flint
Lansing
Muskegon
Pellston
Trav. City
Detroit
Hancock
Houghton
Kalamzoo
Pontiac
Detroit
Grand Rapids
Benton Harbor
Ann Arbor
Iron Moun.
Fort Wayne, IN
South Bend, IN
Columbus, OH
Defiance, OH
Rhinelander, WI
Ashland, WI

(b)


Total Rut
Total rut (in.)
1.05
1
0.95
0.9
0.85
0.8
Adrian
Gaylord
Battle Creek
Detroit
Flint
Lansing
Muskegon
Pellston
Trav. City
Detroit
Hancock
Houghton
Kalamzoo
Pontiac
Detroit
Grand Rapids
Benton Harbor
Ann Arbor
Iron Moun.
Fort Wayne, IN
South Bend, IN
Columbus, OH
Defiance, OH
Rhinelander, WI
Ashland, WI

(c)


Top-Down Cracking
Top-down cracking (ft/mile)
370
360
350
340
330
320
310
300
290
280
270
Adrian
Gaylord
Battle Creek
Detroit
Flint
Lansing
Muskegon
Pellston
Trav. City
Detroit
Hancock
Houghton
Kalamzoo
Pontiac
Detroit
Grand Rapids
Benton Harbor
Ann Arbor
Iron Moun.
Fort Wayne, IN
South Bend, IN
Columbus, OH
Defiance, OH
Rhinelander, WI
Ashland, WI

(d)

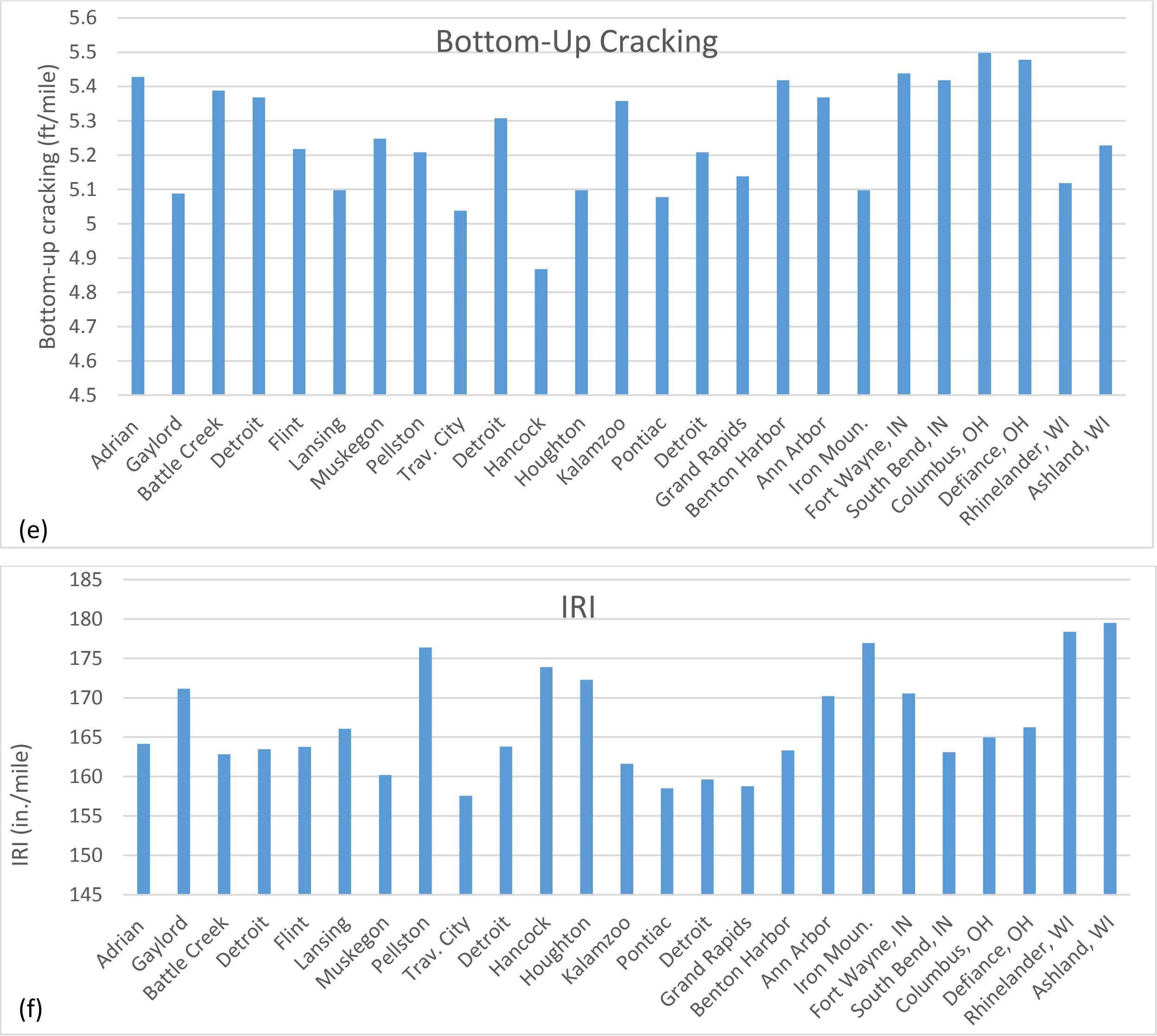


Figure 4-4: Flexible pavement distress prediction results under the medium traffic level: (a) (a) thermal cracking comparisons; (b) AC rutting comparisons; (c) total rutting comparisons; (d) top-down cracking comparisons; (e) bottom-up cracking comparisons; and (f) IRI comparisons

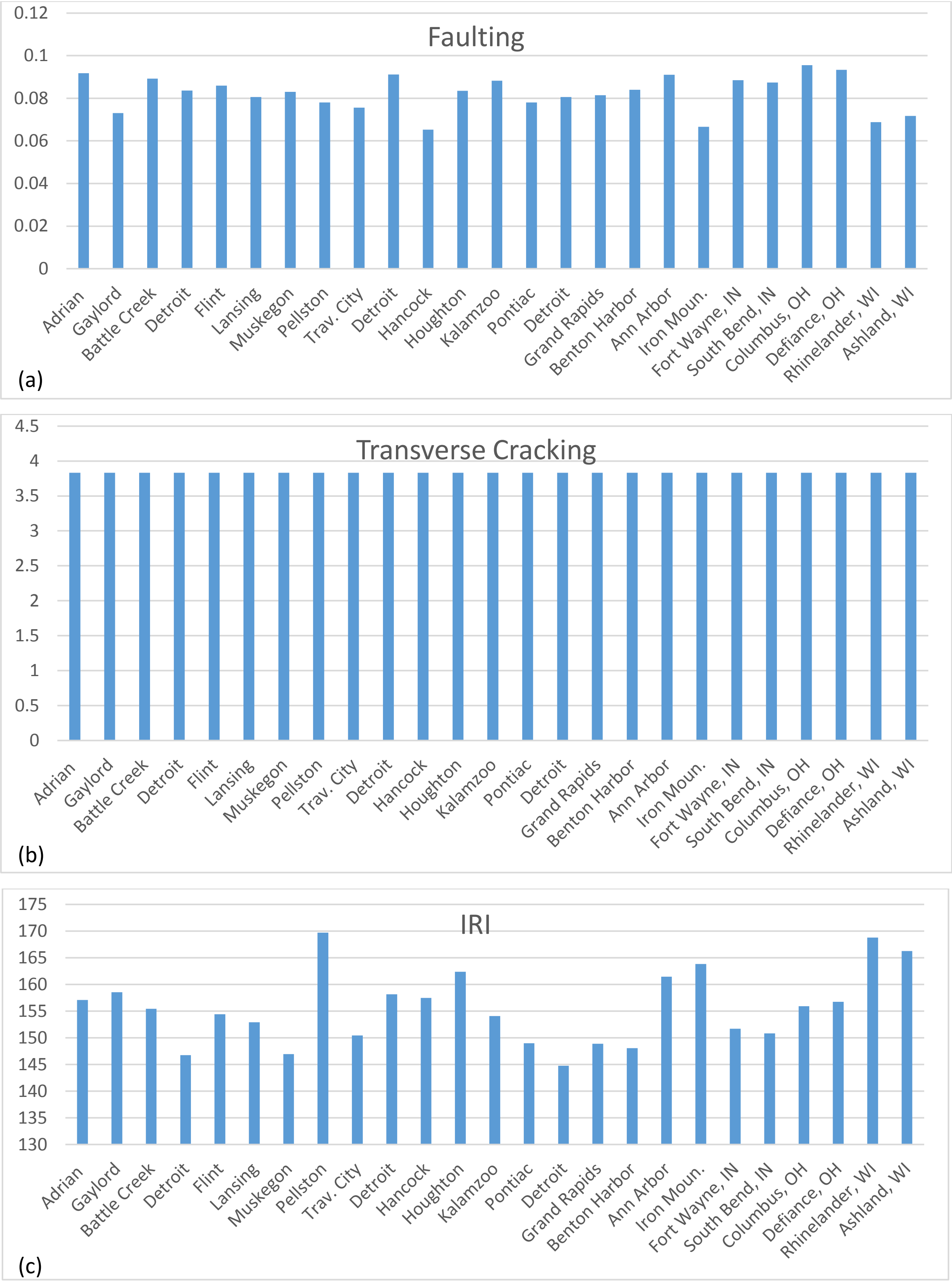


Figure 4-5: Rigid pavement distress prediction results under the heavy traffic level: (a) faulting comparisons; (b) transverse cracking comparisons; and (c) IRI comparisons

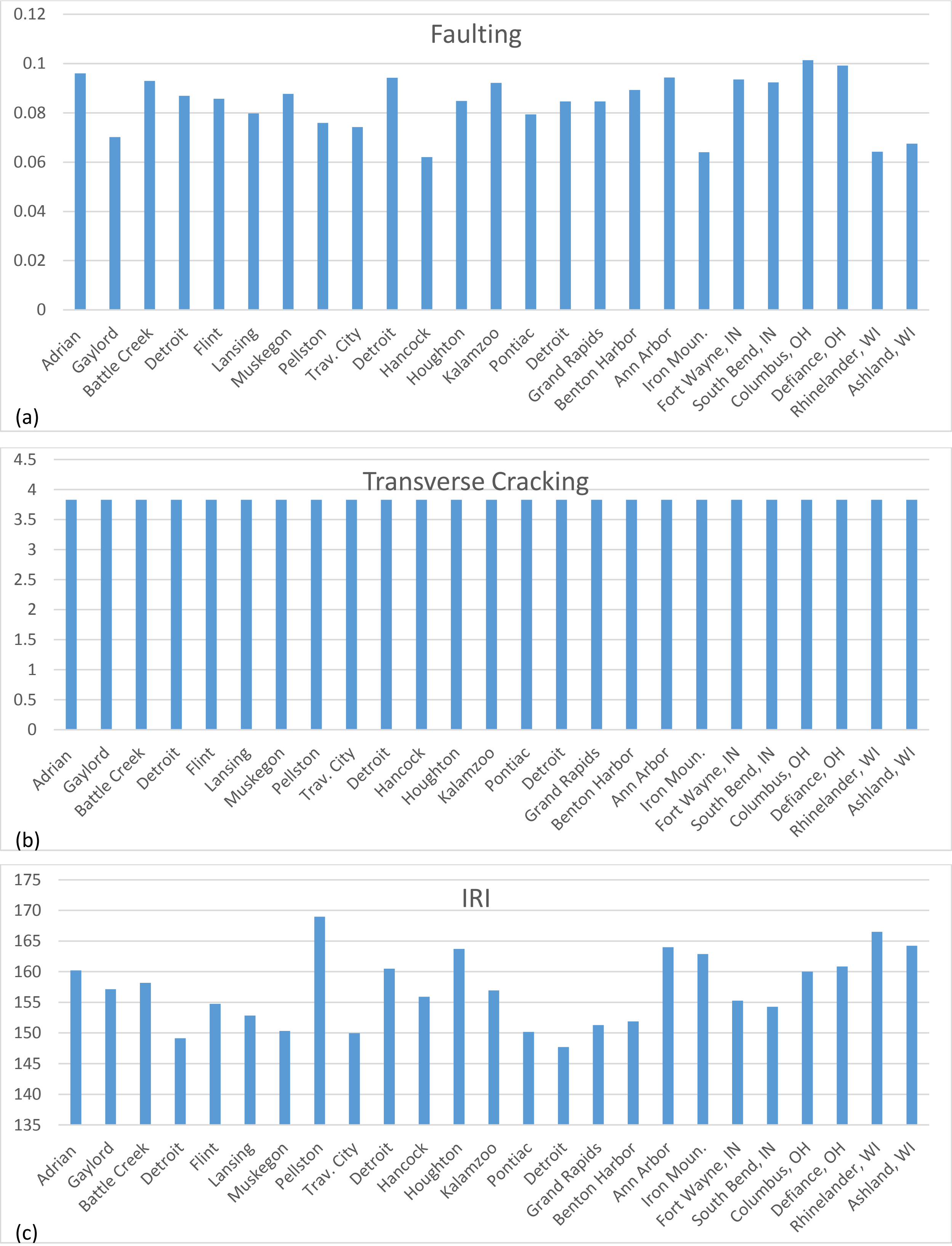


Figure 4-6: Rigid pavement distress prediction results under the medium traffic level: (a) faulting comparisons; (b) transverse cracking comparisons; and (c) IRI comparisons

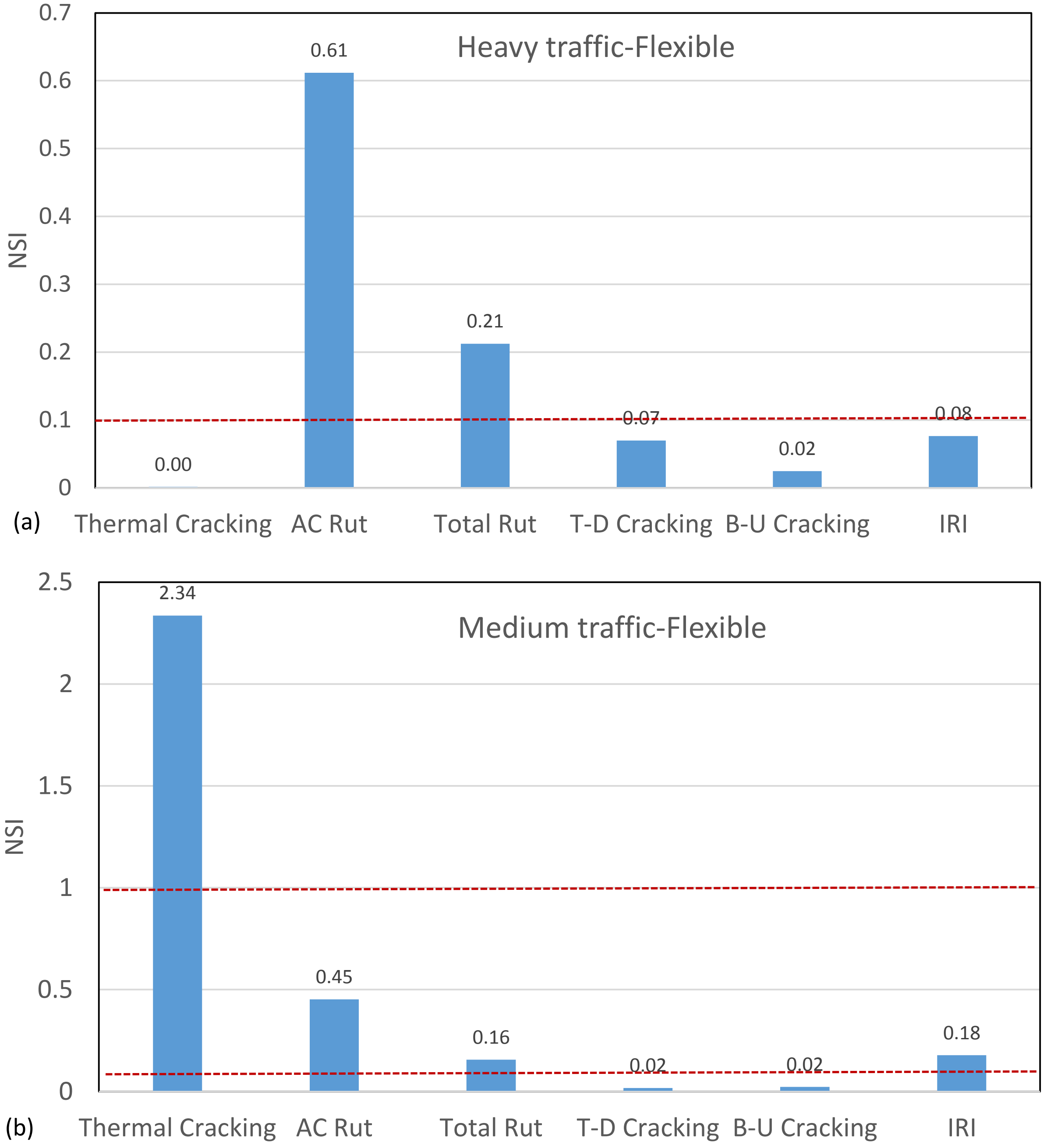


Figure 4-7: NSI of distress predictions to weather station change of flexible pavement: (a) under heavy traffic level; and (b) under medium traffic level

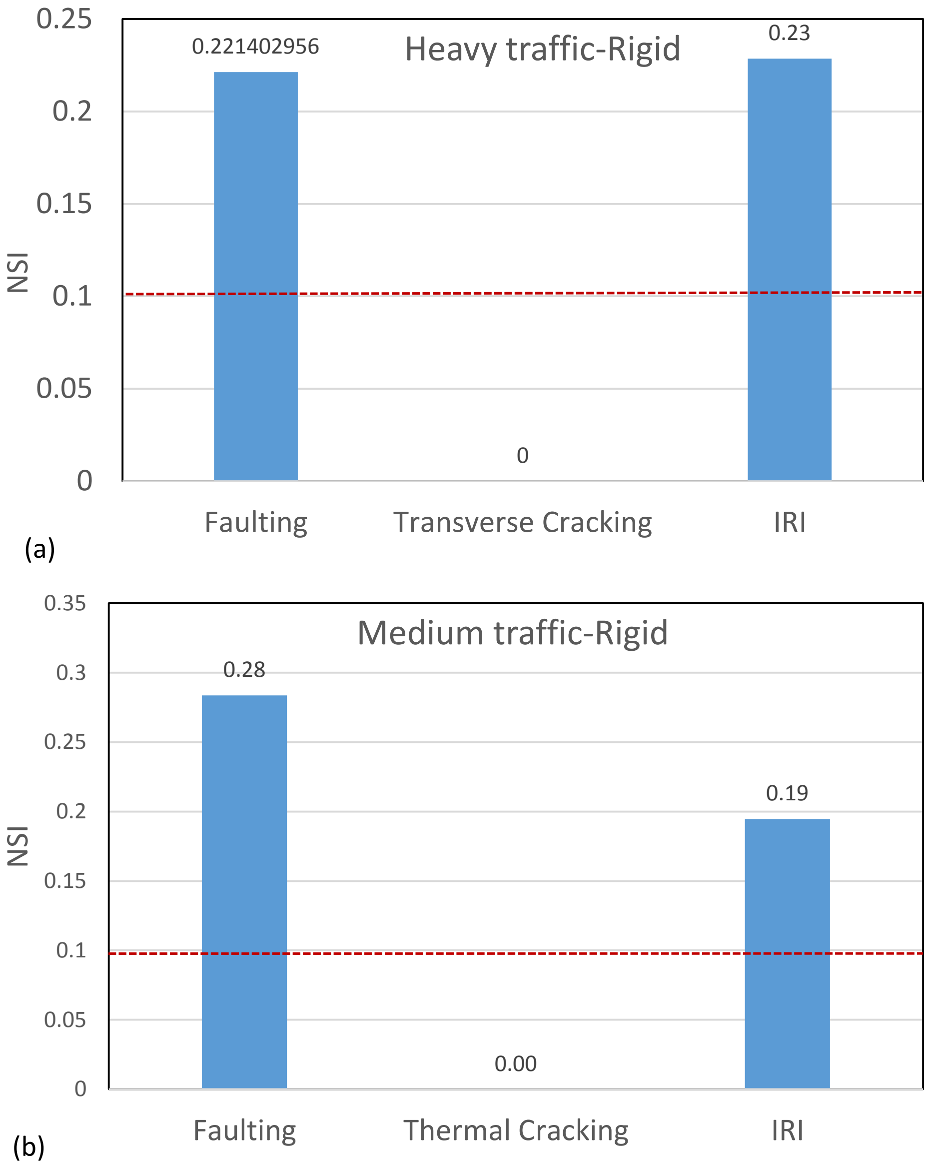


Figure 4-8: NSI of distress predictions to weather station change of rigid pavement: (a) under heavy traffic level; and (b) under medium traffic level

4.4 Sensitivity to individual variable change

The experience in some other states is that changes in climatic variables can have significant effects on the design results of the PMED software [5, 13]. In this section, the research team aims to find out if these individual climatic variables have significant effects on the design results.

Two pavement types (flexible and rigid) and two traffic levels (medium and heavy) were used for this purpose. The general inputs of the design are shown in Table 4-1 to Table 4-3. The weather stations used for this analysis are the same as in Figure 4-2, and the NSI will again be used as a measure of sensitivity [5]. The following steps were carried out to evaluate the sensitivity of the design results to individual variable change:

1) Select the input parameters. The five climatic variables are the inputs. Each time only one variable is adjusted while all others are fixed.
2) Select the representative weather stations. Representative stations are selected from the 24 weather stations in Michigan in order to reduce computation time. The selection of the representative stations follows two criteria: 1) they should cover the coldest, hottest and moderate regions in Michigan; and 2) they should geographically represent regions throughout the state where pavement designs may differ. According to the sensitivity analysis results, Iron Mountain and Pellston exhibited the highest thermal cracking, while Gaylord and Lansing showed moderate thermal cracking. Adrian and Hancock showed the highest and lowest rutting, respectively. Pellston is close to Gaylord and shows similar thermal cracking as Iron Mountain, so Pellston was not considered as a representative station. Six representative stations are selected based on the geographical and climatic consideration: Hancock, Iron Mountain, Muskegon, Gaylord, Lansing, and Adrian. The six stations are shown in Figure 4-9.

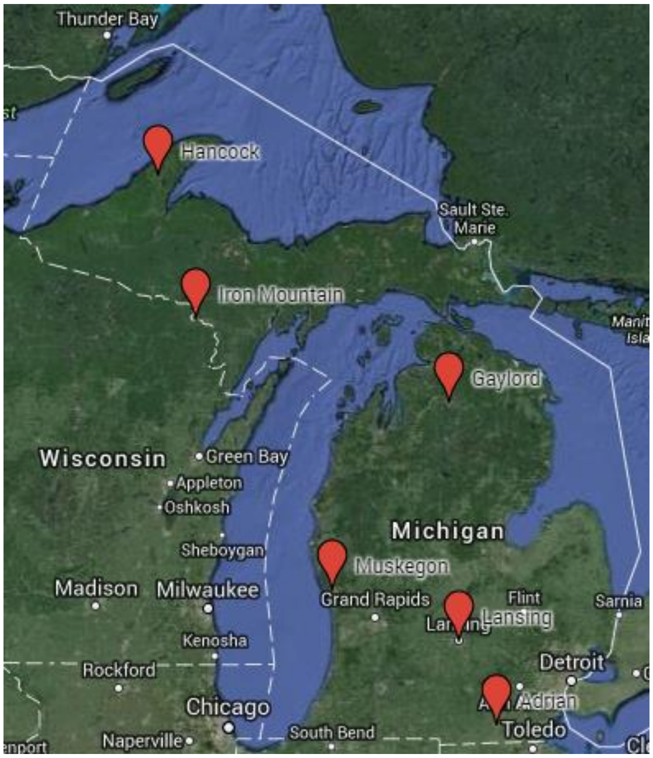


Figure 4-9: Representative stations for the sensitivity analysis

3) Adjust the climatic variable values. The sensitivity analysis is conducted by changing the individual variable value--for instance, increasing or decreasing each temperature data point in the current climate data file by 10%. For other variables which have lower or upper limits, addition or subtraction may change the variables beyond their limits. In this case, the data is reset as the limit value to make it realistic. Then, the actual average change is calculated, which will be used to calculate the sensitivity index. The reason a 10% change was used rather than 20% or 50% change is that a 10% change can reflect the sensitivity of distress predictions to the reasonable changes in current climate conditions.
4) Run the software and obtain the distress results using the original and modified climatic files. As previously mentioned, two types of pavement types and two traffic levels are used.
5) Calculate the NSI and determine the threshold value, following the approach of Schwartz et al. [35]. Then the average NSI of all the selected stations is calculated to determine the sensitivity.

6) Determine if the design results are sensitive to a certain climatic variable. The NSI can provide the thresholds of sensitive, very sensitive and hypersensitive. With the combination of the annual climatic change, one can determine if the design results are sensitive to a certain variable given design inputs for Michigan.

The sensitivity to each variable was analyzed through adjusting the current variable value as follows, with NSI calculations following Equation (1):

Temperature: According to the NSI determination developed by Schwartz et al. [35], a percent change can be used to evaluate the sensitivity. However, temperature has both positive and negative values in Fahrenheit. To address this concern, the adjustment of a negative value was based on an absolute value. For instance, for temperature values of -10 ℉ and 20 ℉, the temperatures after an increase of 10% are -9 ℉ and 22 ℉, respectively. For the sensitivity analysis, each temperature value was increased and decreased by 10% to create two additional climatic files. The NSI values from the 10% increase and 10% decrease were calculated separately. Afterward, the final NSI was calculated as the average value of the two NSI values.

Wind speed: Sensitivity to wind speed was analyzed through adjusting current wind speed by a percentage. Each wind speed data point was increased and decreased by 10% to create two new files. All four other variables were fixed. The NSI values from the 10% increase and 10% decrease were calculated separately. Afterward, the final NSI was calculated as the average value of the two NSI values.

Percent sunshine: The sensitivity to wind speed was analyzed through adjusting current percent sunshine by a percentage. Each wind speed data point was first increased and decreased by 10% to create two new files. However, since percent sunshine has a cap, the values beyond the cap were reset as 100%. Then, the actual average percent sunshine change was recalculated. The final NSI was obtained by a weighted average of the two NSI values calculated from the increase and decrease.

Precipitation: The sensitivity to precipitation was analyzed using the same method as the wind speed. Each precipitation data point was increased and decreased by 10% to create two new files. All other variables were fixed. The NSI calculation was the same as that above.

Relative humidity: The relative humidity data adjustment is the same as that of the percent sunshine.

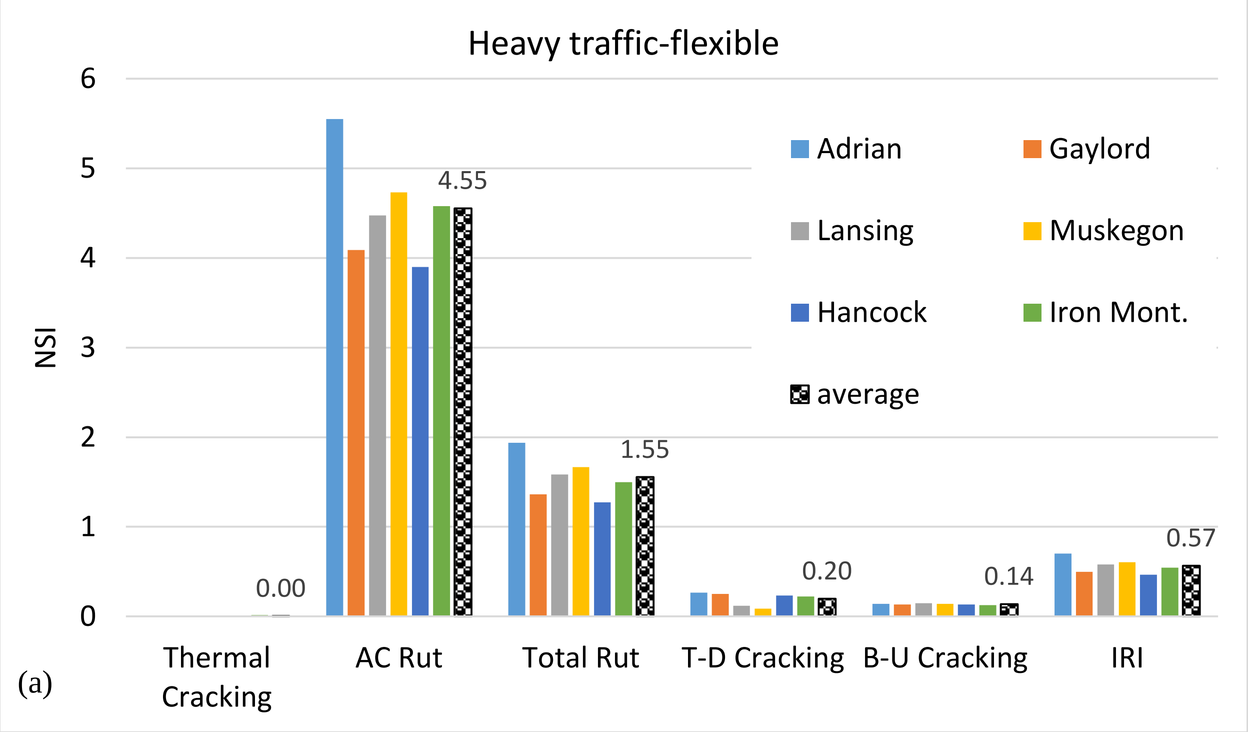
4.4.1 Distress prediction sensitivity to temperature

Figure 4-10 shows the NSI values of predicted distress due to temperature changes for the flexible pavement designs under high and medium traffic levels. The average NSI values of AC rut and total rut are higher than 1.0 under both high and medium traffic levels, indicating that predictions of these two distresses are very sensitive to temperature. The NSI values of top-down cracking, bottom-up cracking and IRI under both high and medium traffic levels are higher than or very close to 0.1 (the NSI of the top-down cracking under medium traffic is 0.09). This indicates that the predictions of top-down cracking, bottom-up cracking and IRI are sensitive to temperature change for flexible pavement. In terms of the thermal cracking, the NSI values under heavy traffic and medium traffic are very different. NSI values of all six representative stations are zero in the heavy traffic design. The reason of this is that the typical flexible pavement design in Michigan for heavy traffic roads is adequately designed for thermal cracking. Since the primary goal of the design is to reduce traffic related distresses, it is very possible that the thermal cracking is not a critical issue for designs with thick HMA layers and superior HMA properties. In this case, the effect of temperature change on thermal cracking cannot be reflected in the heavy traffic pavement designs. However, for the medium traffic design, both the thinner HMA layer and less compliant HMA properties at cold temperatures make the distress predictions more susceptible to thermal cracking as compared to the heavy traffic design. In this regard, the effect of temperature change on thermal cracking predictions is easier to observe. It turns out that the thermal cracking prediction is very sensitive to temperature change in the medium traffic design.

Figure 4-11 shows the NSI values of distress predictions with temperature change for the rigid pavement designs under high and medium traffics. Three distresses were predicted: faulting, transverse cracking and IRI. It was found that the NSI values in the heavy traffic and medium traffic designs exhibited similar patterns. The NSI values of faulting and IRI predictions are between 0.1 and 1, indicating the predictions of these two distresses are sensitive to temperature change. On the other hand, the NSI values of transverse cracking prediction are 0 for both the high and medium traffic designs because the transverse cracking did not change at all after the temperature increase or decrease. Similar to the thermal cracking prediction of the flexible pavement design for heavy traffic roads, this indicates that the transverse cracking of typical rigid pavement design in Michigan under high and medium traffics is not an issue according to the PMED predictions, and the transverse cracking prediction is not sensitive to temperature. This may not be the case when designs are closer to the failure threshold through reduced PCC thickness, reduced PCC strength, increased built-in curl, etc. The sensitivity of distress predictions to temperature change for flexible and rigid pavement designs is summarized in Table 4-6. The detailed values of the distress predictions can be found in Appendix F.

Table 4-6: Summary of distress prediction sensitivity to temperature change

Distresses	**Flexible pavement**		**Distresses**	**Rigid pavement**
	Heavy traffic	**Medium traffic**		**High/Medium traffic**
Thermal Cracking	Not sensitive	Very sensitive	**Faulting**	Sensitive
AC Rutting	Very sensitive			
Total Rutting	Very sensitive		**Transverse Crack**	Not sensitive
Top-down Cracking	Sensitive			
Bottom-up Cracking	Sensitive		**IRI**	Sensitive
IRI	Sensitive			



(a)

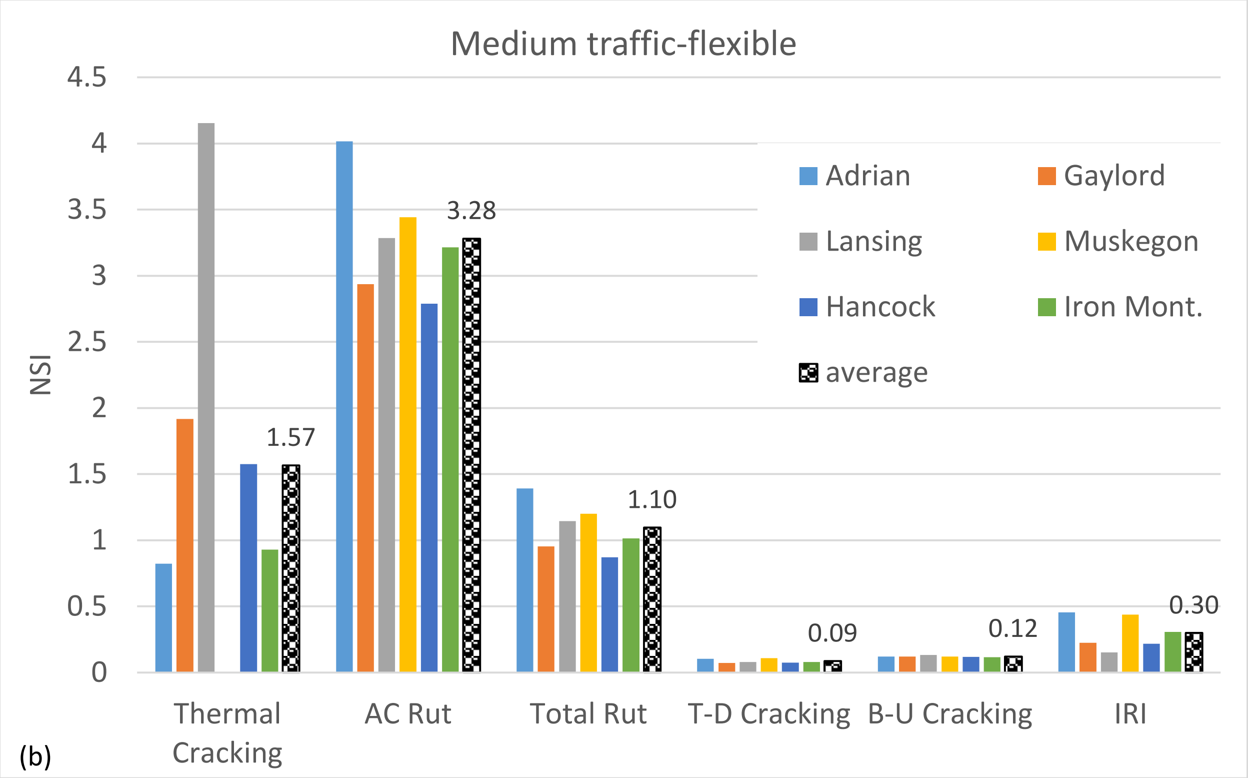
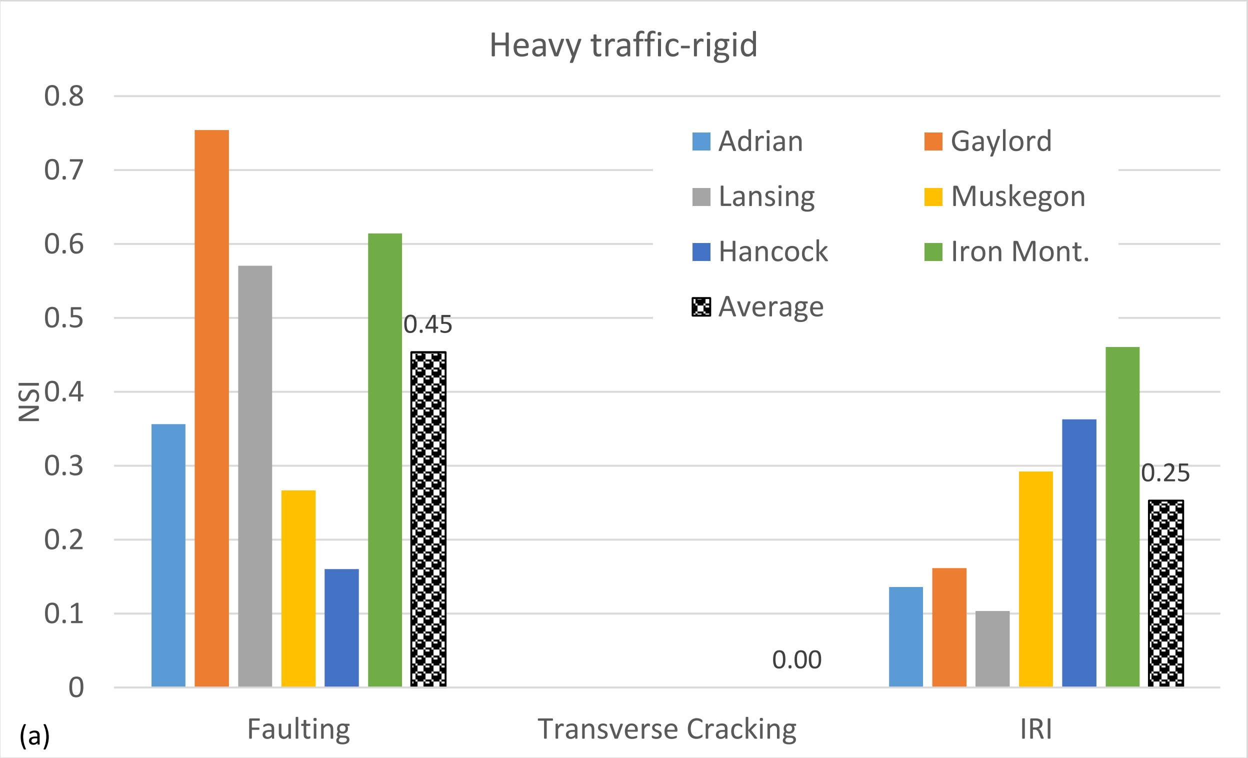


Figure 4-10: The NSI values of distress predictions with temperature change for flexible pavement design: (a) heavy traffic design; and (b) medium traffic design



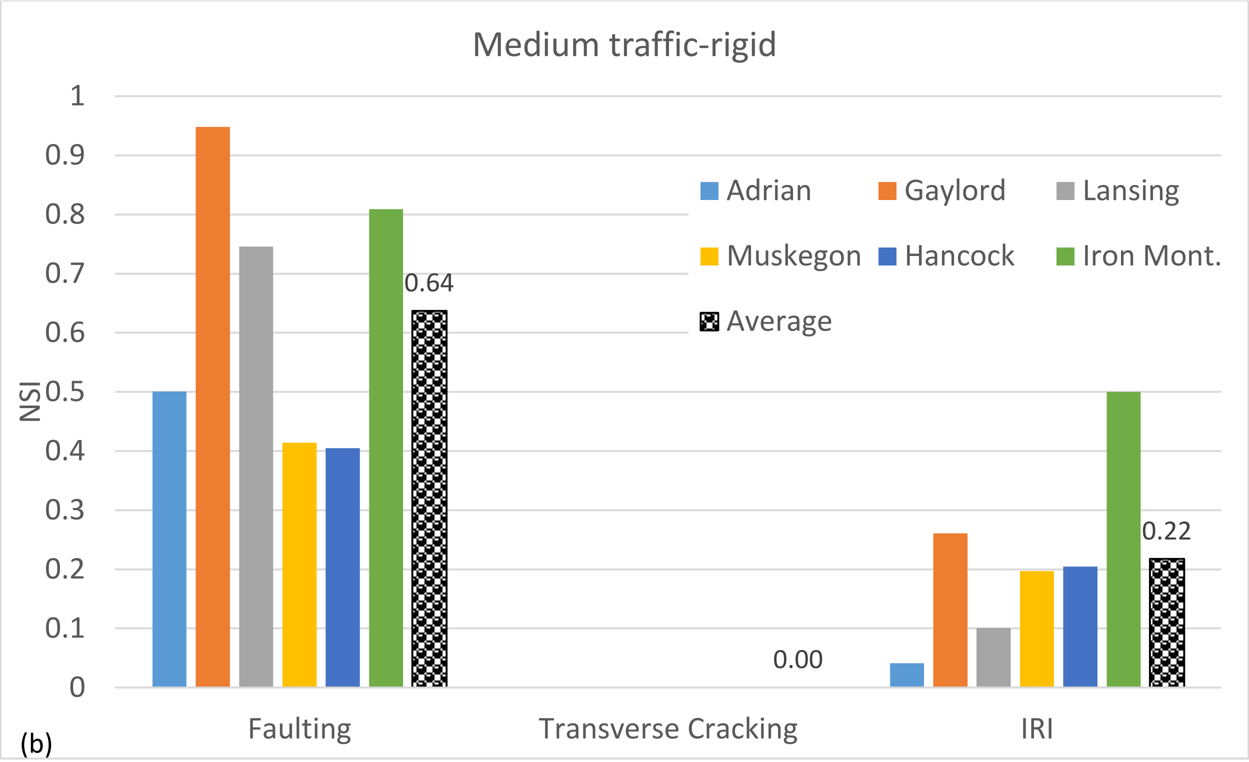


Figure 4-11: The NSI values of distress predictions with temperature change for rigid pavement designs: (a) heavy traffic design; and (b) medium traffic design

4.4.2 *Distress prediction sensitivity to wind speed*

Figure 4-12 displays the NSI of distress predictions for flexible pavement due to changes in wind speed. In the design for heavy traffic conditions, the average NSI for thermal cracking is zero, meaning that the thermal cracking predictions are the same after the wind speed is increased or reduced by 10%. This is due to the high thickness and superior performance of the HMA layers used in the heavy traffic design. The average NSI of AC rut and total rut are 0.52 and 0.18, respectively, indicating that these rutting predictions are sensitive to wind speed change. In fact, the NSI values for all six stations are higher than 0.1. The main reason for this is that wind can reduce the pavement surface temperature when the air temperature is high in summer. Thus, the rutting can be reduced if the wind speed increased, which is shown in the results in Appendix F. The predictions of top-down cracking, bottom-up cracking and IRI were not sensitive to wind speed, with the corresponding NSI values less than 0.1. For the flexible pavement design for medium traffic, similar to the heavy traffic design, AC rutting and total rutting are sensitive to wind speed, while the top-down cracking, bottom-up cracking, and IRI are not. It was found that the average NSI for thermal cracking is 0.25, indicating sensitivity to wind speed change. A closer look at the results indicated that the NSI variation of thermal cracking among the six stations is somewhat high. This may be due to the very different climate conditions among the six stations.

Figure 4-13 shows the NSI for distress predictions due to wind speed changes for rigid pavement designs. For the faulting predictions, five out of the six NSI values are lower than 0.1 for both the heavy traffic and medium traffic designs, indicating that faulting prediction is overall not sensitive to wind speed. All of the six NSI values for IRI are lower than 0.1, and all of the NSI values for transverse cracking are zero, indicating that these distress predictions are not sensitive to wind speed either. This supports the findings of Qin and Hiller [36] that the EICM model is quite insensitive to wind speed for convection cooling in comparison to other temperature prediction models.

Table 4-7: Summary of distress prediction sensitivity to wind speed

Distresses	**Flexible pavement**		**Distresses**	**Rigid pavement**
	Heavy traffic	**Medium traffic**		**High/Medium traffic**
Thermal Cracking	Not sensitive	Sensitive	**Faulting**	Not sensitive
AC Rutting	Sensitive			
Total Rutting	Sensitive		**Transverse Crack**	
Top-down Cracking	Not sensitive			
Bottom-up Cracking	Not sensitive		**IRI**	
IRI	Not sensitive			

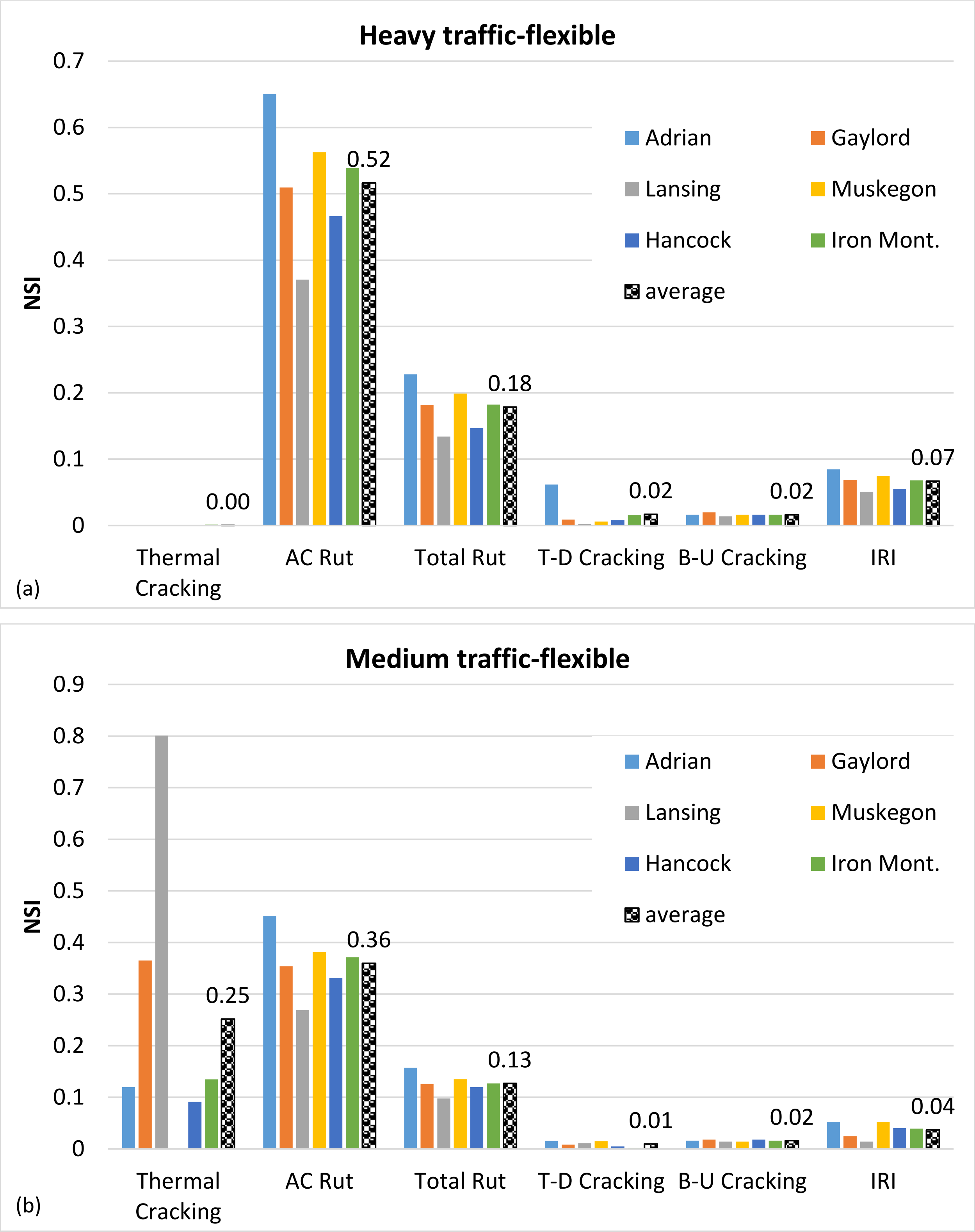


Figure 4-12: The NSI values of distress predictions due to wind speed change for flexible pavement design: (a) heavy traffic design; and (b) medium traffic design

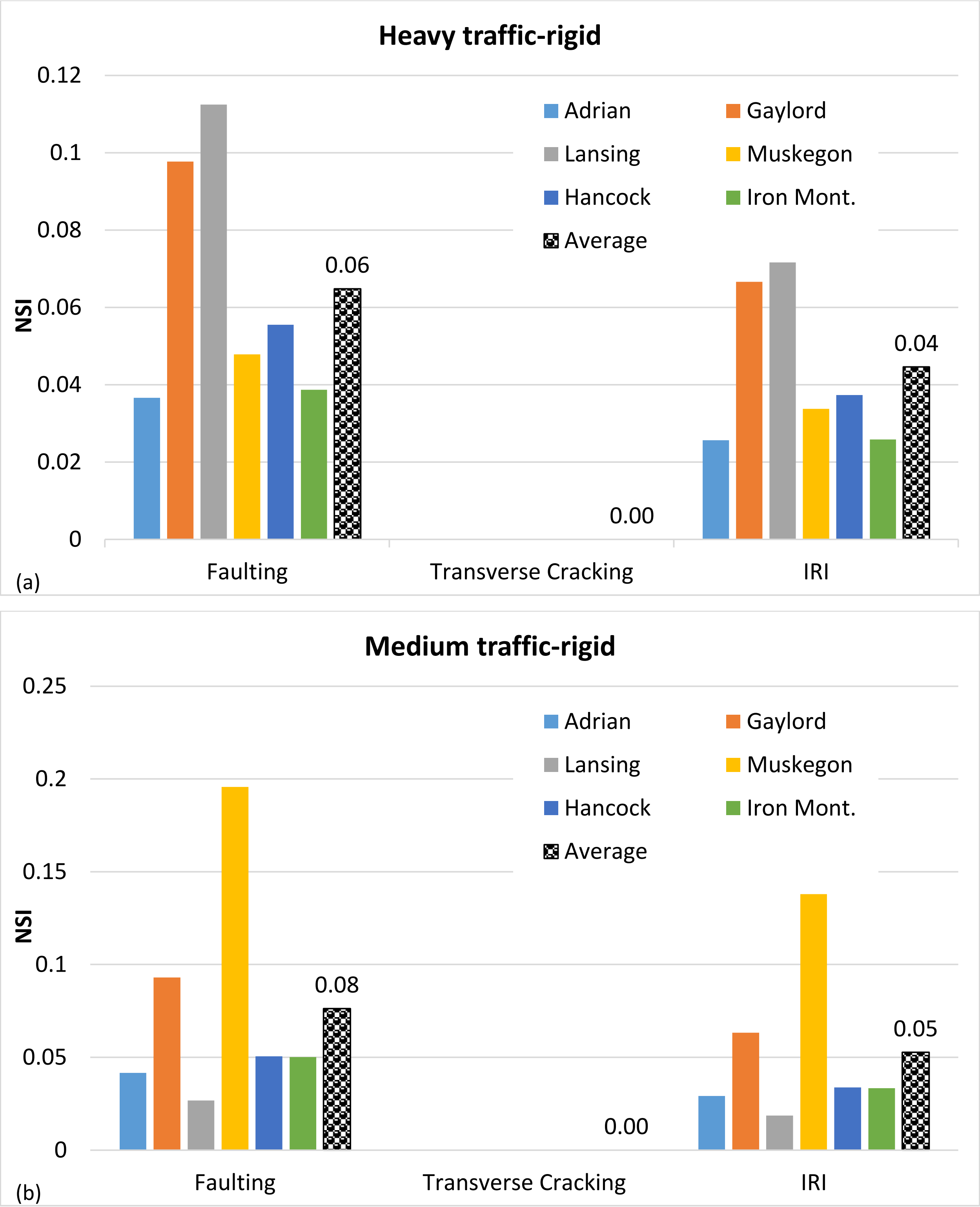
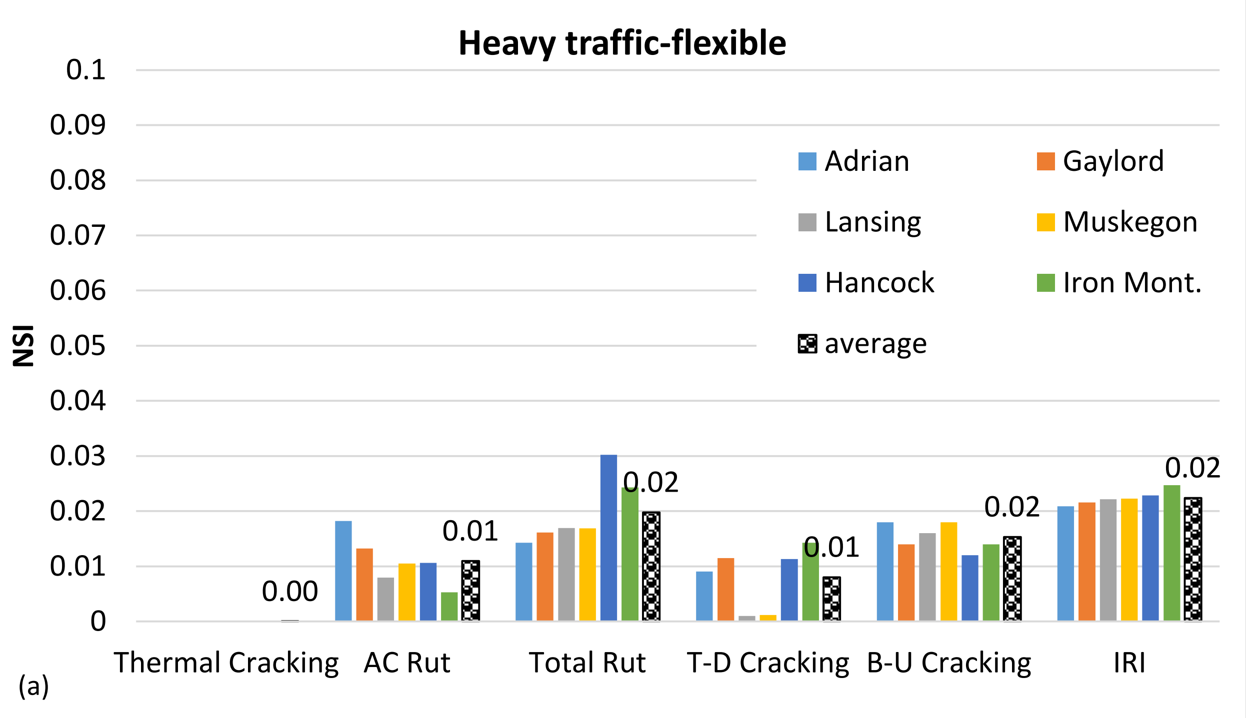


Figure 4-13: The NSI values of distress predictions due to wind speed change for rigid pavement designs: (a) heavy traffic design; and (b) medium traffic design

4.4.3 *Distress prediction sensitivity to precipitation*

Figure 4-14 displays the NSI of distress predictions due to precipitation changes for flexible pavement. It was observed that most of the NSI values were far lower than 0.1, indicating that the distress predictions are not sensitive to precipitation. It is interesting to note that the NSI of thermal cracking predictions in Hancock and Iron Mountain are higher than others. The reason for this may be the lower precipitation in Hancock and Iron Mountain. Precipitation can affect the infiltration throughout the pavement and therefore increase the material degradation. The EICM mainly predicts the temperature and moisture throughout the pavement. Although precipitation is not considered in the heat transfer prediction, the moisture throughout the pavement structure may have impacts on performance of base and subbase. The average annual precipitations in Hancock and Iron Mountain are 21.5 and 22.5 inches, respectively, while in Adrian, Gaylord, Lansing, Muskegon, and Iron Mountain are 28.9, 27.3, 28.8, and 30.5 inches, respectively. Figure 4-15 shows the NSI of distress predictions due to precipitation changes for rigid pavement. It was also found that none of the NSI values are higher than 0.1. This means that the distress prediction results are not sensitive to precipitation for either flexible or rigid pavement designs.



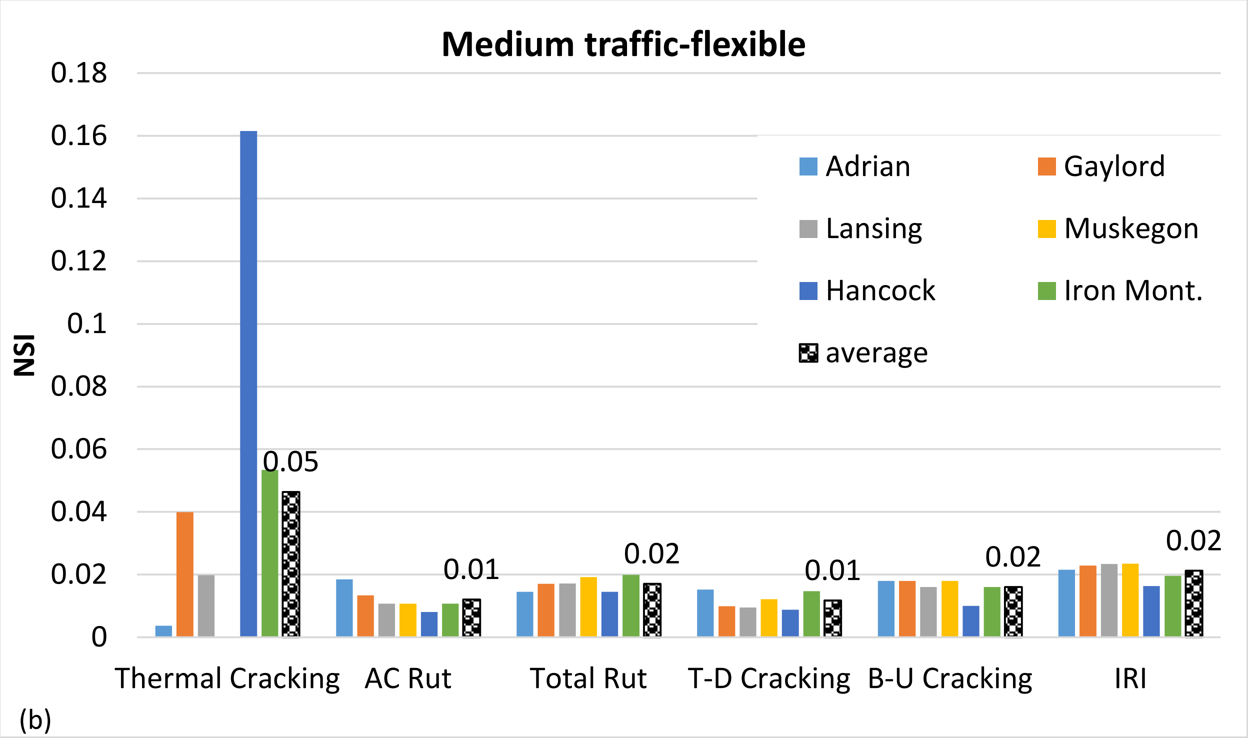
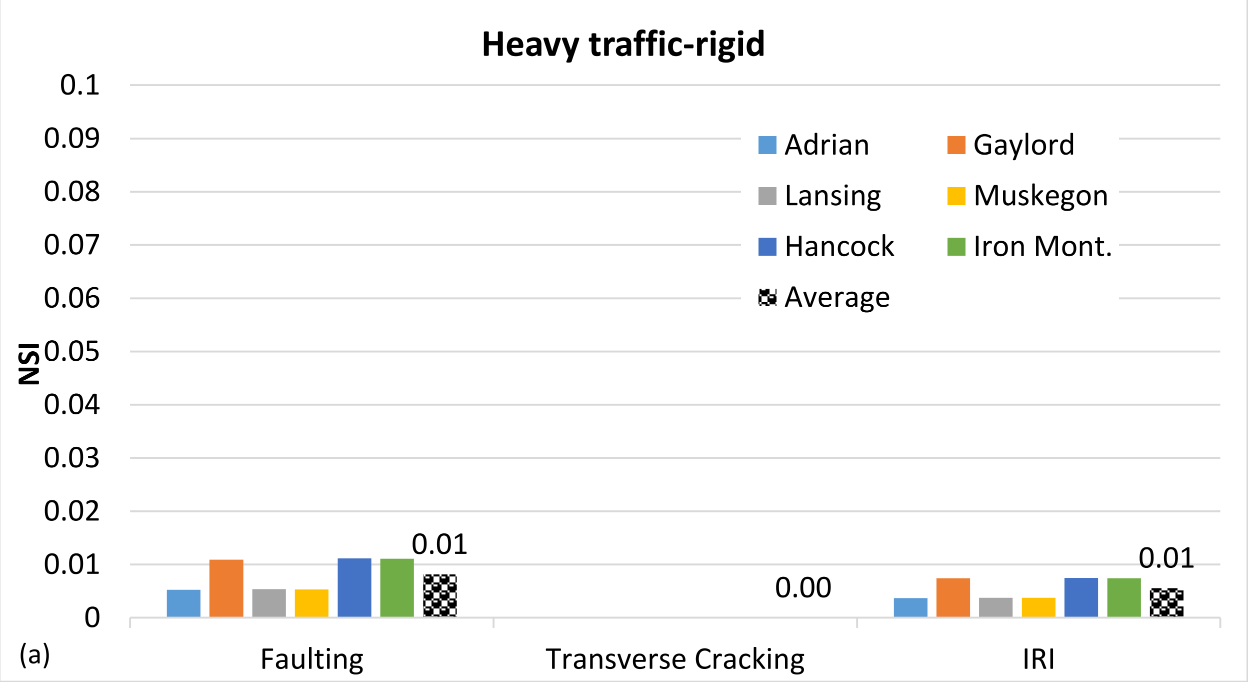


Figure 4-14: The NSI values of distress predictions due to precipitation change for flexible pavement design: (a) heavy traffic design; and (b) medium traffic design



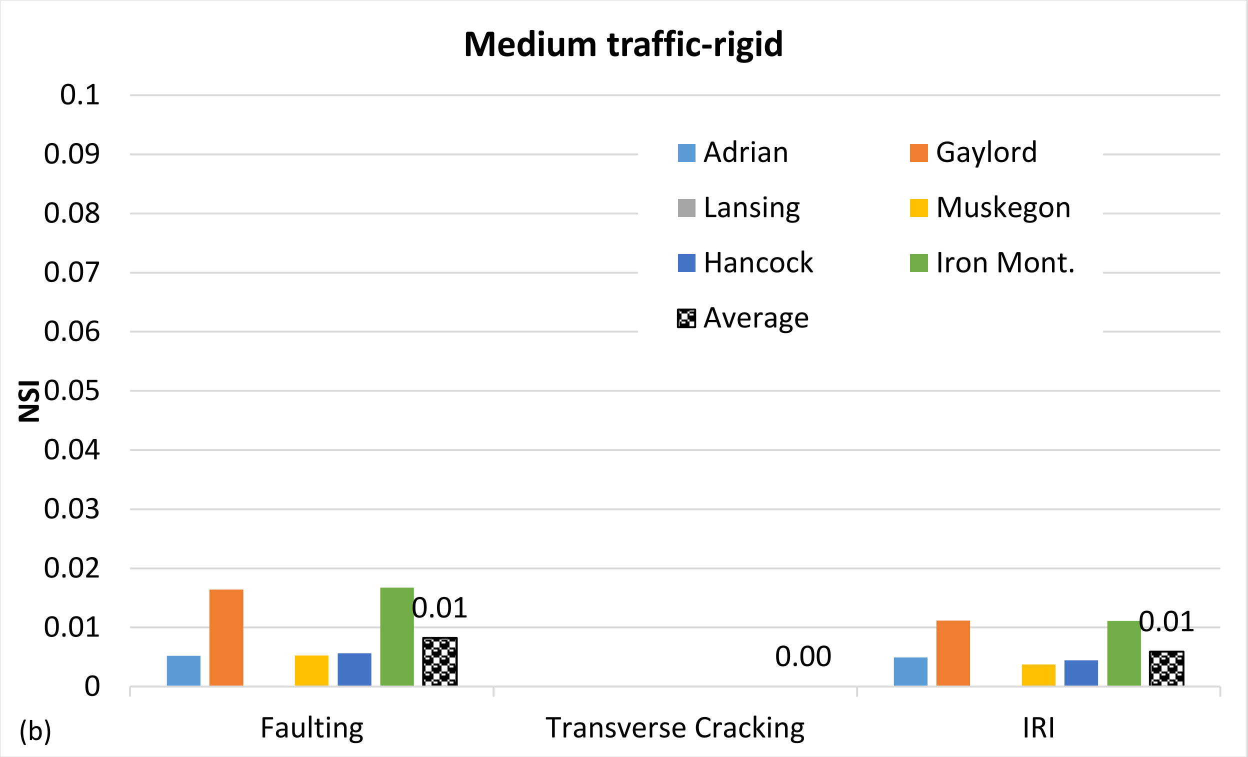


Figure 4-15: The NSI values of distress predictions due to precipitation change for rigid pavement designs: (a) heavy traffic design; and (b) medium traffic design

4.4.4 Distress prediction sensitivity to percent sunshine

Figure 4-16 and Figure 4-17 show the NSI values of distress predictions due to changes in percent sunshine for flexible pavement and rigid pavement designs, respectively. In the flexible pavement design, all of the NSI values are far lower than 0.1 except for the NSI of thermal cracking prediction. Although one out of the six NSI values for thermal cracking prediction is higher than 0.1, the average NSI value of thermal cracking is only 0.07. This indicates the thermal cracking is, overall, not sensitive to percent sunshine. The reason why the NSI of thermal cracking prediction in Hancock is much higher than others is still unknown. In the rigid pavement design, all of the NSI values are far lower than 0.1 for both the heavy traffic and medium traffic designs, meaning the distress predictions in rigid pavement designs are not sensitive to changes in percent sunshine.

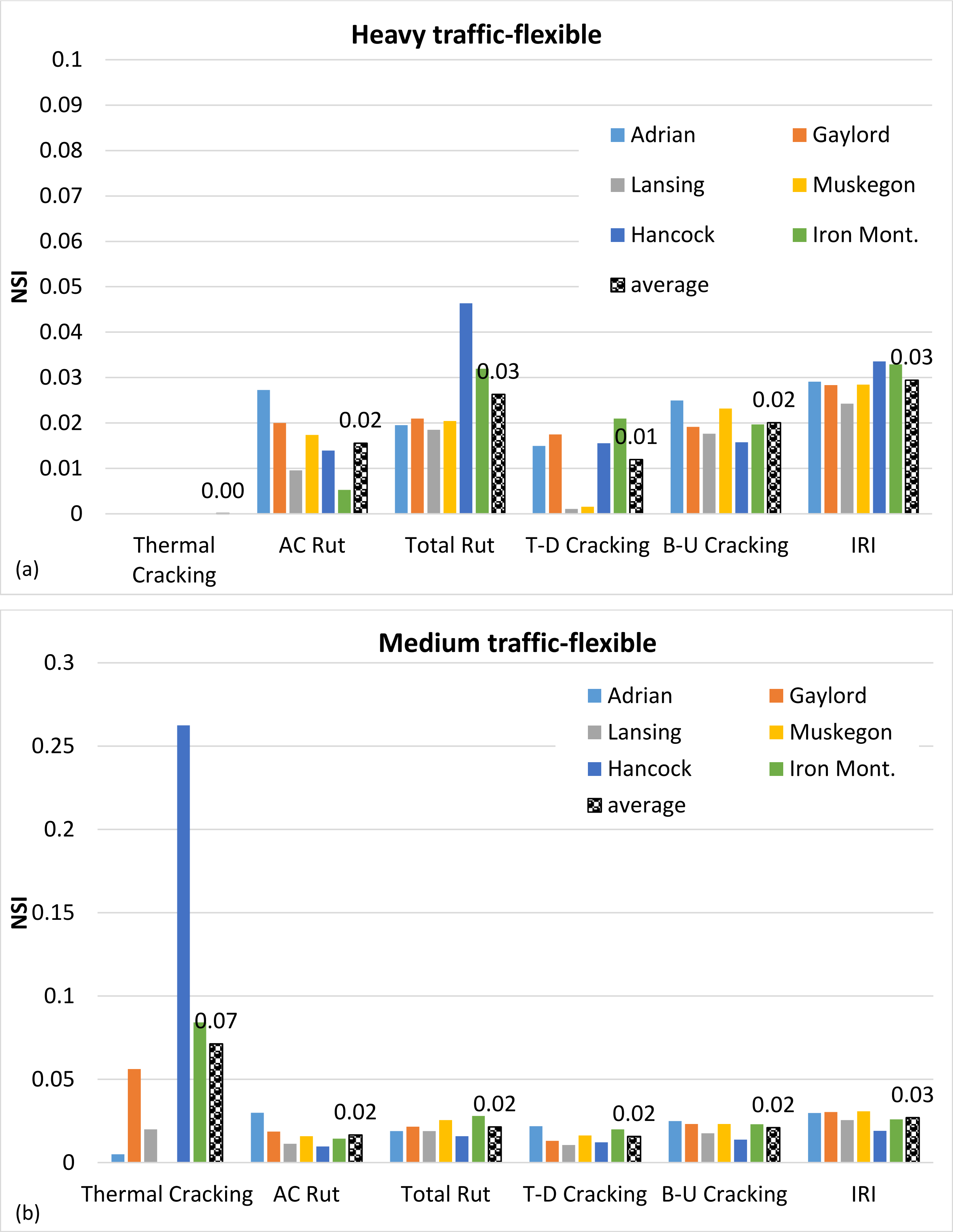


Figure 4-16: The NSI values of distress predictions due to change in percent sunshine for flexible pavement design: (a) heavy traffic design; and (b) medium traffic design

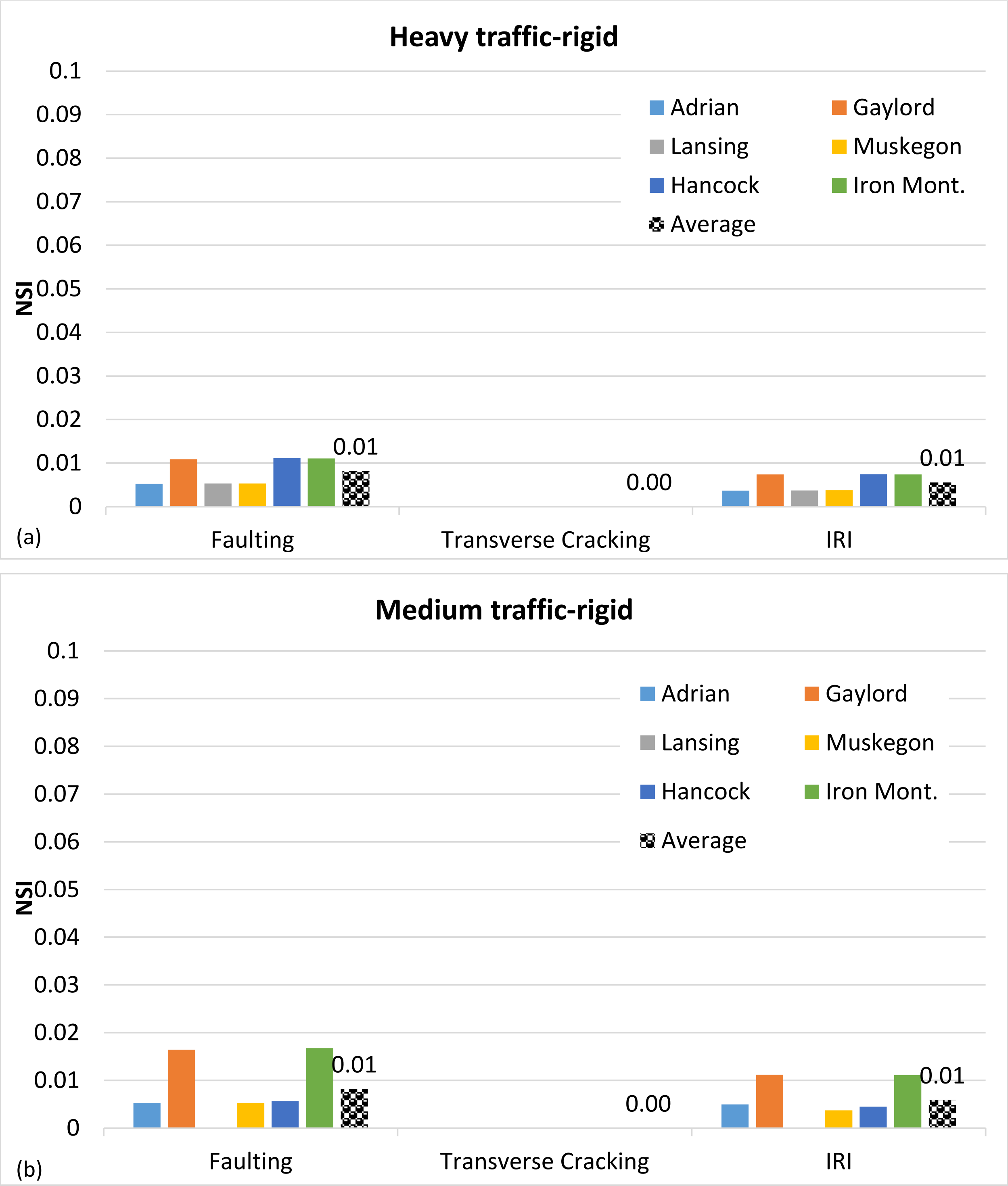
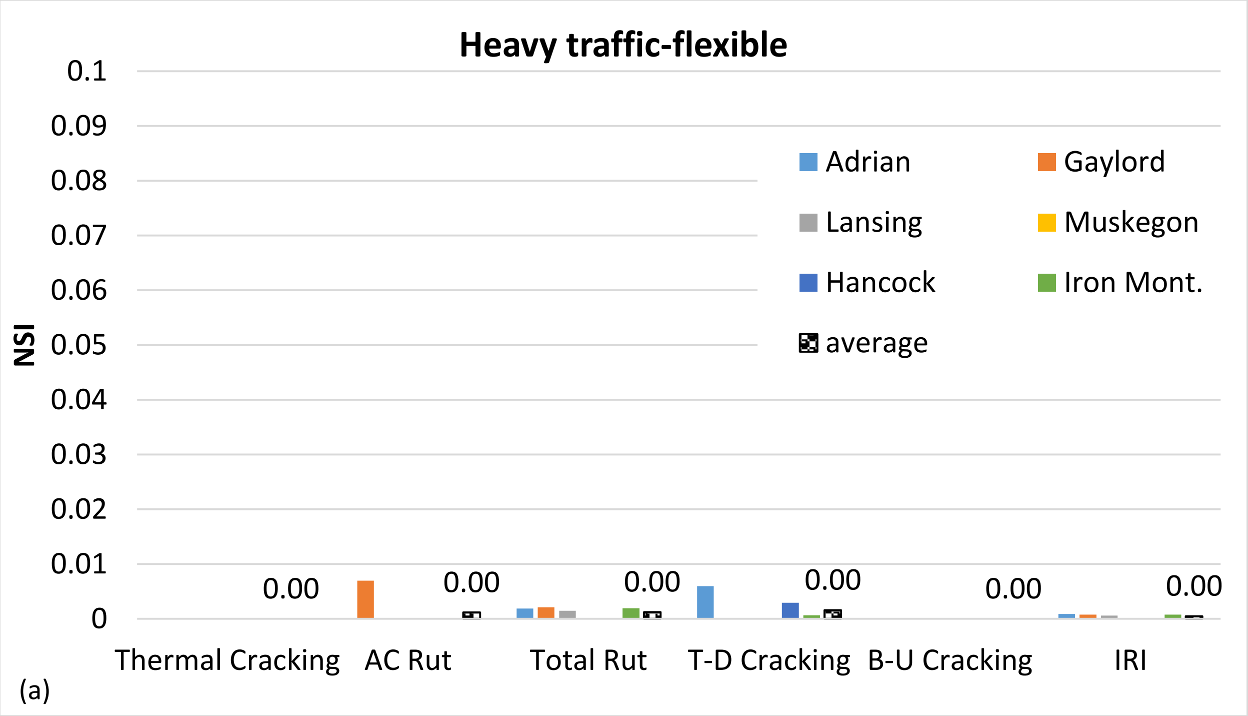


Figure 4-17: The NSI values of distress predictions due to change in percent sunshine for rigid pavement designs: (a) heavy traffic design; and (b) medium traffic design

4.4.5 Distress prediction sensitivity to relative humidity

Figure 4-18 displays the NSI of distress predictions due to changes in relative humidity for flexible pavement. It was found that all of the NSI values for both heavy traffic and medium traffic designs are lower than 0.1, meaning that the flexible pavement distress predictions are not sensitive to changes in relative humidity.

Figure 4-19 shows the NSI of distress predictions due to changes in relative humidity for rigid pavement. In the heavy traffic design, most of the NSI values of faulting and IRI are lower than 0.1. The average NSI values for faulting and IRI are 0.07 and 0.05, respectively. Thus, it is reasonable to consider that the distress predictions are not sensitive to changes in relative humidity for high rigid pavement design. In the medium traffic design, however, three out of the six NSI values of faulting prediction are higher than 0.1. The average NSI value is 0.1, equal to the threshold of sensitivity. Thus, we can conclude that the faulting prediction of rigid pavement is sensitive to changes in relative humidity in some regions of Michigan but not in others.



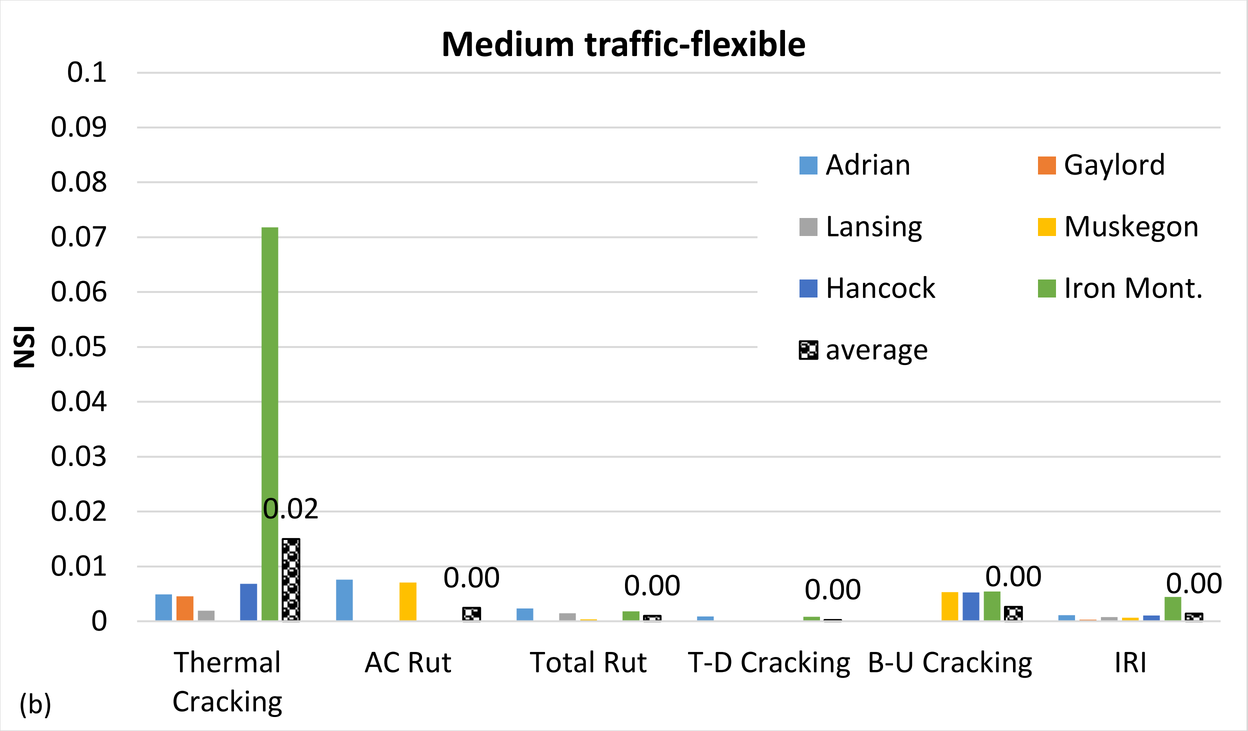
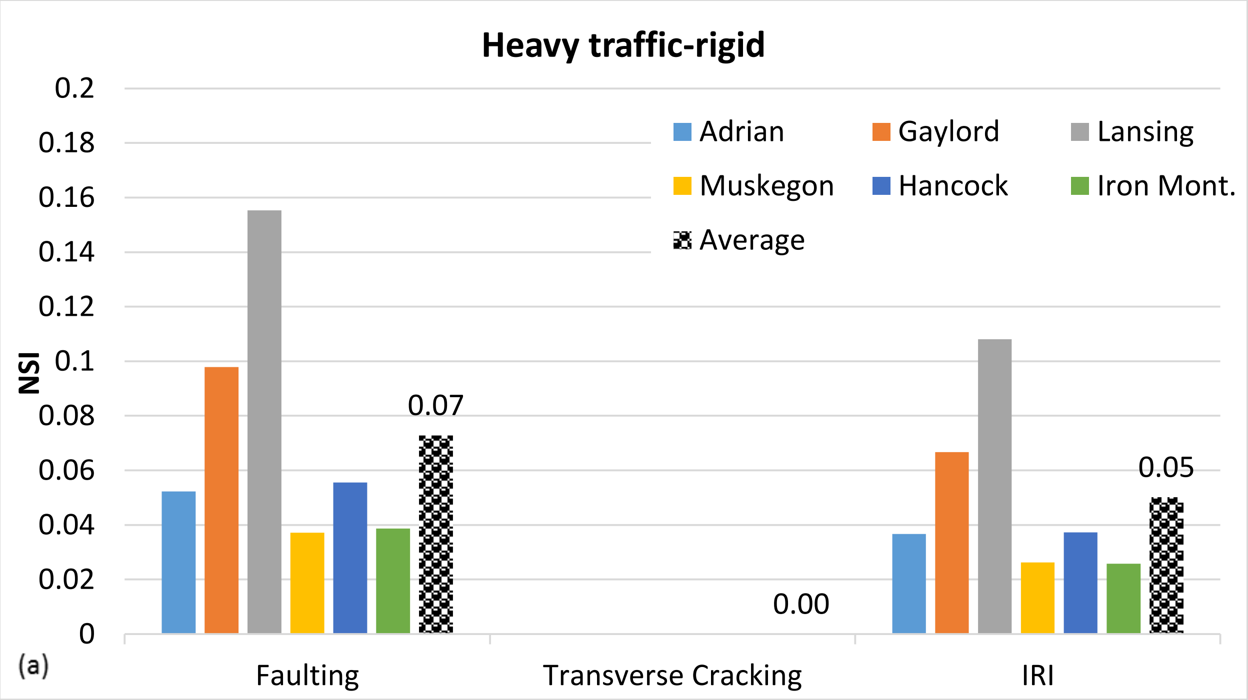


Figure 4-18: The NSI values of distress predictions due to change in relative humidity for flexible pavement design: (a) heavy traffic design; and (b) medium traffic design



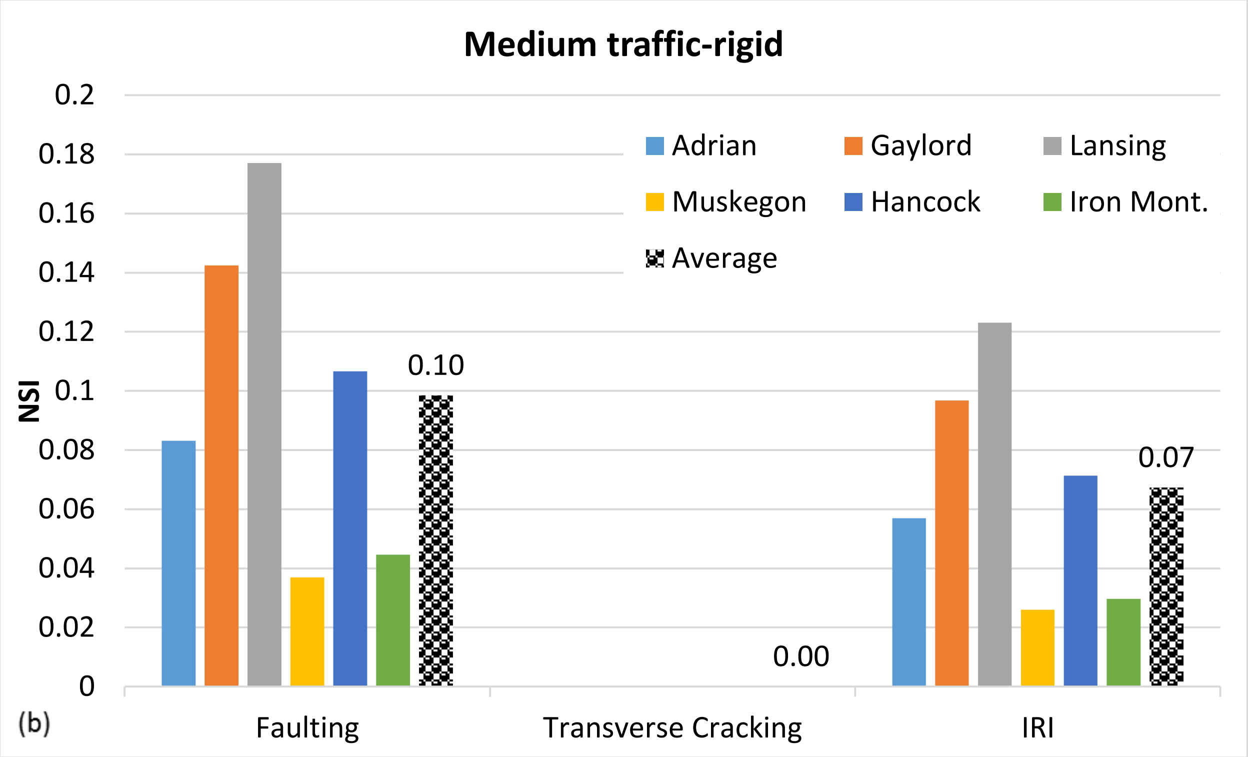
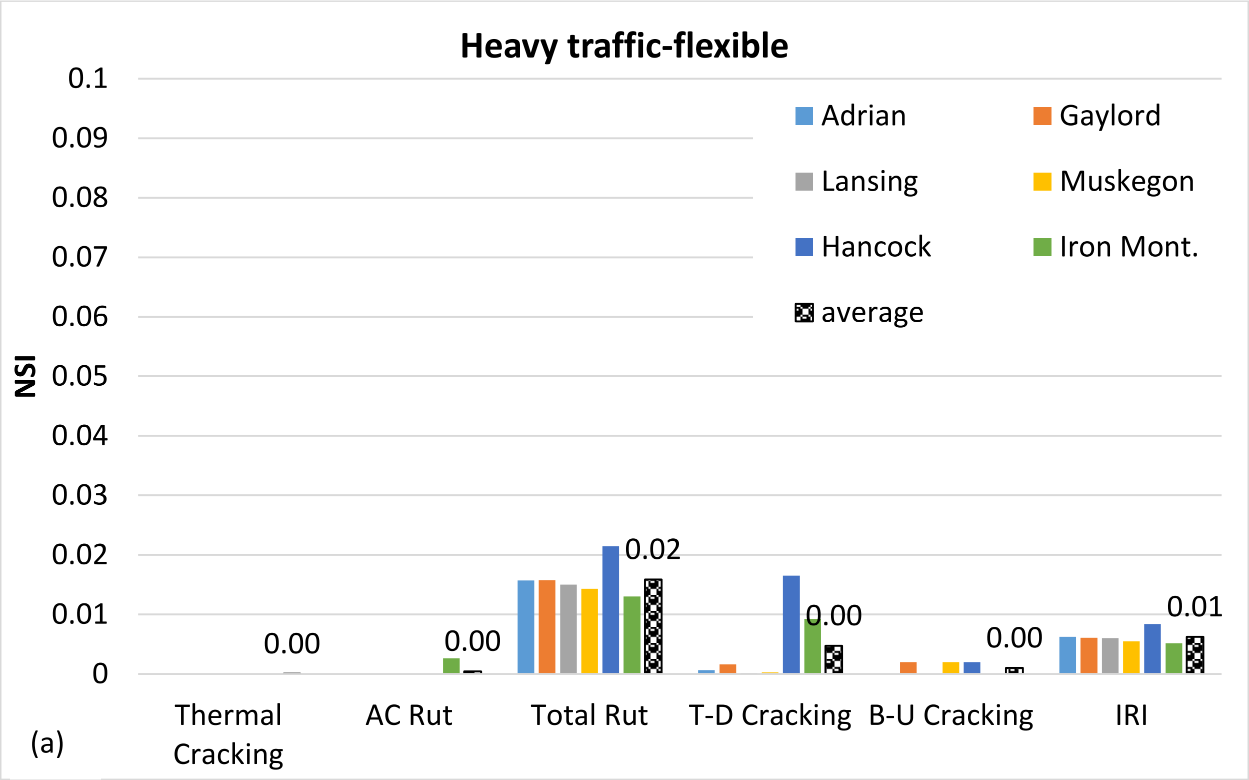


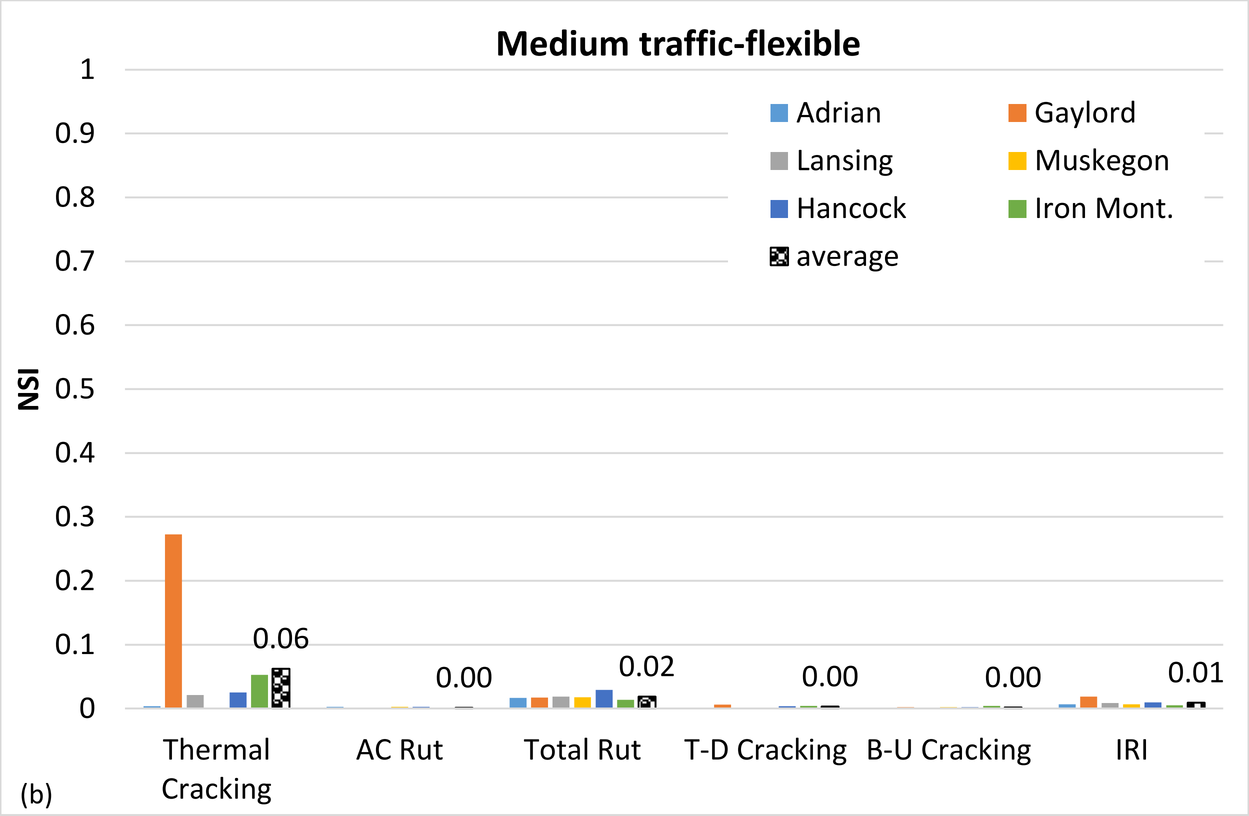
Figure 4-19: The NSI values of distress predictions due to change in relative humidity for rigid pavement designs: (a) heavy traffic design; and (b) medium traffic design

4.5 Sensitivity to depth to water table

The sensitivity of the design results to changes in the depth to water table was evaluated using the same approach as was used for the individual weather data. In the current PMED software, the default value of depth to water table is 10 feet. This value was manually changed to 11 and 9 feet, corresponding to a 10% increase and decrease, respectively. The NSI is calculated for each case using the same equation as used in the individual variable analysis, and the representative NSI is computed as the average of the two values. In addition, a -50% increase (from 10 to 5 feet) was also applied to represent a substantial change in the depth to water table.

Figure 4-20 displays the NSI values of distress predictions due to changes in the water table when a ±10% change is applied. It can be found that almost all of the NSI values were lower than 0.1. Although the NSI of thermal cracking in Gaylord is higher than 0.1, the average NSI of thermal cracking for the six stations was 0.06, which is lower than the threshold of sensitivity. Figure 4-21 displays the NSI values of distress predictions due to changes in the depth to water table. It was also found that the average NSI values were lower than 0.1 although the NSI value in Gaylord is higher than 0.1. Hence, distress predictions are generally not sensitive to changes in water table depth.





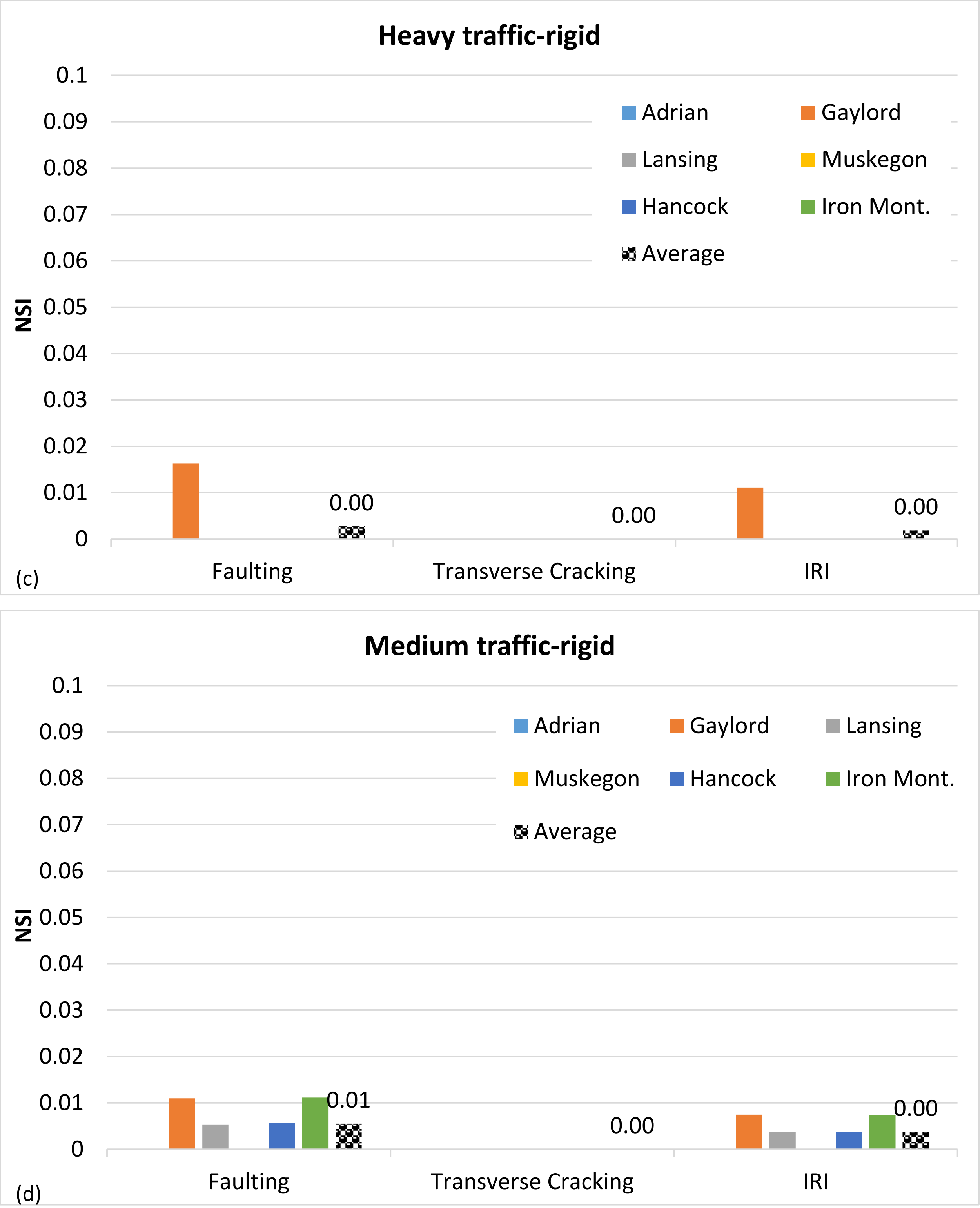
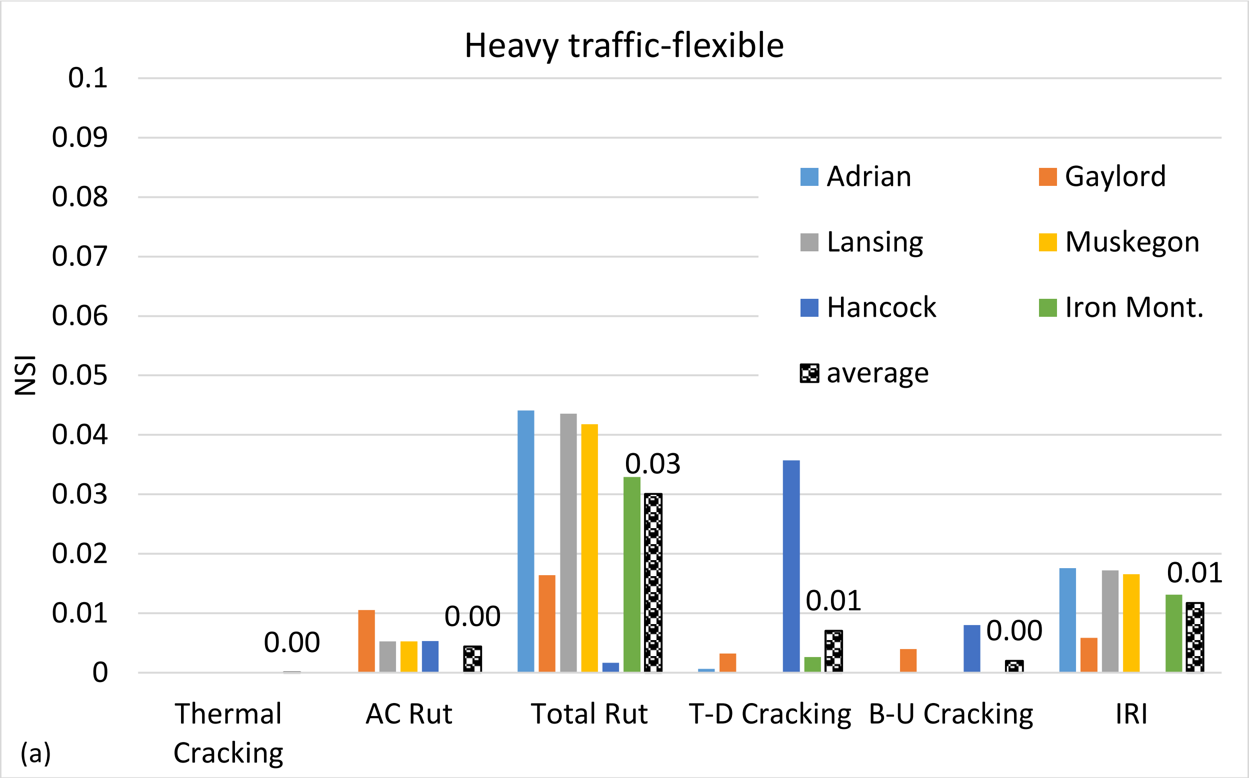
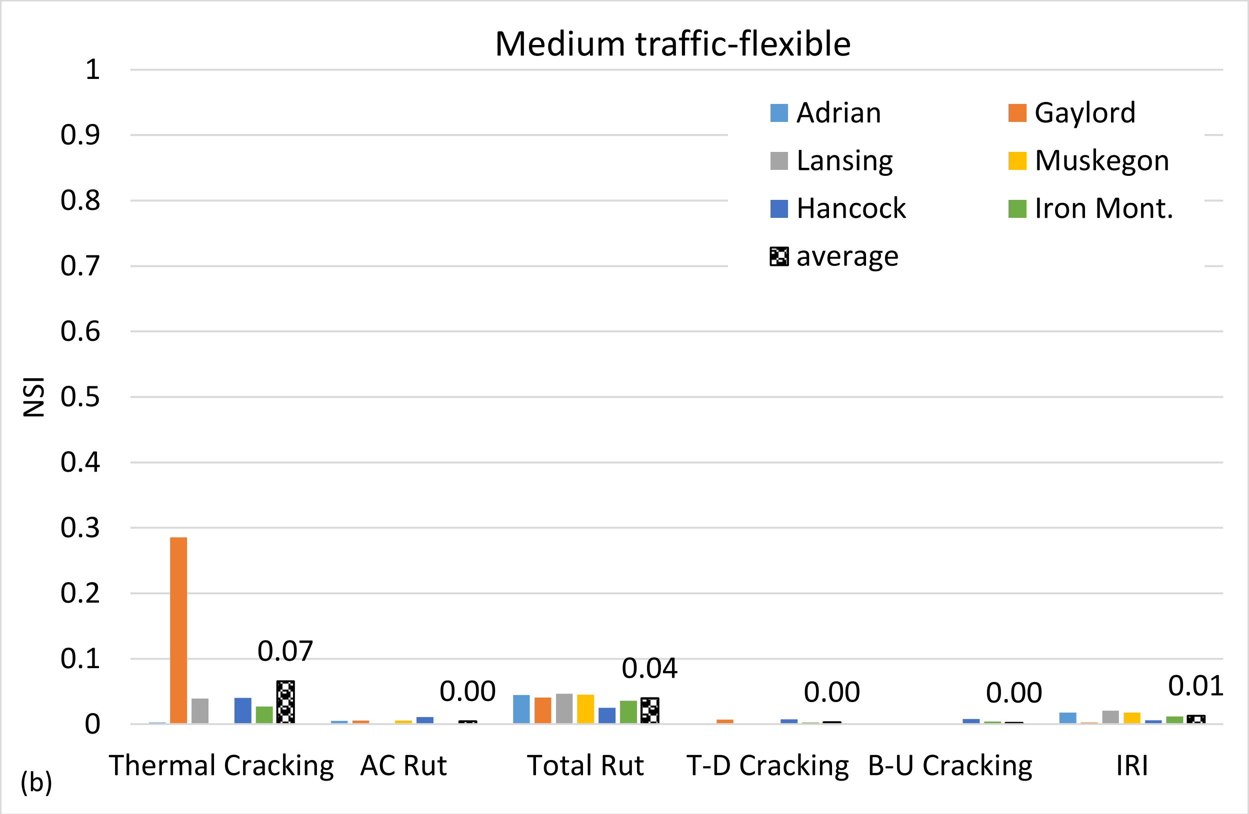


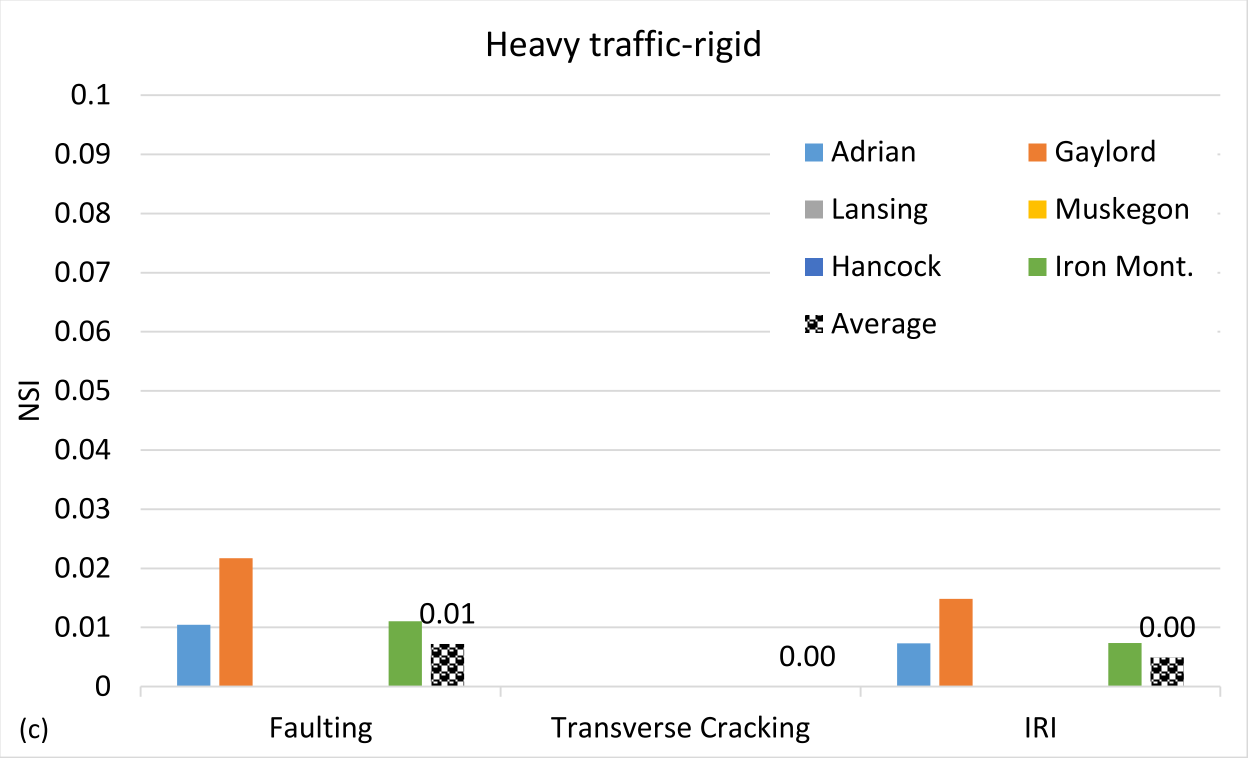
Figure 4-20: The NSI values of distress predictions due to changes in water table depth (change by ±10%): a) heavy traffic for flexible pavement; b) medium traffic for flexible pavement; c) heavy traffic for rigid pavement; and d) medium traffic for rigid pavement.


Heavy traffic-flexible
NSI
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
Adrian
Gaylord
Lansing
Muskegon
Hancock
Iron Mont.
average
0.00
0.00
0.03
0.01
0.00
0.01
Thermal Cracking
AC Rut
Total Rut
T-D Cracking
B-U Cracking
IRI

(a)


Medium traffic-flexible
NSI
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Adrian
Gaylord
Lansing
Muskegon
Hancock
Iron Mont.
average
0.07
0.00
0.04
0.00
0.00
0.01
Thermal Cracking
AC Rut
Total Rut
T-D Cracking
B-U Cracking
IRI

(b)



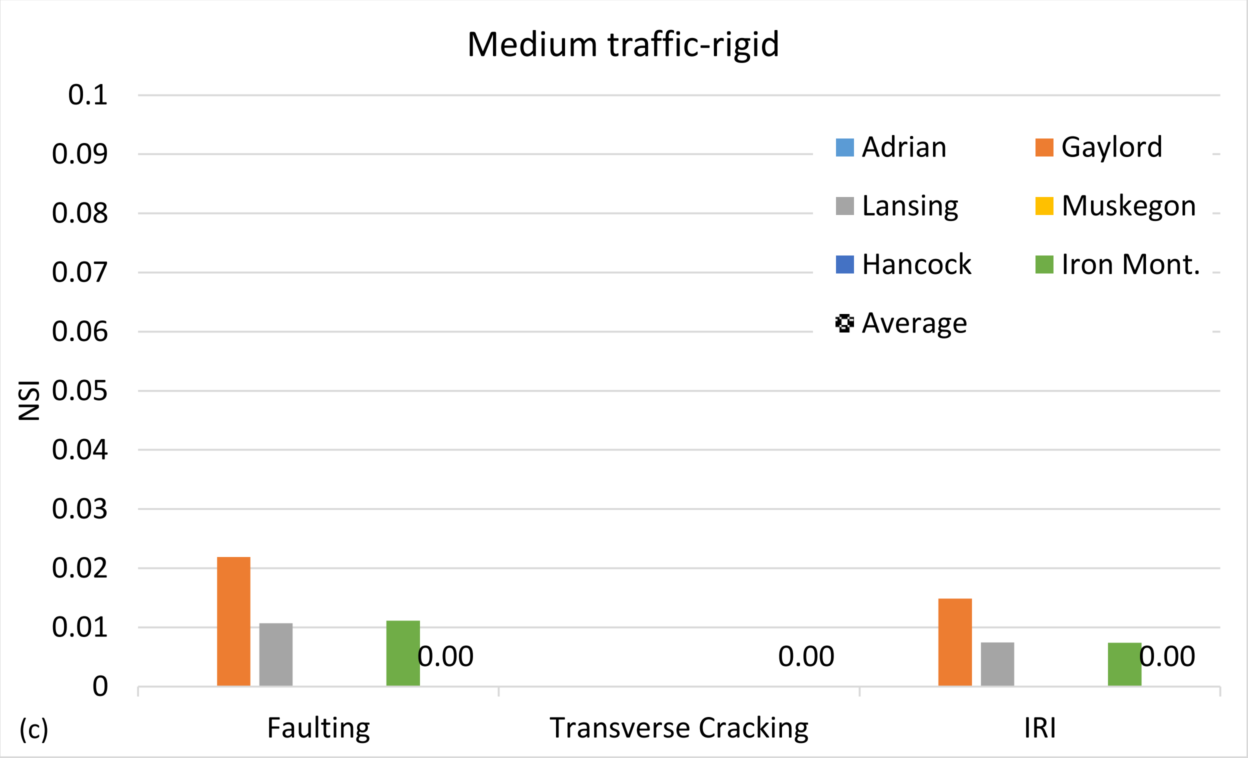


Figure 4-21: The NSI values of distress predictions due to changes in water table depth (change by -50%) a) heavy traffic for flexible pavement; b) medium traffic for flexible pavement; c) heavy traffic for rigid pavement; and d) medium traffic for rigid pavement.

4.6 Sensitivity to annual weather variability

The data length in the current climatic files of Michigan varies from 5 to 10 years. To run PMED, at least one complete year of climate data is needed. When the design life of the pavement is longer than the total time length of the database, the climate data will repeat. Weather data for longer periods can reduce the sensitivity of pavement design to outlier weather patterns. The yearly weather variability may have great influence on the design results. The MEPDG development team claimed that 15 to 20 years of data can represent the climate of certain location well [37]. Another reason for the analysis of sensitivity to annual weather variability is to find out a potential minimum length of weather data from other resources to use as a new station in PMED. To understand the sensitivity to annual weather variability, blocks of years were extracted from the climatic file to make new climatic files. The design results using the new climatic files and the original climatic files were then compared.

Table 4-8: Blocks of data selected from the original climatic files

Climatic files	Year blocks				
	Original files	1-year	2-year block	4-year block	6-year block
Adrian-Cold	1998~2005	1998~1999*	2002~2004	1998~2002	1998-2004
Adrian-Hot		2002~2003	2001~2003	2001~2005	1999-2005
Lansing-Cold	1997~2005	2000~2001	1999~2001	1997~2001	1997-2003
Lansing-Hot		2002~2003	2001~2003	2001~2005	1999-2005
Muskegon-Cold	1997~2005	2004~2005	2003~2005	1997~2001	1997-2003
Muskegon-Hot		1999~2000	1998~2000	2001~2005	1999-2005
Iron Mont.-Cold	1997~2005	1998~1999	2002~2004	1997~2001	1997-2003
Iron Mont.-Hot		2002~2003	2001~2003	2001~2005	1999-2005
*1998~1999 is a 1-year block from May 1st 1998 to April 30th 1999.					

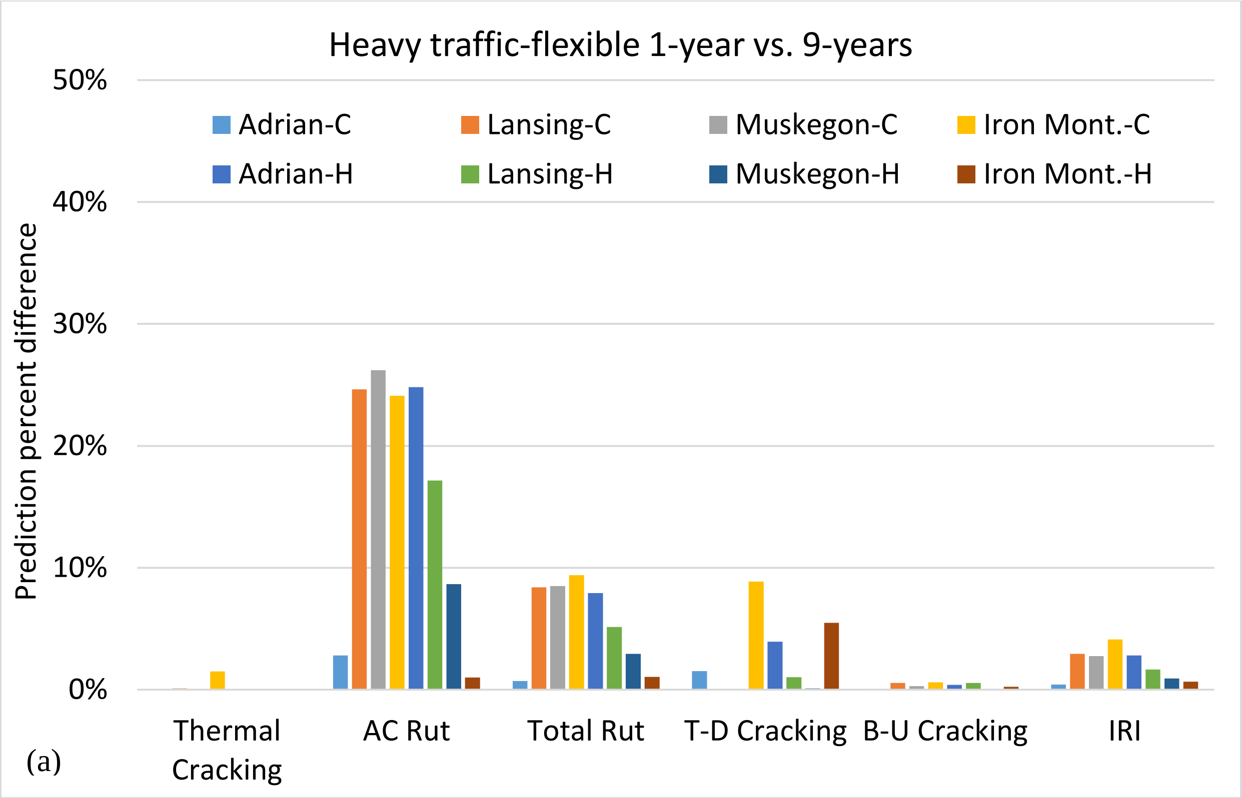
The 1-year, 2-year, 4-year and 6-year blocks of weather data were extracted from the original climatic files. For the 1-year data, the year having the highest number of cold hours lower than -4 ℉ (-20 ℃) and the year having the highest number of hot hours higher than 86 ℉ (30 ℃) were extracted to make new climatic files. For the 2-year data, the two consecutive years having the highest number of cold hours and the two consecutive years having the highest number of hot hours were selected. For the 4- and 6-year data, the first 4- and 6-year blocks of data and the last 4- and 6-year blocks of data were extracted. It should be noted that it is possible for a given year to have both the highest number of cold hours and the highest number of hot hours, but this did not occur in our sampling. The detailed information of the new files is shown in Table 4-8. It was observed that the year having the highest hot hours and the year having the highest cold hours are not the same in all the four stations. Four stations with at least 8 full years of data were selected for the analysis. Again, two pavement types and two traffic levels were studied.

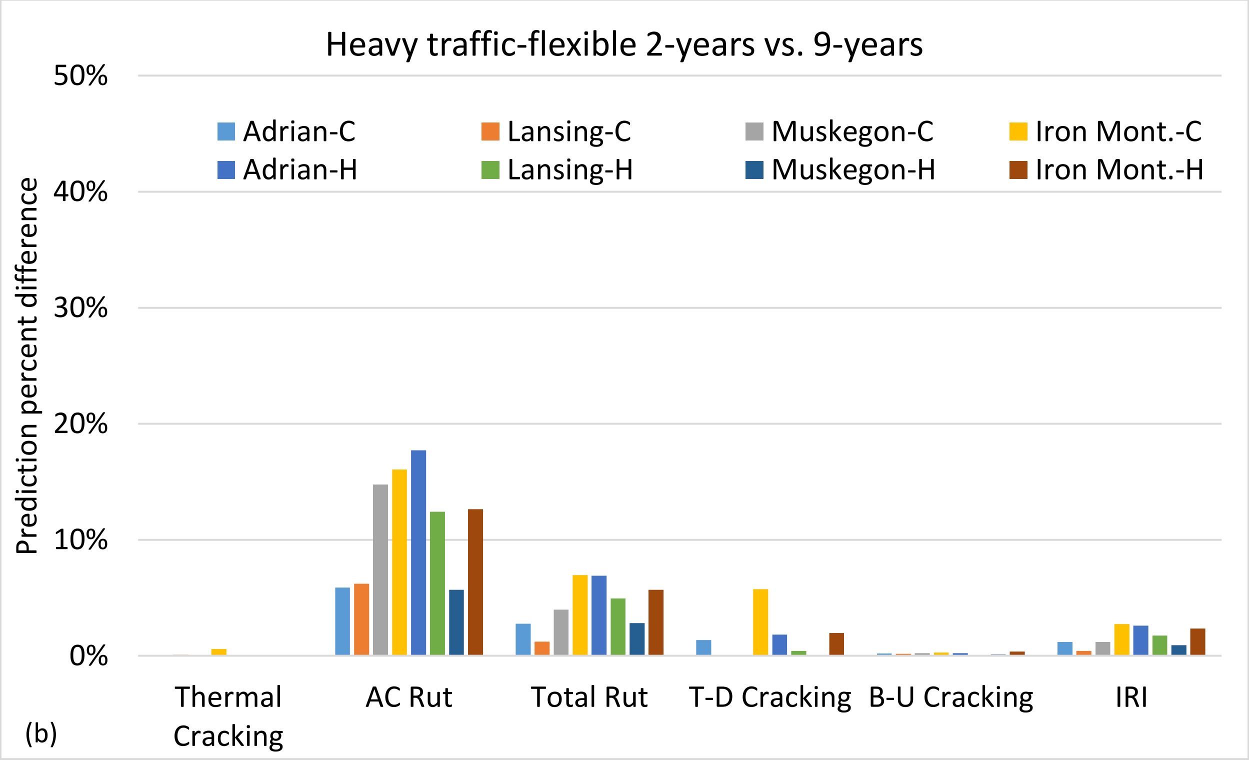
Figure 4-22 to Figure 4-25 illustrate the effects of yearly weather variation on PMED distress predictions expressed by the distress prediction difference (DPD). The DPD is defined as the percentage of the difference of the two values out of the smaller value of the two. It is expressed in Equation (4).

$$DPD = \frac{|DP1 - DP2|}{Min(DP1, DP2)} \times 100\% \tag{4}$$

Where, DPD is the distress prediction difference; DP1 is the distress prediction 1; DP2 is the distress prediction 2; | | is the absolute value; $Min(DP1, DP2)$ is the minimum of DP1 and DP2.

When DPD is higher than 10%, it is an indication that there is a visible difference between the two distress predictions. It can be seen that with the increase of data length, the distress predictions are closer to those based on 9-year climatic data. When the data length is only one year, many of the DPD values are higher than 10%, indicating that the distress predictions are sensitive to yearly variation. The most sensitive distress predictions are the thermal cracking and AC rutting of flexible pavement, and the faulting and IRI of rigid pavement. When the weather data length increases to 2 years, the DPD values overall are much lower. Nevertheless, some DPD values are still higher than 0.1. This indicates that 2 years of weather data is not adequate for reliable designs. When the data length is 4 years, all of the NSI values are lower than 0.1 except for one—the thermal cracking prediction of flexible pavement for medium traffic in Lansing, which has a rather high value of 0.6. When the data length increases to 6 years, the NSI values are further reduced, and the NSI of thermal cracking prediction in Lansing is about 0.2. A closer inspection of the climatic data for Lansing showed that the years 1997~1999 have much fewer cold hours than the following years, which is why there is a perceptible difference between the thermal cracking predictions using the 6-year and 9-year blocks of data. Since the thermal cracking prediction for flexible pavement under medium traffic in Lansing is only one out of 144 predictions (6 stations, 6 distresses, 2 pavement types, and 2 traffic levels), it can be regarded as an exception. Hence, the research team recommends a minimum data length of 4 years, but only if a longer data record cannot be obtained. This may limit the current use of data sources such as the MDOT RWIS data in the PMED at this time.


Heavy traffic-flexible 1-year vs. 9-years
50%
40%
30%
20%
10%
0%
Prediction percent difference
Adrian-C
Lansing-C
Muskegon-C
Iron Mont.-C
Adrian-H
Lansing-H
Muskegon-H
Iron Mont.-H
Thermal Cracking
AC Rut
Total Rut
T-D Cracking
B-U Cracking
IRI
(a)


Heavy traffic-flexible 2-years vs. 9-years
50%
40%
30%
20%
10%
0%
Prediction percent difference
Adrian-C
Lansing-C
Muskegon-C
Iron Mont.-C
Adrian-H
Lansing-H
Muskegon-H
Iron Mont.-H
Thermal Cracking
AC Rut
Total Rut
T-D Cracking
B-U Cracking
IRI
(b)

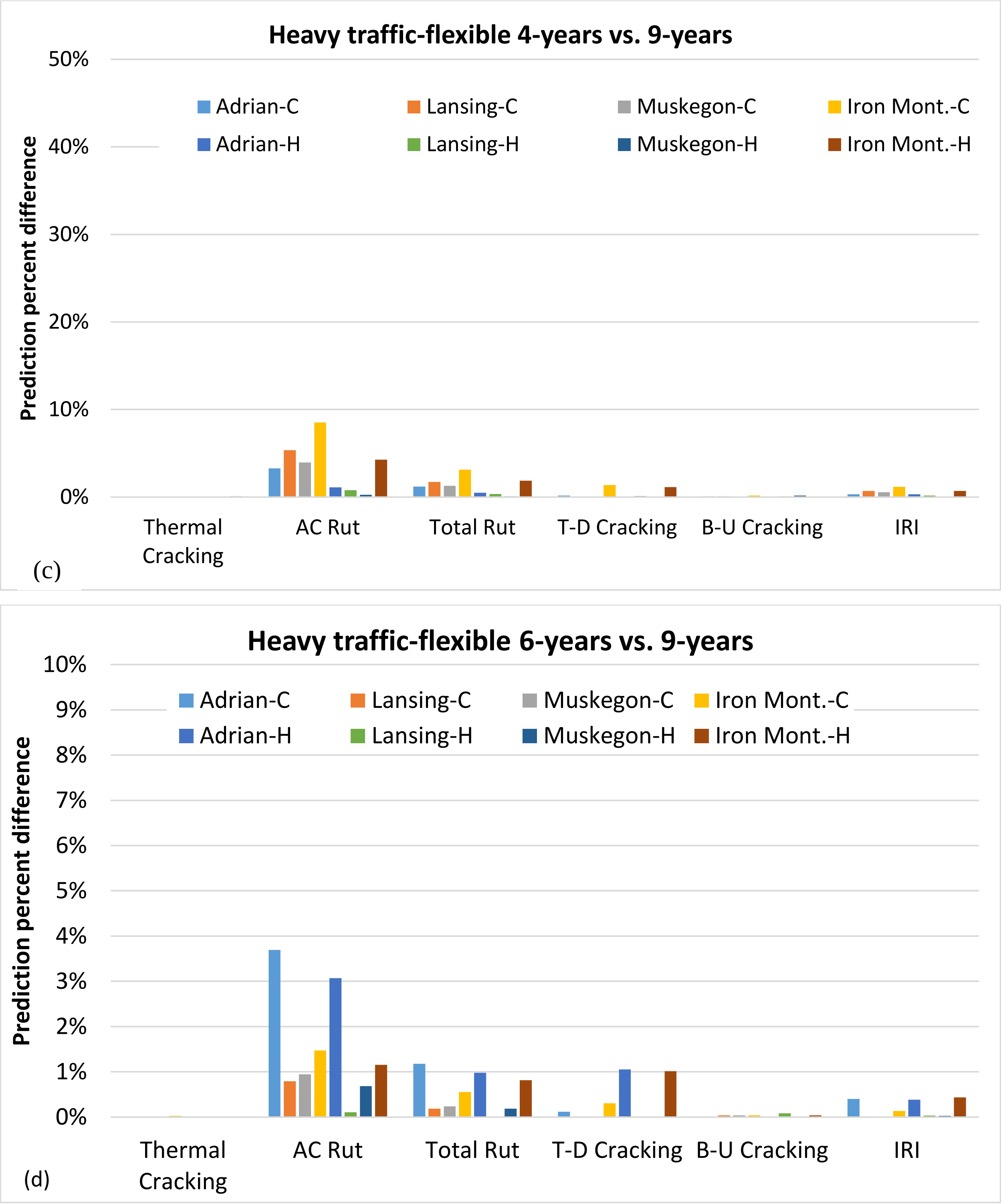
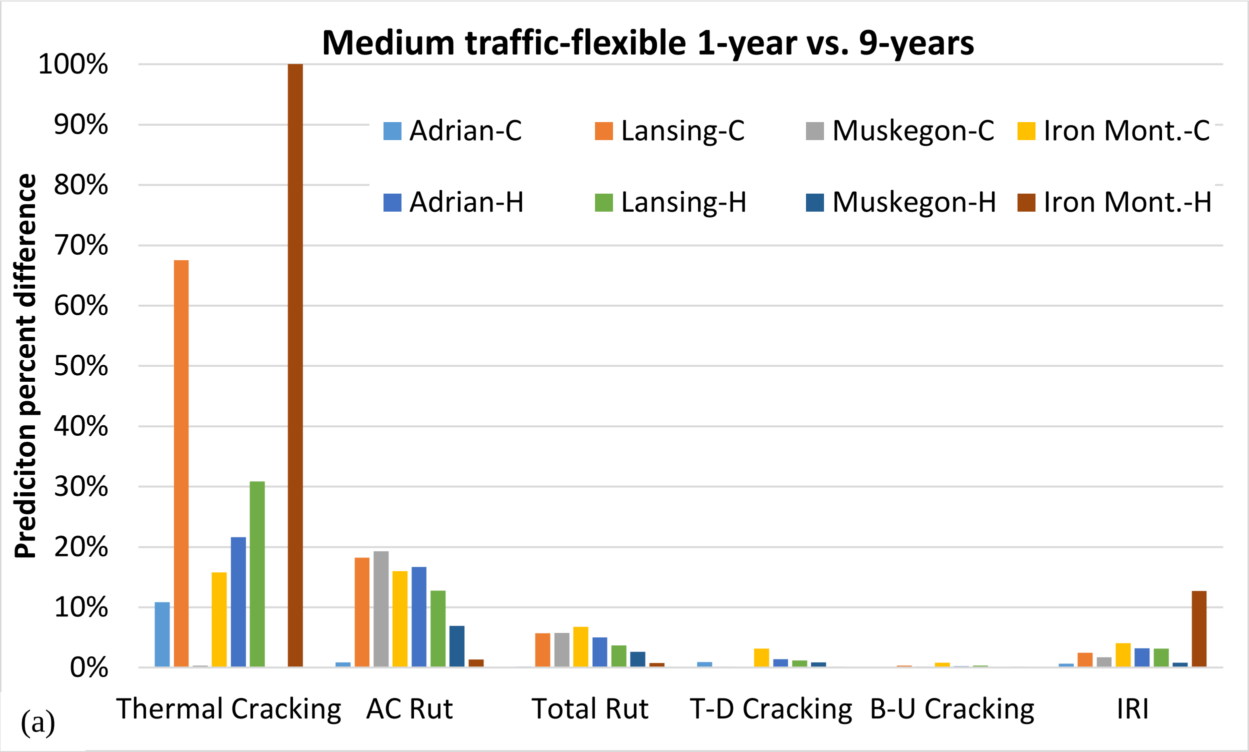
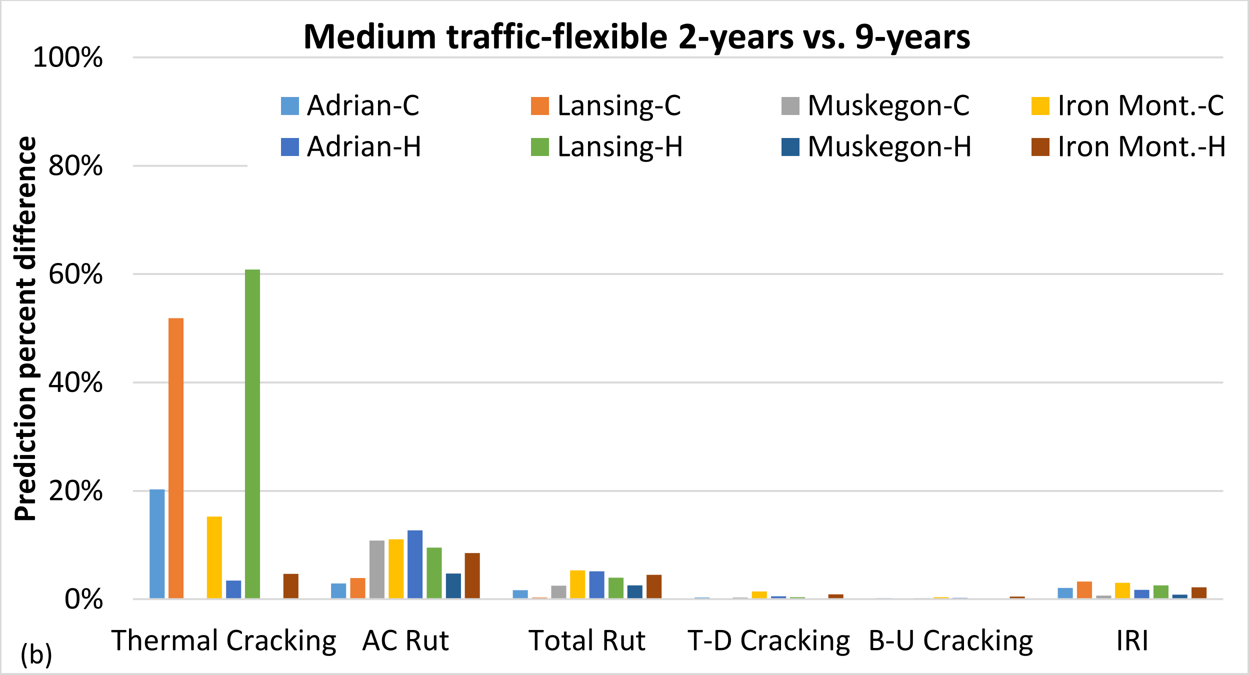


Figure 4-22: The effect of annual weather variability on PMED prediction results of flexible pavement for heavy traffic designs, quantified by NSI: a) 1-year vs. 9-years; b) 2-years vs. 9-years; c) 4-years vs. 9-years; and d) 6-years vs. 9-years.


Medium traffic-flexible 1-year vs. 9-years
Prediciton percent difference
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Adrian-C
Lansing-C
Muskegon-C
Iron Mont.-C
Adrian-H
Lansing-H
Muskegon-H
Iron Mont.-H
Thermal Cracking
AC Rut
Total Rut
T-D Cracking
B-U Cracking
IRI
(a)


Medium traffic-flexible 2-years vs. 9-years
Prediction percent difference
100%
80%
60%
40%
20%
0%
Adrian-C
Lansing-C
Muskegon-C
Iron Mont.-C
Adrian-H
Lansing-H
Muskegon-H
Iron Mont.-H
Thermal Cracking
AC Rut
Total Rut
T-D Cracking
B-U Cracking
IRI
(b)

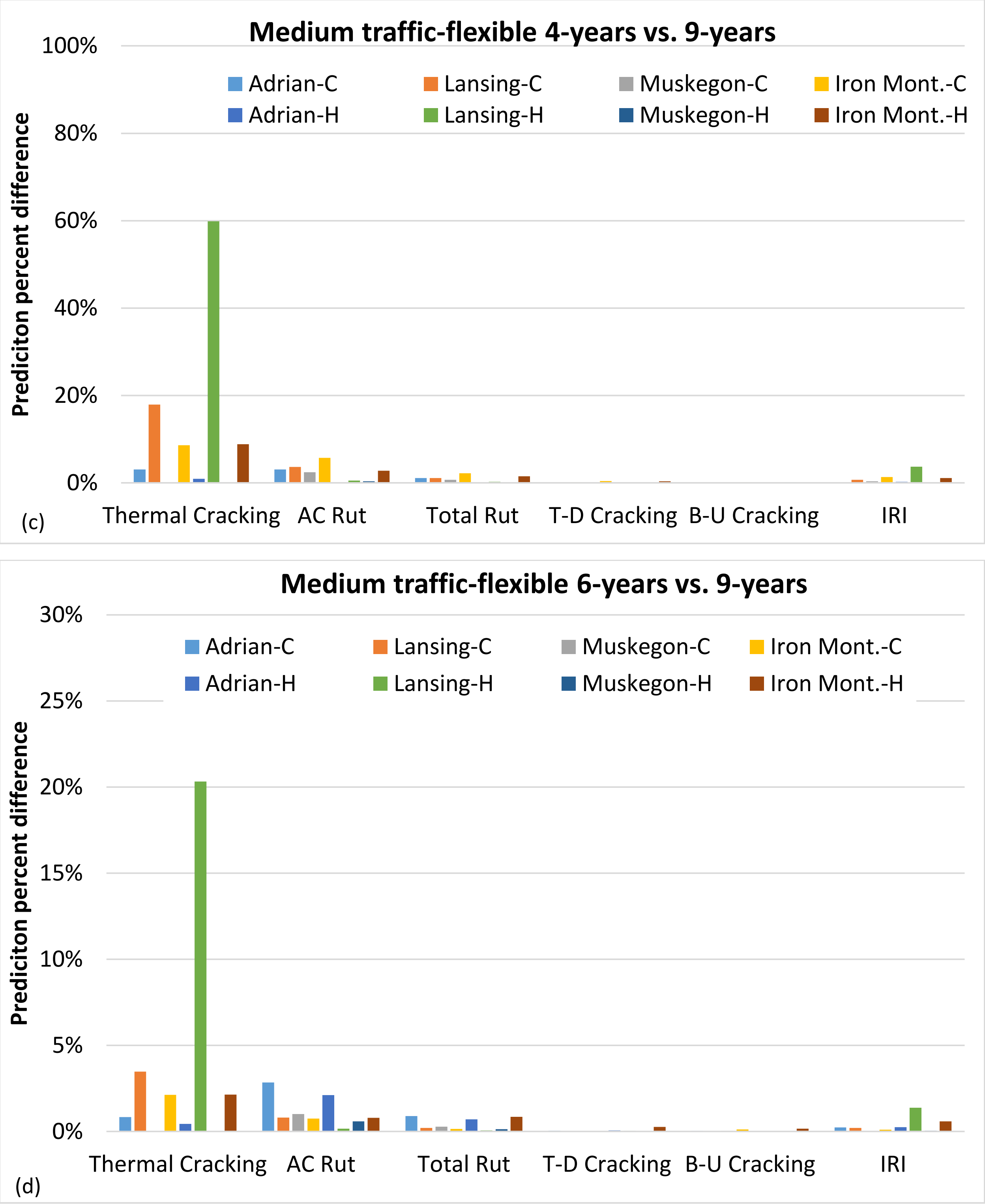
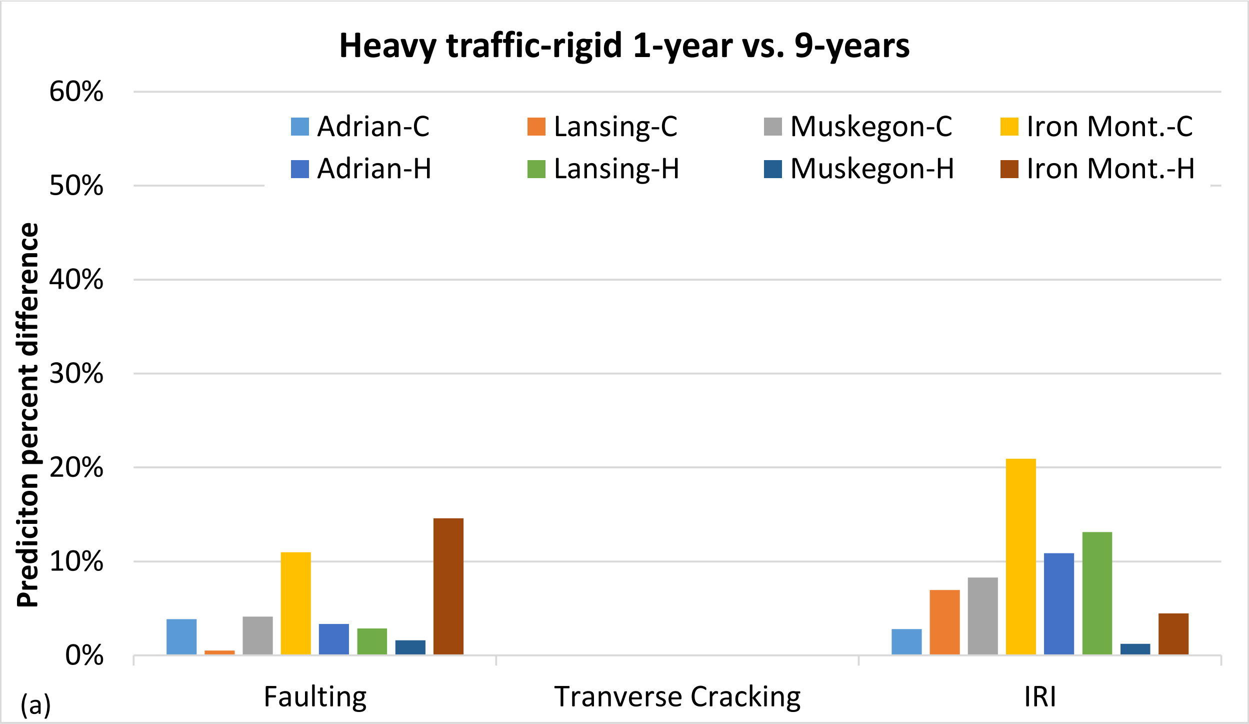
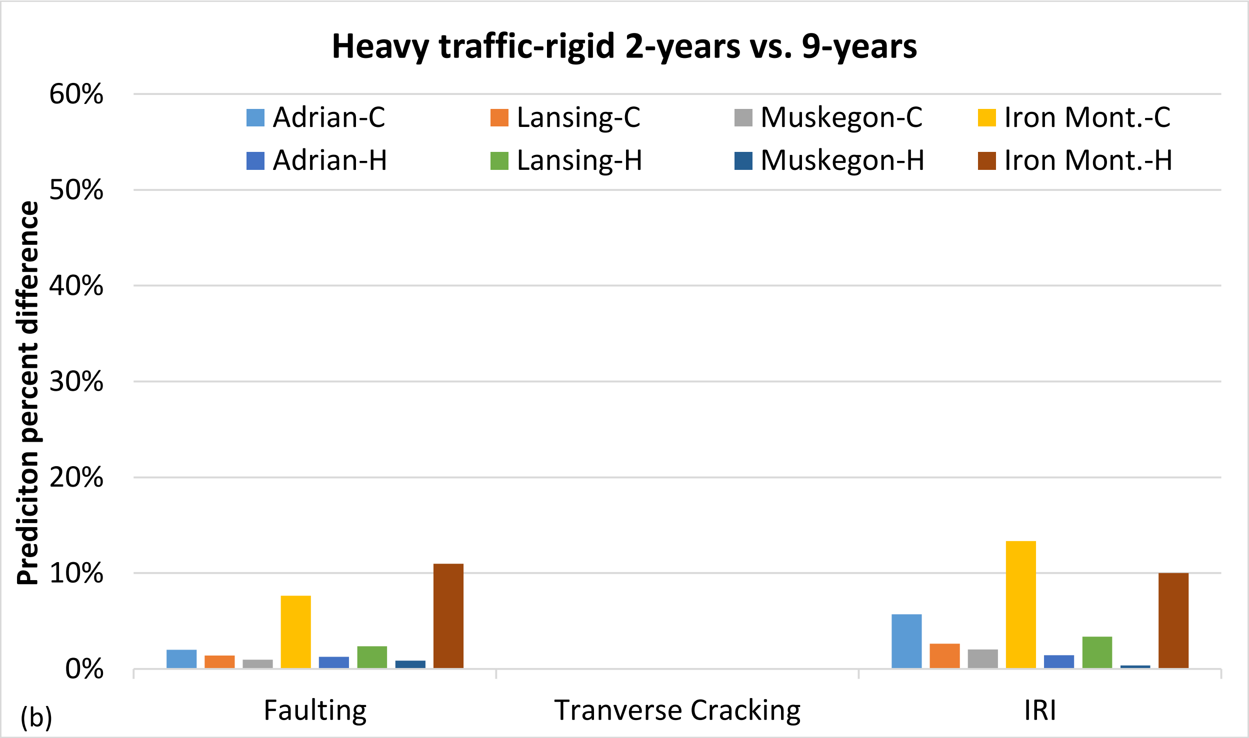


Figure 4-23: The effect of annual weather variability on PMED prediction results of flexible pavement for medium traffic designs, quantified by NSI: a) 1-year vs. 9-years; b) 2-years vs. 9-years; c) 4-years vs. 9-years; and d) 6-years vs. 9-years.


Heavy traffic-rigid 1-year vs. 9-years
Prediciton percent difference
60%
50%
40%
30%
20%
10%
0%
Adrian-C
Lansing-C
Muskegon-C
Iron Mont.-C
Adrian-H
Lansing-H
Muskegon-H
Iron Mont.-H
Faulting
Tranverse Cracking
IRI
(a)


Heavy traffic-rigid 2-years vs. 9-years
Prediciton percent difference
60%
50%
40%
30%
20%
10%
0%
Adrian-C
Lansing-C
Muskegon-C
Iron Mont.-C
Adrian-H
Lansing-H
Muskegon-H
Iron Mont.-H
Faulting
Tranverse Cracking
IRI
(b)

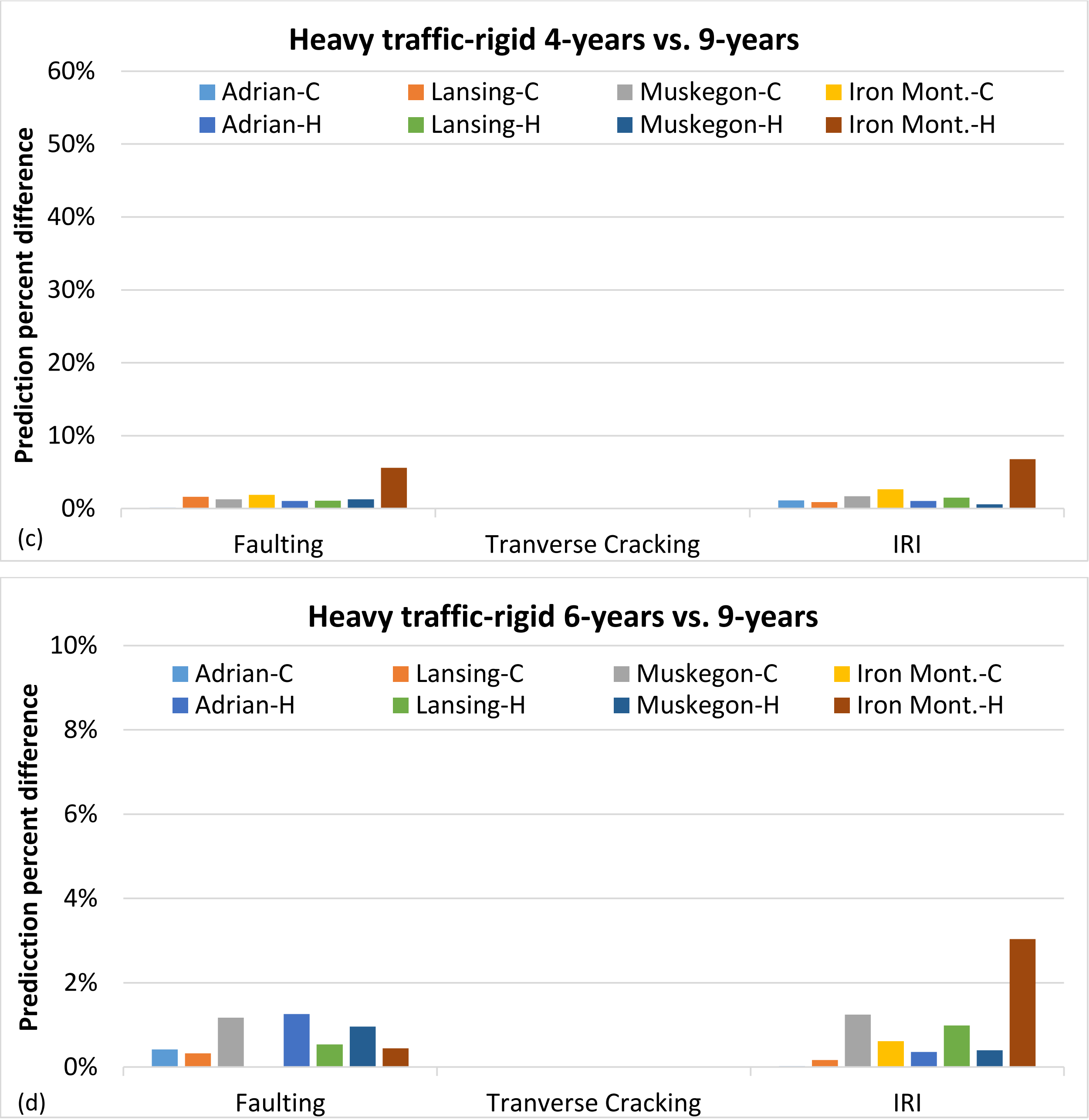
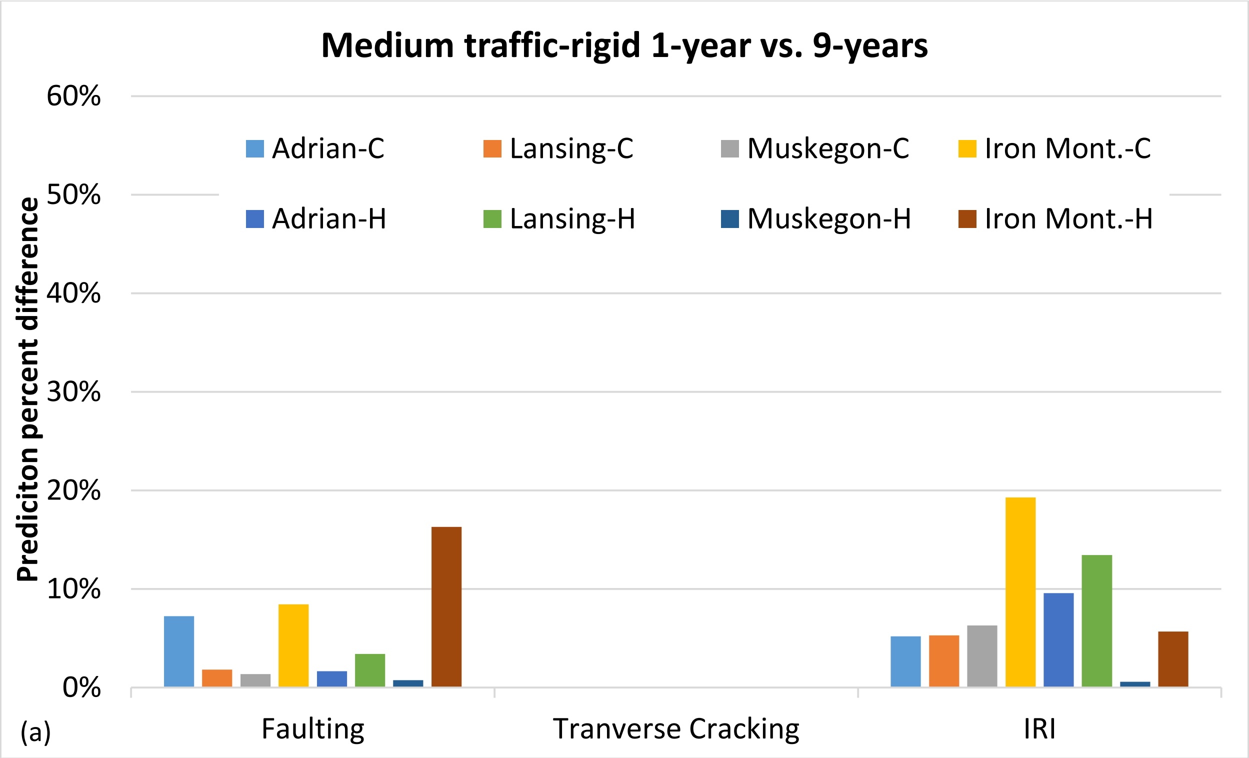
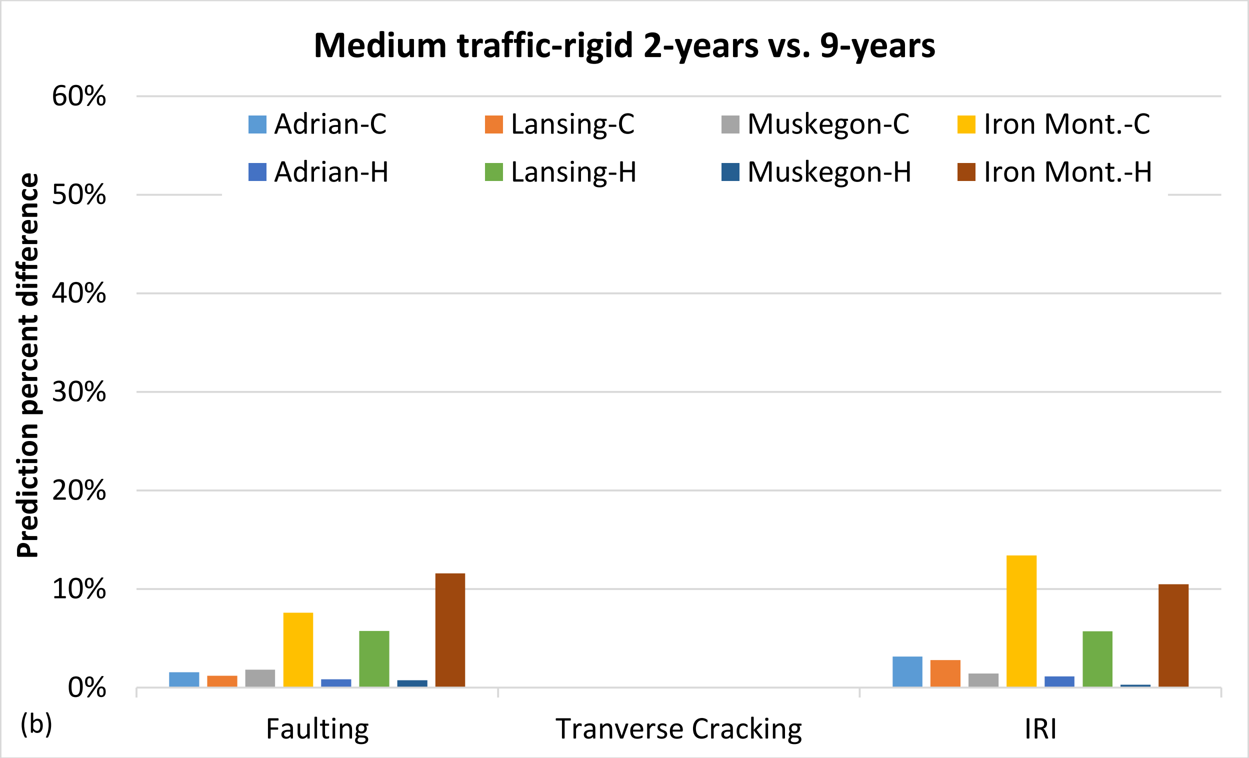
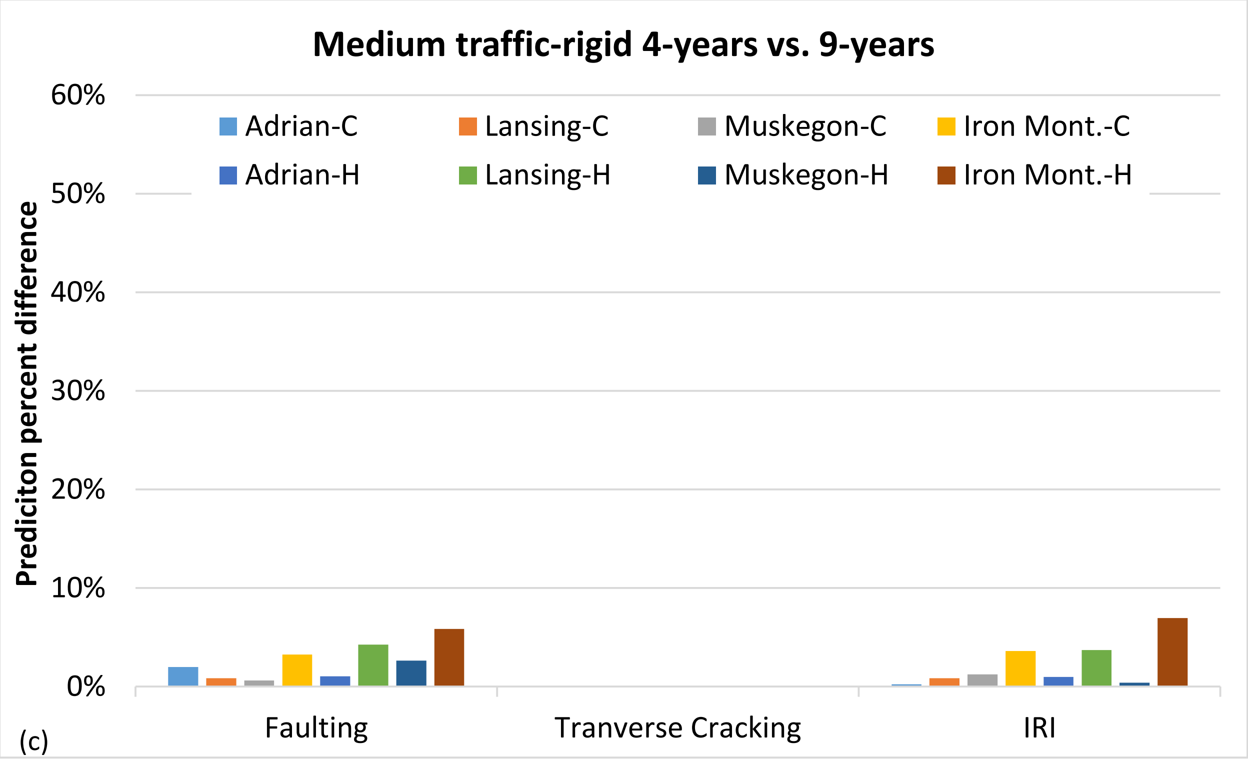


Figure 4-24: The effect of annual weather variability on PMED prediction results of rigid pavement for heavy traffic designs, quantified by NSI: a) 1-year vs. 9-years; b) 2-years vs. 9-years; c) 4-years vs. 9-years; and d) 6-years vs. 9-years.


Medium traffic-rigid 1-year vs. 9-years
Prediciton percent difference
60%
50%
40%
30%
20%
10%
0%
Adrian-C
Lansing-C
Muskegon-C
Iron Mont.-C
Adrian-H
Lansing-H
Muskegon-H
Iron Mont.-H
Faulting
Tranverse Cracking
IRI
(a)


Medium traffic-rigid 2-years vs. 9-years
Prediction percent difference
60%
50%
40%
30%
20%
10%
0%
Adrian-C
Lansing-C
Muskegon-C
Iron Mont.-C
Adrian-H
Lansing-H
Muskegon-H
Iron Mont.-H
Faulting
Tranverse Cracking
IRI
(b)



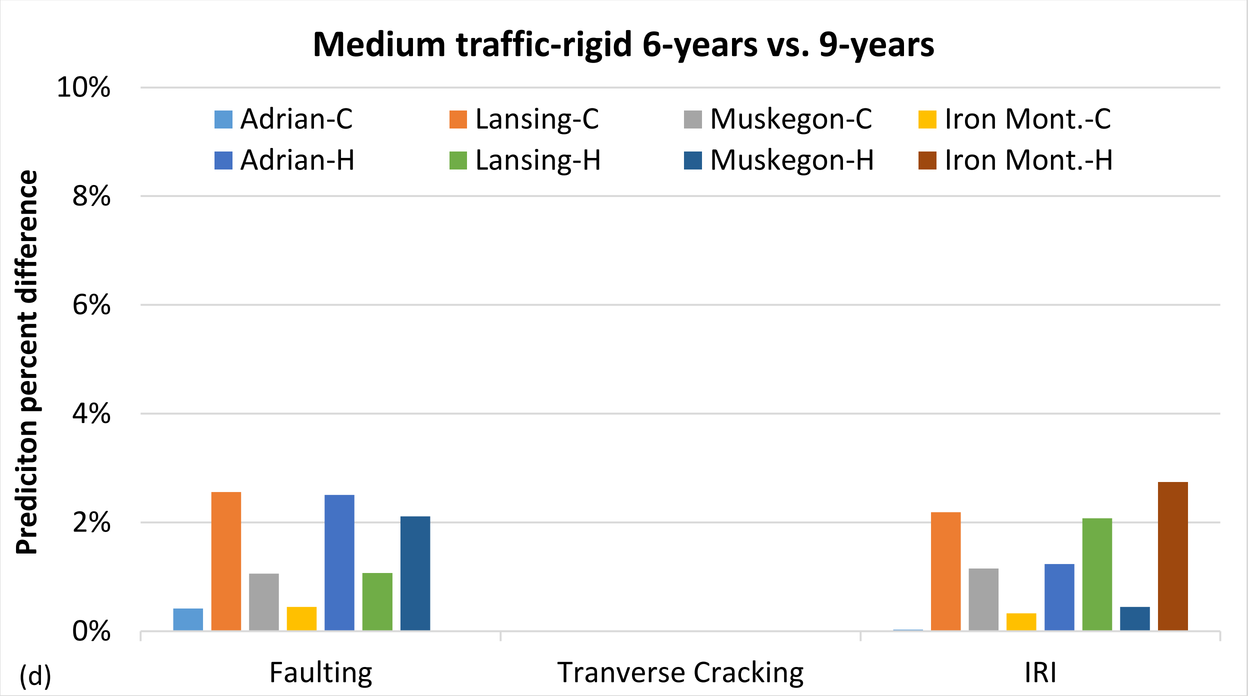


Figure 4-25: The effect of annual weather variability on PMED prediction results of rigid pavement for medium traffic designs, quantified by NSI: a) 1-year vs. 9-years; b) 2-years vs. 9-years; c) 4-years vs. 9-years; and d) 6-years vs. 9-years.

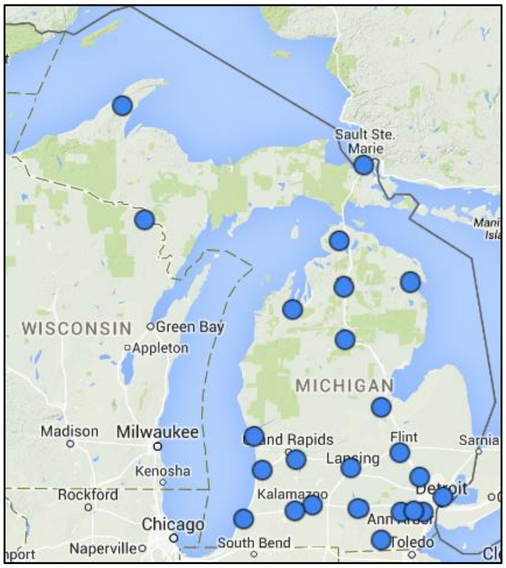
CHAPTER 5: ADDITIONAL WEATHER STATIONS AND DATA EXTENSION OF EXISTING CLIMATIC FILES IN PMED

As previously mentioned, the current weather data used in PMED are from the NCDC database. There are 24 weather stations in Michigan, but the distribution of these stations is not balanced geographically. Figure 5-1 shows the distribution of weather stations in the PMED, with most of these stations located in the southern part of the Lower Peninsula. In addition, two of the four stations in the Upper Peninsula are near borders with Ontario and Wisconsin. This makes a large area in Upper Peninsula and middle part of Lower Peninsula poorly represented geographically. This chapter looks at the potential for adding new stations from other sources of data, as well as extending the number of years of available data for existing stations in the PMED.

5.1 Sources of additional weather data

5.1.1 The AWOS/ASOS data

One potential climatic data resource is the automated weather observation system (AWOS) and automated surface observation system (ASOS). Figure 5-2 shows the ASOS/AWOS weather station distribution in Michigan collected by the Iowa Environmental Mesonet (IEM) [15]. The station distribution density is much higher than that of the PMED. The weather information in the AWOS/ASOS climatic files includes temperature, dew point, relative humidity, wind speed, wind direction, precipitation, sea level pressure, cloud coverage of four sky levels, and sky level altitude. The time interval of the recorded climatic data is generally one hour, but with some missing hours and some hours with multiple observations. The climatic files can be directly exported with the text format, which can be opened by either MS Excel or Notepad for conversion to the format necessary for the PMED.



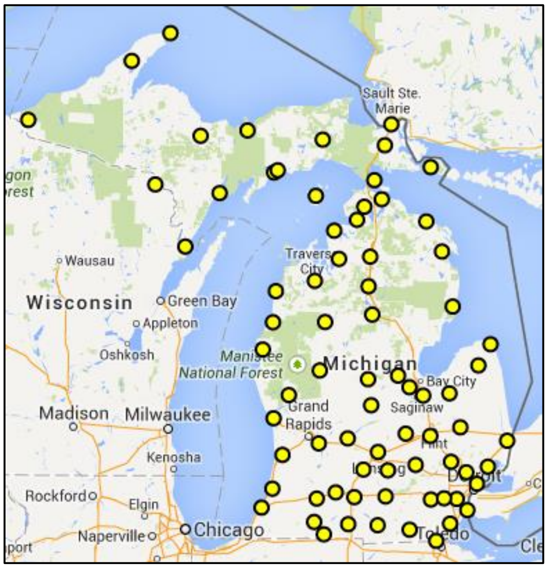


Figure 5-1: Weather station distribution in Michigan in PMED.

Figure 5-2: ASOS/AWOS station distribution in Michigan. Adapted from IEM [15].

5.1.2 MDOT RWIS data

The Michigan Road Weather Information System (RWIS) climatic data are collected by MDOT to monitor local pavement and weather conditions along key routes in the state road network. A typical RWIS climatic data file includes air temperature, dew point, relative humidity, wind speed, visibility, precipitation type and intensity, water level, road temperature, sub surface temperature, etc. The climatic data are collected every five minutes. Thus, RWIS data includes all the variables needed by PMED except for the percent sunshine. The distribution of the RWIS weather stations in Michigan is shown in Figure 5-3. Since most of these stations are in the Upper Peninsula and northern Lower Michigan, these sites would supplement the existing PMED station locations well geographically.

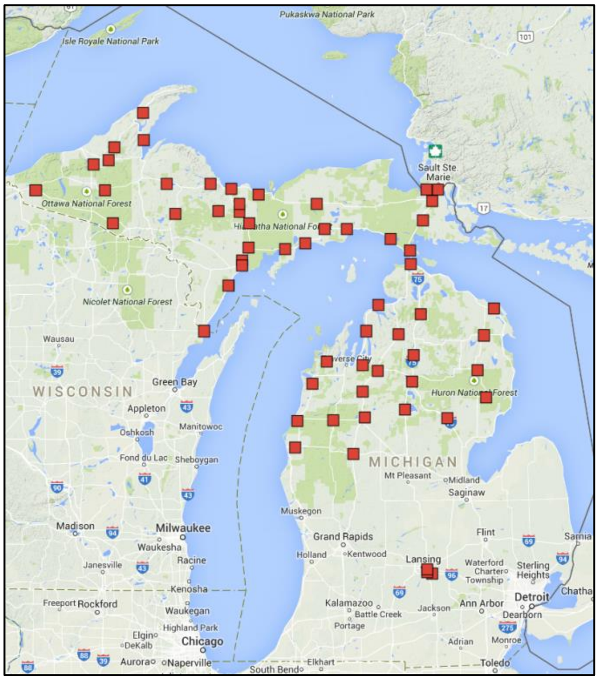


Figure 5-3: Current RWIS station distribution in Michigan

5.2 Additional weather stations

Currently, there are 59 and 74 weather stations in the RWIS and ASOS networks, respectively. The distributions of the stations in the current PMED and in the RWIS and ASOS are shown in Figure 5-4 and Figure 5-5. It can be seen that the RWIS stations and ASOS stations fill many gap areas currently in PMED. As shown in Figure 5-4, the density of the RWIS stations is higher in the Upper Peninsula and the northern part of the Lower Peninsula. If the climate zones are not well defined, the additional stations should foremost fill the gap regions of existing stations geographically. Based on this, fourteen potential stations were initially selected from the RWIS to fill the gap regions, as shown by the blue marks in Figure 5-4. However, the central part of the Lower Peninsula is still not well represented. As shown in Figure 5-5, all the stations in the PMED have the same geographical coordinates as the ASOS stations, indicating that these weather stations are located in the same airports. Fifteen additional stations were initially selected from the ASOS to fill the gap regions, as shown by the blue marks in Figure 5-5.

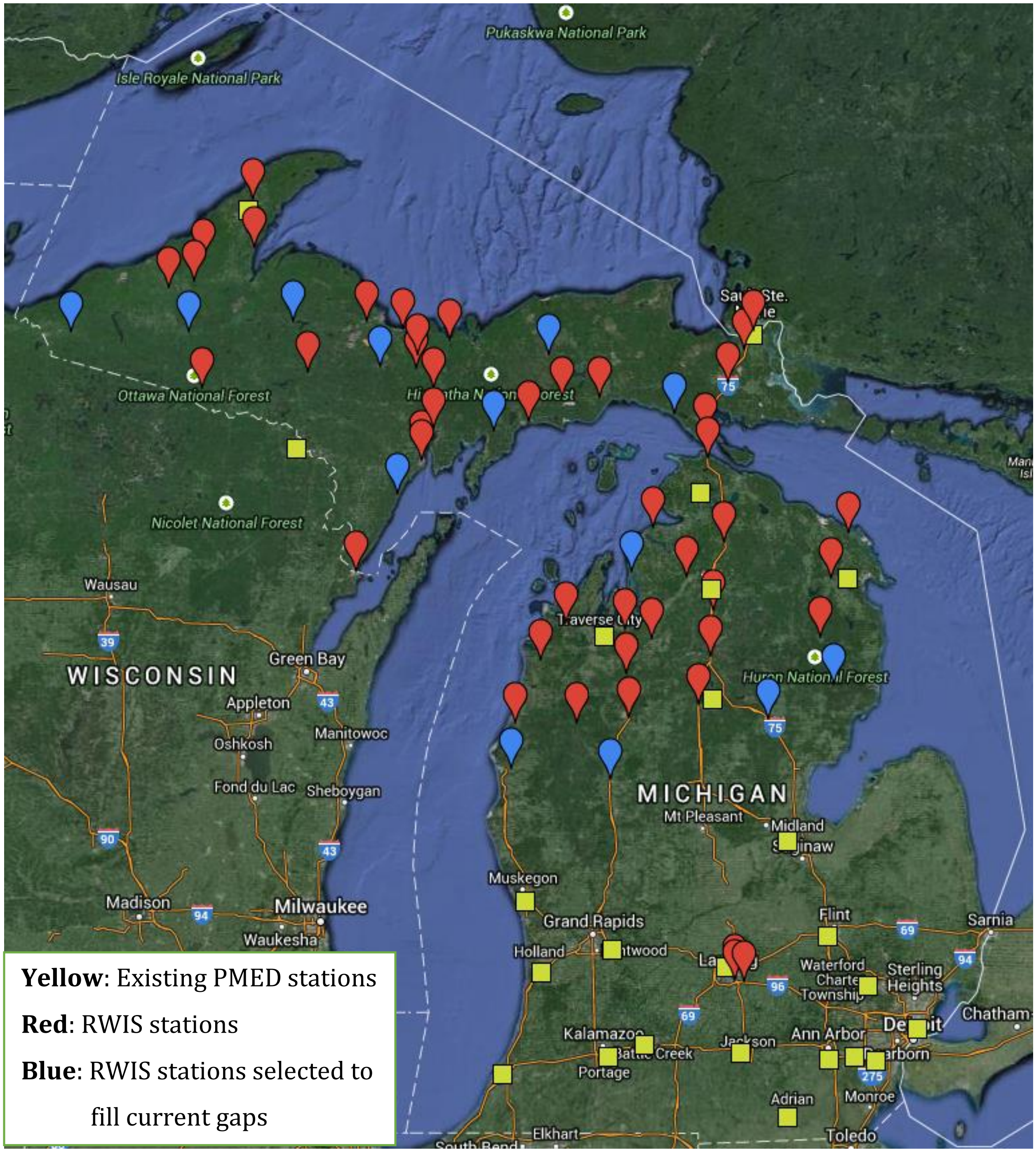


Figure 5-4: Potential locations for additional weather stations from RWIS

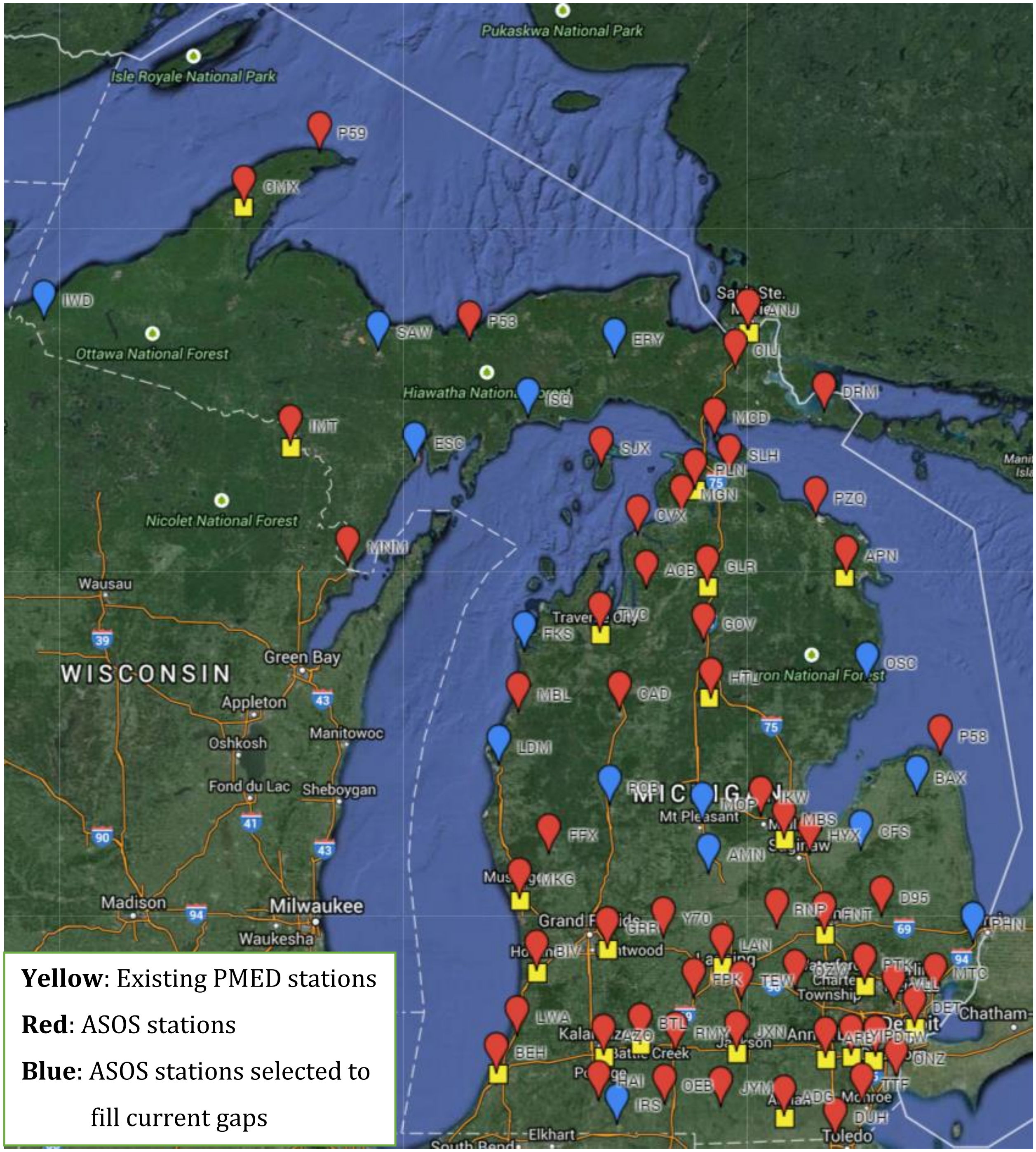


Figure 5-5: Potential locations for additional weather stations from ASOS

5.3 The ASOS climatic data compilation

As mentioned above, 15 additional weather stations have been selected from ASOS stations to fill the gap regions of existing stations. The climatic files can be downloaded from the Iowa

Environmental Mesonet [15]. Many of the stations contain historical data from year 1995 to 2014. However, many stations have continuous missing months for the first half of year 2000, presenting a challenge to use. To ensure the reliability and precision, the extracted climatic files starts from September or October 2000, depending on the data quality. The data end date is the end of the year 2014. Thus, most of the additional stations have about 14 years of data available for use in the PMED. In addition, it was found that precipitation data are missing for the three stations in the Upper Peninsula: SAW in Gwinn, ERY in Newberry, and ISQ in Manistique.

5.3.1 Climatic file download

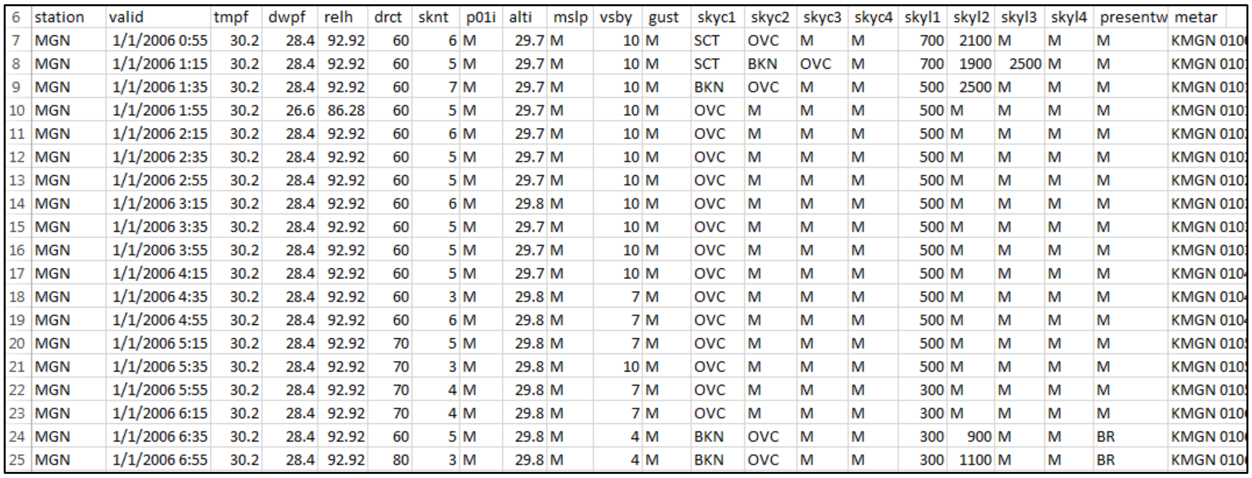
Six steps are required to download the climatic data from the Iowa Environmental Mesonet: 1) select the station; 2) select climatic variables; 3) specify date range; 4) select time zone; 5) select download option; and 6) get data. The time zone selection is a factor needing to be addressed here. Although the majority of Michigan is in the Eastern Time Zone, the research team recommends using the Universal Time and then shifting the data 5 hours backward, except for those in the Central Time Zone (e.g. Iron Mountain), which would be shifted back 6 hours. Universal Time is equivalent to Greenwich Mean Time, which is 5 hours ahead of the Eastern Standard Time. This addresses the issue of daylight savings time (DST). For instance, DST in 2015 starts at 2 am on March 8 and ends at the 2 am on November 1. If the Eastern Time zone is used, there would be a one hour missing on March 8 and one hour repeating on November 1. Thus, the DST data should be shifted backward by one hour to produce a continuous data set. However, since the dates of DST vary from one year to another, it would be more complicated to make this shift than consistently using the Universal Time.

5.3.2 Climatic file editing

Figure 5-6 shows an example of the original climatic file exported from the ASOS historical database and opened in MS Excel. With a number of unnecessary variables in the spreadsheet, the contents must be edited to satisfy the format requirements in the PMED. The editing process includes the following steps. The data editing was achieved by VBA programs.

1) Delete the non-essential variable columns to keep only the time and the five variables required in the PMED;
2) Delete the excessive rows. Most of the data were recorded at the minutes of 53, 55 or 56 of each hour. Thus, the data recorded at other times within the same hour are deleted.

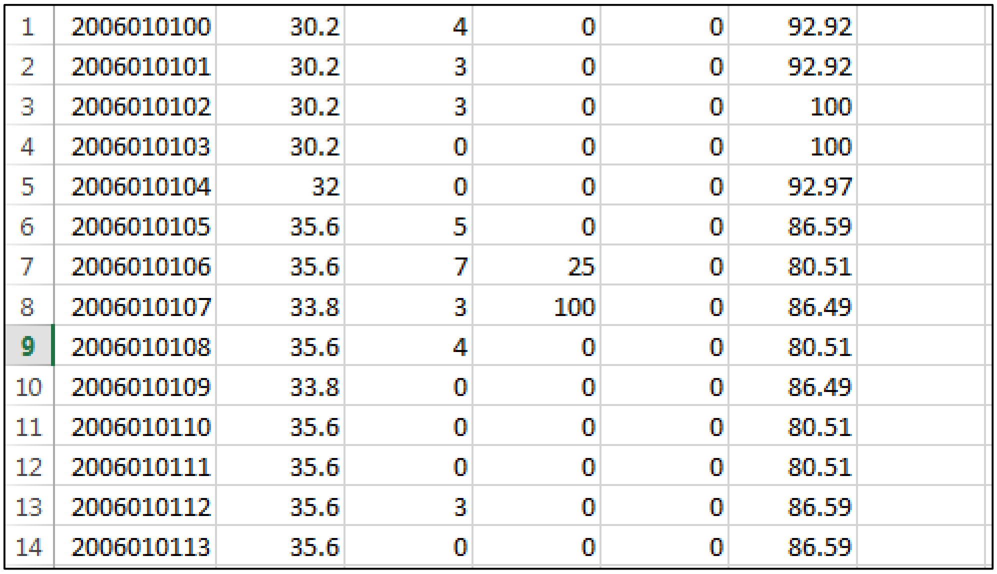
3) Some precipitation values are recorded as “M”. While the ASOS User’s Guide mentions that the “M” indicates a missing value [38], the research team found that the annual total precipitation of some selected stations are very close to that in the existing files if the “M” is represented as zero. The detailed comparison will be shown later.
4) Convert the cloud coverage to a specific value. In an ASOS climatic data file, the cloud coverage is represented as one of the following: “CLR”, “FEW”, “SCT”, “BKN”, “OBC”, and “VV”. The detailed representations are shown in Table 2-1. In addition, there are four layers of cloud coverage with different heights in the ASOS data. To calculate the percent sunshine, the highest cloud coverage of the four layers is selected for the cloud coverage representation.
5) Address the input of wind speed. It should be noted here although the unit of wind speed should be mph in the PMED, knot is actually used in existing files with which the PMED has been calibrated. The research team has verified this through comparing the newly downloaded data and the existing data. To be consistent with the existing data, knot is used in the newly downloaded climatic files.
6) Convert the time format to “yyyymmddhh” and make a backward shift of five hours (e.g. 2001050400 is changed to 2001050319).
7) Edit the precipitation column. A daily precipitation value is used and placed at the hour 12 pm in the MEPDG and PMED. In the ASOS raw data, the precipitation is an hourly value, so the daily precipitation should be calculated by an accumulation and placed at the hour 12 pm to match ME inputs.
8) Change the order of the five variables in the climatic files. In the NCDC climatic files, the order of the five parameters is temperature, wind speed, percent sunshine, precipitation and relative humidity. In the ASOS data files, the order is temperature, relative humidity, wind speed, precipitation, and percent sunshine. The file after the data editing is shown in Figure 5-7.
9) Convert the values of temperature, wind speed, percent sunshine, and relative humidity to integers. The existing climatic files uses integers for all the variables except for precipitation. A rounding-off method is used to convert the variable values into integers.



6	station	valid	tmpf	dwpf	relh	drct	sknt	p01i	alti	mslp	vsby	gust	skyc1	skyc2	skyc3	skyc4	skyl1	skyl2	skyl3	skyl4	presentw	metar
7	MGN	1/1/2006 0:55	30.2	28.4	92.92	60	6	M	29.7	M	10	M	SCT	OVC	M	M	700	2100	M	M	M	KMGN 010
8	MGN	1/1/2006 1:15	30.2	28.4	92.92	60	5	M	29.7	M	10	M	SCT	BKN	OVC	M	700	1900	2500	M	M	KMGN 010
9	MGN	1/1/2006 1:35	30.2	28.4	92.92	60	7	M	29.7	M	10	M	BKN	OVC	M	M	500	2500	M	M	M	KMGN 010
10	MGN	1/1/2006 1:55	30.2	26.6	86.28	60	5	M	29.7	M	10	M	OVC	M	M	M	500	M	M	M	M	KMGN 010
11	MGN	1/1/2006 2:15	30.2	28.4	92.92	60	6	M	29.7	M	10	M	OVC	M	M	M	500	M	M	M	M	KMGN 010
12	MGN	1/1/2006 2:35	30.2	28.4	92.92	60	5	M	29.7	M	10	M	OVC	M	M	M	500	M	M	M	M	KMGN 010
13	MGN	1/1/2006 2:55	30.2	28.4	92.92	60	5	M	29.7	M	10	M	OVC	M	M	M	500	M	M	M	M	KMGN 010
14	MGN	1/1/2006 3:15	30.2	28.4	92.92	60	6	M	29.8	M	10	M	OVC	M	M	M	500	M	M	M	M	KMGN 010
15	MGN	1/1/2006 3:35	30.2	28.4	92.92	60	5	M	29.7	M	10	M	OVC	M	M	M	500	M	M	M	M	KMGN 010
16	MGN	1/1/2006 3:55	30.2	28.4	92.92	60	5	M	29.7	M	10	M	OVC	M	M	M	500	M	M	M	M	KMGN 010
17	MGN	1/1/2006 4:15	30.2	28.4	92.92	60	5	M	29.7	M	10	M	OVC	M	M	M	500	M	M	M	M	KMGN 010
18	MGN	1/1/2006 4:35	30.2	28.4	92.92	60	3	M	29.8	M	7	M	OVC	M	M	M	500	M	M	M	M	KMGN 010
19	MGN	1/1/2006 4:55	30.2	28.4	92.92	60	6	M	29.8	M	7	M	OVC	M	M	M	500	M	M	M	M	KMGN 010
20	MGN	1/1/2006 5:15	30.2	28.4	92.92	70	5	M	29.8	M	7	M	OVC	M	M	M	500	M	M	M	M	KMGN 010
21	MGN	1/1/2006 5:35	30.2	28.4	92.92	70	3	M	29.8	M	10	M	OVC	M	M	M	500	M	M	M	M	KMGN 010
22	MGN	1/1/2006 5:55	30.2	28.4	92.92	70	4	M	29.8	M	7	M	OVC	M	M	M	300	M	M	M	M	KMGN 010
23	MGN	1/1/2006 6:15	30.2	28.4	92.92	70	4	M	29.8	M	7	M	OVC	M	M	M	300	M	M	M	M	KMGN 010
24	MGN	1/1/2006 6:35	30.2	28.4	92.92	60	5	M	29.8	M	4	M	BKN	OVC	M	M	300	900	M	M	BR	KMGN 010
25	MGN	1/1/2006 6:55	30.2	28.4	92.92	80	3	M	29.8	M	4	M	BKN	OVC	M	M	300	1100	M	M	BR	KMGN 010

Note: **tmpf**: temperature, ℉; **relh**: relative humidity; **sknt**: wind speed, knots; **p01i**: precipitation, inch; **skyc1**: sky level 1 coverage.

Figure 5-6:An example of climatic file in Lansing from ASOS station opened by MS Excel



1	2006010100	30.2	4	0	0	92.92	
2	2006010101	30.2	3	0	0	92.92	
3	2006010102	30.2	3	0	0	100	
4	2006010103	30.2	0	0	0	100	
5	2006010104	32	0	0	0	92.97	
6	2006010105	35.6	5	0	0	86.59	
7	2006010106	35.6	7	25	0	80.51	
8	2006010107	33.8	3	100	0	86.49	
9	2006010108	35.6	4	0	0	80.51	
10	2006010109	33.8	0	0	0	86.49	
11	2006010110	35.6	0	0	0	80.51	
12	2006010111	35.6	0	0	0	80.51	
13	2006010112	35.6	3	0	0	86.59	
14	2006010113	35.6	0	0	0	86.59	

Figure 5-7: The file after editing with user-written VBA program in MS Excel

5.3.3 Quality and quantity check of the ASOS data

The quantity and quality of the ASOS data determine how reliably it can be utilized in the PMED. The quantity of the data is affected by the potential missing or repeated months, days and hours. The quality of the data is affected by potential outliers and erroneous data. A preview of some downloaded climatic files showed that most of the climatic files have two missing months of data in March and April of 2000. In addition, we also found that there are quite a few missing days of data in the first eight months of 2000. Therefore, we downloaded the climatic data from

09/01/2000 to 12/31/2014 for the additional 14 weather stations. Some stations have historical data beginning later than 09/01/2000. In this case, the data range download would be from the earliest date to 12/31/2014. For existing weather stations, we downloaded the weather data from 03/01/2006 to 12/31/2014, since the existing climatic files end on 02/28/2006. The detailed procedure of how to download and edit the climatic files is shown in a separate file of the deliverables.

The climatic files from weather stations in Alma, Hancock and Big Rapids were selected as examples for the quantity and quality check. The quantity check results are shown in Table 5-1. As seen from this table, the climatic files from Alma, Hancock and Big Rapids have data lengths of 14, 8, and 14 years, respectively. As mentioned above, the reason we downloaded files for Hancock from 03/2006 is that the existing data ends in 02/2006. The total hours of these data are 122,765, 78,783, and 122,765, respectively. No entire month of missing data was found in the climatic files, but some missing days and hours of data were found. The total number of missing days is less than 30. We have verified in Chapter 3 that using the neighboring station data to fill an entire missing month of data in existing climatic files is feasible. Considering that the climatic files we downloaded here have longer records than the existing files, the effect of these missing days of data should be lower. There are a few hundreds of missing hours for all the three files, corresponding to 0.20%, 0.34%, and 0.35% missing data at the three stations, respectively. This amount of missing data is not expected to affect PMED results provided there is a reliable method for filling missing data.

The quality check results of the three stations are shown in Table 5-2. The amount of bad (erroneous or missing) data for each variable was listed. The amount of erroneous data for temperature is very low. The amount erroneous data for wind speed is slightly higher, corresponding to 1.07%, 2.47%, and 1.19% at the three stations, respectively. Hancock has a large amount of bad percent sunshine data because there are three entire years of percent sunshine data missing. The feasibility of using neighboring data to fill such a large amount of percent sunshine data will be discussed in the later sections.

Table 5-1: Quantity check of three randomly selected ASOS/AWOS stations

Stations	Time length	Missing months	Number of missing days	Number of missing hours
Alma	09/2000~12/2014	No	28	246
Hancock	03/2006~ 12/2014	No	7	270
Big Rapid	09/2000~12/2014	No	20	424

Table 5-2: Quality check of three randomly selected ASOS/AWOS stations

Stations	Number of bad data				
	Temperature	Wind speed	Percent sunshine	Precipitation	Relative humidity
Alma	129	1325	483	0	181
Hancock	192	1943	26,713*	0	195
Big Rapid	294	1465	458	0	374
*Note: More than three entire years of percent sunshine data is missing					

5.3.4 Missing data filling and erroneous data correction

The data filling and erroneous data correction operations for the additional ASOS data are much more complicated than for the existing climatic files due to the significantly larger numbers of missing and erroneous data. The missing data can be categorized into two groups: 1) entire days of missing data; 2) missing hours of data. First, the missing data were filled with data from neighboring stations. If the data in neighboring stations is also missing, the average data from the previous and next hours was used to fill the missing hour. If neighboring stations have entire days of missing data, then the data in the previous and next days was used to fill the entire day of missing data. The erroneous data correction procedure is the same as applied to the existing climatic files.

5.3.5 Evaluation on data source

Since the data length of existing climatic files will be extended and additional weather stations will be added, and the original data source of the existing files is unknown, it is important that the data source of the newly downloaded ASOS climatic files is the same as that of the existing NCDC climatic files. To evaluate the data source consistency, existing files and the newly downloaded files from four stations were selected for a comparison: Lansing, Detroit, Gaylord and Hancock. For this analysis, the data range is from January 2001 to December 2005 (5 entire years), considering that all the existing climatic files end in February 2006. Table 5-3 shows some comparison results between the existing climatic files (from NCDC) and the ASOS files. The comparisons include the average annual value, standard deviation and the coefficient of determination (square of correlation coefficient, denoted as R^2) of all individual climate variables. It was found that both the average annual value and the standard deviation from existing files and the ASOS files are very close to each other. In fact, the majority of the data sets are exactly the same to each other. This is evidence that the ASOS climatic files downloaded from the IEM and the data from existing files are from the same source database. Figure 5-8 presents a direct comparison for the five variables in Gaylord as an example. It can be found the two data sets have a high correlation coefficient. The only perceptible difference between the existing data and the ASOS data is the precipitation. The average annual precipitation in the ASOS data is about 5% lower than that in the existing files. One reason for this is that the ASOS data only record the precipitation when it is higher than 0.01 inch, while some precipitation values in the existing files are 0.001 inch. As a result, the ASOS data has a lower average annual precipitation. Nevertheless, the sensitivity analysis in Chapter 4 has shown that the design results using PMED are not sensitive to precipitation. Specifically, according to the analysis in Chapter 4, a 5% change in precipitation results in distress prediction changes less than 1%, which is negligible. Thus, it is safe to use the ASOS data downloaded from the IEM for additional weather stations and for extending existing data records. The percent sunshine comparison looks scattered and yet has an R^2 of 0.9946. The reason of this is that most of the percent sunshine values are 0, 25, 50, 75, and 100, so the data points overlap in the graph. In fact, only about 150 out of the 43,824 data points of percent sunshine from ASOS and existing files were not the same.

Table 5-3: Comparison of the average annual value (AVGE), standard deviation (STD), and coefficient of determination (R^2) between the existing data and the data from ASOS for the four stations

Variables		Temperature		Wind speed		Percent sunshine		Precipitation		Relative humidity	
Sources		NCDC	ASOS	NCDC	ASOS	NCDC	ASOS	NCDC	ASOS	NCDC	ASOS
Gaylord	AVGE	43.60	43.60	6.77	6.77	47.23	47.11	36.08	34.00	75.30	75.09
	STD	20.52	20.52	4.55	4.55	46.16	46.2	1.96	2.75	18.40	18.46
	R^2	0.999		0.997		0.995		0.921		0.998	
Detroit	AVGE	50.80	50.85	7.26	7.26	54.79	54.77	33.26	31.23	67.98	67.76
	STD	19.78	19.75	4.13	4.14	45.82	45.86	3.95	4.01	17.05	17.08
	R^2	0.993		0.996		0.996		0.938		0.997	
Lansing	AVGE	48.51	48.52	7.71	7.71	33.06	33	36.33	34.59	73.09	72.87
	STD	20	20	4.73	4.73	36.44	36.45	5.70	5.13	17.23	17.28
	R^2	0.999		0.998		0.997		0.957		0.999	
Hancock	AVGE	40.70	40.71	8.57	8.57	46.26	46.02	20.86	19.33	76.64	76.43
	STD	20.32	20.32	5.54	5.54	46.69	46.74	2.36	2.12	16.48	16.55
	R^2	0.999		0.996		0.991		0.970		0.998	

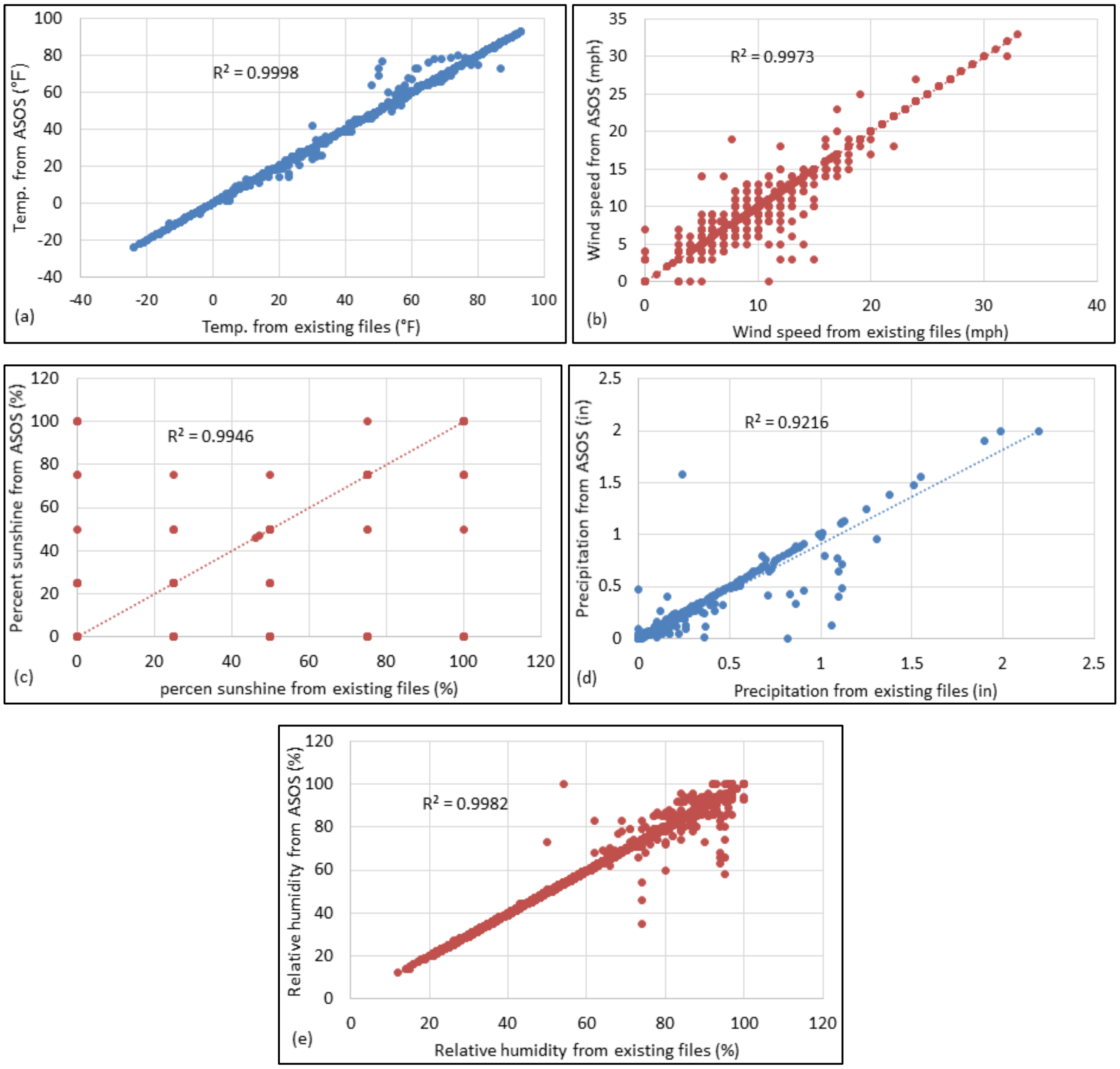


Figure 5-8: Comparison between the existing climatic files and the files from ASOS for Gaylord: (a) Temperature (deg. F), (b) Wind speed (mph), (c) Percent sunshine (%), (d) Precipitation (in), (e) Relative humidity (e). Note that Percent sunshine has many overlapping data points at values of 0%, 25%, 50%, 75%, and 100%, which leads to the high R^2 value.

5.3.6 Verification of data filling and correction quality

In Chapter 3, we have analyzed the data filling and correction quality in existing climatic files. In this section, we are doing the verification of data filling and correction quality for the newly added ASOS climatic files. The above section has shown that the ASOS data downloaded from the IEM can be used to extend existing data records and add weather stations to PMED. The next step is to prove that the data filling and correction method proposed above is acceptable as well. From the data quantity and quality check, the main concerns of the ASOS climatic files are the missing days and missing hours. Some of the missing days or missing hours can be filled with data from neighboring stations, while some others cannot because these days are also missing at the neighboring stations. To verify the missing data filling method, some entire days and hours are manually deleted from complete climatic files and then these days and hours are filled using the approach described in Section 5.3.4. The amount of each type of missing data is first estimated to determine the amount of data to be deleted in the tests. If the missing days cannot be filled with data from neighboring stations, they are filled with the average of the previous and subsequent days. A similar method is used for the missing hours which cannot be filled with data from neighboring stations. If subsequent data is also missing, only the data in the previous hour is used. Following a review of the missing ASOS data, the following four cases were tested:

1) <u>Missing days which can be filled with neighboring data</u>. Ten missing days were randomly selected for evaluating the filling procedure.
2) <u>Missing days which cannot be filled with neighboring data</u>. Ten missing days were randomly selected for evaluating the filling procedure.
3) <u>Missing or erroneous hours which can be filled with neighboring data</u>. One thousand (1000) missing hours were randomly selected for evaluating the filling procedure.
4) <u>Missing or erroneous hours which cannot be filled with neighboring data</u>. One thousand (1000) missing hours were randomly selected for evaluating the filling procedure.

Four stations were selected to evaluate the filling procedure: Frankfort, Oscoda, Detroit, and Lansing. The locations of the four stations and their neighboring stations are shown in Figure 5-9. The green arrows indicate the four stations and their neighbors. In each of the four climatic files, 20 entire days and 2000 hours were manually deleted, including all of the five variables. The first 10 days and 1000 hours were filled with the data from the neighboring stations. The other 10 days and 1000 hours were filled using the previous/subsequent days and previous/subsequent hours, respectively. The missing data percentage of the four stations ranges from 1.6% to 2.8%. New climatic files were generated after the missing data was filled. These corrected files and the original files were imported into the PMED to compare the distress predictions. The comparison results are shown in Table 5-5 and Table 5-6. The distress predictions using the original and modified climatic files were very close. Most of the distress prediction differences were lower than 1%. Prediction differences of 4.06% and 3.45% for thermal cracking and AC rut, respectively, were observed in Lansing. Although the two values are higher than others, these values are lower than 5% and are acceptable. The maximum difference of distress predictions for concrete pavement is 0.5%, which is at a very low level. Therefore, it is safe to use the proposed method to fill the missing data in the original ASOS climatic files. Based on this approach, 15 additional climatic files were generated, most of which start from 2001 and end in 2014. In addition, all the existing climatic files have been extended from 02/28/2006 to 12/31/2014 based on the filling and correction approaches described above.

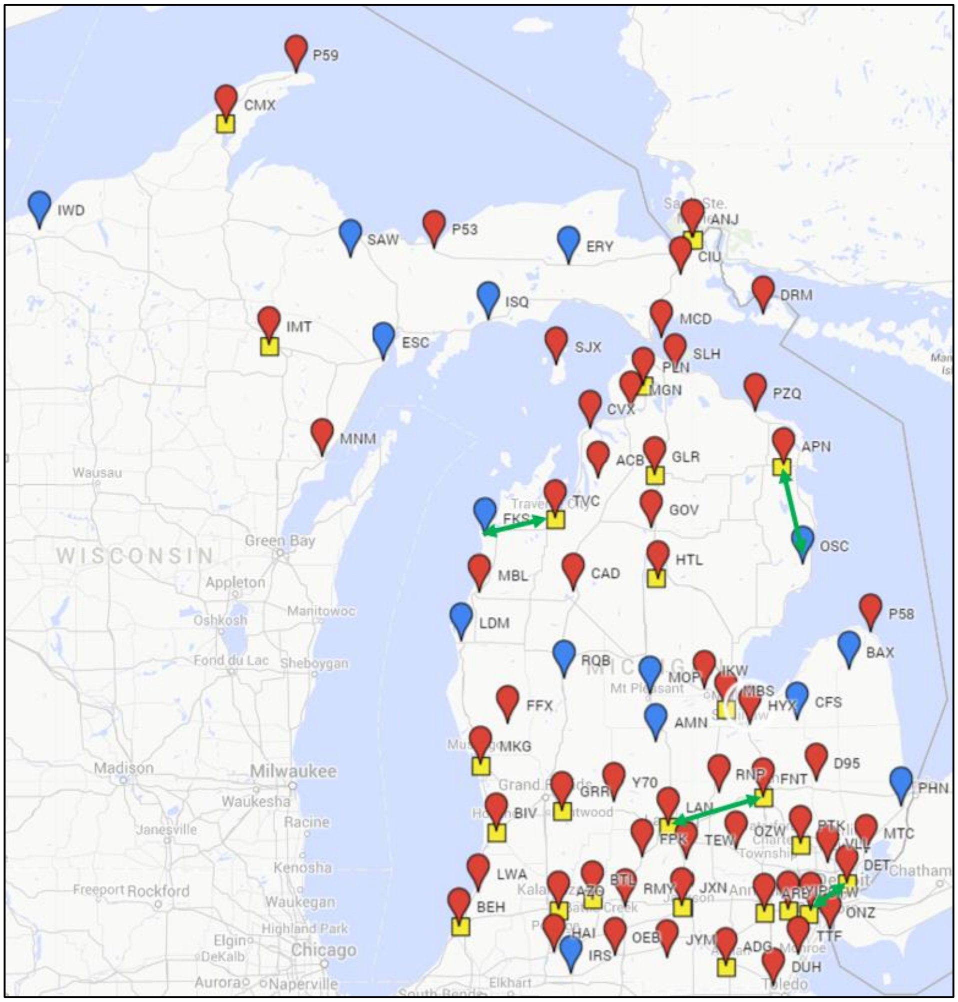


Figure 5-9: The locations of the four stations used for the data filling and correction evaluation (neighboring stations: FKS and TVC; APN and OSC; LAN and FNT; DTW and DET)

Table 5-4: Information of the four stations used to evaluate the data filling and correction quality

Stations	Data length (month)	Neighboring station	Percent of missing/ erroneous data (%)
FKS (Frankfort)	124	TVC (Traverse City)	2.8
OSC (Oscoda)	172	APN (Alpena)	2.0
DET (Detroit)	171	DTW (Detroit/Wayne)	2.0
LAN (Lansing)	222	FNT (Flint)	1.6

Table 5-5: Comparison of distress predictions for flexible pavement using the original data and corrected data

Distress Predictions		IRI	Total Rutting	Bottom-up Cracking	Thermal Cracking	Top-down Cracking	AC rutting
OSC	Original	170.19	0.92	4.85	2020.26	311.50	0.31
	Corrected	170.25	0.92	4.85	2016.92	311.62	0.31
	Difference	0.04%	0.00%	0.00%	0.17%	0.04%	0.00%
DET	Original	164.05	1.01	5.43	85.66	331.99	0.38
	Corrected	164.00	1.01	5.43	85.78	331.87	0.38
	Difference	0.03%	0.00%	0.00%	0.14%	0.04%	0.00%
LAN	Original	164.15	0.92	5.19	709.6	313.39	0.29
	Corrected	163.98	0.93	5.19	680.8	313.66	0.30
	Difference	0.10%	1.09%	0.00%	4.06%	0.09%	3.45%
FKS	Original	155.86	0.95	4.95	83.38	311.51	0.34
	Corrected	156.19	0.95	4.95	83.38	311.37	0.34
	Difference	0.21%	0.00%	0.00%	0.00%	0.04%	0.00%

Table 5-6: Comparison of distress predictions for concrete pavement using the original and corrected data

Distress Predictions		IRI	Joint faulting	Transverse cracking
OSC	Original	182.84	0.04	4.25
	Corrected	183.84	0.04	4.25
	Difference	0.5%	0.0%	0.0%
DET	Original	153.68	0.05	4.25
	Corrected	153.64	0.05	4.25
	Difference	0.0%	0.0%	0.0%
LAN	Original	170.28	0.05	3.83
	Corrected	170.5	0.05	3.83
	Difference	0.1%	0.0%	0.0%
FKS	Original	145.41	0.02	3.83
	Corrected	145.51	0.02	3.83
	Difference	0.1%	0.0%	0.0%

5.3.7 Feasibility of using neighboring data to fill large amount of missing data for percent sunshine and precipitation

There are three entire years of percent sunshine missing at the stations of CMX, SAW, ESC, ISQ, and ERY in the Upper Peninsula. In addition, all the precipitation data at the stations of SAW, ESC, ISQ and ERY are missing. These missing data should be filled before they can be used. Since it has been found that Michigan pavement designs are not sensitive to the percent sunshine and precipitation, it is possible to use data from others stations in the Upper Peninsula to fill this missing data. The airport names and locations of these weather stations are shown in Table 5-7.To evaluate the effect of using the neighboring data, the stations in Iron Mountain (IMT) and Sault Ste. Marie (ANJ) were selected, since the four stations with missing percent sunshine and precipitation data are located between these two stations. The data ranges of IMT and ANJ are 11/1996-12/2014 and 01/1997-12/2014, respectively, and thus they have the data range from 01/1997-12/2014 in common. The average annual percent sunshine and precipitation in the two stations were shown in Table 5-8. The percent sunshine and precipitation differences between the two stations were 2.4% and 10.5 inches, respectively. The precipitation difference is close to the maximum difference among all the stations of Michigan in the PMED. If such a different precipitation has little effect on the distress predictions, there would be confidence to use neighboring data to fill the missing precipitation records. The percent sunshine data was swapped between IMT and ANJ, while keeping the other data the same (the actual data measured at that station). A similar swap was done with the precipitation data. The description of the data replacement is shown in Table 5-9. The typical Michigan flexible and rigid pavements under the medium traffic level were run using these swapped files. In addition, the slab thickness of the rigid pavement was reduced from 10 inches to 8 inches to allow some transverse cracking since none was observed during the original runs of these designs. The distress predictions using Files 1, 2 and 3 were then compared, and the results are shown in Table 5-10 and Table 5-11, respectively. These comparisons show that even if all the percent sunshine data or precipitation data from 1997 to 2014 are replaced, the distress predictions are still very close. The only perceptible difference is the transverse cracking of ANJ after the percent sunshine is changed. The relative difference is 5.23%, which is still acceptable. These results are not surprising because that the weather stations in the Upper Peninsula have similar weather patterns and percent sunshine and precipitation are not critical variables for flexible pavement design. This indicates that it is feasible to use the data from either IMT or ANJ percent sunshine and precipitation data for the four stations in the Upper Peninsula. Considering that the difference of percent sunshine between IMT and ANJ is very low, the percent sunshine in IMT was used to fill the SAW, ESC, and ISQ, while that in ANJ was used to fill the ERY. The original missing is from 01/2007 to 01/2010.In addition, with the recognition that precipitation difference between IMT and CIU is kind of high, the precipitation data of the four stations were obtained through weighted average of these in IMT and CIU. Details of the precipitations are here based on their relative distances:

SAW=2/3*IMT+1/3*ANJ
ESC=2/3*IMT+1/3*ANJ
ISQ=1/2*IMT+1/2*ANJ
ERY=1/3*IMT+2/3*ANJ

Table 5-7: List of airport ID and their names and locations in Michigan

Airport ID	Airport Name	Location
CMX	Houghton County Memorial Airport	Calumet, MI
SAW	Sawyer International Airport	Gwinn, MI
ESC	Delta County Airport	Escanaba, MI
ISQ	Schoolcraft County Airport	Manistique, MI
ERY	Luce County Airport	Newberry, MI
IWD	Gogebic Iron County Airport	Ironwood, MI
FKS	Frankfort Dow Memorial Field Airport	Frankfort, MI
LDM	Mason County Airport	Ludington, MI
RQB	Roben-Hood Airport	Big Rapids, MI
MOP	Mt Pleasant Municipal Airport	Mt Pleasant, MI
AMN	Gratiot Community Airport	Alma, MI
OSC	Oscoda-Wurtsmith Airport	Oscoda, MI
BAX	Huron County Memorial Airport	Bad Axe, MI
CFS	Tuscola Area Airport	Caro, MI
PHN	St. Clair County International Airport	Smiths Creek, MI
IRS	Kirsch Municipal Airport	Sturgis, MI

Table 5-8: Average precipitation and percent sunshine of the two stations

Stations	Average annual % sunshine	Average annual precipitation (in)
IMT	49.9	21.9
ANJ	47.5	32.4

Table 5-9: Data replacement of percent sunshine and precipitation between the files

Stations	File 1	File 2	File 3
IMT	Original data	All percent sunshine data from 1997 to 2014 is replaced by that in ANJ; others kept same	All precipitation data from 1997 to 2014 is replaced by that in ANJ; others kept same
ANJ	Original data	All percent sunshine data from 1997 to 2014 is replaced by that in IMT; others kept same	All precipitation data from 1997 to 2014 is replaced by that in IMT; others kept same

Table 5-10: The comparisons of distress predictions for flexible pavement using Files 1, 2 and 3

Stations	IRI	Total rutting	Bottom-up cracking	Thermal cracking	Top-down cracking	AC rutting
ANJ	176.1	0.92	5.09	2414	345	0.28
ANJ-2*	175.6	0.91	5.08	2375	342.6	0.27
ANJ-3**	174.9	0.91	4.92	2403	334	0.28
IMT	178.1	0.96	5.11	2476	343	0.32
IMT-2*	177.3	0.96	5.13	2341	341	0.32
IMT-3**	179.2	0.96	5.29	2488	359	0.32
*: all percent sunshine data is replaced; **: all precipitation data is replaced						

Table 5-11: The comparisons of distress predictions for rigid pavement using Files 1, 2 and 3

Stations	IRI	Joint faulting	Transverse cracking
ANJ	160.49	0.07	6.11
ANJ-2*	160.18	0.07	5.79
ANJ-3**	159.61	0.07	6.13
IMT	172.53	0.08	6.61
IMT-2*	172.75	0.08	6.56
IMT-3**	173.77	0.08	6.56
*: all percent sunshine data is replaced; **: all precipitation data is replaced			

Based on this analysis, the large amount of missing data for percent sunshine and precipitation in the Upper Peninsula was filled with data from stations IMT and ANJ. The four weather stations in the Upper Peninsula were then added to PMED. The full distribution of the existing and new weather stations is shown in Figure 5-10.

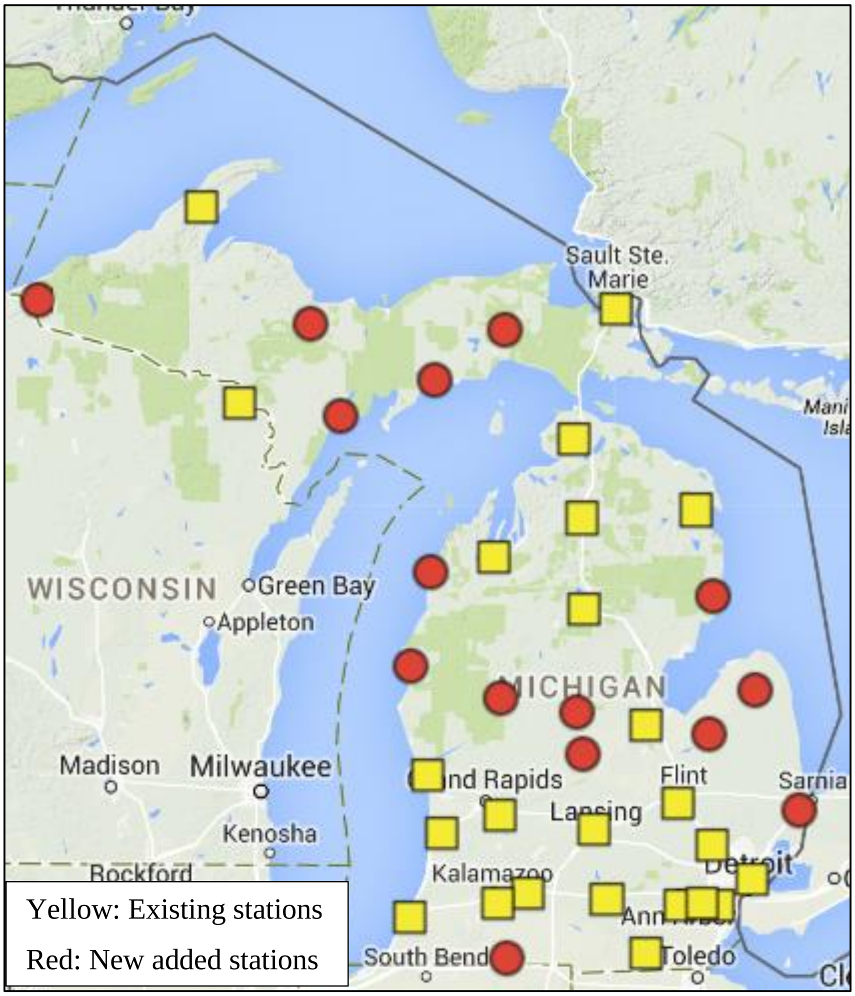


Figure 5-10: Existing stations and the newly added stations in Michigan

5.4 RWIS climatic data compilation

5.4.1 Obtaining climatic file

Since the RWIS weather data is operated by MDOT, the climatic files of the RWIS data can be obtained directly from MDOT. The research team has obtained two such files (Calumet and Waters) with a data length of one entire year. The file format is text which can be opened and edited in MS Excel.

5.4.2 Climatic file editing

Similar as the ASOS data, the RWIS climatic files also need to be edited for incorporation into the PMED. Figure 5-11 shows an example of the RWIS climatic data file opened in MS Excel.

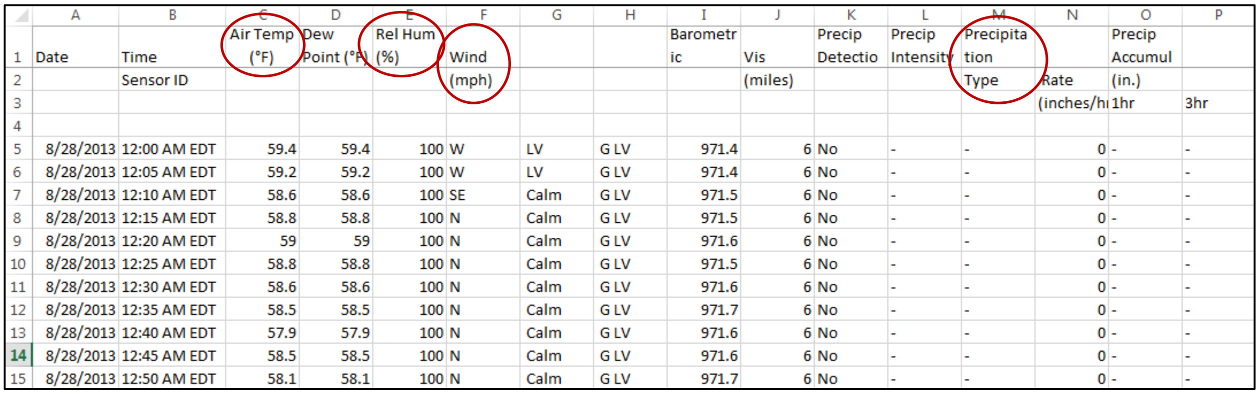
To convert a RWIS climatic data file to a file that can be directly used in the PMED, the following steps need to be taken:

1) Delete all the unnecessary columns and keep only the ones with the air temperature, wind speed, precipitation, and relative humidity.
2) The precipitation in the RWIS climatic data file is recorded by rate (inches per hour) on a five-minute basis. This needs to be accumulated to an hourly precipitation. The precipitation depth in each hourly interval is calculated as:

$$hourly\ precipitation = \sum_{1}^{12} precipitation\ rate \times 5/60$$

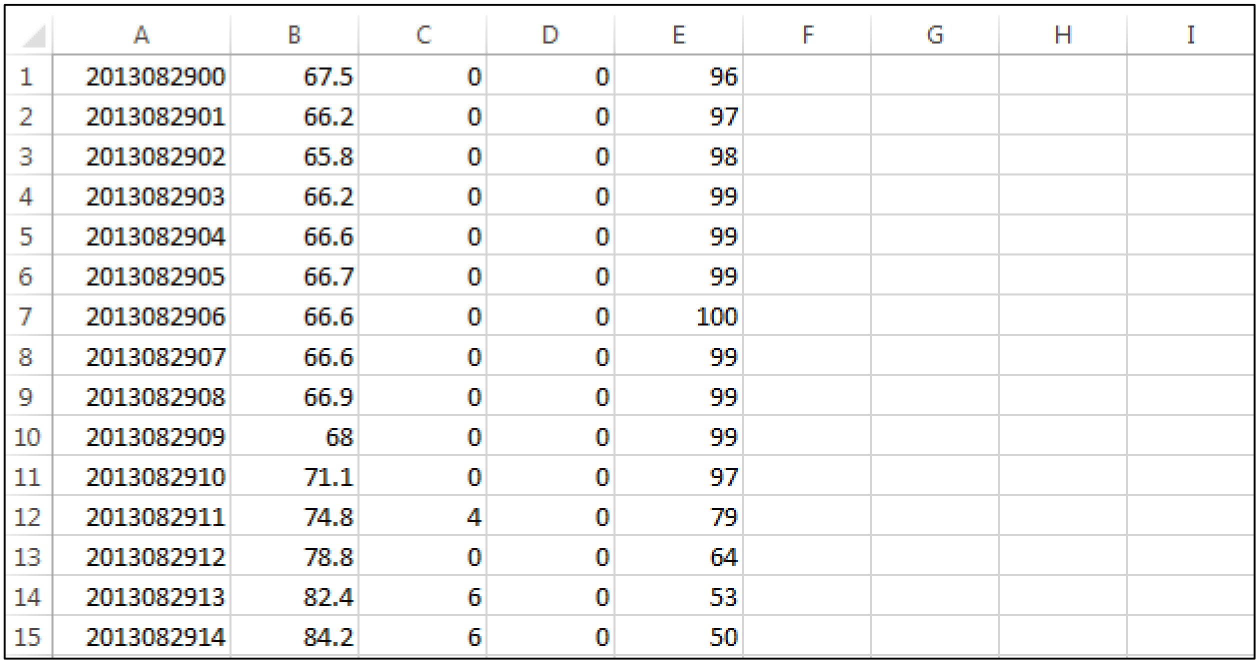
3) The hourly precipitation shall then be accumulated to a daily precipitation and put at the hour 12 pm to meet the requirement of the EICM.
4) Delete unnecessary rows and keep only the ones recorded at the “00” minute of each hour.
5) Edit the date and time to a format of “yyyymmddhh”.
6) Some of the wind speed values are represented by “LV” and “Calm”, which are regarded as zero.
7) Re-order the four variables as required by the PMED software.

All these steps were achieved using the user-written VBA programs. The VBA code is shown in Appendix C, Code 8. An example file after this editing process is shown in Figure 5-12. The four variables are in the order required by the PMED, and a new climatic file can be produced with the addition of percent sunshine. The percent sunshine can be added from the neighboring stations of the existing files or ASOS files. If MDOT has a plan to add devices to measure the cloud coverage in the future, the percent sunshine can be incorporated directly. It is easy to add percent sunshine data from ASOS weather stations close to a RWIS station. The detailed procedure to compiling the ASOS data has been described in Section 5.3. If an ASOS climatic data file has been compiled, a user can open the ASOS file and the RWIS file in MS Excel and simply copy the percent sunshine column from the ASOS file and paste into the RWIS file manually.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	Date	Time	Air Temp (°F)	Dew Point (°F)	Rel Hum (%)	Wind			Barometric	Vis	Precip Detectio	Precip Intensity	Precipitation		Precip Accumul	
2		Sensor ID				(mph)				(miles)			Type	Rate	(in.)	
3														(inches/hı	1hr	3hr
4																
5	8/28/2013	12:00 AM EDT	59.4	59.4	100	W	LV	G LV	971.4	6	No	-	-	0	-	-
6	8/28/2013	12:05 AM EDT	59.2	59.2	100	W	LV	G LV	971.4	6	No	-	-	0	-	-
7	8/28/2013	12:10 AM EDT	58.6	58.6	100	SE	Calm	G LV	971.5	6	No	-	-	0	-	-
8	8/28/2013	12:15 AM EDT	58.8	58.8	100	N	Calm	G LV	971.5	6	No	-	-	0	-	-
9	8/28/2013	12:20 AM EDT	59	59	100	N	Calm	G LV	971.6	6	No	-	-	0	-	-
10	8/28/2013	12:25 AM EDT	58.8	58.8	100	N	Calm	G LV	971.5	6	No	-	-	0	-	-
11	8/28/2013	12:30 AM EDT	58.6	58.6	100	N	Calm	G LV	971.6	6	No	-	-	0	-	-
12	8/28/2013	12:35 AM EDT	58.5	58.5	100	N	Calm	G LV	971.7	6	No	-	-	0	-	-
13	8/28/2013	12:40 AM EDT	57.9	57.9	100	N	Calm	G LV	971.6	6	No	-	-	0	-	-
14	8/28/2013	12:45 AM EDT	58.5	58.5	100	N	Calm	G LV	971.6	6	No	-	-	0	-	-
15	8/28/2013	12:50 AM EDT	58.1	58.1	100	N	Calm	G LV	971.7	6	No	-	-	0	-	-

Figure 5-11: Example of a climatic data file from a RWIS station opened by MS Excel



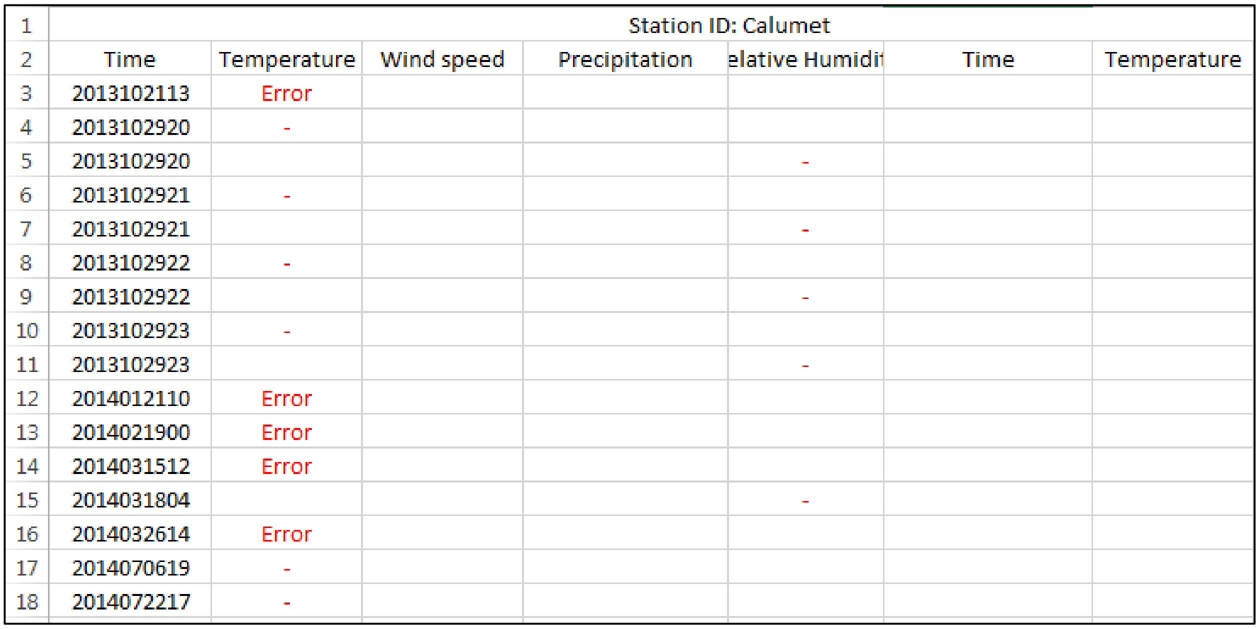
	A	B	C	D	E	F	G	H	I
1	2013082900	67.5	0	0	96				
2	2013082901	66.2	0	0	97				
3	2013082902	65.8	0	0	98				
4	2013082903	66.2	0	0	99				
5	2013082904	66.6	0	0	99				
6	2013082905	66.7	0	0	99				
7	2013082906	66.6	0	0	100				
8	2013082907	66.6	0	0	99				
9	2013082908	66.9	0	0	99				
10	2013082909	68	0	0	99				
11	2013082910	71.1	0	0	97				
12	2013082911	74.8	4	0	79				
13	2013082912	78.8	0	0	64				
14	2013082913	82.4	6	0	53				
15	2013082914	84.2	6	0	50				

Figure 5-12: MS Excel file after editing with a user-written VBA program

5.4.3 Quality and quantity check

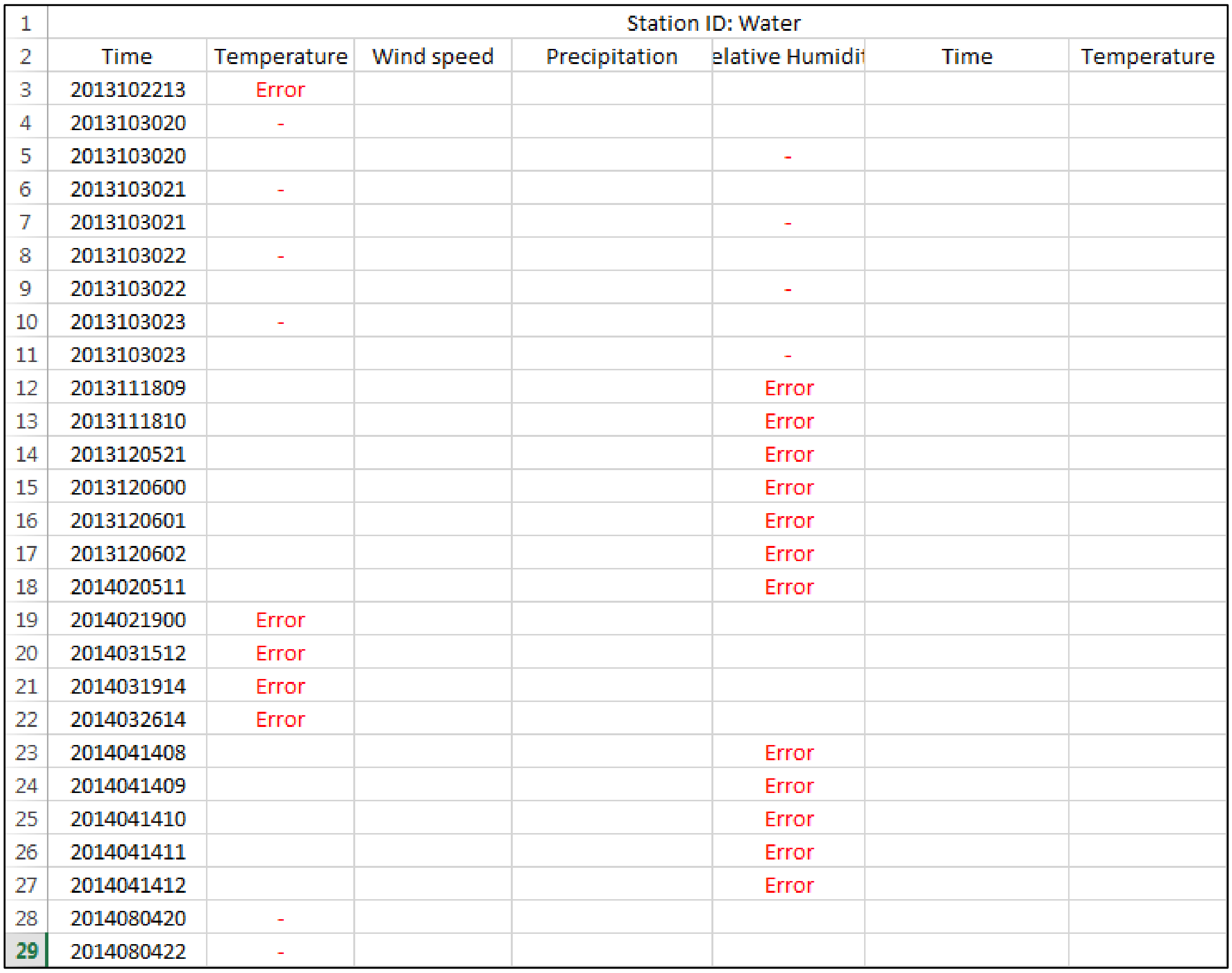
The quality and quantity of the RWIS files were verified. The procedures for these checks were the same as for existing climatic data files, as described in Chapter 3. The quality check includes checking for outliers and errors. The detailed criteria for the quality check are described in the Section 3.2. The quality check results for the two RWIS climatic data files are shown in Figure 5-13 and Figure 5-14. It was found that there are some erroneous data denoted as "error" or "-" in both the files. The research team read through the original climatic file and found that

“-”indicates “missing,” i.e., there was no data recorded at that time. There are a total of 16 and 27 erroneous data in the climatic files collected at Calumet and Waters, respectively. No outliers or dramatic hourly temperature changes (>30℉) were found in the two files.



1	Station ID: Calumet						
2	Time	Temperature	Wind speed	Precipitation	elative Humidit	Time	Temperature
3	2013102113	Error					
4	2013102920	-					
5	2013102920				-		
6	2013102921	-					
7	2013102921				-		
8	2013102922	-					
9	2013102922				-		
10	2013102923	-					
11	2013102923				-		
12	2014012110	Error					
13	2014021900	Error					
14	2014031512	Error					
15	2014031804				-		
16	2014032614	Error					
17	2014070619	-					
18	2014072217	-					

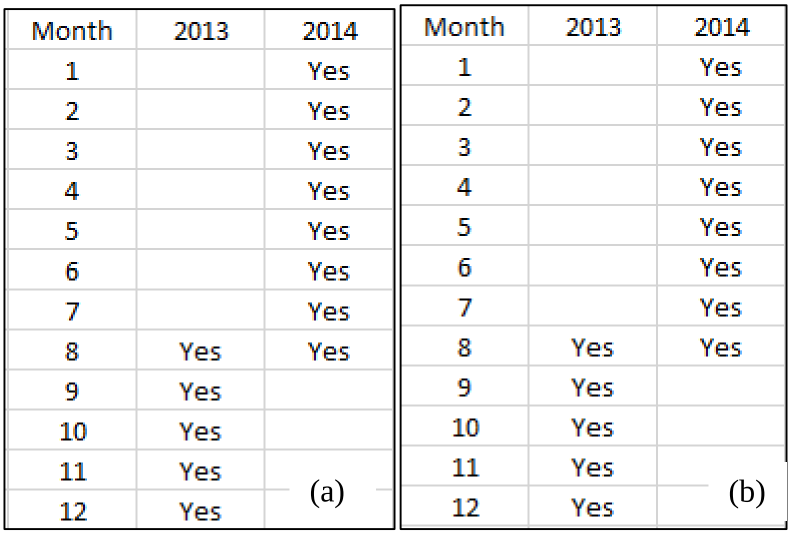
Figure 5-13: Quality check results for the RWIS climatic data file collected at Calumet



1	Station ID: Water						
2	Time	Temperature	Wind speed	Precipitation	elative Humidit	Time	Temperature
3	2013102213	Error					
4	2013103020	-					
5	2013103020				-		
6	2013103021	-					
7	2013103021				-		
8	2013103022	-					
9	2013103022				-		
10	2013103023	-					
11	2013103023				-		
12	2013111809				Error		
13	2013111810				Error		
14	2013120521				Error		
15	2013120600				Error		
16	2013120601				Error		
17	2013120602				Error		
18	2014020511				Error		
19	2014021900	Error					
20	2014031512	Error					
21	2014031914	Error					
22	2014032614	Error					
23	2014041408				Error		
24	2014041409				Error		
25	2014041410				Error		
26	2014041411				Error		
27	2014041412				Error		
28	2014080420	-					
29	2014080422	-					

Figure 5-14: Quality check results for the RWIS climatic data file collected at Waters

The quantity check of the RWIS climatic files mainly includes the check of missing months, days and hours. In the missing month check, if there is a missing month, it would be highlighted in red. In the missing days and hours check, if there is a missing day or hour, the two successive data spanning the missing data period are shown. The quantity check was conducted by the user-written VBA programs, and the results are shown in Figure 5-15 and Figure 5-16. It was found that both the climatic files have 12 months of data, and there is no missing month within them, as shown in Figure 5-15. However, there are some missing days and hours in the two files. In Figure 5-16 (b), date1 and date2 are two successive data. It can be found that date1 is 03/22/2014, while the next data is for 03/26/2014, and thus there are three days of data missing in the file. Similarly, hour1 and hour2 are two successive data points, indicating that there are some missing hours in both the climatic files. The total missing hours in the first and second RWIS files are 22 and 36, for Calumet and Waters respectively. In addition, three entire days of missing data was found in the Waters climatic file. Considering there are 8760 hours a year, this amount of missing hours is very low, and the data filling using the method described above should be very reliable. Entire days of missing data can be filled with the data from neighboring stations. Repeated hours were also found in both the files--the hour of 2013110301 in the first file and the hour of 2013110401 in the second file appear twice. This is due to daylight savings time. It was also found that there is a missing hour at 2014031002, which is the beginning of daylight savings time in 2014. As a result, a one-hour shift needs to be made for the daylight savings time to make the data record continuous. This can require manual data editing because the dates of daylight saving time vary in different years.



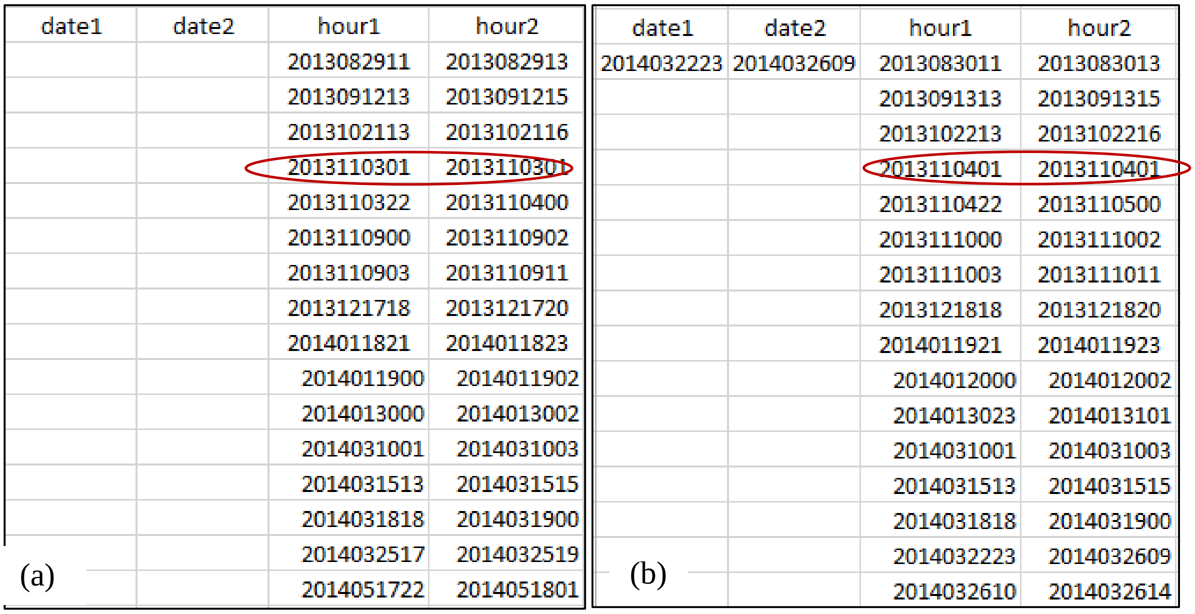
Month	2013	2014
1		Yes
2		Yes
3		Yes
4		Yes
5		Yes
6		Yes
7		Yes
8	Yes	Yes
9	Yes	
10	Yes	
11	Yes	
12	Yes	

(a)

Month	2013	2014
1		Yes
2		Yes
3		Yes
4		Yes
5		Yes
6		Yes
7		Yes
8	Yes	Yes
9	Yes	
10	Yes	
11	Yes	
12	Yes	

(b)

Figure 5-15: Missing month check results of the two climatic files: a) RWIS station at Calumet; and b) RWIS station at Waters



(a)

date1	date2	hour1	hour2
		2013082911	2013082913
		2013091213	2013091215
		2013102113	2013102116
		2013110301	2013110301
		2013110322	2013110400
		2013110900	2013110902
		2013110903	2013110911
		2013121718	2013121720
		2014011821	2014011823
		2014011900	2014011902
		2014013000	2014013002
		2014031001	2014031003
		2014031513	2014031515
		2014031818	2014031900
		2014032517	2014032519
		2014051722	2014051801

(b)

date1	date2	hour1	hour2
2014032223	2014032609	2013083011	2013083013
		2013091313	2013091315
		2013102213	2013102216
		2013110401	2013110401
		2013110422	2013110500
		2013111000	2013111002
		2013111003	2013111011
		2013121818	2013121820
		2014011921	2014011923
		2014012000	2014012002
		2014013023	2014013101
		2014031001	2014031003
		2014031513	2014031515
		2014031818	2014031900
		2014032223	2014032609
		2014032610	2014032614

Figure 5-16: The missing days and hours check of the two climatic files: a) RWIS station at Calumet; and b) RWIS station at Waters

5.4.4 Filling missing data and correcting erroneous data

The methods of filling missing data and correcting erroneous data in the RWIS climatic files are the same as for the ASOS climatic files. Since the amounts of missing data and erroneous data in the RWIS climatic files are very low, data filling and correction should not affect PMED results significantly. The RWIS data is not recommended in this stage because of relatively few years of data. In the future, it can be utilized as a supplement data is collected over a longer time span.

CHAPTER 6: CLIMATE ZONES OF MICHIGAN FOR FLEXIBLE PAVEMENT DESIGNS BASED ON MULTIPLE CLIMATE VARIABLES AND DISTRESS PREDICTIONS

Climate zones are regions with homogeneous climatic conditions. Since climate is an important factor affecting pavement performance, PMED results should also be homogeneous across an identified zone. According to the sensitivity analysis in this study, temperature, wind speed and percent sunshine are the three most important factors affecting temperatures throughout pavement structures and, hence, the distress predictions. Air temperature has been used to divide climate zones in previous studies [39]; however, pavement temperature is the most important factor affecting pavement performance [5, 40]. While predicted pavement performance can also be affected by wind speed and percent sunshine, it is better to use pavement temperature as a parameter for climate zone delineation. Therefore, in this study, pavement surface temperature is used to create the climate zones for the purpose of pavement design in Michigan.

The pavement surface temperature is predicted by the EICM based on the air temperature, percent sunshine and wind speed. Figure 6-1 shows an example of the comparison between air temperature and pavement surface temperature in 72 continuous hours. It was found that overall the surface temperature is higher than the air temperature. In addition, it was observed that the percent sunshine has visible influence on pavement surface temperature. When the percent sunshine is low, the difference between the pavement surface temperature and the air temperature is also low, as seen in the first 30 hours. When the percent sunshine is high, the pavement surface temperature increases significantly, as seen in the last 20 hours. Based on this, pavement surface temperature, which takes into account the air temperature, percent sunshine and wind speed, is regarded as a parameter for the climate zone creation. In addition, this study also looks at using pavement distress predictions to create the climate zones. Specifically, the total rutting and thermal cracking predictions are used because they are the two most sensitive distresses in flexible pavements to climatic changes in Michigan.

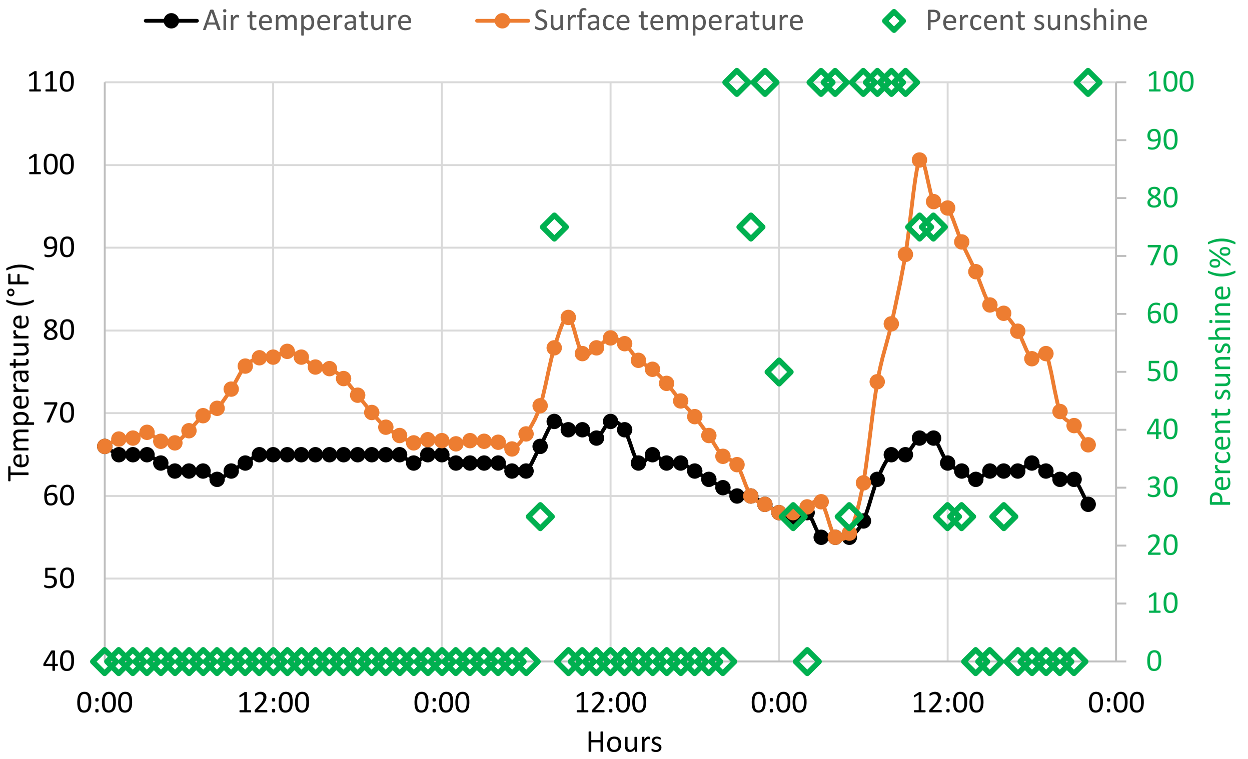


Figure 6-1: Example patterns of air temperature, percent sunshine, and the pavement surface temperature predicted from the EICM in 72 continuous hours

6.1 Climate zones based on pavement surface temperature

In this study, the annual mean surface temperature (AMST), mean surface temperature in hot seasons (MSTH) (July and August), and the mean surface temperature in cold seasons (MSTC) (January and February) are used. The AMST is a general parameter affecting pavement performance. Generally, a higher AMST leads to higher rutting depth, lower fatigue cracking and lower thermal cracking. MSTH is an important factor affecting pavement rutting performance since rutting normally occurs during the hotter months of the summer. MSTC is an important factor affecting thermal cracking since thermal cracking normally occurs in winter. Therefore, all these three parameters are used for climate zone delineation in Michigan.

The AMST, MSTH and MSTC in all the 39 (existing and newly adapted) sites were predicted through the EICM and shown in Figure 6-2 to Figure 6-4. It can be found that overall the surface temperatures increase with the decrease of latitude. The differences between the maximum and minimum AMST, MSTH and MSTC values are 10.6, 9.1 and 13.1°F, respectively. The criterion for determining a climate zone is that the AMST, MSTH and MSTC should be within a range of 2.5°F, thereby leading to similar performance of pavement structures. The climate zone divisions using the three temperatures are illustrated in Figure 6-2 to Figure 6-4.We recently did some studies on the correlation between temperature indices and distress prediction at MTU. The results showed that for 10% difference in thermal cracking, the temperature threshold should be less than 1 F, which is not realistic. For 10% difference in rutting, the temperature threshold is about 4.5 F. The value of 2.5 F was selected as a compromise.

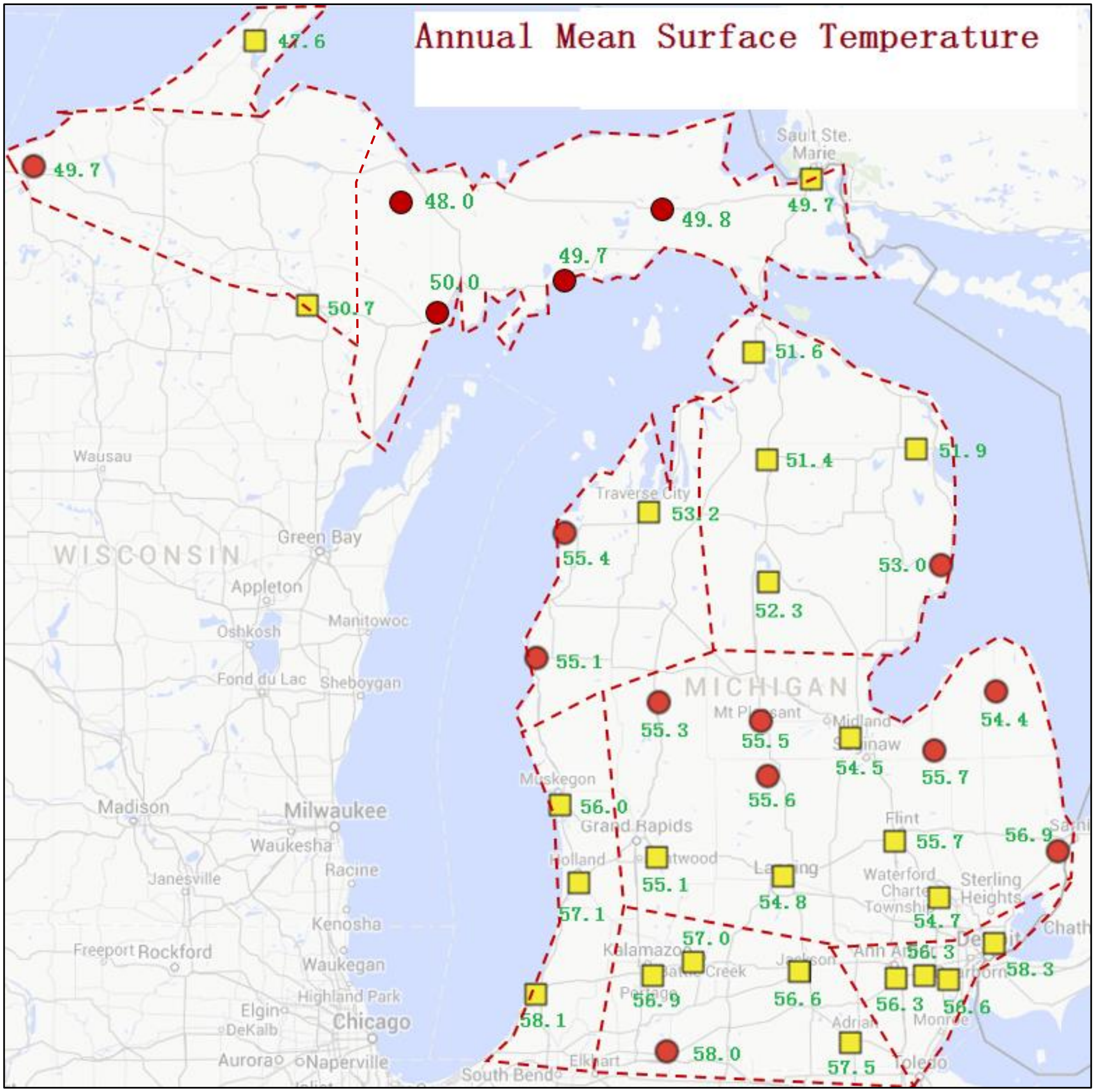


Figure 6-2: Climate zones based on annual mean surface temperature

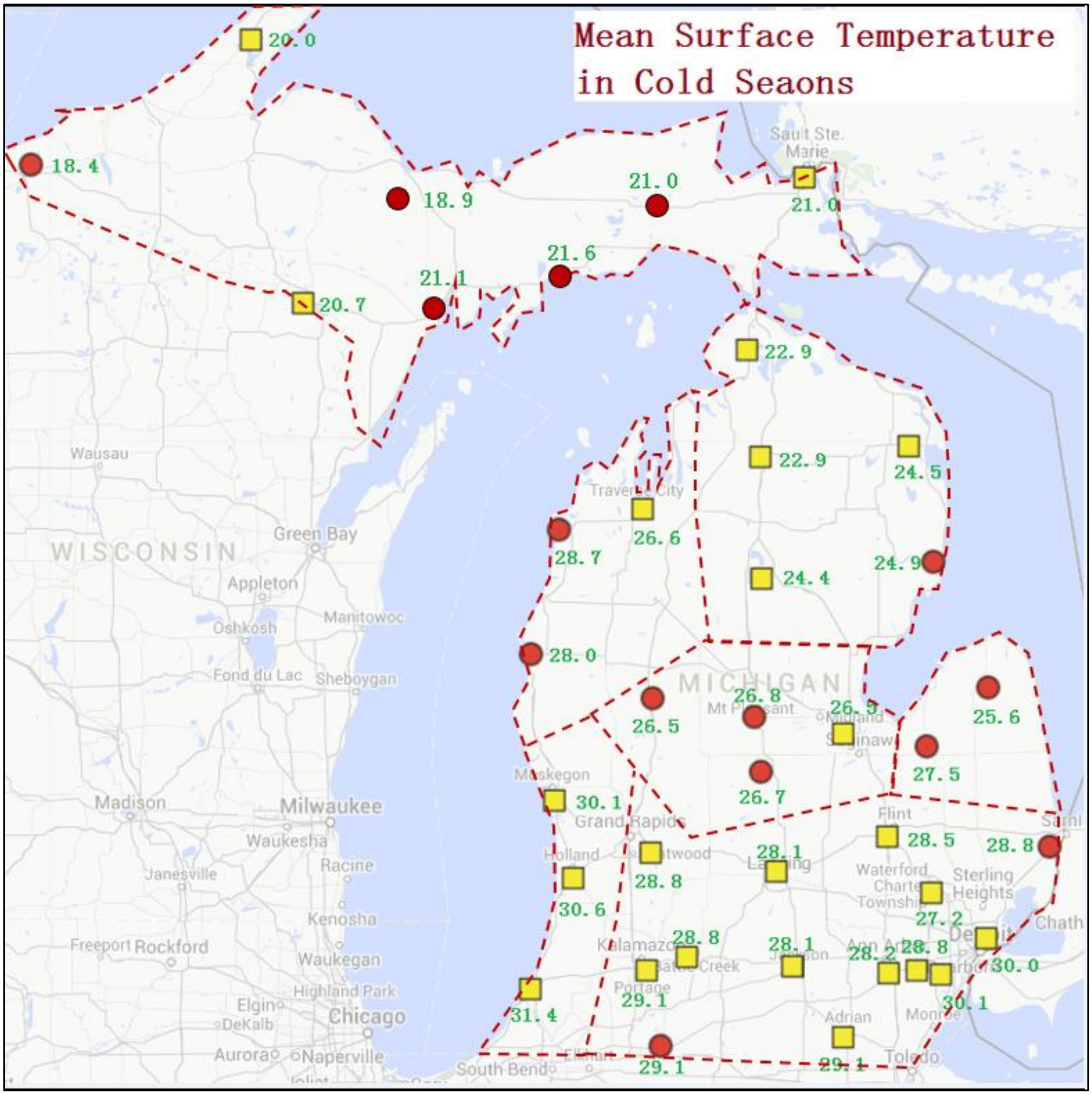


Figure 6-3: Climate zones based on mean surface temperature in cold seasons

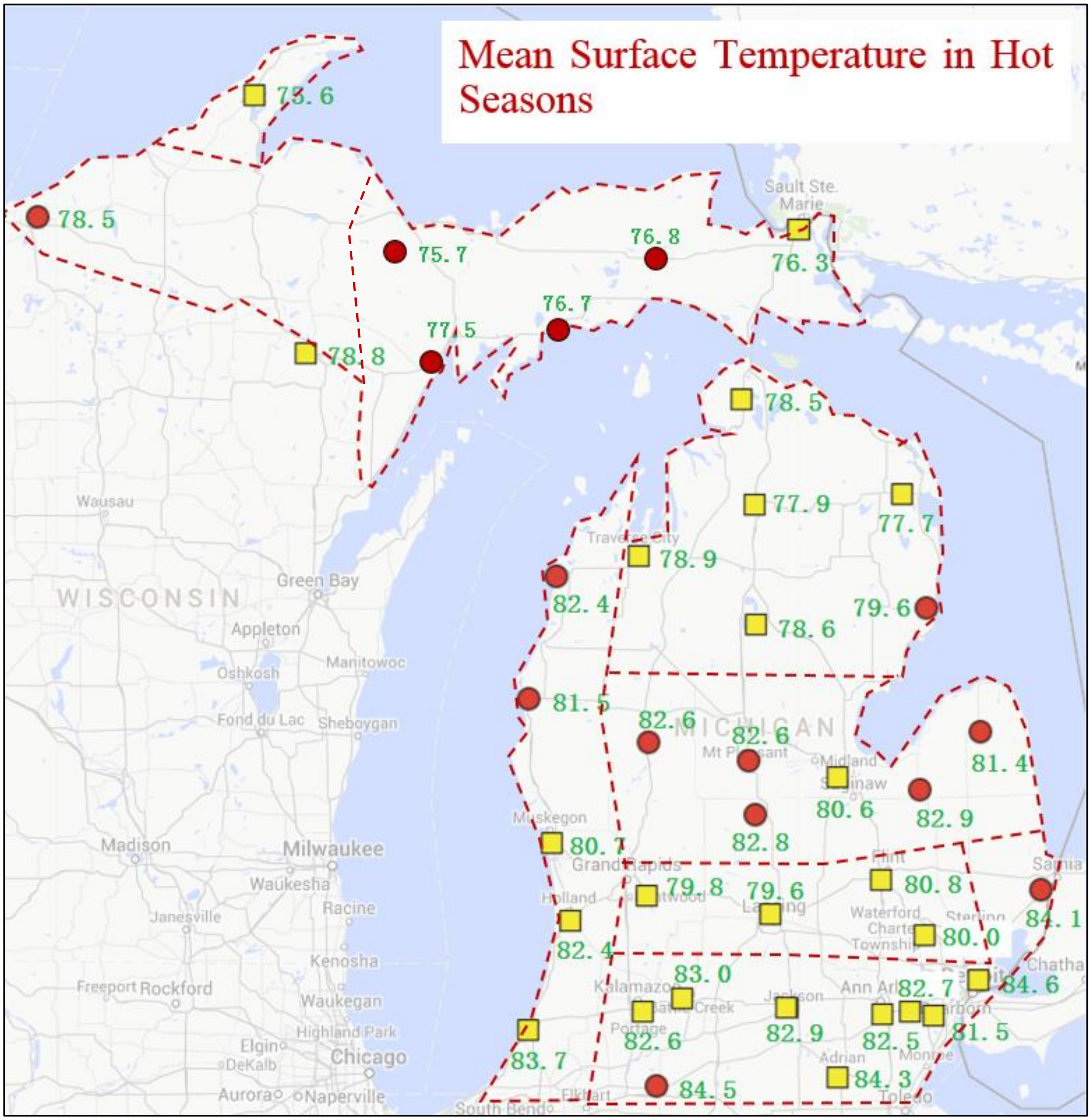


Figure 6-4: Climate zones based on mean surface temperature in hot seasons

6.2 Climate zones based on distress predictions

While similar temperature parameters may lead to homogeneous climate zones, a more accurate approach may be to look for similar predicted pavement performance as the criterion for determining climate zones in the state. The thermal cracking and total rutting predictions in all 39 locations were obtained from PMED using typical Michigan flexible pavements under a medium traffic level. The thermal cracking predictions vary considerably, as seen in Figure 6-5. Visible differences in total rutting predictions were also observed (Figure 6-6). Considering the large variation, the overall criterion to determine the climate zones based on thermal predictions is the following: when the thermal cracking predictions are lower than the design limit, the maximum difference within the climate zone should be less than 10% of the design limit; when the thermal cracking predictions are higher than the design limit, the maximum difference within the climate zone should be less than 10% of the minimum distress prediction. The criterion to determine the climate zones based on total rutting predictions is that the maximum difference of predicted rutting within the same zone should be less than 10% of the design limit of Michigan. Michigan's design limit for total rutting is 0.5 inch, so the maximum difference within a climate zone should be no more than 0.05 inch. This 10% of the design limit corresponds to an NSI value of 0.1, which is the threshold of sensitivity. According to this criterion, the difference between the maximum and minimum thermal cracking in the same zone should be less than 100 ft/mile when the thermal cracking predictions are less than 1000 ft/mile. The climate zones based on these two criteria are illustrated in Figure 6-5 and Figure 6-6. It should be noted that because of the erratic fluctuation of thermal cracking in some places, the climate zones in this region are not established. It is noted as an "undefined region", as shown in Figure 6-5.

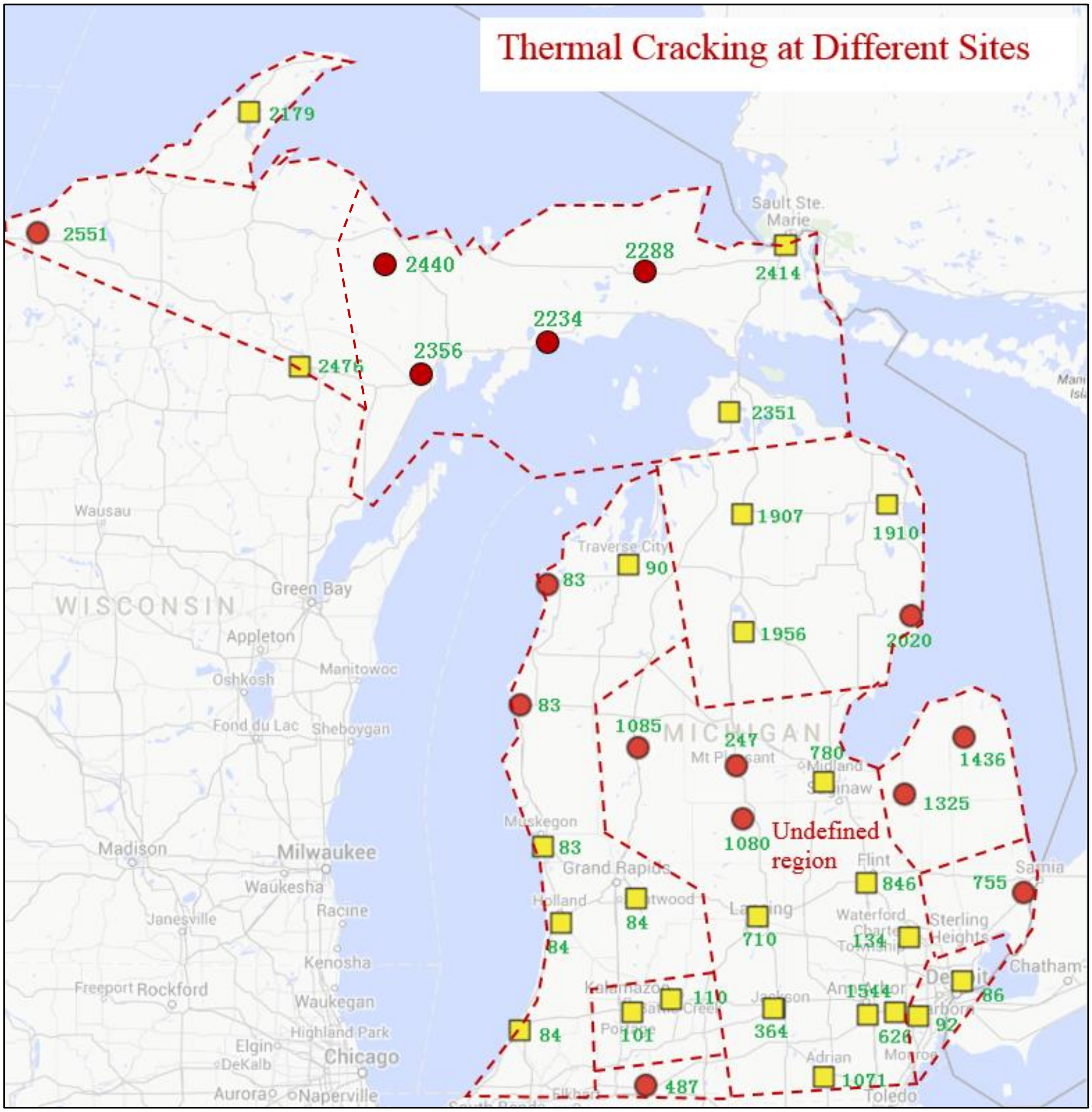


Figure 6-5: Thermal cracking predictions in different sites using PMED

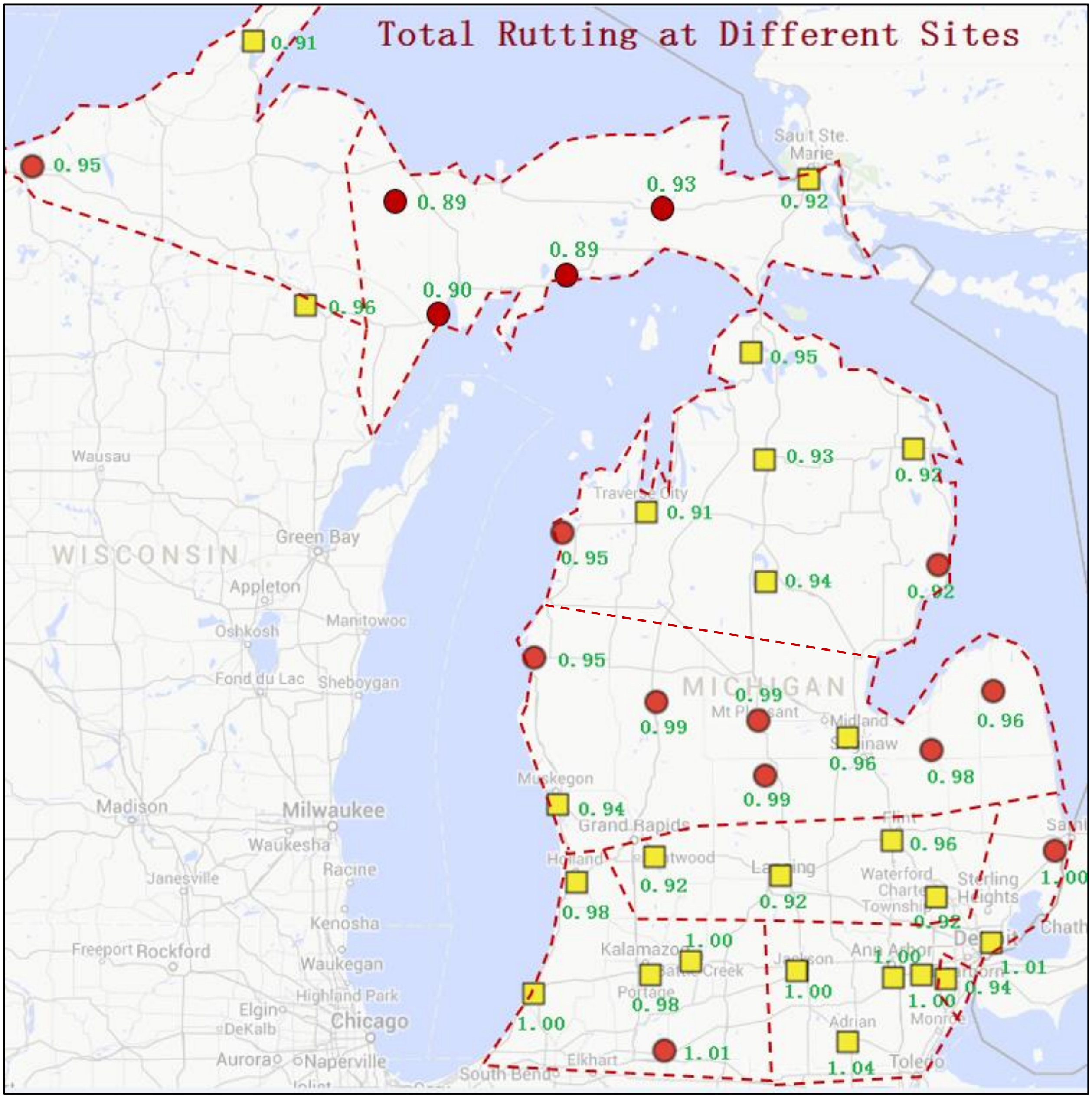


Figure 6-6: Total rutting predictions at different sites using PMED

6.3 Climate zones based on surface temperatures and distress predictions

Comprehensive climate zone delineation based on surface temperatures and distress predictions takes into account all the five climate zone division results above. Fifteen climate zones were created as shown in Figure 6-7 and are described below. These zones are based on visual examination and comparison of the distress predictions and some climatic variables. We have five parameters to divide the zones, and then we made the final zones that can meet the requirements of the five zones for individual parameters. E.g. places A, B, and C are in the same zone in Map 1; place A and B are in one zone, while C is in another zone in Map 2. Then, with the combination of Maps 1 and 2, places A and B are in one zone, while place C is in another zone.

Climate zone 1: Keweenaw Peninsula. The Keweenaw Peninsula is regarded as a separate zone in three of the five maps, as shown from Figure 6-2 to Figure 6-6. In the other two maps, the Keweenaw Peninsula is in the same zone with the rest of the Upper Peninsula. For consistency in all five maps, it is recommended to establish it as a separate climate zone.

Climate zone 2: Western Upper Peninsula (excluding the Keweenaw Peninsula). In all of the five maps, this area is in the same climate zone. Since this area has visibly higher mean temperature in summer and higher rutting predictions, it is separated from the eastern U.P. to be regarded as a climate zone.

Climate zone 3: Eastern Upper Peninsula. In all the five maps, this area is in the same climate zone. In one map, this area is in the same zone with some parts of the Lower Peninsula. Considering that it is geographically separate from the Lower Peninsula, it is regarded as a climate zone.

Climate zone 4: Northern Michigan. In four out of the five maps, this area is regarded as a single climate zone, except for the climate zone based on thermal cracking, as shown in Figure 6-5, where Pellston is placed in a climate zone with the Upper Peninsula. The thermal cracking prediction in Pellston is somewhat distant from the other four places in this zone. Nevertheless, all the three types of mean temperatures and the rutting prediction predictions showed that Pellston can be in the same climate zone with the other places in this region. Therefore, it is not necessary to put Pellston as a separate climate zone, and we recommend this region be considered as a single climate zone.

Climate zone 5: Western Lake Shore. Because of the lake effect, the western lake shore has mild winters in terms of mean surface temperature and thermal cracking predictions. Nevertheless, among the five stations along the western shore, Benton Harbor (most southern one) has visibly higher temperature than Frankfort (most northern one). Therefore, Benton Harbor is not included in this zone.

Climate zone 6: Cherry Capitol. Traverse City is a place with warm winters and cool summers. Its mean temperature in winter is visibly higher than places to the east. Meanwhile, its mean temperature in summer is lower than places to the west. Therefore, a separate climate zone is recommended for this region, between the western lake shore and the northeastern Lower Peninsula.

Climate zone 7: Mid-Michigan. This zone covers four weather stations, located in the cities of Big Rapids, Mt. Pleasant, Alma and Saginaw. In all the five maps, these four sites are in the same zone. This zone has visibly lower temperature in summer and lower rutting predictions compared to the region to the south, so it is to be regarded as a separate climate zone. Although the thermal cracking in this zone varies significantly in an erratic way, all the three temperature parameters and the rutting predictions are very close. Taking account into the high fluctuation of thermal cracking predictions, we do not recommend dividing them into several micro climate zones based only on the thermal cracking prediction.

Climate zone 8: The Thumb. This zones covers two stations, Bad Axe and Caro, where are in the same zone in all of the five maps. Considering that these two cities have visibly lower temperatures and higher thermal cracking predictions than Sarnia and Flint to their south, this region is regarded as a separate climate zone.

Climate zone 9: Capitol Corridor. This region covers four weather stations, located in the cities of Grand Rapids, Lansing, Flint and Waterford. These four sites are in the same zone in four out of the five maps. The only exception is the Figure 6-5, in which the thermal cracking prediction in Grand Rapids is much lower than other three. However, the annual mean temperature and the mean temperature in cold seasons are very close among these four stations. In addition, Grand Rapids cannot be assigned in the Western Lake Shore zone because it has visibly lower temperature in hot seasons and lower rutting predictions. Considering that high fluctuation of the thermal cracking prediction, Grand Rapids is regarded to be in the same zone with the other three cities.

Climate zone 10: Southwest Lake Shore. Because of its lower latitude, this region has higher temperatures than the upper part of the Western Lake Shore. Meanwhile, this region has higher temperature than its eastern neighbors because of the lake effect. This can be seen from the mean temperature in cold seasons and the thermal cracking predictions. Therefore, this region is regarded as a separate climate zone.

Climate zone 11: Kalamazoo. This region covers three weather stations: Kalamazoo, Battle Creek and Sturgis. These three stations are in the same zone in all of the five maps. The thermal cracking and rutting predictions in this region are somewhat different in areas to the east, so we recommend this region be considered a separate climate zone.

Climate zone 12: Downriver. This zone only covers a small region surrounding the Detroit metropolitan airport. This is a typical micro zone. This zone has warmer winters and cooler summers than its surroundings.

Climate zone 13: Detroit. This zone only covers the city of Detroit. This is also a micro zone. This zone has winters as warm as the Detroit metropolitan airport but even hotter summers.

Climate zone 14: Ann Arbor. This region covers four weather stations located in the cities of Jackson, Ann Arbor, Adrian and Ypsilanti. These four stations are in the same zone in all the five maps. Because they have different temperatures and thermal cracking predictions from Detroit, they are assigned in a separate climate zone.

Climate zone 15: Port Huron. This region includes only one weather station, located in Sarnia. Although Sarnia is located in Canada, it may be used for climate zone creation. This zone has higher temperatures in summer and higher rutting predictions than its western neighbors. Meanwhile, it has significantly higher thermal cracking predictions than Detroit. As a result, it is regarded as a separate climate zone.

In this approach, the state has been divided into fifteen climate zones. It should be noted that the climate zone creation is based on the pavement surface temperature (taking account into air temperature, wind speed and percent sunshine) and predicted performance values of flexible pavement at the 39 sites. We are confident that all the sites in the same climate zone have similar temperature patterns and similar distress predictions for flexible pavements. However, the borders of neighboring zones can be slightly uncertain between two weather stations. With the increase of the weather station density, the climate zone delineation may be more reliable.

Climate zone division based on rigid pavement performance predictions has not been considered in this study and is recommended as future work.

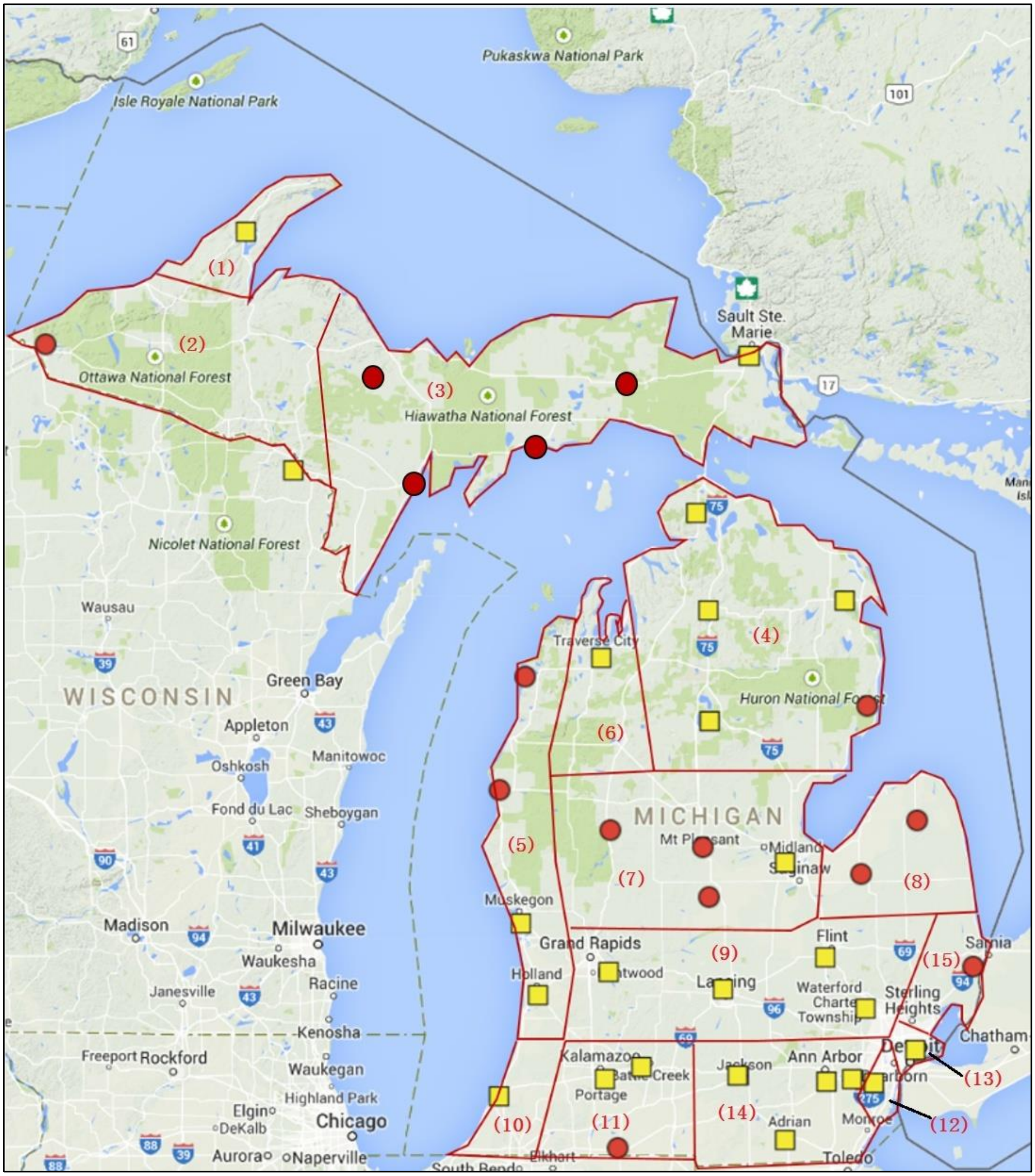


Figure 6-7: Recommended climate zones based on pavement surface temperatures and distress predictions

CHAPTER 7: SUMMARY AND CONCLUSION

The State of Michigan currently has 24 weather stations in the pavement design software Pavement ME Design (PMED). Five of these stations have an entire month of missing data, and as a result cannot be used in the PMED as a single weather station. These months of missing data should be filled in using a reliable method. For the remaining 19 weather stations currently used in the PMED, they may contain some missing or erroneous data. Therefore, the quantity and quality of the climatic files from these stations were checked. In addition, the 24 weather stations are not geographically distributed throughout the state. As a result, there are some gap regions among the existing weather stations. Accordingly, the main objectives of this study were: 1) check the quantity and quality of the weather data in existing climatic files (Chapter 3); 2) fill the missing data and correct the erroneous data in existing climatic files (Chapter 3); 3) analyze the sensitivity of PMED design results to climatic inputs (Chapter 4); 4) find additional weather data resources (Chapter 5); 5) identify additional weather stations in the gap regions of existing weather stations and extend the data length of existing climatic files (Chapter 5); and 6) create climate zones for Michigan for the purpose of benefiting pavement design (Chapter 6). Some findings and conclusions can be summarized as below:

a) The quantity check results showed that there are no other missing days or hours in all the 24 climatic files except one entire missing month in 5 stations. The quality check results showed that there are some outliers and erroneous data in the existing climatic files. These outliers and erroneous data include: unrecognized strings, nulls, values out of range, and sharp hourly temperature changes. The quantity and quality check was conducted using user-written Visual Basic for Applications (VBA) programs in MS Excel.

b) After the quantity and quality check, the missing data were filled and the erroneous data were corrected. For the entire month of missing data, both the statistical analysis and the PMED design results indicated that using the data from neighboring stations was the most accurate approach for replacement.

c) The sensitivity of PMED design results to climatic inputs was comprehensively analyzed. The varied climatic inputs include the selected weather station, the five individual climate variables, depth to water table, and annual weather variability. The overall sensitivity analysis is summarized in Table 7-1. Some detailed sensitivity analysis results are as below. Typical Michigan flexible and rigid pavements under high and medium traffic levels were used for the sensitivity analysis. The sensitivity analysis on weather station selection showed that most of the distress predictions were sensitive or very sensitive to weather station changes. Thermal cracking was the distress most sensitive to a weather station change. The sensitivity analysis on individual climatic variables showed that temperature and wind speed were the two most critical variables, while results tended not to be sensitive to percent sunshine, relative humidity, precipitation and depth to water table except for one or two predictions. Relative humidity had a higher impact on rigid pavement than on flexible pavement. The sensitivity analysis on annual weather data changes showed that annual weather variability had a significant influence on the PMED design results. In addition, it was recommended that a minimum of 4 years of data is required to make reliable designs, but longer data lengths were also encouraged to capture extreme weather event probabilities.

d) Two potential sources of additional weather data were found: the Automated Surface Observing System (ASOS) and the Michigan Road Weather Information System (RWIS). It was found that ASOS has a large amount of weather stations throughout the state of Michigan; the RWIS has adequate weather stations in the Upper Peninsula and the northern half of the Lower Peninsula, but few stations in the southern half of the Lower Peninsula. The ASOS weather stations mostly have data lengths of more than 10 years, while the RWIS currently does not have an adequate quantity of weather data. The research team successfully converted the ASOS climatic files and RWIS climatic files into the format required by the PMED using user-written VBA programs. The quantity and quality checks were conducted for three AWOS/ASOS climatic files and two RWIS climatic files. The missing data were then filled and erroneous data corrected in the ASOS climatic files. It was found that the ASOS data is from the same data source as that in the existing climatic files, but more stations were available to supplement the existing locations. Thus, 15 weather stations were added to fill the gap regions in Michigan. The 15 new climatic files cover historical data from 2000 to 2014. In addition, the data length of all existing 24 climatic files has been extended by 8 years from February 2006 to December 2014, for a total climatic file data length of up to 19 years.

e) Climate zones as an alternative to adding more stations was studied as well. The climate zones were created based on flexible pavement surface temperatures and performance predictions. The annual mean surface temperature, mean surface temperature in hot seasons, mean surface temperature in cold seasons, thermal cracking predictions, and total rutting predictions were utilized to divide climate zones separately. Using the approach, 15 climate zones were developed taking account into all five of these factors in the state of Michigan.

Table 7-1: Summary of distress prediction sensitivity to climate variables

Variables	Flexible pavement		Rigid pavement	
	High traffic	Medium traffic	High traffic	Medium traffic
Temperature	Very sensitive	Very sensitive	Sensitive	Sensitive
Wind speed	Sensitive	Sensitive	Not sensitive	Not sensitive
% sunshine	Not sensitive	Not sensitive	Not sensitive	Not sensitive
Precipitation	Not sensitive	Not sensitive	Not sensitive	Not sensitive
Relative humidity	Not sensitive	Not sensitive	Not sensitive	Sensitive
Station change	Sensitive	Very sensitive	Sensitive	Sensitive
Depth to water table	Not sensitive	Not sensitive	Not sensitive	Not sensitive
Data length	Sensitive	Sensitive	Sensitive	Sensitive

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APPENDIX A: QUANTITY CHECK RESULTS OF THE CLIMATIC FILES

Station ID: 04839

Mon\Year	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
1		Missing	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
3		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
4		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
5		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
6		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
7	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
8	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
9	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
10	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
11	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
12	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	

Station ID: 14833

Mon\Year	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
1						Yes	Yes	Yes	Yes	Yes	Yes
2						Yes	Yes	Yes	Yes	Yes	Yes
3						Yes	Yes	Yes	Yes	Yes	
4						Yes	Yes	Yes	Yes	Yes	
5						Yes	Yes	Yes	Yes	Yes	
6						Yes	Yes	Yes	Yes	Yes	
7						Yes	Yes	Yes	Yes	Yes	
8						Yes	Yes	Yes	Yes	Yes	
9						Yes	Yes	Yes	Yes	Yes	
10					Yes	Yes	Yes	Yes	Yes	Yes	
11					Missing	Yes	Yes	Yes	Yes	Yes	
12					Yes	Yes	Yes	Yes	Yes	Yes	

Station ID: 14847

Mon\Year	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
1		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
3		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	

4		Yes	Missing	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
5		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
6		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
7		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
8		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
9		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
10		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
11		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
12		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	

Station ID: 14845

Mon\Year	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
1				Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2				Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
3				Yes	Yes	Yes	Yes	Yes	Yes	Yes	
4				Yes	Yes	Yes	Yes	Yes	Yes	Yes	
5				Yes	Yes	Yes	Yes	Yes	Yes	Yes	
6				Yes	Yes	Yes	Yes	Yes	Yes	Yes	
7				Yes	Yes	Yes	Yes	Yes	Yes	Yes	
8				Yes	Yes	Yes	Yes	Yes	Yes	Yes	
9			Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
10			Yes	Yes	Yes	Yes	Yes	Yes	Missing	Yes	
11			Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
12			Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	

Station ID: 94849

Mon\Year	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
1		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
3		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
4		Yes	Yes	Yes	Yes	Yes	Missing	Yes	Yes	Yes	
5		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
6		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
7	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
8	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
9	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
10	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
11	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
12	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	

Station ID: 04854

Mon\Year	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
1				Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2				Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
3			Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
4			Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
5			Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
6			Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
7			Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
8			Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
9			Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
10			Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
11			Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
12			Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
Station ID: 14815											
Mon\Year	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
1				Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2			Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
3			Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
4			Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
5			Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
6			Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
7			Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
8			Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
9			Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
10			Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
11			Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
12			Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
Station ID: 14822											
Mon\Year	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
1						Yes	Yes	Yes	Yes	Yes	Yes
2						Yes	Yes	Yes	Yes	Yes	Yes
3						Yes	Yes	Yes	Yes	Yes	
4						Yes	Yes	Yes	Yes	Yes	
5						Yes	Yes	Yes	Yes	Yes	
6						Yes	Yes	Yes	Yes	Yes	
7						Yes	Yes	Yes	Yes	Yes	
8						Yes	Yes	Yes	Yes	Yes	
9						Yes	Yes	Yes	Yes	Yes	
10					Yes	Yes	Yes	Yes	Yes	Yes	
11					Yes	Yes	Yes	Yes	Yes	Yes	
12					Yes	Yes	Yes	Yes	Yes	Yes	

Station ID: 14826

Mon\Year	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	
1		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
2		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
3		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
4		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
5		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
6		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
7	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
8	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
9	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
10	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
11	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
12	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	

Station ID: 14836

Mon\Year	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
1		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
3		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
4		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
5		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
6		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
7	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
8	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
9	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
10	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
11	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
12	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	

Station ID: 14840

Mon\Year	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
1		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
3		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
4		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
5		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
6		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
7	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
8	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
9	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
10	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
11	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	

12	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
Station ID: 14841											
Mon\Year	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
1						Yes	Yes	Yes	Yes	Yes	Yes
2						Yes	Yes	Yes	Yes	Yes	Yes
3						Yes	Yes	Yes	Yes	Yes	
4						Yes	Yes	Yes	Yes	Yes	
5						Yes	Yes	Yes	Yes	Yes	
6						Yes	Yes	Yes	Yes	Yes	
7						Yes	Yes	Yes	Yes	Yes	
8					Yes	Yes	Yes	Yes	Yes	Yes	
9					Yes	Yes	Yes	Yes	Yes	Yes	
10					Yes	Yes	Yes	Yes	Yes	Yes	
11					Yes	Yes	Yes	Yes	Yes	Yes	
12					Yes	Yes	Yes	Yes	Yes	Yes	
Station ID: 14850											
Mon\Year	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	
1				Yes	Yes	Yes	Yes	Yes	Yes	Yes	
2				Yes	Yes	Yes	Yes	Yes	Yes	Yes	
3				Yes	Yes	Yes	Yes	Yes	Yes	Yes	
4				Yes	Yes	Yes	Yes	Yes	Yes	Yes	
5				Yes	Yes	Yes	Yes	Yes	Yes	Yes	
6			Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
7			Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
8			Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
9			Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
10			Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
11			Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
12			Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
Station ID: 14853											
Mon\Year	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	
1					Yes	Yes	Yes	Yes	Yes	Yes	
2					Yes	Yes	Yes	Yes	Yes	Yes	
3				Yes	Yes	Yes	Yes	Yes	Yes	Yes	
4				Yes	Yes	Yes	Yes	Yes	Yes	Yes	
5				Yes	Yes	Yes	Yes	Yes	Yes	Yes	
6				Yes	Yes	Yes	Yes	Yes	Yes	Yes	
7				Yes	Yes	Yes	Yes	Yes	Yes	Yes	
8				Yes	Yes	Yes	Yes	Yes	Yes	Yes	
9				Yes	Yes	Yes	Yes	Yes	Yes	Yes	
10				Yes	Yes	Yes	Yes	Yes	Yes	Yes	

11				Yes	Yes	Yes	Yes	Yes	Yes	Yes	
12				Yes	Yes	Yes	Yes	Yes	Yes	Yes	
Station ID: 14858											
Mon\Year	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
1						Yes	Yes	Yes	Yes	Yes	Yes
2						Yes	Yes	Yes	Yes	Yes	Yes
3						Yes	Yes	Yes	Yes	Yes	
4						Yes	Yes	Yes	Yes	Yes	
5						Yes	Yes	Yes	Yes	Yes	
6						Yes	Yes	Yes	Yes	Yes	
7						Yes	Yes	Yes	Yes	Yes	
8						Yes	Yes	Yes	Yes	Yes	
9					Yes	Yes	Yes	Yes	Yes	Yes	
10					Yes	Yes	Yes	Yes	Yes	Yes	
11					Yes	Yes	Yes	Yes	Yes	Yes	
12					Yes	Yes	Yes	Yes	Yes	Yes	
Station ID: 94814											
Mon\Year	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
1		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
3		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
4		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
5		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
6		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
7	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
8	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
9	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
10	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
11	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
12	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
Station ID: 94815											
Mon\Year	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
1			Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2			Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
3			Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
4			Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
5			Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
6			Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
7			Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
8			Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
9			Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	

10			Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
11			Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
12			Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
Station ID: 94817											
Mon\Year	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
1				Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2				Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
3				Yes	Yes	Yes	Yes	Yes	Yes	Yes	
4				Yes	Yes	Yes	Yes	Yes	Yes	Yes	
5				Yes	Yes	Yes	Yes	Yes	Yes	Yes	
6				Yes	Yes	Yes	Yes	Yes	Yes	Yes	
7				Yes	Yes	Yes	Yes	Yes	Yes	Yes	
8			Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
9			Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
10			Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
11			Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
12			Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
Station ID: 94847											
Mon\Year	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
1		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
3		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
4		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
5		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
6		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
7	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
8	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
9	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
10	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
11	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
12	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
Station ID: 94860											
Mon\Year	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
1		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
3		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
4		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
5		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
6		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
7	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
8	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	

9	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
10	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
11	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
12	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
Station ID: 94871											
Mon\Year	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
1		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
3		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
4		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
5		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
6		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
7	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
8	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
9	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
10	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
11	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
12	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
Station ID: 94889											
Mon\Year	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
1				Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2				Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
3				Yes	Yes	Yes	Yes	Yes	Yes	Yes	
4				Yes	Yes	Yes	Yes	Yes	Yes	Yes	
5				Yes	Yes	Yes	Yes	Yes	Yes	Yes	
6				Yes	Yes	Yes	Yes	Yes	Yes	Yes	
7				Yes	Yes	Yes	Yes	Yes	Yes	Yes	
8				Yes	Yes	Yes	Yes	Yes	Yes	Yes	
9				Yes	Yes	Yes	Yes	Yes	Yes	Yes	
10				Yes	Yes	Yes	Yes	Yes	Yes	Yes	
11			Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
12			Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
Station ID: 94893											
Mon\Year	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
1		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
3		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
4		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
5		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
6		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
7		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	

8		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
9		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
10		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
11	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
12	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	

APPENDIX B: QUALITY CHECK RESULTS OF THE CLIMATIC FILES

Station ID: 04839

Time	Temperature	Wind speed	Percent sunshine	Precipitation	Relative Humidity	Time	Suspicious Temperature
1997020209					1	2003110419	38
1997020422					104	2004090620	68
1997020423					3	2004090621	15
1997020821					104	2004090622	15
1997020822					105	2004090623	61
1997022002					127	2004090705	61
1997061222					103	2004090706	18
1997061504					103	2004090707	18
1997061805					103	2004090708	67
1997081902					103		
1997082500					104		
1997090702					103		
1997091421					104		
1997091703					104		
1998040205	Null						
1998040216	Null						
1998082023					1		
1999021205	Null						
1999021216	Null						
1999101009					0		
1999101015					0		
1999101016					6.3		

Station ID: 04847

Time	Temperature	Wind speed	Rercent sunshine	Precipitation	Relative Humidity	Time	Suspicious Temperature
1998010421					10		
1998010422					11		
1998122421					1		
1998122422					3.5		
1998122423					6		
1998122503					1		
1999111309					0		
2000011321					2		
2000011322					5.5		
2000011323					9		
2002031616	M						

2003071005	Null						
2003071016	Null						
2004011705	Null						
2004011716	Null						
Station ID: 04854							
Time	Temperature	Wind speed	Percent sunshine	Precipitation	Relative Humidity	Time	Suspicious Temperature
Station ID: 14815							
Time	Temperature	Wind speed	Percent sunshine	Precipitation	Relative Humidity	Time	Suspicious Temperature
1998043021					0		
1998083108					6.3		
1998083109					0		
1999071306					0		
1999071312					0		
2002123105	Null						
2002123116	Null						
Station ID: 14822							
Time	Temperature	Wind speed	Percent sunshine	Precipitation	Relative Humidity	Time	Suspicious Temperature
2003012005	Null						
2003012016	Null						
2003012105	Null						
2003012116	Null						
2003013005	Null						
2003013016	Null						
2003070505	Null						
2003070516	Null						
2003080205	Null						
2003080216	Null						
2003091305	Null						
2003091316	Null						
2005061111					8		
2005061112					8		
2005061113					9.8		
2005061114					11.5		
Station ID: 14826							
Time	Temperature	Wind speed	Percent sunshine	Precipitation	Relative Humidity	Time	Suspicious Temperature

Station ID: 14833							
Time	Temperature	Wind speed	Percent sunshine	Precipitation	Relative Humidity	Time	Suspicious Temperature
2002120605	Null					2004090620	70
2002120616	Null					2004090621	9
2003100405	Null					2004090623	8
2003100416	Null					2004090700	65
Station ID: 14836							
Time	Temperature	Wind speed	Percent sunshine	Precipitation	Relative Humidity	Time	Suspicious Temperature
1996071607					9.3		
1996071608					4.7		
1996071609					0		
1996071610					4.3		
1996071611					8.7		
1996071622					10.5		
1996071623					1		
1996071701					8.7		
1996071702					4.3		
1996071703					0		
1996071704					4.7		
1996071705					9.3		
1996090412					8		
1996110623					1		
1999031202					***		
1999062009					0		
1999111323					1		
Station ID: 14840							
Time	Temperature	Wind speed	Percent sunshine	Precipitation	Relative Humidity	Time	Suspicious Temperature
1996071409					0		
1996071410					4		
1996071411					8		
1996071421					0		
1996071422					0.5		
1996071423					1		
1996071501					10		
1996071502					5		
1996071503					0		

1996071504					5.3		
1996071505					10.7		
1996121909					3		
Station ID: 14841							
Time	Temperature	Wind speed	Percent sunshine	Precipitation	Relative Humidity	Time	Suspicious Temperature
2003070205	Null						
2003070216	Null						
Station ID: 14845							
Time	Temperature	Wind speed	Percent sunshine	Precipitation	Relative Humidity	Time	Suspicious Temperature
1998090503					103	1998090714	102.2
2001090911					4	1998090715	72.9
2004051004					8	2001080221	75
2004051005					6	2001080222	36
2004051006					9	2001080300	36
						2001080301	74
						2001080314	85
						2001080315	37
						2001080316	67
						2001090903	65
						2001090904	29
						2001090905	63
						2004090622	66
						2004090623	9
						2004090700	63
						2004090705	57
						2004090706	9
						2004090707	60
						2004092111	51
						2004092112	80
Station ID: 14847							
Time	Temperature	Wind speed	Percent sunshine	Precipitation	Relative Humidity	Time	Suspicious Temperature
1998071303					0	1997093023	72
1999072423					1	1997100100	39.9
1999072500					0	2004090621	57
1999072501					0	2004090622	5
1999072502					0	2004090623	57
1999072503					0	2004090704	57

1999072504					4.3	2004090705	1
1999072505					8.7	2004090706	56
1999072507					8.7	2004090707	-2
1999072508					4.3	2004090708	60
1999072509					0	2004092112	50
						2004092113	76

Station ID: 14850

Time	Temperature	Wind speed	Percent sunshine	Precipitation	Relative Humidity	Time	Suspicious Temperature
1999051621					0		

Station ID: 14853

Time	Temperature	Wind speed	Percent sunshine	Precipitation	Relative Humidity	Time	Suspicious Temperature
1999051003					0		
1999061321					9		
2002121005	Null						
2002121016	Null						
2002121105	Null						
2002121116	Null						
2003081405	Null						
2003081416	Null						
2003081505	Null						
2003081516	Null						
2005050705					6		

Station ID: 14858

Time	Temperature	Wind speed	Percent sunshine	Precipitation	Relative Humidity	Time	Suspicious Temperature
2004012205	Null						
2004012216	Null						
2004012305	Null						
2004012316	Null						

Station ID: 94814

Time	Temperature	Wind speed	Percent sunshine	Precipitation	Relative Humidity	Time	Suspicious Temperature
2003030613					11		
2005040416					11		

Station ID: 94815

Time	Temperature	Wind speed	Percent sunshine	Precipitation	Relative Humidity	Time	Suspicious Temperature

Station ID: 94817

Time	Temperature	Wind speed	Percent sunshine	Precipitation	Relative Humidity	Time	Suspicious Temperature
2001031300					10		

Station ID: 94847

Time	Temperature	Wind speed	Percent sunshine	Precipitation	Relative Humidity	Time	Suspicious Temperature
1998041604					5		
2003081505	Null						
2003081516	Null						

Station ID: 94849

Time	Temperature	Wind speed	Percent sunshine	Precipitation	Relative Humidity	Time	Suspicious Temperature
1996082202					104	1999031405	34
1996113001					104	1999031406	7
1999091819					10.7	2004090620	70
1999091820					5.3	2004090621	7
1999091821					0	2004090623	7
1999091822					1	2004090700	60
1999091823					2	2004090704	58
1999091902					7.7	2004090705	7
1999091903					0	2004090707	8
1999091904					10.3	2004090708	63
1999112521					0	2004092112	46
1999112522					1.5	2004092113	82
1999112523					3		
1999112603					0		
2005040415					11		

Station ID: 94860

Time	Temperature	Wind speed	Percent sunshine	Precipitation	Relative Humidity	Time	Suspicious Temperature
1999072523					1		

Station ID: 94871

Time	Temperature	Wind speed	Percent sunshine	Precipitation	Relative Humidity	Time	Suspicious Temperature
1997102503					0		
1997102504					10		
1997102508					10		
1997102509					0		
1997102510					9		

1997102514					9		
1997102515					0		
1997102516					10.7		
1997102520					11.3		
1997102521					1		
1997102522					1.5		
1997102523					2		
1998062603					0		
1998062623					1		
1998062701					8		
1998062702					4		
1998062703					0		
1998062704					3.7		
1998062705					7.3		
1998062706					11		
1998062707					7.3		
1998062708					3.7		
1998062709					0		
1998062718					0		
1998062719					0		
1998062720					0		
1998062721					0		
1998062722					0.5		
1998062723					1		
1998062800					11		
2000010209					0		
2000010210					6.3		
2000010214					6.3		
2000010215					0		
2000010216					7.3		
2000010220					7.3		
2000010221					0		
2000010222					1		
2000010223					2		
2000010303					0		
2003012705	Null						
2003012716	Null						
2003012805	Null						
2003012816	Null						
Station ID: 94889							

Time	Temperature	Wind speed	Percent sunshine	Precipitation	Relative Humidity	Time	Suspicious Temperature
1999010301					11		
1999040409					0		
1999040410					9.7		
1999040415					0		
1999040423					2		
2003081405	Null						
2003081416	Null						
2004011505	Null						
2004011516	Null						

Station ID: 94893

Time	Temperature	Wind speed	Percent sunshine	Precipitation	Relative Humidity	Time	Suspicious Temperature
						1997093023	72.4
						1997100100	30
						2005090411	11
						2005090412	78

APPENDIX C: VBA CODES USED FOR THE DATA EDITING

Code 1: Missing months checking

```
Sub check_month()

Dim iAs Long
Dim j As Integer
Dim k As Integer
Dim l As Integer
Dim stat As String
Dim data(13, 12) As String

Sheets(1).Cells(2, 1) = "Mon\Year"

Address = "please input station ID"
stat = InputBox(Address)

j = 1996
For i = 2 To 12
Sheets(1).Cells(2, i) = j
    j = j + 1
Next i

j = 1
For i = 3 To 14
Sheets(1).Cells(i, 1) = j
    j = j + 1
Next i

For i = 1 To 13
    For j = 1 To 12
data(i, j) = "Missing"
    Next j
Next i


Workbooks.Open Filename:="D:\stations\" & stat & ".xlsx"
ActiveWindow.Visible = True

s = ActiveWorkbook.Sheets(1).Cells(1, 1).Value
         s1 = Int(s / 1000000)
         s2 = Int(s / 10000) - Int(s / 1000000) * 100
         If s1 = 1996 Then
            If s2 > 1 Then
                For i = 2 To s2
data(i, 2) = " "
                Next i
            End If
        End If

         If s1 > 1996 Then
            k = s1 - 1995
                For i = 2 To k
                    For j = 2 To 13
data(j, i) = " "
                    Next j
                Next i
            If s2 > 1 Then
                l = s1 - 1994
                     For i = 2 To s2
```

```
data(i, l) = " "
                Next i
          End If
       End If

For i = 1 To 100000

   If IsNull(ActiveWorkbook.Sheets(1).Cells(i, 1).Value) Then
       Exit For
   Else
       s = ActiveWorkbook.Sheets(1).Cells(i, 1).Value
        s1 = Int(s / 1000000)
        s2 = Int(s / 10000) - Int(s / 1000000) * 100
        k = s1 - 1994
        l = s2 + 1
data(l, k) = "Yes"
   End If
Next i
   If s1 = 2006 Then
       If s2 < 12 Then
          For i = (s2 + 2) To 13
data(i, 12) = " "
             Next i
       End If
   End If
   If s1 < 2006 Then
       k = s1 - 1993
          For i = k To 12
             For j = 2 To 13
data(j, i) = " "
             Next j
          Next i
       If s2 < 12 Then
          l = s1 - 1994
             For i = (s2 + 2) To 13
data(i, l) = " "
             Next i
       End If
   End If


Workbooks("example.xlsx").Activate
Sheets(1).Cells(1, 1) = "Station ID: " & stat
For i = 2 To 13
   For j = 2 To 12
Sheets(1).Cells(i + 1, j) = data(i, j)
       If Sheets(1).Cells(i + 1, j) = "Yes" Then
Sheets(1).Cells(i + 1, j).Select
Selection.Font.ColorIndex = 1
       End If
       If Sheets(1).Cells(i + 1, j) = "Missing" Then
Sheets(1).Cells(i + 1, j).Select
Selection.Font.ColorIndex = 3
       End If
       Next j
Next i
Workbooks(stat & ".xlsx").Close
End Sub
```

Code 2: Missing days and hours checking

```
Sub check_days_hours()
Address = "please input station ID"
stat = InputBox(Address)
Workbooks.Open Filename:="E:\stations\" & stat & ".xlsx"
ActiveWindow.Visible = True

Dim a(1000, 2) As Long
Dim b(1000, 2) As Long
'==============================check missing days and hours=========================
k = 1
j = 1
For i = 1 To 100000

    If IsNull(ActiveWorkbook.Sheets(1).Cells(i + 1, 1).Value) Then     'attention hear, the cell should be i+1, not i
        Exit For
    Else
        s1 = ActiveWorkbook.Sheets(1).Cells(i, 1).Value
        s2 = ActiveWorkbook.Sheets(1).Cells(i + 1, 1).Value
            mon1 = Mid(s1, 5, 2)
            mon2 = Mid(s2, 5, 2)
            date1 = Mid(s1, 7, 2)
            date2 = Mid(s2, 7, 2)
            hour1 = Right(s1, 2)
            hour2 = Right(s2, 2)
            delt1 = date2 - date1
            delt2 = CInt(hour2) - CInt(hour1)        'change the string to number


        Select Case mon1            'check missing datas
            Case 1, 3, 5, 7, 8, 10, 13
                If delt1 <> 0 And delt1 <> 1 And delt1 <> -30 Then
a(k, 1) = s1
a(k, 2) = s2
                    k = k + 1
                End If
            Case 4, 6, 9, 11
                If delt1 <> 0 And delt1 <> 1 And delt1 <> -29 Then
a(k, 1) = s1
a(k, 2) = s2
                    k = k + 1
                End If
            Case 2
                If delt1 <> 0 And delt1 <> 1 And delt1 <> -28 And delt1 <> -27 Then
a(k, 1) = s1
a(k, 2) = s2
                    k = k + 1
                End If
        End Select

If (delt1 = 0 And delt2 <> 1) Or (delt1 = 1 And delt2 <> -23) Or (delt1 < 0 And delt2 <> -23) Or (delt2 <> 1 And delt2
<> -23) Then 'check missing hours
b(j, 1) = s1
b(j, 2) = s2
            j = j + 1
        End If
    End If
Next i

Workbooks(stat & ".xlsx").Close
```

```
'========================================show the missing dates and hours================
Workbooks("Application.xlsm").Activate
Sheets(1).Cells(20, 1) = "date1"
Sheets(1).Cells(20, 2) = "date2"
Sheets(1).Cells(20, 3) = "hour1"
Sheets(1).Cells(20, 4) = "hour2"
  If k > 1 Then
        For i = 1 To k
Sheets(1).Cells(i + 20, 1) = a(i, 1)
Sheets(1).Cells(i + 20, 2) = a(i, 2)
        Next i
  End If

  If j > 1 Then
        For i = 1 To j
Sheets(1).Cells(i + 20, 3) = b(i, 1)
Sheets(1).Cells(i + 20, 4) = b(i, 2)
        Next i
  End If
End Sub
```

Code 3: Data Quality check

```
Sub check_quality()
Dim iAs Long
Dim j As Integer
Dim stat As String
Dim a1(1000) As String
Dim a2(1000) As String
Dim a3(1000) As String
Dim a4(1000) As String
Dim a5(1000) As String
Dim a6(1000) As String
Dim b1(1000) As String
Dim b2(1000) As String

Address = "please input station ID"
stat = InputBox(Address)
Workbooks.Open Filename:="E:\stations\" & stat & ".xlsx"
ActiveWindow.Visible = True

'==========================check quality================
j = 1
k = 1
For i = 1 To 100000

    If IsNull(ActiveWorkbook.Sheets(1).Cells(i, 1).Value) Then
        Exit For
    Else
        s1 = ActiveWorkbook.Sheets(1).Cells(i, 1).Value
        s2 = ActiveWorkbook.Sheets(1).Cells(i, 2).Value
        s3 = ActiveWorkbook.Sheets(1).Cells(i, 3).Value
        s4 = ActiveWorkbook.Sheets(1).Cells(i, 4).Value
        s5 = ActiveWorkbook.Sheets(1).Cells(i, 5).Value
        s6 = ActiveWorkbook.Sheets(1).Cells(i, 6).Value

        If IsNull(ActiveWorkbook.Sheets(1).Cells(i, 2).Value) Then
a1(j) = s1
a2(j) = "Null"
            j = j + 1
ElseIfIsNumeric(s2) = False Then
a1(j) = s1
a2(j) = s2
            j = j + 1
            Else
            If s2 > 112 Or s2 < -51 Then         'temperature check
a1(j) = s1
a2(j) = s2
                    j = j + 1
            End If
        End If

        If IsNull(ActiveWorkbook.Sheets(1).Cells(i, 3).Value) Then
a1(j) = s1
a3(j) = "Null"
            j = j + 1
ElseIfIsNumeric(s3) = False Then
a1(j) = s1
a3(j) = s3
            j = j + 1
            Else
            If s3 < 0 Or s3 > 70 Then            'wind speed check
```

```
a1(j) = s1
a3(j) = s3
          If a1(j) = a1(j - 1) Then
a3(j - 1) = a3(j)
            j = j - 1
          End If
          j = j + 1
      End If
    End If

    If IsNull(ActiveWorkbook.Sheets(1).Cells(i, 4).Value) Then
a1(j) = s1
a4(j) = "Null"
      j = j + 1
ElseIfIsNumeric(s4) = False Then
a1(j) = s1
a4(j) = s4
      j = j + 1
      Else
      If s4 < 0 Or s4 > 100 Then          'sunshine check
a1(j) = s1
a4(j) = s4
          If a1(j) = a1(j - 1) Then
a4(j - 1) = a4(j)
            j = j - 1
          End If
          j = j + 1
      End If
    End If

    If IsNull(ActiveWorkbook.Sheets(1).Cells(i, 5).Value) Then
a1(j) = s1
a5(j) = "Null"
      j = j + 1
ElseIfIsNumeric(s5) = False Then
a1(j) = s1
a5(j) = s5
      j = j + 1
      Else
      If s5 < 0 Then          'precipitation check
a1(j) = s1
a5(j) = s5
          If a1(j) = a1(j - 1) Then
a5(j - 1) = a5(j)
            j = j - 1
          End If
          j = j + 1
      End If
    End If

    If IsNull(ActiveWorkbook.Sheets(1).Cells(i, 6).Value) Then
a1(j) = s1
a6(j) = "Null"
      j = j + 1
ElseIfIsNumeric(s6) = False Then
a1(j) = s1
a6(j) = s6
      j = j + 1
      Else
      If s6 < 12 Or s6 > 100 Then          'relative humidity check
a1(j) = s1
a6(j) = s6
```

```
               If a1(j) = a1(j - 1) Then
a6(j - 1) = a6(j)
                 j = j - 1
               End If
               j = j + 1
           End If
         End If

         If IsNull(ActiveWorkbook.Sheets(1).Cells(i + 1, 1).Value) Then         'check the unnormal temperature change
         Exit For
         Else
           t1 = ActiveWorkbook.Sheets(1).Cells(i + 1, 1).Value
           t2 = ActiveWorkbook.Sheets(1).Cells(i + 1, 2).Value
           If IsNumeric(s2) And IsNumeric(t2) Then
           If t2 - s2 > 25 Or t2 - s2 < -25 Then
             If b1(k - 1) = s1 Then
               k = k - 1
             End If
b1(k) = s1
b1(k + 1) = t1
b2(k) = s2
b2(k + 1) = t2
             k = k + 2
           End If
           End If
         End If

   End If
Next i
'===================write the error data into the excel=================
Workbooks("application.xlsm").Activate
For i = 1 To 300
   For n = 1 To 10
Sheets(2).Cells(i, n) = " "       'clear the sheet first
   Next n
Next i
Sheets(2).Cells(1, 1) = "Station ID: " & stat
Sheets(2).Cells(2, 1) = "Time"
Sheets(2).Cells(2, 2) = "Temperature"
Sheets(2).Cells(2, 3) = "Wind speed"
Sheets(2).Cells(2, 4) = "Rercent sunshine"
Sheets(2).Cells(2, 5) = "Precipitation"
Sheets(2).Cells(2, 6) = "Relative Humidity"
Sheets(2).Cells(2, 7) = "Time"
Sheets(2).Cells(2, 8) = "Temperature"
If j > 1 Then
   For i = 1 To j
Sheets(2).Cells(i + 2, 1) = a1(i)     'write error data
Sheets(2).Cells(i + 2, 2) = a2(i)
Sheets(2).Cells(i + 2, 3) = a3(i)
Sheets(2).Cells(i + 2, 4) = a4(i)
Sheets(2).Cells(i + 2, 5) = a5(i)
Sheets(2).Cells(i + 2, 6) = a6(i)

Sheets(2).Cells(i + 2, 2).Select
Selection.Font.ColorIndex = 3
Sheets(2).Cells(i + 2, 3).Select
Selection.Font.ColorIndex = 3
Sheets(2).Cells(i + 2, 4).Select
Selection.Font.ColorIndex = 3
Sheets(2).Cells(i + 2, 5).Select
Selection.Font.ColorIndex = 3
```

```
Sheets(2).Cells(i + 2, 6).Select
Selection.Font.ColorIndex = 3
    Next i
End If
If k > 1 Then
    For i = 1 To k
Sheets(2).Cells(i + 2, 7) = b1(i)     'write inormal temperature change
Sheets(2).Cells(i + 2, 8) = b2(i)
    Next i
End If


Workbooks(stat & ".xlsx").Close
End Sub
```

Code 4: Fill missing month

```
Sub fill_missing_month()

Dim s1(4) As Integer

Dim a0(10, 1000) As Long
Dim a1(10, 1000) As Long
Dim a2(10, 1000) As Long
Dim a3(10, 1000) As Long
Dim a4(10, 1000) As Long
Dim a5(10, 1000) As Long
Dim c(10) As Long
Dim b0(1000) As String
Dim b1(1000) As Single
Dim b2(1000) As Single
Dim b3(1000) As Single
Dim b4(1000) As Single
Dim b5(1000) As Single
Dim s As String
Dim m As Long

stat = InputBox("please input station ID")      'input station ID
yr = InputBox("please input missing year")      'input year
mon = InputBox("please input missing month")    'input month
yr2 = yr + 1
Workbooks.Open Filename:="D:\stations\" & stat & ".xlsx"
ActiveWindow.Visible = True

Select Case mon                     'determine the total hours of the missing month
Case 1, 3, 5, 7, 8, 10, 13
hours = 31 * 24
Case 2, 4, 6, 9, 11
hours = 30 * 24
Case 2
If yr / 4 = Int(yr / 4) Then
hours = 29 * 24
Else
hours = 28 * 24
End If
End Select

'===========obtain all the data in the same month from other years==========
j = 1
For i = 1 To 100000
   If IsNull(ActiveWorkbook.Sheets(1).Cells(i, 1).Value) Then
      Exit For
   Else
      s = ActiveWorkbook.Sheets(1).Cells(i, 1).Value
s1(1) = Left(s, 4)
s1(2) = Mid(s, 5, 2)
s1(3) = Mid(s, 7, 2)
s1(4) = Mid(s, 9, 2)
      If s1(1) = yr And s1(2) = mon Then
MsgBox "This month exists already, please try again."
         Exit Sub
      End If

      If s1(2) = mon And s1(3) = 1 And s1(4) = 0 Then

c(j) = i                    'the row number
```

```
            j = j + 1
        End If

        If s1(1) = yr And s1(2) = mon + 1 And s1(3) = 1 And s1(4) = 0 Then
            row00 = i
        End If
    End If
Next i

For k = 1 To hours
For i = 1 To j - 1
    m = c(i)
    cc = ActiveWorkbook.Sheets(1).Cells(m, 1).Value
b0(k) = yr& Right(cc, 6)

b1(k) = b1(k) + ActiveWorkbook.Sheets(1).Cells(m, 2).Value
b2(k) = b2(k) + ActiveWorkbook.Sheets(1).Cells(m, 3).Value
b3(k) = b3(k) + ActiveWorkbook.Sheets(1).Cells(m, 4).Value
b4(k) = b4(k) + ActiveWorkbook.Sheets(1).Cells(m, 5).Value
b5(k) = b5(k) + ActiveWorkbook.Sheets(1).Cells(m, 6).Value
Next i
b1(k) = Int(b1(k) * 10 / (j - 1)) / 10
b2(k) = Int(b2(k) * 10 / (j - 1)) / 10
b3(k) = Int(b3(k) * 10 / (j - 1)) / 10
b4(k) = Int(b4(k) * 10 / (j - 1)) / 10
b5(k) = Int(b5(k) * 10 / (j - 1)) / 10
For i = 1 To j - 1
c(i) = c(i) + 1
Next i
Next k

For i = 1 To hours
Cells(row00, 1).EntireRow.Insert       'insert empty rows
Next i

For i = 1 To hours
j = row00 + i - 1
Sheets(1).Cells(j, 1).Value = b0(i)
Sheets(1).Cells(j, 2).Value = b1(i)
Sheets(1).Cells(j, 3).Value = b2(i)
Sheets(1).Cells(j, 4).Value = b3(i)
Sheets(1).Cells(j, 5).Value = b4(i)
Sheets(1).Cells(j, 6).Value = b5(i)
Next i

MsgBox "Missing data filling completed."

End Sub
```

Code 5: Erroneous data correction

```
Sub Correct_data()
Dim a(2) As Single
Address = "please input station ID"
stat = InputBox(Address)
Workbooks.Open Filename:="E:\stations\" & stat & ".xlsx"
ActiveWindow.Visible = True

For i = 1 To 100000
    If IsNull(ActiveWorkbook.Sheets(1).Cells(i, 1).Value) Then
        Exit For
    Else
        s1 = ActiveWorkbook.Sheets(1).Cells(i, 1).Value
        s2 = ActiveWorkbook.Sheets(1).Cells(i, 2).Value
        s3 = ActiveWorkbook.Sheets(1).Cells(i, 3).Value
        s4 = ActiveWorkbook.Sheets(1).Cells(i, 4).Value
        s5 = ActiveWorkbook.Sheets(1).Cells(i, 5).Value
        s6 = ActiveWorkbook.Sheets(1).Cells(i, 6).Value

        If s2 > 112 Or s2 < -51 Then         'temperature check
a(1) = ActiveWorkbook.Sheets(1).Cells(i - 1, 2).Value
a(2) = ActiveWorkbook.Sheets(1).Cells(i + 1, 2).Value
                 If -51 <a(1) And a(1) < 112 And -51 < a(2) And a(2) < 112 Then
ActiveWorkbook.Sheets(1).Cells(i, 2).Value = (a(1) + a(2)) / 2
                End If
        End If
        If s3 < 0 Or s3 > 70 Then            'wind speed check
a(1) = ActiveWorkbook.Sheets(1).Cells(i - 1, 3).Value
a(2) = ActiveWorkbook.Sheets(1).Cells(i + 1, 3).Value
                 If 0 <a(1) And a(1) < 70 And 0 < a(2) And a(2) < 70 Then
ActiveWorkbook.Sheets(1).Cells(i, 3).Value = (a(1) + a(2)) / 2
                End If
        End If

        If s4 <= 12.5 Then         'sunshine check
ActiveWorkbook.Sheets(1).Cells(i, 4).Value = 0


ElseIf 12.5 < s4 And s4 <= 37.5 Then
ActiveWorkbook.Sheets(1).Cells(i, 4).Value = 25

' End If



ElseIf 37.5 < s4 And s4 <= 62.5 Then
ActiveWorkbook.Sheets(1).Cells(i, 4).Value = 50
' End If

ElseIf 62.5 < s4 And s4 <= 87.5 Then
ActiveWorkbook.Sheets(1).Cells(i, 4).Value = 75
' End If

ElseIf 87.5 < s4 Then
ActiveWorkbook.Sheets(1).Cells(i, 4).Value = 100
' End If
           'Else
'ActiveWorkbook.Sheets(1).Cells(i, 4).Value = 100
        End If

        If s5 < 0 Then           'precipitation check
ActiveWorkbook.Sheets(1).Cells(i, 5).Value = 0
```

```
        End If
        If s6 < 12 Then           'relative humidity check
ActiveWorkbook.Sheets(1).Cells(i, 6).Value = 12
        Else
        If s6 > 100 Then         'relative humidity check
ActiveWorkbook.Sheets(1).Cells(i, 6).Value = 100
        End If
        End If
    End If
    Next i
End Sub
```

Code 6: Climatic file format conversion from .xlsx to .hcd

```
Sub Rename()
Dim id As Single
Dim iAs Double
Dim statID As String
Dim addix As String
Dim mybook As Workbook
'-----------------------------------------------------
'--------the following section is to convert the .xlsx files to .hcd files------------
addix = "_m"
For id = 1 To 6
Workbooks.OpenFileName:="E:\ME Design\data correction\" & id &addix& ".xlsx"
Workbooks(id &addix& ".xlsx").SaveAsFileName:="E:\ME Design\data correction\" & id &addix, FileFormat:=xlCSV
Workbooks(id &addix& ".csv").Close 1
Next id

  Dim path, str1 As String
path = "E:\ME Design\data correction\"
  str1 = Dir("E:\ME Design\data correction\*.csv")
  Do While str1 <> ""
    Name path & str1 As path &Split(str1, ".")(0) & "." & "hcd"        '(0)means that the  0th value after the split
    str1 = Dir      '----------return to the next .csv file in the folder
  Loop

End Sub
```

Code 7: Climatic file modification from ASOS to NCDC

```
Sub modify()

Address = "please input station ID"
stat = InputBox(Address)
Workbooks.Open Filename:="E:\ME DESIGN\additional data\" & stat & ".xlsx"
ActiveWindow.Visible = True

Range("U1").Select
Selection.EntireColumn.Delete
Range("T1").Select
Selection.EntireColumn.Delete
Range("S1").Select
Selection.EntireColumn.Delete
Range("R1").Select
Selection.EntireColumn.Delete
Range("Q1").Select
Selection.EntireColumn.Delete
Range("P1").Select
Selection.EntireColumn.Delete
Range("O1").Select
Selection.EntireColumn.Delete
Range("N1").Select
Selection.EntireColumn.Delete
Range("L1").Select
Selection.EntireColumn.Delete
Range("K1").Select
Selection.EntireColumn.Delete
Range("J1").Select
Selection.EntireColumn.Delete
Range("I1").Select
Selection.EntireColumn.Delete
Range("F1").Select
Selection.EntireColumn.Delete
Range("D1").Select
Selection.EntireColumn.Delete
Range("A1").Select
Selection.EntireColumn.Delete

For i = 1 To 4
Columns(3).Insert Shift:=xlShiftToRight
Next i

Sheets(1).Columns(8).Copy Sheets(1).Columns(3)
Sheets(1).Columns(10).Copy Sheets(1).Columns(4)
Sheets(1).Columns(9).Copy Sheets(1).Columns(5)
Sheets(1).Columns(7).Copy Sheets(1).Columns(6)

For i = 1 To 4
Sheets(1).Columns(7).Delete     'delete the last 4 columns in the file
Next i

For i = 1 To 4
Sheets(1).Rows(1).Delete     'delete the first 4 rows in the file
Next i

'========================delete excessive hours========================
i = 1
Dim s0 As String
Dim s1 As String
```

```
Do Until i = 300000

    If IsEmpty(ActiveWorkbook.Sheets(1).Cells(i, 1).Value) Then
        Exit Do
    Else
        s0 = ActiveWorkbook.Sheets(1).Cells(i, 1).Value
        's1 = Format(s, "hhmm")
        's2 = Right(s1, 2)
        s1 = Minute(s0)
        If s1 <> "53" And s1 <> "56" Then
Sheets(1).Rows(i).Delete
i = i - 1
        End If
    End If
i = i + 1
Loop
'===================modify the data of "M" and percent sunshine
Dim s(6) As String
For i = 1 To 300000
    If IsEmpty(ActiveWorkbook.Sheets(1).Cells(i, 1).Value) Then
        Exit For
    Else
s(1) = ActiveWorkbook.Sheets(1).Cells(i, 1).Value
s(4) = ActiveWorkbook.Sheets(1).Cells(i, 4).Value
s(5) = ActiveWorkbook.Sheets(1).Cells(i, 5).Value

        Select Case s(4)
            Case "CLR"
ActiveWorkbook.Sheets(1).Cells(i, 4).Value = 100    'clear cloud
            Case "FEW"
ActiveWorkbook.Sheets(1).Cells(i, 4).Value = 75     'few cloud
            Case "SCT"
ActiveWorkbook.Sheets(1).Cells(i, 4).Value = 50     'scattered
            Case "BKN"
ActiveWorkbook.Sheets(1).Cells(i, 4).Value = 25     'black
            Case "OVC"
ActiveWorkbook.Sheets(1).Cells(i, 4).Value = 0      'over cast
            Case "VV "
ActiveWorkbook.Sheets(1).Cells(i, 4).Value = 0      'over cast
        End Select

        If s(5) = "M" Then
ActiveWorkbook.Sheets(1).Cells(i, 5).Value = 0      ' M means the precipitation is 0
        End If
    End If
Next i

'============change the format of date/time as that in the hcd file===============
For i = 1 To 300000
    If IsEmpty(ActiveWorkbook.Sheets(1).Cells(i, 1).Value) Then
        Exit For
    Else
s(1) = ActiveWorkbook.Sheets(1).Cells(i, 1).Value
ActiveWorkbook.Sheets(1).Cells(i, 8).Value = Format(s(1), "yyyymmddhh")
    End If
Next i

Sheets(1).Columns(8).Copy Sheets(1).Columns(1)      'copy the data in column 8 to column 1
Sheets(1).Columns(8).Delete     'delete the column 8
End Sub
```

Code 8: Climatic file format from RWIS to NCDC

```
'purpose: convert the RWIS climatic file to a NCDC file readable by PMED

Sub modify()

Address = "please input station ID"
stat = InputBox(Address)
Workbooks.Open Filename:="E:\ME DESIGN\RWIS data\" & stat & ".xlsx"
ActiveWindow.Visible = True

'------------------------delete useless columns and rows----------------------------
For i = 1 To 60
Range("O1").Select
Selection.EntireColumn.Delete       '//delete all the columns after column O
Next i

For i = 1 To 6
Range("H1").Select
Selection.EntireColumn.Delete       '//delete columns H, I, J, K, L, M
Next i



Range("F1").Select
Selection.EntireColumn.Delete
Range("D1").Select
Selection.EntireColumn.Delete

For i = 1 To 2
Columns(4).Insert Shift:=xlShiftToRight
Next i
Sheets(1).Columns(8).Copy Sheets(1).Columns(5)
Sheets(1).Columns(7).Copy Sheets(1).Columns(4)
For i = 1 To 2
Sheets(1).Columns(7).Delete     'delete the last 2 columns in the file
Next i

For i = 1 To 4
Sheets(1).Rows(1).Delete     'delete the first 4 rows in the file
Next i
'------------------------------------------------------------------------------------
For i = 1 To 1000000
```

```
    If IsEmpty(ActiveWorkbook.Sheets(1).Cells(i, 1).Value) Then
        If IsEmpty(ActiveWorkbook.Sheets(1).Cells(i + 1, 1).Value) Then
            Exit For
        Else
Sheets(1).Rows(i).Delete
        End If
    End If
Next i
'------------------------------------------------------------------------------------
Dim s(2) As String
Dim s2 As String
Dim time As String
For i = 1 To 1000000
    If IsEmpty(ActiveWorkbook.Sheets(1).Cells(i, 1).Value) Then
        Exit For
    Else
s(1) = ActiveWorkbook.Sheets(1).Cells(i, 1).Value

ActiveWorkbook.Sheets(1).Cells(i, 8).Value = Format(s(1), "yyyymmdd")

s(2) = ActiveWorkbook.Sheets(1).Cells(i, 2).Value
        s2 = Left(s(2), 8)
time = Format(s2, "hhmm")
ActiveWorkbook.Sheets(1).Cells(i, 9).Value = Format(s(1), "yyyymmdd") & time
    End If
Next i
'----------------------------------------------
For i = 1 To 2
Sheets(1).Columns(1).Delete        'delete the first and second column
Next i
Columns(1).Insert Shift:=xlShiftToRight
Sheets(1).Columns(8).Copy Sheets(1).Columns(1)
Sheets(1).Columns(8).Delete
Sheets(1).Columns(7).Delete
'-----------------------------------------------------------------
For i = 1 To 1000000
    If IsEmpty(ActiveWorkbook.Sheets(1).Cells(i, 1).Value) Then
            Exit For
        Else
            If IsNumeric(ActiveWorkbook.Sheets(1).Cells(i, 4).Value) = False Then
ActiveWorkbook.Sheets(1).Cells(i, 4).Value = 0
        End If
```

```
    End If
Next i
'------------------------convert the 5-minute precipitation to hourly value----------------------

Dim pp(12) As Double
Dim pp0 As Double
Dim mm As String
Dim ii As Double
ii = 1
For i = 1 To 1000000
    If IsEmpty(ActiveWorkbook.Sheets(1).Cells(i, 1).Value) Then
        Exit For
    Else
mm = Right(ActiveWorkbook.Sheets(1).Cells(i, 1).Value, 2)
        If mm = "00" Then
pp(1) = ActiveWorkbook.Sheets(1).Cells(i, 4).Value
pp(2) = ActiveWorkbook.Sheets(1).Cells(i + 1, 4).Value
pp(3) = ActiveWorkbook.Sheets(1).Cells(i + 2, 4).Value
pp(4) = ActiveWorkbook.Sheets(1).Cells(i + 3, 4).Value
pp(5) = ActiveWorkbook.Sheets(1).Cells(i + 4, 4).Value
pp(6) = ActiveWorkbook.Sheets(1).Cells(i + 5, 4).Value
pp(7) = ActiveWorkbook.Sheets(1).Cells(i + 6, 4).Value
pp(8) = ActiveWorkbook.Sheets(1).Cells(i + 7, 4).Value
pp(9) = ActiveWorkbook.Sheets(1).Cells(i + 8, 4).Value
pp(10) = ActiveWorkbook.Sheets(1).Cells(i + 9, 4).Value
pp(11) = ActiveWorkbook.Sheets(1).Cells(i + 10, 4).Value
pp(12) = ActiveWorkbook.Sheets(1).Cells(i + 11, 4).Value
            pp0 = (pp(1) + pp(2) + pp(3) + pp(4) + pp(5) + pp(6) + pp(7) + pp(8) + pp(9) + pp(10) + pp(11) + pp(12)) / 12
ActiveWorkbook.Sheets(1).Cells(i, 4).Value = pp0
Sheets(1).Rows(i).Copy Sheets(2).Rows(ii)
ii = ii + 1
        End If
    End If
Next i
'-----------------------------------------------------
Dim hour As String
For i = 1 To 1000000
    If IsEmpty(ActiveWorkbook.Sheets(2).Cells(i, 1).Value) Then
        Exit For
    Else
ActiveWorkbook.Sheets(2).Cells(i, 1).Value = Left(ActiveWorkbook.Sheets(2).Cells(i, 1).Value, 10)
        If IsNumeric(ActiveWorkbook.Sheets(2).Cells(i, 3).Value) = False Then
```

```
ActiveWorkbook.Sheets(2).Cells(i, 3).Value = 0
        End If
    End If
Next i
End Sub
```

APPENDIX D: STATE WIDE TRAFFIC INPUTS

Table D1: Statewide vehicle class distribution in Michigan, from [32]

Truck classes	Distribution (%)
4	1.76
5	27.37
6	5.01
7	0.77
8	4.42
9	45.43
10	7.07
11	1.12
12	0.22
13	6.82

Table D2: Statewide monthly adjustment in Michigan, from [32]

Month	VC4	VC5	VC6	VC7	VC8	VC9	VC10	VC11	VC12	VC13
1	0.81	0.81	0.81	0.81	0.90	0.90	0.90	0.87	0.87	0.87
2	0.89	0.89	0.89	0.89	0.95	0.95	0.95	0.89	0.89	0.89
3	0.88	0.88	0.88	0.88	0.98	0.98	0.98	0.88	0.88	0.88
4	0.93	0.93	0.93	0.93	1.01	1.01	1.01	0.96	0.96	0.96
5	1.02	1.02	1.02	1.02	1.06	1.06	1.06	1.05	1.05	1.05
6	1.14	1.14	1.14	1.14	1.12	1.12	1.12	1.16	1.16	1.16
7	1.18	1.18	1.18	1.18	0.98	0.98	0.98	1.07	1.07	1.07
8	1.19	1.19	1.19	1.19	1.08	1.08	1.08	1.10	1.10	1.10
9	1.13	1.13	1.13	1.13	1.03	1.03	1.03	1.07	1.07	1.07
10	1.06	1.06	1.06	1.06	1.05	1.05	1.05	1.11	1.11	1.11
11	0.96	0.96	0.96	0.96	0.96	0.96	0.96	1.00	1.00	1.00
12	0.82	0.82	0.82	0.82	0.87	0.87	0.87	0.83	0.83	0.83

Table D3: Axles per truck of each vehicle class in statewide, provided by MDOT

Vehicle classes	Single	Tandem	Tridem	Quad
Class 4	1.65	0.36	0	0
Class 5	2	0.05	0	0
Class 6	1	1	0	0
Class 7	1.06	0.06	0.59	0.35
Class 8	2.28	0.74	0	0
Class 9	1.29	1.85	0	0
Class 10	1.54	1	0.31	0.56
Class 11	4.99	0	0	0
Class 12	3.85	0.96	0	0
Class 13	2.03	1.4	0.36	0.61

Table D4: Statewide single axle load spectra, from [32] (same for each month)

Load(kips)	**Vehicle**									
	4	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
3	0.19	2.63	0.33	2.19	1.56	1.42	0.44	1.23	0.93	3.69
4	0.22	15.77	0.88	1.74	2.15	2.76	0.52	1.14	1.57	2.81
5	0.48	17.16	1.22	1.77	3.32	2.48	0.56	2.66	3.14	2.50
6	1.65	15.08	1.81	2.23	5.07	2.88	0.96	6.12	6.75	2.82
7	3.15	8.65	2.18	1.91	6.18	2.47	1.24	5.05	6.29	2.41
8	7.91	9.15	5.14	2.65	10.68	4.72	2.76	7.28	8.68	2.86
9	8.85	5.93	7.38	2.87	11.56	7.33	4.36	8.05	9.41	2.73
10	12.59	5.89	13.84	4.35	14.11	16.74	9.98	12.82	12.69	6.00
11	11.91	4.38	16.11	5.04	9.46	20.72	13.74	10.09	10.09	9.20
12	13.73	4.09	16.50	7.72	8.24	18.78	17.48	9.60	10.07	12.80
13	10.92	3.00	10.85	8.58	6.43	8.21	13.12	8.00	8.35	10.91
14	7.02	1.86	6.30	7.88	4.31	2.89	7.45	5.85	5.11	7.23
15	6.56	1.75	5.55	10.34	4.58	2.04	7.10	6.43	4.82	7.55
16	3.91	1.09	3.18	8.10	3.05	1.30	4.59	4.31	3.01	5.21
17	3.33	1.03	2.71	8.62	3.05	1.55	4.67	4.01	2.81	5.54
18	1.97	0.63	1.62	6.23	1.91	1.12	3.05	2.38	1.76	3.78
19	1.69	0.60	1.47	6.04	1.65	1.06	2.89	2.06	1.51	3.66
20	1.09	0.37	0.94	3.96	0.89	0.57	1.65	1.11	1.03	2.24
21	0.92	0.34	0.82	3.00	0.69	0.41	1.35	0.81	0.75	1.91
22	0.53	0.19	0.44	1.61	0.36	0.20	0.68	0.38	0.46	1.06

Table D4: Statewide single axle load spectra, continued, from [32] (same for each month)

Load(kips)	Vehicle									
	4	5	6	7	8	9	10	11	12	13
23	0.41	0.15	0.30	1.26	0.27	0.15	0.52	0.26	0.27	0.88
24	0.28	0.10	0.19	0.74	0.16	0.08	0.31	0.14	0.15	0.59
25	0.15	0.05	0.09	0.40	0.09	0.04	0.16	0.07	0.12	0.33
26	0.11	0.04	0.05	0.27	0.07	0.03	0.13	0.05	0.11	0.31
27	0.06	0.02	0.04	0.17	0.04	0.02	0.08	0.03	0.03	0.18
28	0.04	0.02	0.02	0.12	0.04	0.01	0.06	0.02	0.02	0.17
29	0.03	0.01	0.01	0.06	0.02	0.01	0.03	0.01	0.02	0.10
30	0.03	0.01	0.01	0.05	0.02	0.01	0.03	0.01	0.01	0.09
31	0.02	0.01	0.01	0.03	0.01	0.00	0.02	0.01	0.01	0.06
32	0.02	0.00	0.01	0.02	0.01	0.00	0.02	0.01	0.02	0.06
33	0.01	0.00	0.00	0.01	0.01	0.00	0.01	0.01	0.01	0.04
34	0.14	0.00	0.00	0.01	0.01	0.00	0.01	0.00	0.00	0.04
35	0.04	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.03
36	0.01	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.02
37	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.02
38	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.02
39	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02
40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03
41	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10

Table D5: Statewide tandem axle load spectra, from [32] (same for each month)

Load (kips)	Vehicle									
	4	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
6	0.08	30.65	4.14	2.48	3.22	1.16	0.25	0.00	0.70	1.54
8	0.40	39.99	13.85	6.14	5.91	2.84	0.96	0.00	1.81	3.51
10	1.13	23.94	10.93	6.66	14.40	6.69	2.90	0.00	4.45	4.99
12	2.17	4.76	6.84	6.79	17.89	9.16	5.88	0.00	6.99	5.69
14	2.60	0.48	6.42	6.82	14.04	8.89	8.08	0.00	10.39	6.00
16	2.91	0.06	6.01	6.67	10.92	7.96	7.86	0.00	12.28	4.44
18	3.48	0.03	5.50	5.95	8.65	7.17	7.06	0.00	13.68	3.15
20	4.26	0.02	5.58	5.53	7.06	6.62	6.59	0.00	13.50	2.90
22	6.01	0.02	5.90	7.67	5.68	6.39	5.96	0.00	11.86	3.54
24	9.23	0.01	6.80	8.36	4.46	6.61	6.01	0.00	10.37	5.09
26	11.21	0.01	5.81	6.66	2.74	5.53	5.47	0.00	6.01	6.05
28	12.99	0.01	5.08	6.15	1.81	5.46	6.11	0.00	3.47	8.03
30	13.64	0.01	4.28	6.29	1.18	5.82	6.85	0.00	1.79	9.68
32	11.61	0.00	3.57	4.82	0.80	6.12	7.44	0.00	1.06	10.11
34	7.94	0.00	2.87	3.54	0.52	5.36	7.07	0.00	0.72	8.54
36	4.76	0.01	2.09	2.66	0.31	3.57	5.62	0.00	0.35	6.36
38	2.56	0.00	1.42	1.89	0.16	2.05	3.83	0.00	0.17	4.20
40	1.42	0.00	0.96	1.36	0.10	1.13	2.40	0.00	0.07	2.51
42	0.74	0.00	0.65	1.26	0.05	0.63	1.44	0.00	0.07	1.50
44	0.41	0.00	0.45	0.61	0.03	0.36	0.84	0.00	0.09	0.88

Table D5: Statewide tandem axle load spectra, continued, from [32] (same for each month)

	Vehicle									
Load (kips)	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
46	0.21	0.00	0.32	0.39	0.02	0.22	0.53	0.00	0.04	0.55
48	0.09	0.00	0.19	0.20	0.02	0.11	0.30	0.00	0.03	0.26
50	0.05	0.00	0.12	0.20	0.01	0.06	0.20	0.00	0.02	0.17
52	0.03	0.00	0.07	0.10	0.01	0.04	0.11	0.00	0.04	0.10
54	0.02	0.00	0.05	0.03	0.01	0.02	0.08	0.00	0.02	0.06
56	0.01	0.00	0.03	0.02	0.00	0.01	0.05	0.00	0.01	0.04
58	0.01	0.00	0.02	0.10	0.00	0.01	0.04	0.00	0.00	0.03
60	0.01	0.00	0.01	0.19	0.00	0.01	0.02	0.00	0.01	0.02
62	0.01	0.00	0.01	0.10	0.00	0.00	0.02	0.00	0.00	0.02
64	0.01	0.00	0.01	0.11	0.00	0.00	0.01	0.00	0.00	0.01
66	0.00	0.00	0.01	0.01	0.00	0.00	0.01	0.00	0.00	0.01
68	0.00	0.00	0.01	0.01	0.00	0.00	0.01	0.00	0.00	0.01
70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
72	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
74	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00
76	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00
78	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00
80	0.00	0.00	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.00
82	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00

Table D6: Statewide tridem axle load spectra, from [32] (same for each month)

Load (kips)	Vehicle Class									
	4	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
12	66.67	48.28	29.51	3.45	20.89	59.19	14.02	23.31	13.28	24.40
15	0.00	1.08	9.20	2.96	2.33	13.03	12.57	20.89	6.38	13.34
18	0.00	0.43	7.60	3.94	3.34	7.89	11.89	15.88	6.74	7.79
21	0.00	0.15	10.35	5.86	4.26	6.51	11.26	12.00	6.00	4.71
24	0.00	0.73	4.73	6.99	3.71	2.78	9.06	5.80	4.37	3.05
27	0.00	3.13	3.55	7.34	4.32	1.87	7.22	2.61	4.53	2.32
30	0.00	3.83	6.27	8.79	5.24	2.51	5.85	2.08	8.01	2.54
33	0.00	0.70	4.18	8.78	4.89	1.02	4.47	2.06	5.61	3.14
36	0.00	15.59	2.11	10.33	3.91	0.66	4.65	2.94	6.25	4.83
39	0.00	0.70	2.22	10.85	5.00	0.55	4.57	1.10	8.04	6.25
42	26.66	3.48	1.79	9.73	3.99	0.59	3.71	2.98	6.70	6.14
45	6.67	2.93	1.70	7.82	4.53	0.84	3.30	1.95	6.08	6.12
48	0.00	3.33	1.19	5.51	4.96	0.36	2.44	1.87	3.48	5.01
51	0.00	1.78	3.12	3.08	4.98	0.46	1.64	0.72	5.81	3.40
54	0.00	4.48	0.96	1.90	5.98	0.27	1.21	1.27	2.22	2.46
57	0.00	0.00	0.00	1.02	5.00	0.23	0.79	0.41	0.98	1.60
60	0.00	0.00	0.10	0.52	3.10	0.32	0.48	0.40	0.89	1.00
63	0.00	0.00	2.09	0.39	1.51	0.12	0.30	0.16	0.96	0.72
66	0.00	0.00	1.96	0.30	1.40	0.10	0.18	0.99	1.39	0.39
69	0.00	6.25	1.47	0.17	1.59	0.25	0.14	0.20	0.38	0.24

Table D6: Statewide tridem axle load spectra, continued, from [32] (same for each month)

Load (kips)	**Vehicle Class**									
	4	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
72	0.00	0.00	2.94	0.06	1.16	0.12	0.09	0.38	0.11	0.18
75	0.00	0.00	0.02	0.03	0.99	0.09	0.06	0.00	0.08	0.10
78	0.00	0.00	0.00	0.03	1.12	0.07	0.03	0.00	0.23	0.08
81	0.00	0.00	1.47	0.01	1.42	0.05	0.02	0.00	0.20	0.05
84	0.00	3.13	0.00	0.02	0.06	0.02	0.01	0.00	0.41	0.03
87	0.00	0.00	0.45	0.01	0.05	0.04	0.01	0.00	0.07	0.03
90	0.00	0.00	0.00	0.00	0.10	0.02	0.01	0.00	0.09	0.01
93	0.00	0.00	0.04	0.00	0.01	0.02	0.00	0.00	0.35	0.02
96	0.00	0.00	0.00	0.01	0.00	0.02	0.00	0.00	0.03	0.01
99	0.00	0.00	0.98	0.03	0.10	0.00	0.01	0.00	0.10	0.01
102	0.00	0.00	0.00	0.07	0.06	0.00	0.01	0.00	0.23	0.03

Table D7: Statewide quad axle load spectra, from [32] (same for each month)

	Vehicle Class									
Load (kips)	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
12	66.67	48.28	29.51	0.66	20.89	59.19	1.74	23.31	13.28	1.49
15	0.00	1.08	9.20	0.64	2.33	13.03	3.36	20.89	6.38	2.70
18	0.00	0.43	7.60	0.67	3.34	7.89	6.69	15.88	6.74	4.32
21	0.00	0.15	10.35	1.33	4.26	6.51	7.49	12.00	6.00	5.58
24	0.00	0.73	4.73	2.34	3.71	2.78	7.04	5.80	4.37	5.46
27	0.00	3.13	3.55	2.65	4.32	1.87	6.08	2.61	4.53	4.84
30	0.00	3.83	6.27	3.72	5.24	2.51	5.62	2.08	8.01	4.05
33	0.00	0.70	4.18	4.73	4.89	1.02	4.19	2.06	5.61	2.67
36	0.00	15.59	2.11	6.32	3.91	0.66	3.43	2.94	6.25	2.27
39	0.00	0.70	2.22	7.74	5.00	0.55	2.74	1.10	8.04	2.12
42	26.66	3.48	1.79	9.55	3.99	0.59	2.10	2.98	6.70	2.22
45	6.67	2.93	1.70	11.63	4.53	0.84	2.03	1.95	6.08	2.94
48	0.00	3.33	1.19	12.07	4.96	0.36	2.09	1.87	3.48	3.68
51	0.00	1.78	3.12	10.45	4.98	0.46	2.17	0.72	5.81	3.96
54	0.00	4.48	0.96	9.03	5.98	0.27	2.52	1.27	2.22	4.68
57	0.00	0.00	0.00	6.40	5.00	0.23	2.89	0.41	0.98	4.59
60	0.00	0.00	0.10	3.74	3.10	0.32	3.17	0.40	0.89	3.98
63	0.00	0.00	2.09	2.27	1.51	0.12	3.68	0.16	0.96	3.85
66	0.00	0.00	1.96	1.36	1.40	0.10	3.23	0.99	1.39	3.17
69	0.00	6.25	1.47	0.87	1.59	0.25	3.20	0.20	0.38	3.05

Table D7: Statewide quad axle load spectra, continued, from [32]

	Vehicle Class									
Load (kips)	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
12	66.67	48.28	29.51	0.66	20.89	59.19	1.74	23.31	13.28	1.49
15	0.00	1.08	9.20	0.64	2.33	13.03	3.36	20.89	6.38	2.70
18	0.00	0.43	7.60	0.67	3.34	7.89	6.69	15.88	6.74	4.32
21	0.00	0.15	10.35	1.33	4.26	6.51	7.49	12.00	6.00	5.58
24	0.00	0.73	4.73	2.34	3.71	2.78	7.04	5.80	4.37	5.46
27	0.00	3.13	3.55	2.65	4.32	1.87	6.08	2.61	4.53	4.84
30	0.00	3.83	6.27	3.72	5.24	2.51	5.62	2.08	8.01	4.05
33	0.00	0.70	4.18	4.73	4.89	1.02	4.19	2.06	5.61	2.67
36	0.00	15.59	2.11	6.32	3.91	0.66	3.43	2.94	6.25	2.27
39	0.00	0.70	2.22	7.74	5.00	0.55	2.74	1.10	8.04	2.12
42	26.66	3.48	1.79	9.55	3.99	0.59	2.10	2.98	6.70	2.22
45	6.67	2.93	1.70	11.63	4.53	0.84	2.03	1.95	6.08	2.94
48	0.00	3.33	1.19	12.07	4.96	0.36	2.09	1.87	3.48	3.68
51	0.00	1.78	3.12	10.45	4.98	0.46	2.17	0.72	5.81	3.96
54	0.00	4.48	0.96	9.03	5.98	0.27	2.52	1.27	2.22	4.68
57	0.00	0.00	0.00	6.40	5.00	0.23	2.89	0.41	0.98	4.59
60	0.00	0.00	0.10	3.74	3.10	0.32	3.17	0.40	0.89	3.98
63	0.00	0.00	2.09	2.27	1.51	0.12	3.68	0.16	0.96	3.85
66	0.00	0.00	1.96	1.36	1.40	0.10	3.23	0.99	1.39	3.17
69	0.00	6.25	1.47	0.87	1.59	0.25	3.20	0.20	0.38	3.05

APPENDIX E: MATERIAL PROPERTY INPUTS

Table E1: Dynamic modulus of the GGSP used in this study, psi, (binder PG70-28)

Temperature(°F)	Frequencies (Hz)			
	0.1	1	10	25
14	1629514	2153352	2630586	2799118
40	661855	1079685	1584526	1794689
70	173055	334119	609288	754744.2
100	50467	95233	187136	244658
130	21349	35244	64219	83316

Table E2: Dynamic modulus of the 4E30 used in this study, psi, (binder PG70-28)

Temperature(°F)	Frequencies (Hz)			
	0.1	1	10	25
14	2156592	2673390	3115609	3267107
40	947228	1453365	2005105	2222261
70	226539	457420	820258	999796
100	47149	109235	240639	321415
130	13275	29598	68765	96000

Table E3: Dynamic modulus of the 3E30 used in this study, psi, (binder PG64-22)

Temperature(°F)	Frequencies (Hz)			
	0.1	1	10	25
14	2602496	3107239	3504324	3632770
40	1412074	2021209	2608731	2821328
70	449716	843194	1379247	1617638
100	110059	248812	515511	665725
130	30773	69675	160816	221826

Table E4: Dynamic modulus of the 5E10 used in this study, psi, (binder PG64-28)

Temperature(°F)	Frequencies (Hz)			
	0.1	1	10	25
14	1943087	2425736	2844513	2989406
40	831277	1289174	1795464	1996816
70	190407	392032	713565	874246
100	37177	89353	202149	272283
130	9706	22838	55389	78407

Table E5: Dynamic modulus of the 4E10 used in this study, psi, (binder PG64-28)

Temperature(°F)	Frequencies (Hz)			
	0.1	1	10	25
14	2190296	2698519	3135781	3286619
40	988583	1492572	2036331	2249775
70	245747	487661	857698	1038060
100	50559	118799	259946	345107
130	13124	31084	74411	104314

Table E6: Dynamic modulus of the 3E10 used in this study, psi, (binder PG58-22)

Temperature(°F)	Frequencies (Hz)			
	0.1	1	10	25
14	2285121	2894324	3422692	3605022
40	1052736	1640293	2278667	2528669
70	270163	559499	1008063	1226373
100	52910	133579	307656	414302
130	11498	29890	77974	112647

Table E7: Creep compliance of the GGSP used in this study, 1/psi, (binder PG70-28)

Time (sec)	Temperature (˚F)		
	-4	14	32
1	3.66E-07	4.94E-07	7.74E-07
2	3.83E-07	5.34E-07	8.71E-07
5	4.11E-07	5.99E-07	1.03E-06
10	4.36E-07	6.60E-07	1.19E-06
20	4.66E-07	7.33E-07	1.38E-06
50	5.13E-07	8.54E-07	1.71E-06
100	5.58E-07	9.69E-07	2.03E-06

Table E8: Creep compliance of the 4E30 used in this study, 1/psi, (binder PG70-28)

Time (sec)	Temperature (˚F)		
	-4	14	32
1	3.03E-07	3.89E-07	5.77E-07
2	3.13E-07	4.13E-07	6.37E-07
5	3.29E-07	4.51E-07	7.33E-07
10	3.44E-07	4.86E-07	8.25E-07
20	3.60E-07	5.28E-07	9.35E-07
50	3.86E-07	5.95E-07	1.12E-06
100	4.10E-07	6.57E-07	1.30E-06

Table E9: Creep compliance of the 3E30 used in this study, 1/psi, (binder PG64-22)

Time (sec)	Temperature (˚F)		
	-4	14	32
1	2.79E-07	3.33E-07	4.42E-07
2	2.87E-07	3.50E-07	4.78E-07
5	3.00E-07	3.77E-07	5.40E-07
10	3.11E-07	4.02E-07	5.96E-07
20	3.24E-07	4.31E-07	6.66E-07
50	3.45E-07	4.78E-07	7.82E-07
100	3.64E-07	5.23E-07	8.94E-07

Table E10: Creep compliance of the 5E10 used in this study, 1/psi, (binder PG64-28)

Time (sec)	Temperature (˚F)		
	-4	14	32
1	3.30E-07	4.29E-07	6.46E-07
2	3.42E-07	4.57E-07	7.15E-07
5	3.60E-07	5.00E-07	8.25E-07
10	3.76E-07	5.40E-07	9.31E-07
20	3.95E-07	5.87E-07	1.06E-06
50	4.25E-07	6.64E-07	1.28E-06
100	4.52E-07	7.35E-07	1.49E-06

Table E11: Creep compliance of the 4E10 used in this study, 1/psi, (binder PG64-28)

Time (sec)	Temperature (˚F)		
	-4	14	32
1	3.05E-07	3.91E-07	5.75E-07
2	3.15E-07	4.15E-07	6.33E-07
5	3.31E-07	4.52E-07	7.26E-07
10	3.45E-07	4.86E-07	8.16E-07
20	3.62E-07	5.27E-07	9.22E-07
50	3.88E-07	5.91E-07	1.10E-06
100	4.11E-07	6.52E-07	1.28E-06

Table E12: Creep compliance of the 3E10 used in this study, 1/psi, (binder PG58-22)

Time (sec)	Temperature (˚F)		
	-4	14	32
1	2.87E-07	3.67E-07	5.32E-07
2	2.98E-07	3.91E-07	5.88E-07
5	3.16E-07	4.31E-07	6.84E-07
10	3.32E-07	4.67E-07	7.74E-07
20	3.51E-07	5.12E-07	8.86E-07
50	3.81E-07	5.83E-07	1.08E-06
100	4.08E-07	6.52E-07	1.27E-06

Table E13: Dynamic shear modulus and phase angle of PG 70-28 at 10 rad/s

Temperature (°F)	Dynamic shear modulus (psi)	Phase angle (°)
40	10651693.5	57.2
70	1295577.1	58.5
100	114851	59.5
130	12660.6	60.2
168	1791.7	60.8

Table E14: Dynamic shear modulus and phase angle of PG 70-28 at 10 rad/s

Temperature (°F)	Dynamic shear modulus (psi)	Phase angle (°)
40	15522432.6	46.1
70	2723528.3	58.4
100	234411.5	69
130	15452.3	77.3
168	885.3	84.4

Table E15: Dynamic shear modulus and phase angle of PG 64-28 at 10 rad/s

Temperature (°F)	Dynamic shear modulus (psi)	Phase angle (°)
40	9799661.3	52.2
70	1439853.3	59.9
100	122051.7	66.3
130	10313.5	71.2
168	975.2	75.5

Table E16: Dynamic shear modulus and phase angle of PG 58-22 at 10 rad/s

Temperature (°F)	Dynamic shear modulus (psi)	Phase angle (°)
40	11843112.7	47.3
70	2023700.3	59.7
100	155618.5	70.2
130	9667.5	78.3
168	610.5	84.8

APPENDIX F: DETAILED DISTRESS PREDICTIONS IN THE SENSITIVITY ANALYSIS

Table F0: Station ID and the cities where the stations are located

Station ID	04847	04854	14836	14840	14858	94893
City name	Adrian	Gaylord	Lansing	Muskegon	Hancock	Iron. Mountain

Table F1: Sensitivity to temperature

a) Distress predictions of flexible pavement under heavy traffic design

Weather data	Distresses	Station ID					
		04847	04854	14836	14840	14858	94893
Original weather data	Thermal Cracking (ft/mi)	84.34	84.34	84.34	84.34	83.36	84.42
	AC Rut (in.)	0.50	0.37	0.36	0.41	0.35	0.41
	Total Rut (in.)	1.15	1.03	1.01	1.06	1.01	1.07
	Top-down Cracking (ft/mi)	313.36	335.72	267.14	269.39	406.29	383.35
	Bottom-up Cracking (ft/mi)	6.05	5.65	5.71	5.87	5.44	5.69
	IRI (in./mi)	172.33	165.77	164.47	167.15	164.64	167.78
Temperature increased by 10%	Thermal Cracking (ft/mi)	84.34	84.34	84.34	84.34	83.35	83.69
	AC Rut (in.)	0.66	0.49	0.49	0.55	0.46	0.53
	Total Rut (in.)	1.32	1.14	1.14	1.20	1.12	1.19
	Top-down Cracking (ft/mi)	398.21	319.72	280.44	300.45	378.08	396.95
	Bottom-up Cracking (ft/mi)	6.40	6.02	6.07	6.22	5.79	6.01
	IRI (in./mi)	181.13	171.98	171.65	174.70	170.27	174.37
Temperature decreased by 10%	Thermal Cracking (ft/mi)	84.34	83.35	84.34	84.34	83.37	86.73
	AC Rut (in.)	0.38	0.28	0.26	0.31	0.27	0.31
	Total Rut (in.)	1.03	0.94	0.91	0.95	0.93	0.97
	Top-down Cracking (ft/mi)	292.05	419.58	301.13	273.50	471.65	458.57
	Bottom-up Cracking (ft/mi)	5.70	5.35	5.33	5.52	5.12	5.38
	IRI (in./mi)	165.85	161.13	159.00	161.54	160.10	162.53

b) Distress predictions of flexible pavement under medium traffic design

Weather data	Distresses	Station ID					
		04847	04854	14836	14840	14858	94893
Original weather data	Thermal Cracking (ft/mi)	124.12	1786.20	1180.49	83.37	2267.25	2419.64
	AC Rut (in.)	0.37	0.28	0.27	0.31	0.26	0.30
	Total Rut (in.)	1.00	0.91	0.90	0.94	0.90	0.94
	top-down Cracking (ft/mi)	331.55	325.16	305.49	316.03	341.68	336.56
	bottom-up Cracking (ft/mi)	5.43	5.09	5.10	5.25	4.87	5.10
	IRI (in./mi)	164.17	171.15	166.06	160.18	173.90	176.96
Temperature increased by 10%	Thermal Cracking (ft/mi)	96.32	1584.16	762.59	83.35	2076.47	2308.06
	AC Rut (in.)	0.48	0.36	0.36	0.40	0.34	0.39
	Total Rut (in.)	1.12	0.99	1.00	1.04	0.98	1.03
	top-down Cracking (ft/mi)	354.44	338.28	329.43	339.98	342.00	343.27
	bottom-up Cracking (ft/mi)	5.73	5.41	5.41	5.54	5.19	5.42
	IRI (in./mi)	170.22	174.26	168.22	165.53	176.42	180.83
Temperature decreased by 10%	Thermal Cracking (ft/mi)	260.87	1967.52	1593.26	83.43	2391.67	2494.02
	AC Rut (in.)	0.28	0.21	0.20	0.23	0.20	0.23
	Total Rut (in.)	0.91	0.85	0.82	0.86	0.85	0.88
	top-down Cracking (ft/mi)	312.65	341.26	297.16	296.20	371.31	361.35
	bottom-up Cracking (ft/mi)	5.12	4.80	4.75	4.93	4.60	4.84
	IRI (in./mi)	160.32	169.35	164.90	155.97	171.69	174.15

c) Distress predictions of rigid pavement under heavy traffic design

Weather data	Distresses	Station ID					
		04847	04854	14836	14840	14858	94893
Original weather data	Faulting (in.)	0.09	0.07	0.08	0.08	0.07	0.07
	Transverse Cracking (% slabs)	3.83	3.83	3.83	3.83	3.83	3.83
	IRI (in./mile)	157.09	158.52	152.90	146.95	157.49	163.81
Temperature increased by 10%	Faulting (in.)	0.10	0.08	0.08	0.08	0.07	0.08
	Transverse Cracking (% slabs)	3.83	3.83	3.83	3.83	3.83	3.83
	IRI (in./mile)	156.08	160.96	151.61	142.82	155.93	168.26
Temperature decreased by 10%	Faulting (in.)	0.09	0.06	0.07	0.08	0.07	0.07
	Transverse Cracking (% slabs)	3.83	3.83	3.83	3.83	3.83	3.83
	IRI (in./mile)	159.05	159.60	151.93	149.19	163.85	169.41

d) Distress predictions of rigid pavement under medium traffic design

Weather data	Distresses	Station ID					
		04847	04854	14836	14840	14858	94893
Original weather data	Faulting (in.)	0.10	0.07	0.08	0.09	0.06	0.06
	Transverse Cracking (% slabs)	3.83	3.83	3.83	3.83	3.83	3.83
	IRI (in./mile)	160.22	157.13	152.85	150.33	155.92	162.87
Temperature increased by 10%	Faulting (in.)	0.10	0.08	0.09	0.09	0.07	0.08
	Transverse Cracking (% slabs)	3.83	3.83	3.83	3.83	3.83	3.83
	IRI (in./mile)	159.95	161.98	154.59	146.27	155.02	169.10
Temperature decreased by 10%	Faulting (in.)	0.09	0.06	0.07	0.08	0.06	0.06
	Transverse Cracking (% slabs)	3.83	3.83	3.83	3.83	3.83	3.83
	IRI (in./mile)	160.85	157.96	152.40	150.57	159.49	167.54

Table F2: Sensitivity to wind speed

a) Distress predictions of flexible pavement under heavy traffic design

Weather data	Distresses	Station ID					
		04847	04854	14836	14840	14858	94893
Original weather data	Thermal Cracking (ft/mi)	84.34	84.34	84.34	84.34	83.36	84.42
	AC Rut (in.)	0.50	0.37	0.36	0.41	0.35	0.41
	Total Rut (in.)	1.15	1.03	1.01	1.06	1.01	1.07
	top-down Cracking (ft/mi)	313.36	335.72	267.14	269.39	406.29	383.35
	bottom-up Cracking (ft/mi)	6.05	5.65	5.71	5.87	5.44	5.69
	IRI (in./mi)	172.33	165.77	164.47	167.15	164.64	167.78
Wind speed increased by 10%	Thermal Cracking (ft/mi)	84.34	84.34	84.34	84.34	83.36	84.57
	AC Rut (in.)	0.48	0.36	0.35	0.39	0.34	0.40
	Total Rut (in.)	1.14	1.01	1.00	1.05	1.00	1.05
	top-down Cracking (ft/mi)	301.69	339.02	266.71	268.81	403.14	381.87
	bottom-up Cracking (ft/mi)	6.01	5.61	5.68	5.83	5.40	5.65
	IRI (in./mi)	171.47	165.08	163.95	166.37	164.22	167.09
Wind speed decreased by 10%	Thermal Cracking (ft/mi)	84.34	84.34	84.34	84.34	83.35	84.24
	AC Rut (in.)	0.52	0.39	0.37	0.42	0.37	0.42
	Total Rut (in.)	1.17	1.04	1.02	1.08	1.03	1.08
	top-down Cracking (ft/mi)	326.33	336.04	267.56	271.13	406.07	387.99
	bottom-up Cracking (ft/mi)	6.09	5.71	5.75	5.91	5.48	5.73
	IRI (in./mi)	173.31	166.59	165.06	168.00	165.43	168.57

b) Distress predictions of flexible pavement under medium traffic design

Weather data	Distresses	Station ID					
		04847	04854	14836	14840	14858	94893
Original weather data	Thermal Cracking (ft/mi)	124.12	1786.20	1180.49	83.37	2267.25	2419.64
	AC Rut (in.)	0.37	0.28	0.27	0.31	0.26	0.30
	Total Rut (in.)	1.00	0.91	0.90	0.94	0.90	0.94
	top-down Cracking (ft/mi)	331.55	325.16	305.49	316.03	341.68	336.56
	bottom-up Cracking (ft/mi)	5.43	5.09	5.10	5.25	4.87	5.10
	IRI (in./mi)	164.17	171.15	166.06	160.18	173.90	176.96
Wind speed increased by 10%	Thermal Cracking (ft/mi)	137.12	1837.80	1243.46	83.38	2277.45	2436.79
	AC Rut (in.)	0.36	0.27	0.27	0.30	0.25	0.29
	Total Rut (in.)	0.99	0.90	0.89	0.93	0.89	0.93
	top-down Cracking (ft/mi)	328.58	324.20	303.67	313.26	342.53	337.20
	bottom-up Cracking (ft/mi)	5.38	5.04	5.07	5.21	4.83	5.07
	IRI (in./mi)	163.63	171.01	166.12	159.67	173.44	176.63
Wind speed decreased by 10%	Thermal Cracking (ft/mi)	113.18	1764.79	1083.27	83.37	2259.22	2409.85
	AC Rut (in.)	0.38	0.29	0.28	0.32	0.27	0.31
	Total Rut (in.)	1.01	0.92	0.91	0.95	0.91	0.95
	top-down Cracking (ft/mi)	334.86	327.52	308.03	319.20	342.75	336.78
	bottom-up Cracking (ft/mi)	5.46	5.13	5.14	5.28	4.92	5.15
	IRI (in./mi)	164.76	171.54	165.82	160.80	174.32	177.48

c) Distress predictions of rigid pavement under heavy traffic design

Weather data	Distresses	Station ID					
		04847	04854	14836	14840	14858	94893
Original weather data	Faulting (in.)	0.09	0.07	0.08	0.08	0.07	0.07
	Transverse Cracking (% slabs)	3.83	3.83	3.83	3.83	3.83	3.83
	IRI (in./mile)	157.09	158.52	152.90	146.95	157.49	163.81
Wind speed increased by 10%	Faulting (in.)	0.09	0.07	0.08	0.08	0.06	0.07
	Transverse Cracking (% slabs)	3.83	3.83	3.83	3.83	3.83	3.83
	IRI (in./mile)	156.83	157.95	151.27	146.62	157.16	163.41
Wind speed decreased by 10%	Faulting (in.)	0.09	0.07	0.08	0.08	0.07	0.07
	Transverse Cracking (% slabs)	3.83	3.83	3.83	3.83	3.83	3.83
	IRI (in./mile)	157.39	159.41	152.98	147.36	157.97	163.97

d) Distress predictions of rigid pavement under medium traffic design

Weather data	Distresses	Station ID					
		04847	04854	14836	14840	14858	94893
Original weather data	Faulting (in.)	0.10	0.07	0.08	0.09	0.06	0.06
	Transverse Cracking (% slabs)	3.83	3.83	3.83	3.83	3.83	3.83
	IRI (in./mile)	160.22	157.13	152.85	150.33	155.92	162.87
Wind speed increased by 10%	Faulting (in.)	0.10	0.07	0.08	0.08	0.06	0.06
	Transverse Cracking (% slabs)	3.83	3.83	3.83	3.83	3.83	3.83
	IRI (in./mile)	159.89	156.56	152.61	147.73	155.50	162.47
Wind speed decreased by 10%	Faulting (in.)	0.10	0.07	0.08	0.09	0.06	0.06
	Transverse Cracking (% slabs)	3.83	3.83	3.83	3.83	3.83	3.83
	IRI (in./mile)	160.53	157.94	153.01	150.74	156.24	163.19

Table F3: Sensitivity to percent sunshine

a) Distress predictions of flexible pavement under heavy traffic design

Weather data	Distresses	Station ID					
		04847	04854	14836	14840	14858	94893
Original weather data	Thermal Cracking (ft/mi)	84.34	84.34	84.34	84.34	83.36	84.42
	AC Rut (in.)	0.50	0.37	0.36	0.41	0.35	0.41
	Total Rut (in.)	1.15	1.03	1.01	1.06	1.01	1.07
	top-down Cracking (ft/mi)	313.36	335.72	267.14	269.39	406.29	383.35
	bottom-up Cracking (ft/mi)	6.05	5.65	5.71	5.87	5.44	5.69
	IRI (in./mi)	172.33	165.77	164.47	167.15	164.64	167.78
Percent sunshine increased by 10%	Thermal Cracking (ft/mi)	84.34	84.34	84.34	84.34	83.36	84.43
	AC Rut (in.)	0.50	0.37	0.36	0.41	0.35	0.41
	Total Rut (in.)	1.16	1.03	1.01	1.06	1.01	1.07
	top-down Cracking (ft/mi)	310.63	339.44	267.33	269.62	403.56	387.16
	bottom-up Cracking (ft/mi)	6.09	5.69	5.75	5.91	5.47	5.73
	IRI (in./mi)	172.53	166.00	164.70	167.36	165.02	168.04
Percent sunshine decreased by 10%	Thermal Cracking (ft/mi)	84.34	84.34	84.34	84.34	83.36	84.42
	AC Rut (in.)	0.50	0.37	0.36	0.41	0.35	0.41
	Total Rut (in.)	1.15	1.03	1.01	1.06	1.01	1.06
	top-down Cracking (ft/mi)	314.25	334.86	266.94	269.15	404.52	381.46
	bottom-up Cracking (ft/mi)	6.00	5.62	5.67	5.82	5.41	5.66
	IRI (in./mi)	172.08	165.53	164.22	166.87	164.52	167.50

b) Distress predictions of flexible pavement under medium traffic design

Weather data	Distresses	Station ID					
		04847	04854	14836	14840	14858	94893
Original weather data	Thermal Cracking (ft/mi)	124.12	1786.20	1180.49	83.37	2267.25	2419.64
	AC Rut (in.)	0.37	0.28	0.27	0.31	0.26	0.30
	Total Rut (in.)	1.00	0.91	0.90	0.94	0.90	0.94
	top-down Cracking (ft/mi)	331.55	325.16	305.49	316.03	341.68	336.56
	bottom-up Cracking (ft/mi)	5.43	5.09	5.10	5.25	4.87	5.10
	IRI (in./mi)	164.17	171.15	166.06	160.18	173.90	176.96
Percent sunshine increased by 10%	Thermal Cracking (ft/mi)	124.43	1791.24	1180.35	83.37	2235.01	2410.97
	AC Rut (in.)	0.37	0.28	0.27	0.31	0.26	0.30
	Total Rut (in.)	1.00	0.91	0.90	0.94	0.90	0.94
	top-down Cracking (ft/mi)	334.66	327.20	307.60	318.55	343.91	339.56
	bottom-up Cracking (ft/mi)	5.47	5.13	5.14	5.29	4.90	5.15
	IRI (in./mi)	164.38	171.40	166.30	160.43	173.80	177.16
Percent sunshine decreased by 10%	Thermal Cracking (ft/mi)	123.70	1789.15	1176.68	83.37	2267.19	2421.65
	AC Rut (in.)	0.37	0.28	0.27	0.31	0.26	0.30
	Total Rut (in.)	1.00	0.91	0.90	0.93	0.90	0.94
	top-down Cracking (ft/mi)	328.58	323.25	303.80	313.69	340.40	333.70
	bottom-up Cracking (ft/mi)	5.38	5.04	5.06	5.20	4.85	5.07
	IRI (in./mi)	163.91	170.90	165.79	159.92	173.63	176.73

c) Distress predictions of rigid pavement under heavy traffic design

Weather data	Distresses	Station ID					
		04847	04854	14836	14840	14858	94893
Original weather data	Faulting (in.)	0.09	0.07	0.08	0.08	0.07	0.07
	Transverse Cracking (% slabs)	3.83	3.83	3.83	3.83	3.83	3.83
	IRI (in./mile)	157.09	158.52	152.90	146.95	157.49	163.81
Percent sunshine increased by 10%	Faulting (in.)	0.09	0.07	0.08	0.08	0.07	0.07
	Transverse Cracking (% slabs)	3.83	3.83	3.83	3.83	3.83	3.83
	IRI (in./mile)	157.15	158.44	152.98	146.95	157.56	163.73
Percent sunshine decreased by 10%	Faulting (in.)	0.09	0.07	0.08	0.08	0.07	0.07
	Transverse Cracking (% slabs)	3.83	3.83	3.83	3.83	3.83	3.83
	IRI (in./mile)	157.07	158.60	152.90	146.87	157.40	163.73

e) Distress predictions of rigid pavement under medium traffic design

Weather data	Distresses	Station ID					
		04847	04854	14836	14840	14858	94893
Original weather data	Faulting (in.)	0.10	0.07	0.08	0.09	0.07	0.07
	Transverse Cracking (% slabs)	6.65	5.84	5.07	5.51	5.95	6.58
	IRI (in./mile)	165.06	160.22	156.65	153.34	162.31	171.12
Percent sunshine increased by 10%	Faulting (in.)	0.10	0.07	0.09	0.09	0.07	0.08
	Transverse Cracking (% slabs)	6.76	5.90	5.15	5.55	5.98	6.65
	IRI (in./mile)	165.89	160.64	157.47	153.83	162.63	171.63
Percent sunshine decreased by 10%	Faulting (in.)	0.10	0.07	0.08	0.09	0.07	0.07
	Transverse Cracking (% slabs)	6.11	5.48	4.88	5.23	5.61	6.06
	IRI (in./mile)	162.33	158.70	155.38	151.38	160.87	169.36

Table F4: Sensitivity to precipitation

a) Distress predictions of flexible pavement under heavy traffic design

Weather data	Distresses	Station ID					
		04847	04854	14836	14840	14858	94893
Original weather data	Thermal Cracking (ft/mi)	84.34	84.34	84.34	84.34	83.36	84.42
	AC Rut (in.)	0.50	0.37	0.36	0.41	0.35	0.41
	Total Rut (in.)	1.15	1.03	1.01	1.06	1.01	1.07
	top-down Cracking (ft/mi)	313.36	335.72	267.14	269.39	406.29	383.35
	bottom-up Cracking (ft/mi)	6.05	5.65	5.71	5.87	5.44	5.69
	IRI (in./mi)	172.33	165.77	164.47	167.15	164.64	167.78
Precipitation increased by 10%	Thermal Cracking (ft/mi)	84.34	84.34	84.34	84.34	83.36	84.43
	AC Rut (in.)	0.50	0.37	0.36	0.41	0.35	0.41
	Total Rut (in.)	1.16	1.03	1.01	1.06	1.01	1.07
	top-down Cracking (ft/mi)	310.63	339.44	267.33	269.62	403.56	387.16
	bottom-up Cracking (ft/mi)	6.09	5.69	5.75	5.91	5.47	5.73
	IRI (in./mi)	172.53	166.00	164.70	167.36	165.02	168.04
Precipitation decreased by 10%	Thermal Cracking (ft/mi)	84.34	84.34	84.34	84.34	83.36	84.42
	AC Rut (in.)	0.50	0.37	0.36	0.41	0.35	0.41
	Total Rut (in.)	1.15	1.03	1.01	1.06	1.01	1.06
	top-down Cracking (ft/mi)	314.25	334.86	266.94	269.15	404.52	381.46
	bottom-up Cracking (ft/mi)	6.00	5.62	5.67	5.82	5.41	5.66
	IRI (in./mi)	172.08	165.53	164.22	166.87	164.52	167.50

b) Distress predictions of flexible pavement under medium traffic design

Weather data	Distresses	Station ID					
		04847	04854	14836	14840	14858	94893
Original weather data	Thermal Cracking (ft/mi)	124.12	1786.20	1180.49	83.37	2267.25	2419.64
	AC Rut (in.)	0.37	0.28	0.27	0.31	0.26	0.30
	Total Rut (in.)	1.00	0.91	0.90	0.94	0.90	0.94
	top-down Cracking (ft/mi)	331.55	325.16	305.49	316.03	341.68	336.56
	bottom-up Cracking (ft/mi)	5.43	5.09	5.10	5.25	4.87	5.10
	IRI (in./mi)	164.17	171.15	166.06	160.18	173.90	176.96
Precipitation increased by 10%	Thermal Cracking (ft/mi)	124.43	1791.24	1180.35	83.37	2235.01	2410.97
	AC Rut (in.)	0.37	0.28	0.27	0.31	0.26	0.30
	Total Rut (in.)	1.00	0.91	0.90	0.94	0.90	0.94
	top-down Cracking (ft/mi)	334.66	327.20	307.60	318.55	343.91	339.56
	bottom-up Cracking (ft/mi)	5.47	5.13	5.14	5.29	4.90	5.15
	IRI (in./mi)	164.38	171.40	166.30	160.43	173.80	177.16
Precipitation decreased by 10%	Thermal Cracking (ft/mi)	123.70	1789.15	1176.68	83.37	2267.19	2421.65
	AC Rut (in.)	0.37	0.28	0.27	0.31	0.26	0.30
	Total Rut (in.)	1.00	0.91	0.90	0.93	0.90	0.94
	top-down Cracking (ft/mi)	328.58	323.25	303.80	313.69	340.40	333.70
	bottom-up Cracking (ft/mi)	5.38	5.04	5.06	5.20	4.85	5.07
	IRI (in./mi)	163.91	170.90	165.79	159.92	173.63	176.73

c) Distress predictions of rigid pavement under heavy traffic design

Weather data	Distresses	Station ID					
		04847	04854	14836	14840	14858	94893
Original weather data	Faulting (in.)	0.09	0.07	0.08	0.08	0.07	0.07
	Transverse Cracking (% slabs)	3.83	3.83	3.83	3.83	3.83	3.83
	IRI (in./mile)	157.09	158.52	152.90	146.95	157.49	163.81
Precipitation increased by 10%	Faulting (in.)	0.09	0.07	0.08	0.08	0.07	0.07
	Transverse Cracking (% slabs)	3.83	3.83	3.83	3.83	3.83	3.83
	IRI (in./mile)	157.15	158.44	152.98	146.95	157.56	163.73
Precipitation decreased by 10%	Faulting (in.)	0.09	0.07	0.08	0.08	0.07	0.07
	Transverse Cracking (% slabs)	3.83	3.83	3.83	3.83	3.83	3.83
	IRI (in./mile)	157.07	158.60	152.90	146.87	157.40	163.73

d) Distress predictions of rigid pavement under medium traffic design

Weather data	Distresses	Station ID					
		04847	04854	14836	14840	14858	94893
Original weather data	Faulting (in.)	0.10	0.07	0.08	0.09	0.06	0.06
	Transverse Cracking (% slabs)	3.83	3.83	3.83	3.83	3.83	3.83
	IRI (in./mile)	160.22	157.13	152.85	150.33	155.92	162.87
Precipitation increased by 10%	Faulting (in.)	0.10	0.07	0.08	0.09	0.06	0.06
	Transverse Cracking (% slabs)	3.83	3.83	3.83	3.83	3.83	3.83
	IRI (in./mile)	160.21	156.96	152.85	150.33	155.83	162.71
Precipitation decreased by 10%	Faulting (in.)	0.10	0.07	0.08	0.09	0.06	0.06
	Transverse Cracking (% slabs)	3.83	3.83	3.83	3.83	3.83	3.83
	IRI (in./mile)	160.13	157.21	152.85	150.25	155.91	162.95

Table F5: Sensitivity to relative humidity

a) Distress predictions of flexible pavement under heavy traffic design

Weather data	Distresses	Station ID					
		04847	04854	14836	14840	14858	94893
Original weather data	Thermal Cracking (ft/mi)	84.34	84.34	84.34	84.34	83.36	84.42
	AC Rut (in.)	0.50	0.37	0.36	0.41	0.35	0.41
	Total Rut (in.)	1.15	1.03	1.01	1.06	1.01	1.07
	top-down Cracking (ft/mi)	313.36	335.72	267.14	269.39	406.29	383.35
	bottom-up Cracking (ft/mi)	6.05	5.65	5.71	5.87	5.44	5.69
	IRI (in./mi)	172.33	165.77	164.47	167.15	164.64	167.78
Relative humidity of the six stations increased by 8.9%, 8.8%, 9.0%, 8.9%, 8.6% and 8.8%, respectively	Thermal Cracking (ft/mi)	84.34	84.34	84.34	84.34	83.36	84.42
	AC Rut (in.)	0.50	0.37	0.36	0.41	0.35	0.41
	Total Rut (in.)	1.15	1.03	1.01	1.06	1.01	1.07
	top-down Cracking (ft/mi)	312.52	335.72	267.13	269.39	405.85	383.25
	bottom-up Cracking (ft/mi)	6.05	5.65	5.71	5.87	5.44	5.69
	IRI (in./mi)	172.32	165.76	164.47	167.15	164.64	167.79
Relative humidity decreased by 10%	Thermal Cracking (ft/mi)	84.34	84.34	84.34	84.34	83.36	84.42
	AC Rut (in.)	0.50	0.37	0.36	0.41	0.35	0.41
	Total Rut (in.)	1.15	1.03	1.01	1.06	1.01	1.07
	top-down Cracking (ft/mi)	312.52	335.72	267.13	269.39	405.85	383.25
	bottom-up Cracking (ft/mi)	6.05	5.65	5.71	5.87	5.44	5.69
	IRI (in./mi)	172.32	165.76	164.47	167.15	164.64	167.79

b) Distress predictions of flexible pavement under medium traffic design

Weather data	Distresses	Station ID					
		04847	04854	14836	14840	14858	94893
Original weather data	Thermal Cracking (ft/mi)	124.12	1786.20	1180.49	83.37	2267.25	2419.64
	AC Rut (in.)	0.37	0.28	0.27	0.31	0.26	0.30
	Total Rut (in.)	1.00	0.91	0.90	0.94	0.90	0.94
	top-down Cracking (ft/mi)	331.55	325.16	305.49	316.03	341.68	336.56
	bottom-up Cracking (ft/mi)	5.43	5.09	5.10	5.25	4.87	5.10
	IRI (in./mi)	164.17	171.15	166.06	160.18	173.90	176.96

Relative humidity of the six stations increased by 8.9%, 8.8%, 9.0%, 8.9%, 8.6% and 8.8%, respectively	Thermal Cracking (ft/mi)	124.47	1786.55	1180.31	83.37	2267.78	2424.94
	AC Rut (in.)	0.37	0.28	0.27	0.31	0.26	0.30
	Total Rut (in.)	1.00	0.91	0.90	0.94	0.90	0.94
	top-down Cracking (ft/mi)	331.67	325.16	305.49	316.03	341.68	336.68
	bottom-up Cracking (ft/mi)	5.43	5.09	5.10	5.24	4.88	5.11
	IRI (in./mi)	164.18	171.15	166.05	160.17	173.90	177.00
Relative humidity decreased by 10%	Thermal Cracking (ft/mi)	124.47	1786.55	1180.31	83.37	2267.78	2424.94
	AC Rut (in.)	0.37	0.28	0.27	0.31	0.26	0.30
	Total Rut (in.)	1.00	0.91	0.90	0.94	0.90	0.94
	top-down Cracking (ft/mi)	331.67	325.16	305.49	316.03	341.68	336.68
	bottom-up Cracking (ft/mi)	5.43	5.09	5.10	5.24	4.88	5.11
	IRI (in./mi)	164.18	171.15	166.05	160.17	173.90	177.00

c) Distress predictions of rigid pavement under heavy traffic design

Weather data	Distresses	Station ID					
		04847	04854	14836	14840	14858	94893
Original weather data	Faulting (in.)	0.09	0.07	0.08	0.08	0.07	0.07
	Transverse Cracking (% slabs)	3.83	3.83	3.83	3.83	3.83	3.83
	IRI (in./mile)	157.09	158.52	152.90	146.95	157.49	163.81
Relative humidity of the six stations increased by 8.9%, 8.8%, 9.0%, 8.9%, 8.6% and 8.8%, respectively	Faulting (in.)	0.09	0.07	0.08	0.08	0.06	0.07
	Transverse Cracking (% slabs)	3.83	3.83	3.83	3.83	3.83	3.83
	IRI (in./mile)	156.91	157.71	151.11	146.70	157.16	164.22
Relative humidity decreased by 10%	Faulting (in.)	0.09	0.07	0.08	0.08	0.07	0.07
	Transverse Cracking (% slabs)	3.83	3.83	3.83	3.83	3.83	3.83
	IRI (in./mile)	157.71	159.16	153.46	147.28	157.97	163.97

d) Distress predictions of rigid pavement under medium traffic design

Weather data	Distresses	Station ID					
		04847	04854	14836	14840	14858	94893

Original weather data	Faulting (in.)	0.10	0.07	0.08	0.09	0.06	0.06
	Transverse Cracking (% slabs)	3.83	3.83	3.83	3.83	3.83	3.83
	IRI (in./mile)	160.22	157.13	152.85	150.33	155.92	162.87
Relative humidity of the six stations increased by 8.9%, 8.8%, 9.0%, 8.9%, 8.6% and 8.8%, respectively	Faulting (in.)	0.10	0.07	0.08	0.09	0.06	0.06
	Transverse Cracking (% slabs)	3.83	3.83	3.83	3.83	3.83	3.83
	IRI (in./mile)	160.85	155.91	150.74	150.41	155.17	163.19
Relative humidity decreased by 10%	Faulting (in.)	0.10	0.07	0.08	0.09	0.06	0.06
	Transverse Cracking (% slabs)	3.83	3.83	3.83	3.83	3.83	3.83
	IRI (in./mile)	160.85	158.02	153.42	150.82	156.73	163.19

Table F6: Sensitivity to depth to water table

a) Distress predictions of flexible pavement under heavy traffic design

Weather data	Distresses	Station ID					
		04847	04854	14836	14840	14858	94893
Original weather data	Thermal Cracking (ft/mi)	84.34	84.34	84.34	84.34	83.36	84.42
	AC Rut (in.)	0.50	0.37	0.36	0.41	0.35	0.41
	Total Rut (in.)	1.15	1.03	1.01	1.06	1.01	1.07
	top-down Cracking (ft/mi)	313.36	335.72	267.14	269.39	406.29	383.35
	bottom-up Cracking (ft/mi)	6.05	5.65	5.71	5.87	5.44	5.69
	IRI (in./mi)	172.33	165.77	164.47	167.15	164.64	167.78
Depth to water table increased by 10%	Thermal Cracking (ft/mi)	84.34	84.34	84.34	84.34	83.36	84.42
	AC Rut (in.)	0.50	0.37	0.36	0.41	0.35	0.41
	Total Rut (in.)	1.16	1.03	1.01	1.06	1.01	1.07
	top-down Cracking (ft/mi)	313.22	336.04	267.19	269.49	404.63	386.10
	bottom-up Cracking (ft/mi)	6.05	5.65	5.71	5.86	5.43	5.69
	IRI (in./mi)	172.39	165.84	164.54	167.20	164.81	167.87
Depth to water table decreased by 10%	Thermal Cracking (ft/mi)	84.34	84.34	84.34	84.34	83.36	84.40
	AC Rut (in.)	0.50	0.37	0.36	0.41	0.35	0.41
	Total Rut (in.)	1.15	1.03	1.01	1.06	1.01	1.07
	top-down Cracking (ft/mi)	313.24	335.40	267.13	269.39	401.36	384.31
	bottom-up Cracking (ft/mi)	6.05	5.66	5.71	5.87	5.44	5.69
	IRI (in./mi)	172.26	165.71	164.41	167.08	164.62	167.75

b) Distress predictions of flexible pavement under medium traffic design

	Distresses	Station ID

Weather data		04847	04854	14836	14840	14858	94893
Original weather data	Thermal Cracking (ft/mi)	124.12	1786.20	1180.49	83.37	2267.25	2419.64
	AC Rut (in.)	0.37	0.28	0.27	0.31	0.26	0.30
	Total Rut (in.)	1.00	0.91	0.90	0.94	0.90	0.94
	top-down Cracking (ft/mi)	331.55	325.16	305.49	316.03	341.68	336.56
	bottom-up Cracking (ft/mi)	5.43	5.09	5.10	5.25	4.87	5.10
	IRI (in./mi)	164.17	171.15	166.06	160.18	173.90	176.96
Depth to water table increased by 10%	Thermal Cracking (ft/mi)	124.72	1811.25	1180.10	83.37	2267.48	2424.34
	AC Rut (in.)	0.37	0.28	0.27	0.31	0.26	0.30
	Total Rut (in.)	1.00	0.91	0.90	0.94	0.91	0.94
	top-down Cracking (ft/mi)	331.99	326.13	305.90	316.46	342.63	337.52
	bottom-up Cracking (ft/mi)	5.43	5.08	5.10	5.24	4.87	5.11
	IRI (in./mi)	164.26	171.40	166.15	160.26	174.03	177.07
Depth to water table decreased by 10%	Thermal Cracking (ft/mi)	124.24	1815.63	1176.67	83.37	2272.09	2425.45
	AC Rut (in.)	0.37	0.28	0.27	0.31	0.26	0.30
	Total Rut (in.)	1.00	0.91	0.90	0.94	0.90	0.94
	top-down Cracking (ft/mi)	331.45	326.65	305.34	315.89	341.26	335.82
	bottom-up Cracking (ft/mi)	5.43	5.09	5.10	5.25	4.88	5.11
	IRI (in./mi)	164.11	171.29	165.96	160.12	173.82	176.96

c) Distress predictions of rigid pavement under heavy traffic design

Weather data	Distresses	Station ID					
		04847	04854	14836	14840	14858	94893
Original weather data	Faulting (in.)	0.09	0.07	0.08	0.08	0.07	0.07
	Transverse Cracking (% slabs)	3.83	3.83	3.83	3.83	3.83	3.83
	IRI (in./mile)	157.09	158.52	152.90	146.95	157.49	163.81
Depth to water table increased by 10%	Faulting (in.)	0.09	0.07	0.08	0.08	0.07	0.07
	Transverse Cracking (% slabs)	3.83	3.83	3.83	3.83	3.83	3.83
	IRI (in./mile)	157.09	158.44	152.90	146.95	157.49	163.81
Depth to water table decreased by 10%	Faulting (in.)	0.09	0.07	0.08	0.08	0.07	0.07
	Transverse Cracking (% slabs)	3.83	3.83	3.83	3.83	3.83	3.83
	IRI (in./mile)	157.09	158.68	152.90	146.95	157.49	163.81

d) Distress predictions of rigid pavement under medium traffic design

Weather data	Distresses	Station ID

		04847	04854	14836	14840	14858	94893
Original weather data	Faulting (in.)	0.10	0.07	0.08	0.09	0.06	0.06
	Transverse Cracking (% slabs)	3.83	3.83	3.83	3.83	3.83	3.83
	IRI (in./mile)	160.22	157.13	152.85	150.33	155.92	162.87
Depth to water table increased by 10%	Faulting (in.)	0.10	0.07	0.08	0.09	0.06	0.06
	Transverse Cracking (% slabs)	3.83	3.83	3.83	3.83	3.83	3.83
	IRI (in./mile)	160.22	156.96	152.85	150.33	155.84	162.79
Depth to water table decreased by 10%	Faulting (in.)	0.10	0.07	0.08	0.09	0.06	0.06
	Transverse Cracking (% slabs)	3.83	3.83	3.83	3.83	3.83	3.83
	IRI (in./mile)	160.22	157.13	152.93	150.33	155.92	162.95

Table F7: Sensitivity to weather yearly variation

a) Distress predictions of flexible pavement under heavy traffic design using1-year, 2-year, 4-year, 6-year and 9-year blocks of data

Weather data	Distresses	Station ID			
		04847	14836	14840	94893
9-year data	Thermal Cracking (ft/mi)	84.34	84.34	84.34	84.42
	AC Rut (in.)	0.50	0.36	0.41	0.41
	Total Rut (in.)	1.15	1.01	1.06	1.07
	top-down Cracking (ft/mi)	313.36	267.14	269.39	383.35
	bottom-up Cracking (ft/mi)	6.05	5.71	5.87	5.69
	IRI (in./mi)	172.33	164.47	167.15	167.78
1-year coldest data	Thermal Cracking (ft/mi)	84.34	83.36	84.34	99.32
	AC Rut (in.)	0.49	0.30	0.34	0.47
	Total Rut (in.)	1.15	0.95	1.00	1.14
	top-down Cracking (ft/mi)	283.22	265.92	268.46	560.71
	bottom-up Cracking (ft/mi)	6.04	5.57	5.80	5.84
	IRI (in./mi)	171.86	161.28	164.15	172.28
1-year hottest data	Thermal Cracking (ft/mi)	84.34	84.34	84.34	84.34
	AC Rut (in.)	0.56	0.40	0.43	0.41
	Total Rut (in.)	1.21	1.05	1.08	1.06
	top-down Cracking (ft/mi)	392.00	287.70	271.60	273.62
	bottom-up Cracking (ft/mi)	5.95	5.57	5.86	5.63
	IRI (in./mi)	175.39	166.27	168.14	167.07
2-year coldest data	Thermal Cracking (ft/mi)	84.34	83.35	84.34	90.33
	AC Rut (in.)	0.51	0.34	0.37	0.45

	Total Rut (in.)	1.18	1.00	1.03	1.12
	top-down Cracking (ft/mi)	340.62	266.52	268.01	498.38
	bottom-up Cracking (ft/mi)	6.00	5.67	5.81	5.76
	IRI (in./mi)	173.61	164.03	165.85	170.76
2-year hottest data	Thermal Cracking (ft/mi)	84.34	84.34	84.34	84.24
	AC Rut (in.)	0.54	0.39	0.42	0.44
	Total Rut (in.)	1.21	1.05	1.08	1.11
	top-down Cracking (ft/mi)	349.76	275.28	269.73	422.79
	bottom-up Cracking (ft/mi)	6.11	5.70	5.90	5.78
	IRI (in./mi)	175.16	166.38	168.14	170.35
First 4-year data	Thermal Cracking (ft/mi)	84.34	84.34	84.34	84.06
	AC Rut (in.)	0.51	0.35	0.40	0.39
	Total Rut (in.)	1.16	1.00	1.05	1.04
	top-down Cracking (ft/mi)	309.78	266.51	268.81	355.93
	bottom-up Cracking (ft/mi)	6.07	5.69	5.86	5.65
	IRI (in./mi)	172.66	163.73	166.54	166.51
Last 4-year data	Thermal Cracking (ft/mi)	84.34	84.34	84.34	85.18
	AC Rut (in.)	0.50	0.36	0.41	0.42
	Total Rut (in.)	1.16	1.01	1.06	1.08
	top-down Cracking (ft/mi)	313.22	269.39	269.49	406.29
	bottom-up Cracking (ft/mi)	6.05	5.69	5.83	5.69
	IRI (in./mi)	172.66	164.65	167.20	168.55
First 6-year data	Thermal Cracking (ft/mi)	84.34	84.34	84.34	84.17
	AC Rut (in.)	0.51	0.36	0.41	0.41
	Total Rut (in.)	1.16	1.01	1.06	1.06
	top-down Cracking (ft/mi)	315.72	267.19	269.39	377.33
	bottom-up Cracking (ft/mi)	6.05	5.70	5.86	5.70
	IRI (in./mi)	172.76	164.48	167.14	167.64
Last 6-year data	Thermal Cracking (ft/mi)	84.34	84.34	84.34	84.44
	AC Rut (in.)	0.51	0.36	0.41	0.41
	Total Rut (in.)	1.16	1.01	1.06	1.07
	top-down Cracking (ft/mi)	334.44	267.19	269.49	403.56
	bottom-up Cracking (ft/mi)	6.05	5.69	5.87	5.70
	IRI (in./mi)	172.74	164.51	167.18	168.26

b) Distress predictions of flexible pavement under medium traffic design using 1-year, 2-year, 4-year, 6-year and 9-year blocks of data

Weather data	Distresses	Station ID

		04847	14836	14840	94893
9-year data	Thermal Cracking (ft/mi)	124.12	1180.49	83.37	2419.64
	AC Rut (in.)	0.37	0.27	0.31	0.30
	Total Rut (in.)	1.00	0.90	0.94	0.94
	top-down Cracking (ft/mi)	331.55	305.49	316.03	336.56
	bottom-up Cracking (ft/mi)	5.43	5.10	5.25	5.10
	IRI (in./mi)	164.17	166.06	160.18	176.96
1-year coldest data	Thermal Cracking (ft/mi)	232.64	1856.08	86.71	2577.28
	AC Rut (in.)	0.37	0.23	0.26	0.34
	Total Rut (in.)	1.00	0.86	0.89	0.99
	top-down Cracking (ft/mi)	349.66	303.11	316.32	399.25
	bottom-up Cracking (ft/mi)	5.43	5.02	5.21	5.30
	IRI (in./mi)	164.86	168.74	158.29	181.37
1-year hottest data	Thermal Cracking (ft/mi)	340.41	1489.20	83.36	520.65
	AC Rut (in.)	0.41	0.30	0.32	0.31
	Total Rut (in.)	1.04	0.93	0.96	0.93
	top-down Cracking (ft/mi)	359.33	328.68	333.58	334.34
	bottom-up Cracking (ft/mi)	5.37	5.02	5.24	5.07
	IRI (in./mi)	167.63	169.48	161.07	163.13
2-year coldest data	Thermal Cracking (ft/mi)	326.91	1699.23	83.74	2572.42
	AC Rut (in.)	0.38	0.26	0.28	0.33
	Total Rut (in.)	1.02	0.90	0.92	0.98
	top-down Cracking (ft/mi)	337.32	303.66	309.61	364.74
	bottom-up Cracking (ft/mi)	5.39	5.07	5.21	5.19
	IRI (in./mi)	166.46	169.63	159.45	180.26
2-year hottest data	Thermal Cracking (ft/mi)	89.79	571.74	83.44	2466.24
	AC Rut (in.)	0.40	0.30	0.32	0.32
	Total Rut (in.)	1.04	0.93	0.96	0.97
	top-down Cracking (ft/mi)	342.63	312.94	317.67	354.13
	bottom-up Cracking (ft/mi)	5.49	5.12	5.27	5.22
	IRI (in./mi)	166.08	163.30	161.07	179.38
First 4-year data	Thermal Cracking (ft/mi)	93.45	1359.90	83.35	2333.48
	AC Rut (in.)	0.38	0.26	0.30	0.29
	Total Rut (in.)	1.01	0.89	0.93	0.92

	top-down Cracking (ft/mi)	332.09	302.40	313.10	328.36
	bottom-up Cracking (ft/mi)	5.44	5.08	5.24	5.07
	IRI (in./mi)	164.26	166.81	159.79	175.46
Last 4-year data	Thermal Cracking (ft/mi)	133.80	581.72	83.47	2508.03
	AC Rut (in.)	0.37	0.27	0.31	0.31
	Total Rut (in.)	1.00	0.90	0.94	0.95
	top-down Cracking (ft/mi)	333.70	306.17	316.04	343.91
	bottom-up Cracking (ft/mi)	5.44	5.10	5.22	5.12
	IRI (in./mi)	164.42	161.99	160.22	178.20
First 6-year data	Thermal Cracking (ft/mi)	115.77	1145.76	83.35	2398.34
	AC Rut (in.)	0.38	0.27	0.31	0.30
	Total Rut (in.)	1.01	0.90	0.94	0.94
	top-down Cracking (ft/mi)	332.42	305.92	316.29	336.68
	bottom-up Cracking (ft/mi)	5.42	5.10	5.24	5.13
	IRI (in./mi)	164.43	165.83	160.19	176.84
Last 6-year data	Thermal Cracking (ft/mi)	119.61	1383.67	83.38	2441.08
	AC Rut (in.)	0.38	0.27	0.30	0.30
	Total Rut (in.)	1.01	0.90	0.94	0.95
	top-down Cracking (ft/mi)	332.84	306.06	316.47	342.00
	bottom-up Cracking (ft/mi)	5.43	5.10	5.25	5.14
	IRI (in./mi)	164.44	167.56	160.22	177.60

c) Distress predictions of rigid pavement under heavy traffic design using 1-year, 2-year, 4-year, 6-year and 9-year blocks of data

Weather data	Distresses	Station ID			
		04847	14836	14840	94893
9-year data	Faulting (in.)	0.09	0.08	0.08	0.07
	Transverse Cracking (% slabs)	3.83	3.83	3.83	3.83
	IRI (in./mile)	157.09	152.90	146.95	163.81
1-year coldest data	Faulting (in.)	0.10	0.08	0.09	0.08
	Transverse Cracking (% slabs)	3.83	3.83	3.83	3.83
	IRI (in./mile)	160.14	160.48	155.98	186.64

1-year hottest data	Faulting (in.)	0.10	0.08	0.08	0.08
	Transverse Cracking (% slabs)	3.83	3.83	3.83	3.83
	IRI (in./mile)	168.93	167.22	148.28	168.68
2-year coldest data	Faulting (in.)	0.09	0.08	0.08	0.08
	Transverse Cracking (% slabs)	3.83	3.83	3.83	3.83
	IRI (in./mile)	163.30	155.78	149.17	178.37
2-year hottest data	Faulting (in.)	0.09	0.08	0.08	0.08
	Transverse Cracking (% slabs)	3.83	3.83	3.83	3.83
	IRI (in./mile)	158.63	156.57	146.55	174.73
First 4-year data	Faulting (in.)	0.09	0.08	0.08	0.06
	Transverse Cracking (% slabs)	3.83	3.83	3.83	3.83
	IRI (in./mile)	155.85	151.92	145.10	160.92
Last 4-year data	Faulting (in.)	0.09	0.08	0.08	0.07
	Transverse Cracking (% slabs)	3.83	3.83	3.83	3.83
	IRI (in./mile)	158.21	154.54	147.59	171.18
First 6-year data	Faulting (in.)	0.09	0.08	0.08	0.07
	Transverse Cracking (% slabs)	3.83	3.83	3.83	3.83
	IRI (in./mile)	157.11	153.07	145.59	163.14
Last 6-year data	Faulting (in.)	0.09	0.08	0.08	0.07
	Transverse Cracking (% slabs)	3.83	3.83	3.83	3.83
	IRI (in./mile)	156.70	153.97	147.38	167.12

d) Distress predictions of rigid pavement under medium traffic design using 1-year, 2-year, 4-year, 6-year and 9-year blocks of data

Weather data	Distresses	Station ID			
		04847	14836	14840	94893
9-year data	Faulting (in.)	0.10	0.08	0.09	0.06
	Transverse Cracking (% slabs)	3.83	3.83	3.83	3.83
	IRI (in./mile)	160.22	152.85	150.33	162.87
1-year coldest data	Faulting (in.)	0.10	0.08	0.09	0.07
	Transverse Cracking (% slabs)	3.83	3.83	3.83	3.83
	IRI (in./mile)	165.89	158.64	157.21	183.91
1-year hottest data	Faulting (in.)	0.10	0.08	0.09	0.08

	Transverse Cracking (% slabs)	3.83	3.83	3.83	3.83
	IRI (in./mile)	170.68	167.50	150.99	169.08
2-year coldest data	Faulting (in.)	0.09	0.08	0.09	0.07
	Transverse Cracking (% slabs)	3.83	3.83	3.83	3.83
	IRI (in./mile)	163.65	155.90	151.87	177.46
2-year hottest data	Faulting (in.)	0.10	0.09	0.09	0.08
	Transverse Cracking (% slabs)	3.83	3.83	3.83	3.83
	IRI (in./mile)	161.44	159.06	150.01	174.30
First 4-year data	Faulting (in.)	0.10	0.08	0.09	0.06
	Transverse Cracking (% slabs)	3.83	3.83	3.83	3.83
	IRI (in./mile)	160.49	153.79	149.00	158.95
Last 4-year data	Faulting (in.)	0.10	0.08	0.08	0.07
	Transverse Cracking (% slabs)	3.83	3.83	3.83	3.83
	IRI (in./mile)	161.30	156.88	149.91	170.46
First 6-year data	Faulting (in.)	0.10	0.08	0.09	0.06
	Transverse Cracking (% slabs)	3.83	3.83	3.83	3.83
	IRI (in./mile)	160.26	155.23	149.08	162.52
Last 4-year data	Faulting (in.)	0.09	0.08	0.09	0.06
	Transverse Cracking (% slabs)	3.83	3.83	3.83	3.83
	IRI (in./mile)	158.88	155.11	149.85	165.87