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Real Life Experiences with Major Pavement Types

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NOTICE

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16. Abstract

Pavement performance is a complex issue which depends on many contributing factors. Examining the performance of real-life pavements across the state determines what the actual service lives are for the pavements. For the purposes of this study, only selected LTPP projects were examined, along with a database containing all the historic repair projects completed in Indiana. Pertinent information present in the Indiana Historic Contracts Database was extracted concerning the types of pavement repair and treatments options commonly employed within the state, the time between repairs, etc. These data were used to determine descriptive statistical parameters and was summarized in graph form.

Similarly, data about selected LTPP GPS and SPS sites were downloaded from the online website, LTPP InfoPave and a comparative study between companion sites was performed. These data included study site and pavement-related information, such as construction dates, pavement structure details, maintenance and repair history, and pavement distress surveys. These data were used to draw conclusions about the impact of treatment applications, climatic and geologic factors, traffic volume, and pavement structures on pavement performance. Gaps in knowledge about pavement failure modes, distress data, and effectiveness of treatment applications mentioned in the contracts database file hampered efforts to form a complete picture of the effectiveness of treatment options and their timely (or untimely) application. Similarly, details about pavement mixture design and differentiating factors between companion sites prevented researchers from narrowing down the causes leading to the observed pavement distress.

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EXECUTIVE SUMMARY

Introduction

From engineering economics point of view, treatment options for pavements can range from routine maintenance or preventive maintenance to full-structural replacement, with many intermediate steps in-between. The benefits of timely treatment application and the implementation of a robust and strategic preventive maintenance plan can go a long way in mitigating major and expensive repairs.

Differences in treatment/repair applications, pavement cross-sections, and in-situ conditions can vastly impact long-term pavement performance. In some cases, the influence of climatic, geologic, and traffic conditions can have a more dominant influence pavement performance than differences in their structure or mix design factors.

Findings

1. Data analysis of the Historic Contracts Database shows that the most common types of repair and treatment options in the state of Indiana, ranked in decreasing order, were (1) partial 3R, (2) major structural overlays, (3) resurfacing—non 3R/4R standards, (4) preventive overlays and (5) minor structural overlays (formerly, functional overlays).
2. Frequency distribution data indicates that the average time between recurrence of these repair projects ranges from 11.8 years (resurfacing) to 13.5 years (minor structural overlays), with a standard deviation of approximately 6 years in all repair types.
3. The distribution of partial 3R projects, resurfacing projects (not in accordance with 3R/4R standards), and minor structural overlay projects were weighted to the left of maximum frequency, indicating that such projects were more frequent in the earlier part of the pavement life.
4. Major structural overlays and preventive overlays were weighted to the right of maximum frequency. In other words, such treatments last longer or are used during the latter part of pavement life.
5. The LTPP sites selected for this study that were situated in the southern part of the state had higher precipitation levels and lower values of freezing indices compared with sites located in the northern and central portions of the state.
6. The effectiveness of partial-depth patching to repair PCC joints was validated by the low levels of spalled transverse joints of the treated SPS-4 section versus the untreated companion section.
7. Based on the comparison of the JRCP GPS-4 sites, it appears that a combination of several factors, including climate, traffic, type of soil in the subgrade and type of bound base used, had noticeable influence on the overall performance of the pavements.
8. Types of seal coat treatments (slurry seal, crack seal, and aggregate seal coat) used in the SPS-3 asphalt concrete sections did not impact their rutting resistance. However, the section that received aggregate seal coat had fewer thermal (transverse) cracks than sections with the other two treatment methods.
9. No differences in rut resistance or transverse crack count was observed between the SPS-9 asphalt concrete sites analyzed in this study. The test variables in these mix and binder validation study site does not appear to have impacted their overall performance.
10. The GPS-2 section with a granular subbase layer had a lower transverse crack count when compared to the section without a granular subbase. This factor did not impact the rut depth values of these two sections.

Implementation

The findings of this research provide additional, objective insights into the most common types of repairs of deteriorated pavements in Indiana and the frequencies at which such repairs were performed. Identification of these parameters allows INDOT to ensure that existing (or modified) specifications and design philosophies account for these factors. The data presented in the report can be considered when performing life cycle costs analysis; thus, it has a potential to inform future management and design decisions and maximize their cost effectiveness. The results can be implemented by asset management, design, materials and construction personnel through policies, specifications, and construction memos.

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LIST OF ABBREVIATIONS (in order of first occurrence)

INDOT=	Indiana Department of Transportation
LTPP=	Long Term Pavement Performance
PCC=	Portland Cement Concrete
SPS=	Specific Pavement Studies
JRCP=	Jointed Reinforced Concrete Pavement
GPS=	General Pavement Studies
SAC=	Study Advisory Committee
LCCA=	Life-Cycle Cost Analysis
HMA=	Hot Mix Asphalt
NCAT=	National Center for Asphalt Technology
SHRP=	Strategic Highway Research Program
JPCP=	Jointed Plain Concrete Pavement
ACP=	Asphalt Concrete Pavement
FI=	Freezing Index
AADTT=	Annual Average Daily Truck Traffic
AADT=	Annual Average Daily Traffic
M&R=	Maintenance and Repair
IRI=	International Roughness Index
DGA=	Dense Graded Asphalt

1. BACKGROUND AND INTRODUCTION

The original purpose of this study was to explore why pavements fail in Indiana, how long they typically perform and what are the life-cycle costs associated with those pavements. Having such data would help determine the accuracy of the original design assumptions and predictions. The study was to include flexible, rigid, and composite pavements. In cases where a predominant failure mechanism could be identified, preventive measures could be adopted in future designs and maintenance measures to reduce the likelihood of recurrence of similar distresses. Since the study involved exploring old, past projects, it is quite likely that the state agency has already implemented preventive measures that effectively eliminated or minimized the original cause of distress. In such situations, the effectiveness of these distress prevention measures could be evaluated in this study, thus laying the framework for future evaluations.

After a preliminary study of non-interstate and interstate projects within the state and input from the Study Advisory Committee (SAC) members, a number of pavement sections (both good and poor performers) were identified for the detailed study to meet the research project objectives. The data needed for this detailed study included design documents, as-built plans, contract documents, maintenance records, video logs, interviews with district/design/materials personnel, and Life-Cycle Cost Analysis (LCCA). However, due an on-going digitization effort by the state agency of old construction documents into microfilm and the COVID-19 quarantine rules, the research team was unable to gain access to most of the necessary files. This led to a change in project scope and objectives which were agreed to by the SAC members following discussions during project update meetings. As such, this following report presents the findings reflecting these modified study objectives which were as follows. (a) Analyze the record of maintenance events present in the Historic Contracts Database regarding the most common types of pavement repair and treatment options in the state of Indiana. (b) Compare the pavement distress, performance and maintenance performed of similar LTPP sites within the shortlisted test sections.

Pavement performance is a complex issue which depends on many contributing factors. Examining the performance of real-life pavements across the state also allows for determination of what the actual service lives are. However, delving in detail into the design, construction, maintenance and performance records will be a time-consuming process so, for the purposes of this study, only selected LTPP projects were examined, along with a database containing all the historic repair projects completed in the state of Indiana.

One of the objectives of this study was to analyze the vast amount of data present in the Indiana Historic Contracts Database with the objective of extracting pertinent information about the types of pavement repair and treatments options commonly employed within the state. To attain this objective, the data was first sorted based on roadway ID, followed by type of project, from and to mile marker information, length of the project, project award date, etc. Overlapping sections of roadway with similar treatments were further separated in order to determine timing and frequency of such repairs. The second objective was to compare the influence of pavement design parameters, climate, in-situ soil conditions, types of maintenance and repair treatments, and other such factors on the pavement performance. To this end, data was extracted from the LTPP InfoPave website, which serves as a vast repository of information on pavements across the U.S. and Canada. With the input from the SAC, a number of LTPP sites, containing both the rigid and flexible pavements, were shortlisted for comparative study. These experimental study sites belonged to either the GPS or SPS groups within the LTPP program. Data contained within this repository include such parameters as pavement construction dates, pavement cross-section details, length of monitoring period, types of repairs, traffic count, climatic conditions, pavement distress survey results, etc.

The data collected from these two sources were used to determine descriptive statistical parameters, such as averages, standard deviations, maxima and minima, etc., that were summarized in the form of graphs and tables detailing climatic, traffic, and repair details. While the contracts database provided information about the major types of repairs, their frequency, and such, it did not contain pavement distress data nor did it contain information about types of pavement failure modes observed in the treated roadways. Further, there was also a lack of access (due to on-going digitization efforts and COVID-19 related restrictions) to original designs, as-built plans, and video logs to observe changes in time, etc. This gap in knowledge has hampered efforts to form a complete picture regarding the effectiveness of the treatment options, the timing of their application with respect to observed pavement distress. As such, potential for development of conclusive recommendations regarding changes to the existing maintenance and repair practices were severely limited.

Similarly, the LTPP Database did not contain mix design details of the GPS and SPS sections that could aid in clearly identifying the differentiating pavement-related parameters between companion sites. This prevented the researchers from narrowing down the factors that could be used to explain (or account for) the differences in observed distress levels.

2. CONTRACT HISTORY DATABASE

The Indiana Department of Transportation (INDOT) Contract History Database (Microsoft Access file) contains records of repair and maintenance activities performed on state's pavements since the late 1940s. Each record entry contains information such as, the road ID, length, location ("from" and "to" mile marker and county), designation number, type of surface, work description, work type, date awarded, etc. The database was last updated in 2014.

This section presents the results of the analysis of data extracted from the database file. Before performing the analysis, the entries present in the database were sorted according to roadway ID, age, mile marker, type of work, and other details to extract such information as: most common types of repairs, time between repairs, etc.

2.1 Sorting of the Available Data by Repair Type

Based on the level of pavement improvement required, repair work can be classified as resurfacing, restoration, and rehabilitation. According to the *2013 Indiana Design Manual*, resurfacing is defined as "*…placement of additional material over the existing restored or rehabilitated roadway or structure to improve serviceability or to provide additional strength.*" Restoration or rehabilitation are defined as "*…work required to return the existing pavement to a condition of adequate structural support or to a condition adequate for the placement of an additional stage of construction.*" (INDOT, 2022, Chapter 302). All of these procedures require either partial (resurfacing) or complete (restoration or rehabilitation) milling of existing pavement.

Improvement of asphalt pavements can be either structural or functional (INDOT, 2022, Chapters 601–607). If a pavement is still structurally sound, rehabilitation work, by means of preventive maintenance or application of functional overlay, is necessary to bring the pavement back into service. Preventive maintenance is limited to a maximum total depth of 40 mm, while the total depth of functional overlays is limited to 75 mm.

Asphalt pavements maintenance operations classified as "structural" involve complete removal and replacement of all (i.e., base, intermediate, and surface) pavement layers. On the other hand, maintenance operations classified as "functional" only involve replacement of the surface and intermediate layers. The underlying, unmilled pavement must be structurally sound for the application of a functional treatment. Complete replacement is required for pavements that have lost structural integrity. Regardless of the type of the maintenance operation performed, the resulting pavement smoothness should be comparable to that of a relatively new pavement.

As mentioned earlier, this study involved analysis of INDOT's Contract History Database containing a list of pavement treatment work performed on non-interstate road sections throughout the state of Indiana from circa 1945 through 2014.

The main types of repair work found in this database were categorized as follows: overlays (minor structural, major structural and preventive), partial 3R, and resurfacing–non-3R/4R standards. A partial 3R non-freeway project can include any resurfacing, restoration and rehabilitation (hence, "3R") that extends the service life of the pavement while improving road safety. Repairs of this nature are required to be cost-effective, largely using the existing geometry, and do not involve acquisition of additional right-of-way. Some examples of partial 3R projects include, pavement resurfacing, lane and shoulder widening, drainage improvements, relocating utility poles, etc. Further details about 3R repairs are given in the *Indiana Design Manual* (INDOT, 2022).

2.1.1 Overlay Projects

The most popular method of conventional rehabilitation treatment for asphalt pavements is the installation of the HMA overlays as they are fast and cost-effective for correcting pavement deficiencies and restoring user satisfaction while contributing to its structural capacity (Holtz et al., 2015). However, this conventional treatment method often results in poor long-term performance.

Reconstruction (4R) projects involve more intensive work compared with 3R projects. They require more extensive repair work such as the removal and replacement of at least 30% of the pavement area, removal of 8″ of existing asphalt pavement, introduction of additional lanes to accommodate traffic, etc. Lastly, among other non-freeway work, those requiring addition of mainline to an existing pavement, changes/revisions to vertical and/or horizontal alignment, right-of-way acquisition are categorized as reconstruction (4R), non-freeway projects.

To analyze the large amount (about 5,000 entries) of flexible pavement data available in the INDOT's database, the entries were sorted in the following order: road ID, mile marker (from and to), length, award date and treatment type. Only non-interstate flexible pavements were considered for this study as there were insufficient number of entries for both, the flexible interstate pavements and any type of PCC pavements.

Figure 2.1 shows the frequency of minor structural overlay projects (count = 135) plotted against time between such repairs. The average and standard deviation values for this dataset were, respectively, 13.5 years and 6.2 years. The highest number of such repair projects occurred between 15–18 years, which is close to the design life of a typical flexible pavement (20 years). This type of repair was seldom performed on pavements older than the typical design (≈20 years). This is to be expected as pavements with service life >20 years are rare and have been usually replaced by this time. About 74 functional overlay projects were undertaken before the maximum frequency shown in Figure 2.1 (i.e., before 15–18 years after original construction) whereas only 24 projects were undertaken after that period.

Figure 2.2 shows a histogram of frequency of major structural overlay repairs (count = 413) as a function of time between such repairs. The average time was 11.8 years (which was about 2 years earlier than the average for minor structural overlay work), with a standard deviation of 6.4 years. Data also indicate that the maximum number of major structural overlays was about two times the number of minor structural overlays.

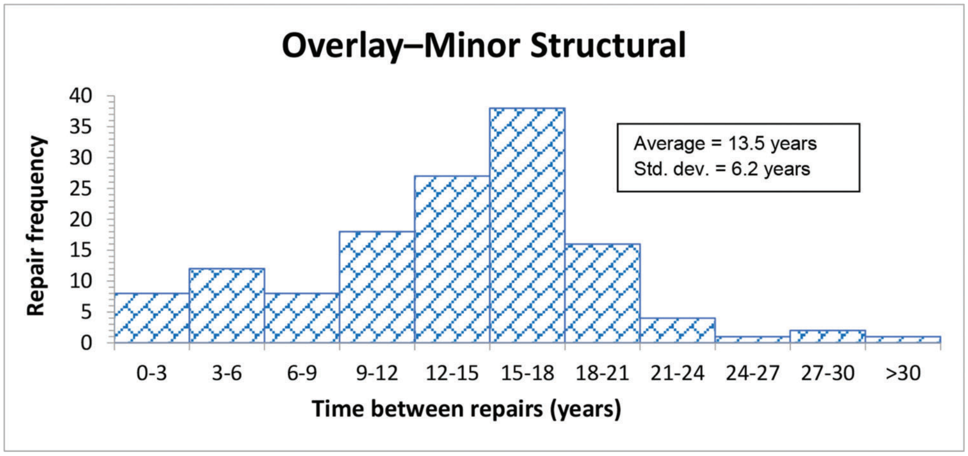

Figure 2.1 Histogram of the minor structural overlay repair projects.

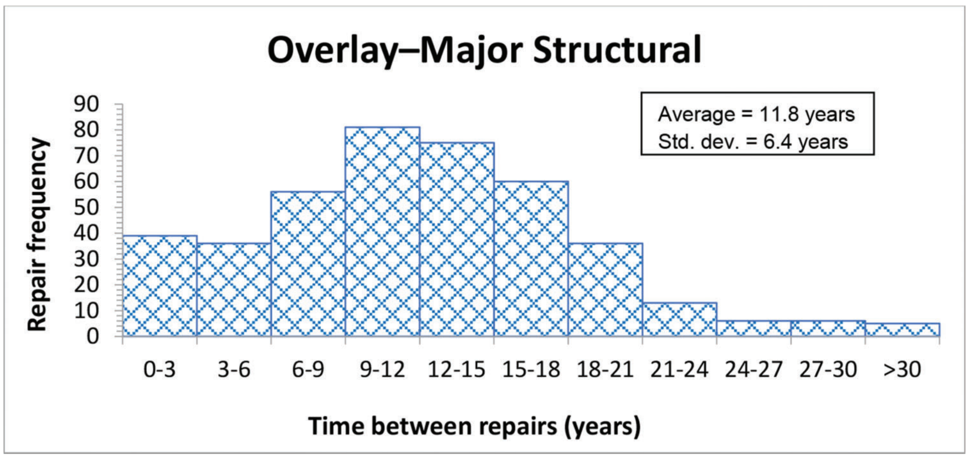

Figure 2.2 Histogram of the major structural overlay repair projects.

Majority of the work was found to occur at a frequency of 9–12 years, which is about 6 years earlier than the frequency for minor structural overlays. Unlike in the case of minor structural overlays, the data is somewhat skewed to the right of maximum (later age). A total of 131 projects were undertaken before the maximum and 201 projects after the maximum. This is to be expected as major structural overlays tend to be more intensive than functional and are not undertaken unless the pavement deficiencies cannot be initially fixed by relatively lighter, low intensity repairs.

Lastly, Figure 2.3 shows the frequency of preventive overlay projects (count = 251) recorded in the database. The average and standard deviation of time between repair are 12.6 and 6.0 years, respectively. While the standard deviations of the three repair categories are similar (6.0–6.4 years), the mean age for preventive overlays (12.6 years) is between that of major structural (11.8 years) and minor structural (13.5 years) repairs. Moreover, the number of preventive overlay projects appears to be weighted to the right of the maximum (9–12 years), with 62 and 124 projects before and after the maximum, respectively. In other words, the frequency of such repairs is higher after 9–12 years, until the end of service life, similar to what was observed the case of major structural overlays.

2.1.2 Partial 3R Projects

As in the case of overlays, which were divided into preventive, functional and structural, partial 3R projects are also subdivided into three types of treatments: preventive maintenance, functional and structural. The overall aim of a partial 3R project is "*…is to preserve and maintain the existing highway system*" (INDOT, 2022, Chapter 56). The purpose of partial 3R preventive maintenance treatment is to preserve the pavement while extending its surface life. Pavement distress caused by traffic and environmental conditions can lead to a poor road quality. These types of distress are usually addressed by partial 3R works, which tend to be less intensive than purely overlay type of treatments.

Different types of partial 3R projects are used to address or control different types of pavement deficiencies. Preventive maintenance is used to address lighter forms of distress, so as to retard serious structural problems early-on by taking preemptive measures. As the name implies, it is a surface preservation

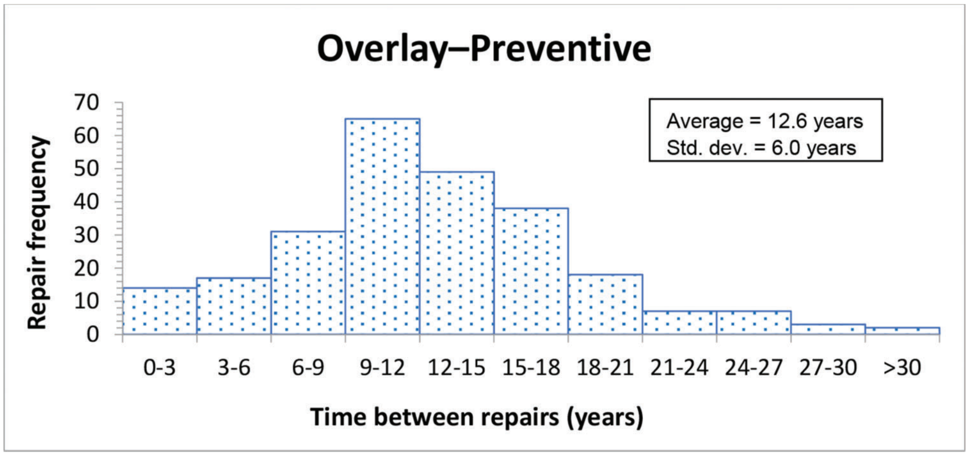

Figure 2.3 Histogram of preventive overlay repair projects.

measure and includes chip sealing, crack sealing, HMA inlay and overlay, sand sealing, diamond grinding, etc., in asphalt concrete pavements. They are designed to last for 4–12 years depending on the type and extent of treatment performed. On the other end of the spectrum are structural treatments, which are designed to strengthen the pavement structure and restore pavement smoothness. Load-related distresses are fixed using structural treatments on existing pavement structures. The typical design life of these treatments is 10–30 years and involve milling off damaged portions of the pavement and replacement with an overlay. Functional treatments belonging to partial 3R repair category are designed to improve road serviceability by reducing roughness and improving frictional properties. Functional treatments primarily address smoothness issues if the underlying structure is sound. Like structural treatments, functional treatments are also designed to last 10–30 years.

Figure 2.4 shows the frequency of the partial 3R projects. Compared to the three types of overlay repair projects mentioned earlier, partial 3R repairs were the most frequent (573 entries) type present in the database. The average time between partial 3R repair was 12.3 years, with a standard deviation of 5.7 years. Based on the distribution shown in Figure 2.4, majority of these repairs occur before the maximum frequency is reached at 12–15 years, i.e., the frequencies are somewhat weighted to the left of maximum. A total of 239 such projects were done before the maximum and 162 projects were carried out post-peak. Since partial 3R projects are less work intensive than overlay treatments, this is an expected finding from the data.

Based on the occurrence of the peak frequency (12–15 years) and the skewed distribution to the left of maximum frequency, it may be concluded that most of the partial 3R projects were preventive maintenance treatment projects (design life of 4–12 years).

2.1.3 Resurfacing–Non 3R/4R Standards Projects

Figure 2.5 shows the last repair category found in the database which was resurfacing–non 3R/4R standards (271 entries). This type of repair occurred at an average pavement age of 11.8 years, with a standard deviation of 6.1 years. Majority of such works were conducted between 9–15 years of age; sharply falling off on both sides of this time period. At peak frequency, the number of such projects (78) was similar to counts seen in structural and preventive cases, 81 and 65, respectively.

2.2 Sorting of the Available Data by the Treatment Code

The database was also sorted based on the code assigned to each surface type or thickness. Five codes (O, T, A, R, and S) found in the database are as follows, with the first three covering a majority of the projects.

T (Thin) = Thin overlay with milling
O (Over) = Thick asphalt overlay on JCP
A (Asphalt) = Asphalt surface (otherwise, unknown)
R (Rubble) = Rubblization of JCP with asphalt overlay
S (C & S) = Crack and seat of JCP with asphalt overlay

2.2.1 T (Thin) = Thin Overlay with Milling

Figure 2.6 shows the distribution of repairs that were on the T ("thin asphalt overlay over JCP") category. The dataset for repairs coded T had 183 entries and included partial 3R, overlays (structural, functional and preventive maintenance), or simply rehabilitation projects. Thin overlays were designed to correct surface defects over structurally sound pavements. The majority of such repairs were conducted between 12–15 years, beyond which (i.e., after the peak) the total number of such projects decreased to ≈43. The total count before the peak was 99. This trend is similar to that observed in partial 3R dataset (Figure 2.4), discussed in the previous section. The values of the average and standard deviation for this dataset were, respectively, 11.3 and 5.9 years.

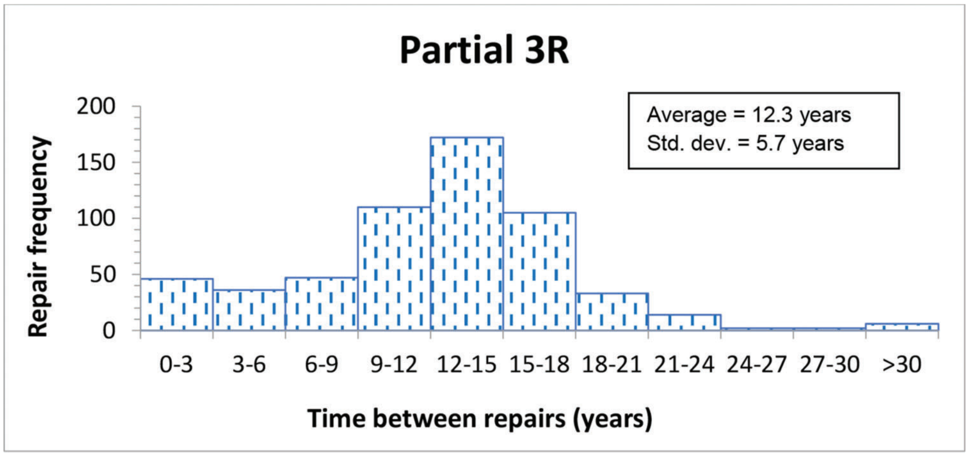

Figure 2.4 Histogram of partial 3R repair projects.

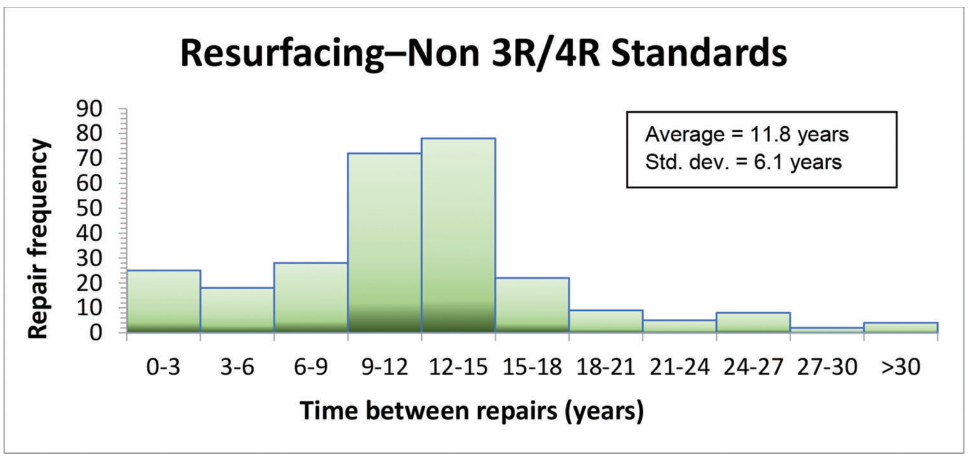

Figure 2.5 Resurfacing repair projects.

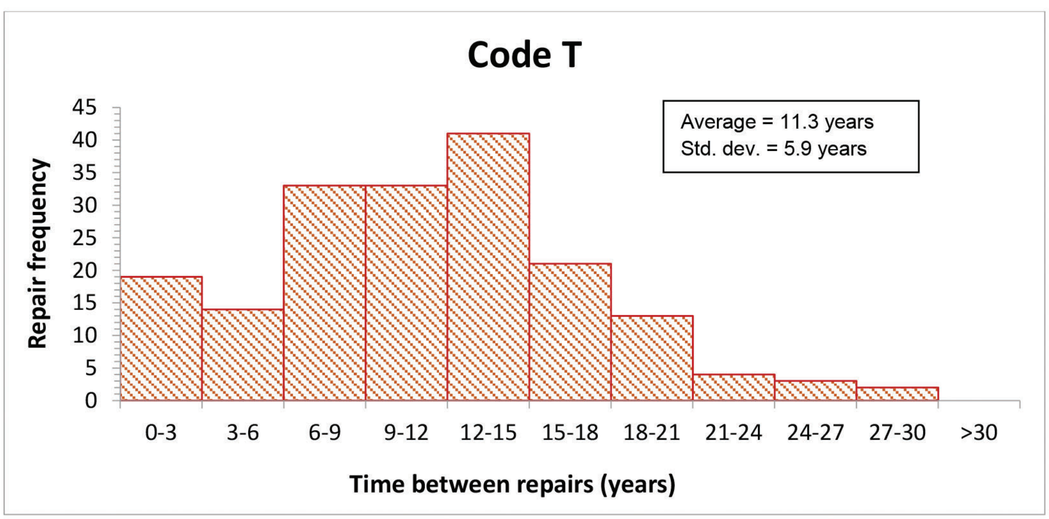

Figure 2.6 Thin asphalt overlay with milling.

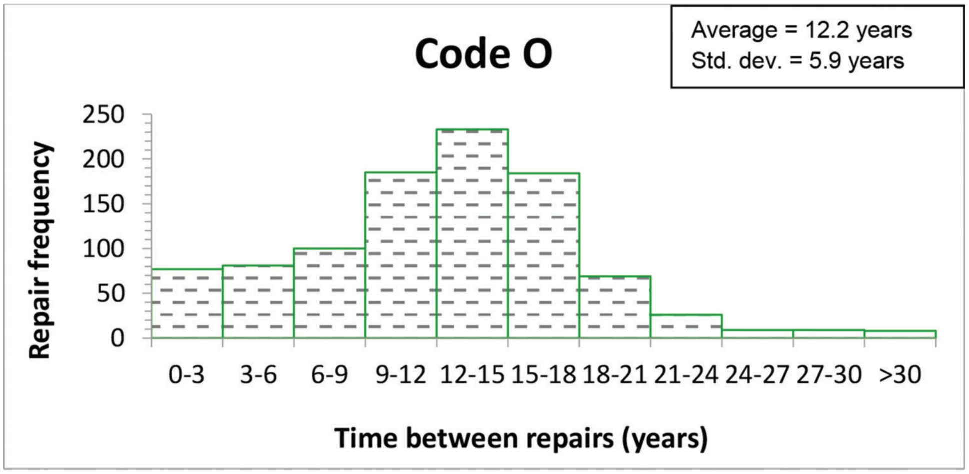

Figure 2.7 Thick asphalt overlay over JCP.

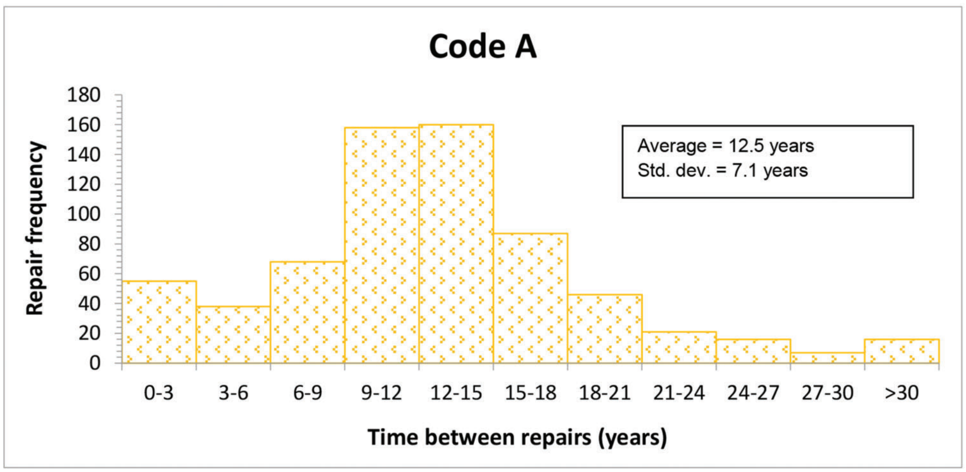

Figure 2.8 Asphalt surface (plus unknowns).

2.2.2 O (Over) = Thick Asphalt Overlay Over JCP

Figure 2.7 shows the distribution of repairs that fell under the code O (thick asphalt overlay over JCP) category. Thick overlays were used to correct structural defects in pavements. In addition to some partial 3R repairs and HMA overlays (functional and preventive maintenance), others included "HMA overlays with multiple structural layers," "resurfacing over asphalt pavement" and "milled surface with asphalt overlay." The highest frequency of such projects occurred between 12–15 years, with majority of them (319) occurring before this age, a trend similar to that observed in the case of code T projects. The average and standard deviation of this dataset (981 entries) were 12.2 and 5.9 years, respectively.

2.2.3 A (Asphalt) = Asphalt Surface (Otherwise, Unknown)

Code A was assigned to projects that included new road construction, reconstruction projects (3R/4R standards), rehabilitation projects (3R/4R standards), resurfacing projects (non-3R/4R standards), in addition to partial 3R and HMA overlay projects. This data distribution as a function of time between repairs is presented in Figure 2.8. The average time between repairs is 12.5 years with a standard deviation of 7.1 years (673 entries). The majority of works were performed between 9- to 15-year period. Post peak count as ≈193 and ≈320 before the peak.

2.2.4 R (Rubble) and S (C & S) = Rubblization and Crack and Seat of JCP with Asphalt Overlay)

Data from R (Rubble) = rubblization of JCP with asphalt overlay and S (C & S) = crack and seat of JCP with asphalt overlay categories were combined together due to similarity of such repairs and the scarcity of these datapoints (count = 11). Repair works that were coded S included, road rehabilitation (3R/4R standards) and crack and seat PCCP with HMA overlay. However, due to the small size of the dataset, no valid or sound conclusions can be drawn from it.

2.3 Summary

In their 2018 National Center for Asphalt Technology (NCAT) report (Robbins & Tran, 2018), researchers Robbins and Tran reviewed the initial service life of ≈121 sections of concrete pavements and of ≈206 sections of asphalt pavements. Based on the analysis of 23 sections located in the north central region of the country, the average service life of flexible pavements was found to be around 19.4 years, with a standard deviation of 4.4 years. The range of service life was found to be between 10.7–26.5 years. The analysis of 69 sections of the PCC pavements located within the same (i.e., the north central) region of the US revealed that the average service life was around 23.7 years, with a standard deviation of 5.7 years. The range of service life of rigid pavements was reported to be between 14.7–35.4 years.

Data presented in Section 2.1 show that the number of partial 3R treatments was the highest (573 entries), followed by major structural overlays (413). All repair types had similar standard deviations, ranging between 5.1 and 6.4 years. Major structural and preventive overlays were weighted to the right of maximum frequency, which indicated that these treatments were not as frequent as the other treatment methods. This is to be expected, as major structural overlays are more work-intensive than minor structural overlays, for example, and not needed as often to remedy lighter forms of pavement distress/deficiencies. It is also indicative that such treatments last longer. Minor structural overlays, partial 3R and resurfacing–non 3R/4R standards data were weighted to the left of maximum frequency, indicating that they are more frequent or likely to be used more often to fix pavement distress.

Major structural and preventive overlays were at their maximum between 9–12 years, while resurfacing projects maximum was spread over 9–15 years. Partial 3R repairs peaked between 12–15 years and functional overlays between 15–18 years. The maximum number of major structural overlays was approximately twice the number of minor structural overlays. The location of the peak frequency and the data weighted to the left of maximum for partial 3R projects indicate that most of these projects were, most likely, of the preventive maintenance type.

Data sorted based on surface/thickness code assigned are not as clear-cut as those based on specific maintenance treatment method presented in Section 2.1. For example, code A (Asphalt surface (otherwise, unknown)) included a variety of asphalt surface projects and also some unknown cases. Treatments marked by code O (thick overlay on JCP) were represented in the highest number, 980 entries, and occurred most frequently between 12–15 years.

3. LONG-TERM PAVEMENT PERFORMANCE SECTIONS

In addition to the Historic Contract Database discussed in the previous chapter, a study of selected Long-Term Pavement Performance (LTPP) test sections constructed under the original Strategic Highway Research Program (SHRP) in the mid to late 1990s, were also conducted. The LTPP program began in the late 1980s and included both General Pavement Studies (GPS) and Specific Pavement Studies (SPS) experiments. While GPS sites focused on pavement structure factors, SPS sites focused on specific pavement design factors. GPS sites were constructed with one of the eight prevalent structural designs, GPS-1 to GPS-8. Each GPS site constituted a single test section, where the influence of climatic, traffic, geologic, or other service conditions on pavement performance could be studied. On the other hand, each of the SPS sites included multiple sections, each with a different critical design factor. Since the multiple sections were subjected to the same traffic, climate, geologic conditions, and other external factors, such approach allowed for studying of the differences in pavement performance as a function of the variation in the specific design factors.

Data collected through the LTPP program included such variables as traffic, climate, smoothness, pavement distress, longitudinal and transverse profiles, maintenance events, etc., in addition to information about site location, pavement structure, date of construction and other related details. This information is available online through the LTPP InfoPave website (FHWA, n.d.) and can be extracted for analysis to present a broader, perspective of pavement performance within the state, region or nationally.

Based on the guidance provided by the members of the Study Advisory Committee (SAC), several rigid and flexible pavement sections were selected for analysis in this project. Information about the selected sections are shown in Tables 3.1 and 3.2, respectively.

Table 3.1 shows a list of four GPS and two SPS sites (totaling five specific sections) containing concrete (rigid) pavements, selected for analysis in this report. Two of these sites contained Jointed Reinforced Concrete Pavements (JRCP) and the remaining 8 contained Jointed Plain Concrete Pavements (JPCP). Table 3.2 shows the 13 Asphalt Concrete Pavements (ACP) sites that will be discussed in this report. The tables also show the county, route/direction and LTPP classification of the study sites.

3.1 Concrete Sections

Of the 10 rigid pavement sites listed in Table 3.1, five sites are GPS and the remaining five are SPS sites. The location of the GPS sites is shown in Figure 3.1. The pavement sites are located on roadways that are classified according to their function within the US DOT network. The functional classifications for rural and urban road network in Indiana are shown in Table 3.3, in decreasing order of mobility or increasing order of access. All the sites selected for analysis fall within the "2, north-central" region of LTPP classification (Jackson & Puccinell, 2006) and experience "wet-freeze" climatic conditions. "Wet" conditions imply an annual precipitation of ≥508 mm/year and "freeze" conditions

TABLE 3.1
List of LTPP study sites (Rigid Pavements–JPCP and JRCP)

Section	Surface	LTPP Experiment No.	County	Route/Direction
18-4021	JRCP	GPS-4	Hamilton	US 31, NB
18-4042	JRCP	GPS-4	Posey	IN-62, WB
18-3030	JPCP	GPS-3	Delaware	IN-332, WB
18-3031	JPCP	GPS-3	Posey	IN-62, WB
18-0601	JPCP	SPS-6	Marshall	US 31, NB
18-0602		(3 sections)		
18-0605				
18-A410	JPCP	SPS-4	Posey	IN-62, WB
18-A430		(2 sections)		

TABLE 3.2
List of LTPP study sites (Asphalt Concrete Pavements–ACP)

Section	Surface	LTPP Experiment No.	County	Route/Direction
18-1028	ACP	GPS-1 & 6S	Spencer	I-64, EB
18-1037	ACP	GPS-1, 6S & 6D	Spencer	IN-66, EB
18-2008	ACP	GPS-2 & 6B, 6D, 6S	Allen	US 27, SB
18-2009	ACP	GPS-2	Hamilton	IN-37, NB
18-A310	ACP	SPS-3	Spencer	I-64, EB
18-A320		(5 sections)		
18-A330				
18-A340				
18-A350				
18-0901	ACP	SPS-9C	Tippecanoe	I-65, SB
18-0902		(4 sections)		
18-0904				
18-0905				

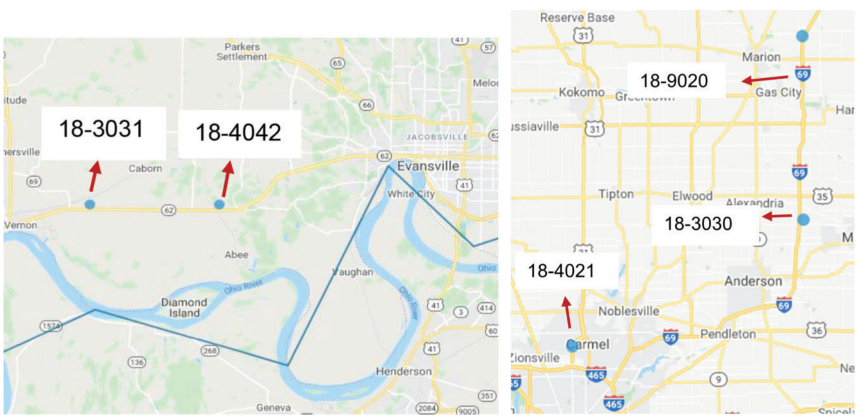

Figure 3.1 Location of the selected five GPS sites within the state.

TABLE 3.3
Functional classifications of roadways in Indiana

Rural	Urban
Principal Arterial–Interstate	Principal Arterial–Interstate
Principal Arterial–Other	Principal Arterial–Other Freeways and Expressways
Minor Arterial	Principal Arterial–Other (no control of access)
Major Collector	Minor Arterial
Minor Collector	Collector
Local Collector	

TABLE 3.4
LTPP study dates and climate data for the PCC sections

ID	Construction Date	Inclusion into LTPP	Out-of-Study Date	Precipitation (Avg/Min/Max) mm/year	Freezing Index (Avg/Min/Max) C deg-days
18-4021	Jan 1975	Jan 1987	Apr 2000	1131/928/1559	327/138/475
18-4042	Jan 1974	Jan 1987	Aug 2016	1366/957/1900	168/54/323
18-3030	Jan 1981	Jan 1987	May 2009	1220/934/1583	328/119/482
18-3031	Jan 1977	Jan 1987	Apr 2017	1313/950/1817	168/55/327
18-0601	Jan 1972	Jan 1987	Jul 1993	1109/867/1384	373/192/547
18-0602	Jan 1972	Jan 1987	Oct 2005	1076/866/1384	382/192/547
18-0605	Jan 1972	Jan 1987	Oct 2005	1076/866/1384	382/192/547
18-A410	Jul 1977	Jan 1991	Dec 2005	1246/1023/1621	159/71/255
18-A430	Jul 1977	Jan 1991	Dec 2005	1246/1023/1621	159/71/255

Note: Cells with red text are GPS sections and cells with black text are SPS sections.

imply FI ≥ 83.2 C deg-days. The average annual precipitation and average annual freezing indices, along with minima and maxima are shown in Table 3.4. The northern sites within the state had lower than average precipitation (≈1,100 mm/year) and higher than average FI (≈350 C/deg-days) than the southern sites (≈1,300 mm/year and ≈160 C/deg-days, respectively).

3.1.1 GPS-4 Sites = Jointed Reinforced Concrete Pavements (JRCP)

The Jointed Reinforced Concrete Pavements (JRCP) sections of the GPS-4 experiment were designed with doweled joints spaced <6.1-m (20-ft) apart for load transfer. Most types of base layers were permitted, except for cracked and seated PCC, unstabilized coarse-grained subgrade and fine-grained soil. If granular base was used in the pavement design, a seal coat over the base was allowed.

The two JRCP sections (18-4021 and 18-4042) are located in the Hamilton and Posey counties of Indiana, respectively. These two sections were included into the LTPP program in 1987, which was 8 and 7 years after original construction, respectively. The section on northbound US 31 (18-4021) was an urban principal artery which was taken out of LTPP monitoring plan in April 2000, much earlier than the rural minor artery (SR-62 WB, 18-4042), which was taken out-of-status in August 2016.

The subgrade soil at 18-4021 was fine-grained soil (sandy lean clay), while that at 18-4042 was coarse grained soil (silty sand). Both sections had 4 in. of bound base layer, either dense-graded, cold-laid, plant mix (18-4021) or hot-mix asphalt (18-4042). The depth of the portland concrete layer at the US 31 site was 11.2 in., 2 in. thicker than the SR-62 site (9.2 in.), to account for the anticipated heavier traffic loads on the urban, principal artery (US 31).

Since both these sites were located in the wet-freeze region, the amount of annual precipitation received was similar, as shown in Figure 3.2, with the southern site (SR-62) receiving slightly higher amount of precipitation (1,366 mm vs. 1,131 mm). The average freezing index (FI) data presented in Figure 3.3 show that the northern site (US 31) has a higher FI (327 C deg-days vs. 168 C deg-days), as expected due to its geographic location relative to SR-62.

The traffic volumes at the JPCP GPS-4 sites is shown in Figure 3.4. Although US 31 is an urban principal arterial road and SR-62 is a rural minor arterial road, during the overlapping LTPP monitoring period from 1987–2000 both sites experienced similar truck traffic, as indicated by the Annual Average Daily Truck Traffic (AADTT) count. After 2000, US 31 was taken out of the LTPP program. However, the Annual Average Daily Traffic (AADT) was higher for US 31 site, that site being located close to major city (Indianapolis-Carmel metropolitan area).

The LTPP InfoPave website also maintains a record of Maintanence and Repair (M&R) details, such as the type of repair and the date when it was undertaken at the site. These events are shown on the plot of International Roughness Index (IRI) versus time in Figure 3.5. At the end of LTPP monitoring phase, the pavement roughness is these two sections was still low (<3 m/km), which is representative of new pavements.

Two M&R projects were performed on US 31 (18-4021) site; both of which were partial-depth patching of PCC during the LTPP study period. Partial-depth patching is typically limited to top one-third of the concrete depth and is done to improve pavement ride quality. Seven years after the site was accepted in the LTPP study, the first partial-depth repair work (1994) was done at locations other than pavement joints. The second repair, which was performed 4 years later in 1998, included joint locations as well as locations away from joints. The site was taken out of study in 2000, that is 2 years after the second repair event.

At the SR-62 site (18-4042), a total of five M&R projects were performed at the end of 10, 15, 16, and 22 (×2) years, from the time the pavement was accepted into the LTPP monitoring plan. Most of the repair work involved partial-depth patching of the PCC pavement at joints. The timing between successive partial-depth repairs was not regular, and varied from 1 year, 6 years, and 2 months. There was also one instance of full-depth patching away from joint and transverse

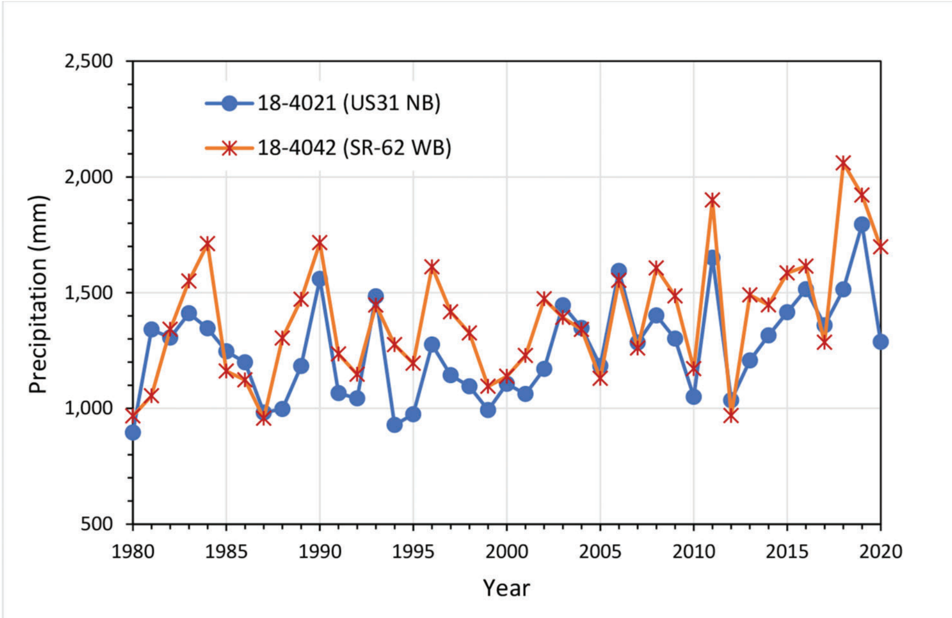

Figure 3.2 Annual average precipitation at the JPCP GPS-4 sites.

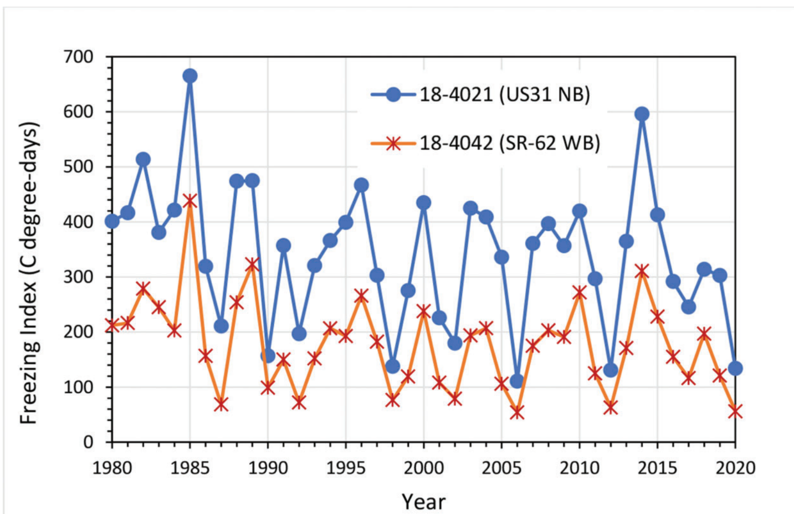

Figure 3.3 Annual average freezing index at the JPCP GPS-4 sites.

joint sealing. This repair was performed in 1997, i.e., 10 years after the site was brought into the LTPP program. The pavement was taken out of study 7 years after the last repair project, in 2016. No change in IRI (a measure of pavement smoothness) was observed after the M&R projects were performed on the pavements.

The two types of pavement distress monitored in JRCP sections are "Transverse Cracking" and "Spalling" of longitudinal and transverse joints. According to the *LTPP Distress Identification Manual* (FHWA, 2014), spalling is defined as "…cracking, breaking, chipping, or fraying of slab edge within 0.3 m from the face of a joint." Depending on the width of the crack, they are labelled low (<75 mm), moderate (75–150 mm) and high (>150 mm) severity. In the case of spalling near longitudinal joints, only affected joints with lengths ≥0.1 m are recorded along with level of severity. A transverse joint is considered to be damaged by spalling, only if spalling extends >10% of the joint length.

Transverse cracking mainly occurs perpendicular to the pavement centerline. These cracks are considered significant and counted only if they cross the "imaginary" mid-lane of the pavment slab. Low severity cracks may or may not show spalling along ≤10% of the crack length. Moderate and high severity transverse cracks show spalling >10% to ≤50% of the crack length, ≥50% of the crack length, respectively.

Pavement performance, assessed by manual distress surveys conducted as a part of the LTPP evaluation (Table 3.5), considers the degree of spalling and transverse cracking observed at these sites. The table also shows the M&R events shaded in yellow. The total

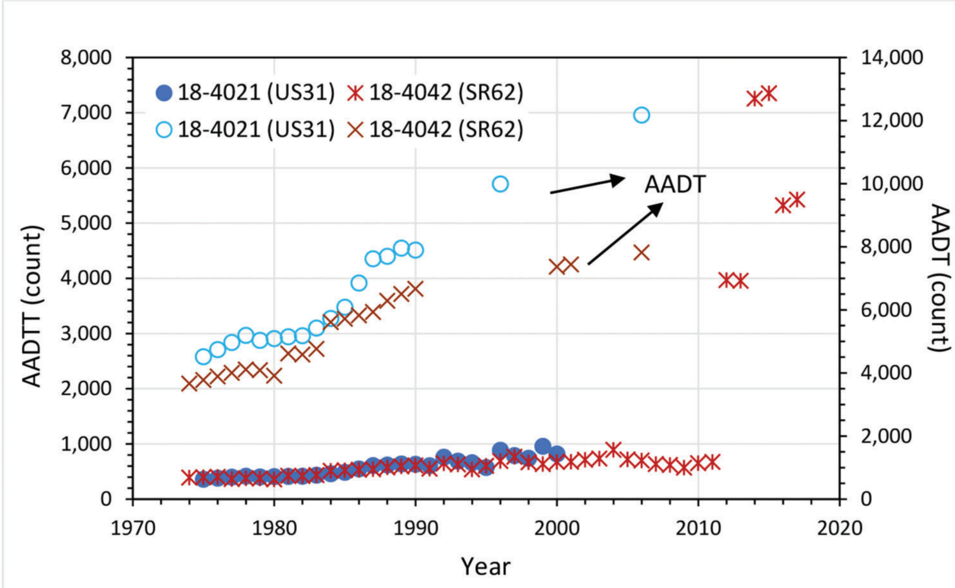

Figure 3.4 Traffic volume on the JPCP GPS-4 sites.

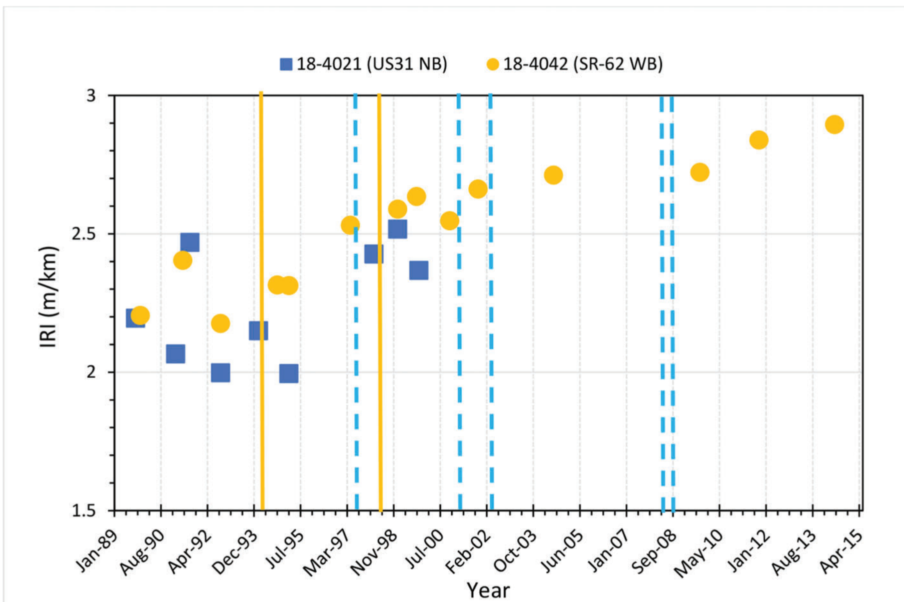

Figure 3.5 IRI and construction events at the JPCP GPS-4 sites.

spalling count on the 18-4021 (US 31 NB) section reached its highest value (8 count) after 12 years in-service (in March of 1999). That section was taken out of LTPP monitoring the following year. On the other hand, 18-4042 (SR-62 WB) section reached the same level of spalling at the end of 17 years (in July 2004). Total transverse cracking count was high in section 18-4021, between 13–15 throughout the study period. The transverse crack count in section 18-4042 stayed low (1–7). No improvement in either distress parameters was observed after the M&R events.

Based on this analysis, it may be concluded that the better performance (in terms of observed distress) of the rural arterial pavement on SR-62 may be attributed to a combination of factors, such as, the lower overall traffic volume, warmer temperatures along with lower freezing index, subgrade soil conditions and the type of asphalt treatment used in the base layer, when compared with that of the urban arterial pavement on US 31. The implementation of partial-depth repairs did not improve the observed distress in either of these GPS-4 sections.

3.1.2 GPS-3 Sites = Jointed Plain Concrete Pavements (JPCP)

Unlike the GPS-4 experimental sites, GPS-3 experiments within the LTPP program did not permit the use of any load-transfer devices in their JPCP pavement

TABLE 3.5
Pavement distress survey data for GPS-4 sites (FHWA, n.d.)

	Spalled Transverse Joints (count)		Transverse Cracking (count)	
Survey Date	**18-4021 (US 31 NB)**	**18-4042 (SR-62 WB)**	**18-4021 (US 31 NB)**	**18-4042 (SR-62 WB)**
Jun-89		0		1
Sep-89	0		15	
May-91		0		1
Apr-92	0		13	
Oct-92		0		1
Nov-92	1		13	
Jun-94	—		—	
Jul-94	2		13	
Oct-94		0		1
Mar-96	2	2	16	1
Jun-97		—		—
Jun-98	—		—	
Feb-99		0		1
Mar-99	8		14	
Feb-01		4		4
Jun-02		—		—
Oct-02		4		2
Jan-03		4		4
Jun-03		—		—
Jul-04		8		7
Apr-09		—		—
May-09		0		1
Jun-09		—		—
Sep-09		2		1
Oct-11		8		2

Note: Cells with red dashes indicate M&R events.

design. Only few restrictions were placed on the type of base layers that could be used in the pavement design. Exceptions to the types of base layers permitted were the same as that for GPS-4 sites. In the case of granular bases, the use of a seal coat was allowed as a part of this experiment.

The two sites selected for comparative analysis in this report were 18-3030 and 18-3031, located as shown in Figure 3.1. Section 18-3030 is located on westbound SR-332 in Delaware County and is considered to be a "Rural Major Collector." Section 18-3031 is located on a westbound "rural minor arterial" road, SR-62, in Posey County. These two pavements were initially constructed in 1981 and 1977, respectively, and were both incorporated into the LTPP monitoring status in 1987. The Rural Major Collector site was taken out of study in May 2009, while the site on the Rural Minor Arterial road was made "inactive" in April 2017.

Untreated fine-grained (sandy lean clay) soil constituted the subgrade material at section 18-3030. Subgrade soil at 18-3031 site was also fine-grained, but of the lean inorganic clay type. Both test sections had ≈4.5 in. of bound, base layer, with HMA at the 18-3030 site and with asphalt-treated mixture at the 18-3031 site. One other difference in the pavement cross-sections was that the overlying portland cement concrete (PCC) layer at SR-332 (18-3030) was 8.1-in. thick, while the thickness of the PCC layer at SR-62 (18-3031) site was about 10.2 in. It is understood that the extra 2 in. thickness was required at the 18-3031 site (Rural Minor Arterial) to accommodate the higher traffic volume on this pavement, relative to the other section (18-3030).

Both sites received similar average annual precipitation (see Figure 3.6 and Table 3.4), but the differences between their average annual freezing indices was significant, as shown in Figure 3.7. The average FIs were 328 C deg-days and 168 C deg-days, respectively. This is due to the northerly location of the SR-332 site w.r.t. SR-32 site and hence it being subject to colder temperatures that occur in the northern half of Indiana during the winter months.

Truck traffic on the SR-62 site (18-3031) was higher than that observed on SR-332 site (18-3030), as expected on a rural minor arterial road versus a rural major collector. This was, however, only true until approximately 1995, after which both sites experienced similar truck volumes. A similar trend was also observed in AADT data, which was initially low on SR-332 site, but towards the late 1990s exceeded that reported on SR-62 site. These trends can be seen in Figure 3.8. It is not known why there is marked jump in AADTT and AADT starting in the year 2012.

The 18-3030 site was initially constructed in 1981 and accepted for study into the LTPP program in 1987. Table 3.6 shows the distress survey data and M&R events shaded yellow. Only one M&R project was performed on 18-3030 site during the time it was in the LTPP study program (in September 2002, 15 years from the time monitoring commenced). That M&R event involved partial-depth patching of the PCC pavement at joints. As mentioned earlier, partial-depth patching is usually done to improve rideability or pavement smoothness. During the study period, there was a low but steady increase in the number of spalled transverse joints (from 2 to 9). However, about 1 month after the partial depth patching was completed in September 2002, the count inexplicably jumped to the 20. In a 2005 distress survey, the count increased to 27. This section was taken out of study in May 2009 (~7 years after the patching work in 2002). There was no sudden increase in AADTT or AADT nor was there any extreme weather event preceding this spike in spalling. Although, Figure 3.9, which illustrates the change in IRI with time, does show a slight increase IRI around this time (September 2002), it should be noted that, in general, the overall values of IRI do not point to poor pavement smoothness in either test section.

The 18-3031 site was in the study longer (from 1987, until April 2017) and had three M&R jobs performed on the site. The first rehabilitation work was performed 11.5 years after the site was accepted into the program. The work involved transverse joint sealing, lane-shoulder longitudinal joint sealing, and full-depth patching of PCC pavements away from joints. Unlike partial-depth patching, full-depth patching involves the complete removal of the damaged pavement section across the entire lane width and replacement with new concrete.

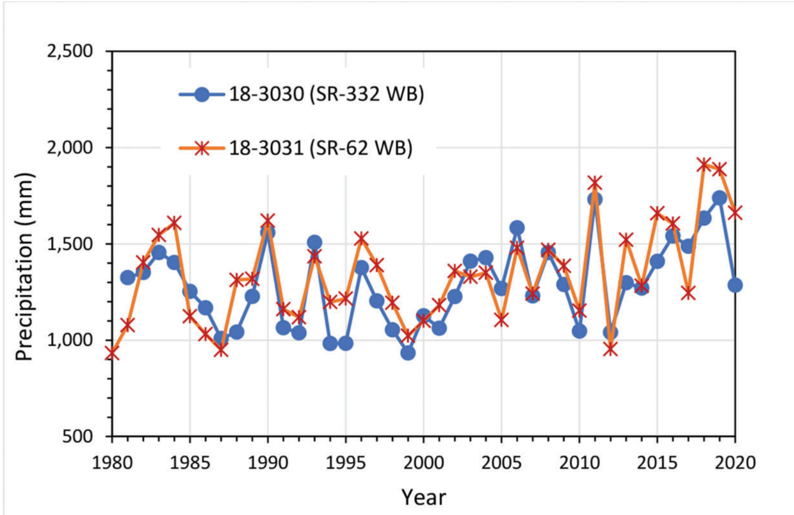

Figure 3.6 Annual average precipitation at the JRCP GPS-3 sites.

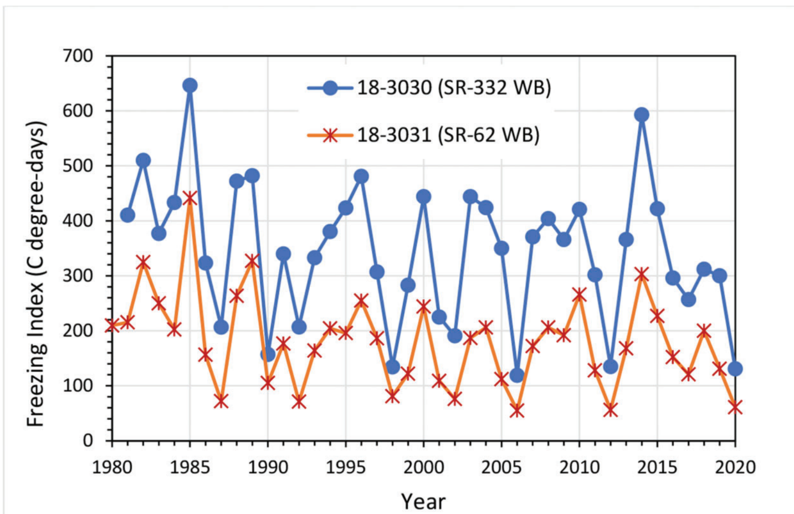

Figure 3.7 Annual average freezing index at the JRCP GPS-3 sites.

In addition to improving/restoring rideability, deteriorated joints and cracks can also be replaced using this method. Two other M&R events were recorded 22 years and 3 years later (in 2009 and 2012, respectively). These repairs involved partial-depth patching at joints.

With regard to joint distress (see Table 3.6), no spalling was observed at transverse joints in SR-62 (18-3031) pavement until much later in 2008, which is about 21 years into the monitoring period. Partial-depth patching was performed a year later in 2009, which decreased the spalling crack count to 6, but in 2016, the number of spalled joints increased rapidly to 30; and the site was taken out of study the following year. In this section, the spike in spalled cracks around 2009 and 2012 may be attributed to the sudden increase in AADT and AADTT, as shown in Figure 3.8. Transverse cracking count in this section was negligible (<3) all through the monitoring period. Section 18-3030 had a slightly higher count (maximum of 7).

GPS-3 section 18-3031 on US 62 performed better than the section 18-3030 (SR-332), as evidenced by distress survey data. This may be attributed to a combination of higher pavement depth (extra 2 in.), warmer climate (lower FI), and the type of bound base material (asphalt treated mixture vs. HMA).

3.1.3 SPS-4 Sites = Preventive Maintenance Effectiveness of Rigid Pavements (JPCP)

The SPS-4 experiments were designed to look into "preventive maintenance effectiveness of rigid pavements." The types of maintenance treatments allowed in the SPS-4 sites were joint sealing and joint sealing with underseal, designed to preserve and extend pavement service life, safety and ride quality. Comparisons could then be drawn between the performance of treated versus untreated sections. Unlike GPS sites, SPS sites included multiple, specially-constructed test sections all

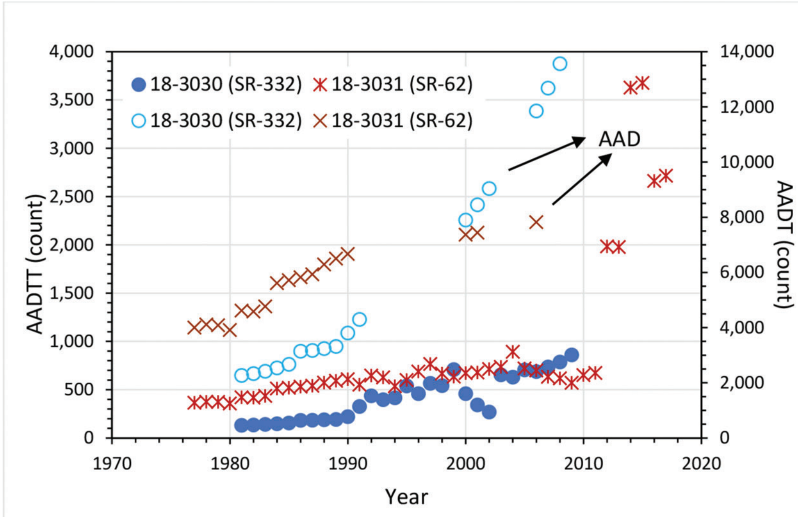

Figure 3.8 Traffic volume on the JRCP GPS-3 sites.

TABLE 3.6
Pavement distress survey data for GPS-3 sites (FHWA, n.d.)

	Spalled Transverse Joints (count)		Transverse Cracking (count)	
Survey Date	**18-3030 (SR-332 WB)**	**18-3031 (SR-62 WB)**	**18-3030 (SR-332 WB)**	**18-3031 (SR-62 WB)**
Sep-89	2		2	
Jun-90		0		1
May-91		0		0
May-91		0		1
Oct-92		0		3
Nov-92	3		3	
Mar-93		0		0
Jul-94	3		0	
Jun-95		0		0
Mar-96	8	1	7	0
Mar-98	7		1	
Jun-98		—		—
Feb-99		0		0
Feb-01		0		1
Mar-01	9		1	
Sep-01	0		2	
Sep-02	—		—	
Oct-02	20	0	5	0
Jul-03		0		0
Oct-05	27		2	
Jun-08		0		0
Jun-08		5		0
May-09		17		0
Jun-09		—		—
Sep-09		6		0
Oct-11		13		0
Jun-12		—		—
Oct-16		30		2

Note: Cells with red dashes indicate M&R events.

installed at the same test location. They are designed to allows researchers or local agencies to study the impact of changing a specific design parameter or construction feature, in this case method of preventive maintenance.

The two adjacent SPS-4 sections selected for this report (18-A410 and 18-A430) were located on westbound SR-62, along the Ohio River Scenic Byway, near Mt. Vernon, IN (as shown in Figure 3.10). The test sections on SR-62 were on a two-lane, rural minor arterial road initially constructed in July 1977 and added to the LTPP monitoring program in January 1991. Both sections were removed from LTPP monitoring program after 14 years, in December 2005.

By virtue of the location proximity of SPS-4 sites to the GPS-3 site, 18-3031, the values of annual averages of precipitation, freezing indices and traffic count at these sites are identical to the section 18-3031 data, presented earlier in Figures 3.6, 3.7, 3.8, respectively. The soil subgrade at this location was fine-grained (silty clay). The pavement structure at both sections was composed of bound base (asphalt mixture), 3.5 in. thick at 18-A410 and 4 in. thick at 18-A430, overlaid with PCC layer ≈10.4 in.

During the period of LTPP study, the transverse joint sealing and lane-shoulder longitudinal joint sealing was performed on both sections early on, just 10 months after the sites were incorporated in to the LTPP program (see Table 3.7 and Figure 3.11). No further M&R work was performed on 18-A430 section, and it was taken out of the study in 2005. However, partial-depth patching of PCC joints was performed in 2000 and 2003, in section 18-A410. The occurance of these M&R events are superimposed on the plot showing IRI trends in Figure 3.11.

As shown in Table 3.7, in section 18-A410, both spalled transverse joint count and transverse crack count remained low, a maximum 3 and 4, respectively, during the pavement monitoring period. Section 18-A430 did not show any transverse cracking; but the number of spalled joints increased from 1 to 10 between March 1993 and June 1995 and dropped to 0 in 1999. No cause can be found to explain this fluctuation. It may be attributed to inconsistency in manual surveys

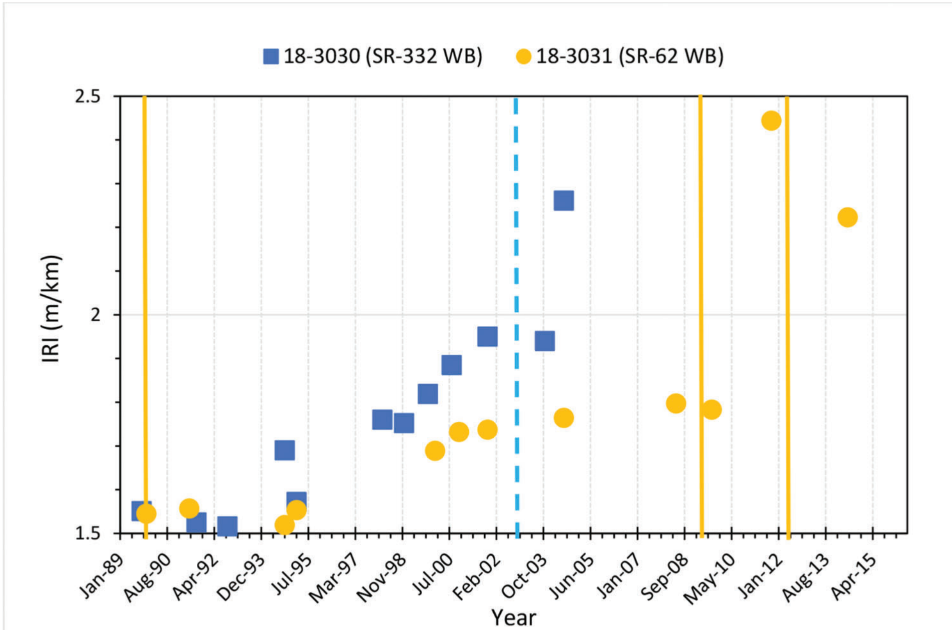

Figure 3.9 IRI and construction events at the JRCP GPS-3 sites.

Figure 3.10 Location of the two JPCP SPS-4 sites.

TABLE 3.7
Pavement distress survey data for SPS-4 sites (FHWA, n.d.)

	Spalled Transverse Joints (count)		Transverse Cracking (count)	
Survey Date	18-A410 (SR-62 WB)	18-A430 (SR-62 WB)	18-A410 (SR-62 WB)	18-A430 (SR-62 WB)
May-91	2	1	0	0
Oct-91	—	—	—	—
Mar-93	0	1	0	0
Jun-95	1	10	0	0
Feb-99	0	0	0	0
Jun-00	—		—	
Feb-01	1	2	4	0
Jun-03	—		—	
Jun-04	3	1	1	0

Note: Cells with red dashes indicate M&R events.

due to technician inexperience or undocumented M&R events. In addition, the overall IRI in both sections remained low (see Figure 3.11), and was comparable to that of a new pavement all through the study period.

Since SPS-4 sections are designed to study the effectiveness of preventive maintenance on PCC, the observed differences in pavements distress and IRI may be ascribed to the joint patching repairs done on the 18-A410 site, but not on the 18-A430 site. As mentioned earlier, partial-depth patching of joints was performed in section 18-A410 twice, and this maintenance procedure was apparently effective in decreasing the number of spalled joints in this section.

3.1.4 SPS-6 Sites = Rehabilitation of Jointed Portland Cement Concrete (JPCP)

SPS-6 experiments focus on the influence of pavement type (plain or reinforced), existing pavement condition, climatic region and traffic on rehabilitation methods used in Jointed Portland Cement Concrete (JPCC) pavements. The rehabilitation options can include pavements with or without AC overlays. The permitted rehabilitation methods in SPS-6 experimental sites were as follows (a) surface preparation with or without an AC overlay (102 mm), (b) crack/break and seat with two AC overlay options (102 mm or 203 mm) and (c) limited surface preparation for 102-mm thick AC overlay with sawn and sealed joints.

All three SPS-6 sections selected for this report are constructed of plain, nonreinforced concrete, on northbound US 31, in Marshall County (see Figure 3.12), classifed as a rural principal arterial–other. All sections were originally constructed in 1972 and brought into the LTPP monitoring program 1987. The pavement

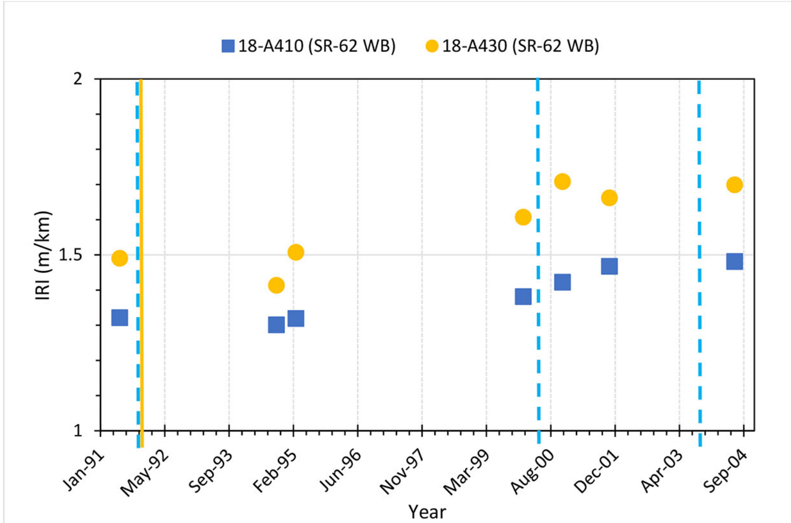

Figure 3.11 IRI and M&R events at the JPCP SPS-4 sites.

Figure 3.12 Location of the three JPCP SPS-6 sites.

cross-section was made up of 4 in.-bound base (dense-graded, cold-laid, mixed in-place) and 10 in. of PCC layer on the top. The pavement structure rested on untreated subgrade composed of fine-graded soils (sandy clays). Since all three sections were located along the same route and in close proximity to each other, they were subjected to the same climatic (Figure 3.13) and traffic conditions (Figure 3.14). The average annual precipitation received was around 1,100 mm, with a minimum and maximum of 866 mm and 1,384 mm, respectively. The average annual freezing index was 380 C deg-days. The traffic count showed a steadily increasing trend during the study period.

As shown in Figure 3.15, the initial IRI values at the 18-0601 section were slightly higher than the IRI of other two sections. The summary of distress survey data collected from these sections is presented in Table 3.8. The distress survey conducted in April 1990 indicated that section 18-0601 had about 18 spalled transverse joints, a number lower than the number observed in the other two sections (24 in section 18-0602 and 25 in section 18-0605). Only one M&R work was undertaken on this section, in June 1992, and involved partial-depth patching at joints, after which the number of spalled transverse joints dropped to zero. The number of transverse cracks in this section was 12 but dropped to 4 after the M&R project. The site was, however, quickly taken out of monitoring status a year later in 1993 (overall monitoring period of 6 years). The timing of all M&R events for the three sections is also shown in the plot of IRI vs. year (Figure 3.15). The IRI values remained low (<3 m/km) in all sections throughout the monitoring period.

Extensive rehabilitation work (involving six M&R events each) was performed on sections 18-0602 and 18-0605 during their monitoring period. As already mentioned, before the first rehabilitation project was performed on sections 18-0602 and 18-0605 (in June 1990), the distress survey conducted in April 1990 indicated the presence of, respectively, 24 and 25 of spalled transverse joints. To fix the observed pavement distress, full-depth transverse joint patching and joint-load transfer restoration work was performed on these two sections. In addition, asphalt concrete (AC) shoulder restoration and longitudinal subdrain installation work was done in section 18-0605. Despite the restoration work performed on these two sections the number of spalled transverse joints continued to increase and reached 50 (for each of the sections) in May 1995. In July 1995, the second repair work was undertaken which included grinding of the surface and full-depth patching of PCC away from joints. Extra rehabilitation work on section 18-0605 included partial-depth patching at PCC joints. These repairs reduced the number of spalled transverse joints to ≈29 at time of the next survey in July 1996.

Between September 2001 and December 2001, the number of spalled transverse joints in the two sections

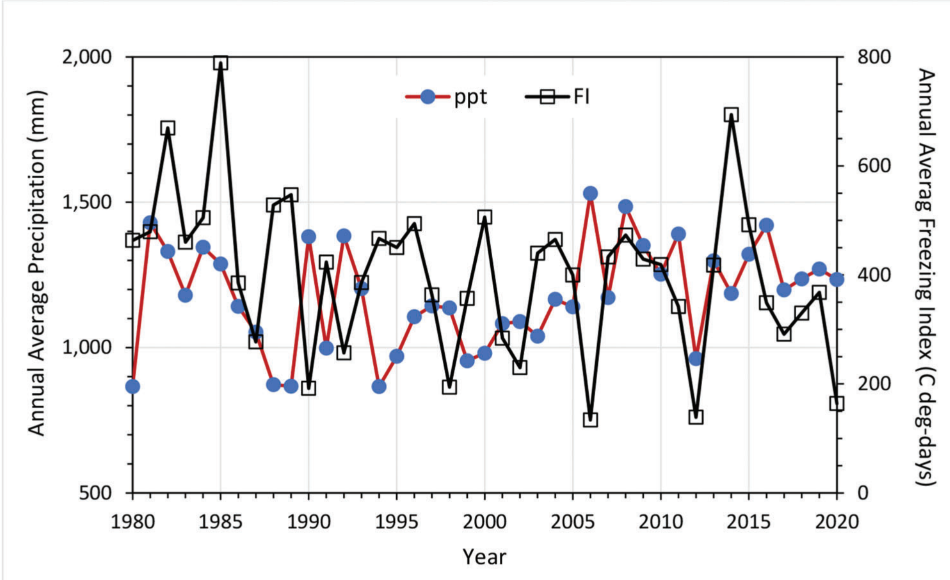

Figure 3.13 Precipitation and freezing indices at the JPCP SPS-6 sites.

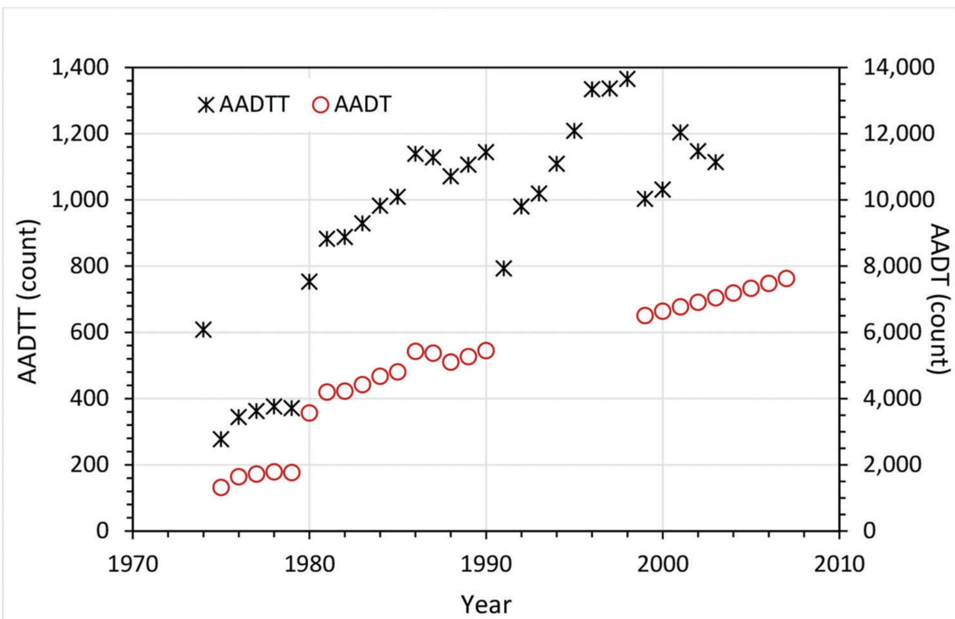

Figure 3.14 Traffic volume at the JPCP SPS-6 sites.

suddenly dropped from ≈20 to ≈6, for no obvious reason. After December 2001, the low count held steady until both sections were taken out of study in October 2005. These steady, low numbers may be explained by the two more M&R events at were performed on these two sections in the interim. Potholes were patched by spreading HMA by hand and compacting with a truck. This was done in June 2003 and lastly, partial-depth patching of PCC away from joints was performed once more in June 2005. These two sections did not show any transverse cracking.

It is not apparent as to why section 18-0601 with lower pavement distress that the other two sections, was taken out of study barely 6 years since its initiation into the program. In the remaining two sections that were monitored for 18 years, the benefits of the applied treatment method were either not apparent in the pavement distress surveys conducted shortly after treatment or may be considered short-lived and minimal at best.

3.2 Summary of Data Analysis for Concrete Pavement Sections

Comparison of the two JRCP GPS-4 sites indicated that the pavement built on the coarse-grained soil with HMA bound base layer performed better than the

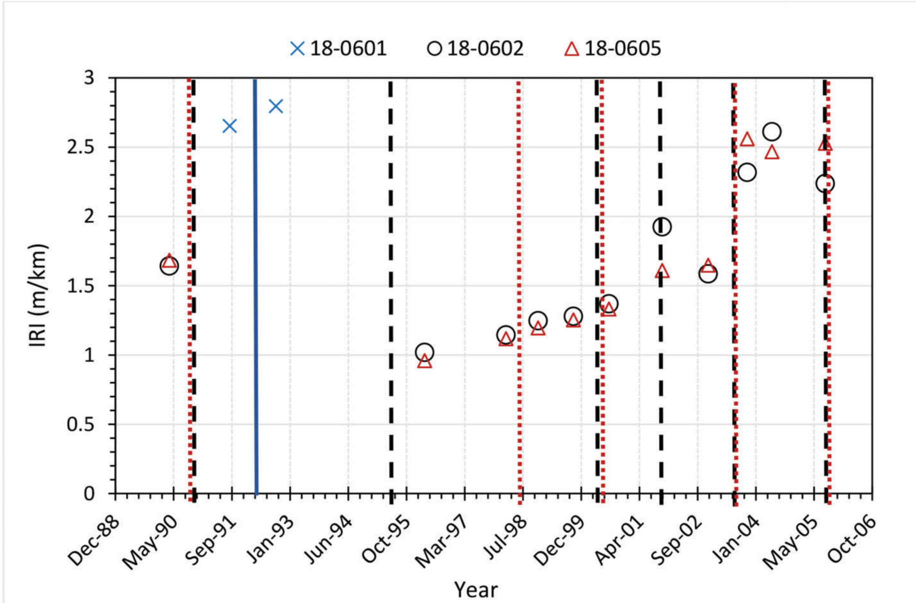

Figure 3.15 IRI and M&R events at the JPCP SPS-6 sites.

section built on fine-grained soil overlaid with cold-laid plant mix. Additionally, the lower traffic volume, and more favorable climatic conditions may have contributed to its overall better performance. The employment of partial-depth repairs did not improve the observed distress in either of these GPS-4 sections.

In the case of the two JPCP GPS-3 sites, multiple factors appear to have impacted the pavement performance. The contribution of these factors, i.e., pavement thickness (extra 2 in.), climatic conditions (lower FI), type of base layer (asphalt mixture) and subgrade soil (lean inorganic clay) resulted in one test section (18-3031) out lasting the other pavement section.

The effectiveness of using partial-depth patching to repair PCC joints was validated by the low spalled transverse joint count in the treated section, as compared with the untreated section (SPS-4 sites).

It is unclear why the selected SPS-6 sites were classified as such, as most of the work done to fix the spalled joints was preventive maintenance (partial-depth patching), rather than pavement rehabilitation. Only one M&R event in these sections involved rehabilitation with minimal surface preparation (by grinding) followed by full-depth patching of PCC away from joint locations. The benefits of the chosen preventive maintenance methods were short-lived and repeated treatments were required to maintain low distress levels.

3.3 Asphalt Sections

The original LTPP GPS experiments were constructed using the common pavement types in use in the U.S. On the other hand, the LTPP SPS sections were constructed to study specific engineering factors in the mix design. The original six GPS experiments (GPS-1 to GPS-6) and nine SPS experiments (SPS-1 to SPS-9) were later modified and relabeled to accommodate current, evolving and/or local agency practices. GPS-6 experiments, pertaining to AC overlay of AC pavement, were subdivided based on the type of pretreatment performed over the existing pavement. These subdivisions are presented in Table 3.9. The experiment numbers for the flexible pavement sections shown in Table 3.2 also show the original and the revised labels (GPS 6B, 6D, and 6S).

LTPP manual distress surveys of AC pavements provide rutting, transverse cracking and IRI data which can be used to assess pavement performance. Transverse cracks in AC pavements are also classifed as low (width $\leq$ 6 mm), medium (width $>$ 6 mm to $\leq$ 19 mm) and high (width $>$ 19 mm) intensity and the overall transverse count is used in analyzing pavement performance.

Of the 14 selected ACP sites listed in Table 3.2, five were GPS sites and the remaining 9 were SPS sites. Table 3.10 shows the LTPP study dates and climate data for the selected AC sites discussed in this report. The average annual precipitation at the sites located in the nothern part of the state was $\approx$1,100 mm/year, while the southern sites had $\approx$1,300 mm/year. Similarly, the FIs for the northern sites were higher ($\approx$340 C/deg-days) than those for the southern sites ($\approx$165 C/deg-days).

3.3.1 SPS-9C Sites = Superpave Asphalt Binder Study, AC Over CRCP (ACP)

As a part of the extensive research done to improve performance of asphalt pavements under the Strategic Highway Research Program (SHRP), physical properties

TABLE 3.8
Pavement distress survey data for SPS-6 sites (FHWA, n.d.)

	Spalled Transverse Joints (count)			Transverse Cracking (count)		
Survey Date	**18-0601 (US 31 NB)**	**18-0602 (US 31 NB)**	**18-0605 (US 31 NB)**	**18-0601 (US 31 NB)**	**18-0602 (US 31 NB)**	**18-0605 (US 31 NB)**
Feb-90	0	0	13	12	0	0
Apr-90	18	24	25	1	0	0
Jun-90		—	—		—	—
Jun-91	2	15	46	8	0	0
Sep-91	0	0		3	0	
Apr-92	0	10	22	4	0	0
Jun-92	—			—		
Sep-92	0	9	25	4	0	0
Jun-93		27	36		0	0
Aug-93		5	19		0	0
May-95		50	50		0	0
Jul-95		—	—		—	—
Jul-96		30	28		0	1
Jun-98			—			—
Jul-98		8	9		0	
Aug-99		31	23		0	0
Apr-00		—	—		—	—
Apr-00		8	2		0	0
Jun-01		—			—	
Sep-01		25	19		0	0
Dec-01		7	5		0	0
Nov-02		7	4		0	0
Jun-03					—	—
Jul-03		3	2		0	0
Jun-04		2	0		0	0
Jun-05		—	—		—	—
Sep-05		3	11		0	1

Note: Cells with red dashes indicate M&R events.

TABLE 3.9
Relabeled GPS-6 experiments

Existing Pavement	Pre-Treatment	Overlay	New Class
Rehabilitated AC Surfaced Pavement Classifications			
GPS-1 GPS-2 SPS-1 SPS-3 SPS-8 (AC) SPS-9 (New)	None or Maintenance and Repair	Conventional AC	GPS-6B
GPS-1 GPS-2 SPS-1 SPS-3 SPS-8 (AC) SPS-9 (New)	None or Maintenance and Repair	Modified AC	GPS-6C
GPS-1 GPS-2 SPS-1 SPS-3 SPS-8 (AC) SPS-9 (New)	Structural Milling, Fabric	Any AC	GPS-6S
AC Over AC Classifications			
GPS-6 SPS-5 SPS-9	None or Maintenance and Repair	Conventional AC	GPS-6D
GPS-6 SPS-5 SPS-9	None or Maintenance and Repair	Modified AC	GPS-6C
GPS-6 SPS-5 SPS-9	Structural Milling, Fabric	Any AC	GPS-6S

of asphalt binders were also studied and new tests to study these properties were developed. Performance Grading (PG) system for asphalt binders was introduced as a part of Superpave Mix Design.

The four SPS-9 sections selected for this report were located on southbound I-65, in Tippecanoe County, IN near Prophetstown State Park, as shown in Figure 3.16. The pavement was originally constructed in 1970 and brought into the LTPP monitoring program in 1992. It is classified as a rural principal arterial–interstate. The annual mean precipitation and freezing index at the sites during the study period (from 1992 until 2004), were

TABLE 3.10
LTPP study dates and climate data for the AC sections

ID	Construction Date	Inclusion into LTPP	Out-of-Study Date	Precipitation (Avg/Min/Max) mm/year	Freezing Index (Avg/Min/Max) C deg-days
18-1028	Jan 1975	Jan 1987	May 2017	1397/981/1983	166/54/322
18-1037	Jan 1983	Jan 1987	Sep 2020	1410/957/2060	163/54/323
18-2008	Jan 1980	Jan 1987	Apr 2017	1146/816/1581	370/123/666
18-2009	Jan 1981	Jan 1987	Apr 1999	1133/929/1559	319/138/475
18-A310	Jan 1975	Jan 1987	Jun 1995	1354/981/1683	164/69/313
18-A320					
18-A330					
18-A340					
18-A350					
18-0901	Nov 1970	Jan 1992	Aug 2004	1024/821/1325	339/168/469
18-0902					
18-0904					
18-0905					

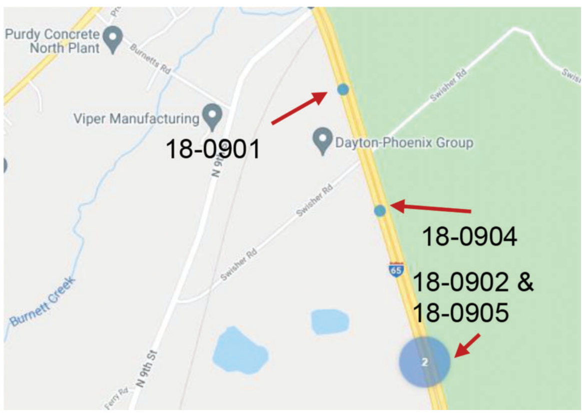

Figure 3.16 Location of ACP SPS-9 sections.

1,084 mm/year and 339 C deg-days, respectively. The trends in precipitation and FI can be seen in Figure 3.17. Sections 18-0901 and 18-0904 were placed on top of untreated, coarse-grained subgrade soil (clayey sand) and had similar pavement cross-section. Going from bottom to the top layer, there were two layers of fine-grained subbase (20 in. and 24 in. thick sandy clay), (b) ≈6 in. of uncrushed gravel base, (c) ≈9 in. of Continuously Reinforced Concrete Pavement (CRCP) and lastly (d) 3 layers of dense-graded HMA (≈5.2 in. total thickness). The subgrade under sections 18-0902 and 18-0905 was also untreated, coarse-grained soil, but classified as poorly graded sand. This subgrade was topped with (a) one layer of subbase composed of fine-grained soil (≈18 in.-thick, sandy clay), (b) ≈5.8 in. of uncrushed gravel base, (c) ≈9.5 in. of CRCP and lastly, (d) 3 layers of dense-graded HMA (≈5.5 in. total thickness).

Prior to the placement of the AC overlay in 1992, work was performed on all four sections on the underlying CRCP layer. In three sections, 18-0902, 18-0904, and 18-0905, the M&R work involved full-depth transverse joint repair patching, longitudinal subdrains repair and joint load-transfer restoration. In section 18-0901, only longitudinal subdrains were installed prior to AC overlay placement. No other repair work was done on sections 18-0902, 18-0904, and 18-0905 until they were taken out of the monitoring program in 2004. On section 18-0901, manual spot patching work was done in June 2001 and involved hand spreading of HMA followed by roller compaction.

Figure 3.18 shows the increase in volume of truck traffic along the interstate during the study period. The monitored truck count showed an increase from 3,000 to 5,400, approximately. No AADT count data was obtained for this period. During the study period, the IRI of the four test sections remained low, but had a slowly increasing trend (Figure 3.19). Poor ride quality was not of concern on these sections. The M&R work was done on the test sections soon after its incorporation into the LTPP monitoring program, and this event is also shown on the plot of IRI vs. time (Figure 3.19).

Rut depth measurements, taken as a part of the manual distress surveys, indicated that the pavement did not undergo excessive rutting, with the maximum observed rut depths under 6 mm (1/4 in.) as shown in Table 3.11. However, in general, the number of transverse cracks increased significantly after August 2000. Transverse cracking in AC pavements typically occurs after a severe thermal event, i.e., a cold spell. Examination of the precipitation and freezing index plots around this period do not show the occurance of such extreme events. The precipitation preceding this survey date was low and the fluctuations in the freezing index was about normal. The number of transverse cracks in section 18-0902 remained lower than in the other three sections. Since this is a binder validation experiment site, it is possible that the low temperature binder grade in this section was selected to withstand the low pavement temperatures expected at this location. As a part of the experimental design, the low temperature grades used in the other sections were, more than likely, warmer than that recommended by

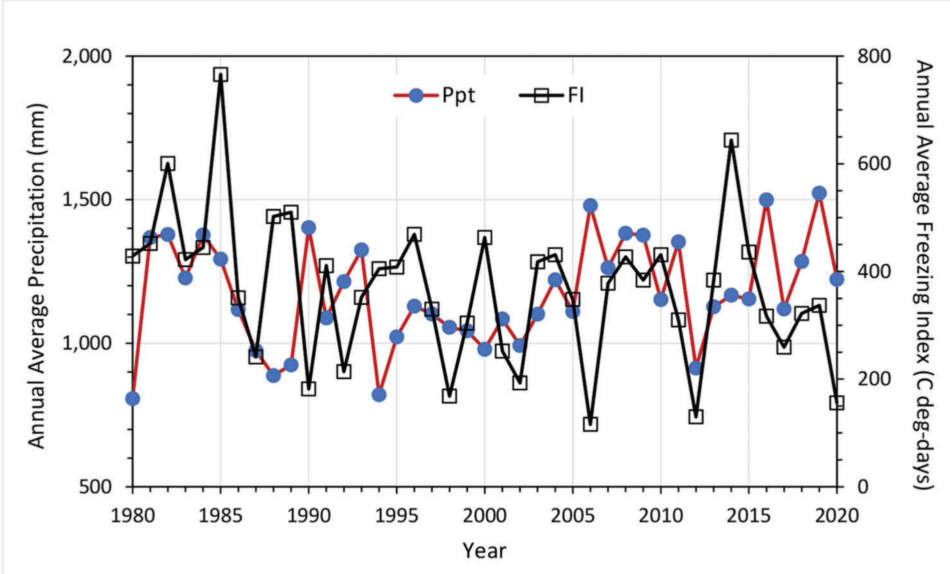

Figure 3.17 Precipitation and freezing index at the ACP SPS-9 sections.

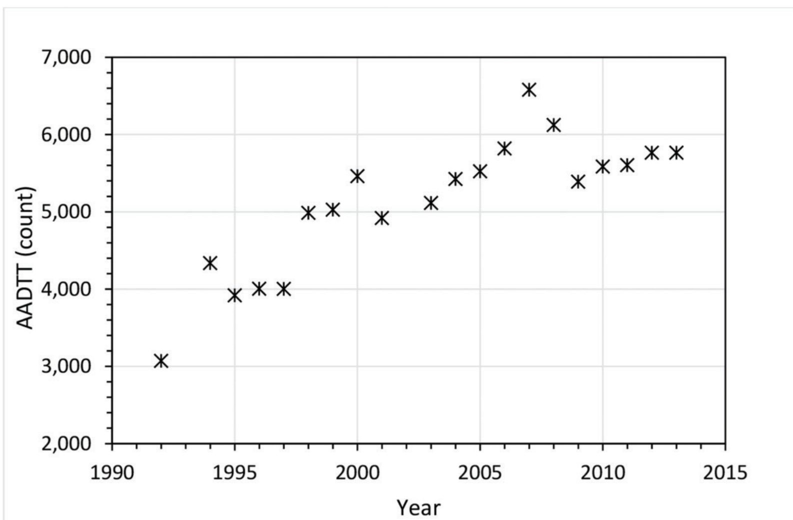

Figure 3.18 Traffic volume on the ACP SPS-9 sections.

the Superpave binder selection software, LTPPBind, in use at the time the AC overlay was constructed.

The low number of transverse cracks observed in all four sections in the following winter month (February 2001) cannot be logically explained. While self healing of cracks in asphalt material may be partly responsible for this decrease, the short duration between the two survey dates (August 2000 and February 2001) does not completely explain the observed reduction. Similar high and low transverse crack counts were also observed from surveys taken in July 2003 and June 2004, with no maintanence repair work peformed to explain the observed decrease in crack count. As mentioned earlier, this may be ascribed to technician inexperience in conducting manual distress surveys or due to undocumented M&R events.

3.3.2 SPS-3 Sites = Preventive Maintenance Effectiveness of Flexible Pavements (ACP)

The overall goal of SPS-3 experiments was to compare change in performance of treated section to an untreated section. Comparison of performance between sections with different treatment types was not the aim of SPS-3 experiments. The maintenance treatments allowed on these experimental sections were the use of thin AC overlay, slurry seal, chip seal, and crack seal.

The five SPS-3 sites selected for analysis in this report were located in southern Indiana, in Spencer County, along eastbound I-64 (see Figure 3.20). The average annual precipitation and freezing index values for the period between 1987 and 1995 (study period) were

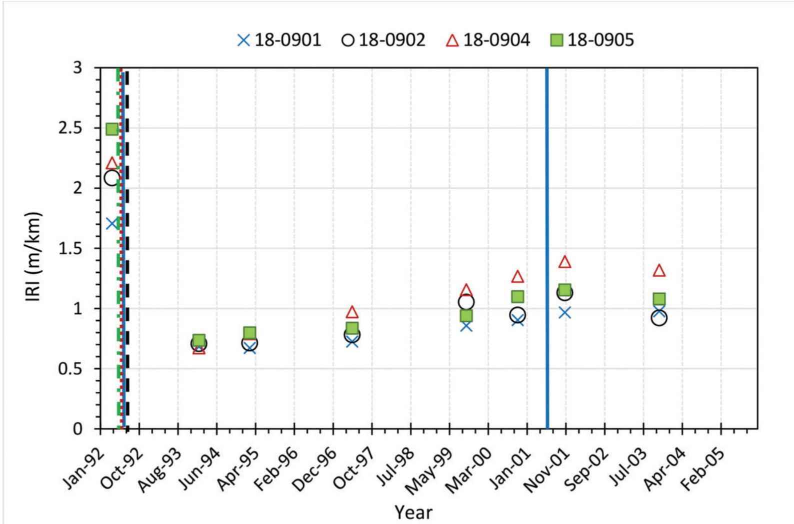

Figure 3.19 IRI and M&R events at the ACP SPS-9 sections.

TABLE 3.11
Pavement distress in the ACP SPS-9 sections (FHWA, n.d.)

	Rut Depth (mm)				Transverse Cracking (count)			
Survey Date	**18-0901 (I-65 SB)**	**18-0902 (I-65 SB)**	**18-0904 (I-65 SB)**	**18-0905 (I-65 SB)**	**18-0901 (I-65 SB)**	**18-0902 (I-65 SB)**	**18-0904 (I-65 SB)**	**18-0905 (I-65 SB)**
Apr-92	4	3						
Jul-92	—	—	—	—	—	—	—	—
Feb-94	5				4	7	7	7
Jul-94	5	5	6	4	3	6	6	6
Nov-94	4	3	4	4	4	7	7	7
Mar-96	4	4	5	5	3	5	7	7
Aug-00	5	3	4	5	18	7	14	11
Feb-01	5	5	4	5	6	0	8	8
Jun-01	—				—			
Jul-03	4	3	4	3	54	20	74	44
Jun-04	6	6	5	5	18	9	8	11

Note: Cells with red dashes indicate M&R events.

1,384 mm and 164°C degree-days, respectively. These values were typical of the annual averages, with no presence of noticeably, extreme cold or wet years. Figure 3.21 shows the variation in average annual of precipitation and freezing index vaules. Traffic count was lower than that observed at the previously discussed SPS-9 sites (located along I-65), which was also classifed as a rural principal arterial–interstate. Both AADT and AADTT showed an increase until 1989 and then dropped slightly toward the end of the study period (see Figure 3.22).

The pavement cross-section was composed of ≈15.5-in. thick, full-depth asphalt concrete layer, placed in six lifts over untreated subgrade (lean inorganic clay). The lift thickness of the six layers ranged from 1.1 in.–4.9 in., with thicker lifts at the bottom and thinner nearer the surface. Of the five sections, no maintenance work was done on 18-A340 pavement during the 8-year study period, as it was the control (untreated) section. An asphalt overlay was placed in section 18-A310 in March 1992. Maintenance work was performed on sections 18-A320 (slurry seal coat), 18-A330 (crack sealing), and 18-A350 (aggregate seal coat) in August 1990. These M&R events are shown in Figure 3.23 along with the IRI of the pavement.

The IRI of sections 18-A330, 18-A340, and 18-A350 remained more or less stable and low, over the entire monitoring period, both before and after treatment application. Section 18-A320 had the highest IRI all through. IRI was not impacted by the application of slurry seal coat, aggregate seal coat or crack sealing. Only section 18-A310, which had the AC overlay installed in March 1992, showed a drop in IRI. Regardless, the IRI in all sections remained low through the study period and was comparable to that of a new pavement.

Table 3.12 shows the rut depth and transverse crack count observed in the test sections during the study

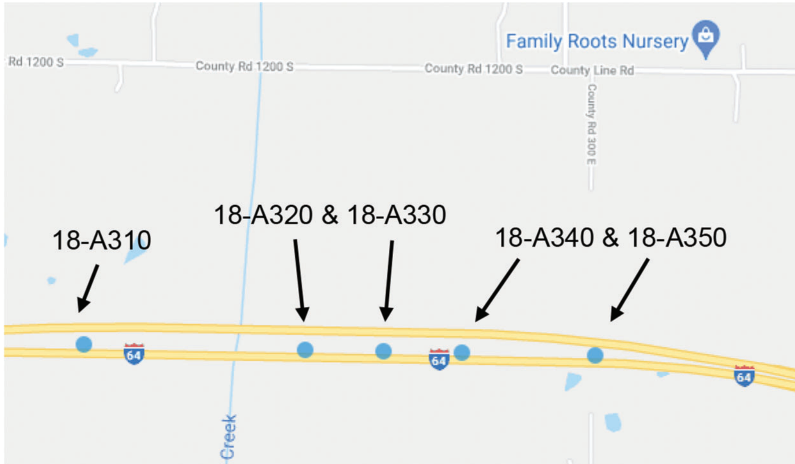

Figure 3.20 Location of ACP SPS-3 sections.

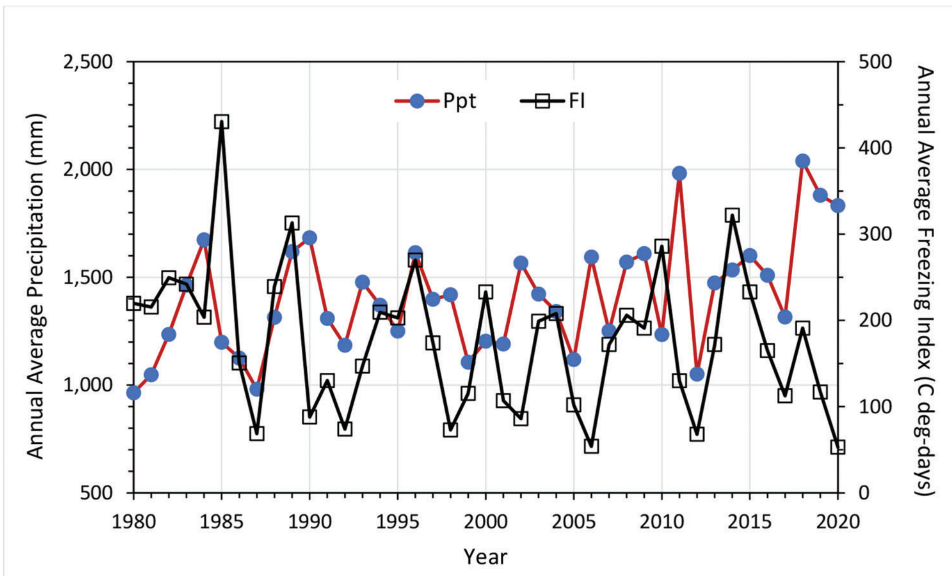

Figure 3.21 Precipitation and freezing index at the ACP SPS-3 sections.

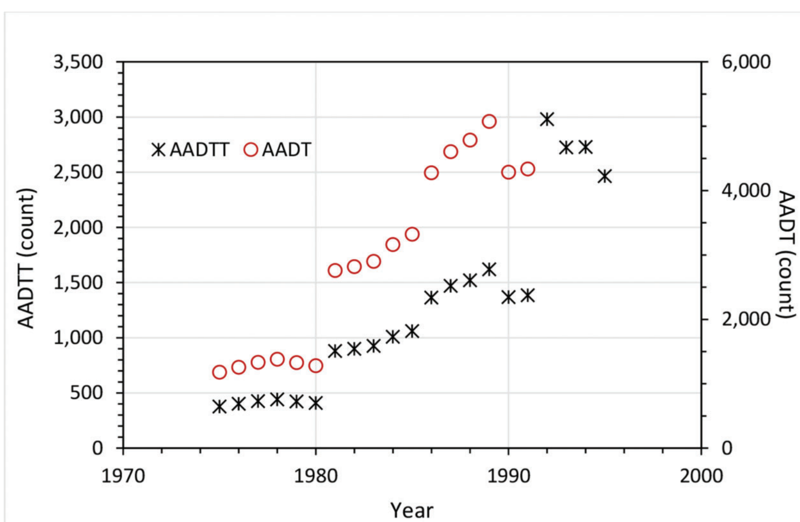

Figure 3.22 Traffic volume on the ACP SPS-3 sections.

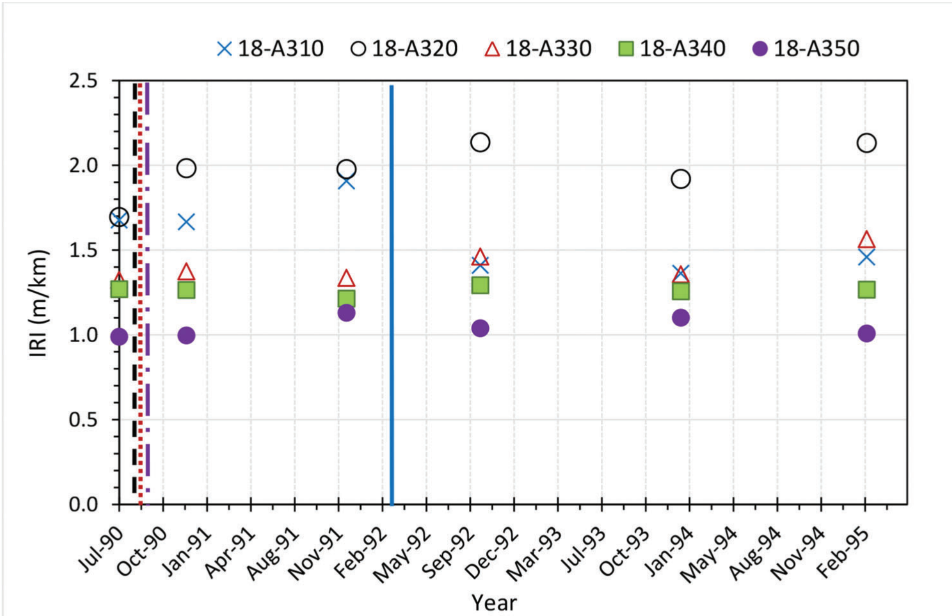

Figure 3.23 IRI and M&R events on the ACP SPS-3 sections.

TABLE 3.12
Pavement distress in the ACP SPS-3 sections (FHWA, n.d.)

	Rut Depth (mm)				
Survey Date	**18-A310 (I-64 EB)**	**18-A320 (I-64 EB)**	**18-A330 (I-64 EB)**	**18-A340 (I-64 EB)**	**18-A350 (I-64 EB)**
Jun-90	19	19	19	17	17
Aug-90		—	—		—
May-91	19	24	19	20	18
Jul-91	17	21			
Dec-91			18	17	13
Mar-92	—				
May-94	9	23	20	19	19

	Transverse Cracking (count)				
Survey Date	**18-A310 (I-64 EB)**	**18-A320 (I-64 EB)**	**18-A330 (I-64 EB)**	**18-A340 (I-64 EB)**	**18-A350 (I-64 EB)**
Jun-90	35	85	62	37	34
Aug-90		—	—		—
Nov-90	6	2	30	11	0
May-91	66	30	69	71	1
Jul-91	12				
Dec-91		5	22	7	3
May-92	0	5	26	7	3
Mar-92	—				
Mar-93	6	43	49	30	9
May-94	14	56	56	45	16
Apr-95	18	56	60	48	17

Note: Cells with red dashes indicate M&R events.

period. The manual distress surveys of all the sections showed that the rut depth was approximately 17–19 mm (3/4 in.) in June 1990, shortly before the August 1990 maintenance treatment application. Except for one section, the remaining sections maintained about the same rut depths at the time of the next survey in May 1991, i.e., no significant increase was observed. The rut depth in section 18-A320, which received the slurry seal coat, increased slightly (by 5 mm). No further changes in the rut depths (minor, if any) were observed in these sections until they were taken out of monitoring status in 1995. After AC overlay was placed in section 18-A310 in March 1992, the rut depth in this section dropped significantly below that of the other sections. The rut resistance of sections treated with slurry seal coat, crack sealing or aggregate seal coat was no different from that of the untreated section (18-A340).

Section 18-A320 had the highest (85) traverse crack count prior to treatment, while sections 18-A310, 18-A330 and 18-A350 had much lower but similar (34–37) numbers. In the three sections that had maintenance treatment done in August 1990, namely, 18-A320, 18-A330, and 18-A350, the crack count dropped significantly. It is unclear why the crack count also dropped in 18-A310, which was treated (AC overlay) later on, in March 1992, and in the untreated 18-A340 section, as observed in the November 1990 survey data.

Section 18-A310 (AC overlay) and 18-A350 (aggregate seal coat) appear to have had lower distress in terms of transverse crack count compared with the untreated section 18-A340. Crack count in the sections with slurry seal coat (18-A320) and crack seal (18-A330) quickly increased a few years after treatment application and even exceeded that of the control (untreated section, 18-A340).

3.3.3 GPS-1 Sites = AC on Granular Base (ACP)

GPS-1 pavement sites include dense-graded asphalt (DGA) layers placed over granular, untreated base, with or without the presence of subbase layers. The subgrade layer may be treated or untreated. Total thickness of the AC layer in these experiments had to be ≥150 mm (6 in.), which includes "full-depth" asphalt pavements. The pavement surface may have a seal coat or a porous friction course.

The two GPS-1 sections selected for analysis in this report were placed on I-64 EB (18-1028) and on SR-66 EB (18-1037), respectively, both located in Spencer County, IN. The exact location of these test sites in shown in Figure 3.24. Interstate-64 (I-64) site is classified as a rural, principal arterial–interstate, whereas SR-66 site is on a rural minor arterial. These sections were brought into the LTPP monitoring program in 1997, but were originally constructed in 1975 and 1983, respectively. The variations in precipitation values and freezing indices over time at these locations are presented in Figure 3.25 and Figure 3.26, respectively. Due their proximity to each other, both test sites received similar precipitation and had similar freezing indices.

Both sections may be considered "full-depth" asphalt pavements (approx. 18 in. thick) placed on top of untreated subgrade. The subgrade at both sites was fine grained soil, but it was a sandy silty clay at 18-1028 site whereas it was lean inorganic clay at 18-1037 site. Section 18-1028 was constructed in June 1995 by milling the original (1975) pavement surface and overlaying it with 18.3-in. layer of hot-mix recycled asphalt concrete. At this point the site was reclassified as GPS-6C, "AC Overlay of Milled AC Pavement Using Conventional or Modified Asphalt." No further maintenance work was performed on this section during the LTTP monitoring period. In section 18-1037, the original pavement surface (1983) was milled off and overlaid with 17.9 in. of asphalt concrete in September 1994. The site classification was changed from GPS-1 to GPS-6S. Crack sealing was performed in June 2000 and 2014. An AC overlay treatment was performed in between these two crack sealing repairs, in 2003. This M&R event again resulted in changing section's classification to a GPS-6D, "AC Overlay over Previously Overlaid AC Pavement Using Conventional Asphalt."

The pavement smoothness, as reflected by IRI, is shown in Figure 3.27. The IRI values on both sections were low throughout the monitoring period, with the interstate (18-1028) having slightly lower values than SR-66 (18-1037), until the first AC overlay events in

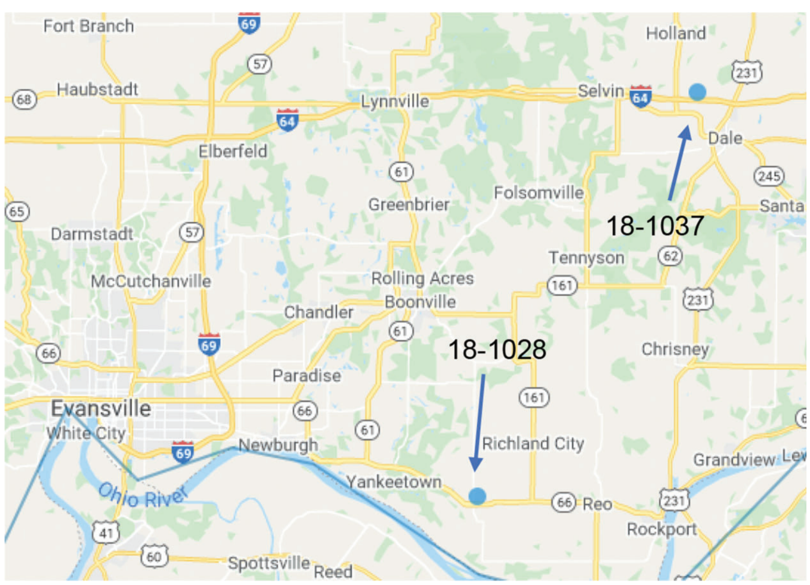

Figure 3.24 Location of ACP GPS-1 sections.

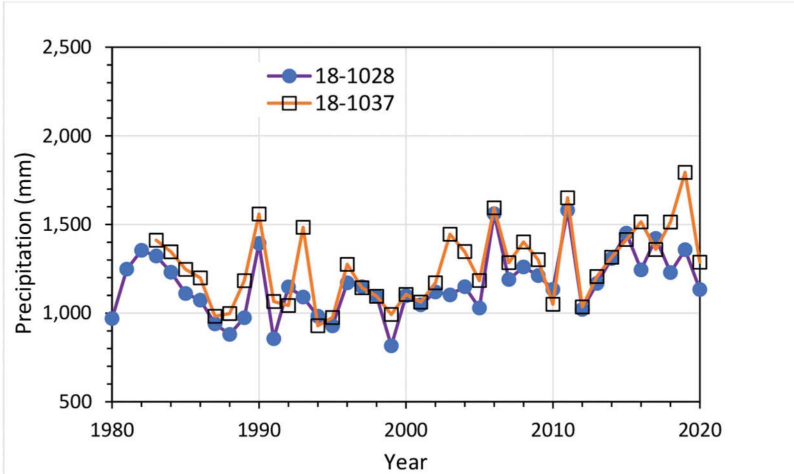

Figure 3.25 Average annual precipitation at the ACP GPS-1 sites.

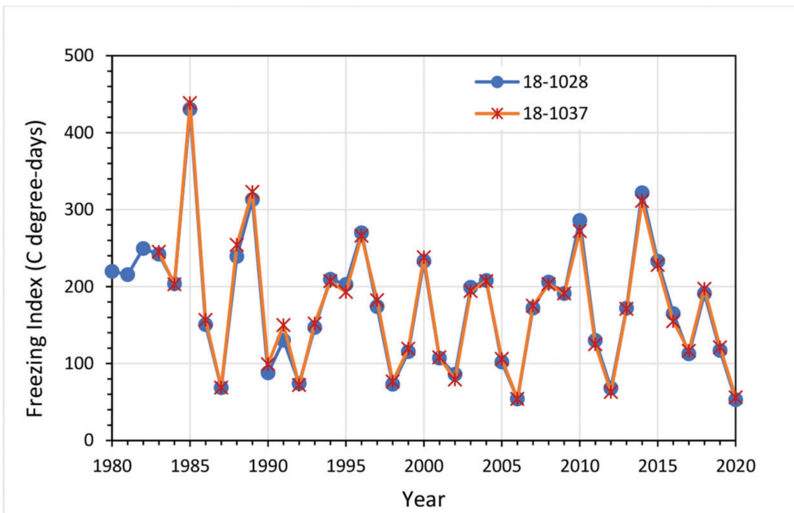

Figure 3.26 Average annual freezing index at the ACP GPS-1 sites.

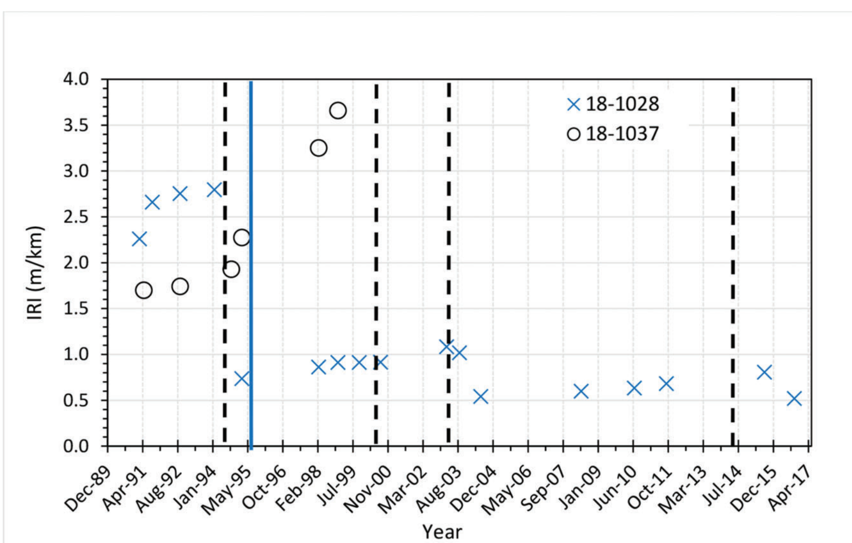

Figure 3.27 IRI and M&R events on the ACP GPS-1 sections.

1995 and 1994, respectively. Following this, IRI of 18-1028 was lower than that of the SR-66 site which increased steadily until 2003, when a second AC overlay was placed at the SR-66 site. As mentioned earlier, no further M&R work was performed on 18-1028. The IRI of this section, while staying low, eventually exceeded that of 18-1037. The truck traffic volume on the interstate site (18-1028) was significantly higher than that on SR-66, as expected. The AADT on both the sections was similar, with the interstate having a slightly higher count. These data are presented in Figure 3.28.

Prior to the first AC overlay repair at the two sites, the rut depth on the SR-66 pavement (18-1037) was 24 mm (≈1 in.) and it was ≈16 mm (≈0.6 in.) on I-64E pavement (18-1027). After the pavement at I-64E was overlaid with an AC overlay in 1995, the rut depth dropped to ≈9 mm. Similarly, the number of transverse cracks also dropped from 35 to 3. The crack count, however, continued to increase with age and reached 24 in 2015, approximately 2 years before the site was taken out of study status in 2017. Rut depth and transverse crack count data are shown in Table 3.13.

After the first AC overlay work was performed on the 18-1037 site (in September 1994), the rut depth dropped from 24 mm to 1 mm. The rut depth level stayed low (<8 mm) until the end of the study period. The transverse crack count was higher at this site and reached 70 in October 1992. The first AC overlay work was done in September 1994, after which the crack count dropped to zero. However, the number of cracks increased rapidly thereafter. In spite of the three M&R treatments (two cases of crack sealing and one installment of AC overlay) the transverse crack count remained high at this test section until the end of study.

3.3.4 GPS-2 Sites = AC on Bound Base (ACP)

GPS-2 sites encompass pavements with dense graded asphalt (DGA) surface layers placed over a bound base layer treated with either bituminous or non-bituminous binders. Examples of bituminous binders are unmodified asphalts, cutbacks, emulsions and road-tars whereas, hydraulic cements, lime, fly ash, and pozzolans are allowed in the non-bituminous binder category. Other base stabilization methods include sand asphalt, soil cement and any practice where the cementing action of the additive/treatment improves the structural properties of the base material.

Section 18-2008 was located on the southbound lane of US-27, near Fort Wayne, IN, in Allen County. Its functional classification was a rural principal arterial–other. It was originally constructed in 1980 and satisfied the requirements for a GPS-2 section of the LTPP program. The pavement cross-section was composed an untreated subgrade (fine grained, sandy lean clay), bound treated base layer (5.2 in. thick) and a full-depth asphalt concrete layer (15.7 in. thick). The treated base layer was open-graded, cold-laid plant mix. The full-depth AC layer was 12.5 in. thick at the time that it was brought in the LTPP program in 1987. Shortly after inclusion of this section into the LTPP program in June 1989, a sand seal coat was applied, followed by placement of AC overlays in June 1994, November 2003 and October 2016. Additionally, shoulder restoration work was performed in June 1994. All these pavement rehabilitation practices increased the pavement thickness to 15.7 in. and changed the GPS classification with each overlay as follows: from GPS-2 to GPS-6B (1994), GPS-6D (2003) and finally, GPS-6S (2016). This section was taken out of study status in April 2017. The pavement distress data collected for this section are shown in Table 3.13.

Section 18-2009 was originally constructed in 1981 on a northbound SR-37 near Noblesville, IN and was classified as a Rural Minor Arterial. In this test section, the bound, treated base layer was 9.8 in. thick, laid over unbound, granular subbase layer 9.5 in. thick. The bound base layer was composed of a 3.3 in. thick dense-graded, cold-laid plant mix and a 6.5 in. thick open-graded cold-laid plant mix. The surface AC

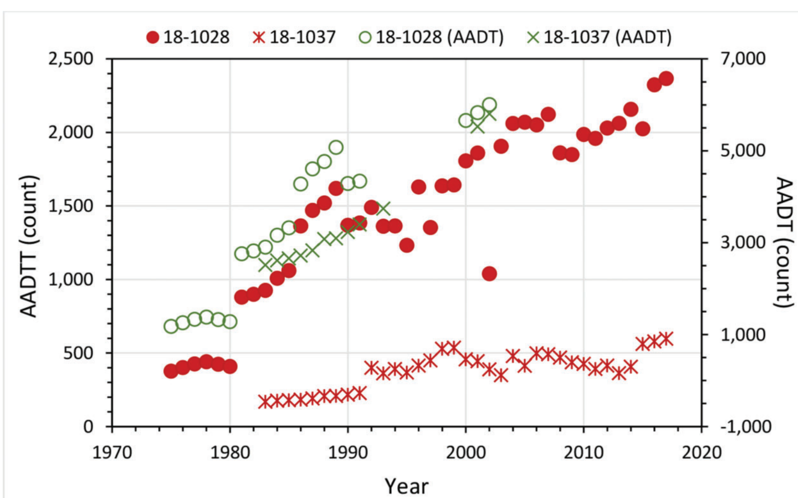

Figure 3.28 Traffic volume on the ACP GPS-1 sections.

TABLE 3.13
Pavement distress in the ACP GPS-1 sections (FHWA, n.d.)

	Rut Depth (mm)			Transverse Cracking (count)	
Survey Date	**18-1028**	**18-1037**	**Survey Date**	**18-1028**	**18-1037**
Jun-90	16		Nov-89	23	56
May-91	17	14	Jun-90	24	
Jul-91	15		May-91	37	49
Oct-92		14	Jul-91	18	
Mar-93	15		Dec-91	12	
May-94	15	24	May-92	13	
May-94	16		Oct-92		70
Sep-94		—	Mar-93	27	0
Apr-95		1	May-94	28	47
Jun-95	—		May-94	32	7
Mar-96		5	Sep-94		—
Feb-99		5	Oct-94		0
May-00		—	Apr-95	35	35
Nov-00		6	Jun-95	—	
Nov-02		4	Mar-96		37
Mar-03		7	Feb-99		45
May-03		—	May-00		—
Aug-05		3	Nov-00		47
Nov-05	7		Nov-02		60
Jun-08	8		Mar-03		66
Jun-09		6	May-03		—
Jul-10	9		Aug-05		1
Oct-11		6	Nov-05	3	
Jun-12	9		Jun-08	5	
Jun-14	9	—	Jun-09		30
Aug-15	9		Jul-10	8	
Jul-16		8	Oct-11		44
			Jun-12	16	
			Jun-14	20	—
			Aug-15	24	
			Jul-16		44

Note: Cells with red dashes indicate M&R events.

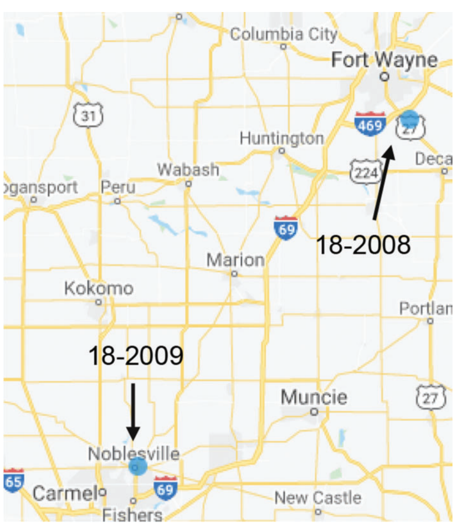

Figure 3.29 Location of ACP GPS-2 sections.

layer was 5.7 in. thick and placed in two lifts, topped with slurry seal. The geographical locations of these two sections are shown in Figure 3.29. This section was monitored by LTPP from 1987 until 1999, a relatively short period compared to section 18-2008 (1987 to 2017).

The average annual precipitation levels and the average annual freezing indices at these two sites were similar, as can be seen in Figure 3.30 and Figure 3.31, respectively. During the study period, both the precipitation and FI, showed fluctuations about the average. While no extreme in average precipitation was recorded at the either of the two sites, both sites showed a high FI in 2014 (see Figure 3.30 and Figure 3.31). Section 18-2009 was out of status at this time, but section 18-2008 was still in the LTPP monitoring plan, which might have impacted the pavement distress observed following this event.

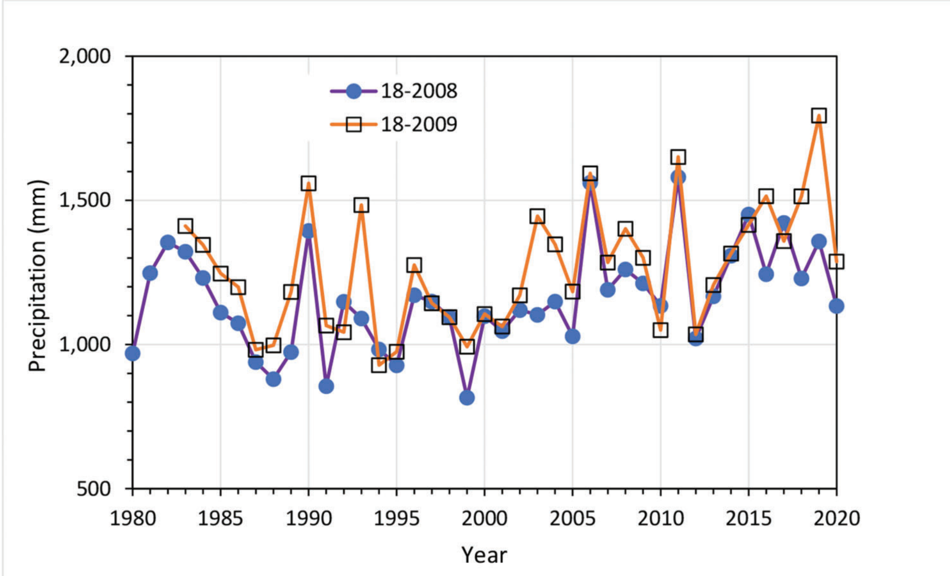

Figure 3.30 Annual average precipitation at the ACP GPS-2 sites.

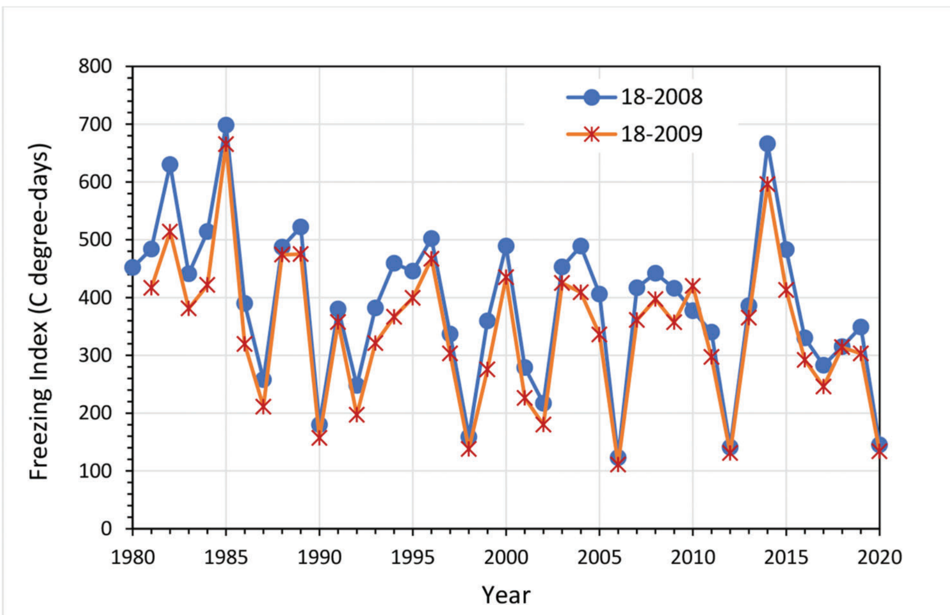

Figure 3.31 Annual average freezing index at the ACP GPS-2 sites.

Overall, the IRI levels for both of these sections can be considered low, with section 18-2008 having initially higher values than section 18-2009. However, after section 18-2008 was resurfaced with an AC overlay in June 1994, the IRI values dropped below 1 m/km and stayed low for the remainder of the study period. The IRI levels of section 18-2009 increased steadily and no repair work was performed on this section during the study period. These data along with the M&R events at these sites are shown in Figure 3.32.

The average annual truck traffic count at these two sites were fairly similar, with a slight decrease after 2000 at the 18-2008 site (see Figure 3.33). The monitored AADT levels at the 18-2008 site showed large fluctuations during the monitoring period, while the AADT at 18-2009 showed a steady, increasing trend during the LTPP monitoring period. The traffic volume did not appear to have caused excessive rut depths at the two sites (see Table 3.14). The pavement at section 18-2008 which was built without the granular subbase experienced ≈12 mm (1/2 in.) rut depth by 1994, while 10 mm (0.4 in.) rut depth was measured in section 18-2009. In 1994, after AC overlay was placed in section 18-2008, that section did not show excessive rutting until the end of the monitoring period. Since section 18-2009 was taken out of study status by 1999, it is not

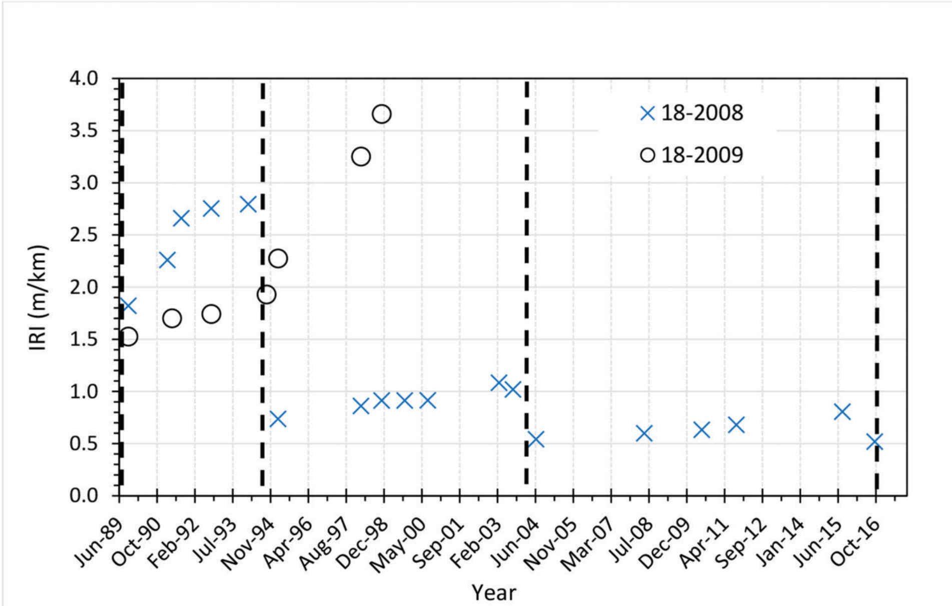

Figure 3.32 IRI and M&R events on the ACP GPS-2 sections.

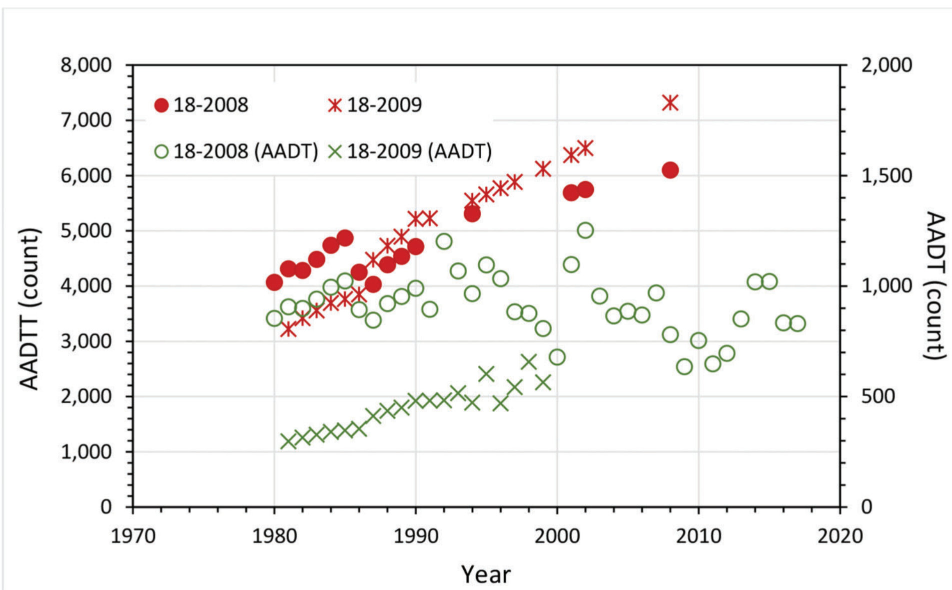

Figure 3.33 Traffic volume on the ACP GPS-2 sections.

possible to compare its long-term rutting performance with the performance of section 18-2008.

Table 3.14 shows the rutting and transverse crack count data for these GPS-2 sections. Transverse crack count, which may be taken as an indicator of low temperature thermal stress response, was significantly higher in section 18-2008, compared with that observed in section 18-2009 (with the unbound granular subbase layer). However, the crack count did decrease after the installation of the AC overlay in 1994 and stayed low thereafter. Since the traffic, temperature profile and climatic conditions at the two locations are similar, it may be inferred that the presence of the unbound subbase in the original pavement cross-section at 18-2009 aided to its better rut resistance and resistance to transverse cracking.

3.4 Summary of Asphalt Pavement Sections

No major differences in either rutting or transverse cracking distresses were observed between the four SPS-9 sections. Neither the slight dissimilarities between the subbase layer nor the underlying subgrade soil appear to have impacted overall pavement performance.

Rutting resistance of sections that received surface treatment (SPS-3 sections), in form of slurry seal coat

TABLE 3.14
Pavement distress in the ACP GPS-2 sections (FHWA, n.d.)

	Rut Depth (mm)			Transverse Cracking (count)	
Survey Date	**18-2008**	**18-2009**	**Survey Date**	**18-2008**	**18-2009**
Jun-89	—		Jun-89	51	
Oct-90	13		Sep-89		13
Apr-92		7	Oct-90	50	
Nov-92	15	10	Apr-92		17
Jun-93		7	Nov-92	52	18
Apr-94	12		Jun-93		16
Jun-94	—		Feb-94	52	
Jul-94		10	Apr-94	62	
Mar-96		8	Jun-94	—	
Jul-96	3		Jul-94		18
Mar-99	2		Apr-95		17
Aug-00	4		Mar-96		27
Jun-02	4		Jul-96	4	
Mar-03	3		Mar-99	0	
Sep-03	5		Aug-00	3	
Nov-03	—		Jun-02	15	
Aug-05	1		Mar-03	0	
Jul-10	1		Nov-03	0	
Jun-12	2		Aug-05	0	
Aug-15	2		Jul-10	3	
Oct-16	—		Jun-12	19	
Nov-16	1		Aug-15	81	
			Oct-06		
			Nov-16	0	

Note: Cells with red dashes or numbers indicate M&R events.

or crack sealing or aggregate seal coat, was no better than the rutting resistance of the untreated section. In terms of thermal crack resistance, section treated with AC overlay and aggregate seal coat appear to have performed better than sections with the untreated section and also better than the other treatment methods used (slurry seal and crack seal).

Following the M&R work (removal of the old pavement and installation of the AC overlay) performed on the two original GPS-1 sites (18-1028 and 18-1037), they were later reclassified as GPS-6S and GPS-6D, respectively. The rut depths in these two sections were comparable after initial AC overlay work. However, transverse crack count was higher in the rural minor arterial section (18-1037) even after two overlays and two crack sealing repairs.

The presence of the granular subbase in section 18-2009 did not improve its rut resistance compared with section 18-2008 (GPS-2 sections). Both sections showed similar performance in terms of rutting behavior. However, the transverse crack count was higher in the section without the granular subbase layer (18-1028).

4. SUMMARY AND CONCLUSIONS

This report draws on findings from the Contracts History Database file for the state of Indiana and the LTPP InfoPave section summaries for selected experimental sites within the state. The findings pertain to the timing between different pavement repair and maintenance options practiced within the state. Some inferences could also be drawn regarding differences in performance (as evidenced by distress measurements reported in the results of manual surveys) of pavements resulting from various treatment options, variations in climatic and subgrade conditions at the site, and details of pavement structure.

The Contract History Database file contains a record of all pavement repair and maintenance tasks performed on the non-interstate roadways since the late 1940s. Available details pertaining to each project included roadway number, location, from and to mile markers, date of letting, designation number, work designation, etc. The LTPP InfoPave Database had extensive data from monitored test sections. These data included original and modified pavement structure, history of maintenance and repairs, traffic volume, climatic data, pavement distress survey data, roughness index, etc.

4.1 Findings from the Contract History Database

The analysis of the database focused on non-interstate, flexible pavements. That database was last updated around 2014, or about 7 years before the preparation of this report. The common types of maintenance and repair projects performed on flexible pavements included (in decreasing order) the following: (a) partial 3R, (b) major structural overlays, (c) resurfacing–non 3R/4R, (d) preventive and (e) minor structural overlays.

The average time between successive partial 3R repairs was 12.3 years with a standard deviation of 5.7 years. A higher number of such repairs occurred before the maximum frequency count, which was observed to take place between 12–15 years. Partial 3R projects are less work intensive than major structural overlays, for example, and hence employed more often to fix lighter pavement issues. The total number of partial 3R projects was 573.

The number of major structural overlays was 413, with an average time of 11.8 years between such projects and standard deviation of 6.4 years. The distribution of this repair/project type was weighted to the right of maximum frequency, which is an expected and logical finding. These projects tend to be more work intensive and are not undertaken until later ages, when pavement distress/deficiencies become more severe. Additionally, this type of repair provides more lasting benefits.

Preventive overlays and resurfacing–non 3R/4R standards were applied at relatively the same numbers (251 vs. 271) of projects. The average time between preventive overlays was 12.6 years, with a standard deviation of 6 years. Similarly, in the case of resurfacing–non 3R/4R standards, the average and standard deviation were 11.8 years and 6.1 years, respectively. However, preventive overlay treatments were weighted to the right of the maximum frequency (longer time between such projects), while resurfacing–non 3R/4R standards were weighted to the left.

The number of minor structural overlay projects in the database was 135, with an average of 13.5 years and standard deviation of 6.2 years. At peak frequency (15–18 years), the number of minor structural overlay projects was half the number of major structural overlay projects. This dataset was also weighted to the left of maximum frequency.

When the project entries were sorted based on work "code," the findings were not as clear cut. This is because some of maintenance and repair projects were cross-listed in more than one "code" category. For example, a Partial 3R project was coded as a "T" or an "O" or an "A." Code O, used for thick overlays over JCP, ranked the highest with 981 entries. Code "A" ranked second with 673 entries and lastly, code "T" representing thin overlays with milling, ranked third (183) in the number of repair projects. The average time between repairs for all three categories was about 12 years.

4.2 Findings from LTPP InfoPave Data

LTPP data from select concrete pavements and asphalt pavement within the state were used to draw comparisons between similar GPS sites and SPS sites. All study sections were located in the north-central region of LTPP regional classification and in the wet-freeze climatic zone. Differences in average annual precipitation and freezing indices arose, with the central and northern sites having lower precipitation and higher FI than their companion sites (if located in the southern parts of the state). These factors contributed to the observed differences in pavement distress and confounded the analysis.

The two JRCP GPS-4 sites (18-4021 and 18-4042) differed in terms of climate, soil subgrade, overall traffic count and type of bound, treated base layer. A combination of all these factors, i.e., warmer temperature, lower FI, lower AADT, coarse-grained subgrade soil, and the presence of HMA-treated base layer, resulted in lower pavement distress in 18-4042. Although many M&R projects were performed on this pavement during the monitoring phase, the companion site (18-4021) showed higher distress even at an early age and was taken out of monitoring status earlier.

Unlike the GPS sections, the SPS sections may be considered to represent a more controlled experiments, in the sense that factors such as traffic volume, climate, and type of subgrade soil are the same between companion sites, due to their proximity to each other. Therefore, differences in pavement performance may be attributed to specific design factors or differences in treatment methods.

The effectiveness of using partial-depth patching to repair PCC joints was validated by the low levels of the spalled transverse joint count in the treated section (18-A410), as compared with the untreated section (18-A430) among the two SPS-4 sites that were compared.

It is unclear why the selected SPS-6 sites were classified as such, as most of the work done to fix the spalled joints was preventive maintenance (partial-depth patching), rather than pavement rehabilitation (which is the purpose of SPS-6 studies). Only one M&R event in these sections involved rehabilitation with minimal surface preparation (by grinding) followed by full-depth patching of PCC away from joint locations.

No major differences in either rutting or transverse cracking distress were observed between the flexible pavements installed in four SPS-9 sections analyzed in this report. Since SPS-9 sites are designed to study mixture or binder validation, these controlling factors (specific mix designs unknown) did not appear to influence and delineate the overall pavement performance between sections. Neither the slight dissimilarities between the subbase layers nor underlying subgrade soils appear to have impacted overall pavement performance.

Rutting resistance of sections that received surface treatment (SPS-3 sections), in the form of slurry seal, crack sealing, or aggregate seal coat, was no better than the rutting resistance of untreated section. In terms of thermal crack resistance, section treated with AC overlay and aggregate seal coat appear to have performed better than sections with the untreated section and also better than the other treatment methods used (slurry seal and crack seal).

Following the M&R work (removal of the old pavement and installation of the AC overlay) performed on the two original GPS-1 sites (18-1028 and 18-1037) they were reclassified as, respectively, GPS-6S and GPS- 6D. The rut depths in these two sections were comparable after initial AC overlay work. However, transverse crack count was higher in the rural minor arterial section (18-1037) even after two overlays and two crack sealing repairs.

The presence of the granular subbase in section 18-2009 did not improve its rutting resistance compared with section 18-2008 (both GPS-2 sections). Both sections showed similar performance in terms of rutting behavior. However, the transverse crack count was higher in section without the granular subbase layer (section 18-1028).

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On March 11, 1937, the Indiana Legislature passed an act which authorized the Indiana State Highway Commission to cooperate with and assist Purdue University in developing the best methods of improving and maintaining the highways of the state and the respective counties thereof. That collaborative effort was called the Joint Highway Research Project (JHRP). In 1997 the collaborative venture was renamed as the Joint Transportation Research Program (JTRP) to reflect the state and national efforts to integrate the management and operation of various transportation modes.

The first studies of JHRP were concerned with Test Road No. 1—evaluation of the weathering characteristics of stabilized materials. After World War II, the JHRP program grew substantially and was regularly producing technical reports. Over 1,600 technical reports are now available, published as part of the JHRP and subsequently JTRP collaborative venture between Purdue University and what is now the Indiana Department of Transportation.

Free online access to all reports is provided through a unique collaboration between JTRP and Purdue Libraries. These are available at http://docs.lib.purdue.edu/jtrp.

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