Effectiveness of Pavement Preservation Techniques

Final Report
May 2019

ASPHALT MATERIALS & PAVEMENTS PROGRAM

IOWA STATE UNIVERSITY
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16. Abstract

Success of pavement preservation depends upon which distresses require proper mitigation. While more robust rehabilitation or reconstruction methods have been proven to eliminate severe pavement defects, they are unlikely to remain the most cost-effective. The key challenge for preservation programs comes from budget and personnel shortages, and without an accurate understanding of local preservation performance, the success of a program in unlikely.

The Iowa Department of Transportation (DOT) has invested in the collection of pavement information, storing it in its own pavement management information system. Combined with construction records, this database can be utilized to extract relevant performance data for various preservation methods. By compiling construction and performance data in one place, effective preservation strategies and cost-effectiveness can be objectively evaluated based on observed performance.

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EFFECTIVENESS OF PAVEMENT PRESERVATION TECHNIQUES

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EXECUTIVE SUMMARY

Tracking the performance of pavement preservation treatments extends beyond research to a movement that seeks to cost-effectively delay pavement deterioration through proactively addressing pavement imperfections before a substantial decrease in serviceability occurs. The objectives of this research are to (1) document the effectiveness of pavement preservation strategies in Iowa by using both qualitative and quantitative metrics and (2) develop an understanding of the important factors that influence the performance of pavement preservation strategies.

An extensive literature review was performed to document previously performed research of pavement preservation. The literature review summarized the commonly performed preservation treatments with a focus on research studies performed in the upper Midwest. The literature review tabulated summaries of expected service life extension for both flexible and rigid pavements. Research reports about pavement preservation treatment selection guidelines were also included. Most past studies based performance on the international roughness index (IRI), the pavement condition index (PCI), and cracking. A voluntary questionnaire was sent to local agencies to better understand pavement preservation at a local level.

The research performed in this study focused on linking pavement performance data collected through the Iowa Department of Transportation's (DOT's) pavement management information system (PMIS) with pavement preservation construction project locations available on the Iowa DOT's electronic records management system. Compilation of PMIS and performance data with preservation treatment applications allowed the research team to develop observed trends for the pavement preservation treatments.

The research reports the life extension determined for the PCI, rutting index, cracking index, and riding index as compiled for the following treatments:

- Microsurfacing
- Slurry seal
- Hot-mixed asphalt (HMA) patching
- HMA crack sealing/filling
- Dowel bar retrofit/diamond grinding
- Grinding and grooving
- Portland cement concrete (PCC) crack sealing/joint filling
- PCC patching

The findings showed that treatment selection is important and that over time, more information can be integrated into this analysis to enhance the validity of the results. Continued collection of the PMIS data will lead to more observations over time. Increasing the number of projects whose performance can be objectively observed is critical to enhancing the data-driven case for pavement preservation treatments.

Additionally, a qualitative look at individual distress parameters, including alligator cracking (HMA only), transverse cracking, longitudinal cracking, durability cracking (PCC only), joint spalling (PCC only), and friction values highlighted additional information that was not evident within the analytical trend fitting. It appeared more often than not that flexible pavement preservation treatments were able to maintain the current condition of the pavement parameters instead of showing significant improvements. As this is not the most ideal finding, it is very important to note that maintenance of condition can become just as important as an original improvement that quickly drops in value. The rigid pavement preservation treatments appeared to improve the individual parameters more frequently, when looking at transverse and longitudinal cracking.

A simple cost-effectiveness analysis determined that microsurfacing and HMA crack sealing/filling and PCC joint sealing were cost effective treatments based on the observed life extension. Many of the slurry seal treatments were being used to address cracking and were not as cost-effective as microsurfacing.

INTRODUCTION

Problem Statement

Pavement preservation has been shown to improve pavement performance, and the desire to maximize Iowa's infrastructure investment has led Iowa to invest in collecting pavement performance information. This data, combined with construction records and typical treatment costs, can provide a better understanding of the effectiveness of pavement preservation techniques on Iowa roadways. Pavement preservation research requires results that clearly demonstrate their effectiveness for enhancing a pavement's ride quality, and delaying deterioration. Pavement preservation performance extends beyond research to an overarching shift in asset management that seeks to cost-effectively delay pavement deterioration through proactively addressing pavement imperfections before a substantial decrease in serviceability. Iowa has actively used pavement preservation methods as a way to extend pavement service life on both Portland cement concrete (PCC) and hot-mixed asphalt (HMA) pavements. Improved understanding of pavement preservation techniques for both PCC and HMA, with a focus on pavement performance over time, is needed. This research compiled construction and performance data in one place so that the cost-effectiveness of preservation strategies can be objectively evaluated based on observed performance.

Objectives

The overreaching objective of pavement preservation is to bolster the pavement network investment and maintain a higher level of service (Brown 1988). This research aimed to improve the understanding of pavement preservation effectiveness in Iowa by focusing on two key areas: (1) measure the effectiveness of pavement preservation using both qualitative and quantitative metrics while considering important factors that influence the performance of pavement preservation strategies and (2) evaluate the cost-benefits of pavement preservation techniques.

Background Summary

New pavement designs require engineers to specify a design life, which establishes a pavement layer thickness. If construction and material quality is adequate, the pavement is anticipated to perform at an acceptable condition for its design life at a reliability level chosen by the design engineer. On the first day after construction, the pavement condition will be at its highest condition level. Over time, deterioration occurs from traffic and environmental conditions leading to the need for maintenance, preservation treatments, and rehabilitation. At the time of construction, it is unknown what types of distresses will present themselves first; however, each distress may require different treatments. Engineers are tasked with selecting the best pavement maintenance and preservation techniques for the roadway. The techniques need to be selected based on the pavement distresses that are meant to be prevented. For example, microsurfacing is effective in filling ruts (Gransberg 2010), but a lower cost fog seal is likely a more cost-effective treatment if the main goal is to seal the surface and prevent cracking.

The Federal Highway Administration (FHWA) provided pavement preservation definitions in a September 2005 memo (FHWA 2005), which has been superseded by FHWA's 2016 memo (FHWA 2016a) titled: Guidance on Highway Preservation and Maintenance. The memo defines preservation as follows: *"Preservation consists of work that is planned and performed to improve or sustain the condition of the transportation facility in a state of good repair. Preservation activities generally do not add capacity or structural value, but do restore the overall condition of the transportation facility."* The effectiveness of pavement preservation treatments is not entirely understood or documented in Iowa. This research aims to better understand the enhancements of pavement preservation strategies for HMA and PCC pavements as well as consider the pre-treatment condition of the pavement.

Budget and personnel shortages for pavement preservation are often cited as a key challenge for preservation programs. The school of thought of "Can we afford to preserve pavements?" should be replaced with "What is the true cost of not preserving pavements?" A recent study by Johnson et al. (2012), in Scotland, concluded that every dollar saved by reducing the maintenance budget led to a net societal loss. Losses included increased rehabilitation costs, vehicle operating costs, travel time costs, and accident costs (Johnston et al. 2013). Qualitative features, such as user dissatisfaction and impacts to the agriculture industry, are not easily quantified but are also important. Allocating funding using a worst-first approach can lead to high pavement preservation costs with less beneficial results. A breakdown of pavement condition ratings from good to poor can help analyze the overall "health" of the network and better categorize pavements that are suitable for preservation techniques (Galehouse et al. 2003).

Collection of pavement condition data has broadened the capabilities for managing a pavement network and assessing the effectiveness of pavement preservation techniques. Iowa has dedicated significant resources to the pavement management information system (PMIS) data collection database, which provides engineers and researchers with the capability to analyze the pavement network performance, but research utilizing the database still requires a significant amount of data compilation from contracts, construction, and materials to be most successful. The project information of cost, condition, construction history, materials data, and traffic loading are influential factors in measuring pavement preservation effectiveness on Iowa's roadway network. Compiling and analyzing pavement performance data is an area of opportunity for improving pavement preservation programs. Linking the pavement performance condition data with contract and material project information can benchmark current pavement preservation effectiveness. As data becomes more widely available, analytical tools and statistical models can be steadily integrated into practice to better understand the reliability of the treatments.

One of the most promising ways to evaluate the effectiveness of performance data is using survivability analysis to determine the probability of long-term success of a preservation technique. This has been done extensively for comparing HMA rehabilitation strategies and has led to improved decision making on the types of rehabilitation strategies that are most effective (Chen et al. 2015). At the time of this research, there are not enough projects with corresponding performance data to conduct a survivability analysis, but it will be possible in the future if current data collection practices continue.

A 2010 study was performed using Indiana Department of Transportation (DOT) data, which focused on preservation effectiveness, and determined triggers for when pavement preservation treatments should occur (Ong et al. 2010). The study evaluated performance curves for preservation treatment and remaining service life, and it provided guidance for the Indiana DOT to integrate the pavement preservation model framework at the district and network level. Table 1 shows a brief summary of the developed guidelines for preventive maintenance.

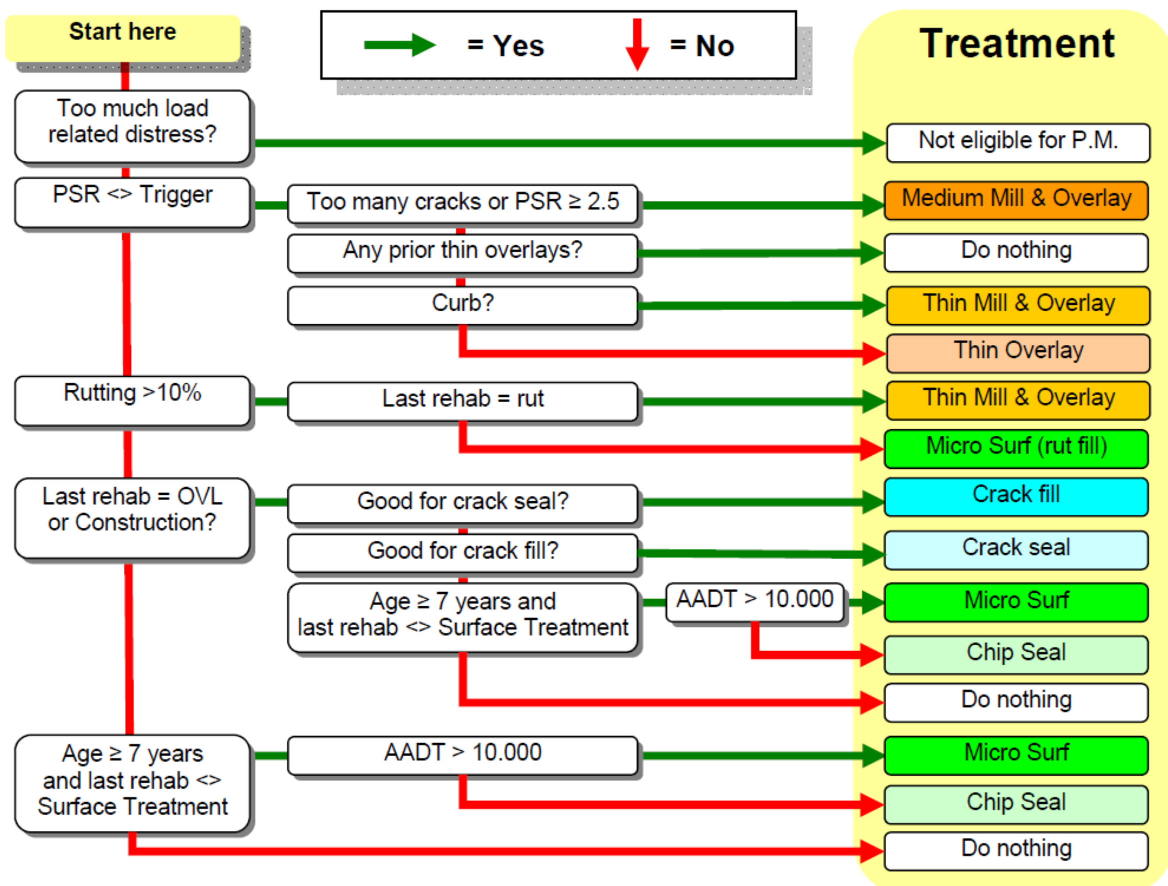
Table 1. Indiana DOT preventive maintenance treatment guidelines

Treatment	AADT[1]	Pavement distress	Rutting (in.)	IRI (in./mi)	Friction treatment?	Surface aging
Crack seal	Any	Low to moderately severe surface cracks	n/a	n/a	No	N/A
Fog seal	<5,000[2]	Low severity environmental cracks	n/a	n/a	No[3]	Reduces aging and oxidation; arrests minor raveling
Seal coat	<5,000[2]	Low severity environmental cracks	<0.25[4]	n/a[4]	Yes	Reduces aging, oxidation and minor raveling
Microsurfacing	Any	Low severity surface cracks	Any	<130	Yes	Reduces aging, oxidation and minor raveling
Ultra-bond white coating	Any	Low to moderately severe surface cracks	<0.25	<140	Yes	Reduces aging, oxidation and moderate raveling
HMA inlay	Any	Low to moderately severe surface cracks	Any	<150	Yes	Reduces aging, oxidation and raveled surface
HMA overlay	Any	Low to moderately severe surface cracks	Any	<150	Yes	Reduces aging, oxidation and moderate raveling

Source: Ong et al. 2010. Notes: 1. For mainline pavement; 2. Unless traffic can be adequately controlled; 3. Treatment may reduce skid numbers; 4. Treatment did not address this.

LITERATURE REVIEW

Decision tools are often used by practitioners for selecting pavement preservation treatments while considering best practice guidelines. Investigating existing decision-matrices in a literature review is beneficial for identifying a consensus of important factors. For example, preservation treatment selection and effectiveness may be impacted based on urban versus rural traffic patterns due to differing speeds and average daily traffic (ADT) levels (Hicks et al. 1999, Ong et al. 2010). Predicted traffic level is a key parameter in preservation selection (Peshkin et al. 2004). The literature shows that Colorado, Texas, and Australia have had success with their pavement preservation techniques on high ADT roadways (Alderson 2006) although special design considerations are needed (Gransberg and James 2005). Several publications containing pavement preservation decision trees list ADT as a key component in the selection process. An example decision tree that was developed in Minnesota is shown in Figure 1.



Wilde et al. 2014, MnDOT

Figure 1. Condensed version of a MnDOT bituminous decision tree

A study by Wilde et al. (2014) for the Minnesota DOT (MnDOT) showed that recommended condition levels for roads that were considered candidates for chip seals is rather large, a pavement condition index (PCI) between 100–66. Excellent ranges from 100–86, good ranges from 85–71, and adequate ranges from 70–51. In contrast, a team of engineers did a survey of roadways in Australia, South Africa, and France, and they discovered that all countries apply chip seals once cracking is in the 1 to 3 mm range rather than waiting for larger cracks to appear (Beatty et al. 2002).

Pavement condition influences pavement preservation effectiveness, so the research team scanned the literature to apply the current best practices and take into consideration these factors when evaluating performance. A few examples of factors that were considered are: pavement construction history, the pavement's functional classification, the time of year pavement preservation treatments were applied, traffic level, surface thickness, and surface wearing considerations.

Recently, Minnesota performed an analysis to determine the life extension a pavement preservation treatment would have to provide in order to be considered cost-effective. Results are shown in Figure 2.

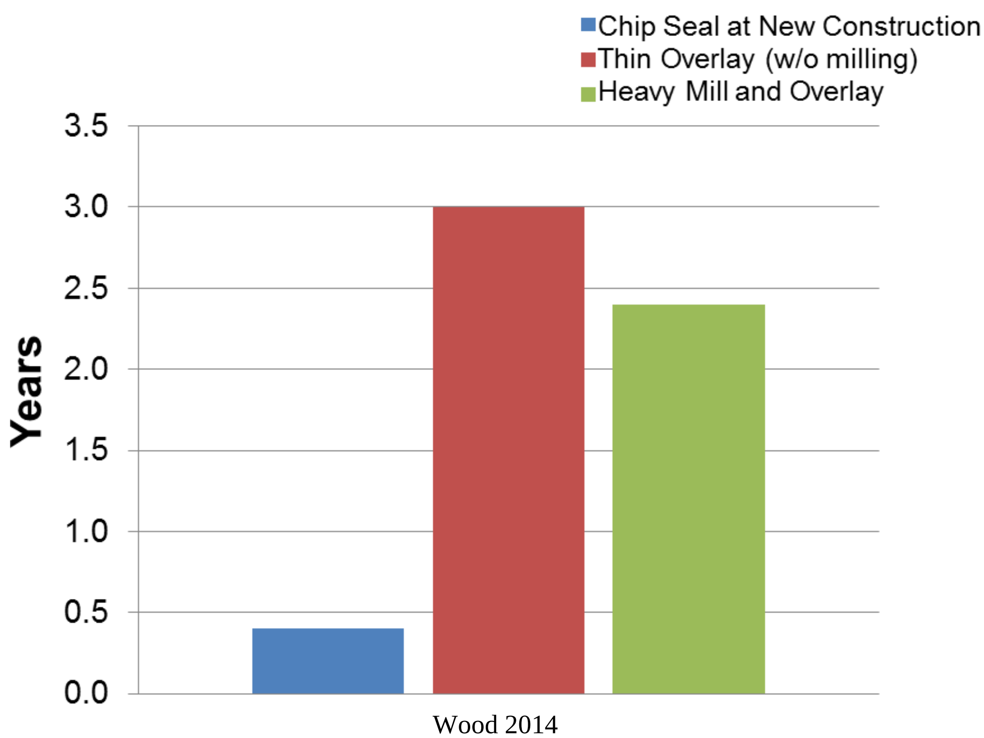


Figure 2. Estimated years of life extension for treatments to be cost-effective

This analysis highlighted the large cost disparity between rehabilitation and preservation techniques using recent cost data (Wilde et al. 2014). The cost disparity is likely to grow as pavement preservation techniques are employed more effectively based on improved understanding of the benefit they provide.

Pavement Treatment Types

There has been a growing interest in evaluating the effectiveness of preservation and maintenance techniques to justify their economic effectiveness and establish guidelines for measuring their economic value for budgeting purposes. As such, the performance of several maintenance and preservation treatments such as slurry seal, crack seal, chip seal, microsurfacing, and sand seal have been evaluated at the national and state level (Hall et al. 2002, Chen et al. 2003, Broughton and Lee 2012, Shirazi et al. 2010, Labi et al. 2007, Lu and Tolliver 2012, Ji et al. 2013). This literature presents a summary of pavement preservation research, techniques, expected treatment life, and current challenges due to data availability or inability to process the data to isolate preservation treatment effects.

Asphalt Maintenance and Pavement Preservation Treatments

Crack Treatment

Crack treating involves packing material into cracks in order to reduce moisture infiltration. Two types of cracks exist: working and non-working. Working cracks are cracks that "open and close with changes in temperature" (South Dakota DOT 2010). Non-working cracks are cracks with low or no movement. Crack sealing/filling does not add any structural benefit to the pavement but is intended to keep water out of the pavement system. Crack sealing/filling is recommended when the pavement is in sound structural condition and the extent of cracking is minimal. Crack treating may result in rougher pavement surfaces (South Dakota DOT 2010). The best practices handbook on asphalt pavement maintenance for MnDOT includes the following strategies for crack treatments:

- Crack repair with sealing: clean and seal
- Crack repair with sealing: saw and seal
- Crack repair with sealing: rout and seal
- Crack filling
- Full-depth and partial-depth crack repair (Johnson 2000)

The cleaning process takes place by blowing out the debris in the crack. In some cases, a saw or router is used to create a reservoir, which is filled with sealant material. Johnson (2000) recommended that crack widths should be less than ¾ in. wide in order to be sealed, and cracks that are wider than ¾ in. should be filled. Several material options are available to seal or fill a crack. Low-modulus rubberized asphalt and rubberized asphalt are more suitable for crack sealing. Rubberized asphalt, crumb rubber, asphalt emulsion, asphalt cement, and cutback asphalt are more suitable for crack filling (Johnson 2000).

According to the Iowa DOT, the definition of crack filling is the process of cleaning and filling surface cracks with filler material. The filler material is emulsified asphalt including polymer-modified cationic rapid-set asphalt emulsion and cationic rapid-set asphalt emulsion (Iowa DOT

2005a). Crack sealing involves routing and cleaning cracks and sealing them with a joint sealer. The joint sealer is hot poured and is composed of petropolymers (Iowa DOT 2005b).

The Michigan DOT (2010) limits the application of crack treatment strategies to pavements with a relatively new surface (i.e., two to four years) on a good base. The life extension of crack treatment is typically up to three years. However, the effectiveness and life extension of crack treatments heavily depends on the width of the crack (Michigan DOT 2010). Similarly, the Nebraska Department of Roads (NDOR) (now the Nebraska DOT) estimated the service life of crack sealing to range from three to five years (NDOR 2002).

Fog Seal

Fog seal or flush seal is the process of applying diluted asphalt emulsion directly on the pavement surface with no aggregate. The treatment does not add structural capacity to the pavement and may result in a negative impact on friction; however, it is effective at sealing the pavement surface and mitigating raveling (South Dakota DOT 2010, Maher et al. 2005, Johnson 2000). The treatment is suitable for both low- and high-volume roads (Johnson 2000). Maher et al. (2005) stated that fog seal is not ideal but could be used for high-volume roads.

Before applying fog seals, pavement surfaces should be treated to address rutting, patching, and cracking. Fog seals are not recommended when the pavement is in poor structural condition or exhibiting flushing/bleeding, friction loss, or thermal cracking (South Dakota DOT 2010). The expected service life of fog seals depends on the underlying pavement properties and exposure to sunlight (Johnson 2000). Fog seals have a fairly short life from one to two years (Johnson 2000). Similarly, Maher et al. (2005) estimated the service life of fog seal to range from one to three years.

Scrub Seals

Scrub seal is the process of spraying a polymer-modified rejuvenating emulsion on the pavement surface. A broom is then dragged across the pavement surface to scrub the emulsified asphalt into the surface cracks. After brooming, a thin layer of uniformly graded, fine aggregate is spread over the emulsified asphalt. Scrub seals are effective in filling narrow cracks, rejuvenating oxidized asphalt, and improving poor friction; however, scrub seals do not add any structural capacity to the pavement structure (South Dakota DOT 2010, Maher et al. 2005). Similar to all preservation treatments, scrub seals are not recommended when the pavement is in poor structural condition (South Dakota DOT 2010). Scrub seals are also a suitable treatment for low- to high-traffic volumes (i.e., less than 1,500 average annual daily traffic [AADT]) (Maher et al. 2005). However, scrub seals are prone to damage by snow plow operations. Additionally, this treatment should not be applied to pavement with rut depths greater than ½ in. (Maher et al. 2005).

Rejuvenators

Rejuvenators are specialized emulsions, which are typically mixtures of asphalt, polymer latex, and other additives. Mostly utilized in fog sealing, rejuvenators are sprayed directly on the pavement surface to soften the existing binder and slow the process of raveling, thermal cracking, and roughness development (South Dakota DOT 2010). Rejuvenators are also utilized in cold in-place recycling projects.

Thin HMA Overlay

Thin HMA overlay involves the application of a thin HMA layer ranging from ¾ to 1 ½ in. to improve ride quality, surface friction, and reduce hydroplaning. Thin HMA overlays are not recommended when the pavement exhibits serious structural failures. According to the National Asphalt Pavement Association (NAPA), thin HMA overlays can be designed to increase the pavement structural capacity when used with well-built pavements (NAPA n.d.). For Iowa roadways, the technology is relatively new and performance has not been extensively studied; however, material properties of the overlay are an important component to performance.

Chip Seal

Chip seal treatments, also known as seal coats, are a non-structural treatment that involves constructing a single thin surface by spraying a bituminous binding agent. Then, uniformly graded aggregate cover is immediately spread over the bituminous surface. Chip seals are used to address small cracks, bleeding, raveling, and loss of surface friction (Wood et al. 2006, Gransberg and James 2005, Maher et al. 2005).

Chip seal is an appropriate treatment for low- and high-traffic volumes (i.e., less than 2,000 and greater than 2,000 AADT, respectively). However, chip seals should not be used in areas with frequent truck turning or braking (Maher et al. 2005). Gransberg and James (2005) estimated that the service life of chip seals is at least five years.

Slurry Seal

Slurry seals are cold-mixed surface treatments that are applied as a protective or preventive maintenance technique to seal small cracks, stop raveling, improve ride quality, and enhance friction properties (Maher et al. 2005, Johnson 2000). The mixture of slurry seals consists of emulsified asphalts, dense graded crushed fine aggregate, mineral filler, or other additives and water (Johnson 2000). There are three types of slurry seals based on the largest aggregate in the mix, which also implies the surface treatment thickness as follows:

- Type I (1/8 in.)
- Type II (1/4 in.)
- Type III (3/8 in.)

Type I is suitable for very low-traffic volumes while Type II is more suitable to medium-traffic volumes. Type III is suitable for high-traffic volumes (i.e., more than 5,000 AADT). Similar to chip seals, slurry seals are prone to damage by snow plowing operations (Maher et al. 2005). The performance of slurry seal depends on traffic loading, environmental conditions, material quality, and mix design. The expected service life of slurry seals is three to five years (Johnson 2000). Similarly, Bolander (2005) estimated the service life of slurry seals to range from 5 to 10 years when the average daily traffic is less than 100, and 5 to 8 years when the average daily traffic is greater than 100.

There are some limitations associated with the application of slurry seal as a surface treatment. NDOR (2002) recommends that slurry seal should not be applied if the wheel path depression is greater than ½ in. In addition, slurry seal should not be applied when structural deficiencies exist (Illinois DOT 2010). Maher et al. (2005) stated that slurry seal should not be applied for roadway gradients steeper than 8%.

Microsurfacing

Microsurfacing is a mixture of polymer-modified emulsified asphalt, mineral aggregate, mineral filler, latex polymer, water, and additives. This treatment is effective at inhibiting raveling and oxidation. The application of microsurfacing is also expected to improve surface friction, sealing surface, and filling wheel ruts up to 1 ¼ in. deep (South Dakota DOT 2010, Maher et al. 2005). Gransberg (2010) defines microsurfacing as "a mixture of cationic polymer-modified asphalt emulsion, 100% crushed aggregate, water, and other additives properly proportioned and spread over a prepared surface." Microsurfacing has three key features that differentiates it from slurry seals. They are as follows:

- The microsurfacing mixture always contains polymers.
- Chemical reactions cause rapid curing.
- The mixture can be placed in layers thicker than one stone deep (Gransberg 2010).

The rapid curing of microsurfacing allows for traffic to be restored quickly, within one hour after application (Lee and Shields 2010). Since microsurfacing does not enhance structural capacity, it is not recommended for pavements exhibiting structural failures (South Dakota DOT 2010).

The service life of microsurfacing depends on the environmental conditions, condition of the pavement, and time of microsurfacing application (Hicks et al. 2000, Maher et al. 2001, Ohio DOT 2001). Typically, microsurfacing service life is greater than seven years for high traffic and can be longer for low-traffic volumes (Maher et al. 2005). A National Cooperative Highway Research Program (NCHRP) synthesis questionnaire of US state highway agencies revealed microsurfacing has an average life of 6 years, within a range of 1 year to 15 years (Gransberg 2010). Johnson (2000) also reported that the expected service life of microsurfacing is about seven or more years, but performance life is dependent on the condition of the pavement before treatment application. The Ohio DOT estimates the service life of microsurfacing to range from five to eight years.

Sand Seal

Sand seals are a thin asphalt surface treatment similar to the chip seal treatment. The main difference between sand seal and chip seal is that a finer aggregate is used in the application process of a sand seal (Maher et al. 2005). Distresses including cracking, raveling, bleeding, and surface wear can be addressed by applying sand seal (Maher et al. 2005). The application of sand seal should be limited to roads with low-traffic volumes (Illinois DOT 2010). Sand seal can improve poor friction and reduce moisture damage, cracking, raveling, roughness, and rutting (Illinois DOT 2010).

Cape Seal

Cape seal is a thin treatment that consists of slurry seal or microsurfacing that is applied to a recent chip seal. The main purpose of the slurry is to fill the voids in the chip seal and prevent chip loss. Cape seals can provide a durable roadway with high skid resistance (Maher et al. 2005). Distresses including longitudinal, transverse, and block cracking can be effectively addressed by applying cape seals. In addition, the treatment can address friction loss, raveling, and minor roughness (Illinois DOT 2010). Cape seals are less prone to damage from snow plowing than chip or slurry seal (Maher et al. 2005).

Summary of Asphalt Preservation Treatment Service Lives

Table 2 shows a summary of the service lives reported by DOTs and other studies. Factors influencing the service life expectancy of these treatments include underlying pavement structure, preservation treatment selection, quality of materials, weather at the time of construction, and the construction practices and workmanship.

Table 2. Service lives of asphalt preservation treatments

Treatment type	Service life (yrs)	Reference
Crack seal	2–8	Illinois DOT 2010
	3–10*	Johnson 2000
	3–5	NDOR 2002
	2–8*	South Dakota DOT 2010
Fog seal	1–4	Hicks et al. 2000
	1–3	Maher et al. 2005
	2–4	Bolander 2005
	1–2	Peshkin et al. 2004
Scrub seal	2–6	Maher et al. 2005
	2–5	NDOR 2002
	5–7	South Dakota DOT 2010
Thin HMA overlay	5–8	NDOR 2002
	8–12**	Ohio DOT 2001
	2–12	Hicks et al. 2000
	7–10	Peshkin et al. 2004
Chip seal	4–7	Raza 1992
	4–6	Illinois DOT 2010
	6–8	South Dakota DOT 2010
	3–7	Hicks et al. 200
Slurry seal	5–10	Bolander 2005
	3–8	Maher et al. 2005
	3–6	Illinois DOT 2010
Microsurfacing	4–7	Illinois DOT 2010
	3–9	Hicks et al. 2000
	5–8	Maher et al. 2005
Sand seal	2–6	Maher et al. 2005
	6–8	South Dakota DOT 2010
	1–5	Bolander 2005
Cape seal	7–15	Maher et al. 2005
	4–7	Illinois DOT 2010
	6–8	Bolander 2005

* varies based on the type of crack seal
** depends on the thickness of the overlay

Concrete Pavement Preservation Treatments

Crack/Joint Sealing

Crack sealing is the process of using hot-poured sealant materials or silicone to seal concrete pavement cracks. The treatment significantly reduces moisture infiltration and retards the rate of crack deterioration. However, ride quality can be affected negatively as a result of the sealing process (South Dakota DOT 2010). The treatment is effective when used to seal transverse or longitudinal cracks with widths less than ¾ in. The performance of this treatment depends on traffic volume and truck levels. Typically, the service life of crack seal ranges from four to eight years (South Dakota DOT 2010).

Joint and crack resealing is a widely used preservation practice performance by many agencies. The process involves resealing joints and cracks by using a sealant material to reduce the amount of moisture infiltration and moisture-related distresses (Smith et al. 2014, South Dakota DOT 2010). The choice of the sealant material depends on several factors including climate conditions, joint/cracking characteristics, traffic level, material availability, and cost (Smith et al. 2014). The service life of joint resealing is from 4 to 15 years for hot-poured asphalt sealant and 10 to 20 years for silicone sealant (South Dakota DOT 2010).

Slab Stabilization

Slab stabilization is the process of inserting cement-based mixtures or polyurethane beneath concrete slabs to restore slab support. It should be noted that it is challenging to identify the presence of voids under concrete slabs. In some cases, slab stabilization is performed where there are no voids under the slabs, which results in an accelerated pavement deterioration (Smith et al. 2014). Slab stabilization is an effective treatment to address loss of support, which is assessed through the analysis of deflection data. Slab stabilization is usually combined with other treatments including patching, diamond grinding, and dowel bar retrofit (Smith et al. 2014).

Partial-Depth Repair (PDR)

Partial-depth repair (PDR) is a process that involves removing a shallow area of deteriorated concrete slab and replacing it with repair material to improve ride quality and enhance the performance of the pavement. The selection of PDR to address the existing distresses depends on the extent of the distresses. It is recommended to apply PDR when distresses are located in the upper one-third to upper one-half of the slab. PDR is an effective treatment to correct several distresses including joint/crack spalling and other localized distressed areas that are limited to a shallow depth of the concrete slab (Smith et al. 2014, South Dakota DOT 2010). However, PDR is not considered an effective treatment to address D-cracking, spalling caused by misalignment of dowel bars, shrinkage, fatigue, or foundation movement (Smith et al. 2014). The expected service life of PDRs typically range from 5 to 15 years.

Full-Depth Repair

Full-depth repair (FDR) is a process of repairing concrete slabs that exhibit various distresses that extend through the full depth of the slab. FDR is an effective treatment to restore ride quality and structural integrity of the pavement. Several distresses can be addressed by applying FDR including transverse cracking, longitudinal cracking, deteriorated joints, blowups, and punchouts (Smith et al. 2014). The treatment involves the removal of the full depth of an existing deteriorated pavement section and then replacing it (South Dakota DOT 2010).

FDRs are not effective when the pavement is severely deteriorated and nearing the end of its fatigue life. Additionally, rigid pavements with material-related problems are suitable candidates for FDR (Smith et al. 2014). The service life of FDRs typically range from 10 to 15 years.

Retrofitted Edge Drains

Retrofitting edge drains is a process that aims at improving subsurface drainage systems, which can improve the performance of pavements (Smith et al. 2014). Retrofitted edge drains work by collecting water that infiltrated the pavement structure and removing it from the pavement. Relatively new pavements that exhibit signs of moisture damage with minimal amount of cracking are good candidates for retrofitted edge drains. While these are the primary candidates, edge drains can benefit drainage issues for any pavement. However, it should be noted that retrofitted edge drains could contribute to pavement deterioration because of loss of support through base material removal.

Dowel Bar Retrofit

Dowel bar retrofit (DBR) is the process of retrofitting/installing dowel bars at transverse joints/cracks. The purpose of the DBR is to reduce deflection and create load transfer imposed by traffic across slabs. The application of DBR improves the pavement structure by reducing pumping, faulting, and corner breaks (Smith et al. 2014, South Dakota DOT 2010). The South Dakota DOT (2010) does not recommend applying DBR when the pavement exhibits significant faulting or structural failure. The service life of DBR ranges from 15 to 20 years (South Dakota DOT 2010).

Diamond Grinding and Grooving

Diamond grinding is a process where a thin layer of the concrete pavement is removed by using a self-propelled machine equipped with diamond blades. The application of diamond grinding restores ride quality, removes joint faulting, and reduces noise levels (Smith et al. 2014, South Dakota DOT 2010). Additionally, diamond grinding is effective in addressing several distresses such as rutting caused by studded tire wear, slab curling, and slab warping. However, pavements that exhibit high levels of roughness, faulting of transverse joints, structural distresses, and D-cracking are not suitable candidates for diamond grinding (Smith et al. 2014). Additionally, it should be noted that the application of diamond grinding may slightly reduce the load-carrying capacity since it removes a part of the slab thickness (Smith et al. 2014). Additionally, diamond grinding should be applied in conjunction with other rehabilitation methods to repair other existing distresses (South Dakota DOT 2010). The service life of diamond grinding is expected to be from 8 to 15 years (South Dakota DOT 2010).

Diamond grooving is a process where diamond saw blades cut into the pavement surface to create parallel grooves. The grooves act as escape channels for surface water and, hence, reduce the potential for wet-weather crashes. Diamond grooving should only be applied to pavements with sound structural and functional conditions (Smith et al. 2014, South Dakota DOT 2010). Similar to diamond grinding, diamond grooving has an expected service life from 8 to 15 years.

Summary of Concrete Preservation Treatment Service Lives

Table 3 shows a summary of the service lives reported by DOTs and other studies. Service life is dependent on the concrete materials, drainage, structural integrity of the pavement at the time of application, and workmanship.

Table 3. Life expectancy of concrete preservation treatments

Treatment type	Service life (years)	Reference
Crack/joint seal	4–7	NDOR 2002
	4–8	South Dakota DOT 2010
	4–8	Illinois DOT 2010
Partial depth repair	10–15	NDOR 2002
	5–15	South Dakota DOT 2010
	5–15	Illinois DOT 2010
Full depth repairs	10–15	NDOR 2002
	10–15	South Dakota DOT 2010
	10–15	Illinois DOT 2010
Dowel bar retrofit	10–15	NDOR 2002
	15–20	South Dakota DOT 2010
Diamond grinding	8–15	Illinois DOT 2010
	12–15	NDOR 2002
	8–15	South Dakota DOT 2010
Diamond grooving	10–15	South Dakota DOT 2010
Joint resealing	4–7	NDOR 2002
	4–20*	South Dakota DOT 2010
	4–8	Illinois DOT 2010

* depends on the sealant material

Treatment Selection for Asphalt Pavements

Several agencies have developed decision-making frameworks to select appropriate pavement preservation treatments based on the condition of the pavement. The Illinois DOT (2010) developed a pavement preservation manual that includes guidelines and a decision matrix for the selection of pavement preservation treatments. The decision matrix considers the severity levels of several distresses as follows:

- Alligator (fatigue) cracking
- Block cracking
- Rutting

- Joint reflection/transverse cracking
- Longitudinal cracking
- Reflective widening cracking
- Centerline deterioration
- Edge cracking
- Permanent patch deterioration
- Shoving, bumps, and corrugations
- Raveling
- Reflective D-cracking
- Friction

In order to address the aforementioned distress and conditions, the decision matrix considers the following:

- Crack filling/sealing
- Fog seal
- Sand seal
- Slurry seal
- Microsurfacing
- Chip seal
- Cape seal
- Cold in-place recycling
- Hot in-place recycling
- Ultra-thin bonded wearing course
- Cold mill

Figure 3 shows the treatment selection guidelines for asphalt concrete pavements.

Pavement Conditions	Distress Levels [1]	Crack Filling	Crack Sealing	Fog Seal [2]	Sand Seal [2]	Slurry Seal	Micro-surfacing	Chip Seal	Cape Seal	CIR [2]	HIR [2]	SMART	Ultra- Thin Bonded Wearing Course	Cold Mill
Alligator/ Fatigue Cracking [3]	L1	F	F	NR	NR	F	F	F	F	F	F	F	F	NR
	L2, L3, L4	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Block Cracking	M1	R	R	F	R	R	R	R	R	R	R	F	F	F
	M2	R	R	NR	NR	F	NR	F	F	F	F	NR	NR	NR
	M3, M4	F	F	NR	NR	NR	NR	NR	NR	F	F	NR	NR	NR
"Stable" Rutting [4]	N1, N2	NR	NR	NR	NR	F	R	F	F	R	R	R*	F	F
	N3	NR	NR	NR	NR	NR	F	NR	NR	R	R	R*	NR	F
Joint Reflection and Transverse Cracking [5]	O1	NR	NR	F	R	F	R	R	R	F	F	R**	F	F
	O2, O3	R	R	NR	NR	NR	F	F	F	F	F	F	NR	NR
	O4, O5	F	F	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Overlayed Patch Reflective Cracking	P1, P2, P3, P4, P5	F*	F*	F*	F*	F*	F*	F*	F*	F*	F*	F*	F*	F*
Longitudinal / Center of Lane Cracking	Q1	R	R	F	F	F	F	F	F	F	F	F	F	F
	Q2, Q3	R	F	NR	NR	NR	F	F	F	F	F	F	F	F
	Q4, Q5	NR	NR	NR	NR	NR	NR	NR	NR	F	F	NR	NR	NR
Reflective Widening Crack	R1	R	R	F	F	F	F	F	F	F	F	F	F	F
	R2, R3	F	F	NR	NR	F	F	F	F	F	F	F	NR	NR
	R4, R5	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Centerline Deterioration	S1, S2, S3, S4	F*	F*	F*	F*	F*	F*	F*	F*	F*	F*	F*	F*	F*
Edge Cracking	T1	F	F	F	R	F	F	R	F	R	R	R**	F	F
	T2	F	F	NR	NR	NR	F	F	F	F	F	F	NR	NR
	T3, T4	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Permanent Patch Deterioration	U1, U2, U3, U4	F*	F*	F*	F*	F*	F*	F*	F*	F*	F*	F*	F*	F*
Shoving, Bumps, Sags, and Corrugation	V1	NR	NR	NR	NR	NR	F	F	F	R	R	R	F	R
	V2, V3	NR	NR	NR	NR	NR	NR	NR	NR	R	R	R	NR	R
Weathering/ Raveling	W1, W2	NR	NR	F	F	R	R	R	R	F	F	F	F	F
	W3, W4	NR	NR	NR	NR	F	F	F	F	R	R	R*	NR	NR
Reflective D-Cracking	X1, X2, X3	NR	NR	NR	NR	NR	NR	NR	NR	F	F	NR	F	F
Friction	Poor	NR	NR	NR	R	R	R	R	R	F	F	R	R	F
ADT	< 5,000	R	R	R	R	R	R	R	R	R	R	R	R	R
	5,000 – 10,000	R	R	F	F	F	R	R	R	F	R	R	R	R
	> 10,000	R	R	NR	NR	NR	F	F	F	NR	R	R	R	R
Relative Cost	($ to $$$$)	$	$	$	$$	$$	$$	$$	$$	$$$	$$$	$$$	$$$	$

Illinois DOT 2010

Figure 3. Treatment selection decision matrix for asphalt concrete pavements

The decision matrix uses the severity level for each distress type to recommend a treatment. The distress levels are identified in a separate distress identification manual by the Illinois DOT (2010). The decision matrix developed by the Illinois DOT provides engineers with three primary levels of consideration for a treatment: recommended, feasible, and not recommended.

The decision matrix also considers the traffic volumes in terms of average daily traffic since some treatments are not recommended for high-traffic volumes e.g., greater than 10,000 vehicles per day. For example, the Illinois DOT (2010) does not recommend applying fog seal, sand seal, microsurfacing, or hot in-place recycling to pavements with high-traffic volumes. The decision matrix also recommends treatments based on the severity and extent levels of different distresses. For example, microsurfacing, cold in-place recycling, and hot in-place recycling are recommended for low-severity rutting. Additionally, the decision matrix indicates whether a specific treatment would be feasible. For example, crack filling/sealing and slurry seals are feasible treatments to address low-severity alligator cracking.

Treatment Selection for Concrete Pavements

Several agencies developed decision-making frameworks to select the appropriate pavement preservation treatment when the condition of the pavement is known. The Illinois DOT (2010) developed a pavement preservation manual that includes guidelines and a decision matrix for the selection of pavement preservation treatments. The decision matrix considers the severity levels of several distresses as follows:

- D-cracking
- Transverse cracking
- Joint deterioration
- Centerline deterioration
- Longitudinal cracking
- Edge punchouts
- Faulting
- Corner breaks
- Map cracking and scaling
- Popouts/high steel
- Patch deterioration
- Ride quality
- Skid resistance

In order to address the aforementioned distresses and conditions, the decision matrix considers several treatments as follows:

- Crack sealing
- Joint resealing
- Diamond grinding
- Diamond grooving
- Ultra-thin bonded wearing course
- Full-depth repairs
- Partial-depth repairs
- Load transfer restoration techniques (e.g., dowel bar retrofitting).

Figure 4 shows the treatment selection guidelines for concrete pavements.

Pavement Conditions	Distress Levels[1]	Crack Sealing	Joint Resealing	Diamond Grinding	Diamond Grooving	Ultra- Thin Bonded Wearing Course	Full-Depth Repairs	Partial-Depth Repairs	LTR[2, 3]
D-cracking	A1, A2	NR	F	NR	NR	F	NR	NR	NR
	A3	NR	NR	NR	NR	NR	F	R	NR
	A4, A5	NR	NR	NR	NR	NR	R	NR	NR
Transverse Cracking	B1	NR	NR	NR	NR	R	NR	NR	NR
	B2, B3	R	NR	NR	NR	F	F	NR	F
	B4, B5	F	NR	NR	NR	NR	F	NR	F
Joint Deterioration	C1, C2	NR	R	R	NR	F	NR	F	F
	C3, C4	NR	F	R*	NR	F	F	R	F
Centerline Deterioration	D1	NR	R	NR	NR	R	NR	NR	NR
	D2	NR	F	NR	NR	F	NR	R	NR
	D3	NR	NR	NR	NR	NR	F	R	NR
Longitudinal Cracking	E1, E2	R	NR	NR	NR	F	F	NR	NR
	E3, E4	F	NR	NR	NR	F	R	NR	NR
Edge Punchouts (CRCP)	F1, F2, F3	NR	NR	NR	NR	F	R	NR	NR
Faulting	G1, G4	NR	R	F	NR	F	NR	NR	NR
	G2, G5	NR	F	R	NR	F	NR	NR	R
	G3, G6	NR	NR	R*	NR	NR	NR	NR	R
Corner Breaks (JPCP)	H1, H2	R	NR	NR	NR	F	F	NR	NR
	H3	NR	NR	NR	NR	NR	R	NR	NR
Map Cracking and Scaling	I1	NR	NR	F	NR	R	NR	NR	NR
	I2	NR	NR	F	NR	R	NR	F	NR
	I3	NR	NR	F	NR	F	NR	F	NR
Popouts/High Steel	J1, J2, J3	NR	NR	NR	NR	F**	NR	F**	NR
Permanent Patch Deterioration	K1, K2, K3	F**	F**	F**	F**	F**	F**	F**	F**
Ride	IRI > 140 in/mi	NR	NR	R	NR	F	NR	NR	F*
Skid	Poor	NR	NR	R	R	R	NR	NR	NR
Relative Cost	($ to $$$$)	$	$	$$	$$	$$$	$$$$	$$$	$$$

Illinois DOT 2010

Figure 4. Treatment selection decision matrix for concrete pavements

The decision matrix uses the severity level for each distress type to recommend a treatment. The distress levels are identified in a separate distress identification manual by the Illinois DOT (2010).

For example, joint resealing and ultra-thin bonded wearing course are feasible treatments to address low-severity D-cracking while other treatments such as diamond grinding, diamond grooving, and partial-/full-depth repairs are not recommended. Additionally, the recommendations provided by the decision matrix can be combined with other necessary actions to ensure the effectiveness of the treatment recommended. For example, diamond grinding is recommended to address high-severity joint deterioration. However, diamond grinding should be used in conjunction with a load transfer restoration treatment, sub-sealing, or undersealing (Illinois DOT 2010). In certain situations, the reduction of thickness in conjunction with structural or material deficiencies can result in further pavement deterioration (Caltrans 2007).

Wilde et al. (2014) developed a decision tree for MnDOT to assist pavement managers in selecting the most appropriate treatment strategy based on the existing condition. The decision tree considers several factors such as pavement age, existing distresses, ride quality index, and structural number. The decision tree provides users with three different alternatives as follows:

- Preventive maintenance
- Rehabilitation
- Reconstruction

Similarly, the South Dakota DOT (2010) developed a set of pavement preservation guidelines. The guidelines consider several preservation treatments as follows:

- Crack sealing
- Joint resealing
- Diamond grinding
- Diamond grooving
- Full-depth repairs
- Partial-depth repairs
- Dowel bar retrofit
- Cross stitching
- Pavement sub-sealing/under sealing
- Pavement jacking/mud jacking.

A decision matrix is provided for several distresses as follows:

- D-cracking
- Joint spalling
- Corner cracking
- Longitudinal cracking
- Punchouts
- Joint seal damage
- Faulting
- Roughness

The South Dakota DOT developed a decision matrix for each type of distress. The decision matrix considered the level of severity and extent of the distress to recommend appropriate treatments. For example, joint resealing is the recommended treatment for a pavement that exhibits low-severity or extensive faulting while diamond grinding, dowel bar retrofit, sub sealing/undersealing, and pavement jacking are feasible treatments (South Dakota DOT 2010). Figure 5 shows an example of the decision matrices developed by the South Dakota DOT (2010).

Pavement Distress	Severity Level [1]	Extents [2]	Crack Sealing	Joint Resealing	Diamond Grinding	Diamond Grooving	Full-Depth Repair	Partial-Depth Repairs	Dowel Bar Retrofit	Cross Stitching	Subsealing/ Undersealing	Pavement Jacking/ Mud Jacking
Longitudinal Cracking	None	Low	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
		Moderate	R	NR	NR	NR	F	NR	NR	R	NR	NR
		High	F	NR	NR	NR	R	NR	NR	F	NR	NR
		Extreme	NR	NR	NR	NR	R	NR	NR	NR	NR	NR

R Recommended treatment
F Feasible Treatment
NR Treatment is not recommended

1
None

2
EXTENTS:

LOW:
1 to 9 % of the slabs

MODERATE:
10 to 24 % of the slabs

HIGH:
25 to 49 % of the slabs

EXTREME:
Greater than 49 % of the slabs

South Dakota DOT 2010

Figure 5. Treatment selection decision matrix

The Michigan DOT developed a capital preventive maintenance manual (Michigan DOT 2010). The manual includes the treatments as follows:

- Full-depth repair
- Joint resealing
- Crack sealing
- Diamond grinding
- Dowel bar retrofit
- Pavement restoration (a combination of full-depth repairs and diamond grinding)

Michigan's selection of treatments is conducted based on visible distresses and threshold values for three major performance indicators including distress index, ride quality index, and international roughness index (IRI). For example, diamond grinding is recommended when the pavement exhibits joint and crack faults less than ¼ in., rut depth less than ¼ in., scaling less than 25%, distress index less than 10, ride quality index less than 54, and IRI less than 107 in./mi.

The Utah DOT developed a pavement preservation manual that provides recommendations for concrete joint sealing and joint spall repair, diamond grinding, slab jacking, or undersealing. The Utah DOT considers dowel bar retrofit, partial-/full-depth repair, slab replacement, and thin bonded/unbonded concrete overlay as rehabilitation treatments. The Utah DOT pavement preservation manual provides recommendations for adequate treatment selection based on the type of pavement condition information. For example, pavement slabs that exhibit movement at the joints or cracks, pumping, or faulting are good candidates for slab jacking or undersealing (Utah DOT 2009).

The Indiana DOT (INDOT) developed a pavement preservation program for their pavement assets (Ong et al. 2010). The preservation program considers different elements including treatment triggers or threshold values, treatment performance models, and pavement remaining service life. The preservation program includes a decision matrix that indicates whether a treatment would be recommended, may be recommended, not recommended, or not applicable given the existing pavement conditions. For example, diamond grinding is not recommended to address poor ride quality while the same treatment is recommended to address fair ride-quality conditions (Ong et al. 2010).

Treatment Performance Evaluation

Many studies evaluated the performance of preservation treatments. It was found that sources of data, treatment types, performance indicators, and statistical methods are the key differences between past studies. Some studies used data from the long-term pavement performance (LTPP) database while other studies used data collected by state highway agencies (SHAs). The type of treatments evaluated are subjected to the amount of data collected and interest in specific treatments by agencies and researchers. The performance indicators used in evaluation are generally IRI, pavement condition rating (PCR), present serviceability index (PSI), structural number (SN), fatigue cracking, and rutting depth. It was also found that the use of specific performance indicators is governed by the data collected by SHAs. In this section, past studies that aimed at evaluating the performance of different pavement performance are analyzed. Table 4 summarizes past related studies, sources of data, treatments analyzed, performance indicators used, and number of segments or test sections studied.

Table 4. Past related studies summary

Study	Data source-location	Treatments	Performance indicators	Number of sections analyzed
Hall et al. 2002	LTPP-United States and Canada (SPS-3)	Thin overlay, slurry seal, crack seal, and chip seal	IRI, rutting, and fatigue cracking	81 sites
Chen et al. 2003	LTPP-Texas	Thin overlay, slurry seal, crack seal, and chip seal	Distress score developed by the Texas DOT	14 test sections
Broughton and Lee 2012	Texas DOT	Microsurfacing	Various distresses-visual inspection	4 segments
Shirazi et al. 2010	LTPP-nationwide	Thin overlay, slurry seal, crack seal, and chip seal	A weighted average index representing Fatigue cracking, rutting, and IRI	81 segments
Labi et al. 2007	Indiana DOT	Microsurfacing	IRI, PCR, and rutting	18 segments
Labi and Sinha 2004	Indiana DOT	Seal coat	PSI	35 segments
Lu and Tolliver 2012	LTPP-nationwide	crack sealing, aggregate seal, seal coat, and chip seal	IRI	97 for aggregate seal, 317 for crack sealing and 13 for chip seal
Ji et al. 2013	Indiana DOT	Microsurfacing	PCR, IRI, and SN	4 sections
Liu et al. 2010	Kansas DOT	Seal coat, slurry seal, cold in-place-recycling, and overlays	Time between consecutive treatments	Varies
Wang et al. 2012	LTPP-several states	Thin overlay, chip seal, crack seal, and slurry seal	IRI	81 segments
Al-Mansour and Sinha 1994	Indiana DOT	Chip seal and sand seal	PSI	34 for chip seal and 20 sand seal
Wu et al. 2010	Texas, Kansas, Michigan, California, Washington, and Minnesota	HMA overlays, chip seals, microsurfacing, crack sealing, slurry seals, and fog seals	PCR	13 for HMA overlay, 15 for chip seal, 9 for microsurfacing, 11 for crack sealing, 3 for slurry seal, 6 for fog seal
		Diamond grinding, dowel bar retrofit, joint sealing, and partial depth repair	PCR	8 for diamond grinding, 14 for dowel bar retrofit, 3 for joint sealing, 4 for partial depth repair
Wang and Wang 2013	LTPP	Thin overlay, chip seal, crack seal, and slurry seal	Friction number	53 sites
Chen et al. 2010	Iowa DOT	Cold in-place recycling	PCI and falling weight deflectometer (FWD) measurements	24 sections
Jahren et al. 1998	Iowa DOT	Cold in-place recycling	PCI and PSI	18 sections

Sources of Data

There are two main sources of data used in evaluating the performance of pavement treatments listed as follows:

- LTPP program database
- Pavement condition data collected by SHAs

The LTPP program, initiated in 1987, represents an important source that contains pavement performance information (FHWA 2016b). The program's LTPP InfoPave web portal contains inventory, material testing, pavement performance monitoring, climate, traffic, maintenance, and rehabilitation data for more than 2,500 test sections located in the US and Canada (FHWA 2016b).

Many studies used the LTPP data to analyze the performance of different pavement treatments. For example, Hall et al. (2002), Shirazi et al. (2010), Lu and Tolliver (2012), Wang and Wang (2013) and Wang et al. (2012) used the LTPP data at a nationwide scale to analyze the performance and effectiveness of several pavement treatments. Chen et al. (2003) and Wang et al. (2012) used the LTPP data to analyze the performance of treatments at a statewide scale.

The use of the LTPP data in performance evaluation at the nationwide level is beneficial because of the large number of sections stored in the LTPP database. However, for some states, using the LTPP data at the state level might not be as reliable as using the LTPP data at the nationwide level because of the small amount of data collected at the state level. For example, Iowa has data for only 66 test sections, which is a small number especially if the data are classified by pavement and treatment types. Thus, there is a need to utilize the data collected by SHAs at the state level to evaluate the performance of pavement treatments.

A few studies have used data collected by SHAs to evaluate a specific treatment that was newly adopted by SHAs. For example, Labi et al. (2007) and Ji et al. (2013) evaluated the performance of microsurfacing in Indiana by using condition data collected from closely monitored sections. Condition data for these sections were collected annually using visual surveys and nondestructive tests. Additionally, Al-Mansour and Sinha (1994) used data collected by the Indiana DOT.

Liu et al. (2010) used data from the Kansas DOT's PMIS to evaluate the performance of thin surface treatments in Kansas. It is worth mentioning that the database used in Labi et al. (2007) contained data about pavement referencing, pavement condition, traffic volume, freeze index, and preservation contracts data, and the PMIS of the Kansas DOT contains traffic, pavement condition, and pavement referencing data. Unlike the aforementioned studies, Chen et al. (2010) and Jahren et al. (1998) used case studies to evaluate the performance of specific treatments in Iowa.

Performance Indicators

There are several performance indicators used to evaluate the performance of maintenance and rehabilitation treatments; these include IRI, PCR, rut depth, and fatigue cracking (Hall et al. 2002, Labi et al. 2007, Wang et al. 2012, Lu and Tolliver 2012). Additionally, other studies used performance indicators that were developed by SHAs such as the distress score developed by the Texas DOT (Chen et al. 2003) while other studies presented a weighted average index that combines several distresses (Shirazi et al. 2010).

Chen et al. (2003) used the distress score concept developed by the Texas DOT to evaluate treatment effectiveness in Texas. The distress score quantifies the visible surface deterioration of pavements and is computed as a function of utility values for rutting, patching, block cracking, alligator cracking, longitudinal cracking, and transverse cracking.

Hall et al. (2002) used road roughness level or ride quality, measured in IRI, to evaluate performance since it is found to be an influential factor that affects overlay treatments. Moreover, Irfan et al. (2009) used IRI for treatment performance evaluation because it’s useful for pavement preservation decisions and is collected on a regular basis. Other studies selected IRI as a performance indicator because the treatments under evaluation are expected to address minor distresses and improve ride quality (Labi et al. 2007, Lu and Tolliver 2012).

Al-Mansour and Sinha (1994) and Labi and Sinha (2004) used the present serviceability index (PSI) to evaluate the performance of seal coats and chip seals in Indiana. Labi and Sinha (2004) acknowledged that PSI may not be the most ideal performance indicator since the PSI is directly associated with ride quality. However, the study used PSI instead of PCR because of the lack of the PCR data. This demonstrates that data collection and the sufficiency of the data collected directly affects the performance evaluation process and the performance indicators used to evaluate the treatments.

Similarly, rut depth was used as a performance indicator to measure the effectiveness of specific treatments on reducing rutting for the short and long term (Labi et al. 2007). Additionally, fatigue cracking was also used to measure treatment effectiveness in terms of the percent of the section area cracked before and after treatment application (Hall et al. 2002).

In addition to using individual performance indicators to measure performance, Labi et al. (2007) used the PCR to represent the overall user perception of road quality. While many studies used common performance indicators to evaluate the performance of treatments, Liu et al. (2010) used the time between two consecutive treatments or time between treatment application and reconstruction to estimate the service life of thin surface treatments. The methodology adopted by Liu (2010) reflects the SHA policy and experience on the estimation of treatment performance. However, it should be noted that this methodology does not consider the delay in consecutive treatment applications due to funding gaps.

Wang and Wang (2013) used the effective friction number to evaluate the effectiveness of preservation treatments. The effective friction number is calculated as the weighted average of the friction number normalized over the total monitoring period.

Kim et al. (2010) used individual distress types to evaluate the performance of cold in-place recycling in Iowa. The study found that the measurement of individual distresses can decrease over time because cracks might have been changed from one type to another and/or there were errors in the measurements.

Finally, a study by Broughton and Lee (2012) used visual inspection of distresses to evaluate the effectiveness of a treatment. Visual inspection is a subjective method that cannot be relied on to evaluate the effectiveness of a treatment. However, visual inspection is the only available method that can be used to evaluate pavement performance when no data are available.

Statistical Methods

Past researchers used statistical significance testing to evaluate the performance of several treatments. Labi and Sinha (2004), Labi et al. (2007), and Lu and Tolliver (2012) used the one-tailed hypothesis test to test the statistical significance of the estimated performance jump at 95% level of confidence while Ji et al. (2013) used the analysis of variance (ANOVA) test to compare the SN and IRI statistical difference before and after treatment application. It is worth mentioning that the aforementioned tests assume a normal distribution of the means of the population, which is not necessarily true in some cases. However, this assumption is considered not to be violated when the sample size is large (e.g., greater than 30).

Wang et al. (2012) also used the paired t-test to evaluate the effectiveness of pavement treatments by analyzing the IRI measurements between control sections and sections that received a specific treatment.

Shirazi et al. (2010) recognized the assumptions associated with parametric tests such as ANOVA and paired t-test and, hence, used the Friedman test, a non-parametric test, to evaluate the treatments' performance.

Wang and Wang (2013) compared the surface friction before and after treatment application by using Fisher's least significant difference (LSD) test. Fisher's LSD test procedure consists of two steps. The first step involves conducting a global test for the "null hypothesis that the expected means of all treatment groups are equal" while the second step is conditional based on the rejection of the null hypothesis. If the null hypothesis is rejected, all pair-wise comparisons are conducted. It is worth noting that the Fisher's LSD test should only be applied to normally distributed data. Hence, Wang and Wang (2013) used the Anderson-Darling test to test the normality of the data.

Al-Mansour and Sinha (1994) classified the pavement sections based on the traffic levels. A threshold value of 2,000 AADT is used to differentiate between low- and high-traffic levels. For each traffic level group, a regression model is developed that predicts the PSI at any given age.

Performance Evaluation

Past studies used different sources of data and methods to estimate service lives of maintenance and preservation to determine positive and negative influential factors. In this section, a summary of findings from past related studies is presented.

Hall et al. (2002) concluded that multiple factors have an effect on flexible pavement HMA overlay performance as follows:

- Pre-treatment IRI has a significant effect on post-treatment IRI.
- Age/average annual temperature has slightly significant effects on IRI.
- Equivalent single axle loads (ESALs) have no significant effect on IRI.
- Age has the most significant effect on rutting.
- Average annual precipitation has a slightly significant effect on rutting.
- Pretreatment cracking has very significant effect on alligator cracking.
- Age and ESALs have slightly significant effects on alligator cracking.

Similarly, Hall et al. (2002) concluded that accumulated ESALs and pre-treatment IRI had significant effects on post-treatment IRI for rigid pavement HMA overlay.

Chen et al. (2003) used the LTPP data in Texas to evaluate the performance of thin overlay, chip seal, crack seal, and slurry seal. It was found that chip seal is the best performer for low- and high-traffic areas, and thin overlay is the most effective treatment to address rutting (Chen et al. 2003).

Labi and Sinha (2004) evaluated the effectiveness of seal coats using the PSI as a performance indicator. The study concluded that seal coats can enhance the pavement performance by an average of 0.23 PSI units. Additionally, seal coats can retard the level of pavement deterioration by an average of 3.38 PSI units per year.

Additionally, Labi et al. (2007) and Ji et al. (2013) evaluated the effectiveness of microsurfacing. Labi et al. (2007) concluded that microsurfacing can improve the pavement performance as follows:

- Reduce the IRI by 0.442 m/km on average
- Reduce rutting by 4 mm on average
- Improve the PCR by 6.2 units

Labi et al. (2007) also determined multiple factors as influential on microsurfacing performance as follows:

- Pretreatment condition
- Freeze index
- Traffic
- Pavement class

Ji et al. (2013) conducted a structural evaluation of pavements by using the SN to accurately evaluate the performance and life extension of microsurfacing. The study concluded the following:

- Microsurfacing is not effective in terms of increasing pavement SN.
- Microsurfacing can offer a life extension from one to one and a half years in terms of SN, two to three years in terms of IRI, and eight years in terms of rutting.
- Resurfacing can offer a life extension from 8 to 10 years in terms of IRI and 10 to 15 years in terms of rutting.

The study also estimated the service life of microsurfacing based on different performance indicators. Microsurfacing had a service life of 2–10 years for IRI, over 10 years for rutting, and 4–15 years for PCR. Service lives are estimated based on the time elapsed for the pavement to revert to the pretreatment condition or a specific condition trigger (Labi et al. 2007). It is worth noting that the service lives estimated by Labi et al. (2007) were calculated using performance models, developed by the Indiana DOT, not actual historical data.

Shirazi et al. (2010) evaluated the performance of thin overlay, slurry seal, chip seal, and crack seal in terms of mitigating the rate of distress propagation. Based on the analysis of 81 segments obtained from the LTPP database, conclusions are as follows:

- Thin overlay and chip seal are effective to mitigate fatigue cracking propagation.
- Thin overlay is the best performer in terms of mitigating rutting and roughness problems.
- Climate condition, traffic, subgrade materials, and pretreatment condition had slightly to no effect on treatments with respect to rutting mitigation.

Based on the LTPP database, Lu and Tolliver (2012) concluded that IRI short-term effectiveness follows a polynomial relationship with the pretreatment condition. The study also concluded the short-term IRI performance jump for several treatments as follows:

- 0 to 2.6 m/km for hot mill overlay
- 0 to 0.44 m/km for crack sealing
- 0 to 1.44 m/km for aggregate seals
- 0 to 1.2 m/km for chip seal

Wang et al. (2012) also used the LTPP database to evaluate the performance of several treatments against control sections. It was concluded that pavement treatment can extend the pavement service life as follows:

- 5.4 years for thin overlay
- 1.9 years for chip seal
- 1.7 years for crack seal
- 1.1 years for slurry seal

Al-Mansour and Sinha (1994) found that the optimal time to perform a seal coat is when the pavement reaches a PSI value of 3.25 by conducting a life-cycle cost analysis (LCCA).

Wang and Wang (2013) used simple descriptive statistics to rank the friction performance of preservation treatments. The study determined that the effectiveness of preservation treatments is ranked as slurry seal, chip seal, thin overlay, and crack seal from the most effective to the least.

Additionally, Wang and Wang (2013) found the following:

- Subgrade type and existing pavement condition have low influence on surface friction.
- Climate and traffic volume have high influence on surface friction.
- There is a correlation between pavement roughness and surface friction for the LTPP control sections and sections with crack seal.

In Iowa, Jahren et al. (1998) evaluated the performance of cold in-place recycling using the PCI and PSI. The researchers reported the predicted service life of cold in-place recycling using regression analysis as 14 to 29 years in terms of PSI and as 14 to 38 in terms of PCI. The study used these average indexes to estimate the service life of cold in-place recycling. Based on a failure threshold value of 25, the predicted service life of cold in-place recycling was from 15 to 26 years.

QUESTIONNAIRE RESULTS

A voluntary survey was sent to county engineers regarding pavement preservation programs and funding throughout the county system. The purpose of the survey was to fill in information gaps in areas where the researchers have little to no compiled information. This section presents a summary of survey findings. The complete list of survey questions are presented in Appendix A.

Annual spending on pavement preservation activities are shown in Figure 6.

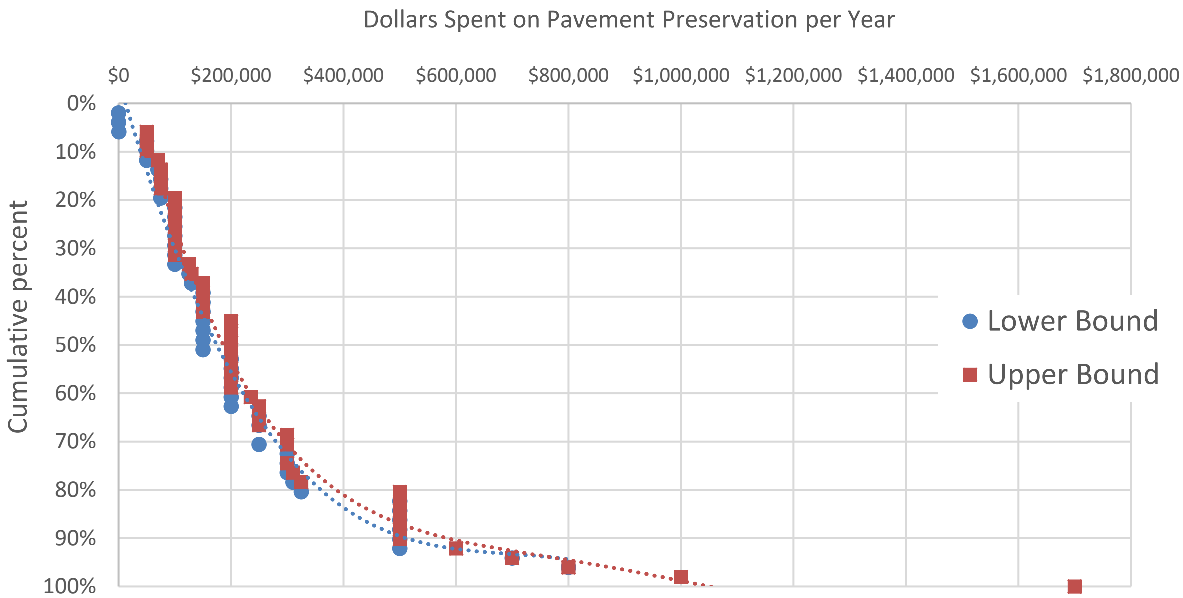


Figure 6. Dollars spent on pavement preservation per year

The funding may vary depending on the year, and funding ranges were often provided. In Figure 6, the lower bound is indicated by the blue circles and the upper bound is indicated by the orange square markers. Both are graphed as a cumulative percentage of the survey findings.

One limitation is the lack of a universally accepted definition of which activities constitute pavement preservation activities, and there is also no distinct line between maintenance activities and preservation activities. The lack of universal definition may lead to differences in reported preservation spending.

Figure 7 presents the respondents’ average spending on pavement preservation. These graphs indicate that 50% of respondents spend around $200,000 or less on pavement preservation per year.

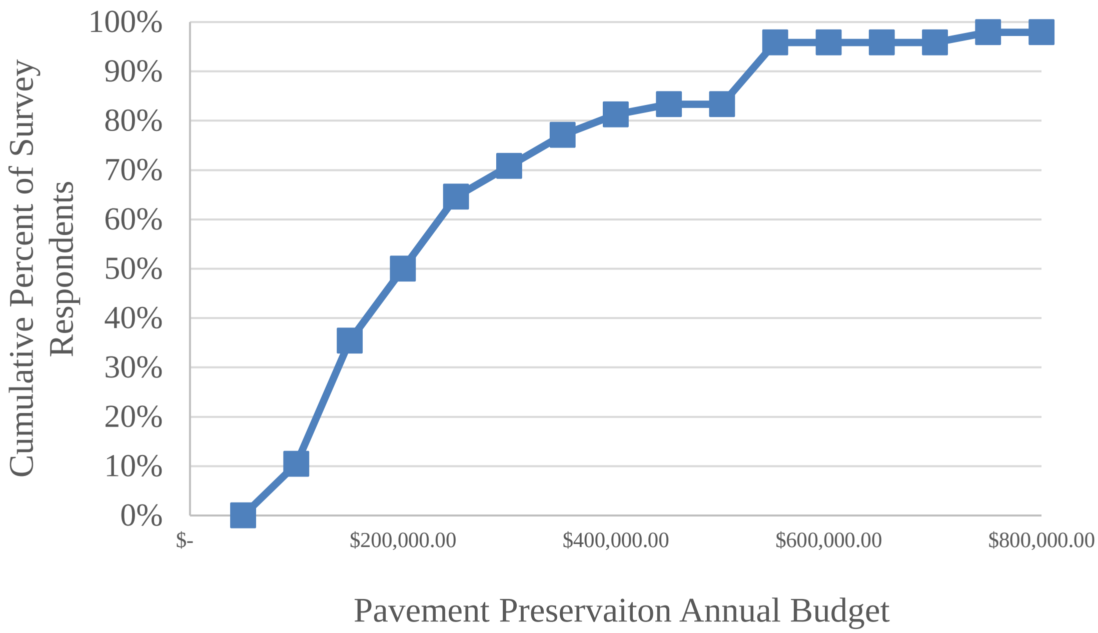


Figure 7. Cumulative budget for pavement preservation

Figure 8 presents the typical types of pavement preservation programs in counties in Iowa. Most have informal programs, and a majority do not have dedicated pavement preservation funding. Five percent of respondents have a formal program with dedicated funding.

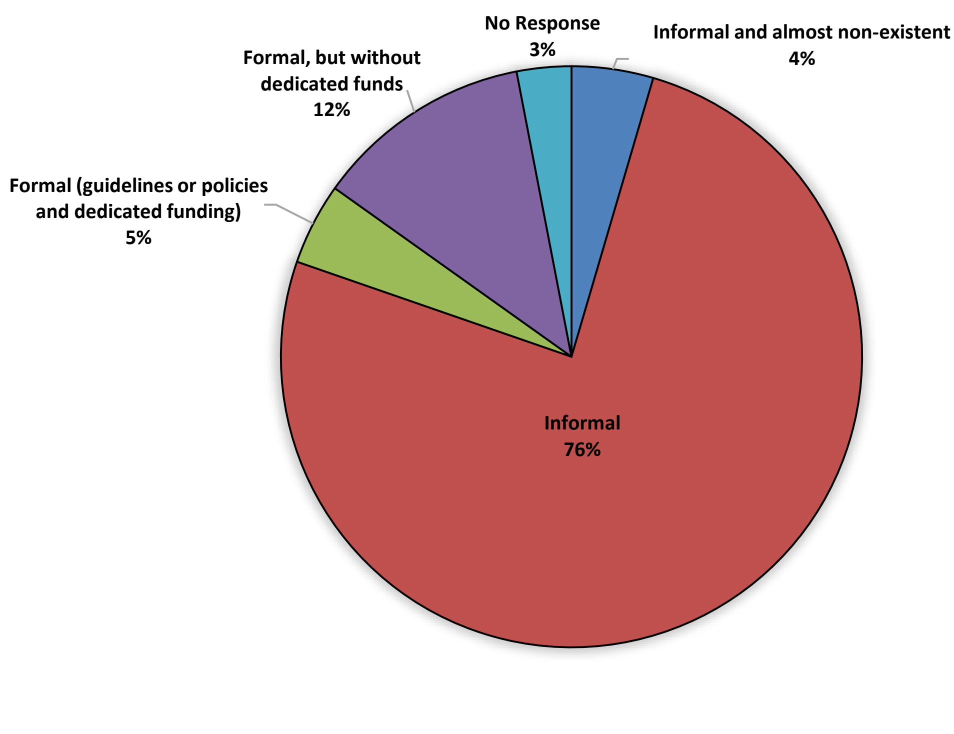


Figure 8. Types of pavement preservation programs in Iowa counties

Figure 9 presents the maturity of the pavement preservation program.

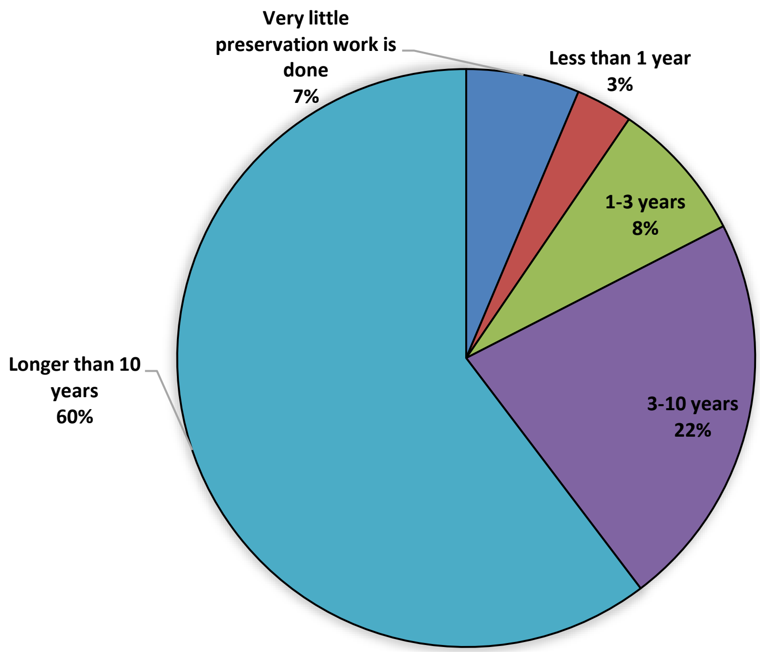


Figure 9. Maturity of pavement preservation program

Most pavement preservation systems in the state have been active for 10 years or more while most others were between 3–10 years. Responses on the current state of pavement preservation programs in agencies across Iowa show that most agencies have an informal program without dedicated funds; those without a formal program indicated interest in implementing a pavement preservation program.

Figures 10 and 11 present the percent of respondents using various pavement preservation treatments on flexible pavements.

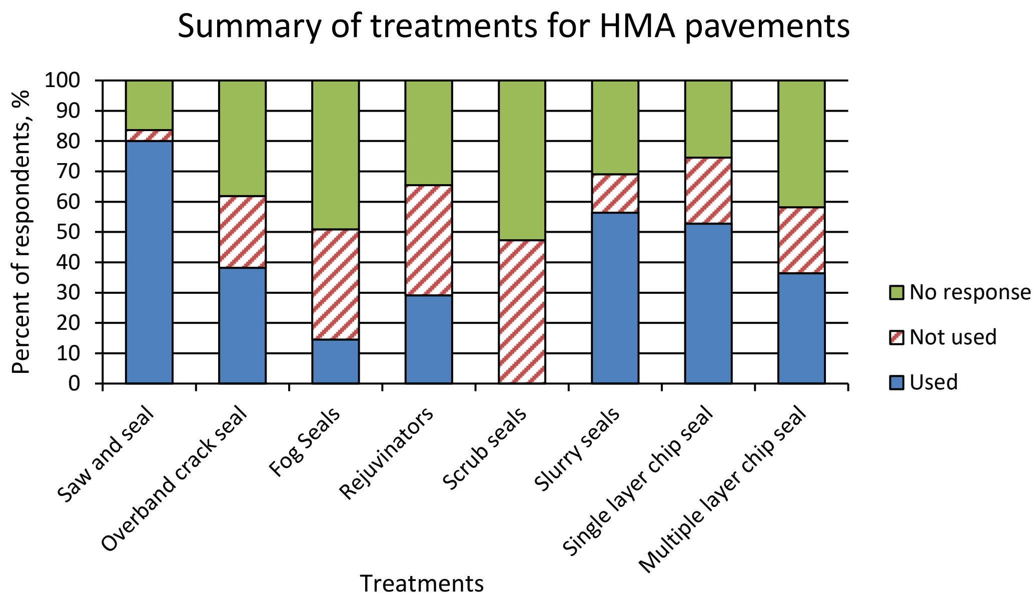


Figure 10. Summary of eight treatment types used on HMA pavements

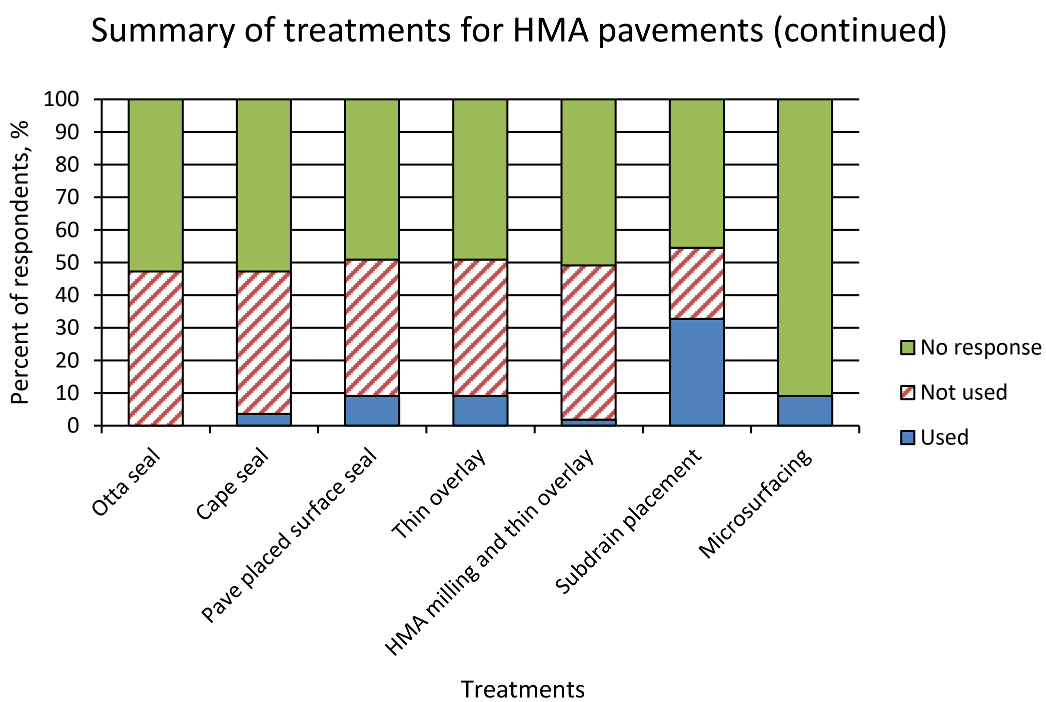


Figure 11. Summary of seven treatment types used on HMA pavements

Sealing cracks was performed by the majority of respondents. The most commonly used seal treatment was slurry seals followed by single-layer and then double-layer chip seals. Most agencies reported high success rates with crack sealing and slurry seals. Two agencies also noted the use of sand sealing on rehabilitation projects, and one agency indicated that they used emulsions to fill up cracks in HMA pavements.

Figures 12 and 13 present the percent of respondents using various pavement preservation treatments on rigid pavements.

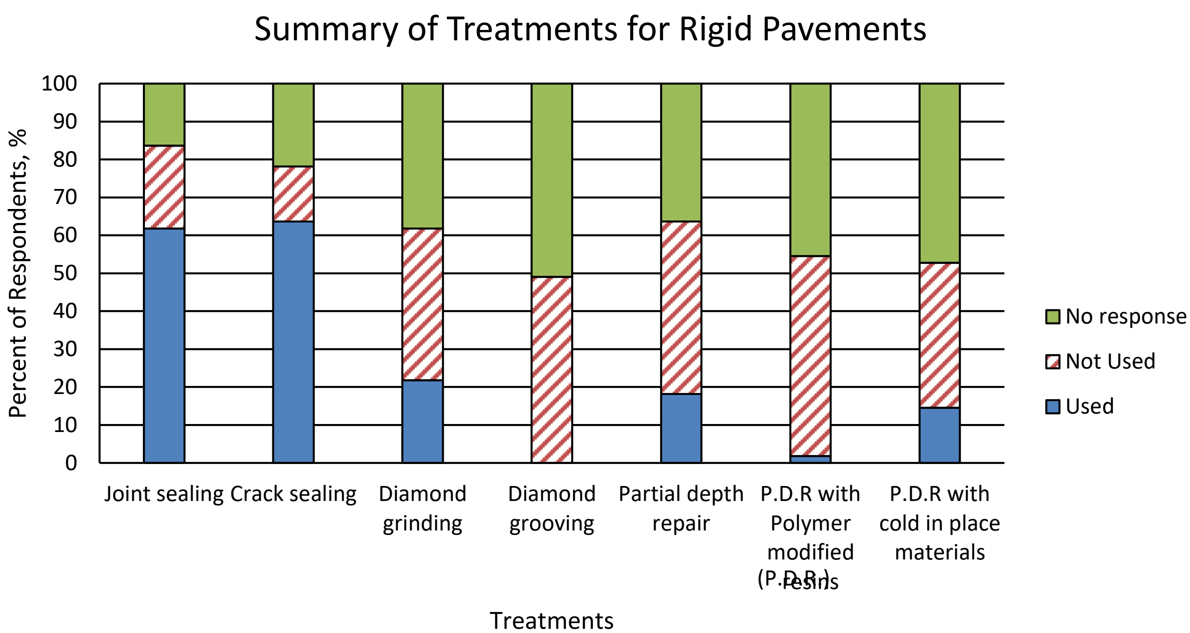


Figure 12. Summary of seven treatment types for PCC pavements

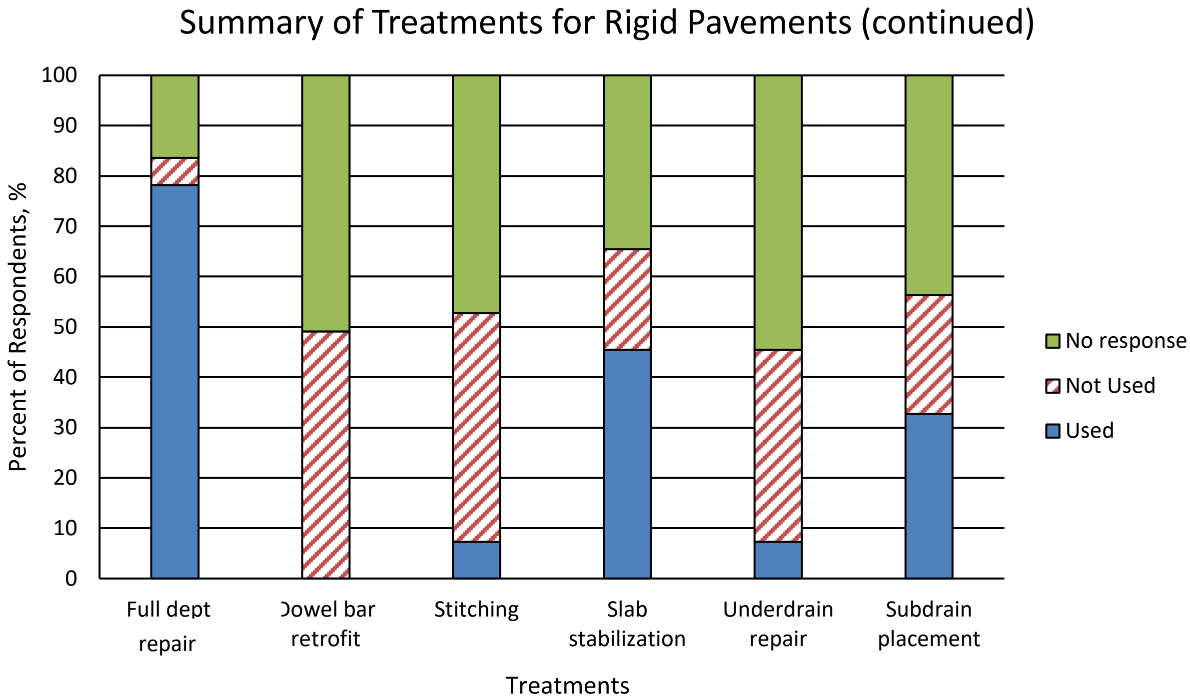


Figure 13. Summary of six treatment types for PCC pavements

The most common PCC treatments were crack and joint sealing as well as full-depth repair. Slab stabilization, diamond grinding, and partial depth repair were also used by respondents.

Developing performance curves for pavement preservation requires the collection of pavement performance data. The survey asked whether pavement performance data is collected and if the agency tracks the performance of preventive maintenance treatments. Figure 14 shows that many agencies do not collect pavement performance data.

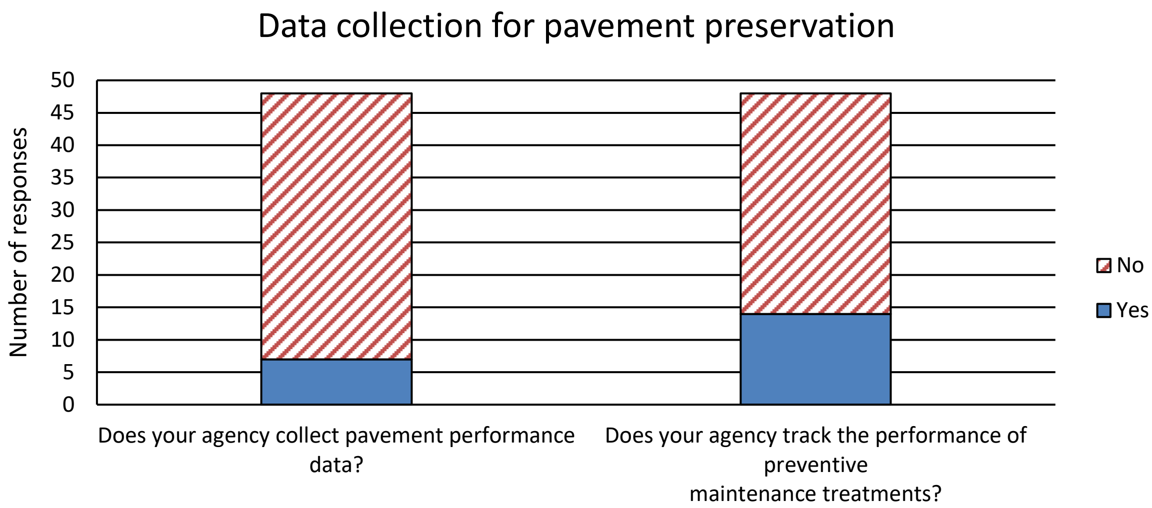


Figure 14. Performance data collection for secondary roads

For this reason, the data-based performance developed in this study used data from the Iowa DOT's pavement management system (PMS). Currently, the Iowa DOT's PMIS is collecting information on the secondary roads network. At the time when the data analysis was performed, there were not enough years of data to develop trends and make meaningful observations.

DATA COLLECTION AND PROCESSING

Source of the Data and Type of Projects

The primary source of data used in this pavement performance analysis was derived from the Iowa DOT's PMS, known within the agency as the PMIS database. This database includes information on all of Iowa's primary roadways as follows:

- Section control information
  - Original smart key identifier
  - Database year
  - Pavement type
  - Description
- Condition data
  - Pavement condition index (Version 2.3) (PCI_2)
  - PCI_2 changes
  - Rutting index (0–100)
  - IRI index (0–100)
  - Faulting index (0–100)
  - Cracking index (0–100)
  - Friction
- Distress data
  - Alligator cracking, ft^2/mi (high [h], medium [m], and low [l] severity)
  - Transverse cracking, count/mi (h, m, and l severity)
  - Longitudinal cracking, ft/mi (h, m, and l severity)
  - Durability cracking, count/mi (h, m, and l severity)
  - Joint spalling, count/mi (h, and m severity)
- More information included within database

The preceding information is collected for every original smart key, a unique identifier of any given length of similar primary roadway pavement, every year since 1998 through 2017, providing a 20 year history of these roadways.

Changes to Data Collection over Time

The collection of this data has been contracted out to a third party and is typically collected every other year. This means that the data is often repeated the second year after collection, ultimately lowering the data resolution of many original smart keys. Changes to how certain distresses are determined can also depend on the method of data collection or the person collecting it. Take IRI for example. Improvements to the laser-mounted scanners underneath data collection vehicles, type of vehicle, or even the type of driver can all impact the numerical value of IRI that is measured. However, part of the IRI data collection relating back to control sections, certain checks and balances are in place. When considering joint spalling of PCC pavements, recorded as a count/mile, interpretation of what exactly a spalled joint is depends upon the system that identifies when a joint has spalled.

Another important criteria to consider is the Iowa DOT's switch from the metric system to the English system of units in 2013. Any non-index based data prior to 2013 need to be converted into English units, whether it consists as a length or area. Examples include converting IRI values from meters/kilometer to inches/mile or converting square meters of alligator cracking to square feet.

One of the most helpful indicators of pavement performance is considered to be the pavement condition index (PCI), denoted as PCI_2 in the PMIS database. The current equation used to determine PCI was determined by InTrans Project 13-455 based off fitting index-related data to the existing PCI values (Bektas et al. 2014). The Iowa DOT modifies all of the input data to appropriately match these updates. This allows the PCI to be compared more uniformly over time. Equation (1) shows the equation for PCI_2:

$$\mathrm{PCI_2} = (0.4 \times \text{Cracking Ind.}) + (0.4 \times \text{ Riding Ind.}) + (0.2 \times \text{Rutting or Faulting Ind.}) \tag{1}$$

Where the indices used to calculate PCI are all on a scale of 0 to 100, and 100 represents the best condition for each index; the cracking index is a scale that weighs the impact of various observed cracking, furthered explained in equations (2) and (3); the riding index is a scale that weighs the impact of the measured IRI values, where any values lower than 32 in./mi result in an index value of 100; and the rutting index is a scale that weighs the depth of wheel path ruts, where any ruts less than 0.5 in. result in an index value of 100. For PCC pavements, the faulting index replaces the rutting index. Lastly, the faulting index is a scale that weighs the severity of observed faulting values, where faulting over 12 mm results in an index value of 0. Flexible pavements are calculated using the rutting index and rigid pavements are calculated using the faulting index (Bektas et al. 2014).

$$\text{Flexible Crack Ind.} = 0.2 \times (\mathrm{TCI}) + 0.1 \times (\mathrm{LCI}) + 0.3 \times (\mathrm{L_{WP}CI}) + 0.4 \times (\mathrm{ACI}) \tag{2}$$

$$\text{Rigid Crack Ind.} = 0.6 \times (\mathrm{TCI}) + 0.4 \times (\mathrm{LCI}) \tag{3}$$

Where TCI is the transverse cracking index; LCI is the longitudinal cracking index; $L_{WP}CI$ is the longitudinal wheel path cracking index; and ACI is the alligator cracking index. All indices presented are also on a zero to 100 scale, where 100 represents a pavement with no cracking/distress.

This current determination of PCI is version 2.3 used by the Iowa DOT. Converting older PMIS PCI values to this current version was completed to form a relatable basis for comparisons between projects over time.

In addition, some of this data has been damaged over the past 20 years through events such as mistakes in data entry, false 0 or perfect 100s in place of blank cell values, combining/deleting of original smart keys, missing data, and other potential factors. Although these irregularities exist within the data, careful inspection and cleaning of these irregularities was performed during the performance modeling and are discussed in further detail within that section.

Matching Projects with Performance Data

Performance analysis was divided into two primary categories, which include an analytical analysis and an anecdotal analysis. PMIS data were used for each analysis; however, some data categories provided better consistency over time and trends that reflected actual construction/preservation activities better than others. A matrix of index-based or counted distress parameters was developed to guide the analyses for eight different pavement preservation treatments. When the original smart keys are shorter or longer than 1 mi, the distress data that was not index-based or counted would need to be divided over the length of the original smart key to create a quantity-per-mile metric. This was important as some of the earlier distress data were a total quantity over the length of the original smart key. Relying on index-based and counted data, the extrapolation of very short and very long original smart key's conversion to quantity-per-mile was not needed.

The ratings shown in the matrix indicate how useful a particular index is at showing the performance of a preservation treatment. For example, in most cases, friction data would not be particularly helpful in analyzing the performance of patching. A major limitation in the data analysis is too low of data resolution. Enhanced resolution would help to improve future analyses for crack sealing/crack filling/joint sealing as well as long-term performance of patching activities. The completed matrix was then utilized to guide the analytical and anecdotal analyses for each pavement preservation treatment. PCI_2, and the indices used to directly calculate it, were included in the analytical analysis, while specific cracking indices, including fatigue, transverse, and longitudinal, as well as the friction index and counted durability-cracking and joint spalling, were examined in the anecdotal analysis.

Seen in Table 5, the lowest row, PMIS data quality, is an indicator of how complete the PMIS data remains across all of the projects from 1998 to 2017.

Table 5. PMIS data that best describes pavement performance of select treatments.

Identification of Important Pavement Indices & Distress Data for Analytical & Anecdotal Analyses Across Multiple Pavement Preservation Treatments			Analytical Analysis					Anecdotal Analysis					
								Index Data				Distress Data	
			PCI_2	Cracking Index	Riding Index	Rutting Index	Faulting Index	Fatigue	Transverse	Longitudinal	Friction	Durability	Joint Spalling
Treatment Application Type	Flexible	Microsurfacing	VH	VH	VH	VH	NA	VH	VH	VH	VH	NA	NA
		Slurry Seal	VH	VH	VH	VH	NA	H	VH	VH	VH	NA	NA
		Patching	VH	H	VH	VH	NA	VH	H	H	NH	NA	NA
		Crack Sealing & Crack Filling	VH	VH	VH	VH	NA	H	VH	VH	NH	NA	NA
	Rigid	Patching*	VH	H	VH	NA	VH	H	H	H	NH	VH	VH
		Crack Filling & Joint Sealing	VH	VH	VH	NA	VH	NA	VH	VH	NH	NH	NH
		Dowel Bar Retrofit & Dia. GND	VH	H	VH	NA	VH	NA	H	H	VH	H	H
		Grinding & Grooving	VH	H	VH	NA	VH	NA	H	H	VH	H	VH
		PMIS Data Quality	G	G	G	G	G	OK	OK	OK	OK	P	P

VH - Very Helpful, H - Helpful, NH - Not Helpful, NA - Not Applicable, G - Good, OK - OK, P - Poor

Note Some PCC Patching was performed on a predominately HMA road

This matrix was set up to guide the performance modeling of these eight pavement preservation methods. When a certain criteria was deemed not applicable or not helpful, performance modeling of that treatment was not performed.

The bottom line of the matrix shows a good, fair, or poor rating of the PMIS data quality for each parameter. This rating was determined according to how complete the data were across all PMIS years. If there were many blanks, false 0s, false 100s, or erratic data, the rating would drop. PCI_2 and the four indices used to calculate PCI_2 were rated very helpful in analytically determining the pavement performance. The quality of these indices within the PMIS database is very strong, allowing for more reliable performance trends to be fit to the data. The grayed-out parameters of the faulting index for flexible pavements and rutting index for rigid pavements reiterates the difference between the calculations of PCI for flexible versus rigid pavements. The other index or counted distress data were less complete within the PMIS database, so an anecdotal analysis was used to determine whether the pavement noticed improvement at relative year zero or if no improvement index improvement could be attributed to the applied treatment. The durability and joint spalling indices, rated poor, are based on the numerical recording of counted distresses, which tended to be highly variable over time, resulting in a general disorder and inconsistent trends for durability and joint spalling.

Data Compilation Strategies

Analytical Analysis

When data quality was strong, do nothing and observed performance trend lines were fit to the various index data when plotted against the relative yearly data. Raw data of cracking, rutting, and other non-indexed values were studied; however, it was found that the indexed values provided rational trends and consistency over time. To compare preservation treatment performance over time, the performance data were labeled relative to the time of preservation treatment application. The year the preservation treatment was applied was set to a relative year zero, 0. The year before and the year after become relative years -1 and 1, respectively.

Figure 15 shows an example of how the performance data may appear over time.

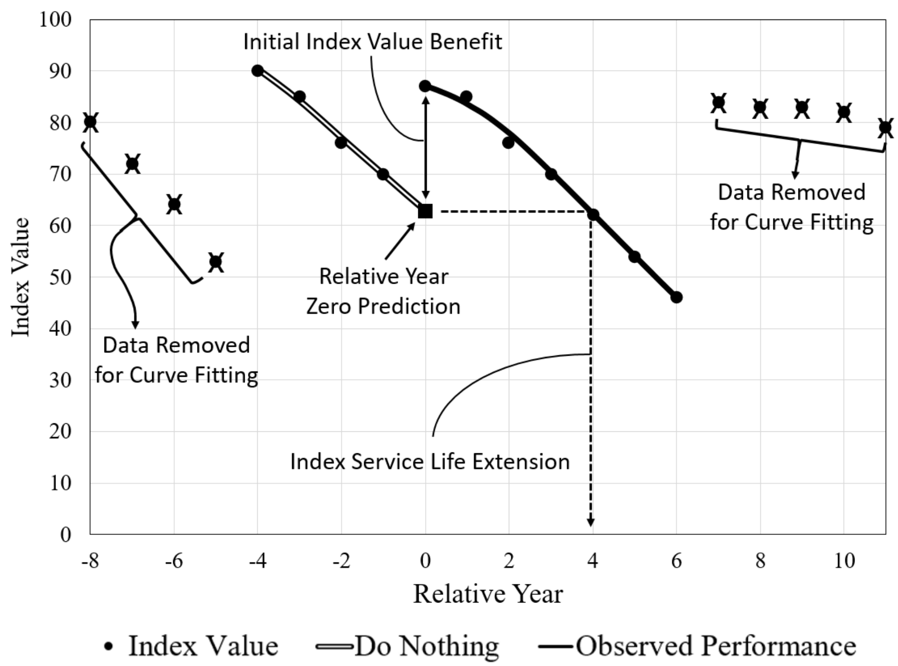


Figure 15. Trend line fitting of index values

Relative year is on the horizontal-axis and the performance index is on the vertical-axis. Year zero indicates the time of preservation treatment application. The years 1 or higher indicate performance after the treatment. The years -1 and less indicate pavement performance before the preservation treatment application. Studies have shown that pre-treatment pavement condition can play a substantial role in the overall performance of a treatment. The figure shows instances of when data is removed from the analysis. A large increase in a performance index indicates a substantial re-construction activity; thus, performance data tied to underlying or removed pavement surfaces is removed from the analysis. If a substantial increase is observed after the preservation application, as illustrated in year seven in the figure, the data is also removed.

Trend lines were fit to the performance data on a project-by-project basis. Figure 15 shows example data from one original smart key, but when the projects cover more than one original smart key, multiple data points will be plotted on similar relative years. For example, if a project covers four original smart keys, then four data points will be plotted for each relative year. The purpose of the trend line is to determine the preservation performance and the predicted performance of the pavement without application of the preservation method. The trend lines were evaluated based on the sum of the squared error values and the combination of boundary conditions, depending on the best function. Functions included the use of a second-order polynomial curve, reflected logistic sigmoidal curve, or flat line were determined as the best representative for fitting a do nothing or observed performance trend line. The equations for these functions can be seen in equations (4), (5), and (6).

$$Linear\ Function: Index\ Value = -ay^2 - by + c \tag{4}$$

$$Second\ Order\ Polynomial\ Function: Index\ Value = -ay^2 - by + c \tag{5}$$

$$Reflected\ Logistic\ Sigmoidal\ Function: Index\ Value = \frac{\mathrm{x}}{1+e^{\mathrm{a}y^{b}-c}} \tag{6}$$

Where a, b, and c are coefficients solved for in attempt to minimize the sum of the squared error; y is the relative year; and index value is the value between 0 and 100 for any given index.

The use of the sum of the squared error values was simply based on which curve resulted in the smallest total squared error, representative of a better description of the data. The fitting of these three functions was performed using a spreadsheet and graphical software to minimize the sum of the squared error among all of the utilized data points.

The boundary conditions applied to the linear and second-order polynomial curves were (1) the curve could never trend upward, (2) negative index values must be substituted with zeros, and (3) values greater than 100 must be substituted with 100. By not allowing the curve to trend upward, a realistic expectation of pavement deterioration was set up. At best, a pavement can only maintain a certain degree of performance. Next, by not allowing negative index values, the resulting fit cannot deteriorate past the lowest boundary of each index, represented by zero. Lastly, by setting the maximum to 100, the resulting fit could not perform outside of the index boundaries. Indices in Iowa’s PMIS cannot be greater than 100.

The benefits of a second-order polynomial curve are (1) a coefficient of zero on the y^2 term results in a linear equation and (2) very strong fits can be obtained with some of the data. The downsides of a second-order polynomial curve are (1) upward trends after relative year zero are often produced, (2) severe deterioration after relative year zero, unrealistic to expected performance, can be formed by just a few errant data points, and (3) linear trends are often upward when the data strongly suggests a maintained performance level.

Reflected logistic sigmoidal (RLS) curves were compared to linear and second-order polynomial functions, or used directly when false upward trends were predicted. An example of a false upward trend can be seen in Figure 16.

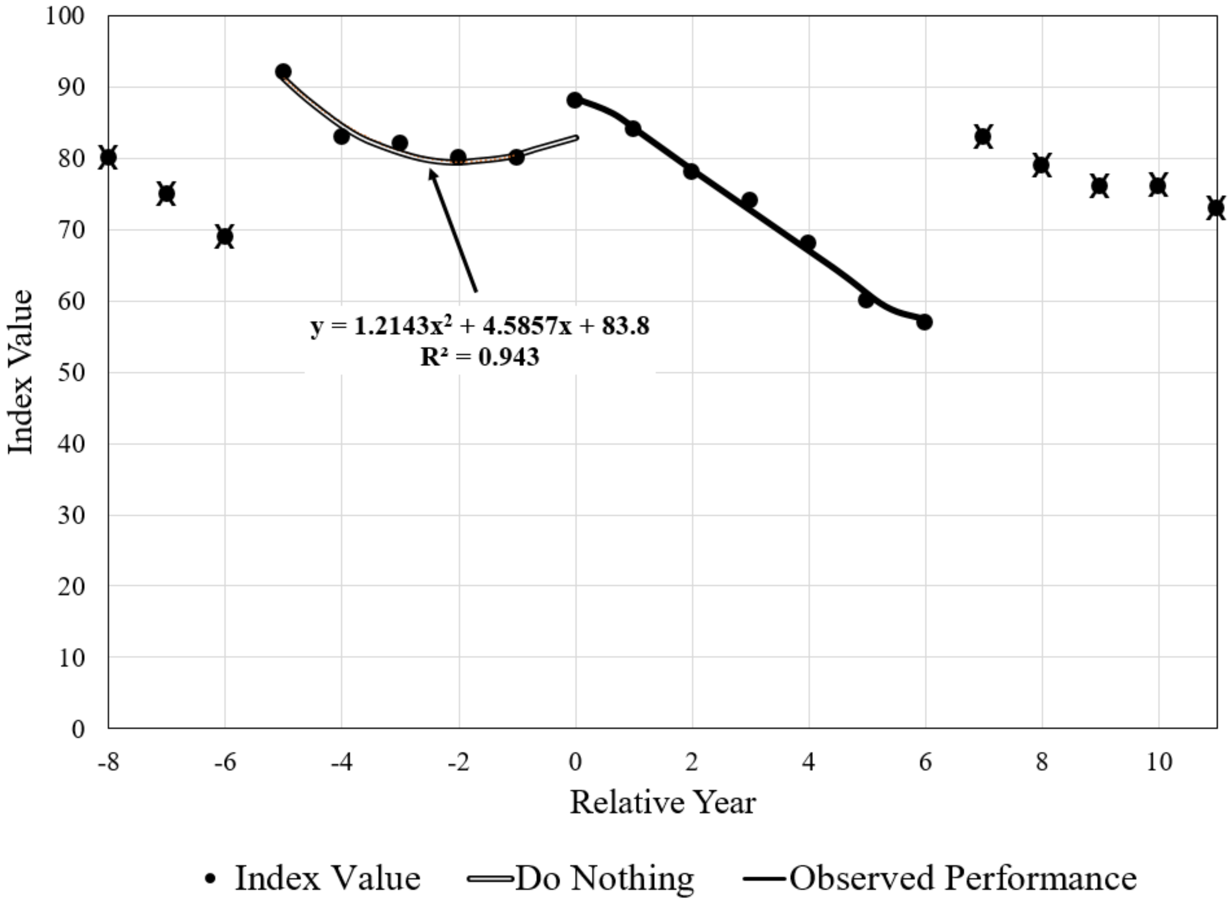


Figure 16. Example of a second order polynomial providing a false upward trend

These RLS functions have a number of benefits when fitting index data. These benefits include (1) they can never have a positive slope; (2) they have a fixed maximum; (3) the have a fixed minimum; and (4) they result in a flat trend when upward movement is detected.

The index benefit throughout each relative year can be determined by calculation of the area between the observed performance and the do nothing trend lines, seen in equation (7).

$$Index\ Benefit = \int_{y-1}^{y} (BFC_{OP.}(y) - BFC_{DN}(y))\, dy \quad (7)$$

Where the index benefit is a numerical value of the difference in index value over the course of the relative year in question with units of index benefit/year; y is the relative year; and BFC is the best fit curve determined for the observed performance (OP) and do nothing (DN) trend lines according to the aforementioned procedure. A graphical representation of PCI index value benefits can be seen in Figure 17.

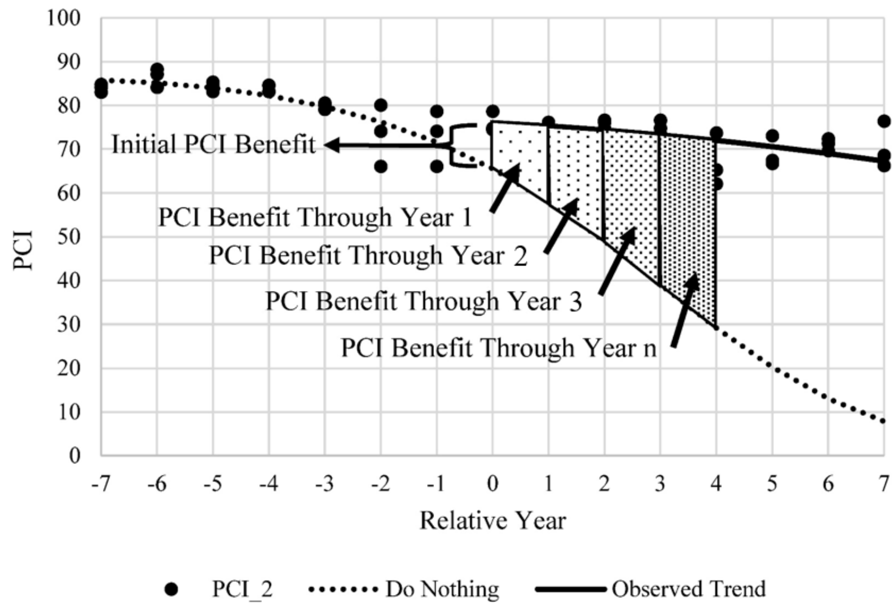


Figure 17. Index value benefit determination

Comparison of these values provides insight on the rate at which a pavement deteriorates after the preservation method was applied in relation to the expected deterioration of the pavement without treatment.

The service life extension of any given index can also be determined by using the DN and OP trend lines. Equation (8) highlights the steps used to calculate the service life extension.

$$f(y_{op}) = Index\ Value_{DN\ (y=0)} \quad (8)$$

Where $f(Y_{OP})$ is the year at which the OP trend line reaches the index value of the DN trend line at relative year zero.

With the possibility of no service life extension, when the observed performance trend line was lower than the do nothing trend line, the service life extension was recorded as a zero value. The other end of this spectrum is when the service life extensions were too large. This could occur if the observed performance trend lines had zero slope or nearly zero slope, resulting in a situation where the predicted deterioration would never fall to its value at relative year zero.

According to Tables 2 and 3, 10 years was chosen as an arbitrary length of service life extension that most of these preservation treatments were found to perform less than. If the calculated service life extensions resulted in values larger than 10 years, a straight line depreciation of said index was calculated to more accurately reflect pavement deterioration. This method involved averaging all of the index service life extensions that were within the range of 0 through 10 years. Then, the initial index value benefits of the service life extensions greater than 10 years were divided by the average service life extension of the values between 0 and 10 years. If the result of this calculation was still greater than 10 years for any given project, the value of 10 years replaced said value. This provided a more reflective result of deteriorative behavior of which a total average index service life for each pavement preservation treatment could be determined. An example of a PCI straight line depreciation of pavement performance deterioration can be seen in Figure 18.

Project Number	Calculated Service Life Extension	Initial Index Improvement	Straight Line Depreciation	Index Improvement Average Discout Rate
	Years	PCI	PCI/Year	Years (PCI/2.92)
MP-006-6(701)209--76-48	5.0	20.6	4.1	5.0
MP-059-3(703)140--76-47	0.4	4.0	11.5	0.4
MP-059-4(703)20--76-36	3.6	5.5	1.5	3.6
MP-067-6(705)48--76-23	0.3	1.4	4.6	0.3
MP-130-6(702)14--76-82	7.8	20.5	2.6	7.8
MP-136-6(701)73--76-31	>10	2.5	-	0.9
MP-140-3(702)10--76-75	1.6	6.3	3.9	1.6
MP-141-4(705)115--76-39	>10	12.1	-	4.2
MP-148-4(709)22--76-87	0.0	2.1	0.0	0.0
MP-151-6(705)11--76-48	0.0	0.0	0.0	0.0
MP-182-3(701)0--76-60	0.0	4.3	0.0	0.0
MP-220-6(705)1--76-48	7.1	7.1	1.0	7.1
MPIN-029-3(714)106--0N-67	>10	19.4	-	6.6
	2.59	8.15	2.92	2.89
	Original Service Life Extension	Average Improvement	Average Discout Rate	Average Service Life Extension

Figure 18. Example of straight line depreciation of PCI deterioration for service lives greater than 10 years

Anecdotal Analysis

When the data quality of certain indices was lower than that of the PCI_2 and its respective indices, a more general graphical approach allowed a simplistic method of preservation performance to be determined. The helpful and very helpful parameters from the anecdotal columns in Table 5 were compared across relative years -2 through 2 for each preservation treatment.

If the treatment showed any index improvement at relative year 0 from relative year 1, the treatment was considered to improve the distress under evaluation. If the pavement showed either worsening distress performance or unchanging distress performance, the treatment was considered to show no observed improvement. The rationale behind this distinction is that if the pavement is not getting worse, but also not increasing in performance, it cannot be deduced that the preservation treatment is the reason for the unchanging performance. The other two categorical assignments in the anecdotal analysis were no trend when the data were not collected or not applicable as determined from Table 5.

An example can be seen in Figure 19.

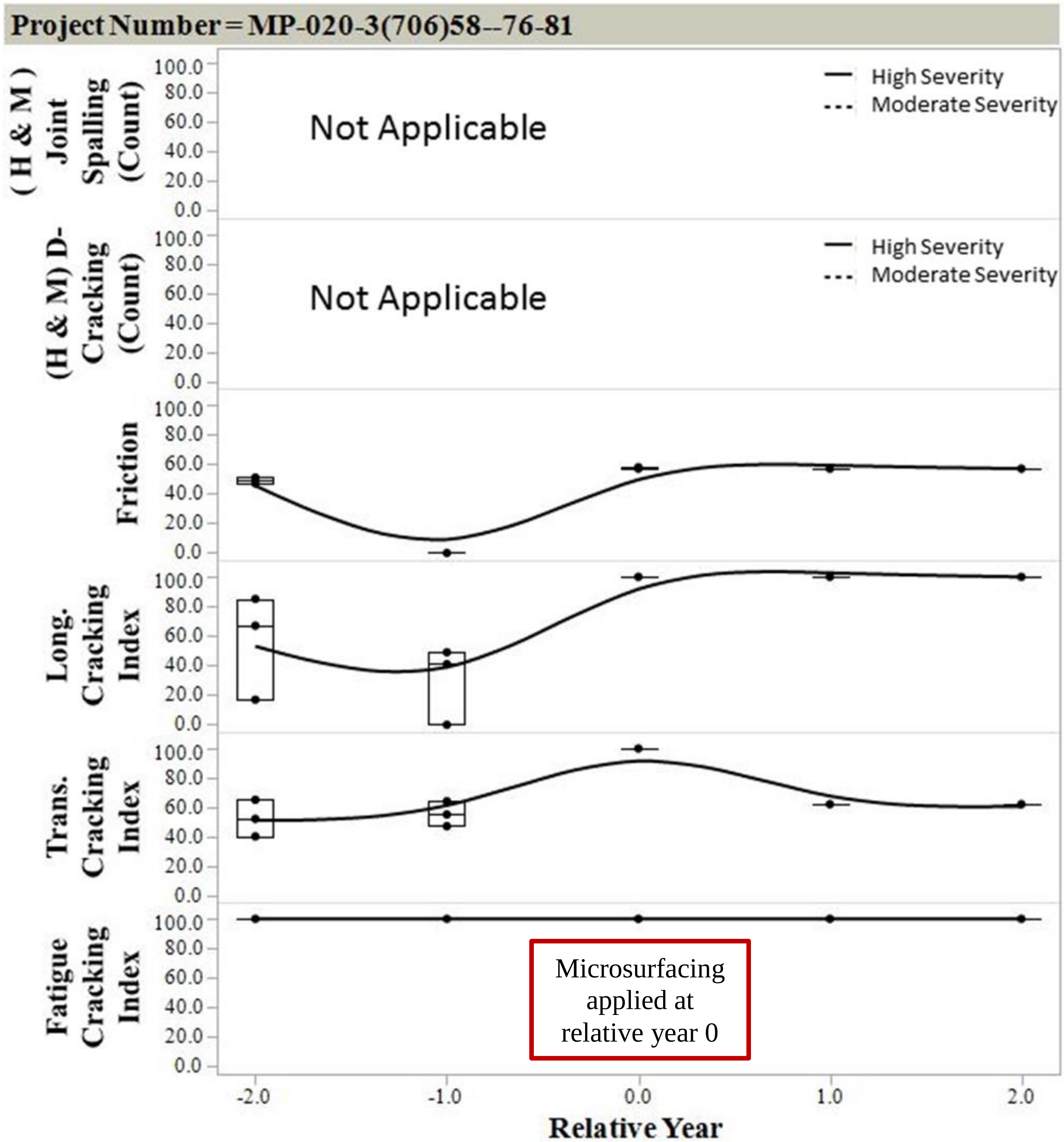


Figure 19. Example anecdotal analysis of a microsurfacing project

This figure shows the graphs for all relavant parameters for the microsurfacing project MP-020-3(706)58—76-81. The box plots within the figure represent the statisitcal quartiles for each year of data. The top and bottom of the box represent the first and third quartiles, respectively. The median value is represented by the horizontal line within the rectangle. Lastly, the whiskers extending above and below the box represent the value plus and minus 1.5 times the interquartile range, defined as the value of quartile 3 minus quartile 1. Values exceeding this range are denoted as outliers. If there is no variability within a given relative year, the entire box plot is represented by a flat line (SAS Institute 2019).

Fatigue cracking showed no observed improvement, while the three remaining applicable indices show improvement of the pavement sections involved in the microsurfacing project.

With each relevant index assigned an anecdotal categorization, each preservation treatment's projects were grouped according to their PCI value at relative year zero. All projects with a predicted PCI value between 75 and 100 were denoted as good projects, while values between 50 and 74.0 were denoted as fair projects, and values between 0 and 49.9 were denoted as poor projects. Then, the most frequently occuring anecdotal categorization was determined within each PCI category. For example, if there were five good projects of a given preservation treatment and thee of them showed improved fatigue cracking performance, and two of them showed no observed improvement, then good projects would be recorded as showing improvement for that preservation treatment.

FLEXIBLE PAVEMENT PRESERVATION PERFORMANCE ANALYSIS

Individual figures for flexible pavement preservation methods containing both the analytical and anecdotal graphical analyses for each project are broken into sections according to the pavement preservation method and can be seen in Appendix B.

Microsurfacing

Project Information

There was a total of 23 microsurfacing projects analyzed in this study as follows:

- MP-003-2(703)183—76-35
- MP-003-2(705)224—76-09
- MP-007-3(703)0—76-18
- MP-009-3(704)5—76-60
- MP-020-3(706)58—76-81
- MP-025-4(702)45—76-01
- MP-030-4(708)12—76-43
- MP-070-5(701)2—76-58
- MP-071-3(710)142—76-81
- MP-075-3(711)101—76-75
- MP-137-5(701)0—76-68
- MP-144-4(700)3—76-08
- MP-149-5(709)12—76-54
- MP-218-2(704)206—76-09
- MPIN-029-4(703)25—0N-65
- MPIN-035-1(708)106—0N-85
- MPIN-035-2(703)216—0N-98
- MPIN-035-2(713)178—0N-17
- MPIN-035-2(714)159—0N-35
- MPIN-035-2(716)175—0N-35
- MPIN-035-2(717)178—0N-17
- MPIN-035-5(701)33—0N-20
- MPIN-080-4(714)40—0N-78

Analytical Analysis

Table 6 shows the index service life extensions for the 23 microsurfacing projects analyzed in this study.

Table 6. Index service life extensions for microsurfacing projects

Averages	# of projects	Index service life extension			
		PCI	Rutting	Riding	Cracking
All projects	23	3.7	2.4	3.3	5.3
Good (75<PCI<100)	1	0.0	1.7	0.0	0.0
Fair (50<PCI<74.9)	19	3.7	2.6	3.4	5.6
Poor (0<PCI<49.9)	3	4.3	1.2	4.0	5.0
Project number	**PCI category**	**PCI**	**Rutting**	**Riding**	**Cracking**
MP-003-2(703)183—76-35	Fair	1.2	>10	>10	0.0
MP-003-2(705)224—76-09	Fair	>10	7.8	>10	>10
MP-007-3(703)0—76-18	Poor	4.8	2.6	6.1	3.7
MP-009-3(704)5—76-60	Fair	4.0	>10	6.0	>10
MP-020-3(706)58—76-81	Fair	>10	>10	>10	>10
MP-025-4(702)45—76-01	Fair	>10	>10	4.3	>10
MP-030-4(708)12—76-43	Fair	7.4	>10	5.2	3.3
MP-070-5(701)2—76-58	Fair	>10	0.0	5.2	>10
MP-071-3(710)142—76-81	Fair	>10	0.0	>10	0.0
MP-075-3(711)101—76-75	Fair	>10	>10	>10	>10
MP-137-5(701)0—76-68	Poor	>10	1.1	>10	>10
MP-144-4(700)3—76-08	Poor	7.1	0.0	5.7	8.8
MP-149-5(709)12—76-54	Fair	6.0	2.8	0.0	>10
MP-218-2(704)206—76-09	Fair	>10	0.0	>10	0.0
MPIN-029-4(703)25—0N-65	Fair	>10	0.0	>10	>10
MPIN-035-1(708)106—0N-85	Fair	>10	0.0	>10	>10
MPIN-035-2(703)216—0N-98	Good	0.0	1.7	0.0	0.0
MPIN-035-2(713)178—0N-17	Fair	>10	0.0	>10	>10
MPIN-035-2(714)159—0N-35	Fair	3.2	>10	>10	1.8
MPIN-035-2(716)175—0N-35	Fair	>10	0.0	>10	>10
MPIN-035-2(717)178—0N-17	Fair	>10	0.0	>10	8.0
MPIN-035-5(701)33—0N-20	Fair	>10	9.0	>10	>10
MPIN-080-4(714)40—0N-78	Fair	>10	0.0	>10	0.0

Note: The index service life extensions in the averages section of the table include the service life extensions greater than 10 years via the straight-line depreciation method discussed in "Analytical Analysis" section.

When broken down by PCI category at relative year zero, a majority of these projects were placed on fair pavements, leaving only one good pavement and three poor pavements.

On average, the PCI service life was increased by 3.7 years. The other three indices recorded a low of 2.4 years of rutting service life improvement, 3.3 years of riding service life improvement, and over 5 years of cracking service life improvement.

When comparing the index service life extensions between PCI categories, some interesting trends were discovered. At first glance, it looks like good pavements perform poorly, while fair and poor pavements see significant extensions in Figure 20. While this seems counter-intuitive, it should be considered that pavements in good condition receiving pavement preservation are providing the value of preventing future distresses.

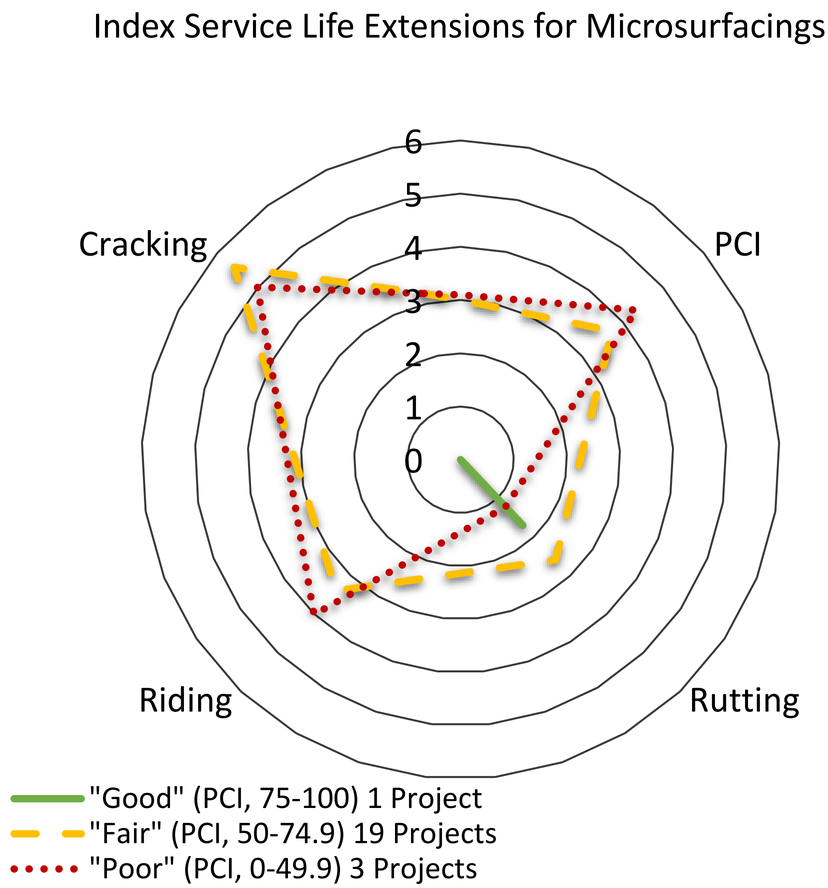


Figure 20. PCI categorical comparison of index service life extensions for microsurfacing projects

In addition, there was only one pavement categorized as good, which shows minimal information.

It is important to note that pavements with PCI values greater than 75 have much less room to improve after treatment, while lower PCI values are more capable of increasing in value. It is also important to note that the cracking index is seeing substantial improvement after microsurfacing, and this is expected since microsurfacing completely covers all of the cracking for the treated area. With the cracks needing to propagate through the new surface, the cracking service life is increased. Another expected trend was to see minimal rutting service life extension. Due to the very thin nature of a microsurfacing, it comes as no surprise that rutting problems were not greatly remedied with this treatment. The other possibility is that these microsurfacings were not placed to target rutting issues, especially if the pavement was not experiencing rutting. Since the rutting improvement was minimal, but the other categories improved, the latter is more likely.

The initial index value benefits, which represent the difference between the OP and DN trend lines at relative year 0, compared to the index value benefits for relative year 4 can be seen in Figure 21.

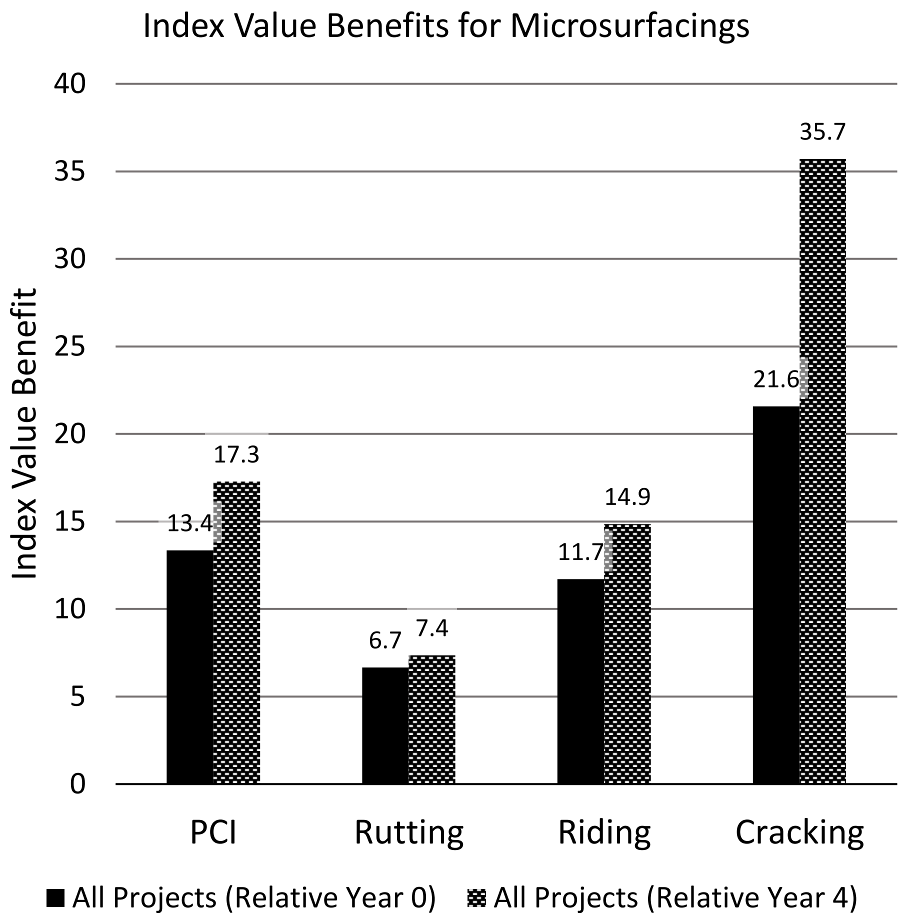


Figure 21. Index value benefits for microsurfacing projects

With the index value benefits for each index increasing at relative year 4, an important performance is discovered. Since the later values are larger, the rate of deterioration of the microsurfacings is slower, on average, than the rate of deterioration prior to the treatment. So not only does a microsurfacing extend these pavements for about four years, it also slows the rate of pavement deterioration.

Anecdotal Analysis

Table 7 shows the results for each microsurfacing anecdotal analysis, and Table 8 shows the collective results using the most frequently reported values for each PCI category.

Table 7. Individual anecdotal results for microsurfacing projects

Project number	PCI category	Fatigue cracking	Transverse cracking	Long. cracking	Friction
MPIN-035-2(703)216—0N-98	Good	NT	NOI	NOI	NOI
MP-003-2(703)183—76-35	Fair	NT	NOI	NOI	NOI
MP-003-2(705)224—76-09	Fair	NOI	NOI	I	I
MP-009-3(704)5—76-60	Fair	NT	NOI	NOI	NOI
MP-020-3(706)58—76-81	Fair	NOI	I	I	I
MP-025-4(702)45—76-01	Fair	NT	I	NOI	NOI
MP-030-4(708)12—76-43	Fair	NT	NOI	I	NOI
MP-070-5(701)2—76-58	Fair	NOI	NOI	NOI	I
MP-071-3(710)142—76-81	Fair	NT	NOI	NOI	NOI
MP-075-3(711)101—76-75	Fair	NT	NOI	I	NOI
MP-149-5(709)12—76-54	Fair	NOI	NOI	NOI	NOI
MP-218-2(704)206—76-09	Fair	NT	NOI	NOI	NOI
MPIN-029-4(703)25—0N-65	Fair	NT	NOI	NOI	NOI
MPIN-035-1(708)106—0N-85	Fair	NT	NOI	NOI	NOI
MPIN-035-2(713)178—0N-17	Fair	NT	I	I	NOI
MPIN-035-2(714)159—0N-35	Fair	NT	NOI	NOI	NOI
MPIN-035-2(716)175—0N-35	Fair	NOI	NOI	I	I
MPIN-035-2(717)178—0N-17	Fair	NT	I	I	NOI
MPIN-035-5(701)33—0N-20	Fair	NT	I	I	NOI
MPIN-080-4(714)40—0N-78	Fair	NT	NOI	NOI	NOI
MP-007-3(703)0—76-18	Poor	NOI	I	I	NOI
MP-137-5(701)0—76-68	Poor	NT	NOI	NOI	NOI
MP-144-4(700)3—76-08	Poor	I	I	I	NOI

Note: NT denotes lack of clear trend, NOI denotes a trend that does not indicate distress improvement, and I denotes a trend that does indicate distress improvement.

Table 8. Collective anecdotal results for microsurfacing projects

PCI category	Good	Fair	Poor
# of projects	1	19	3
Fatigue cracking index	NT:(1/1)	NT:(14/19)	I:(1/3)
Transverse cracking index	NOI:(1/1)	NOI:(14/19)	I:(2/3)
Long. cracking index	NOI:(1/1)	NOI:(11/19)	I:(2/3)
Friction	NOI:(1/1)	NOI:(15/19)	NOI:(3/3)

Note: NT denotes lack of clear trend, NOI denotes a trend that does not indicate distress improvement, and I denotes a trend that does indicate distress improvement.

Much of the fatigue cracking index data were missing values, resulting in many no trend results. Most likely, the fatigue cracking indices would show improvement across all three PCI categories if the data were present. The only improved results were the fatigue, transverse, and longitudinal cracking indices for the poor pavements.

Slurry Seal

Project Information

There was a total of 13 slurry seal projects analyzed in this study. The projects as well as their type of slurry seal application were as follows:

- MP-006-6(701)209—76-48 (longitudinal slurry seal)
- MP-059-3(703)140—76-47 (transverse slurry leveling)
- MP-059-4(703)20—76-36 (center-line slurry seal)
- MP-067-6(705)48—76-23 (longitudinal slurry seal)
- MP-130-6(702)14—76-82 (longitudinal slurry seal)
- MP-136-6(701)73—76-31 (longitudinal and center-line slurry seal)
- MP-140-3(702)10—76-75 (transverse slurry leveling)
- MP-141-4(705)115—76-39 (center-line slurry seal)
- MP-148-4(709)22—76-87 (transverse slurry leveling and center-line slurry seal)
- MP-151-6(705)11—76-48 (transverse slurry leveling)
- MP-182-3(701)0—76-60 (transverse slurry leveling)
- MP-220-6(705)1—76-48 (transverse slurry leveling)
- MPIN-029-3(714)106—0N-67 (center-line slurry seal)

The three application methods that these slurry seals utilized were (1) longitudinal slurry sealing, where the slurry is applied in a strip typically down the wheel path of the pavement; (2) center-line slurry sealing, where the slurry is applied over the center line of the pavement; and (3) transverse slurry leveling, where the slurry is applied in strips across the transverse cracks in attempt to level out the gap between the two pavement sections and temporarily remedy the crack.

Analytical Analysis

Table 9 shows the index service life extensions for the 13 slurry seal projects analyzed in this study.

Table 9. Index service life extensions for slurry seal projects

Averages	# of projects	Index service life extension			
		PCI	**Rutting**	**Riding**	**Cracking**
All projects	13	3.0	2.2	2.6	3.0
Good (75<PCI<100)	1	0.0	0.0	2.6	3.6
Fair (50<PCI<74.9)	8	3.2	2.2	3.9	0.9
Poor (0<PCI<49.9)	4	3.5	2.6	0.1	7.0
Project number	**PCI category**	**PCI**	**Rutting**	**Riding**	**Cracking**
MP-006-6(701)209—76-48 (LS)	Poor	5.0	4.1	0.2	6.5
MP-059-3(703)140—76-47 (TL)	Fair	0.4	5.1	2.4	0.0
MP-059-4(703)20—76-36 (CL)	Fair	3.6	8.9	0.5	4.9
MP-067-6(705)48—76-23 (LS)	Fair	0.3	1.3	0.4	2.3
MP-130-6(702)14—76-82 (LS)	Poor	7.8	0.0	0.0	7.2
MP-136-6(701)73—76-31 (LS/CL)	Poor	>10	0.0	0.0	>10
MP-140-3(702)10—76-75 (TL)	Fair	1.6	2.3	3.4	0.0
MP-141-4(705)115—76-39 (CL)	Fair	>10	0.2	>10	>10
MP-148-4(709)22—76-87 (TL/CL)	Fair	0.0	0.0	>10	0.0
MP-151-6(705)11—76-48 (TL)	Good	0.0	0.0	2.6	>10
MP-182-3(701)0—76-60 (TL)	Poor	0.0	6.2	0.0	5.1
MP-220-6(705)1—76-48 (TL)	Fair	7.1	0.0	>10	0.0
MPIN-029-3(714)106—0N-67 (CL)	Fair	>10	0.0	>10	0.0

Note: The index service life extensions in the averages section of the table include the service life extensions greater than 10 years via the straight-line depreciation method discussed in “Analytical Analysis” section.

Grouped by category according to the DN predictions of PCI at relative year 0, there was one good project, eight fair projects, and four poor projects. The lack of good projects, similar to microsurfacings, highlights the fact that slurry seals and microsurfacings are currently being used to address pavement distresses when they occur instead of being used as a pavement preservation.

On average, the PCI service life was increased by 3.0 years. The other three indices recorded a low of 2.2 years of rutting service life improvement, 2.6 years of riding service life improvement, and 3.0 years of cracking service life improvement.

When comparing the index service life extensions between PCI categories, it looks like the one good pavement only experiences cracking and riding improvement; fair pavements see significant service life extensions for all indices except for the cracking index with only 0.9 years of extension; and poor pavements see significant service life extensions for all indices except for the cracking index with only 0.1 years of extension, as shown in Figure 22.

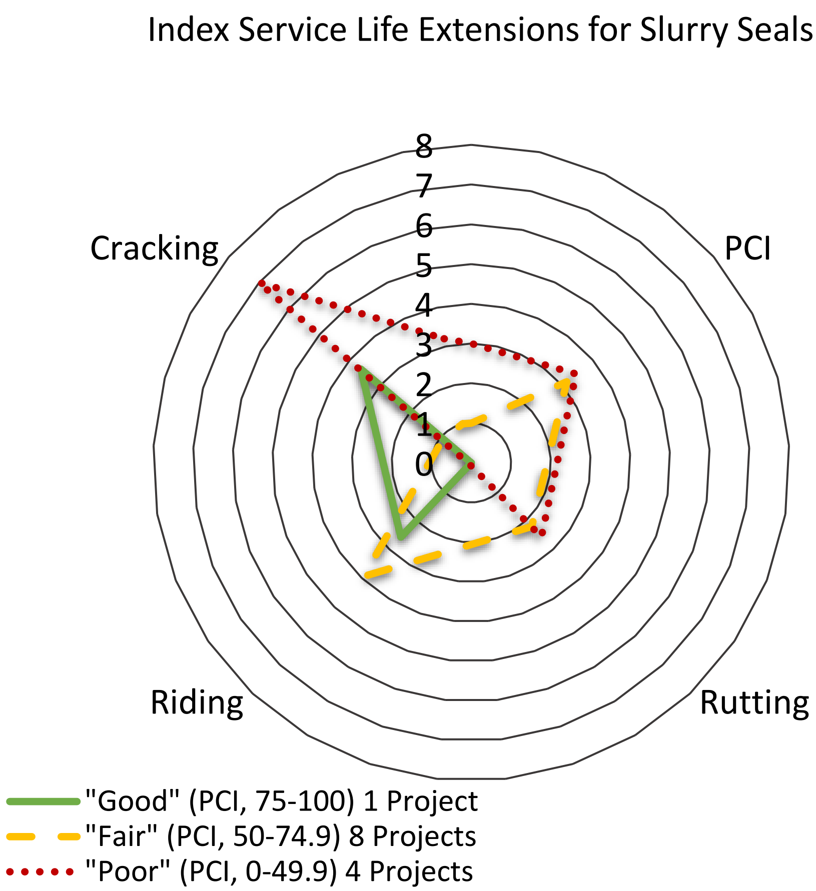


Figure 22. PCI categorical comparison of index service life extensions for slurry seal projects

Again, the amount of room that a pavement has to increase its index service life increases as the original pavement quality decreases.

It is interesting to see how the timing of the slurry seal application can cause significant performance variation within these 13 projects, but the average PCI service life extension of 3.0 years is only marginally smaller than the 3.7 year extension seen in the microsurfacing projects. In addition, microsurfacings will likely prevent future cracking since they are applied over the entire pavement instead of spot treatments like slurry seals.

Seen in Figure 23, the index service lives were compared across the three types of slurry seal application methods.

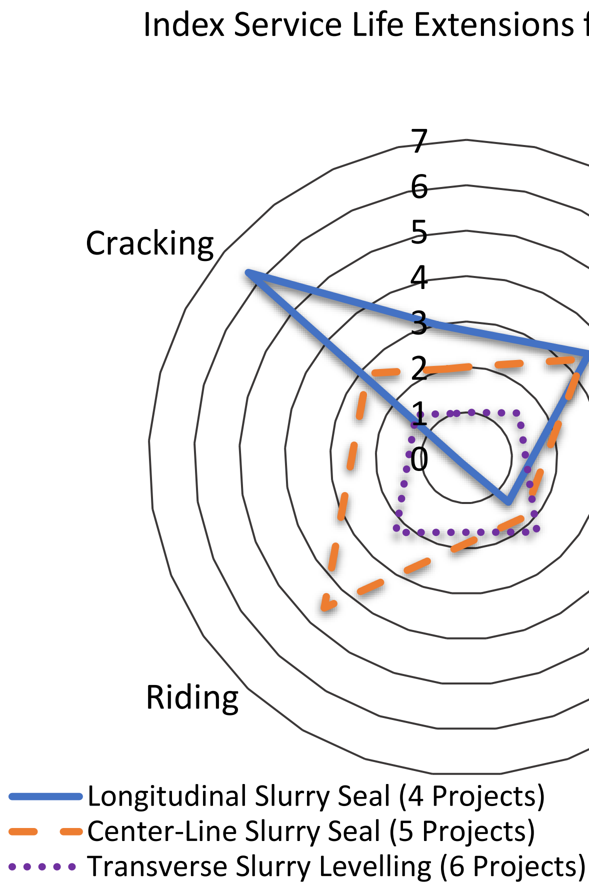


Figure 23. Slurry application comparison of index service life extensions for slurry seal projects

Transverse slurry leveling provided unremarkable results, while the longitudinal slurry sealing showed substantial cracking index service life extension with virtually no improvement to the riding index, and center-line slurry sealing showed substantial riding index service life extension without performing poorly in the other indices. The likely culprit of this increased riding index would be when the constructed center line had ended up within the wheel path as the result of added lanes shifting the original lane placement.

The initial index value benefits, which represent the difference between the OP and DN trend lines at relative year 0, compared to the index value benefits for relative year 4 can be seen in Figure 24.

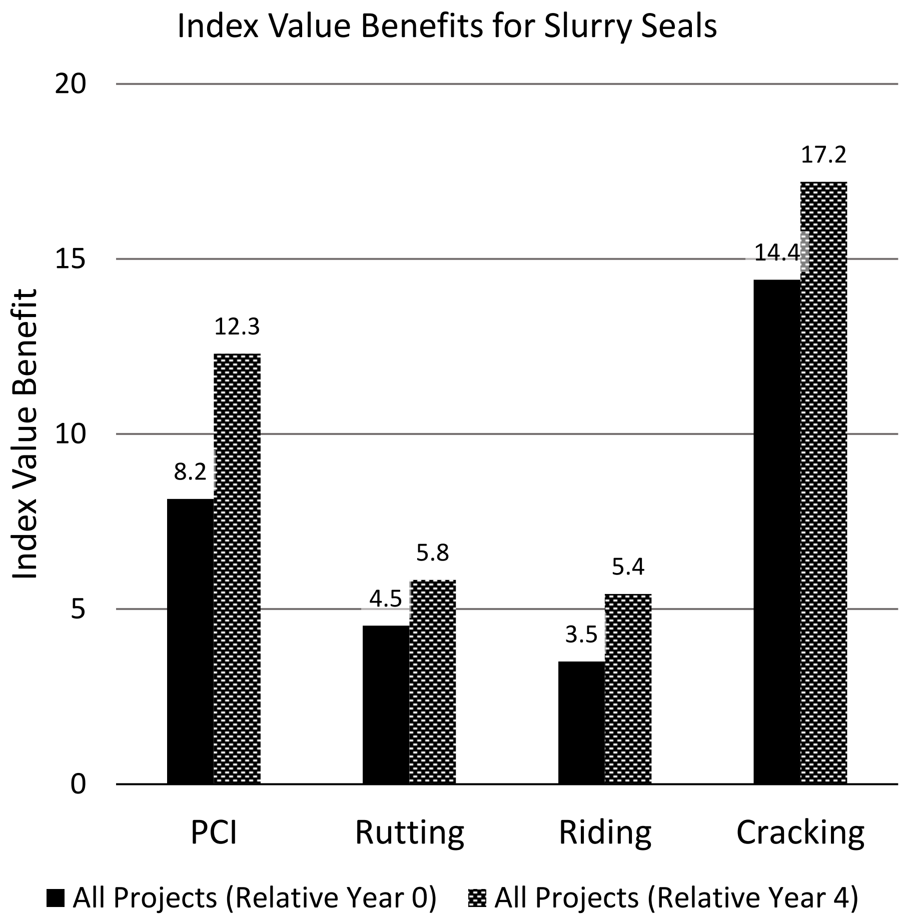


Figure 24. Index value benefits for slurry seal projects

Again, the index value benefits for each index are increasing at relative year 4. Since the later values are larger, the rate of deterioration of the slurry seals is slower, on average, than the rate of deterioration prior to the treatment.

Anecdotal Analysis

Table 10 shows the results for each slurry seal anecdotal analysis, and Table 11 shows the collective results using the most frequently reported values for each PCI category.

Table 10. Individual anecdotal results for slurry seal projects

Project number	PCI category	Fatigue cracking	Transverse cracking	Long. cracking	Friction
MP-151-6(705)11—76-48	Good	NT	NOI	NOI	NOI
MP-059-3(703)140—76-47	Fair	NOI	NOI	NOI	NOI
MP-059-4(703)20—76-36	Fair	NOI	I	I	NOI
MP-067-6(705)48—76-23	Fair	NOI	NOI	NOI	NOI
MP-140-3(702)10—76-75	Fair	NOI	NOI	NOI	NOI
MP-141-4(705)115—76-39	Fair	NOI	NOI	NOI	I
MP-148-4(709)22—76-87	Fair	NT	I	NOI	NOI
MP-220-6(705)1—76-48	Fair	NT	I	NOI	NOI
MPIN-029-3(714)106—0N-67	Fair	NT	NOI	NOI	NOI
MP-006-6(701)209—76-48	Poor	NOI	I	I	NOI
MP-130-6(702)14—76-82	Poor	I	I	NOI	NOI
MP-136-6(701)73—76-31	Poor	NT	NOI	I	NOI
MP-182-3(701)0—76-60	Poor	NOI	NOI	NOI	NOI

Note: NT denotes lack of clear trend; NOI denotes a trend that does not indicate distress improvement; and I denotes a trend that does indicate distress improvement.

Table 11. Collective anecdotal results for slurry seal projects

PCI category	Good	Fair	Poor
# of projects	2	8	4
Fatigue cracking index	NT:(1/1)	NOI:(5/8)	NOI:(2/4)
Transverse cracking index	NOI:(1/1)	NOI:(5/8)	I:(2/4)
Long. cracking index	NOI:(1/1)	NOI:(7/8)	I:(2/4)
Friction	NOI:(1/1)	NOI:(7/8)	NOI:(4/4)

Note: NT denotes lack of clear trend; NOI denotes a trend that does not indicate distress improvement; and I denotes a trend that does indicate distress improvement.

The only improved results were the transverse and longitudinal cracking indices for the poor pavements. Many of the no observed improvement results were from graphs that were maintaining a certain level of performance but simply did not improve. These results are understandable since slurry seals are a spot-applied treatment and not placed over the entire pavement.

HMA Patching

Project Information

There was a total of 34 HMA patching projects analyzed in this study as follows:

- ER-003-5(74)—28-12
- IMN-680-1(146)0—0E-78

- MP-002-4(706)33—76-73
- MP-003-2(702)145—76-99
- MP-004-1(705)24—76-37
- MP-012-3(703)0—76-97
- MP-012-3(705)0—76-97
- MP-014-5(702)43—76-63
- MP-020-1(703)136—76-40
- MP-022-5(704)29—76-92
- MP-030-1(705)156—76-85
- MP-030-1(708)156—76-85
- MP-032-6(701)0—76-31
- MP-044-4(704)46—76-05
- MP-059-3(705)102—76-24
- MP-059-3(706)105—76-24
- MP-059-3(706)130—76-47
- MP-061-5(706)68—76-58
- MP-063-2(707)163—76-07
- MP-064-6(706)50—76-49
- MP-064-6(708)33—76-49
- MP-065-1(707)149—76-42
- MP-071-3(705)125—76-81
- MP-075-3(705)112—76-75
- MP-080-6(701)210—76-48
- MP-092-5(702)233—76-92
- MP-092-5(704)194—76-54
- MP-096-1(702)0—76-64
- MP-122-2(701)7—76-17
- MP-149-6(707)46—76-54
- MP-150-6(703)40—76-10
- MP-175-1(704)188—76-42
- MP-218-2(702)238—76-34
- MP-415-1(707)8—76-77

Analytical Analysis

Table 12 shows the index service life extensions for the 34 HMA patching projects analyzed in this study.

Table 12. Index service life extensions for HMA patching projects

Averages	# of projects	Index service life extension			
		PCI	Rutting	Riding	Cracking
All projects	34	3.4	2.1	2.6	3.5
Good (75<PCI<100)	0	-	-	-	-
Fair (50<PCI<74.9)	19	2.0	2.2	1.8	2.2
Poor (0<PCI<49.9)	15	5.1	1.9	3.5	5.1
Project number	**PCI category**	**PCI**	**Rutting**	**Riding**	**Cracking**
ER-003-5(74)—28-12	Fair	1.3	0.0	0.0	1.6
IMN-680-1(146)0—0E-78	Poor	>10	0.0	>10	>10
MP-002-4(706)33—76-73	Poor	>10	0.0	0.0	0.0
MP-003-2(702)145—76-99	Poor	1.6	0.0	0.0	5.4
MP-004-1(705)24—76-37	Poor	>10	0.0	>10	7.5
MP-012-3(703)0—76-97	Fair	0.0	0.0	3.8	0.7
MP-012-3(705)0—76-97	Fair	0.0	0.0	4.0	0.0
MP-014-5(702)43—76-63	Poor	8.0	0.0	>10	>10
MP-020-1(703)136—76-40	Fair	2.2	5.2	0.0	0.0
MP-022-5(704)29—76-92	Poor	2.6	0.0	6.4	4.9
MP-030-1(705)156—76-85	Fair	0.0	0.0	0.0	3.1
MP-030-1(708)156—76-85	Fair	>10	0.0	>10	0.0
MP-032-6(701)0—76-31	Fair	0.0	0.0	0.9	0.0
MP-044-4(704)46—76-05	Fair	>10	>10	5.1	0.0
MP-059-3(705)102—76-24	Fair	>10	>10	>10	>10
MP-059-3(706)105—76-24	Fair	0.0	0.5	0.0	0.0
MP-059-3(706)130—76-47	Poor	5.4	0.0	0.0	2.5
MP-061-5(706)68—76-58	Fair	0.0	0.0	1.8	>10
MP-063-2(707)163—76-07	Fair	0.8	0.0	0.1	3.7
MP-064-6(706)50—76-49	Poor	4.0	0.0	0.0	>10
MP-064-6(708)33—76-49	Poor	>10	>10	2.4	>10
MP-065-1(707)149—76-42	Fair	6.0	>10	2.7	>10
MP-071-3(705)125—76-81	Fair	0.0	0.9	0.0	0.0
MP-075-3(705)112—76-75	Fair	0.2	1.0	0.1	1.9
MP-080-6(701)210—76-48	Poor	>10	0.0	0.0	>10
MP-092-5(702)233—76-92	Fair	0.0	0.2	0.4	0.0
MP-092-5(704)194—76-54	Poor	>10	0.0	3.3	>10
MP-096-1(702)0—76-64	Fair	0.1	0.0	0.0	1.6
MP-122-2(701)7—76-17	Poor	>10	8.7	>10	9.6
MP-149-6(707)46—76-54	Poor	>10	>10	>10	>10
MP-150-6(703)40—76-10	Fair	0.3	6.7	1.5	0.0
MP-175-1(704)188—76-42	Poor	4.3	0.0	5.9	0.0
MP-218-2(702)238—76-34	Poor	3.2	>10	2.9	2.3
MP-415-1(707)8—76-77	Fair	0.0	0.0	0.0	0.0

Note: The index service life extensions in the averages section of the table include the service life extensions greater than 10 years via the straight-line depreciation method discussed in "Analytical Analysis" section.

When broken down by PCI category at relative year 0, none of these projects were good pavements, 19 of these projects were placed on fair pavements, and 15 projects were placed on poor pavements. Patching is a spot-treatment and will not be able to prevent future cracking and distresses beyond where the new patch is placed. Also, the data resolution limits the effectiveness of this data to truly perform a post-patching evaluation.

On average, the PCI service life was increased by 3.4 years. The other three indices recorded a low of 2.1 years of rutting service life improvement, 2.6 years of riding service life improvement, and 3.5 years of cracking service life improvement.

When comparing the index service life extensions between PCI categories in Figure 25, some interesting trends are discovered.

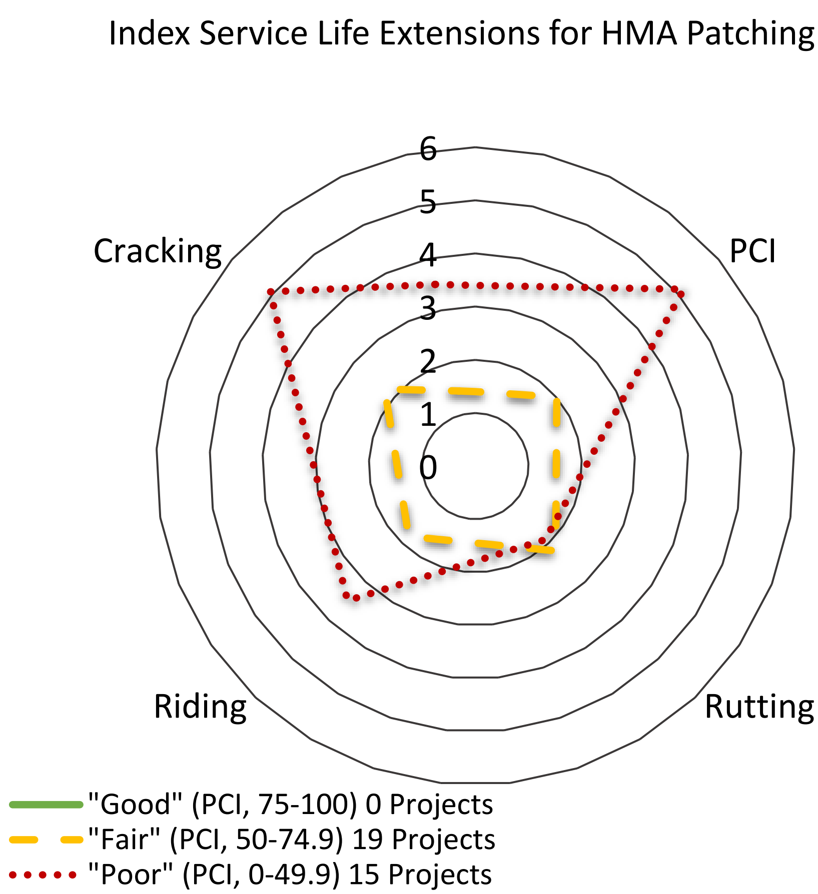


Figure 25. PCI categorical comparison of index service life extensions for HMA patching projects

At first glance, poor pavements saw substantially larger index service life extensions than the fair pavements.

The rather large increase in poor pavement riding index service life extension is attributable to the fact that these patching projects were most likely targeting the most severe riding index problem areas (i.e., potholes and severe cracks). The lack of patching on good pavements is indicative of the fact that pavements in good condition typically do not need to be patched.

The initial index value benefits, the difference between the observed performance and do nothing trend lines at relative year 0, compared to the index value benefits for relative year 4 can be seen in Figure 26.

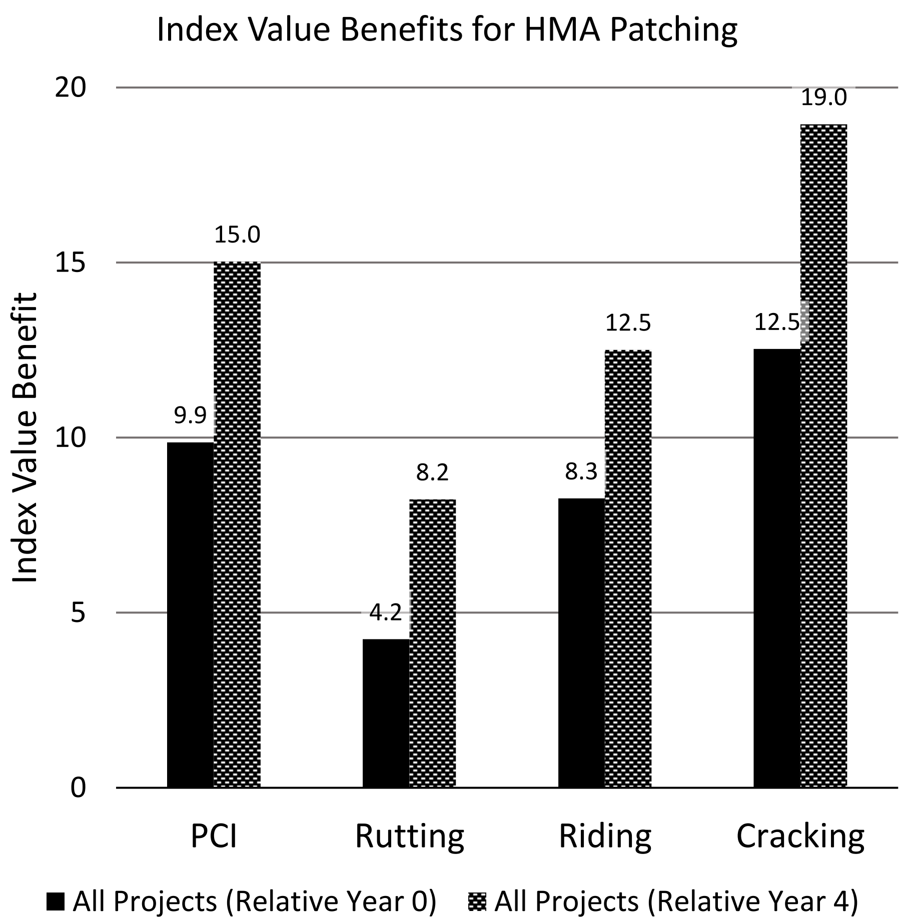


Figure 26. Index value benefits for HMA patching projects

Similar to the microsurfacing and slurry seal results, the rate of deterioration after application of HMA patches has slowed when compared to the rate prior to treatment application.

Anecdotal Analysis

Table 13 shows the results for each HMA patching anecdotal analysis, and Table 14 shows the collective results using the most frequently reported values for each PCI category.

Table 13. Individual anecdotal results for HMA patching projects

Project number	PCI category	Fatigue cracking	Transverse cracking	Long. cracking
ER-003-5(74) —28-12	Fair	NOI	NOI	I
MP-012-3(703)0—76-97	Fair	NOI	NOI	NOI
MP-012-3(705)0—76-97	Fair	NT	I	NOI
MP-020-1(703)136—76-40	Fair	NOI	NOI	NOI
MP-030-1(705)156—76-85	Fair	NT	NOI	NOI
MP-030-1(708)156—76-85	Fair	NT	NOI	NOI
MP-032-6(701)0—76-31	Fair	NT	I	NOI
MP-044-4(704)46—76-05	Fair	NOI	NOI	NOI
MP-059-3(705)102—76-24	Fair	NT	I	I
MP-059-3(706)105—76-24	Fair	NT	I	NOI
MP-061-5(706)68—76-58	Fair	NT	NOI	NOI
MP-063-2(707)163—76-07	Fair	NOI	I	I
MP-065-1(707)149—76-42	Fair	I	I	I
MP-071-3(705)125—76-81	Fair	NOI	NOI	NOI
MP-075-3(705)112—76-75	Fair	I	NOI	NOI
MP-092-5(702)233—76-92	Fair	NOI	NOI	NOI
MP-096-1(702)0—76-64	Fair	NT	NOI	NOI
MP-150-6(703)40—76-10	Fair	NT	NOI	NOI
MP-415-1(707)8—76-77	Fair	NT	I	NOI
IMN-680-1(146)0—0E-78	Poor	I	NOI	NOI
MP-002-4(706)33—76-73	Poor	NT	NOI	I
MP-003-2(702)145—76-99	Poor	NOI	I	NOI
MP-004-1(705)24—76-37	Poor	NT	I	I
MP-014-5(702)43—76-63	Poor	NT	NOI	I
MP-022-5(704)29—76-92	Poor	NT	I	NOI
MP-059-3(706)130—76-47	Poor	NT	I	NOI
MP-064-6(706)50—76-49	Poor	NT	I	NOI
MP-064-6(708)33—76-49	Poor	NT	NOI	I
MP-080-6(701)210—76-48	Poor	NT	NOI	NOI
MP-092-5(704)194v76-54	Poor	NT	NOI	NOI
MP-122-2(701)7—76-17	Poor	NOI	NOI	NOI
MP-149-6(707)46—76-54	Poor	NOI	NOI	NOI
MP-175-1(704)188—76-42	Poor	NT	NOI	NOI
MP-218-2(702)238—76-34	Poor	NOI	I	NOI

Note: NT denotes lack of clear trend; NOI denotes a trend that does not indicate distress improvement; and I denotes a trend that does indicate distress improvement.

Table 14. Collective anecdotal results for HMA patching projects

PCI category	Good	Fair	Poor
# of projects	0	19	15
Fatigue cracking index	-	NT:(10/19)	NT:(10/15)
Transverse cracking index	-	NOI:(12/19)	NOI:(9/15)
Long. cracking index	-	NOI:(15/19)	NOI:(11/15)

Note: NT denotes lack of clear trend; and NOI denotes a trend that does not indicate distress improvement.

Contrary to the results of the analytical analysis, there were no improvements for the analyzed performance indicators. In many of the individual projects, transverse and longitudinal cracking indices saw improvement, but there were more projects determined to have no observable improvements. Overall, this is most likely the result of the very localized approach of patching. While the very worst sections are being restored, the pavement's entire condition is still worsening in terms of these distresses. Figure 27 illustrates the data limitations in looking at individual distresses in an anecdotal analysis.

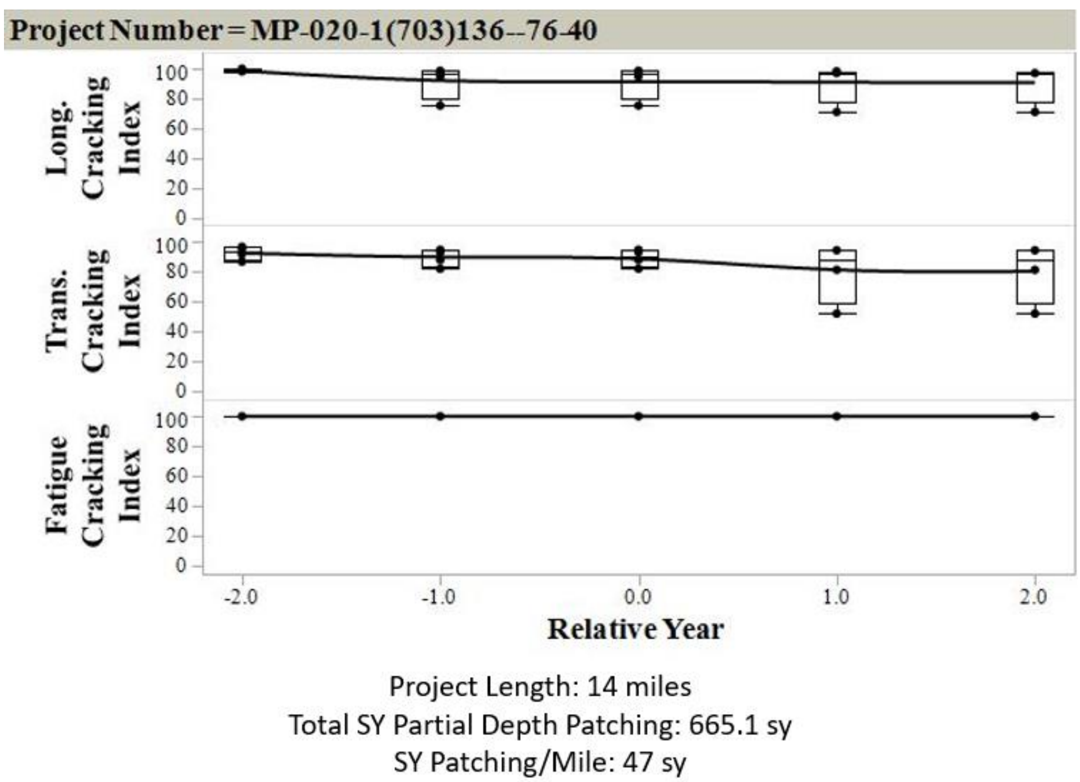


Figure 27. Example indicating how the effect of HMA patching on distress indices

The more localized a treatment, the more important it is to have high resolution data to investigate performance. In the cases where localized data is important, the benefit gets lost in the noise from the continually deteriorating pavement. In contrast, when you have a treatment applied across the entire length and width of the pavement, lower resolution data can be used to observe performance and performance can be observed with more confidence. With a few original smart keys, the resolution of the data simply cannot pick up on small localized improvements. While the distress indices are in good condition, fixing a few problem areas shows no impact on the overall index behavior.

HMA Crack Sealing and Crack Filling

Project Information

There was a total of 33 HMA crack sealing/filling projects analyzed in this study as follows:

- MP-001-6(703)87—76-52
- MP-001-6(704)68—76-92
- MP-003-2(705)210—76-12
- MP-004-3(701)75—76-76
- MP-004-3(705)49—76-13
- MP-006-1(712)135—76-77
- MP-006-6(706)307—76-82
- MP-006-6(707)247—76-52
- MP-009-2(701)109—76-55
- MP-009-2(703)256—76-96
- MP-009-2(703)280—76-03
- MP-014-1(703)106—76-64
- MP-017-1(703)7—76-77
- MP-017-2(703)71—76-99
- MP-017-2(705)78—76-99
- MP-018-2(703)132—76-55
- MP-018-2(703)264—76-33
- MP-018-2(704)141—76-55
- MP-020-6(703)283—76-28
- MP-020-6(705)295—76-31
- MP-029-3(702)127—76-97
- MP-029-3(705)94—76-67
- MP-029-3(706)106—76-67
- MP-030-1(705)139—76-08
- MP-030-6(703)218—76-06
- MP-037-3(705)10—76-67
- MP-048-4(702)1—76-73
- MP-057-2(701)32—76-07
- MP-057-2(701)8—76-12
- MP-057-2(702)25—76-12
- MP-059-3(701)105—76-24
- MP-061-6(709)112—76-82
- MP-063-2(702)225—76-45

Analytical Analysis

Table 15 shows the index service life extensions for the 33 HMA crack sealing/filling projects analyzed in this study.

Table 15. Index service life extensions for HMA crack sealing/filling projects

Averages	# of projects	Index service life extension PCI	Rutting	Riding	Cracking
All projects	33	2.2	2.9	1.6	2.3
Good (75<PCI<100)	6	0.7	3.4	0.0	0.4
Fair (50<PCI<74.9)	21	1.9	2.7	1.7	2.1
Poor (0<PCI<49.9)	6	4.7	3.2	2.9	5.0
Project number	**PCI category**	**PCI**	**Rutting**	**Riding**	**Cracking**
MP-001-6(703)87—76-52	Poor	>10	>10	>10	>10
MP-001-6(704)68—76-92	Fair	1.7	1.0	0.0	1.4
MP-003-2(705)210—76-12	Good	0.0	0.5	0.0	0.0
MP-004-3(701)75—76-76	Fair	0.0	4.2	0.0	0.0
MP-004-3(705)49—76-13	Good	2.7	3.8	0.0	1.9
MP-006-1(712)135—76-77	Fair	0.0	1.4	0.4	1.0
MP-006-6(706)307—76-82	Fair	0.0	>10	>10	0.0
MP-006-6(707)247—76-52	Poor	0.0	0.0	>10	0.0
MP-009-2(701)109—76-55	Fair	0.3	>10	0.5	>10
MP-009-2(703)256—76-96	Fair	0.0	0.0	0.0	0.0
MP-009-2(703)280—76-03	Fair	0.0	0.0	1.7	1.1
MP-014-1(703)106—76-64	Fair	0.0	0.7	3.4	0.0
MP-017-1(703)7—76-77	Poor	>10	>10	0.0	>10
MP-017-2(703)71—76-99	Poor	3.8	5.8	0.0	0.0
MP-017-2(705)78—76-99	Good	1.1	3.8	0.0	0.0
MP-018-2(703)132—76-55	Fair	0.0	7.3	0.0	1.2
MP-018-2(703)264—76-33	Fair	0.4	3.1	0.1	0.3
MP-018-2(704)141—76-55	Fair	3.0	0.0	1.8	3.2
MP-020-6(703)283—76-28	Fair	>10	0.0	1.8	0.0
MP-020-6(705)295—76-31	Fair	>10	0.0	0.0	0.0
MP-029-3(702)127—76-97	Fair	0.3	5.1	0.0	0.3
MP-029-3(705)94—76-67	Fair	>10	>10	6.2	>10
MP-029-3(706)106—76-67	Poor	>10	>10	>10	>10
MP-030-1(705)139—76-08	Good	0.2	5.0	0.0	0.0
MP-030-6(703)218—76-06	Fair	0.9	2.5	0.0	0.0
MP-037-3(705)10—76-67	Fair	1.1	2.4	2.1	1.8
MP-048-4(702)1—76-73	Good	0.4	1.8	0.0	0.3
MP-057-2(701)32—76-07	Fair	2.3	3.8	2.0	2.4
MP-057-2(701)8—76-12	Fair	2.5	6.0	0.4	0.0
MP-057-2(702)25—76-12	Good	0.0	5.7	0.0	0.0
MP-059-3(701)105—76-24	Fair	1.2	>10	2.4	1.8
MP-061-6(709)112—76-82	Fair	>10	>10	>10	>10
MP-063-2(702)225—76-45	Poor	1.7	0.0	0.4	0.0

Note: The index service life extensions in the averages section of the table include the service life extensions greater than 10 years via the straight-line depreciation method discussed in "Analytical Analysis" section.

When broken down by PCI category at relative year 0, 6 of these projects were good pavements, 21 of these projects were placed on fair pavements, and 6 projects were placed on poor pavements.

On average, the PCI service life was increased by 2.2 years and a two year life extension has been found in other crack-sealing studies. The other three indices recorded a low of 1.6 years of riding service life improvement, 2.9 years of rutting service life improvement, and 2.3 years of cracking service life improvement. Even with the notion that crack sealing/filling has minimal pavement impact, the simple action of keeping water out of a pavement structure can prevent further deterioration of a pavement and its subgrade. The improved rutting index seems to highlight a potential anomaly in the collected data because crack sealing/filling would not be anticipated to improve rutting in the pavement. There may be localized improvements due to sealant material in the wheel path or even a general stabilization to the pavement over time.

When comparing the index service life extensions between PCI categories, in Figure 28, a very clear growth with decreasing pavement condition is noticed.

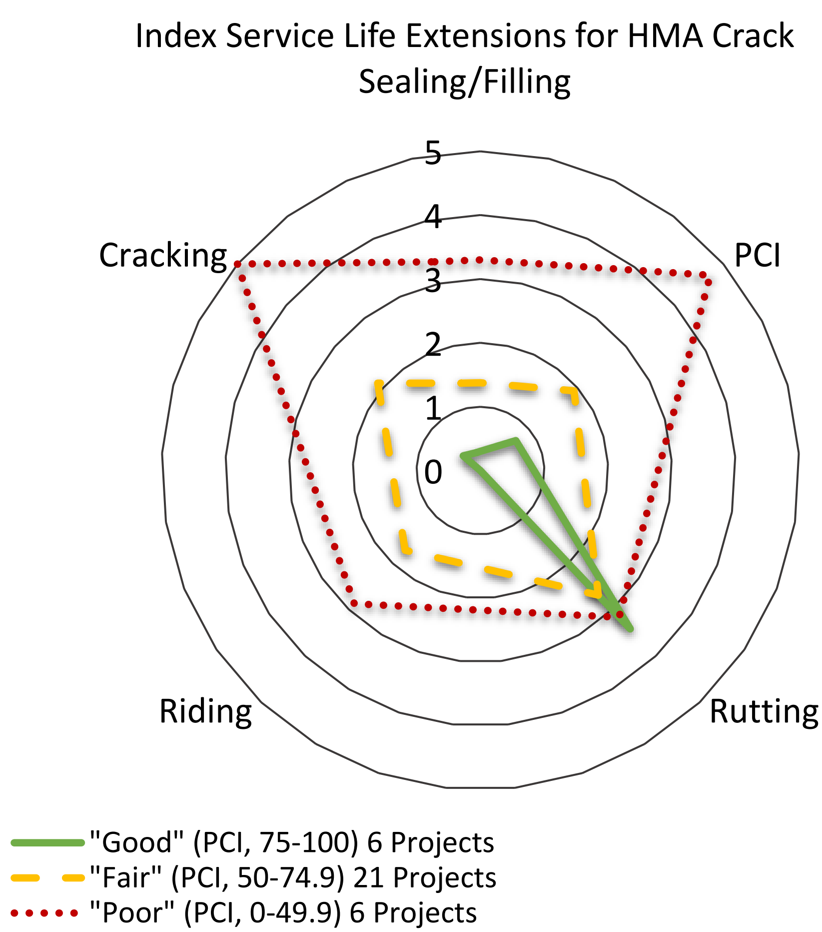


Figure 28. PCI categorical comparison of index service life extensions for HMA crack sealing/filling projects

Poor pavements saw larger index service life extensions than the fair pavements, which most saw larger index service life extensions than the good pavements.

The first thing that this graphs highlights is the increase in cracking index service life for poor and fair pavements, as expected. The good pavements do not see this increase as the severity of the cracking is likely minimal. Interestingly, moderate improvement was seen in the riding index, which reflects the smoothness obtained after filling the cracks with filler material. With the PCI service life extension having an average value of 2.2 years, this treatment was the least effective of the four evaluated flexible pavement preservation treatments. With this treatment being the most economical, the benefit observed for the amount spent still highlights the overall effectiveness of crack sealing/filling.

The initial index value benefits, the difference between the observed performance and do nothing trend lines at relative year 0, compared to the index value benefits for relative year 4 can be seen in Figure 29.

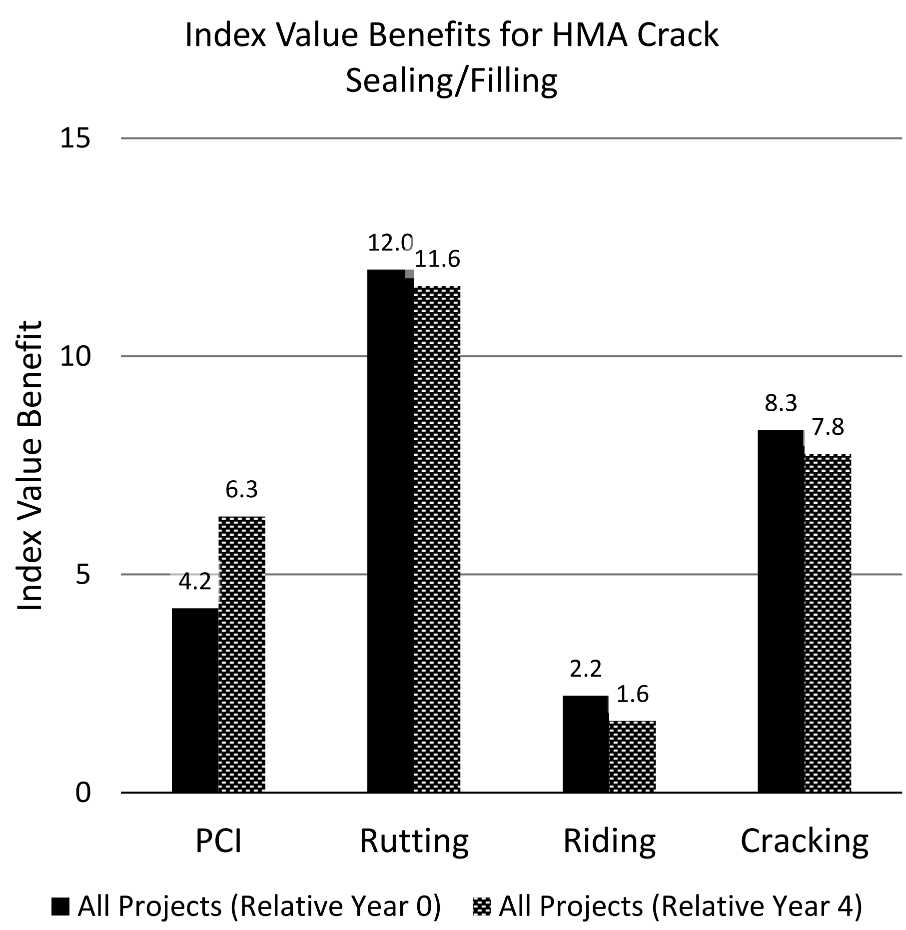


Figure 29. Index value benefits for HMA crack sealing/filling projects

Dissimilar to the previous flexible pavement preservation treatment results, the rate of deterioration after application of HMA crack sealing/filling has slightly increased across the four indices except for the PCI when compared to the rate prior to treatment application. Since crack sealing/filling provides minimal structural change, a pavement that has developed cracking will continue to develop cracking until the causes are addressed. Crack sealing/filling only slows the rate of already developed cracks, not cracks that will develop after application.

Anecdotal Analysis

Table 16 shows the results for each HMA crack sealing/filling anecdotal analysis, and Table 17 shows the collective results using the most frequently reported values for each PCI category.

Table 16. Individual anecdotal results for HMA crack sealing/filling projects

Project number	PCI category	Fatigue cracking	Trans. cracking	Long. cracking
MP-003-2(705)210--76-12	Good	NOI	NOI	NOI
MP-004-3(705)49—76-13	Good	NOI	NOI	NOI
MP-017-2(705)78—76-99	Good	NOI	NOI	NOI
MP-030-1(705)139—76-08	Good	NOI	NOI	NOI
MP-048-4(702)1—76-73	Good	NOI	NOI	NOI
MP-057-2(702)25—76-12	Good	NOI	NOI	NOI
MP-001-6(704)68—76-92	Fair	NOI	I	I
MP-004-3(701)75—76-76	Fair	NOI	NOI	NOI
MP-006-1(712)135—76-77	Fair	NOI	NOI	NOI
MP-006-6(706)307—76-82	Fair	NOI	NOI	NOI
MP-009-2(701)109—76-55	Fair	NOI	NOI	NOI
MP-009-2(703)256—76-96	Fair	NOI	NOI	NOI
MP-009-2(703)280—76-03	Fair	NOI	NOI	NOI
MP-014-1(703)106—76-64	Fair	NOI	NOI	NOI
MP-018-2(703)132—76-55	Fair	NOI	NOI	NOI
MP-018-2(703)264—76-33	Fair	NOI	NOI	NOI
MP-018-2(704)141—76-55	Fair	I	I	NOI
MP-020-6(703)283—76-28	Fair	NT	NOI	NOI
MP-020-6(705)295—76-31	Fair	NT	NOI	NOI
MP-029-3(702)127—76-97	Fair	NT	NOI	NOI
MP-029-3(705)94—76-67	Fair	NT	I	NOI
MP-030-6(703)218—76-06	Fair	NOI	I	NOI
MP-037-3(705)10—76-67	Fair	I	NOI	NOI
MP-057-2(701)32—76-07	Fair	NOI	NOI	NOI
MP-057-2(701)8—76-12	Fair	NOI	NOI	NOI
MP-059-3(701)105—76-24	Fair	NOI	NOI	NOI
MP-061-6(709)112—76-82	Fair	NOI	NOI	NOI
MP-001-6(703)87—76-52	Poor	I	I	I
MP-006-6(707)247—76-52	Poor	NT	NOI	NOI
MP-017-1(703)7—76-77	Poor	NOI	NOI	NOI
MP-017-2(703)71—76-99	Poor	NOI	NOI	NOI
MP-029-3(706)106—76-67	Poor	NT	I	I
MP-063-2(702)225—76-45	Poor	NT	I	NOI

Note: NT denotes lack of clear trend; NOI denotes a trend that does not indicate distress improvement; and I denotes a trend that does indicate distress improvement.

Table 17. Collective anecdotal results for HMA crack sealing/filling projects

PCI category	Good	Fair	Poor
# of projects	7	21	6
Fatigue cracking index	NOI:(6/6)	NOI:(15/21)	NT:(3/6)
Transverse cracking index	NOI:(6/6)	NOI:(17/21)	I:(3/6)
Long. cracking index	NOI:(6/6)	NOI:(20/21)	NOI:(4/6)

Note: NT denotes lack of clear trend; NOI denotes a trend that does not indicate distress improvement; and I denotes a trend that does indicate distress improvement.

The only treatment level improvements for the analyzed performance indicators was transverse cracking of poor pavements. Very few projects saw any improvement after application of HMA crack sealing/filling. Good and fair pavements saw not-treatment level improvements after application.

Chip Seal and Fog Seal

This section does not provide any further analysis of either chip seals or fog seals. The few fog seal projects that were originally examined were discovered to be applied to the interstate shoulders; thus, any pavement performance data from the PMIS database was not in relation to the performance of the shoulders. In addition, the very limited chip seal project data that were obtained were determined to provide no helpful analytical conclusions. The current use and expectation of chip seals and fog seals can be found in the literature review.

RIGID PAVEMENT PRESERVATION PERFORMANCE ANALYSIS

Individual figures for rigid pavement preservation methods containing both the analytical and anecdotal graphical analyses for each project are broken into sections according to the pavement preservation method and can be seen in Appendix C.

PCC Patching

Project Information

There was a total of 14 PCC patching projects analyzed in this study as follows:

- MP-002-4(700)86—76-80
- MP-018-2(704)214—76-34
- MP-018-3(703)20—76-84
- MP-025-4(701)48—76-01
- MP-025-4(702)16—76-80
- MP-030-4(711)0—76-43
- MP-044-4(706)45—76-05
- MP-048-4(707)22—76-69
- MP-075-3(707)101—76-75
- MP-092-4(705)81—76-01
- MP-127-4(702)0—76-43
- MP-148-4(702)50—76-15
- MP-169-4(704)65—76-61
- MP-169-4(708)47—76-88

Analytical Analysis

Table 18 shows the index service life extensions for the 14 PCC patching projects analyzed in this study.

Table 18. Index service life extensions for PCC patching projects

Averages	# of projects	Index service life extension			
		PCI	Faulting	Riding	Cracking
All projects	14	1.5	0.0	2.8	4.3
Good (75<PCI<100)	1	0.1	0.0	9.5	10.0
Fair (50<PCI<74.9)	10	1.0	0.0	1.9	3.0
Poor (0<PCI<49.9)	3	3.9	0.0	3.3	6.7
Project number	**PCI category**	**PCI**	**Faulting**	**Riding**	**Cracking**
MP-002-4(700)86—76-80	Fair	0.0	0.0	0.0	0.0
MP-018-2(704)214—76-34	Fair	0.8	0.0	5.4	>10
MP-018-3(703)20—76-84	Poor	0.0	0.0	0.0	>10
MP-025-4(701)48—76-01	Poor	1.7	0.0	0.0	0.2
MP-025-4(702)16—76-80	Fair	>10	0.0	0.0	0.0
MP-030-4(711)0—76-43	Fair	0.0	0.0	>10	2.1
MP-044-4(706)45—76-05	Good	0.1	0.0	9.5	>10
MP-048-4(707)22—76-69	Fair	3.0	0.0	>10	>10
MP-075-3(707)101—76-75	Fair	0.0	0.0	0.0	0.0
MP-092-4(705)81—76-01	Poor	>10	0.0	>10	>10
MP-127-4(702)0—76-43	Fair	0.0	0.0	1.6	>10
MP-148-4(702)50—76-15	Fair	0.0	0.0	0.9	0.0
MP-169-4(704)65—76-61	Fair	1.1	0.0	>10	0.4
MP-169-4(708)47—76-88	Fair	1.7	0.0	0.0	0.0

Note: The index service life extensions in the averages section of the table include the service life extensions greater than 10 years via the straight-line depreciation method discussed in "Analytical Analysis" section.

When broken down by PCI category at relative year 0, there was 1 good project, 10 fair projects, and 3 poor projects.

For preservation methods including such local remedies, such as patching, a disconnect between the type of data collection and the seen improvement becomes present. The four evaluated indices provide a lower resolution that covers the entirety of a given pavement section, while fixing a severe distress with a patch may not show up as strongly. In this situation, looking at a different PMIS category may shed a new light on the effect of patching. However, the PMIS data column that includes percent of cracked slabs consists almost entirely of error values or zero values. Any other values were completely inconclusive.

On average, the PCI service life was increased by 1.5 years. The other three indices recorded 0.0 years of faulting index service life extension (as a result of no pre-treatment index data in the PMIS database), 2.8 years of riding index service life extension, and 4.3 years of cracking index service life extension.

When comparing the index service life extensions between PCI categories in Figure 30, the 1 good project saw substantial cracking and riding index service life extensions, while the 10 fair projects and the 3 poor projects showed the similar behavior, with the poor projects demonstrating larger index service life extensions.

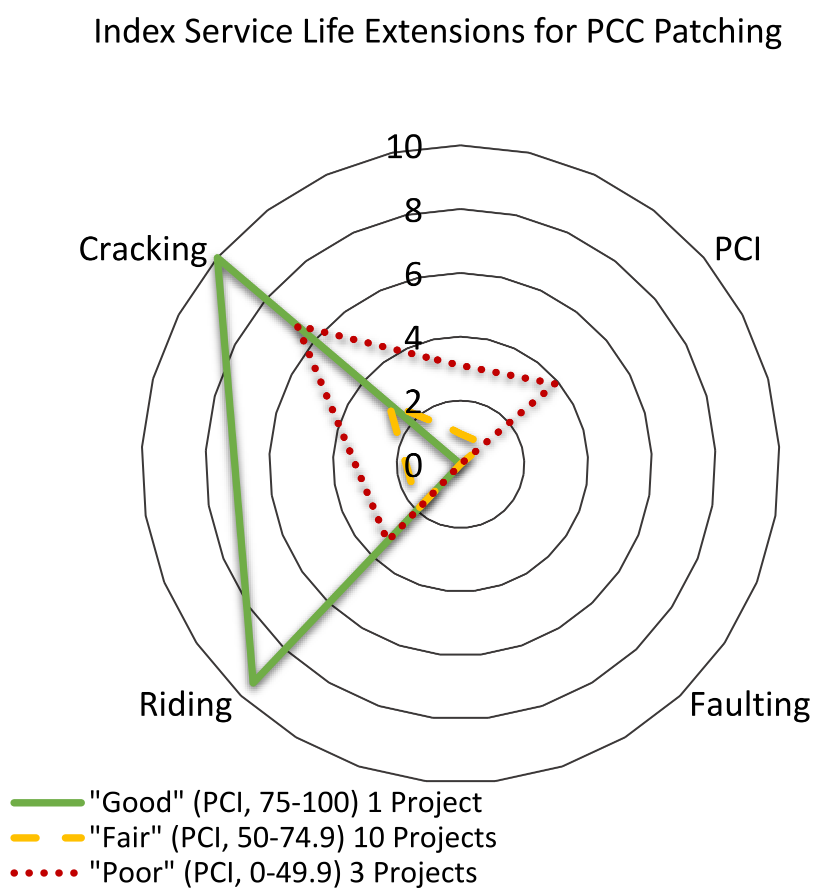


Figure 30. PCI categorical comparison of index service life extensions for PCC patching projects

The one good project appears to be anomalous in performance when comparing the fair and poor projects. Minimal PCI service life extension was observed as PCC patching is spot-applied treatment for which improvement will be less likely to appear in the low resolution of a pavement-wide index. Cracking showed improvement most likely as a result of patching the severely damaged pavement sections within the project.

The initial index value benefits, which represent the difference between the OP and DN trend lines at relative year 0, compared to the index value benefits for relative year 4 can be seen in Figure 31.

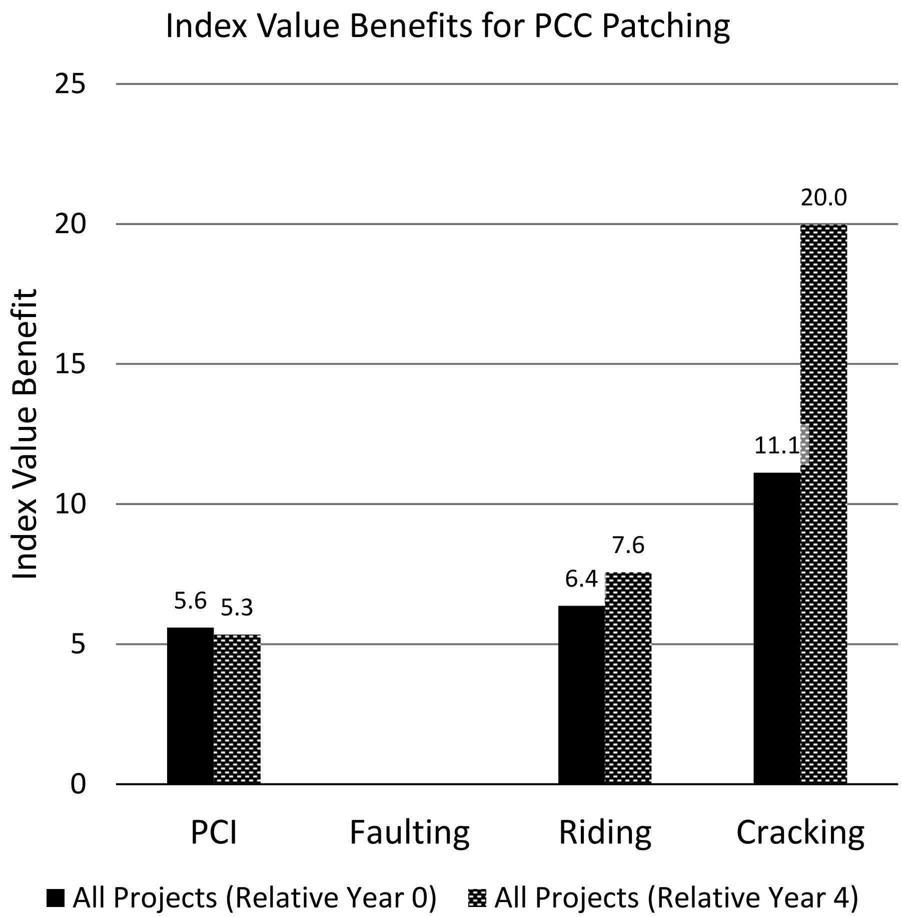


Figure 31. Index value benefits for PCC patching projects

Without the DN and OP trend for the faulting index, no analytical analysis could be determined for that index. Besides that, the only notable information out of the Figure 31 graph is the substantial improvement in the cracking index value benefit between the initial benefit and the relative year 4 benefit. The PCC patches must have been applied to the appropriate sections such that areas of severe cracking were mitigated and controlled after the patching was performed.

Anecdotal Analysis

Table 19 shows the results for each PCC patching anecdotal analysis, and Table 20 shows the collective results using the most frequently reported values for each PCI category.

Table 19. Individual anecdotal results for PCC patching projects

Project number	PCI category	Fatigue cracking	Transverse cracking	Long. cracking	D-cracking	Joint spalling
MP-044-4(706)45—76-05	Good	NT	NOI	NOI	NOI	NOI
MP-002-4(700)86—76-80	Fair	NOI	NOI	NOI	NOI	NOI
MP-018-2(704)214—76-34	Fair	NOI	NOI	NOI	NOI	NOI
MP-025-4(702)16—76-80	Fair	NT	NOI	NOI	NOI	NOI
MP-030-4(711)0—76-43	Fair	NT	NOI	NOI	NOI	NOI
MP-048-4(707)22—76-69	Fair	NT	I	I	NOI	NOI
MP-075-3(707)101—76-75	Fair	NT	NOI	NOI	NOI	NOI
MP-127-4(702)0—76-43	Fair	NT	NOI	NOI	NOI	NOI
MP-148-4(702)50—76-15	Fair	NOI	NOI	NOI	NOI	NOI
MP-169-4(704)65—76-61	Fair	NOI	NOI	NOI	NOI	NOI
MP-169-4(708)47—76-88	Fair	NT	I	NOI	NOI	NOI
MP-018-3(703)20—76-84	Poor	NOI	I	NOI	NOI	NOI
MP-025-4(701)48—76-01	Poor	NOI	NOI	NOI	NOI	NOI
MP-092-4(705)81—76-01	Poor	I	I	I	NOI	NOI

Note: NT denotes lack of clear trend; NOI denotes a trend that does not indicate distress improvement; and I denotes a trend that does indicate distress improvement.

Table 20. Collective anecdotal results for PCC patching projects

PCI category	Good	Fair	Poor
# of projects	1	10	3
Fatigue cracking index	NT:(1/1)	NT:(6/10)	NOI:(2/3)
Transverse cracking index	NOI:(1/1)	NOI:(8/10)	I:(2/3)
Long. cracking index	NOI:(1/1)	NOI:(9/10)	NOI:(2/3)
D-cracking	NOI:(1/1)	NOI:(10/10)	NOI:(3/3)
Joint spalling	NOI:(1/1)	NOI:(10/10)	NOI:(3/3)

Note: NT denotes lack of clear trend; NOI denotes a trend that does not indicate distress improvement; and I denotes a trend that does indicate distress improvement.

Looking at either table, very little improvement was noticed across the board, with the exception of transverse cracking in poor pavements. Again, this is indicative of a high resolution distress being attempted to be measured using a low resolution method. Without a doubt, the patching locations greatly improved the condition of the pavement back to nearly 100%, but these localized spots are not picked up in the PMIS data measurement.

Joint Sealing and Crack Filling

Project Information

There was a total of seven PCC crack filling and joint sealing type projects analyzed in this study as follows:

- MP-002-4(707)15—76-36
- MP-080-4(702)102—76-25
- MP-218-2(702)186—76-07
- MPIN-035-1(705)113—0N-85
- MPIN-080-1(706)142—0N-77
- MPIN-080-4(705)111—0N-25
- MPIN-080-4(706)119—0N-25

Analytical Analysis

Table 21 shows the index service life extensions for the PCC crack filling and joint sealing type projects analyzed in this study.

Table 21. Index service life extensions for PCC crack filling and joint sealing projects

		Index service life extension			
Averages	**# of projects**	**PCI**	**Faulting**	**Riding**	**Cracking**
All projects	7	2.7	0.0	4.1	2.0
Good (75<PCI<100)	2	0.0	0.0	0.6	0.0
Fair (50<PCI<74.9)	2	4.6	0.0	2.7	4.6
Poor (0<PCI<49.9)	3	3.3	0.0	7.3	1.6
Project number	**PCI category**	**PCI**	**Faulting**	**Riding**	**Cracking**
MP-002-4(707)15—76-36	Poor	>10	0.0	>10	1.7
MP-080-4(702)102—76-25	Poor	2.4	0.0	>10	3.0
MP-218-2(702)186—76-07	Poor	4.0	0.0	1.9	0.0
MPIN-035-1(705)113—0N-85	Fair	7.4	0.0	>10	2.6
MPIN-080-1(706)142—0N-77	Fair	>10	0.0	>10	>10
MPIN-080-4(705)111—0N-25	Good	0.0	0.0	1.2	0.0
MPIN-080-4(706)119—0N-25	Good	0.0	0.0	0.0	0.0

Note: The index service life extensions in the averages section of the table include the service life extensions greater than 10 years via the straight-line depreciation method discussed in "Analytical Analysis" section.

When broken down by PCI category at relative year 0, there are two good projects, two fair projects, and three poor projects.

On average, the PCI service life was increased by 2.7 years. The other three indices recorded 0.0 years of faulting index service life extension (as a result of no pre-treatment index data in the PMIS database), 2.0 years of cracking index service life extension, and 4.1 years of riding index service life extension.

When comparing the index service life extensions between PCI categories in Figure 32, there are different behaviors depending on the pre-treatment condition of the pavement. However, the small sample size could be easily skewing the actual results due to the sensitivity of the analysis.

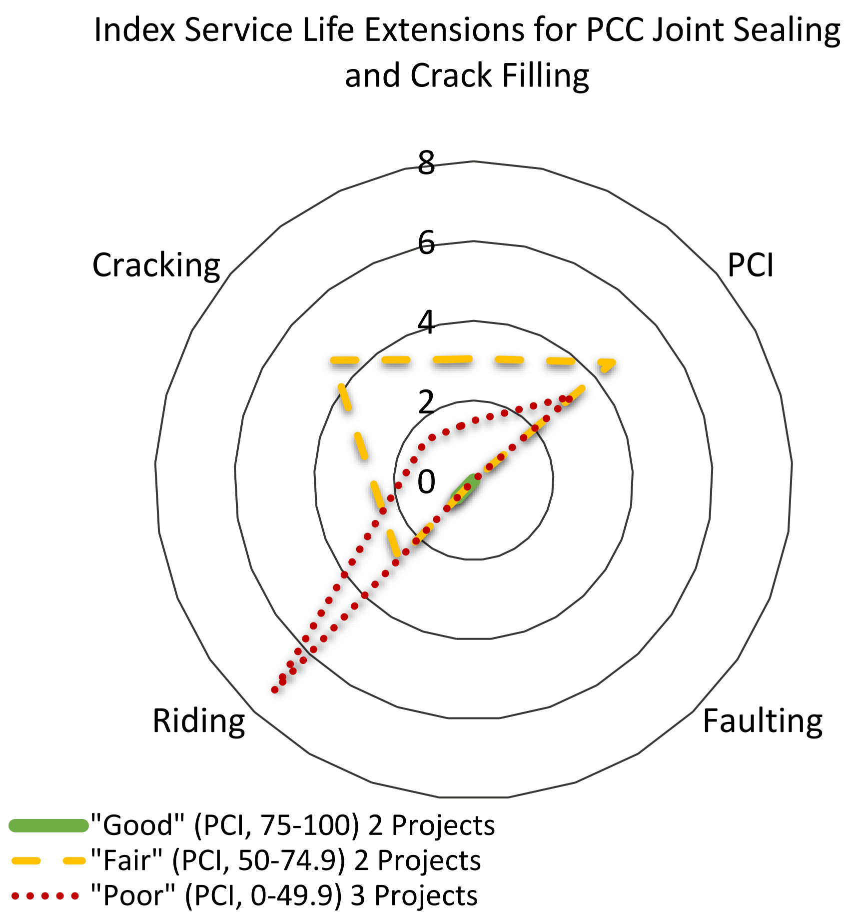


Figure 32. PCI categorical comparison of index service life extensions for PCC crack filling and joint sealing projects

The two good projects saw no improvement except for one instance of a riding index service life extension, but it was very minimal. The fair and poor projects showed promising PCI service life extensions, but the cracking and riding indices were reliant on the analyzed projects. By keeping the water out of the joints and cracks in a PCC pavement, reduction in pumping and base/subgrade infiltration showed the ability to extend the life of the pavement. The smoother surface also extended the riding index service life.

The initial index value benefits, which represents the difference between the OP and DN trend lines at relative year 0, compared to the index value benefits for relative year 4 can be seen in Figure 33.

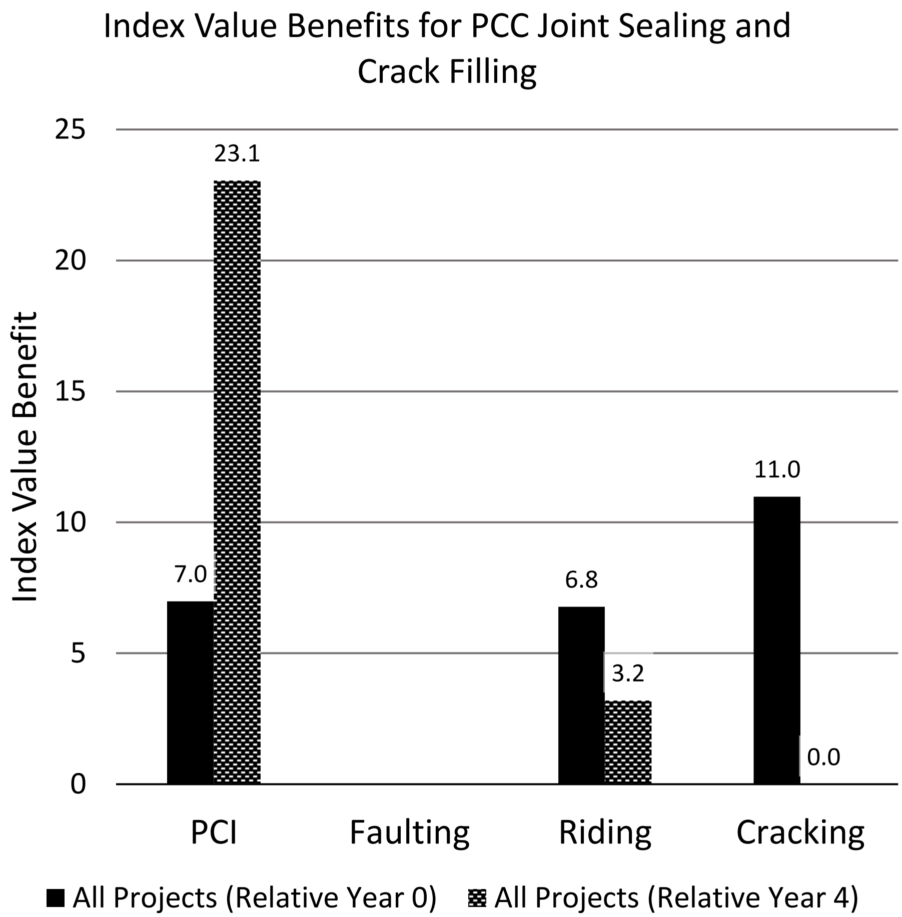


Figure 33. Index value benefits for PCC crack filling and joint sealing projects

Without the DN and OP trend for the faulting index, no analytical analysis could be determined for that index. A very large improvement in PCI benefit between the initial benefit and relative year 4 shows a slower pavement deterioration after sealing joints and filling cracks. This comes back to the importance of keeping water out of a pavement and maintaining the drainage underneath the pavement as well. The drop in cracking index benefit is likely due to other cracks forming or the same cracks growing in size in either width, height, or both.

Anecdotal Analysis

Table 22 shows the results for each PCC crack filling and joint sealing anecdotal analysis, and Table 23 shows the collective results using the most frequently reported values for each PCI category.

Table 22. Individual anecdotal results for PCC crack filling and joint sealing projects

Project number	PCI category	Transverse cracking	Long. cracking
MPIN-080-4(705)111—0N-25	Good	NOI	NOI
MPIN-080-4(706)119—0N-25	Good	NOI	NOI
MPIN-035-1(705)113—0N-85	Fair	I	I
MPIN-080-1(706)142—0N-77	Fair	NOI	NOI
MP-002-4(707)15—76-36	Poor	I	NOI
MP-080-4(702)102—76-25	Poor	I	I
MP-218-2(702)186—76-07	Poor	NOI	NOI

Note: NOI denotes a trend that does not indicate distress improvement; and I denotes a trend that does indicate distress improvement.

Table 23. Collective anecdotal results for PCC crack filling and joint sealing projects

PCI category	Good	Fair	Poor
# of projects	2	2	3
Transverse cracking index	NOI:(2/2)	I:(1/2)	I:(2/3)
Long. cracking index	NOI:(2/2)	I:(1/2)	NOI:(2/3)

Note: NOI denotes a trend that does not indicate distress improvement; and I denotes a trend that does indicate distress improvement.

The two good pavements saw no improvements for either transverse cracking or longitudinal cracking. The two fair pavements performed differently from each other, with one showing improvements in both indices and the other showing no improvement. Lastly, two of three poor pavements saw improved transverse cracking but unimproved longitudinal cracking. The crack sealing on these projects was likely targeting more transverse cracks than longitudinal cracks.

Dowel Bar Retrofit and Diamond Grinding

Project Information

There was a total of four dowel bar retrofit and diamond grind type projects analyzed in this study. The project numbers are as follows:

- NHSN-16301(176)—2R-77
- IMN-080-2(226)45—76-01
- NHSX-020-4(50)—3H-40
- STPN-141-4(28)—2J-14

Analytical Analysis

Table 24 shows the index service life extensions for the dowel bar retrofit and diamond grind type projects analyzed in this study.

Table 24. Index service life extensions for dowel bar retrofit and diamond grind projects

Averages	# of projects	Index service life extension			
		PCI	Faulting	Riding	Cracking
All projects	4	6.7	5.0	10.0	3.0
Good (75<PCI<100)	0	-	-	-	-
Fair (50<PCI<74.9)	2	4.9	5.0	10.0	1.0
Poor (0<PCI<49.9)	2	8.4	5.0	10.0	5.0
Project number	**PCI category**	**PCI**	**Faulting**	**Riding**	**Cracking**
NHSN-16301(176)—2R-77	Poor	>10	0.0	>10	0.0
IMN-080-2(226)45—76-01	Fair	3.2	0.0	>10	1.3
NHSX-020-4(50)—3H-40	Poor	>10	>10	>10	>10
STPN-141-4(28)—2J-14	Fair	>10	>10	>10	>10

Note: The index service life extensions in the averages section of the table include the service life extensions greater than 10 years via the straight-line depreciation method discussed in “Analytical Analysis” section.

When broken down by PCI category at relative year 0, there are zero good projects, two fair projects, and two poor projects.

On average, the PCI service life was increased by 6.7 years. The other three indices recorded 5.0 years of faulting service life extension, 10.0 years of riding index service life extension, and 3.0 years of cracking index service life extension. Note that the straight line depreciation method does not function properly for the faulting or riding indices in this scenario as the only averaged index service life extensions were either zero or greater than 10 years. For this instance, the average of the projects was taken using the values of 0 or 10, resulting in the faulting service life extension of 5.0 and the riding service life extension of 10.0.

When comparing the index service life extensions between PCI categories in Figure 34, the two poor pavements show larger PCI and cracking index service life extensions when compared to the two fair pavements.

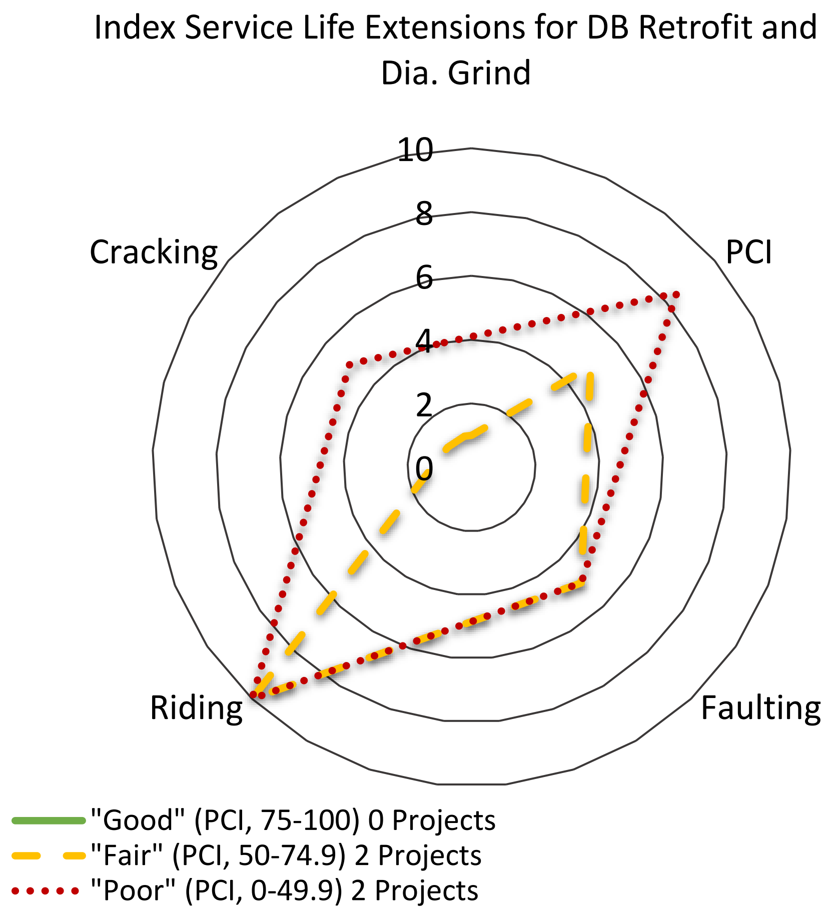


Figure 34. PCI categorical comparison of index service life extensions for dowel bar retrofit and diamond grind projects

This shows again how pavement have more room on the index scales to increase in value when they are starting from a lower position.

The riding and faulting indices are identical between the two PCI categories, but the differences in the other two indices is highly variable due to the limited number of projects. Regardless, obtaining any PCI service life extensions is the result when the faulting issues and surface irregularities are remedied to any extent. The two projects where faulting was recorded as zero resulted from a lack of pre-treatment data. The faulting data for each project after treatment was averaged 77 and 85, respectively. These higher values imply that the treatment was effective, but this cannot be confirmed within the PMIS data.

The initial index value benefits, which represent the difference between the OP and DN trend lines at relative year 0, compared to the index value benefits for relative year 1 can be seen in Figure 35.

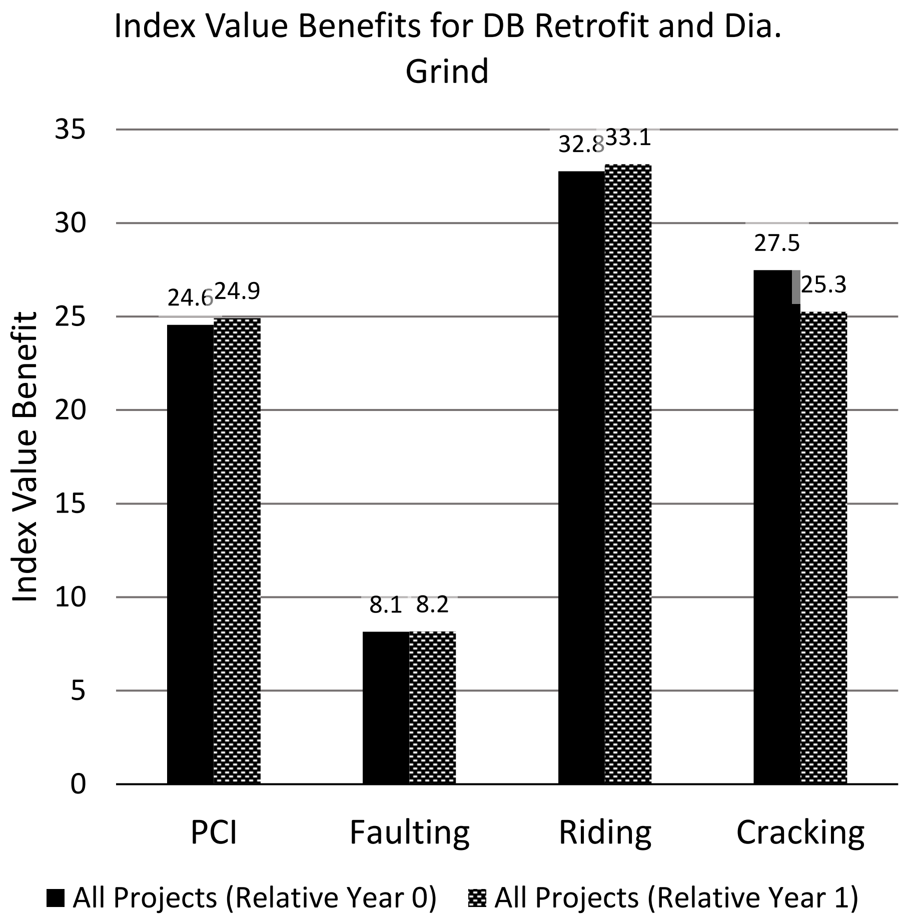


Figure 35. Index value benefits for dowel bar retrofit and diamond grind projects

Contrary to the other preservation treatments, this comparison could only be made at relative year 1 instead of 4 as relative year 0 for these projects was too current for more post-treatment data.

Anecdotal Analysis

Table 25 shows the results for each dowel bar retrofit and diamond grind anecdotal analysis, and Table 26 shows the collective results using the most frequently reported values for each PCI category.

Table 25. Individual anecdotal results for dowel bar retrofit and diamond grind projects

Project number	PCI category	Transverse cracking	Long. cracking	Friction	D-cracking	Joint spalling
NHSN-16301(176)—2R-77	Poor	NOI	NOI	NOI	I	NOI
IMN-080-2(226)45--76-01	Fair	I	I	NOI	NOI	NOI
NHSX-020-4(50)—3H-40	Poor	I	NOI	NOI	NOI	NOI
STPN-141-4(28)—2J-14	Fair	NOI	NOI	NOI	I	NOI

Note: NOI denotes a trend that does not indicate distress improvement; and I denotes a trend that does indicate distress improvement.

Table 26. Collective anecdotal results for dowel bar retrofit and diamond grind projects

PCI category	Good	Fair	Poor
# of projects	0	2	2
Transverse cracking index	-	I:(1/2)	I:(1/2)
Long. cracking index	-	I:(1/2)	NOI:(2/2)
Friction	-	NOI:(2/2)	NOI:(2/2)
D-cracking	-	I:(1/2)	I:(1/2)
Joint spalling	-	NOI:(2/2)	NOI:(2/2)

Note: NOI denotes a trend that does not indicate distress improvement; and I denotes a trend that does indicate distress improvement.

As expected, D-cracking showed some improvement after this treatment when the problematic joints were addressed. For the transverse and longitudinal cracking indices, it appears that the diamond grinding improved the condition for the pavements in worse condition. Again, the sensitivity of the collected analysis is high as a result of the very few projects analyzed for this preservation treatment.

Grinding and Grooving

Project Information

There was a total of two grinding and grooving type projects analyzed in this study as follows:

- MP-151-6(700)16—76-06
- MP-922-6(717)0—76-57

Analytical Analysis

When broken down by PCI category at relative year 0, there are only two fair projects. The lack of projects stems from that fact that very little grinding and grooving is being performed in the past few years, while a lot of grinding was performed in the 1980s. Figures 36 and 37 display the three curve-fit indices used to determine service life extension.

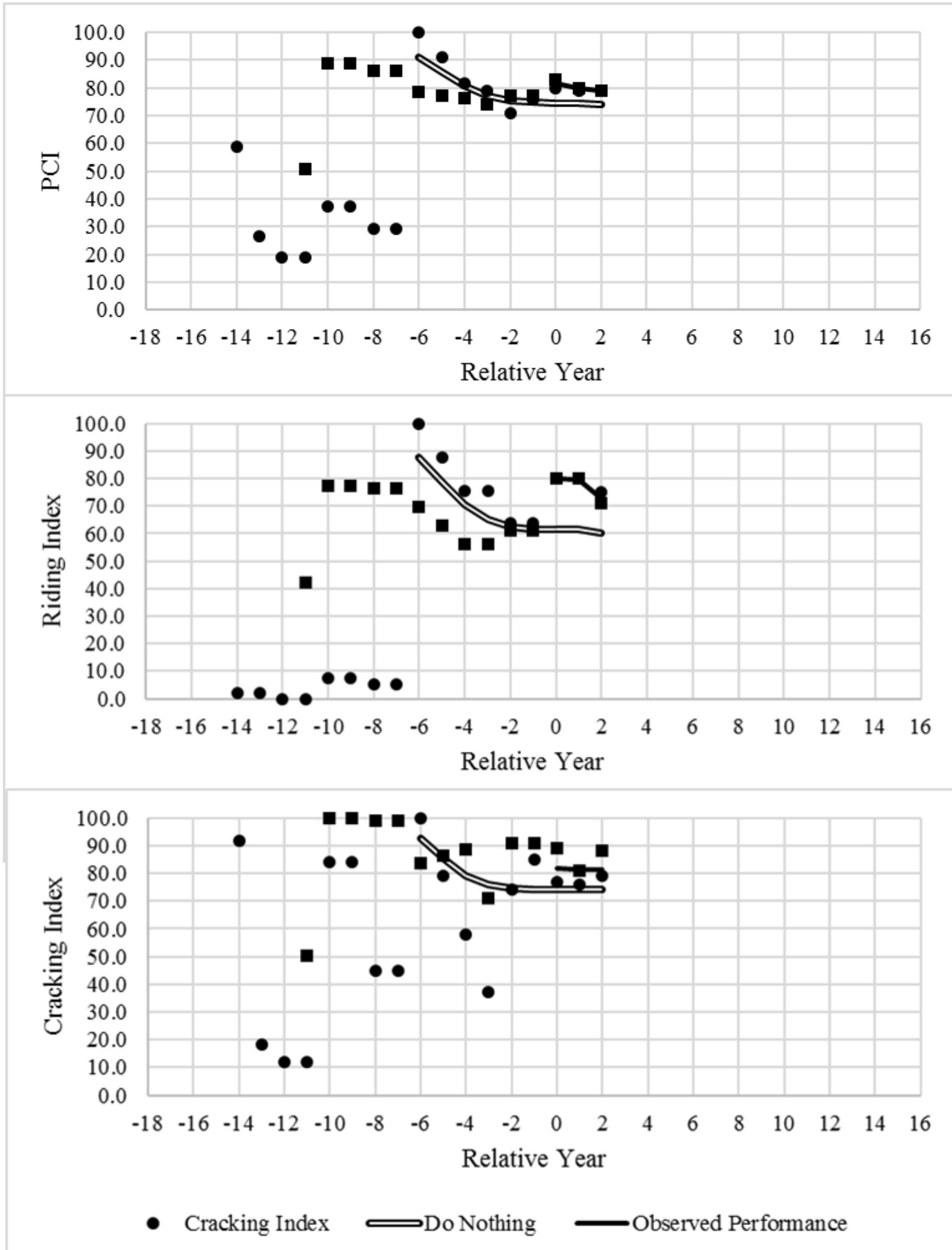


Figure 36. PCI and riding/cracking index graphs for Project MP-151-6(700)16—76-06

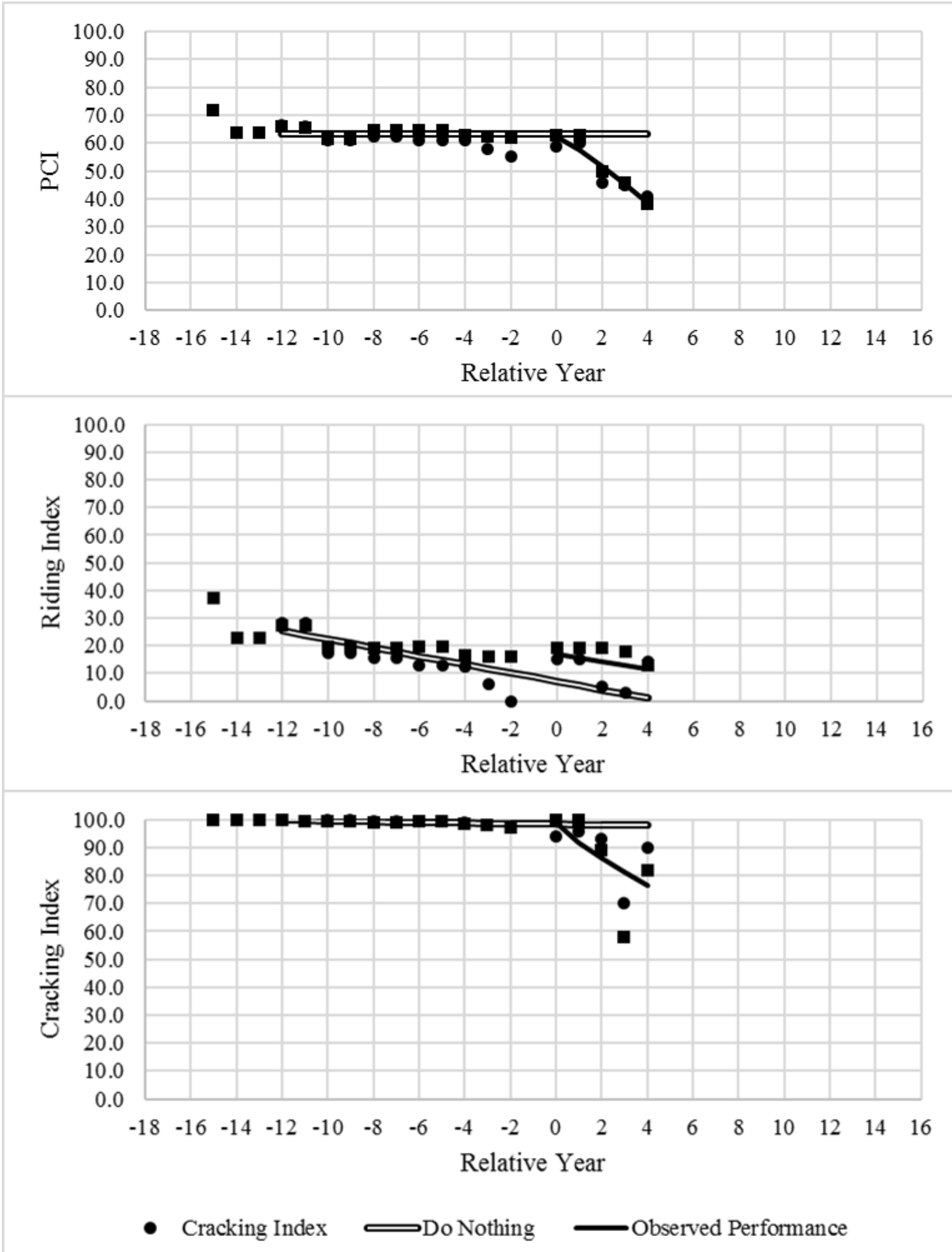


Figure 37. PCI and riding/cracking index graphs for Project MP-922-6(717)0—76-57

On average, the PCI service life was increased by 4.6 years. The other indices recorded 4.8 years of riding index service life extension and 5.0 years for cracking index service life extension. The faulting index data were not complete enough to formulate a DN or OP trend line, resulting in no observed faulting index service life extension. Note that the straight line depreciation method does not function properly for the cracking index in this scenario as the only averaged index service life extension was zero years. For this instance, the average of the two projects was taken using the values of 0 and 10, resulting in the service life extension values of 5.0.

The lack of projects provide a severely limited data set, and the previously discussed averages prevent sound conclusions for the lifespan of this treatment. The difference in behavior between the two projects alone is very apparent. Project MP-151-6(700)16—76-06 was performed on a pavement roughly 10 points higher in PCI and a substantially higher riding index value.

When comparing the index service life extensions between PCI categories, it quickly becomes only a comparison of fair projects, seen in Figure 38.

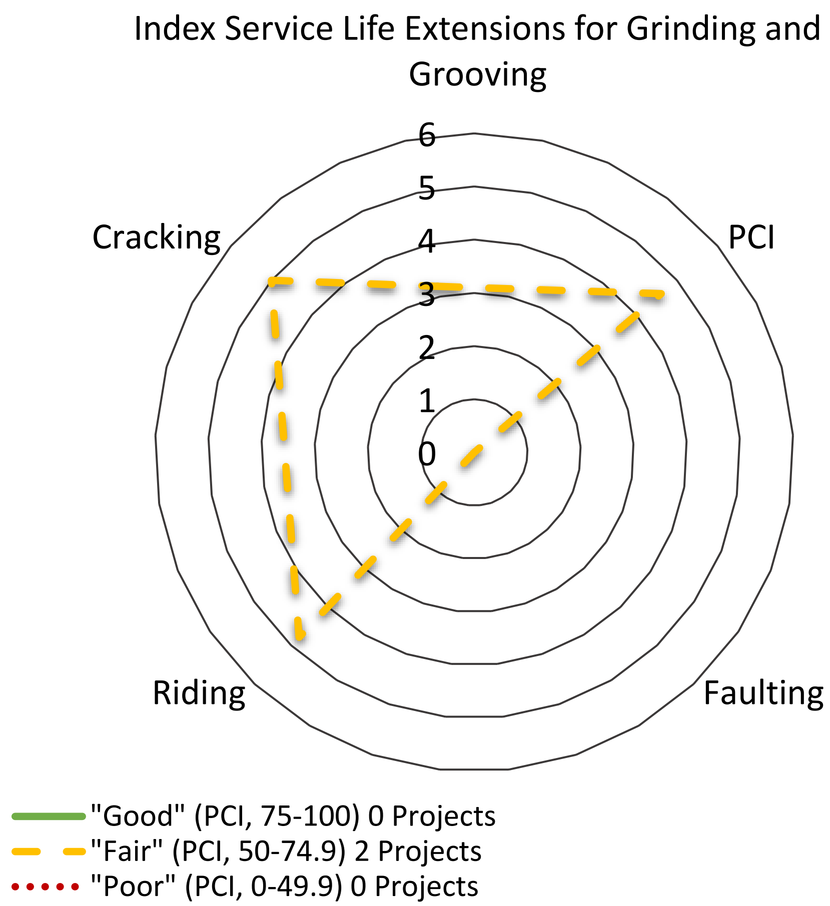


Figure 38. PCI categorical comparison of index service life extensions for grinding and grooving projects

Due to the sensitivity of such few projects, minimal conclusive information can be determined. One project performed well overall after being grinded and grooved, while the other saw no improvement except for the riding index. This is indicative of the grinding proving effective at smoothing the pavement surface.

The initial index value benefits, which represent the difference between the OP and DN trend lines at relative year 0, compared to the index value benefits for relative year 4 can be seen in Figure 39.

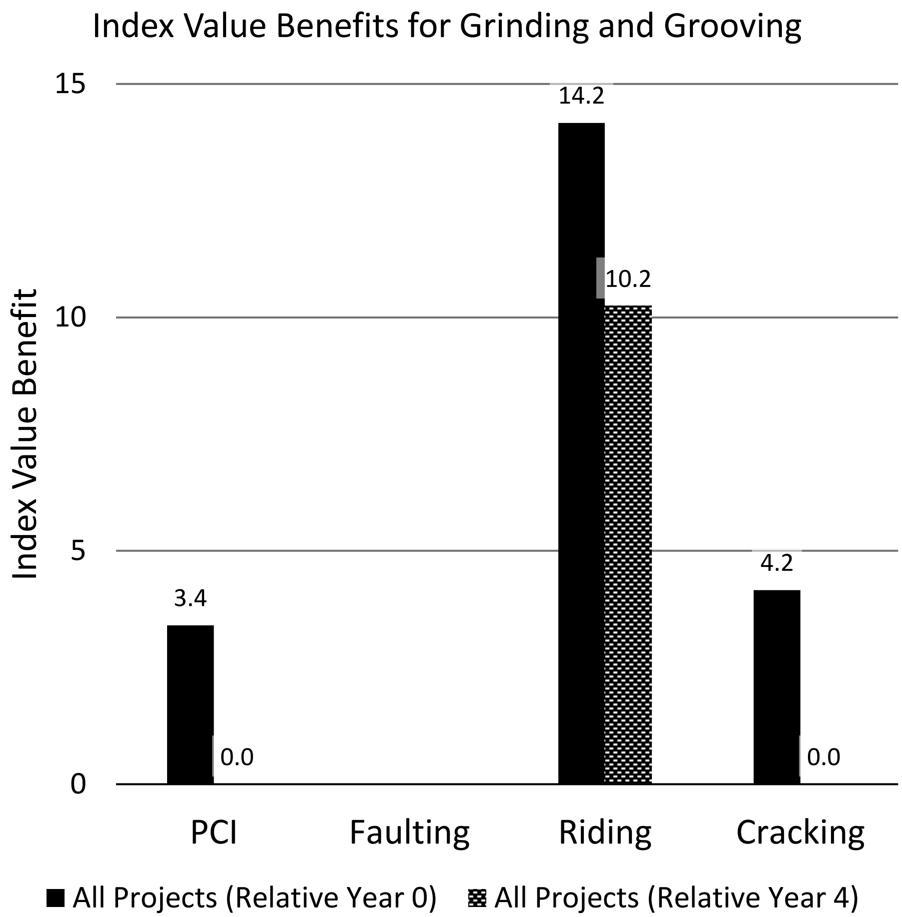


Figure 39. Index value benefits for grinding and grooving projects

With no trends able to be identified from the faulting index data, there are no recorded faulting index value benefits. Again, with such few projects, this analysis is sensitive to minor changes, however, the general trend of later index value benefits decreasing from the initial index value benefits is present. This indicates that pavement deterioration after this preservation method is faster than it would be without grinding and grooving. By removing certain thicknesses from the pavement, pavements can become more susceptible to increased future distresses. However, foundation- or material-related failures are likely controlling the overall pavement performance, regardless of thickness.

Anecdotal Analysis

Table 27 shows the results for each grinding and grooving anecdotal analysis, and Table 28 shows the collective results using the most frequently reported values for each PCI category.

Table 27. Individual anecdotal results for grinding and grooving projects

Project number	PCI category	Transverse cracking	Long. cracking	Friction	D-cracking	Joint spalling
MP-151-6(700)16—76-06	Fair	NOI	NOI	NOI	NOI	NOI
MP-922-6(717)0—76-57	Fair	NOI	NOI	NOI	I	I

Note: NOI denotes a trend that does not indicate distress improvement; and I denotes a trend that does indicate distress improvement.

Table 28. Collective anecdotal results for grinding and grooving projects

PCI category	Good	Fair	Poor
# of projects	0	2	0
Fatigue cracking index	-	-	-
Transverse cracking index	-	NOI:(2/2)	-
Long. cracking index	-	NOI:(2/2)	-
Friction	-	NOI:(2/2)	-
D-cracking	-	I:(1/2)	-
Joint spalling	-	I:(1/2)	-

Note: NOI denotes a trend that does not indicate distress improvement; and I denotes a trend that does indicate distress improvement.

Project MP-922-6(717)0—76-57 showed worse performance in the analytical study, but showed improvement in both D-cracking and joint spalling performance after grinding and grooving, while the other project performed worse in this anecdotal analysis. This highlights the ability for grinding and grooving to address different distresses depending on the pavement in question.

With that in mind, grinding and grooving is not used as a primary attempt to address these pavement distresses. Improvements may coincide with alternative pavement treatments applied in conjunction with the grinding and grooving process.

SUMMARY AND CONCLUSIONS

Flexible Pavement Preservation Methods

A total of 103 projects were included in the analysis of the four flexible pavement preservation methods including microsurfacing, slurry sealing, crack sealing/filling, and patching. Table 29 breaks down the analytical results determined by fitting DN and OP trend lines to the available PMIS data.

Table 29. Collective analytical results for flexible pavement preservation methods

Flexible pavement preservation method	# of projects	Index service life extension (years)			
		PCI	Rutting	Riding	Cracking
Microsurfacing	23	3.7	2.4	3.3	5.3
Slurry seal	13	3.0	2.2	2.6	3.0
Patching	34	3.4	2.1	2.6	3.5
Crack sealing/Filling	33	2.2	2.9	1.6	2.3
Total projects	103	3.1	2.4	2.5	3.5
		Averages			

The most effective flexible pavement preservation method was determined to be microsurfacing when evaluated according to the largest PCI service life increase. With a 3.7 year extension of PCI service life, 3.3 year extension of riding index service life, and 5.3 year extension of cracking index service life, microsurfacing results in the largest overall service life increase followed by patching, slurry sealing, and crack sealing/filling, in that order. Slurry sealing is normally expected to perform at higher service life extensions; however, many of the projects were using slurry sealing as a crack treatment instead of a preservation treatment.

Literature suggested that microsurfacing treatments extend the pavement service life anywhere from three to nine years (Illinois DOT 2010, Hicks et al. 2000, Maher et al. 2005). While on the low end of this expected spectrum, the results were still reasonable. Slurry seals also were expected to extend service life by three to nine years (Bolander 2005, Maher et al. 2005, Illinois DOT 2010). With a determined value of three years PCI service life extension, this preservation technique was low performing. Other literature findings that crack sealing provided 2 to 10 years of service life extension showed the determined PCI extension of 2.2 years was also performing on the low end (Illinois DOT 2010, Johnson 2000, NDOR 2002, South Dakota DOT 2010). Ultimately, these treatments are not meeting the average expectations of increased service life, but they still provide at least a few years of benefit.

A comparison of PCI and the rutting, riding, and cracking indices, seen in Figure 40, show microsurfacing prevented cracking-related distresses, but it also remedied some roughness-related and rutting-related pavement distresses as well.

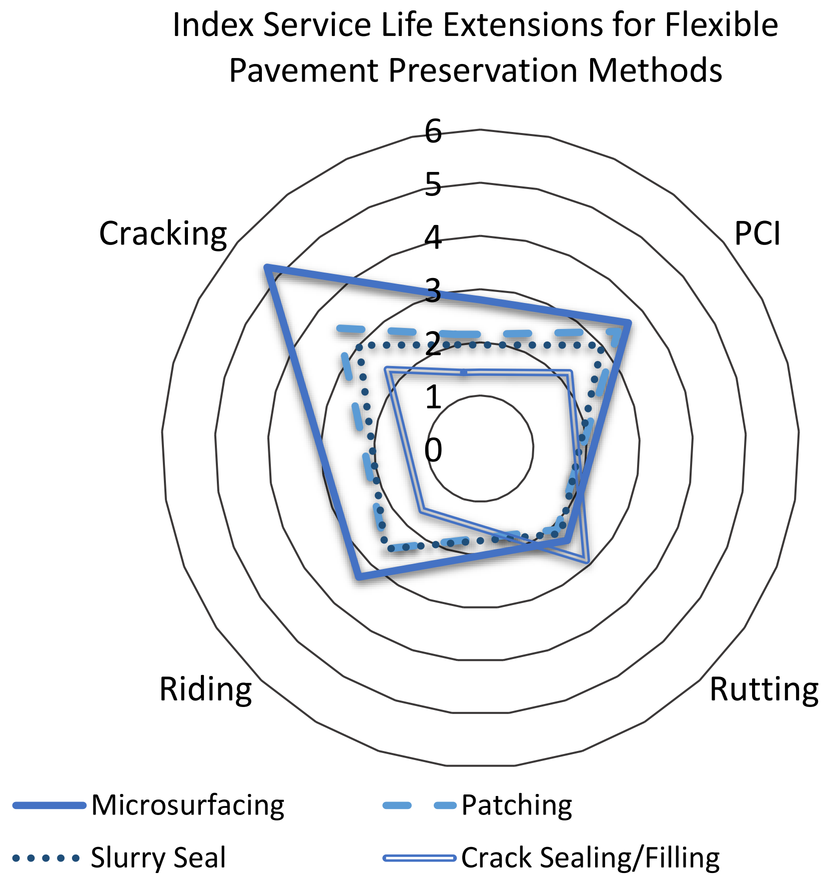


Figure 40. Collective analytical comparison of flexible pavement preservation methods

Seeing how effective patching was highlights the effectiveness of patch application directly to the issues causing lower index performance within a given pavement. All of these methods displayed fairly promising results for extending the life of a pavement. It is important to note that these four global indices used as metrics to evaluate these pavements have the downfall of accurately reflecting smaller treatments, such as crack sealing, due to the lower resolution in data collection. More specific crack distress data were evaluated in the anecdotal analysis instead.

The resulting anecdotal findings, seen in Table 30, show that these preservation methods may be truly preserving the pavement condition more often than improving it.

Table 30. Collective anecdotal results for flexible pavement preservation methods

Flexible pavement preservation method		Microsurfacing			Slurry seal		
PCI category (Relative year 0)	Good, fair, or poor	Good	Fair	Poor	Good	Fair	Poor
PCI data	Fatigue	NT:(1/1)	NT:(14/19)	I:(1/3)	NT:(1/1)	NOI:(5/8)	NOI:(2/4)
	Transverse	NOI:(1/1)	NOI:(14/19)	I:(2/3)	NOI:(1/1)	NOI:(5/8)	I:(2/4)
	Longitudinal	NOI:(1/1)	NOI:(11/19)	I:(2/3)	NOI:(1/1)	NOI:(7/8)	I:(2/4)
	Friction	NOI:(1/1)	NOI:(15/19)	NOI:(3/3)	NOI:(1/1)	NOI:(7/8)	NOI:(4/4)
Flexible pavement preservation method		**Patching**			**Crack sealing and crack filling**		
PCI category (Relative year 0)	Good, fair, or poor	Good	Fair	Poor	Good	Fair	Poor
PCI data	Fatigue	-	NT:(10/19)	NT:(10/15)	NOI:(6/6)	NOI:(15/21)	NT:(3/6)
	Transverse	-	NOI:(12/19)	NOI:(9/15)	NOI:(6/6)	NOI:(17/21)	I:(3/6)
	Longitudinal	-	NOI:(15/19)	NOI:(11/15)	NOI:(6/6)	NOI:(20/21)	NOI:(4/6)
	Friction	-	-	-	-	-	-

Note: I – Improved, NOI – No Observed Improvement, and NT – No Trend; Good: 75<PCI<100, Fair: 50<PCI<74.9, and Poor: 0<PCI<49.9; #/# represents the number of projects with a reported value out of the total evaluated projects.

While improvements can be the most desired outcome of any preservation, the fact that many of these trends resulted in a maintenance of the distress means that the treatments are able to at least slow the rate of pavement deterioration after application. Distresses may show improvement, but maintenance of overall condition is a success.

Rigid Pavement Preservation Methods

A total of 27 projects were included in the analysis of the four rigid pavement preservation methods including dowel bar retrofitting/diamond grinding, grinding and grooving, crack sealing/joint filling, and patching. Analytical results determined by fitting DN and OP trend lines to the available PMIS data were still determined. The results determined in this section are based on very few rigid projects, and consequentially are very sensitive to small variations in PMIS data trends.

The four dowel bar retrofitting and diamond grinding projects, when evaluated, resulted in the largest PCI service life increase with a 6.7 year extension of PCI service life, 5.0 year extension of faulting index service life, and 10.0 year extension of riding index service life. Grinding and grooving appeared to yield promising average service life extensions with 4.6 years of PCI extension, 4.8 years of riding index extension, and 5.0 years of cracking index extension. When these two projects were separately analyzed, it was found that one project was very successful while the other did not improve the four pavement indices. The improvement in the faulting index service life shows that dowel bar retrofit may be used as an effective strategy to reduce the occurrence of reflective cracking in future HMA overlays when used in conjunction with proper HMA materials designed to resist reflective cracking.

In 2008, a study by Cable et al. investigating dowel bar retrofitting, and diamond grinding performance, and best practices was completed. The study found that the IRI was significantly reduced because of diamond grinding, and dowels performed equally in load transfer. Lower IRI values indicate a pavement has a smoother ride. Findings showed fiber reinforced polymer (FRP) dowels performed better in IRI than steel, and a higher number of dowels increases the performance life of the pavement. The report provided an estimation of pavement life extension based on the number of dowels and bar type. The life extension ranges from 7–33 years depending on the number of dowels and the material of the dowel bars (Cable et al. 2008). A California study investigated diamond grinding and found an average life span of 16 to 17 years at approximately 80% reliability (Stubstad et al. 2005). The study also emphasized the importance of proper pavement selection for diamond grinding candidates.

The research team has more confidence in the crack sealing/joint filling results, with its total of seven projects, which showed similar results to the crack treatments for flexible pavements. The PCI service life extension was found to be an average of 2.7 years while the riding and cracking indices showed increases of 4.1 and 2.0 years, respectively. Lastly, the 14 PCC patching projects showed marginal improvement with a PCI service life extension of 1.5 years while the riding and cracking indices saw 2.8 and 4.3 years of service life extension, respectively.

It should be noted that the faulting index values within the PMIS often resulted in the inability to fit trends. With an exceedingly high number of blank or error values, there was minimal data to work with. However, many of the project's post-treatment faulting data showed high faulting index values. Ultimately, the degree to which faulting improvement could be determined was heavily negated by the false zeros or blank cells within the PMIS database.

Literature suggested that partial depth patching should extend the pavement service life anywhere from 5 to 15 years (NDOR 2002, South Dakota DOT 2010, Illinois DOT 2010). The determined PCI service life index was 1.5 years, proving much lower than expected, which could again be attributed to the low resolution of the data. With patching being such a localized pavement treatment, a pavement-wide distress collection is less likely to display the impact of a higher performing patch. So, while the PCI service life is low, it is likely that the data is not reflective of the patching performance alone.

Dowel bar retrofits and diamond grinding/grooving are expected to extend service life by 8 to 15 years (Illinois DOT 2010, NDOR 2002, South Dakota DOT 2010). With dowel bar retrofits and diamond grindings determining a PCI service life extension of 6.7 years and grinding/grooving determining a PCI service life extension of 4.6 years, both preservation methods were low performing. Other literature findings for crack sealing/joint filling provided four to eight years of service life extension showed the determined PCI extension of 2.7 years was also performing below expectations (NDOR 2002, South Dakota DOT 2010, Illinois DOT 2010). Ultimately, these treatments still provide at least a few years of benefit.

A comparison of PCI and the faulting, riding, and cracking indices, seen in Figure 41, shows dowel bar retrofitting and diamond grinding to heavily improve riding-related distresses, but it also remedied some faulting-related pavement distresses as well.

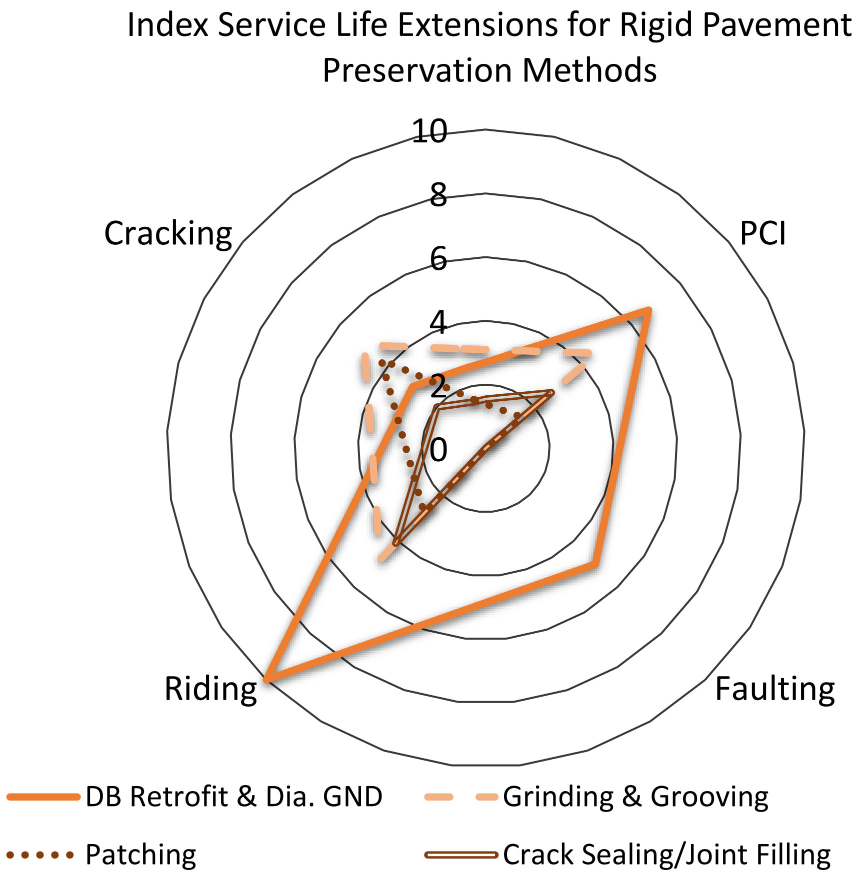


Figure 41. Collective analytical comparison of rigid pavement preservation methods

Seeing how effective patching was highlights the effectiveness of patch application directly to the issues causing lower index performance within a given pavement. All of these methods displayed fairly promising results for extending the life of a pavement. The other three indices showing zero faulting index improvement was discussed earlier in this section. All treatments were shown to increase PCI service life at least some extent, with the smallest improvement of 1.5 years from the patching projects.

The resulting anecdotal findings, seen in Table 31, show that these preservation methods often produced improvement in the pavement condition more often than maintaining it.

Table 31. Collective anecdotal results for rigid pavement preservation methods

Rigid pavement preservation method			Patching			Crack filling and joint sealing		
PCI category (Relative year 0)		Good, fair, or poor	Good	Fair	Poor	Good	Fair	Poor
Pavement condition	Index data	Fatigue	NT:(1/1)	NT:(6/10)	NOI:(2/3)	-	-	-
		Transverse	NOI:(1/1)	NOI:(8/10)	I:(2/3)	NOI:(2/2)	I:(1/2)	I:(2/3)
		Longitudinal	NOI:(1/1)	NOI:(9/10)	NOI:(2/3)	NOI:(2/2)	I:(1/2)	NOI:(2/3)
		Friction	-	-	-	-	-	-
	Counted distress data	Durability	NOI:(1/1)	NOI:(10/10)	NOI:(3/3)	-	-	-
		Joint Spalling	NOI:(1/1)	NOI:(10/10)	NOI:(3/3)	-	-	-
Rigid pavement preservation method			**Dowel bar retrofit and diamond grind**			**Grinding and grooving**		
PCI category (Relative year 0)		Good, fair, or poor	Good	Fair	Poor	Good	Fair	Poor
Pavement condition	Index data	Fatigue	-	-	-	-	-	-
		Transverse	-	I:(1/2)	I:(1/2)	-	NOI:(2/2)	-
		Longitudinal	-	I:(1/2)	NOI:(2/2)	-	NOI:(2/2)	-
		Friction	-	NOI:(2/2)	NOI:(2/2)	-	NOI:(2/2)	-
	Counted distress data	Durability	-	I:(1/2)	I:(1/2)	-	I:(1/2)	-
		Joint Spalling	-	NOI:(2/2)	NOI:(2/2)	-	I:(1/2)	-

Note: I – Improved, NOI – No Observed Improvement, and NT – No Trend; Good: 75<PCI<100, Fair: 50<PCI<74.9, and Poor: 0<PCI<49.9; #/# represents the number of projects with a reported value out of the total evaluated projects.

While improvements are the desired outcome of any preservation, the fact that many of these trends were based on a very limited project base leads to uncertainty with conclusive results in the anecdotal analysis.

Comparative Cost Analysis

Using 2016 Iowa DOT cost data, a simple comparative analysis between the cost of an HMA overlay and microsurfacing, slurry seal, HMA crack sealing/filling, or PCC joint sealing was performed. Utilization of a life-cycle cost analysis for major pavement rehabilitation or reconstruction allowed for a reliable cost estimation for an HMA overlay on a single lane-mile. The comparative analysis of the suggested preservation methods only provides a rough estimation of the preservation benefits. The following assumptions were made:

- The overlay was applied directly to the pavement surface with no milling.
- No additional rock base was needed.
- No HMA/PCC was salvaged.
- The only observed costs were for the construction and maintenance of the HMA overlay.
- The HMA overlay provides a service life of 18 years.

Figure 42 breaks down the construction and maintenance costs for a hypothetical 4 in. HMA overlay where the price/ton for HMA was $58.28, the binder price/ton was $457.00, and the annual maintenance cost was $1,803.63 over a lifespan of 18 service years.

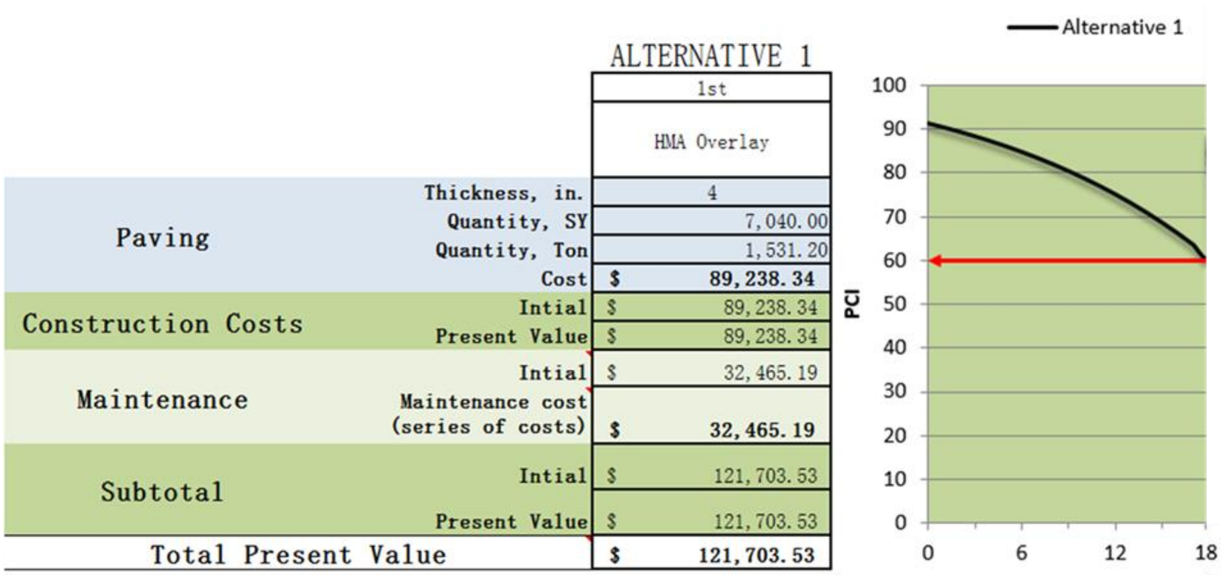


Figure 42. Cost approximation for a 4 in. HMA overlay

With this approximate cost data, Table 32 breaks down the costs for the four pavement preservation methods described in the beginning of this section.

Table 32. Comparison of preservation costs to an HMA overlay

Project type	$/lane mile	Observed PCI service life extension range based on initial PCI category	Average PCI service life extension	$/mile/year	Required service life to pay for itself compared to an HMA overlay	Difference between average PCI service life extension and required service life
Microsurfacing	$23,400.00	(0–4.3)	**3.7**	$6,324.32	3.5	0.2
Slurry seal	$23,200.00	(0–3.5)	**3.0**	$7,733.33	3.4	-0.4
HMA crack filling/sealing	$3,800.00	(0–4.7)	**2.2**	$1,727.27	0.6	1.6
PCC joint sealing	$7,900.00	(0–4.6)	**2.7**	$2,925.93	1.2	1.5
4 in. HMA overlay	$121,710.00	-	**18**	$6,761.67	-	-

The costs for the four preservation methods are based on 2016 Iowa DOT data, while the average PCI service life extension values are derived from the analytical analysis for each treatment. The $/mile/year is the total $/lane-mile divided by the average PCI service life extension. The required service life to pay for itself compared to an HMA overlay is the $/lane-mile of the project type divided by the $/mile/year of the overlay. Finally, the last column shows whether the time to pay for itself is less than or greater than the expected PCI service life of the treatment.

Seen in this analysis, the most effective pavement preservation method of the four is HMA crack sealing/filling with an expected service life extension of 1.6 years longer than it takes to pay for itself. The microsurfacing just makes a positive differential in life versus time to pay, with an additional 0.2 years of PCI service life to spare. With the lower PCI service life extension of the slurry seals, this treatment does not pay for itself before using all of its service life extension. This likely stems from its use as a crack treatment instead of a surface restoration.

It is important to note that these values represent a basic economic comparison, and the number of analyzed projects and sensitivity of PCI service life extension determination could skew the outcome of these preservation methods either way. With more data, the confidence in this data could significantly improve.

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APPENDIX A. QUALTRICS SURVEY

The survey given to each of Iowa's 99 county engineers is included within this appendix. Administered through an online survey application, the survey has been altered to fit the format of this report, as seen below.

Survey Start:

Effectiveness of pavement preservation strategies

We are excited to announce the Iowa Highway Research Board's project investigating the effectiveness of pavement preservation strategies. The goal of the research is to document and understand the effectiveness of pavement preservation strategies in Iowa. Success of this research depends on agencies sharing their experience with pavement preservation techniques. This questionnaire was developed to start documenting the effectiveness of pavement preservation strategies in Iowa and to identify case studies for the research.
The questionnaire was developed based the following definition of preservation: *"Preservation consists of work that is planned and performed to improve or sustain the condition of the transportation facility in a state of good repair. Preservation activities generally do not add capacity or structural value, but do restore the overall condition of the transportation facility."*
Examples of pavement preservation strategies are: **For HMA:** saw and seal or rout and seal cracks, over band crack seal, fog seal, rejuvenators, scrub seal, slurry seal, single layer chip seal, multiple layer chip seal, otta seal, cape seal, paver-placed surface seal (e.g., novachip), thin hma overlay (less than 1.25 inch), cold milling and thin HMA overlay (less than 1.25 inch), profile milling, and underdrain outlet repair and cleaning.
For PCC: concrete joint resealing, concrete crack sealing, diamond grinding, diamond grooving, partial-depth concrete pavement repair, partial-depth concrete pavement repair with polymer modified resins (e.g., fibercrete or techcrete), partial-depth repair with a concrete cold-patch material, full-depth concrete pavement repair, dowel bar retrofit (load-transfer restoration in the direction of traffic), stitching - (repairs and prevents further distress of longitudinal joints and cracks), slab stabilization (undersealing) and slab jacking, underdrain outlet repair and cleaning.
Thank your participation and your valuable contribution to Iowa pavement research.
Ashley Buss, Ph.D. Assistant Professor Iowa State University Department of Civil, Construction and Environmental Engineering 403 Town Engineering Building (515) 294-4645
abuss@iastate.edu

Participant Information:

- Name
- Agency
- Phone Number
- E-mail

May we contact you for follow-up information and/or an interview? (Select One)

- Y/N

Q1 In general, how would you describe your agency's familiarity with pavement preservation and preventive maintenance strategies? (Select One)

Very Familiar
Somewhat Familiar
Minimal Knowledge
No Knowledge

Q2 For a typical year, what is your annual budget for pavement preservation?

(Answer here)

Q3 What percentage of pavement preservation work is done "in house"?

(Answer here)

Q4 How would you describe your agency's pavement preservation program? (Select One)

Formal w/guidelines/policies and dedicated funding
Formal w/o dedicated funds
Informal
Informal and almost non-existent

Q4.B Comments:

(Answer here)

Q5 How long has your pavement preservation program been in place? (Select One)

Very little preservation work is done
<1 year
1-3 years
3-10 years
Longer than 10 years

Q6 If your agency does not currently have a pavement preservation program, is there interest in implementing one? (Select One)

Yes
No
We have a preservation program

Q6.B Comments:

(Answer here)

Q7 Which aspects of pavement preservation guidance would be most helpful for your agency?

(Select all that apply)

- Improved avenues for funding
- Materials selection and specification guidance
- Construction specification guidance
- Selection criteria and guidance for pavement preservation techniques
- Need for training for agencies

Q7.B Please list other aspects that you have experienced:

(Answer here)

Q8 How would you describe the current cost benefits of your pavement preservation and preventative maintenance program? (Select One)

- Observed reduction in cost through the network
- Some examples of cost savings have been identified
- Too early to have documented cost savings
- A few trial projects are planned, no cost data collected
- Work continues an overcoming obstacles for implementing pavement preservation

Q9 How would you describe the current performance benefits of your pavement preservation and preventative maintenance program? (Select One)

- Observed improved pavement performance through the network
- Some examples of improved performance have been identified
- Too early to have documented improved performance
- A few trial projects are planned or have been constructed. No performance data yet
- Work continues on overcoming obstacles for implementing pavement preservation

Q 8/9.B Please list other descriptions of your pavement preventive maintenance program:

(Answer here)

Q10 Prior to a pavement rehabilitation, does your agency apply more than one HMA preventive maintenance treatment? (select the most representative answer)
Example of HMA preservation treatments include**:** saw and seal or rout and seal cracks, over band crack seal, fog seal, rejuvenators, scrub seal, slurry seal, single layer chip seal, multiple layer chip seal, otta seal, cape seal, paver-placed surface seal (e.g., novachip), thin hma overlay (less than 1.25 inch), cold milling and thin HMA overlay (less than 1.25 inch), profile milling, and underdrain outlet repair and cleaning.

(Y/N)

Q11 Prior to a pavement rehabilitation, does your agency apply more than one PCC preventive maintenance treatment? (select the most representative answer) Example of PCC preservation treatments include: concrete joint resealing, concrete crack sealing, diamond grinding, diamond grooving, partial-depth concrete pavement repair, partial-depth concrete pavement repair with polymer modified resins (e.g., fibercrete or techcrete), partial-depth repair with a concrete cold-patch material, full-depth concrete pavement repair, dowel bar retrofit (load-transfer restoration in the direction of traffic), stitching - (repairs and prevents further distress of longitudinal joints and cracks), slab stabilization (undersealing) and slab jacking, underdrain outlet repair and cleaning.

(Y/N)

Q10/11.B Comments:

(Answer here)

Q12 Which of the following HMA preservation treatments are used for pavement preservation? (Answer either completed projects, projects in progress, projects planned, interested in using, or not used for each project type listed below)

Saw and seal or rout and seal cracks
Overband crack seal
Fog seal
Rejuvenators
Scrub seal
Slurry seal
Single layer chip seal
Multiple layer chip seal
Otta seal
Cape seal
Pave-placed surface seal (e.g., Novachip)
Thin HMA overlay (less than 1.25 inch)
Cold milling and thin HMA overlay (less than 1.25 inch)
Profile milling
Underdrain outlet repair and cleaning
Subdrain placement
Other (specify)

Q13 Which of the following PCC preservation treatments are used for pavement preservation? (Answer either completed projects, projects in progress, projects planned, interested in using, or not used for each project type listed below)

Concrete joint sealing
Concrete crack sealing
Diamond grinding
Diamond grooving
Partial-depth concrete pavement repair
Partial-depth concrete pavement repair with polymer modified resins (e.g., Fibercrete or Techcrete)
Partial-depth repair with a concrete cold-patch material
Full-depth concrete pavement repair
Dowel bar retrofit (load-transfer restoration in the direction of traffic)
Stitching (repairs that prevents further distress of longitudinal Joints and cracks)
Slab stabilization (undersealing) and slab jacking
Underdrain outlet repair and cleaning
Subdrain placement

Q14 In your experience, which **three HMA pavement preservation** tools have you experienced the best performance from? Please provide an estimate of pavement life extension in **years** for each selected treatment.

First treatment (1)

Second treatment (2)

Third treatment (3)

Q15 1. In your experience, which **three PCC pavement preservation** tools (have you experienced the best performance from) (do you use the most) (Are most cost-effective)? Please provide an estimate of pavement life extension in **years** for each selected treatment.

First treatment (1)

Second treatment (2)

Third treatment (3)

Q 14/15.B Comments:

(Answer here)

Q16 Does roadway traffic level influence the type of pavement preservation treatments selected?

(Y/N)

Q16.B Comments:

(Answer here)

Q17 Which traffic level (AADT) have you applied most of your **HMA pavement preservation** techniques? (Select all that apply)

Under 750
750-2000
2000-6000
6000-12000
Over 12000

Q18 Which traffic level (AADT) have you applied most of your **PCC pavement preservation** techniques? (Select all that apply)

Under 750
750-2000
2000-6000
6000-12000
Over 12000

Q19 Does your agency have experience working with emulsified asphalt in pavement preservation activities? (Select One)

Extensive experience
Ample experience
Some experience
Little experience
No experience

Q20 Does your agency collect pavement performance data?

(Y/N)

Q20.B Comments:

(Answer here)

Q21 Does your agency track the performance of preventive maintenance treatments?

(Y/N)

Q21.B Please describe the performance tracking process:

(Answer here)

Q22 How would you describe your agency's pavement performance data collection program? (Select One)

Formal w/guidelines or policies and dedicated funding
Formal w/o dedicated funds
Informal

Q22.B Comments:

(Answer here)

Q23 Indicate whether the following asphalt distress data is collected by your agency with a yes or no.

Alligator cracking
Longitudinal cracking
Transverse cracking
Roughness
Rutting
Raveling
Friction
Oxidation
Flushing/Bleeding
Drainage

Q24 Indicate whether the following PCC distress data is collected by your agency with a yes or no.

- Blowups
- Corner Breaks
- Faulting
- Joint distress
- Longitudinal cracking
- Transverse cracking
- Pattern cracking
- Pop-out
- Punch-out
- Spalling

Q25 Are level of service (LOS) indicators used by your agency to determine the pavement condition? (Answer yes or no to each)

- Pavement condition index
- Pavement serviceability index
- International roughness index
- Other

Q26 How would you describe your materials and construction specifications for each **asphalt** preservation treatment listed below? (Answer either recent, adequate, needs improvement, out of date, or doesn't exist to each of the treatments below)

- Saw and seal or rout and seal cracks
- Overband crack seal
- Fog seal
- Rejuvenators
- Scrub seal
- Slurry seal
- Single layer chip seal
- Multiple layer chip seal
- Otta seal
- Cape seal
- Pave-placed surface seal (e.g., Novachip)
- Thin HMA overlay (less than 1.25 inch)
- Cold milling and thin HMA overlay (less than 1.25 inch)
- Profile milling
- Underdrain outlet repair and cleaning
- Subdrain placement
- Other (specify)

Q27 How would you describe your materials and construction specifications for each **PCC** treatment listed below? (Answer either recent, adequate, needs improvement, out of date, or doesn't exist to each of the treatments below)

Concrete joint sealing
Concrete crack sealing
Diamond grinding
Diamond grooving
Partial-depth concrete pavement repair
Partial-depth concrete pavement repair with polymer modified resins (e.g., Fibercrete or Techcrete)
Partial-depth repair with a concrete cold-patch material
Full-depth concrete pavement repair
Dowel bar retrofit (load-transfer restoration in the direction of traffic)
Stitching (repairs that prevents further distress of longitudinal Joints and cracks)
Slab stabilization (undersealing) and slab jacking
Underdrain outlet repair and cleaning
Subdrain placement
Other (Specify)

Q28 How have you developed the specifications used for pavement preservation projects? (Select One)

Developed "in-house"
Adopted from state specification, guidance and recommendations
Adopted from industry guidance and recommendations
Practice-ready research
Consultant
Other

Q29 Does your agency use warranty specifications on any preventive maintenance treatments?

(Y/N)

Q30 Please describe the warranty specifications used:

(Answer here)

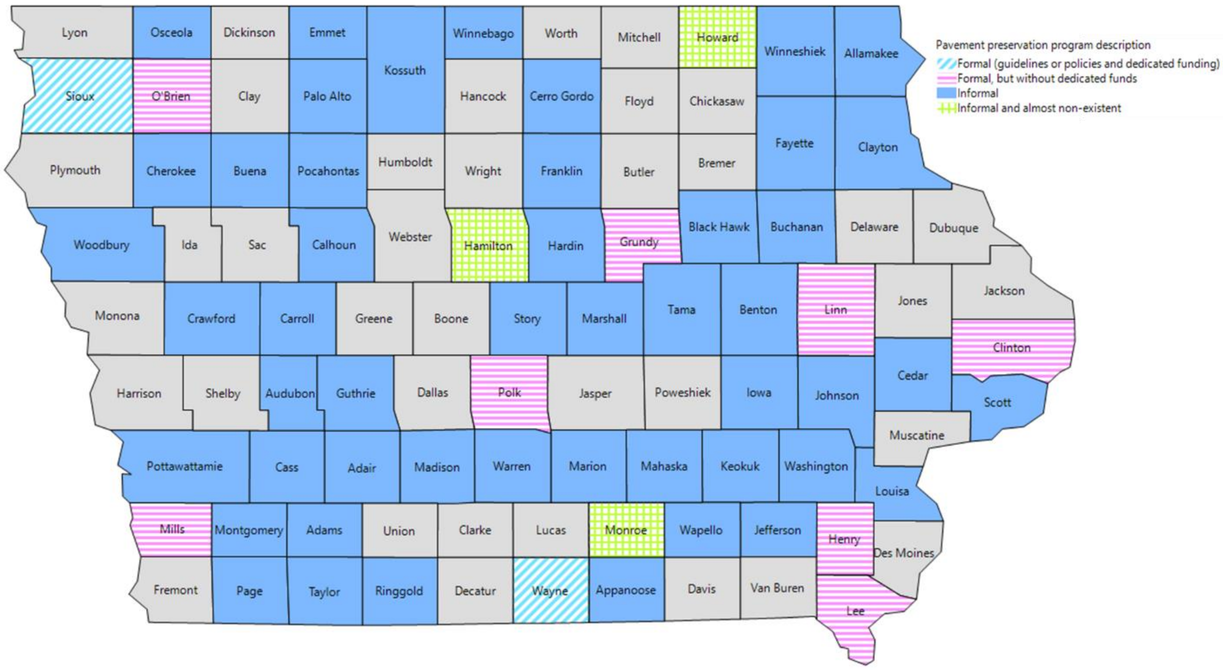


Figure 43. County response to current pavement preservation program

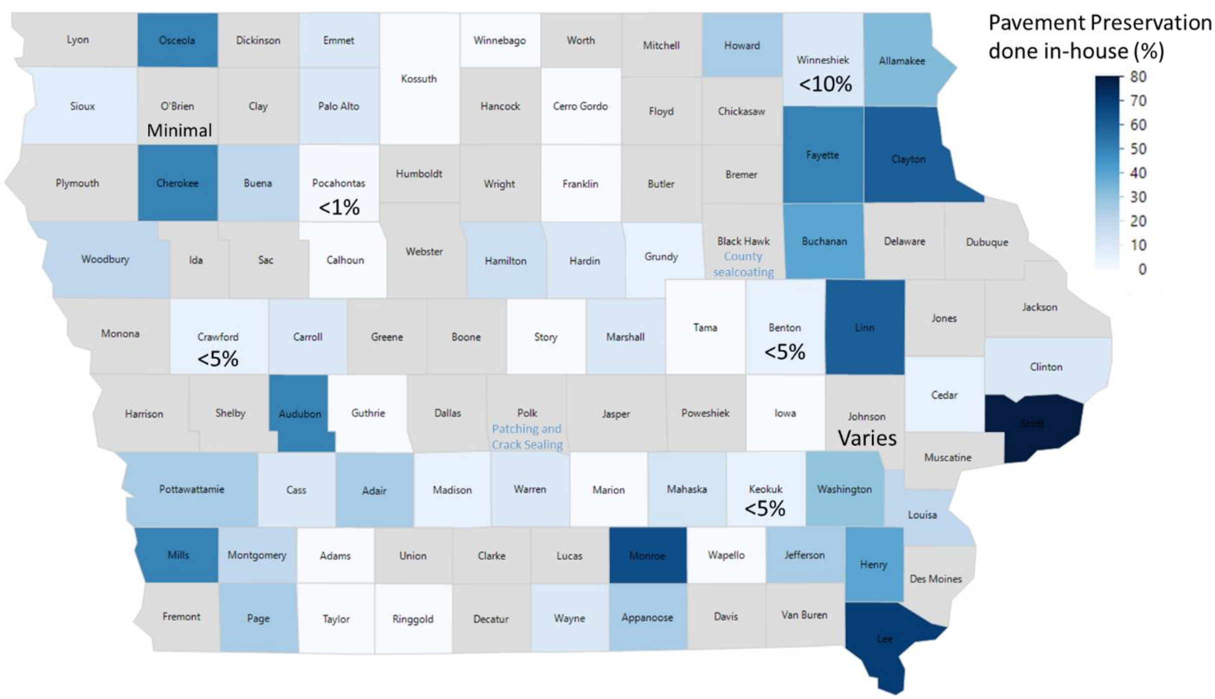


Figure 44. County response to percentage of preservation work performed in-house

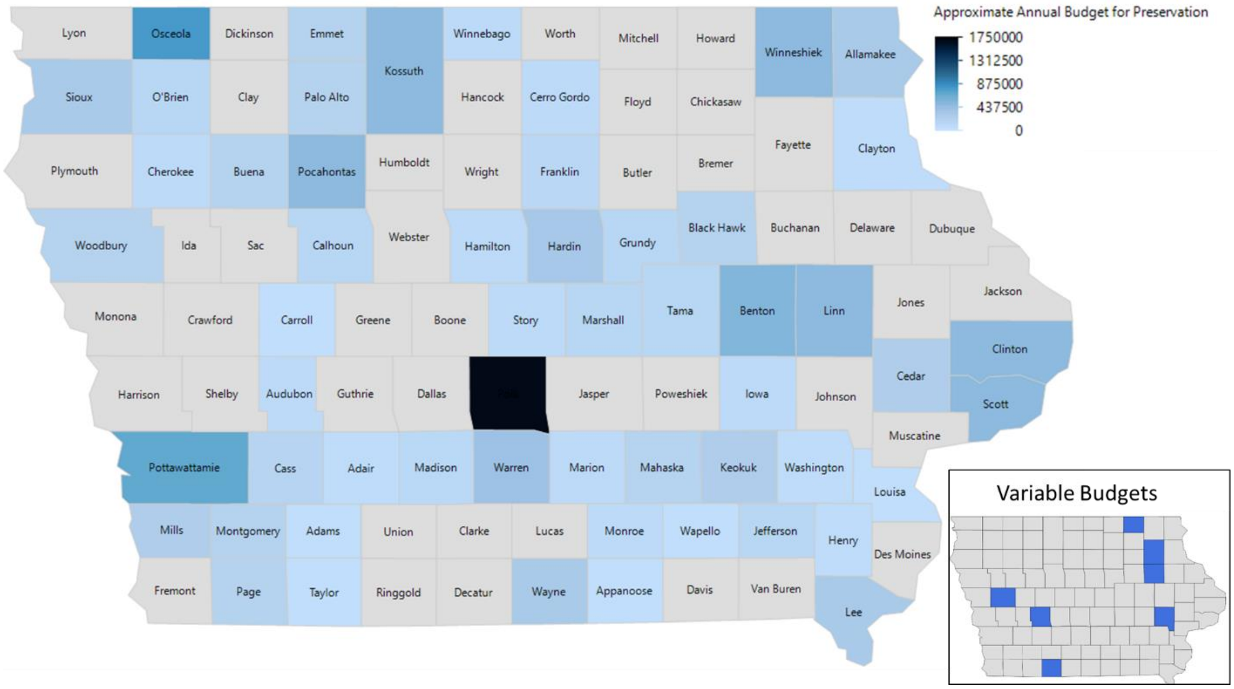


Figure 45. County response of approximate annual budget for preservation

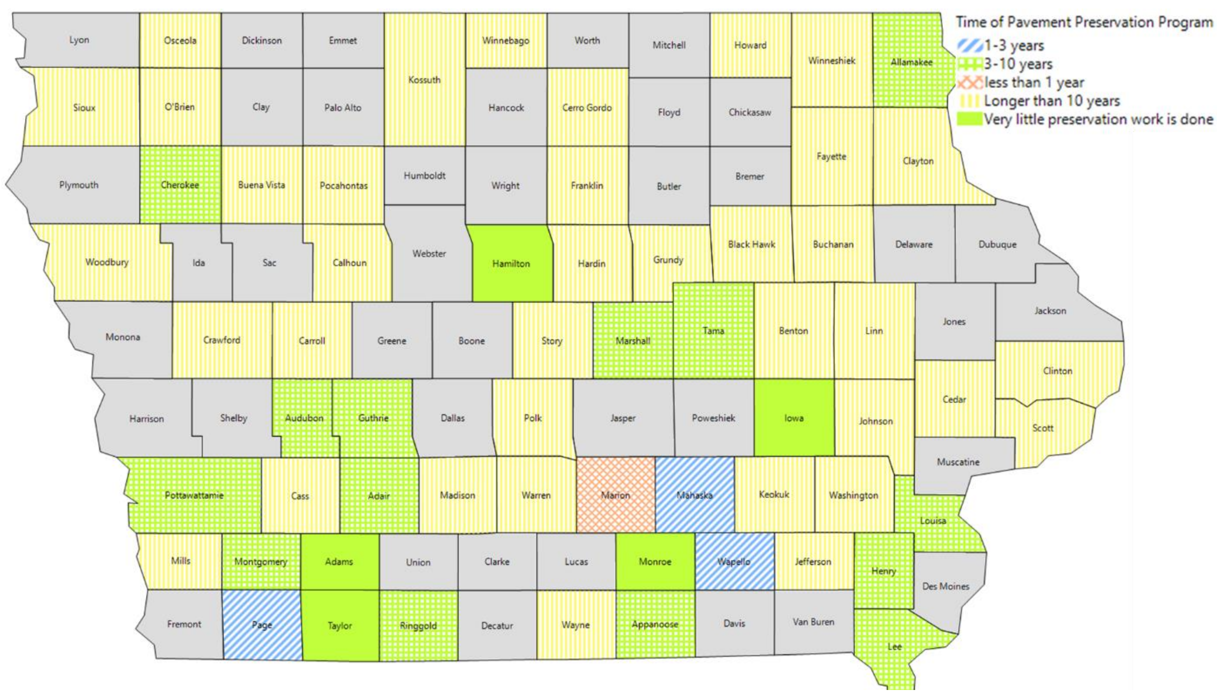


Figure 46. County response of current preservation program age

APPENDIX B. ANALYTICAL AND ANECDOTAL GRAPHS FOR FLEXIBLE PAVEMENT PRESERVATION METHODS

The box plots within adecdotal analysis figures represent the statisitcal quartiles for each year of data. The top and bottom of the box represent the first and third quartiles, respectively. The median value is represented by the horizontal line within the rectangle. Lastly, the whiskers extending above and below the box represent the value plus and minus 1.5 times the interquartile range, defined as the value of quartile 3 minus quartile 1. Values exceeding this range are denoted as outliers. If there is no variability within a given relative year, the entire box plot is represented by a flat line (SAS Institute 2019).

Microsurfacing Projects

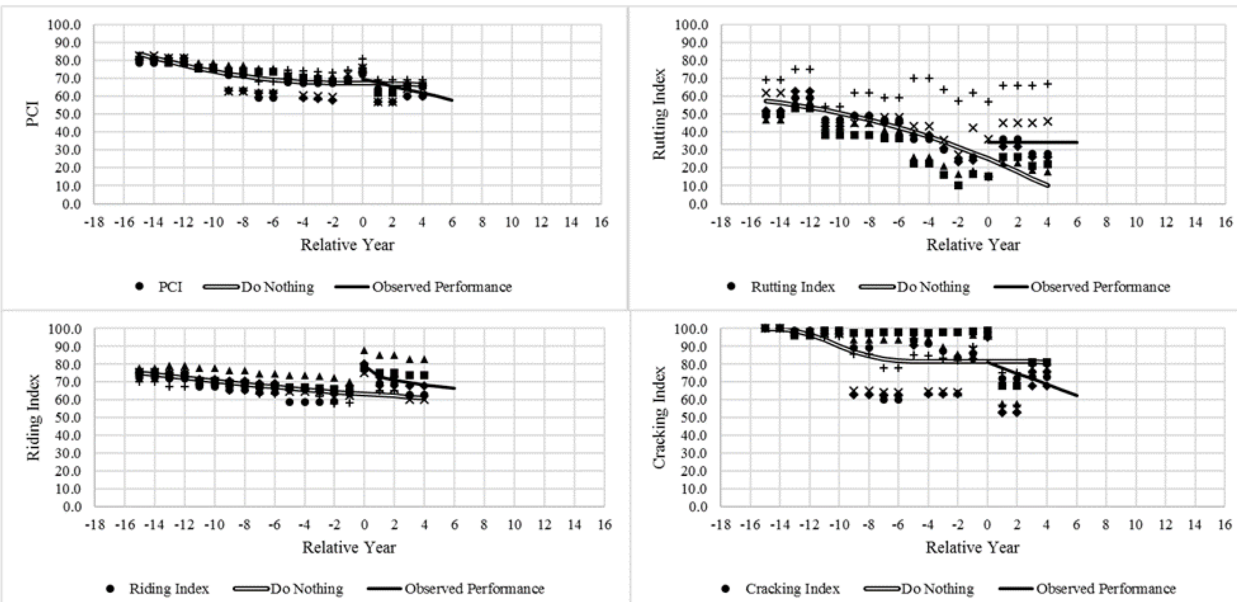


Figure 47. Analytical analysis graphs for project MP-003-2(703)183—76-35

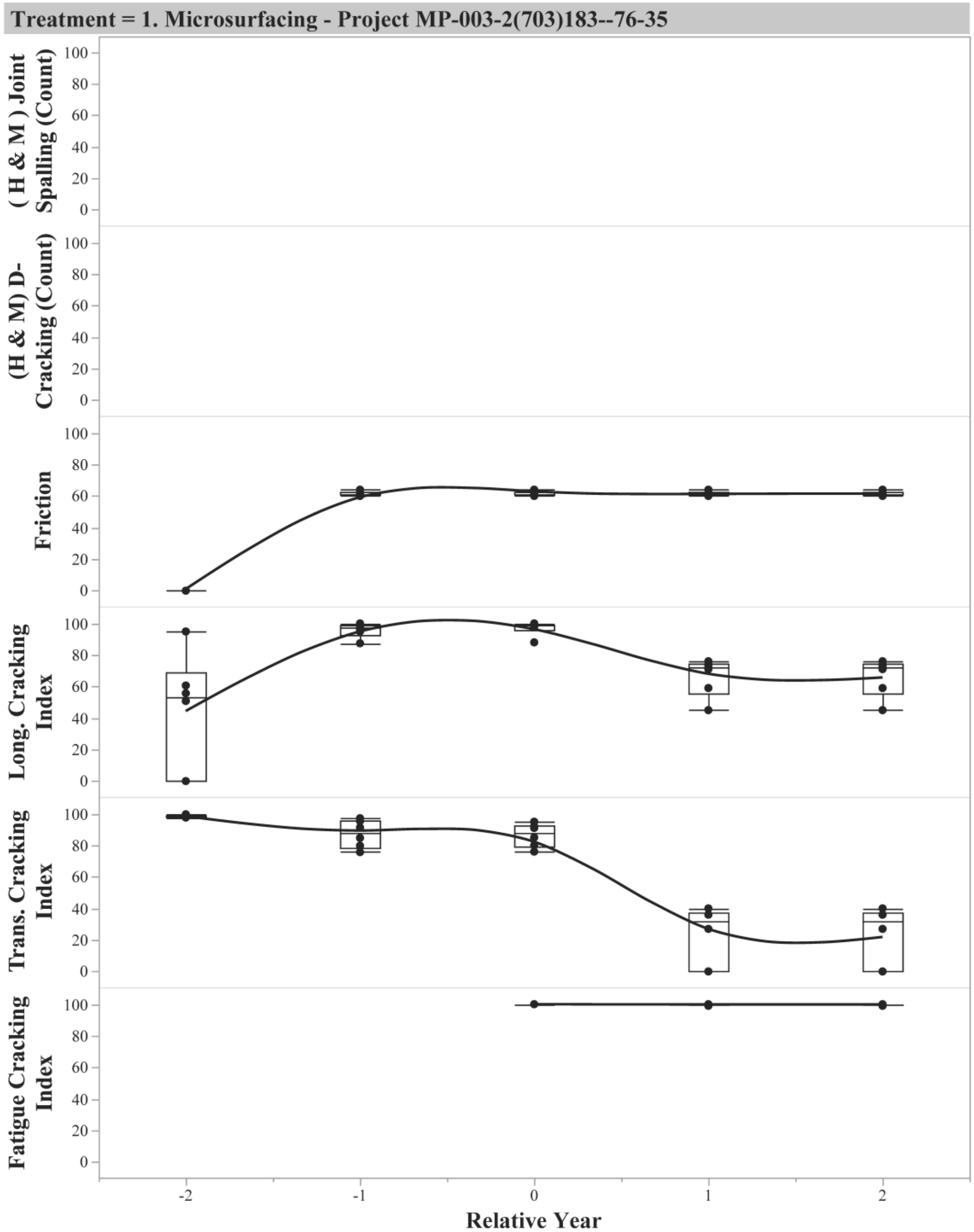


Figure 48. Anecdotal analysis graphs for project MP-003-2(703)183—76-35

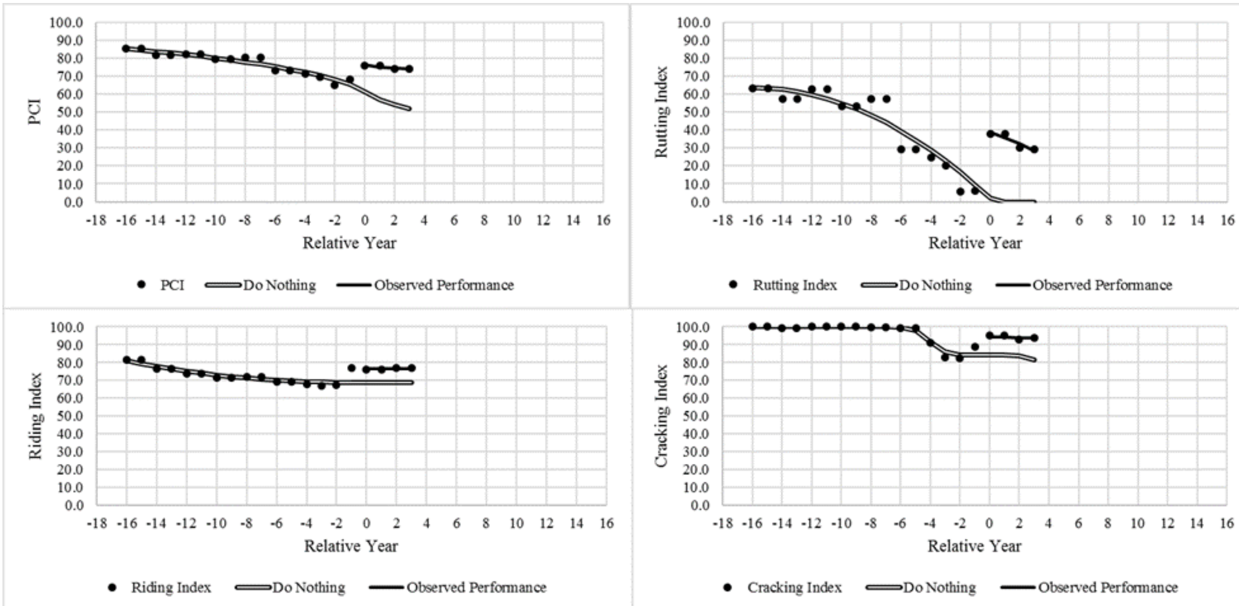


Figure 49. Analytical analysis graphs for project MP-003-2(705)224—76-09

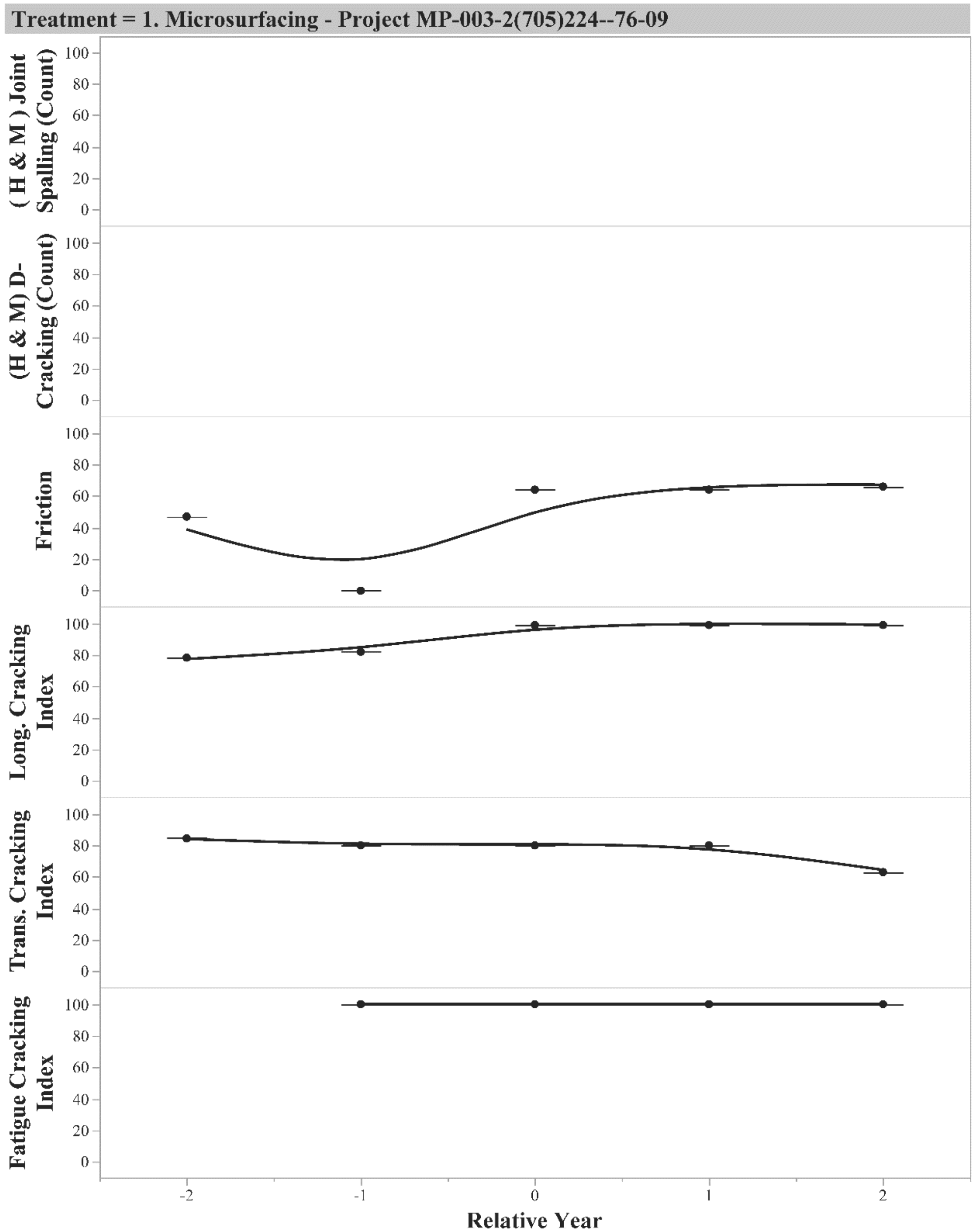


Figure 50. Anecdotal analysis graphs for project MP-003-2(705)224—76-09

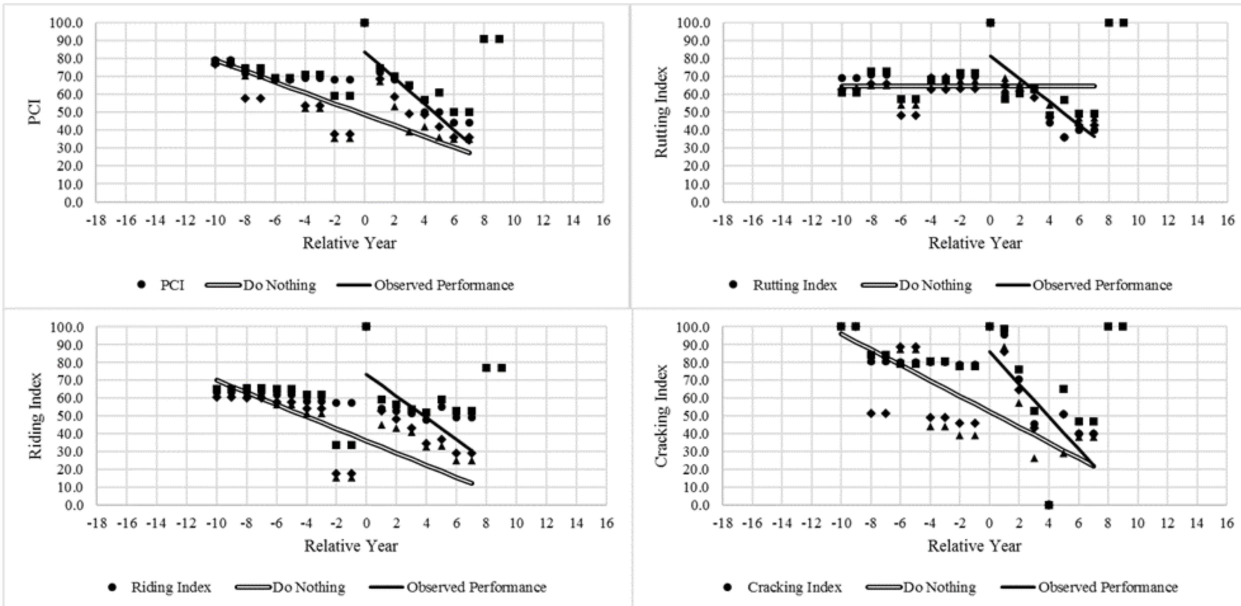


Figure 51. Analytical analysis graphs for project MP-007-3(703)0—76-18

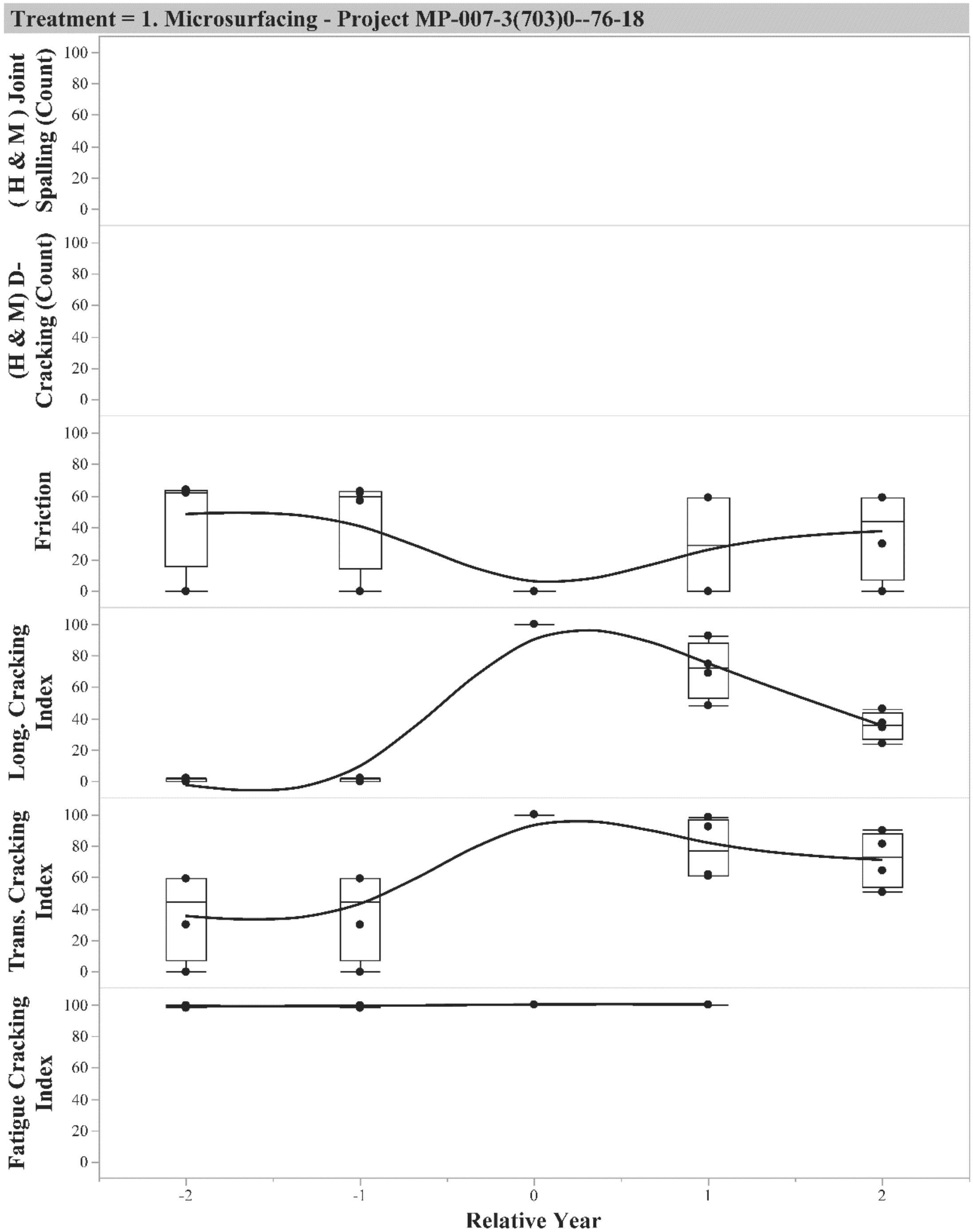


Figure 52. Anecdotal analysis graphs for project MP-007-3(703)0—76-18

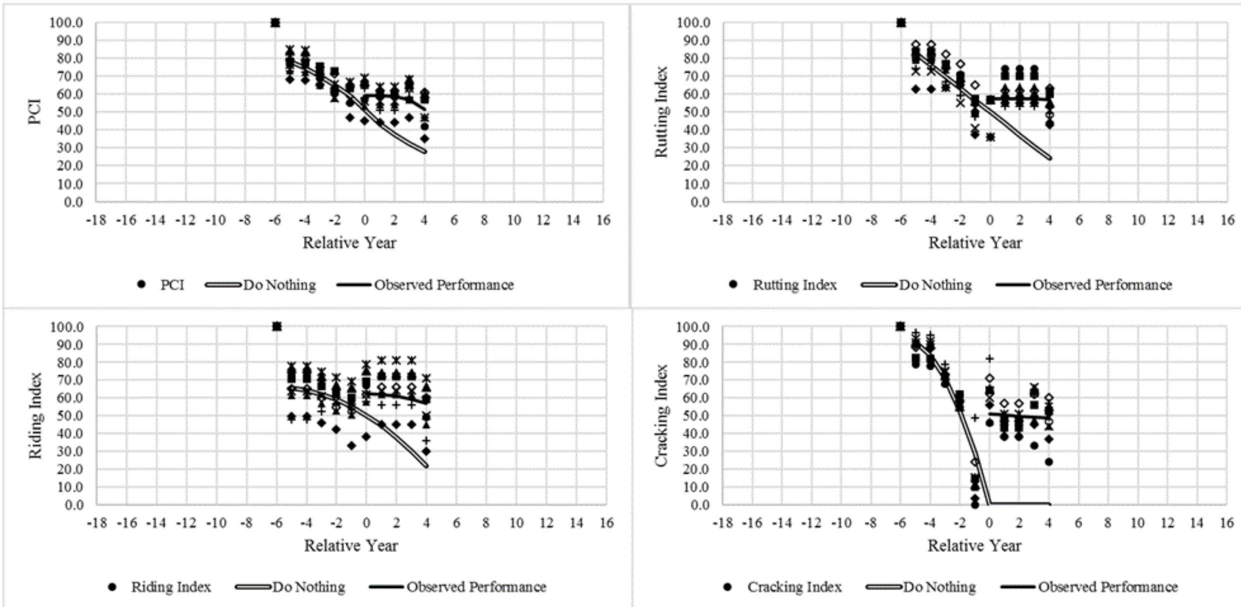


Figure 53. Analytical analysis graphs for project MP-009-3(704)5—76-60

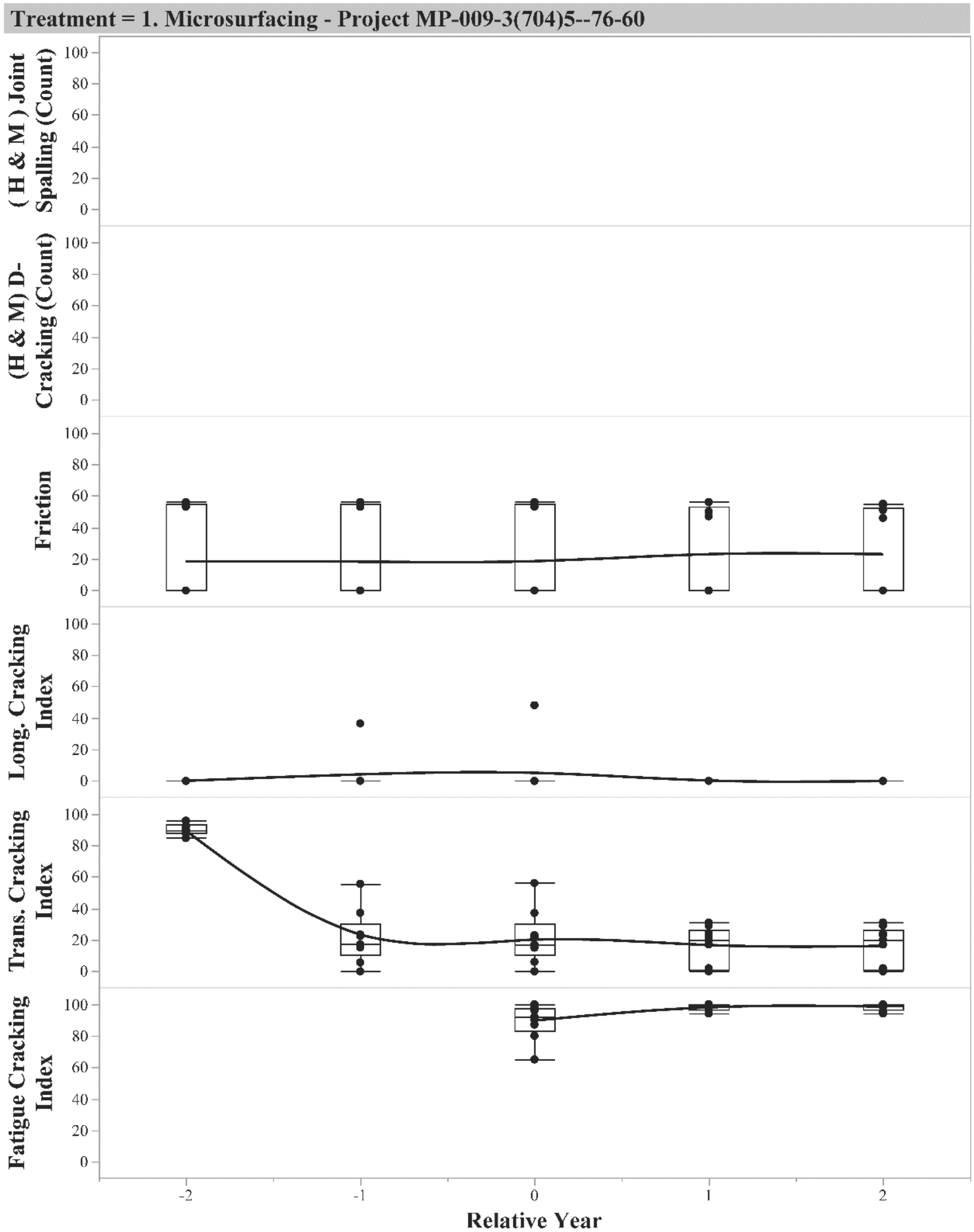


Figure 54. Anecdotal analysis graphs for project MP-009-3(704)5—76-60

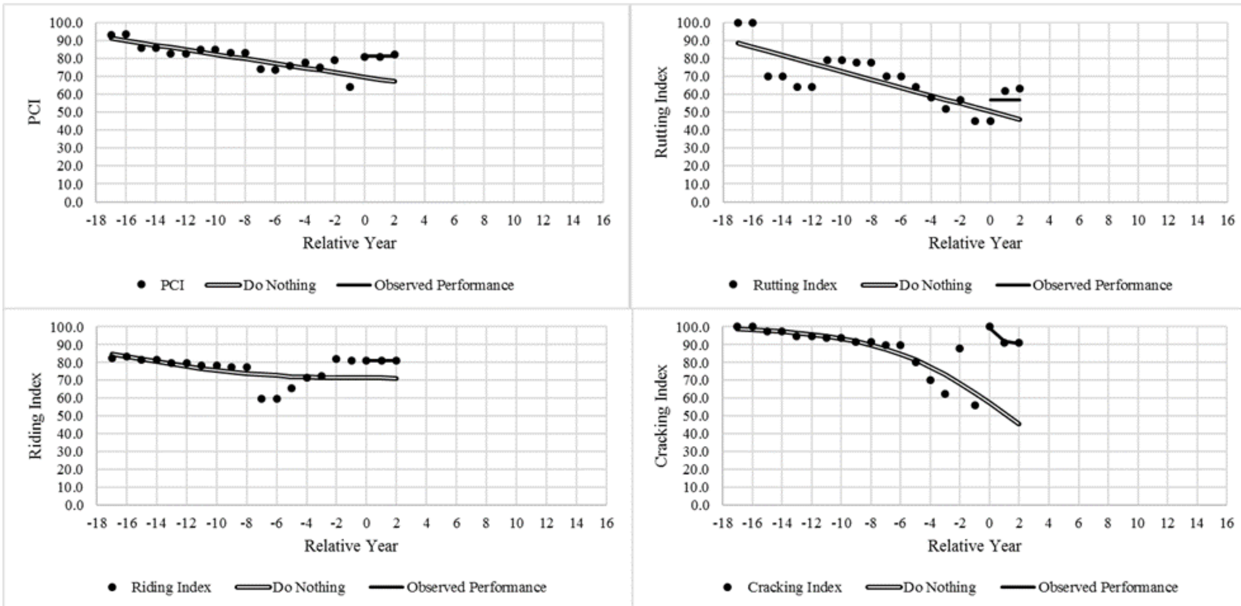


Figure 55. Analytical analysis graphs for project MP-020-3(706)58—76-81

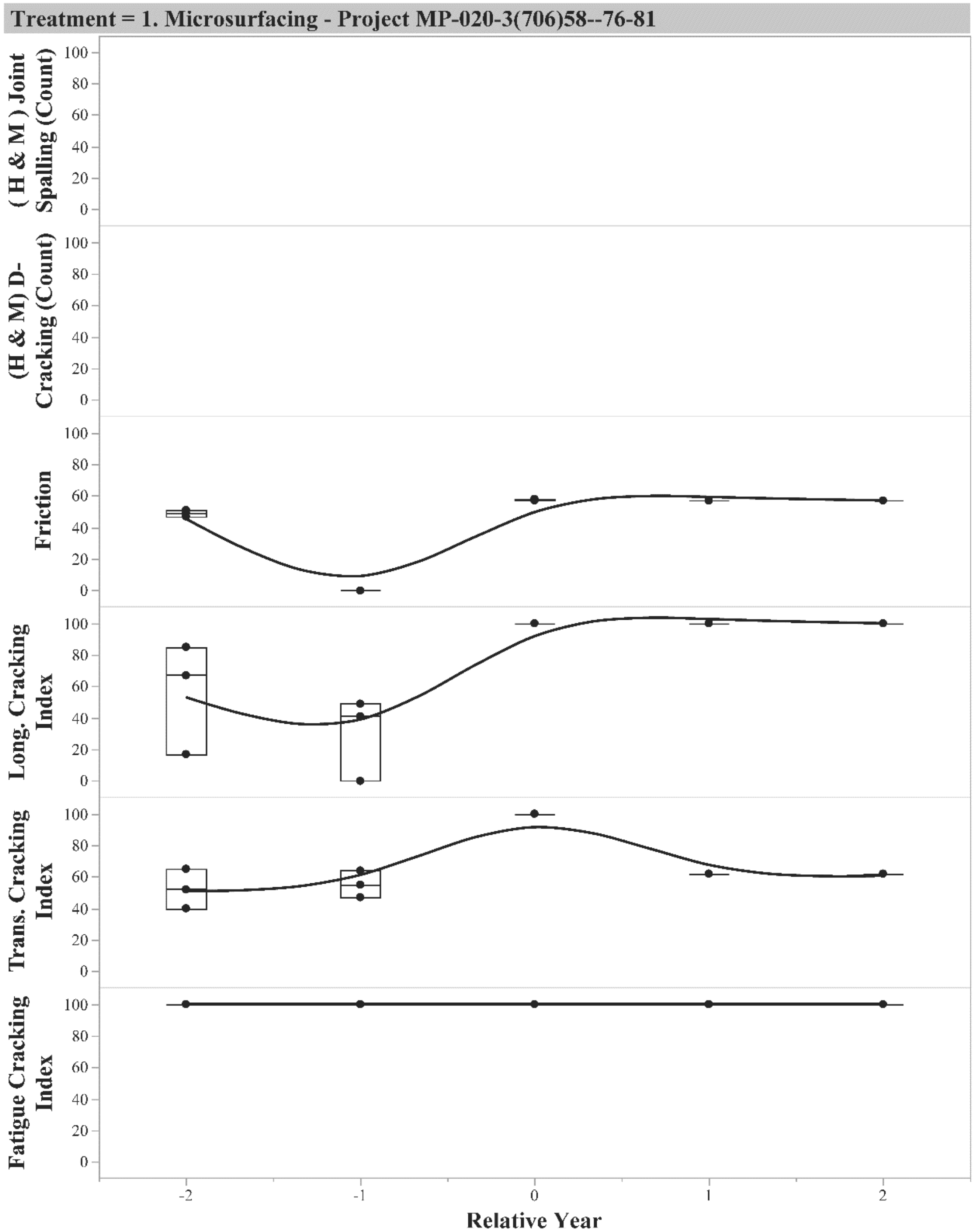


Figure 56. Anecdotal analysis graphs for project MP-020-3(706)58—76-81

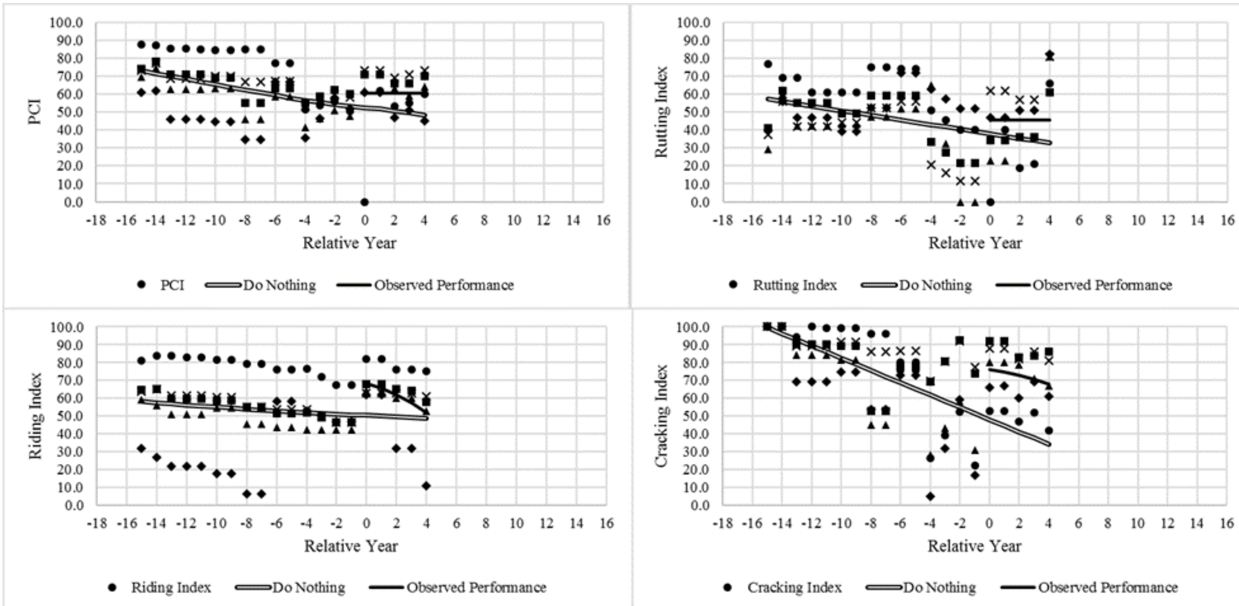


Figure 57. Analytical analysis graphs for project MP-025-4(702)45—76-01

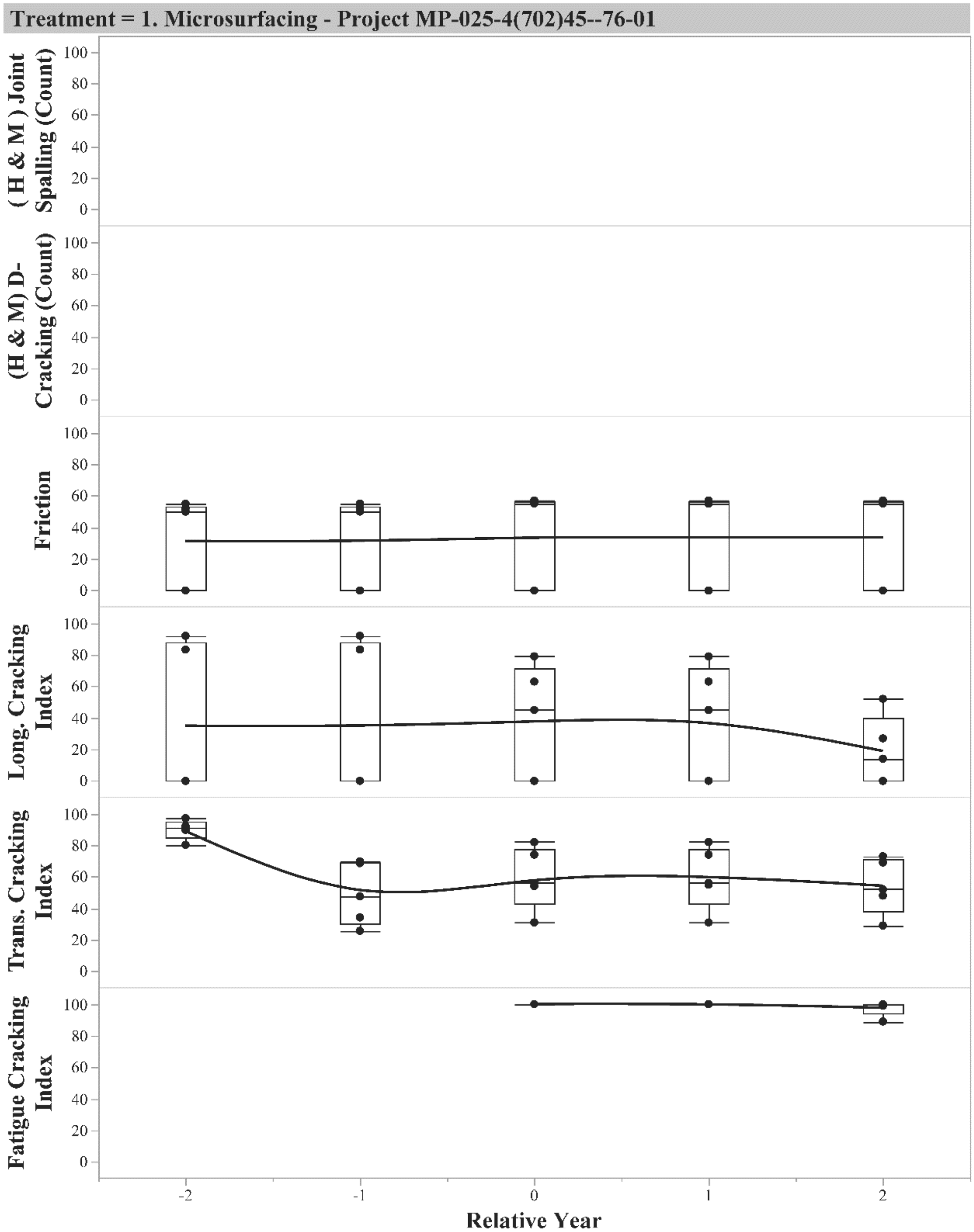


Figure 58. Anecdotal analysis graphs for project MP-025-4(702)45—76-01

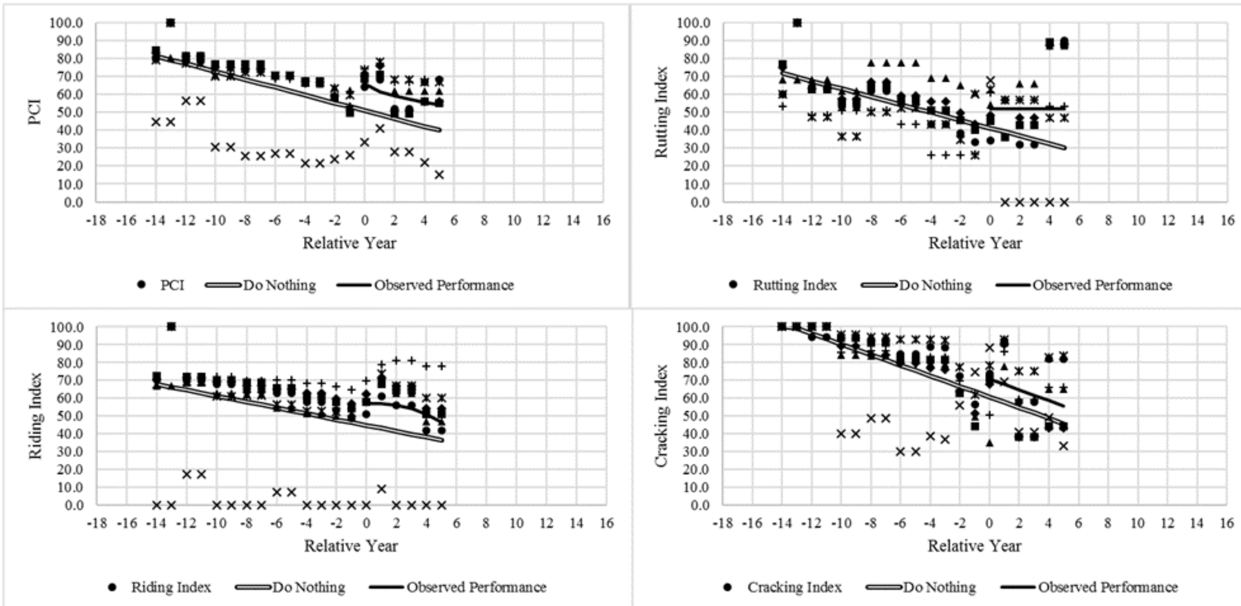


Figure 59. Analytical analysis graphs for project MP-030-4(708)12—76-43

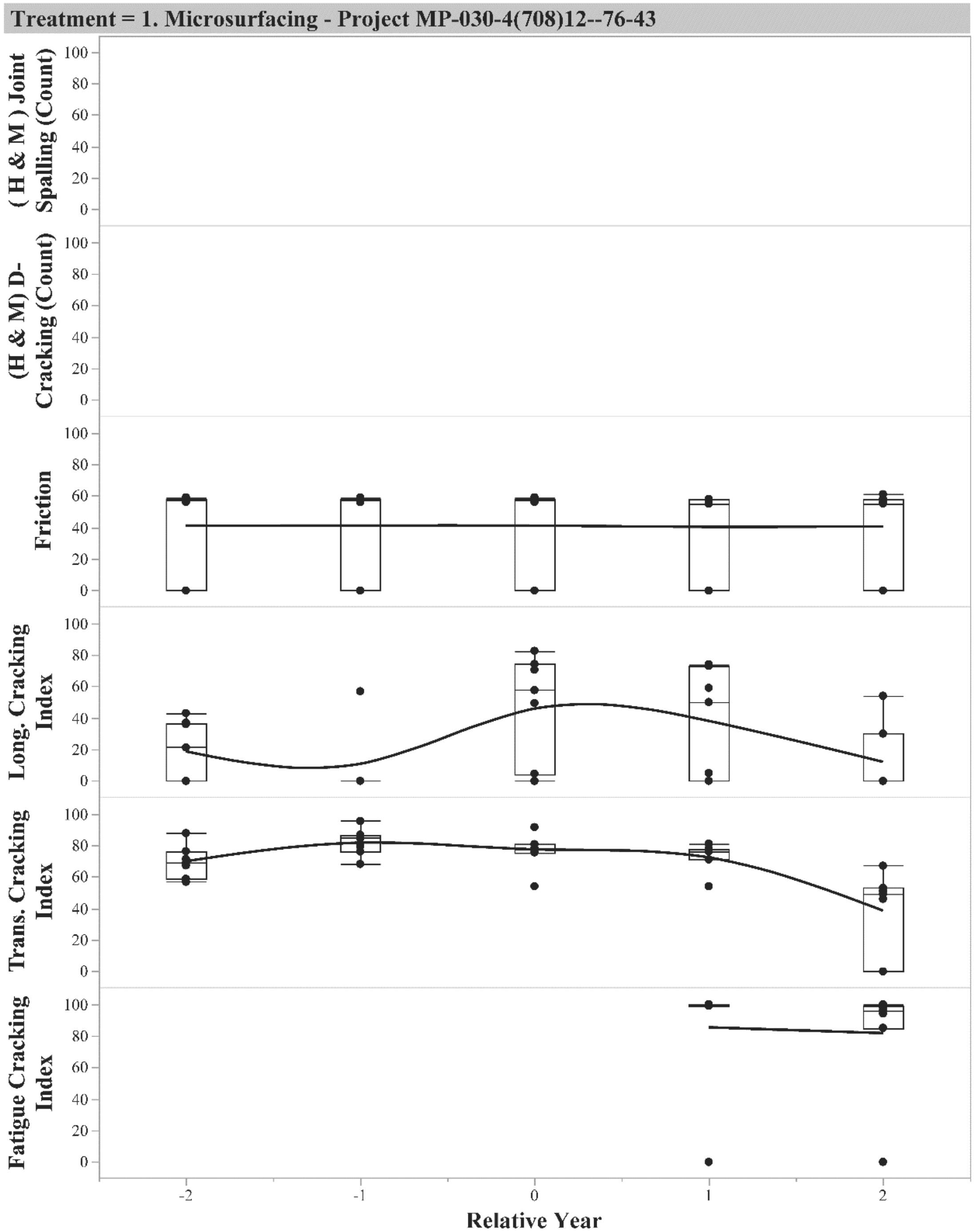


Figure 60. Anecdotal analysis graphs for project MP-030-4(708)12—76-43

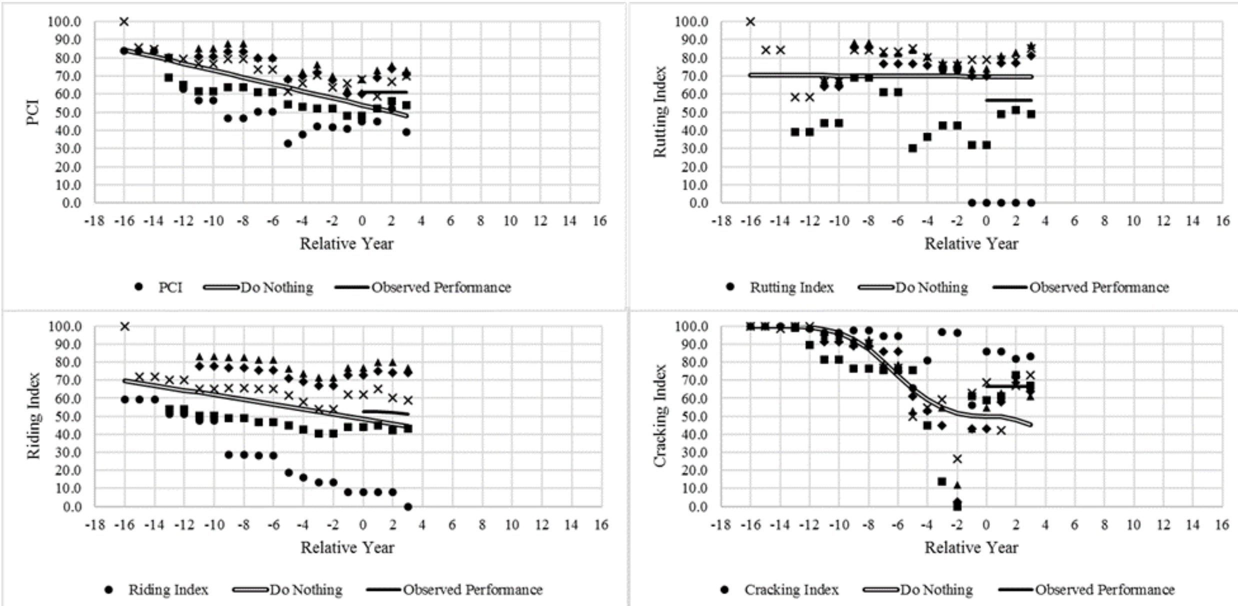


Figure 61. Analytical analysis graphs for project MP-070-5(701)2—76-58

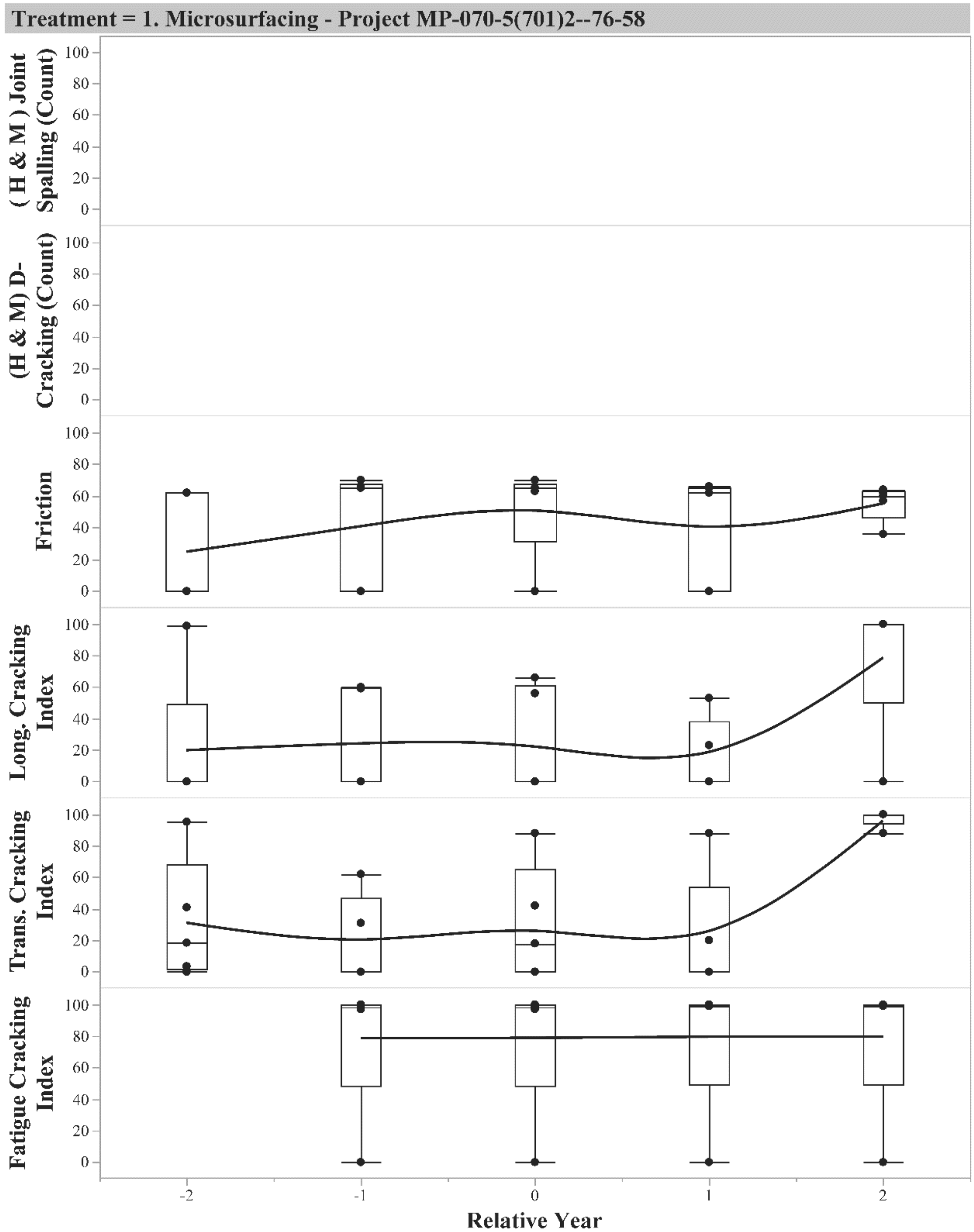


Figure 62. Anecdotal analysis graphs for project MP-070-5(701)2—76-58

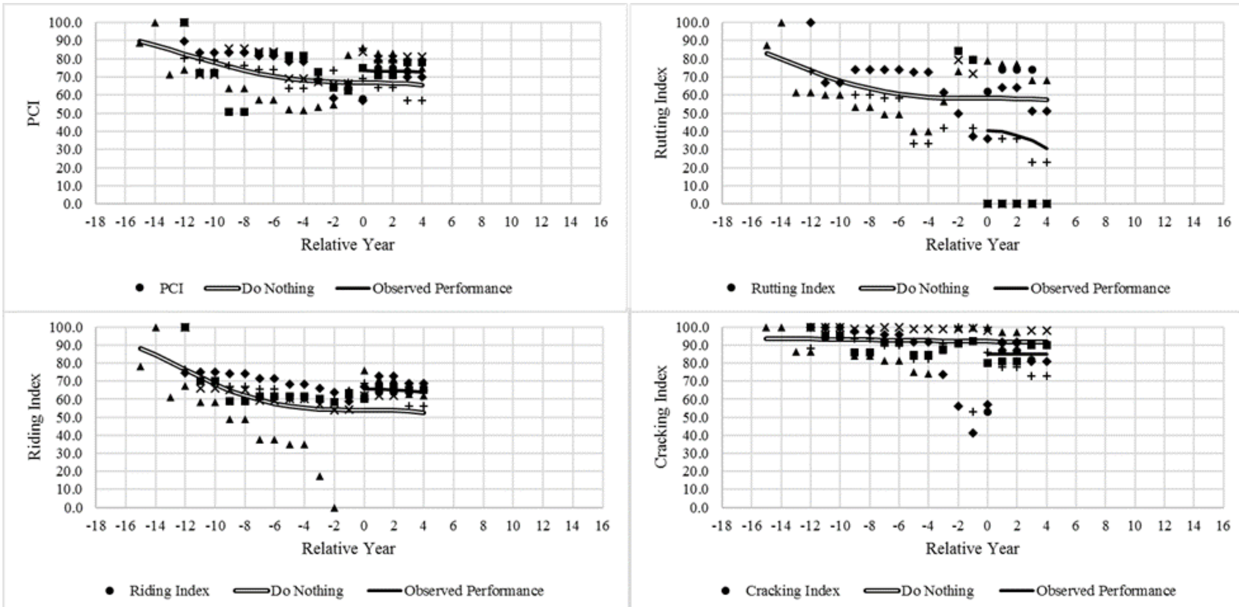


Figure 63. Analytical analysis graphs for project MP-071-3(710)142—76-81

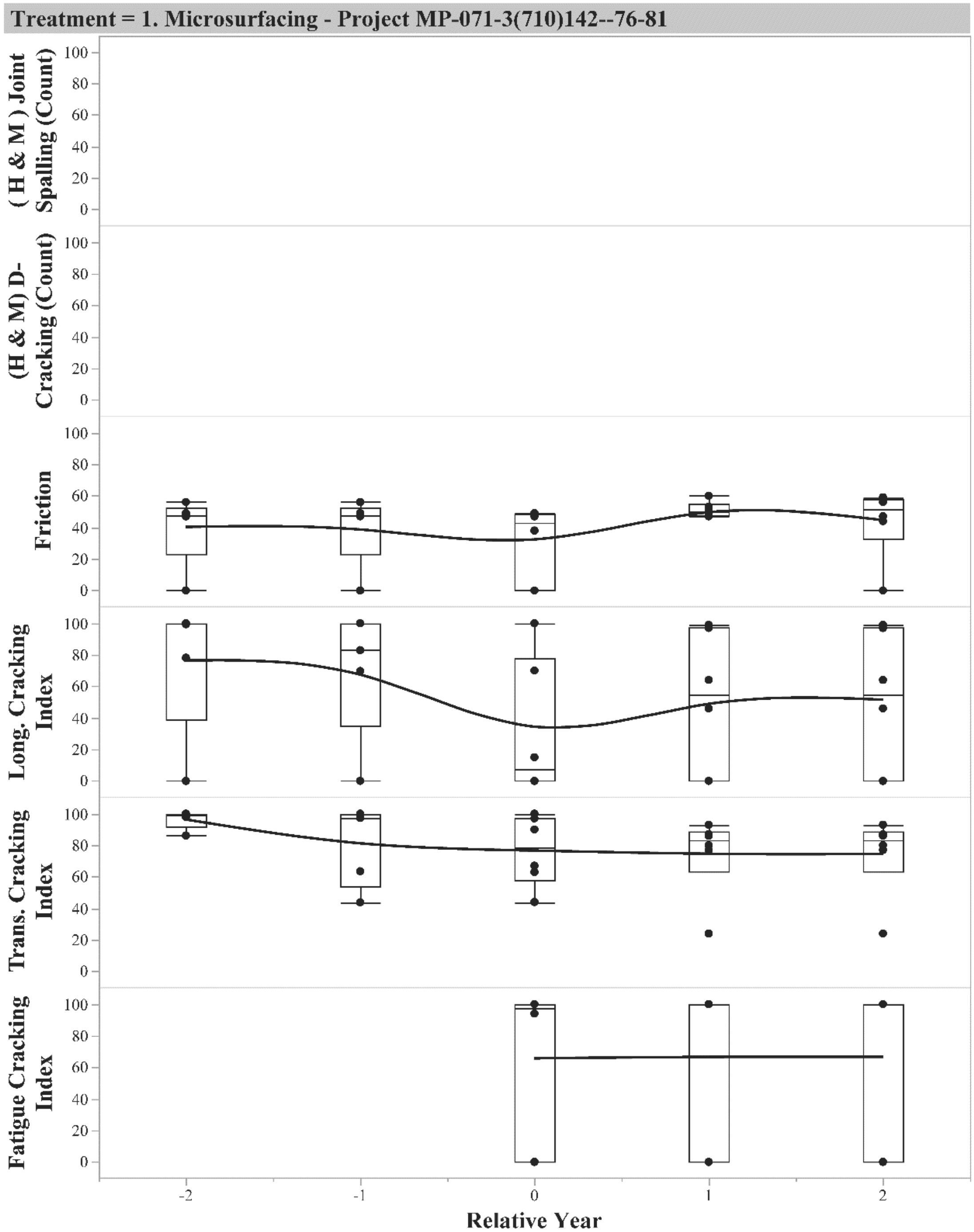


Figure 64. Anecdotal analysis graphs for project MP-071-3(710)142—76-81

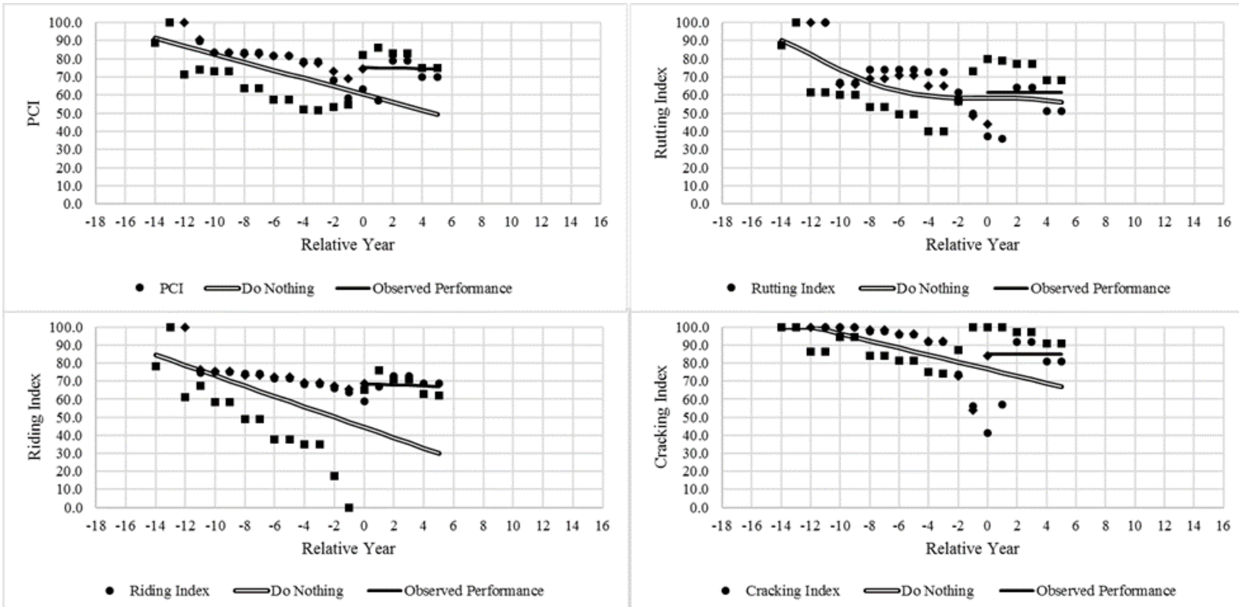


Figure 65. Analytical analysis graphs for project MP-075-3(711)101—76-75

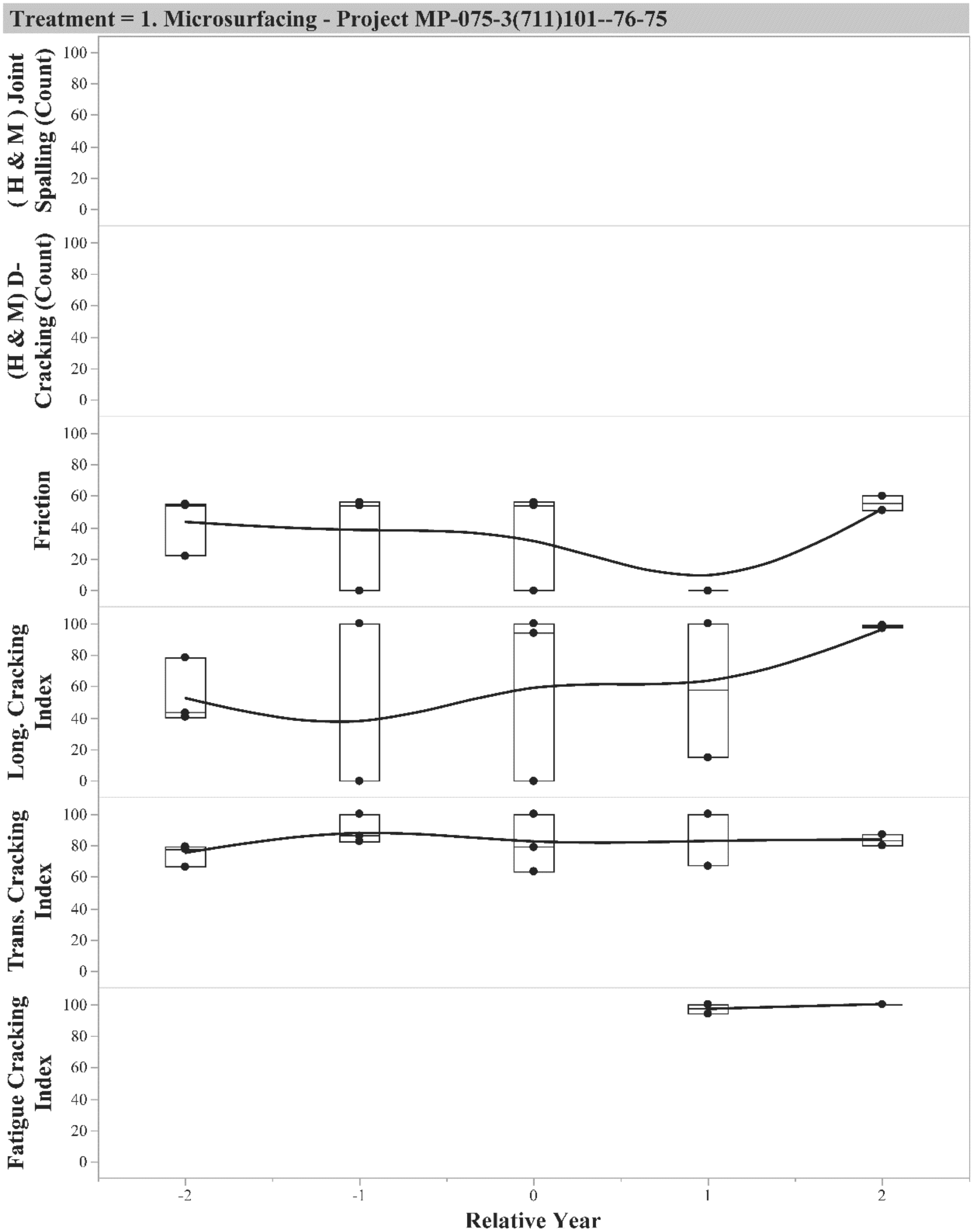


Figure 66. Anecdotal analysis graphs for project MP-075-3(711)101—76-75

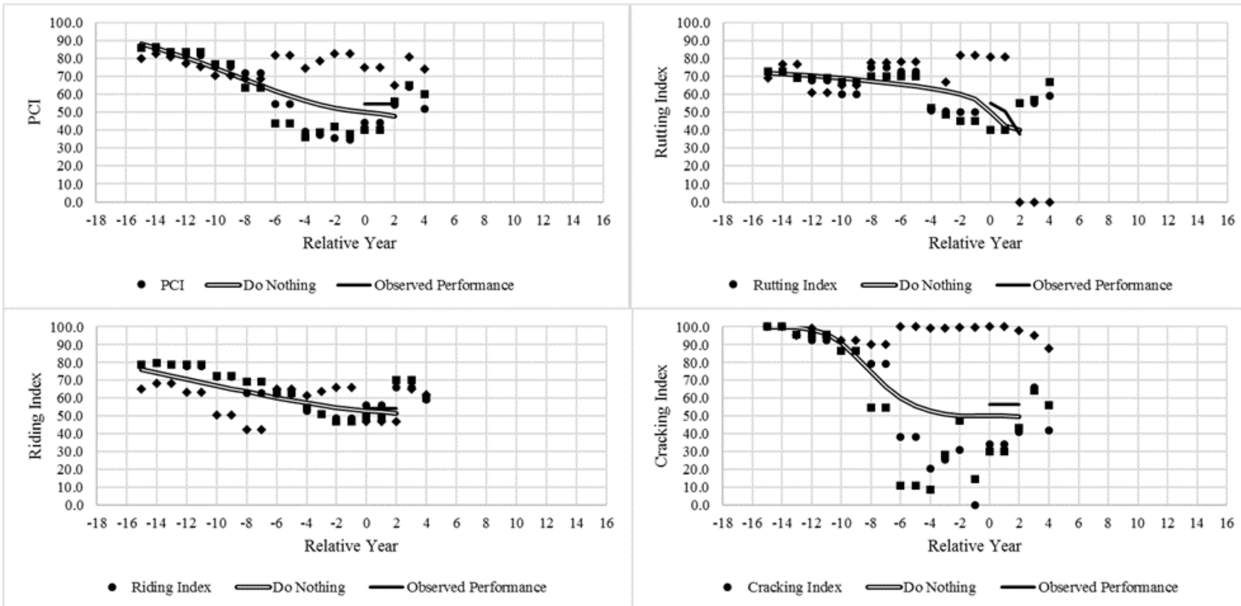


Figure 67. Analytical analysis graphs for project MP-137-5(701)0—76-68

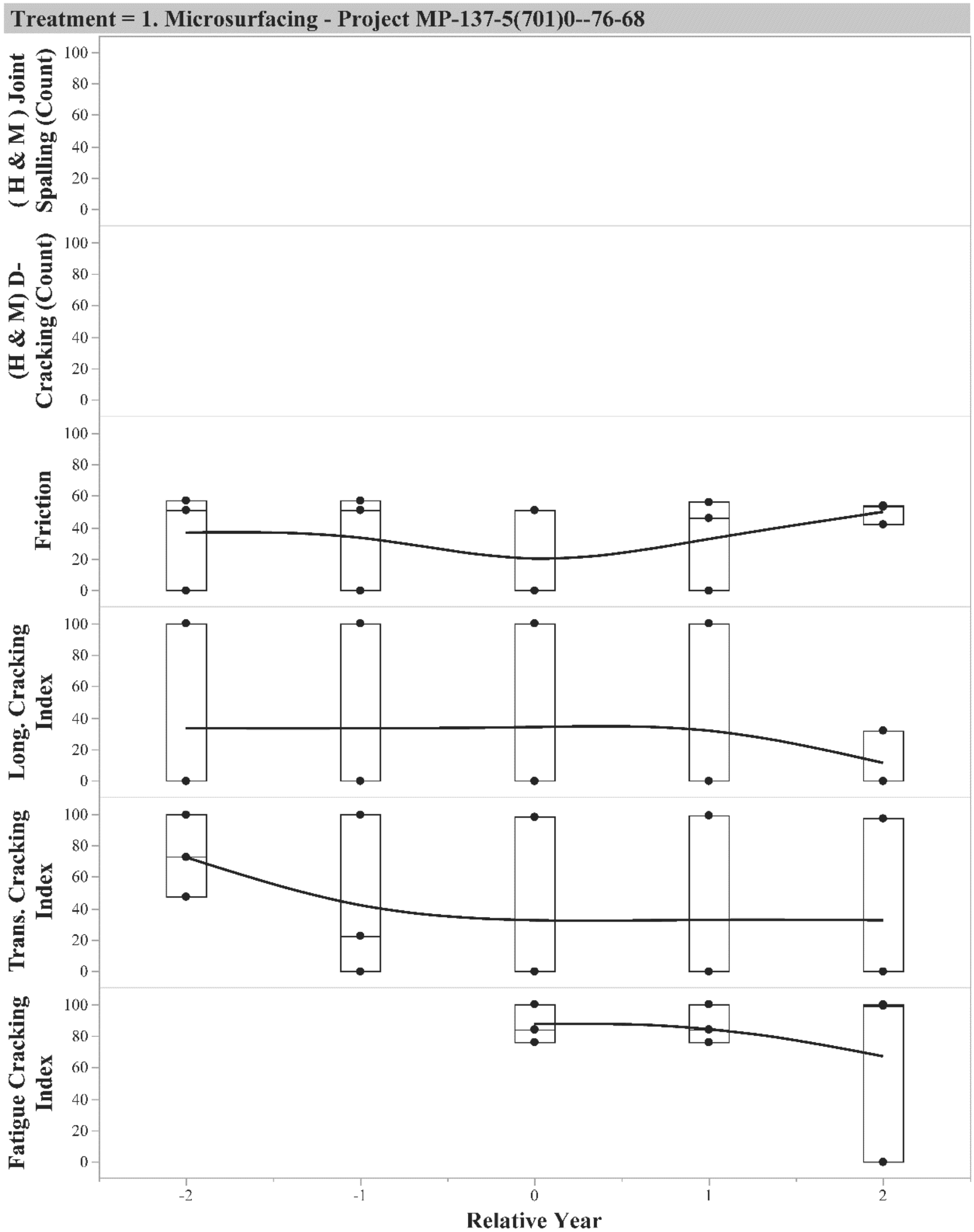


Figure 68. Anecdotal analysis graphs for project MP-137-5(701)0—76-68

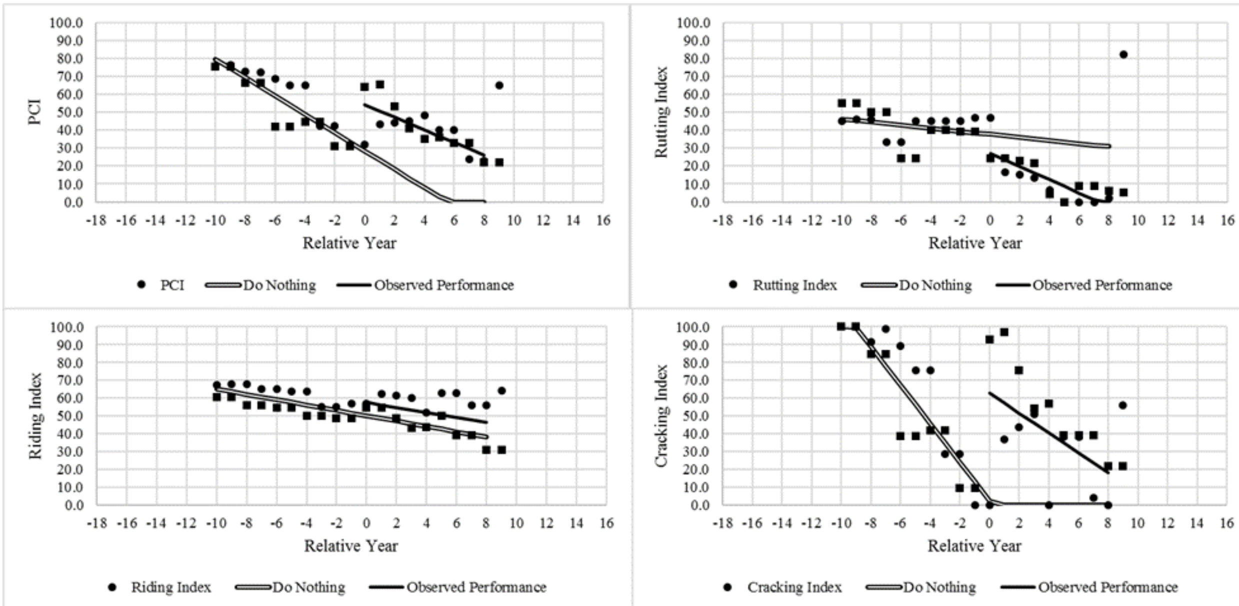


Figure 69. Analytical analysis graphs for project MP-144-4(700)3—76-08

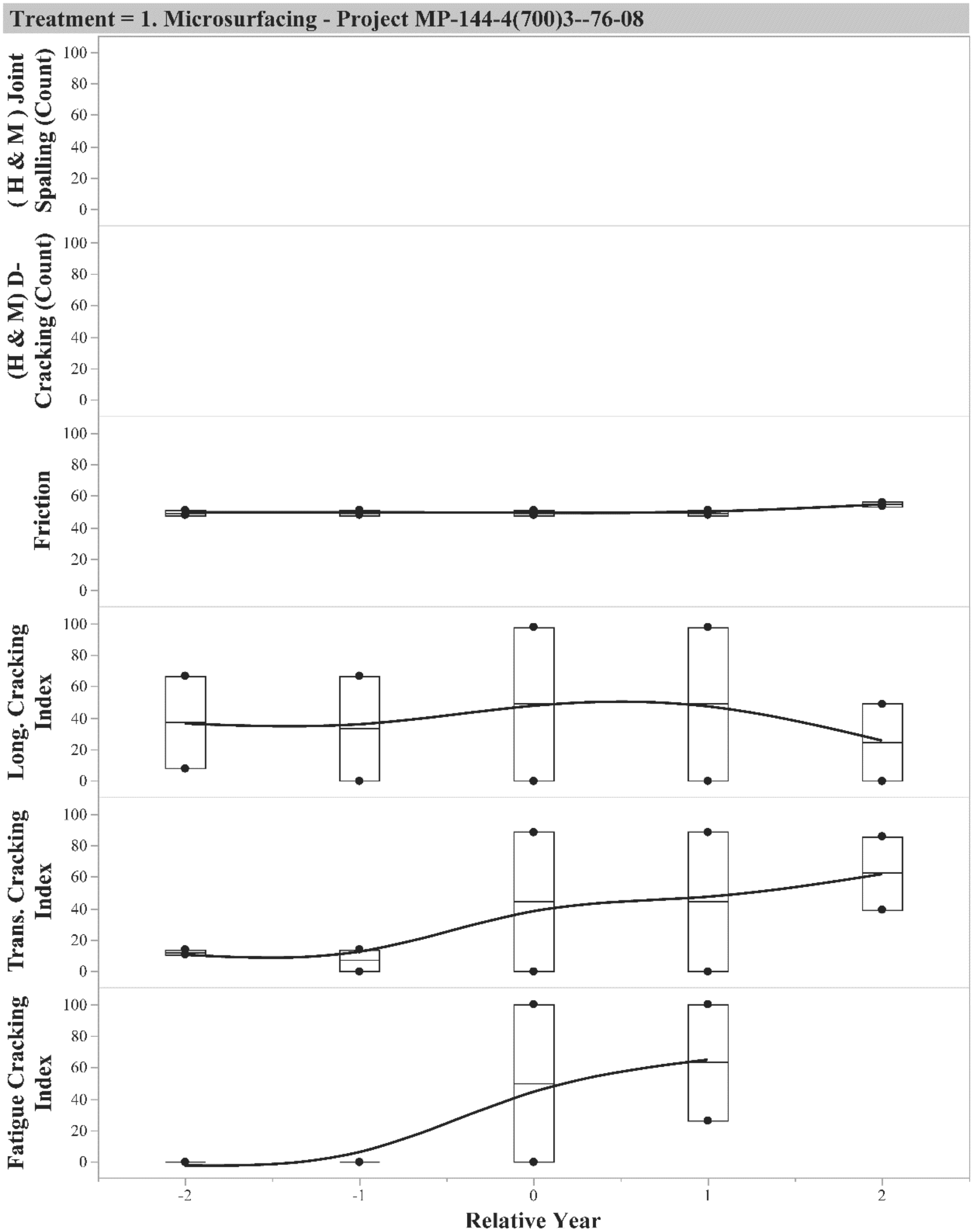


Figure 70. Anecdotal analysis graphs for project MP-144-4(700)3—76-08

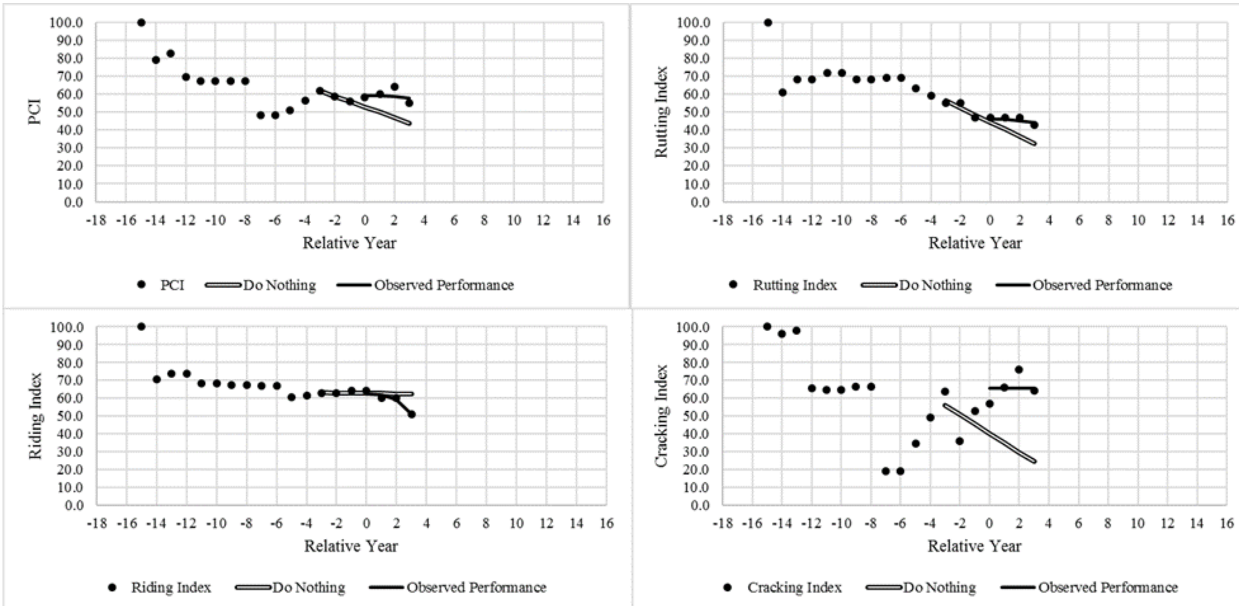


Figure 71. Analytical analysis graphs for project MP-149-5(709)12—76-54

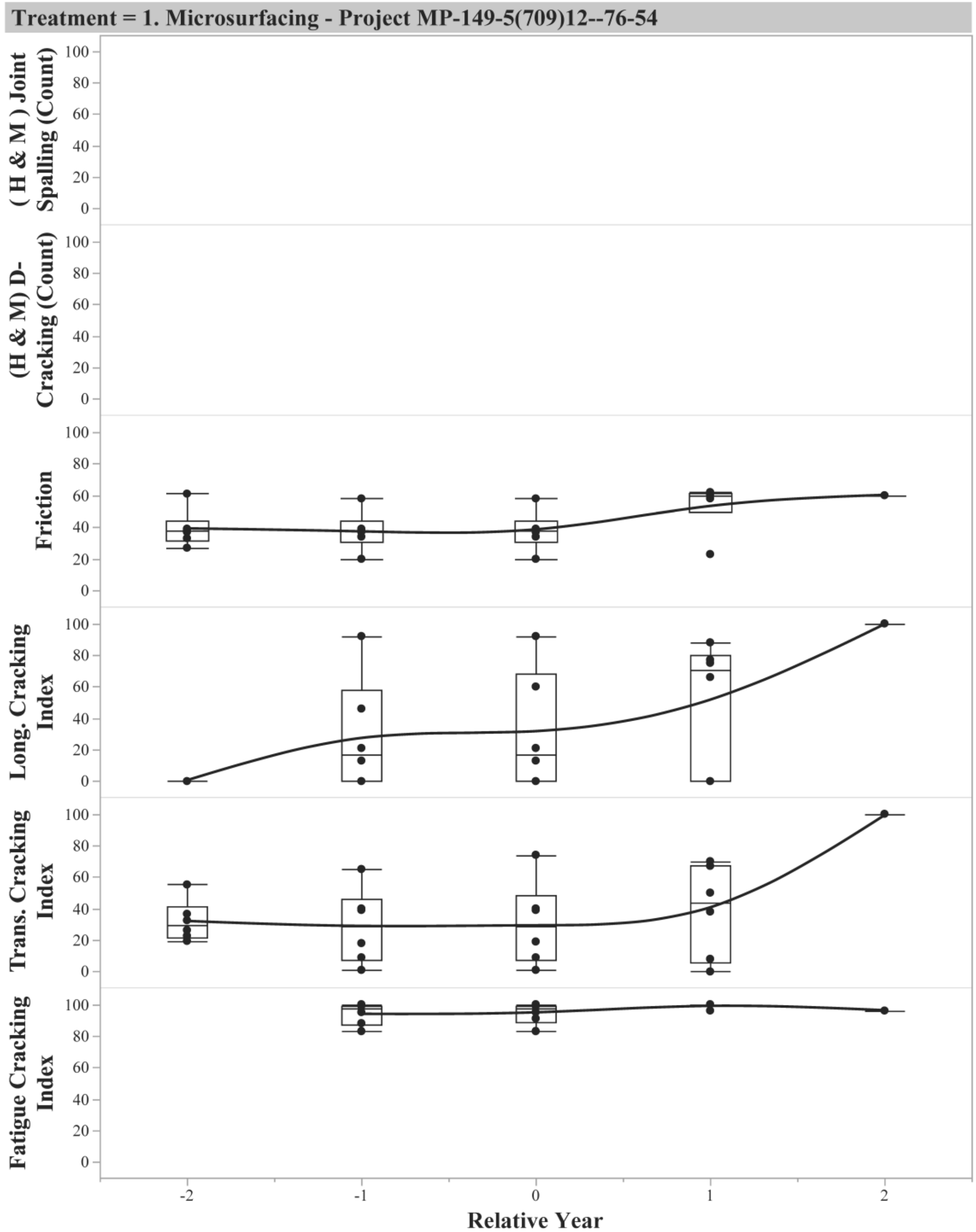


Figure 72. Anecdotal analysis graphs for project MP-149-5(709)12—76-54

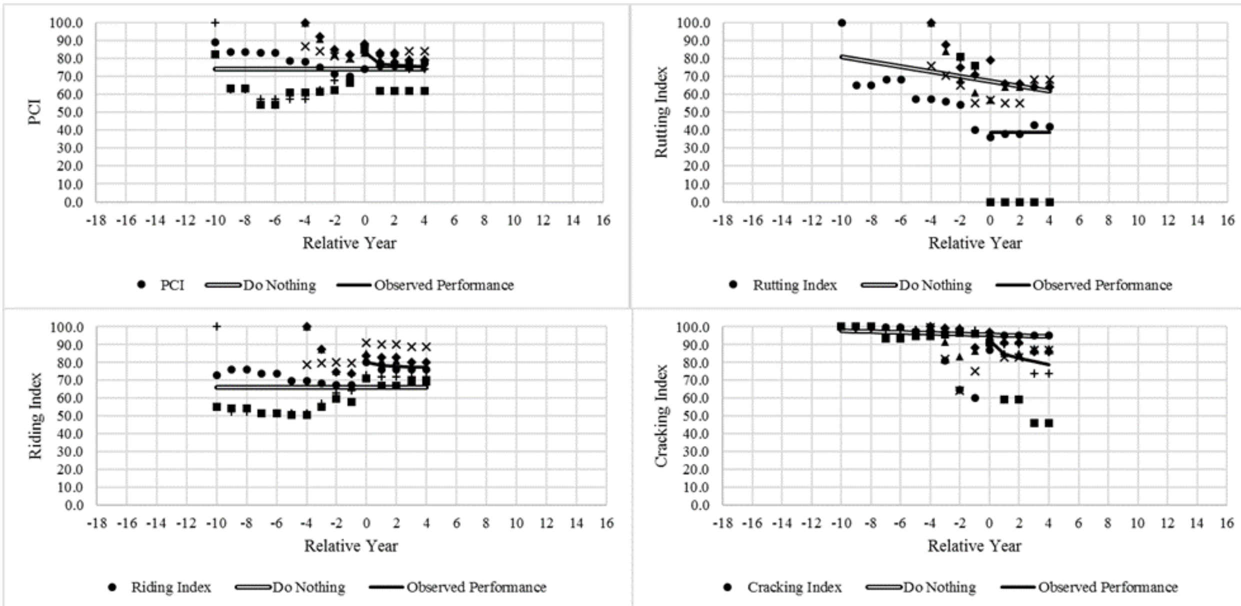


Figure 73. Analytical analysis graphs for project MP-218-2(704)206—76-09

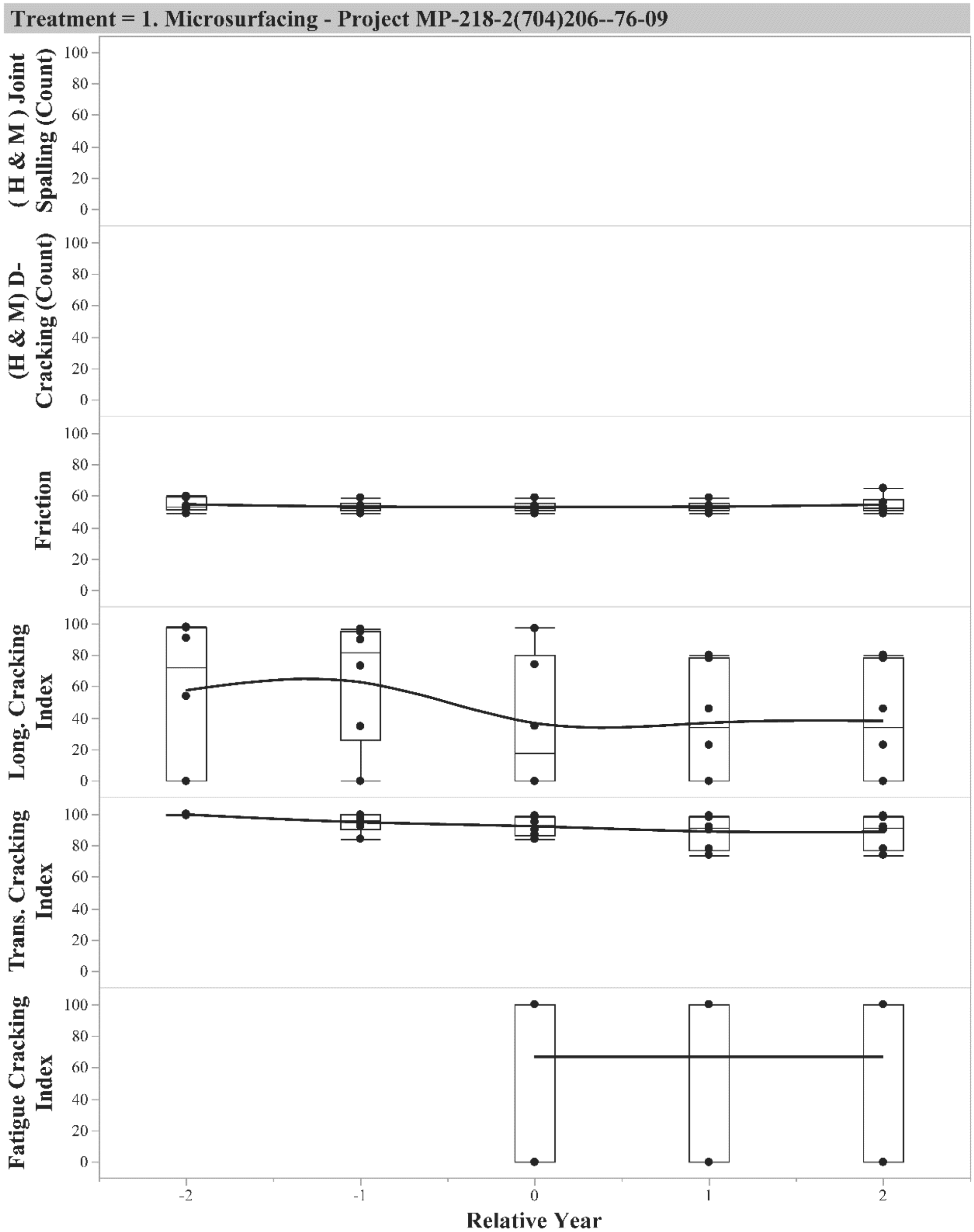


Figure 74. Anecdotal analysis graphs for project MP-218-2(704)206—76-09

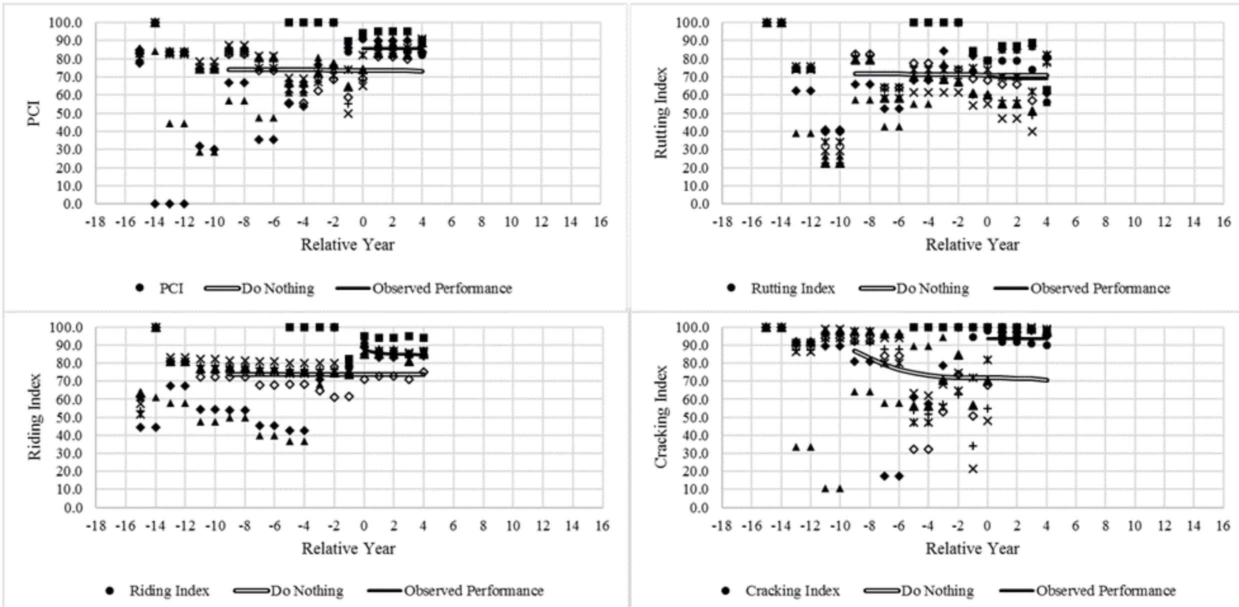


Figure 75. Analytical analysis graphs for project MPIN-029-4(703)25—0N-65

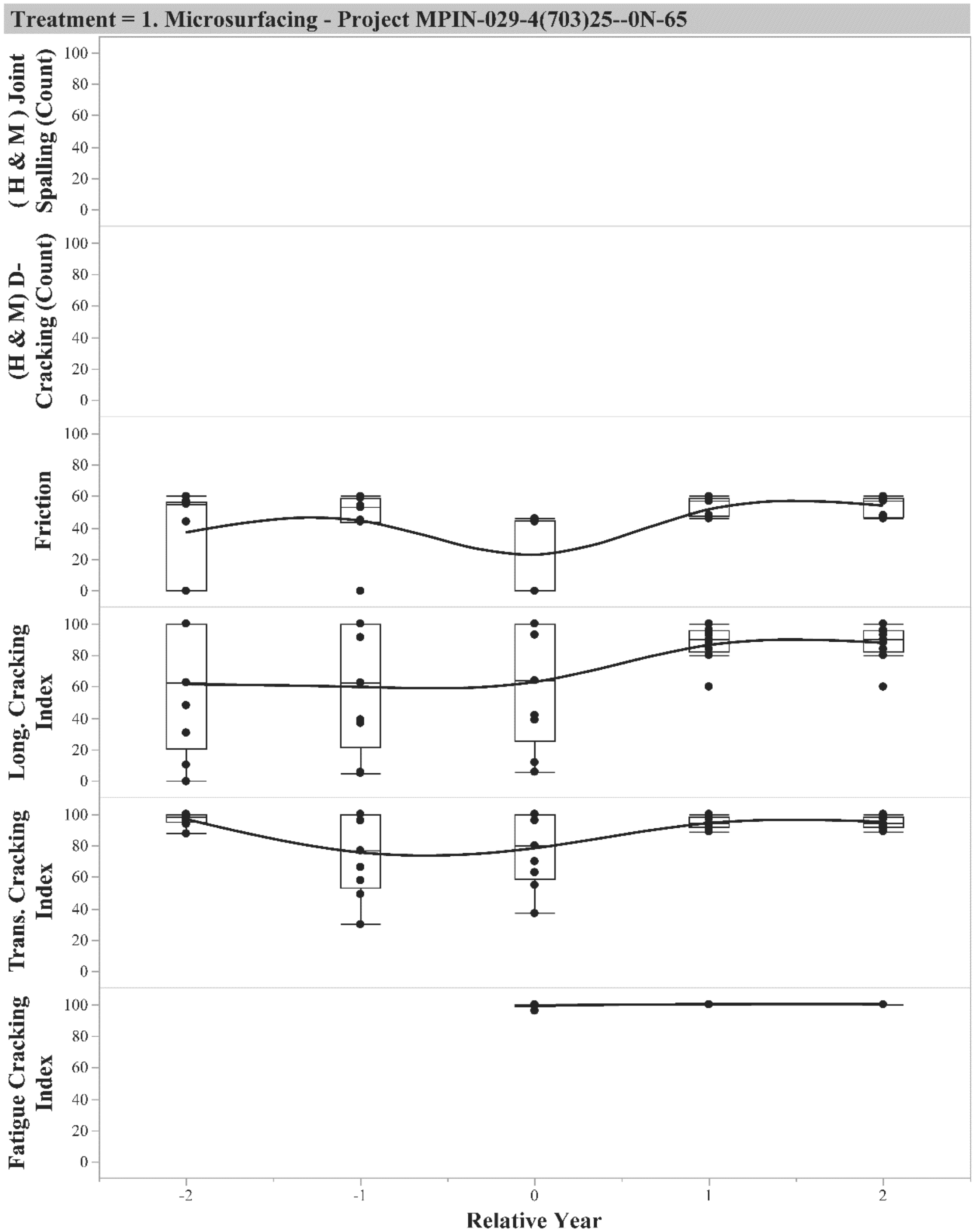


Figure 76. Anecdotal analysis graphs for project MPIN-029-4(703)25—0N-65

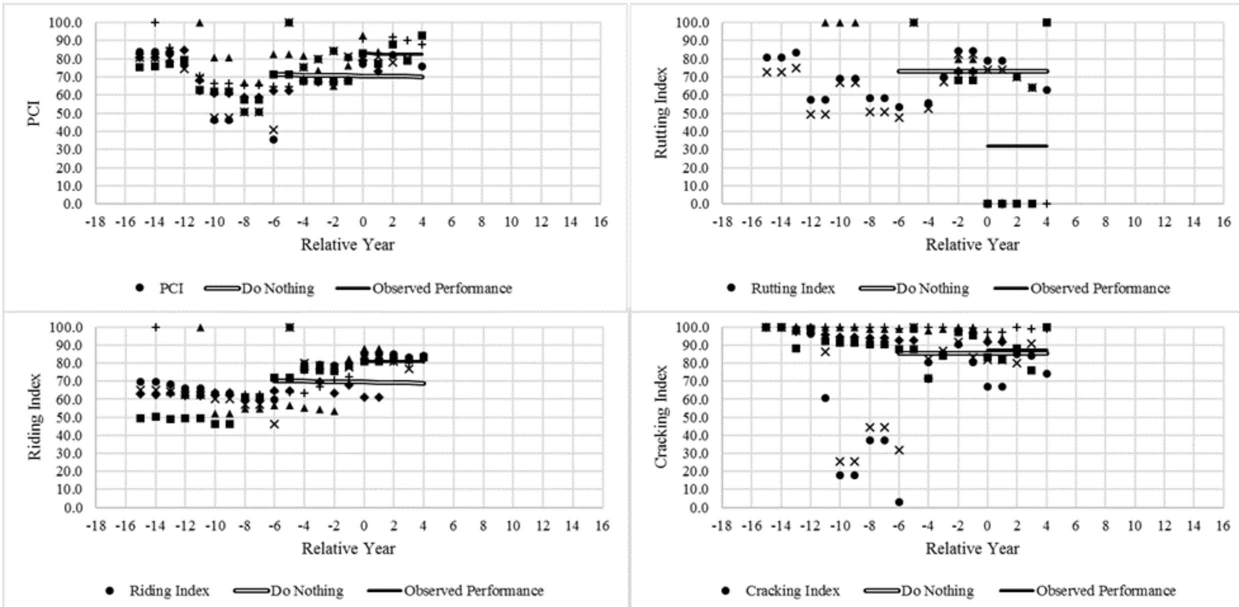


Figure 77. Analytical analysis graphs for project MPIN-035-1(708)106—0N-85

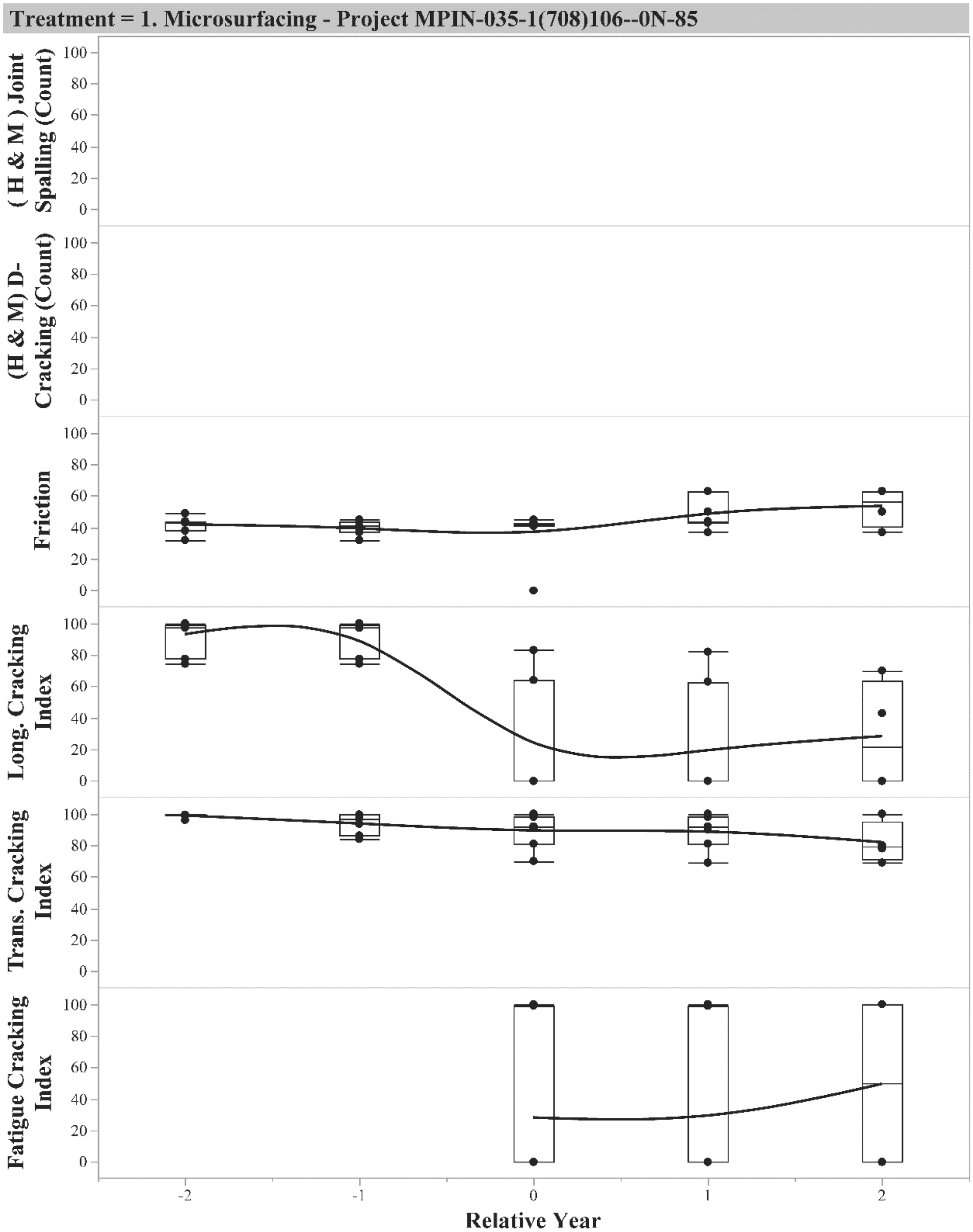


Figure 78. Anecdotal analysis graphs for project MPIN-035-1(708)106—0N-85

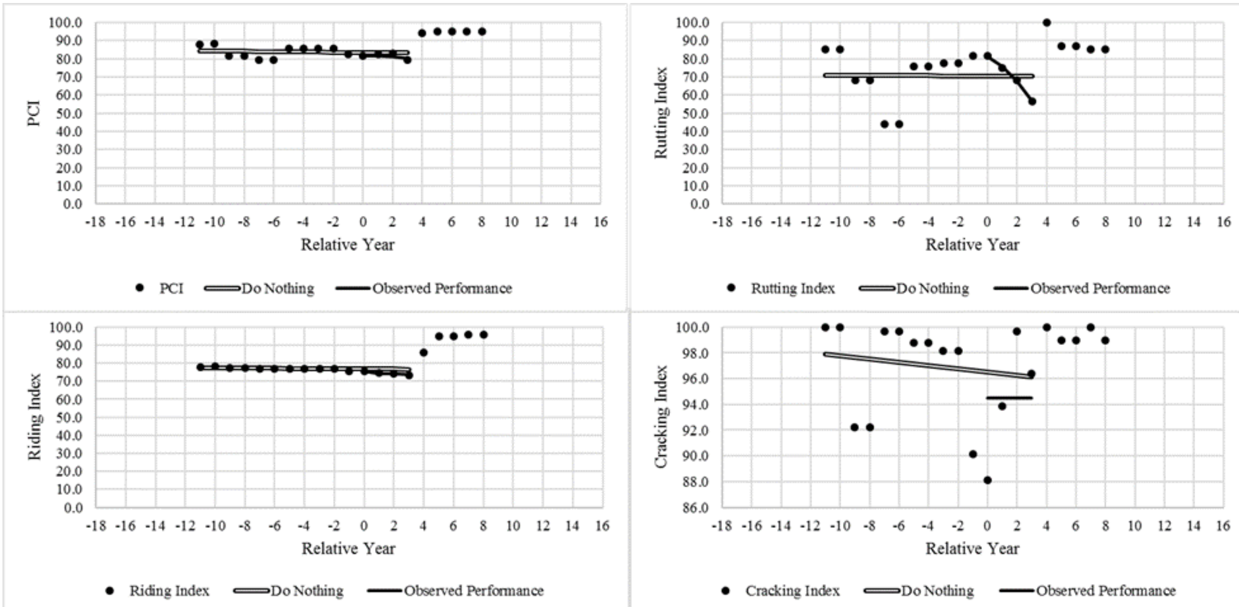


Figure 79. Analytical analysis graphs for project MPIN-035-2(703)216—0N-98

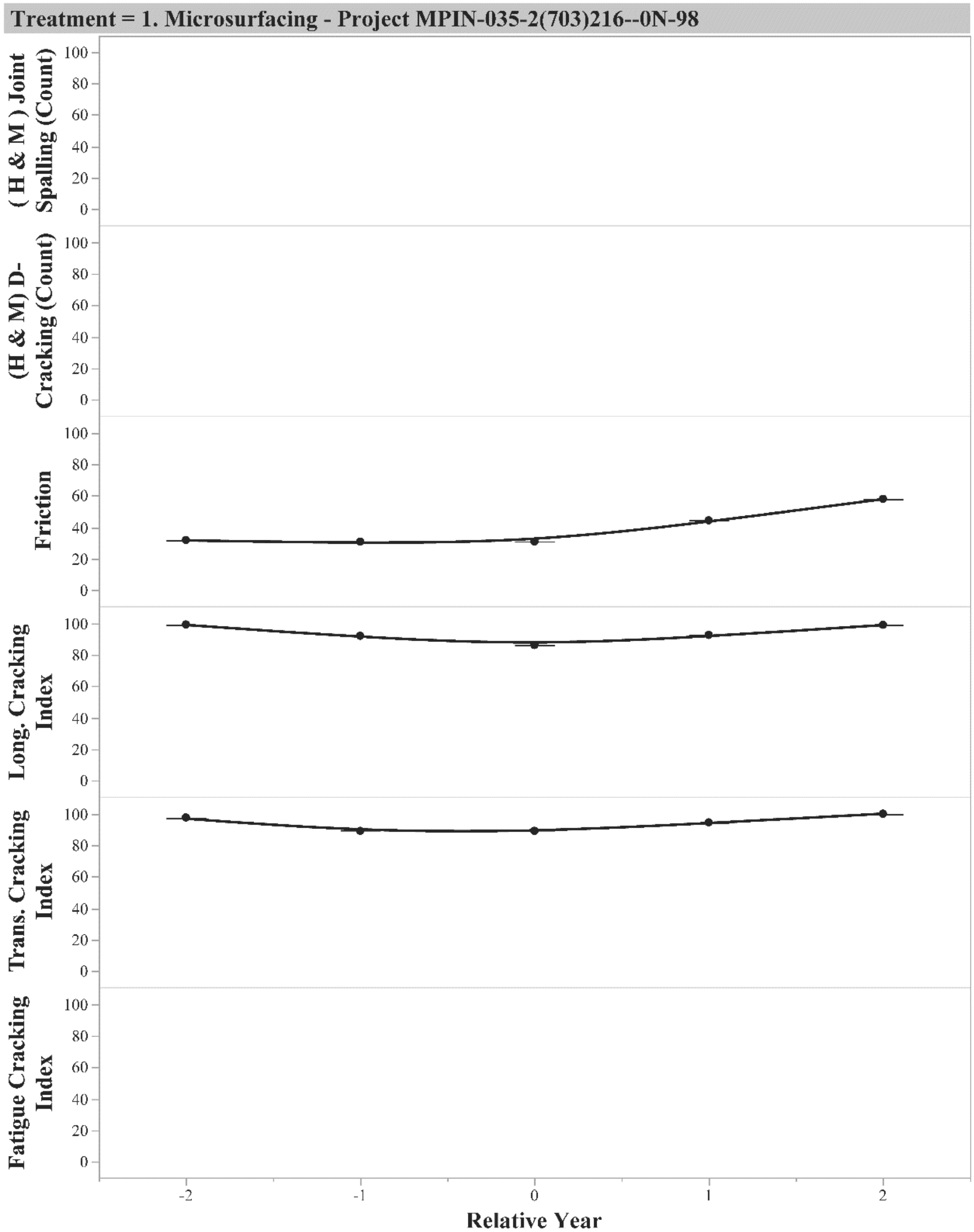


Figure 80. Anecdotal analysis graphs for project MPIN-035-2(703)216—0N-98

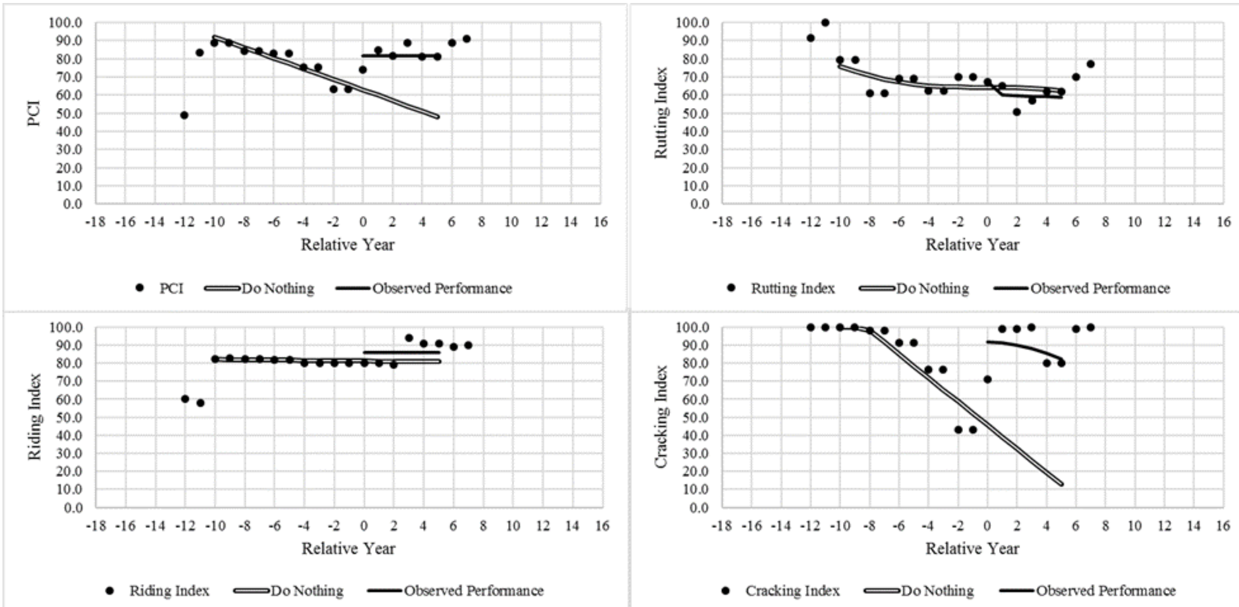


Figure 81. Analytical analysis graphs for project MPIN-035-2(713)178—0N-17

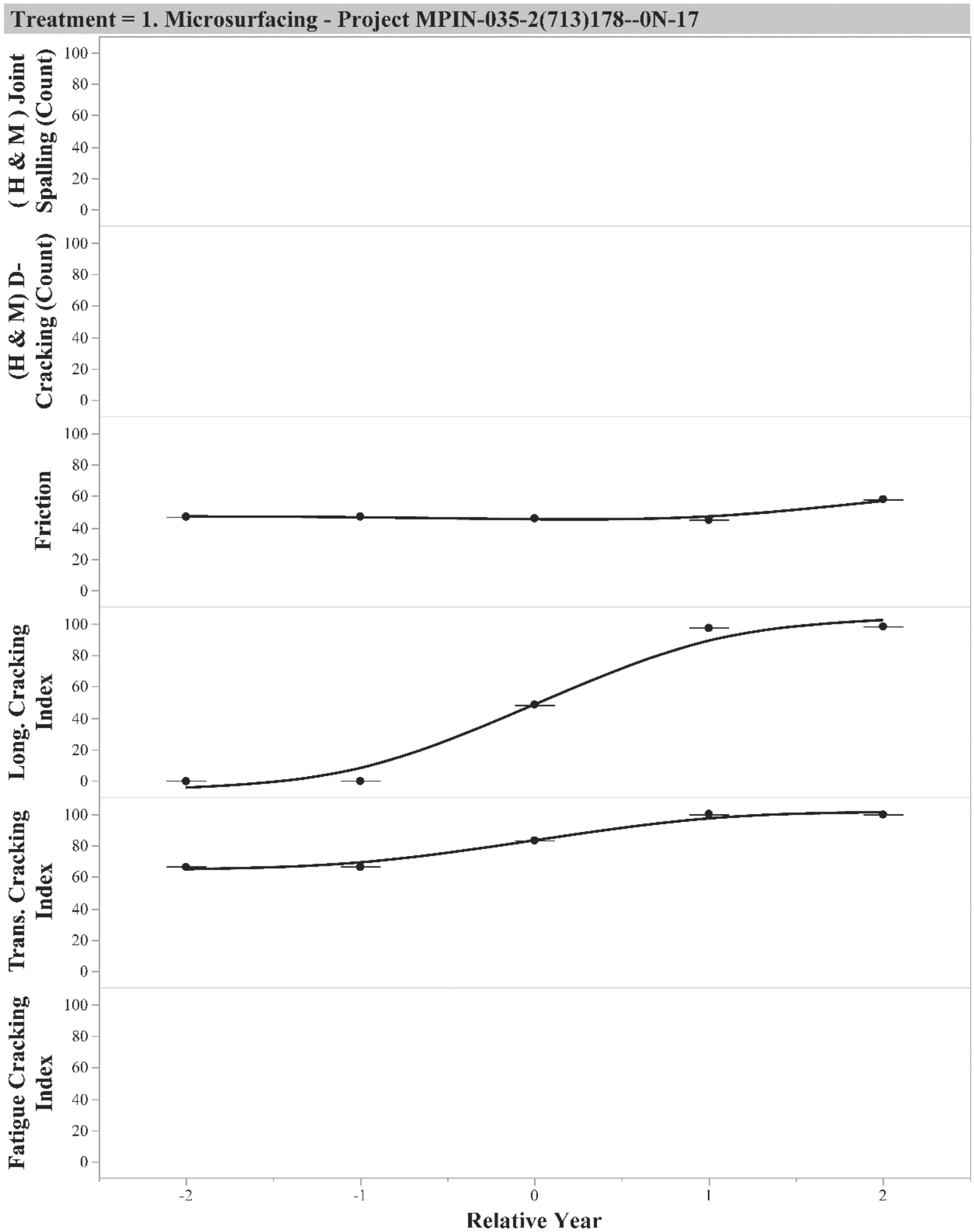


Figure 82. Anecdotal analysis graphs for project MPIN-035-2(713)178—0N-17

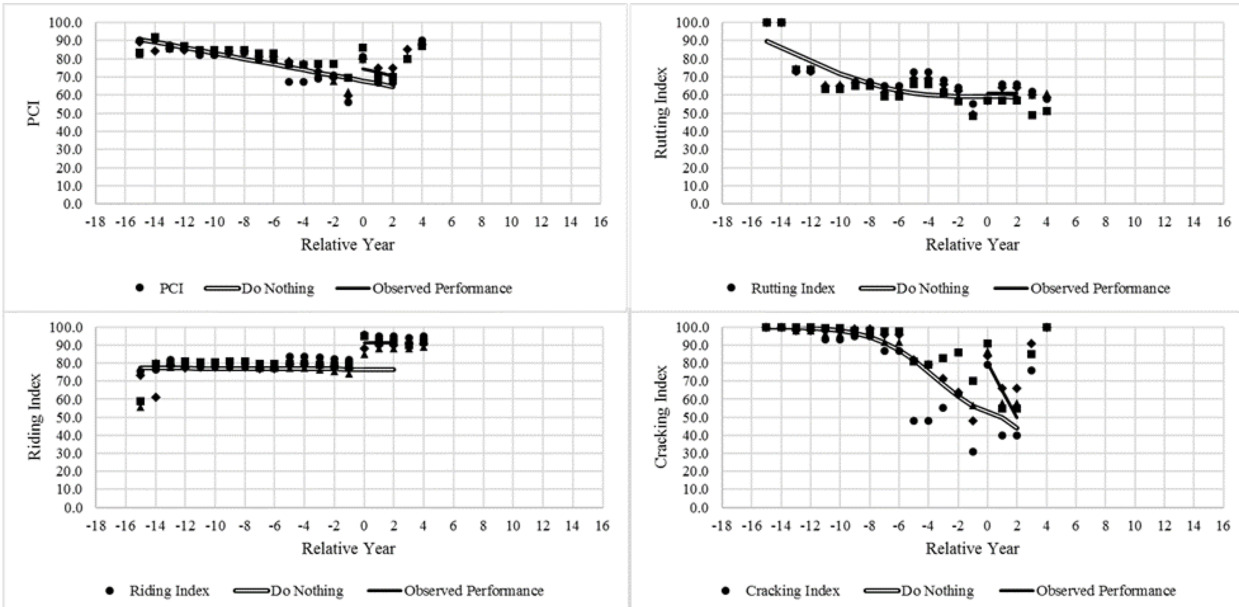


Figure 83. Analytical analysis graphs for project MPIN-035-2(714)159—0N-35

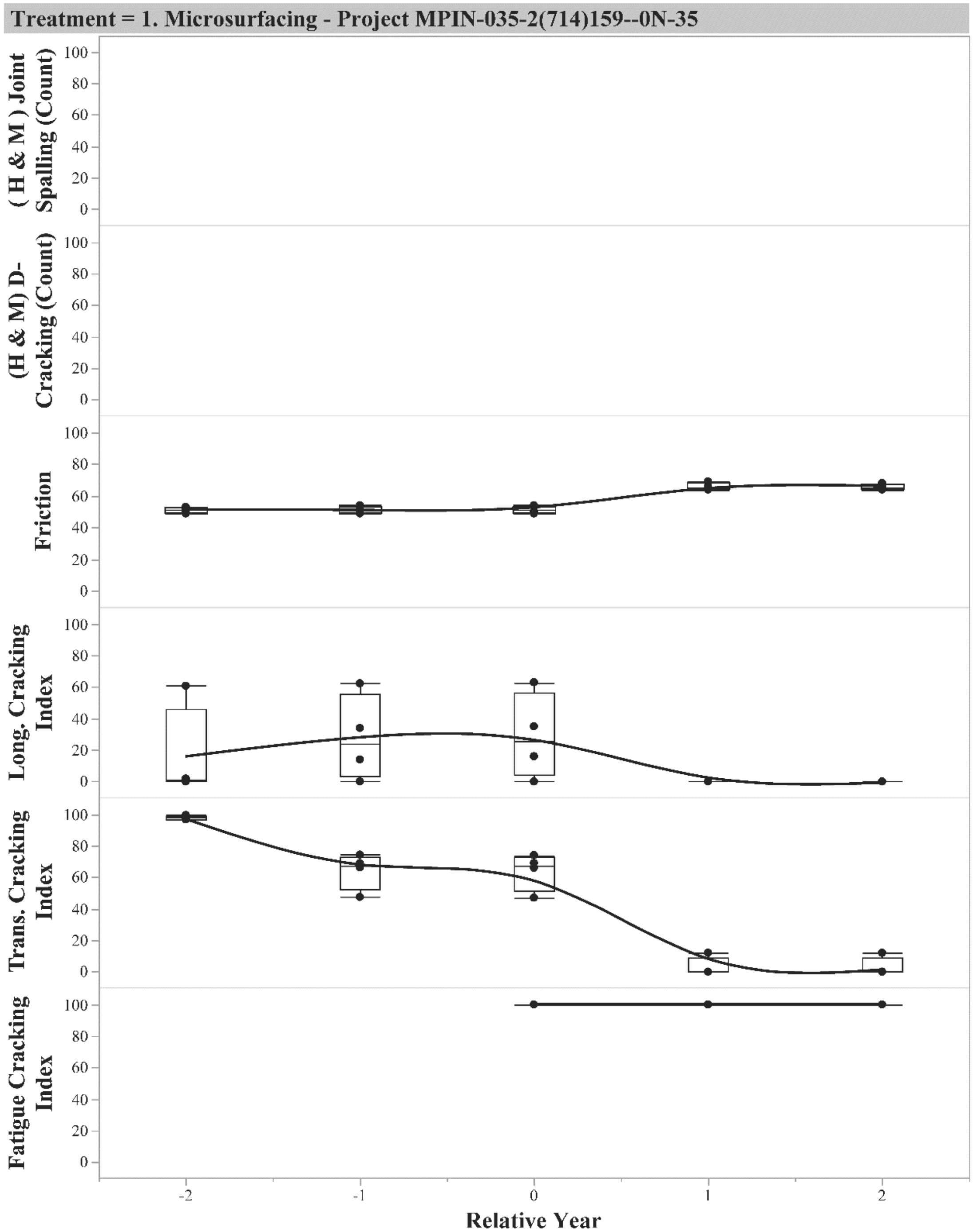


Figure 84. Anecdotal analysis graphs for project MPIN-035-2(714)159—0N-35

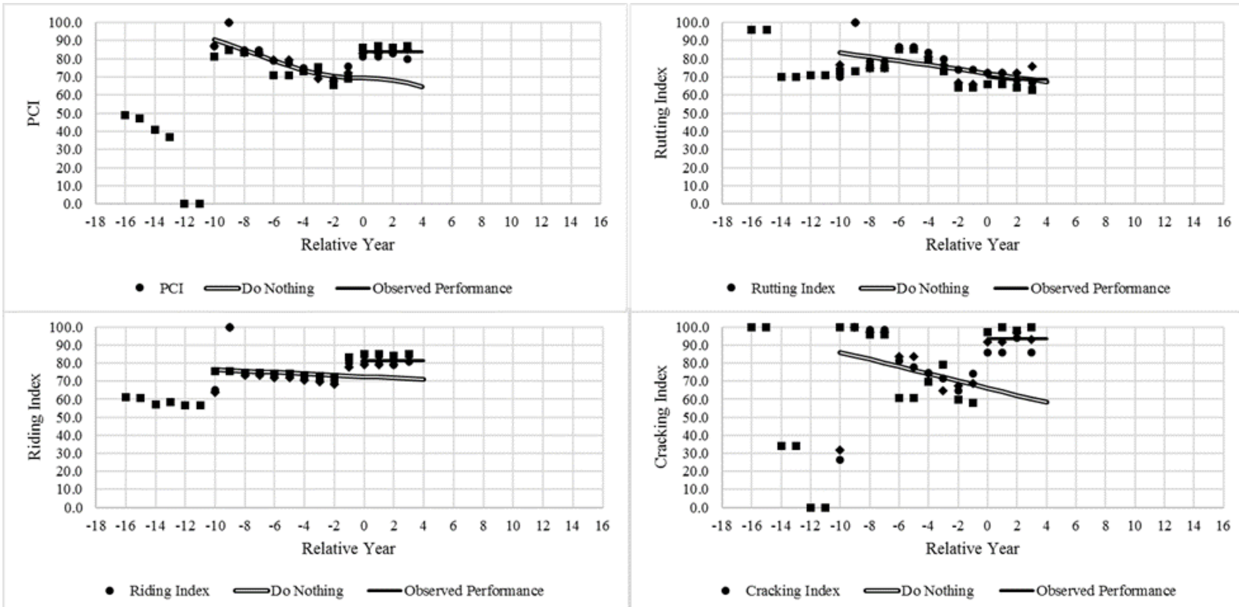


Figure 85. Analytical analysis graphs for project MPIN-035-2(716)175—0N-35

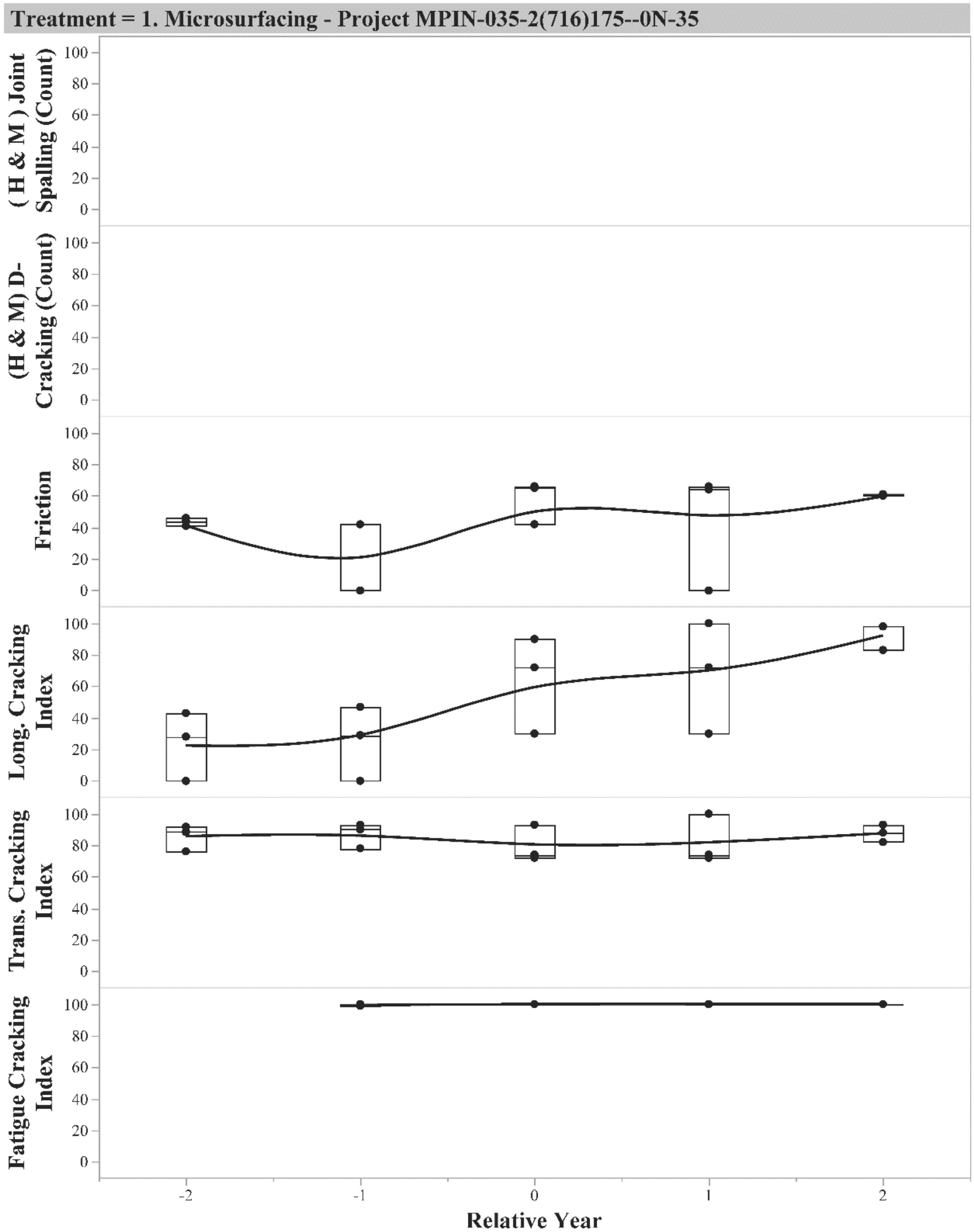


Figure 86. Anecdotal analysis graphs for project MPIN-035-2(716)175—0N-35

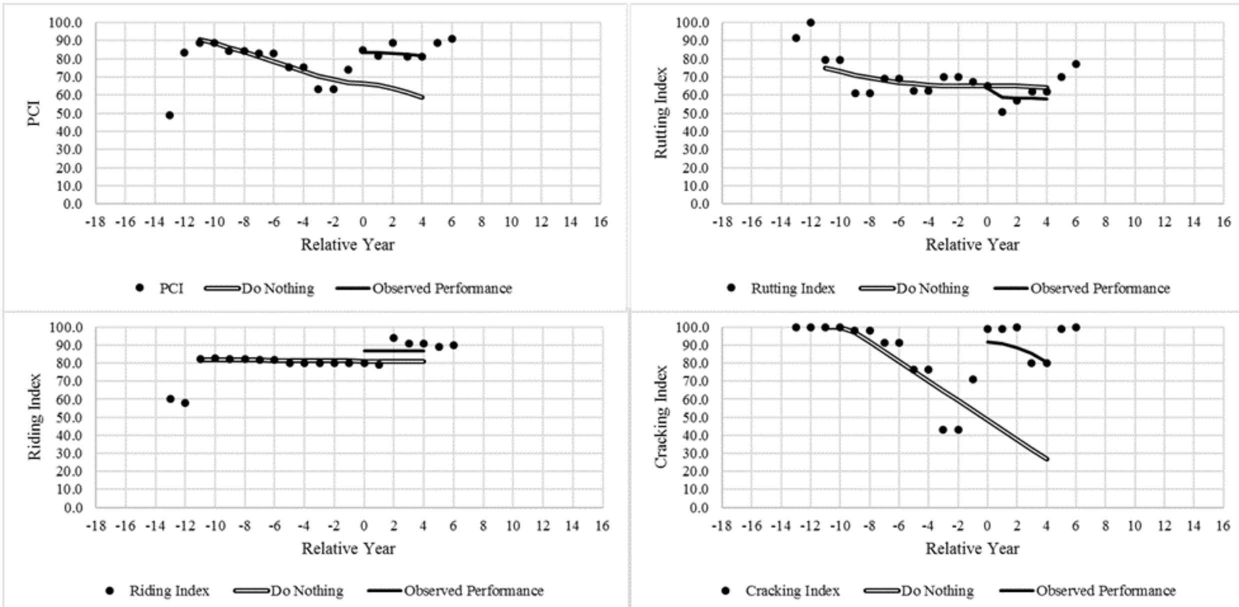


Figure 87. Analytical analysis graphs for project MPIN-035-2(717)178—0N-17

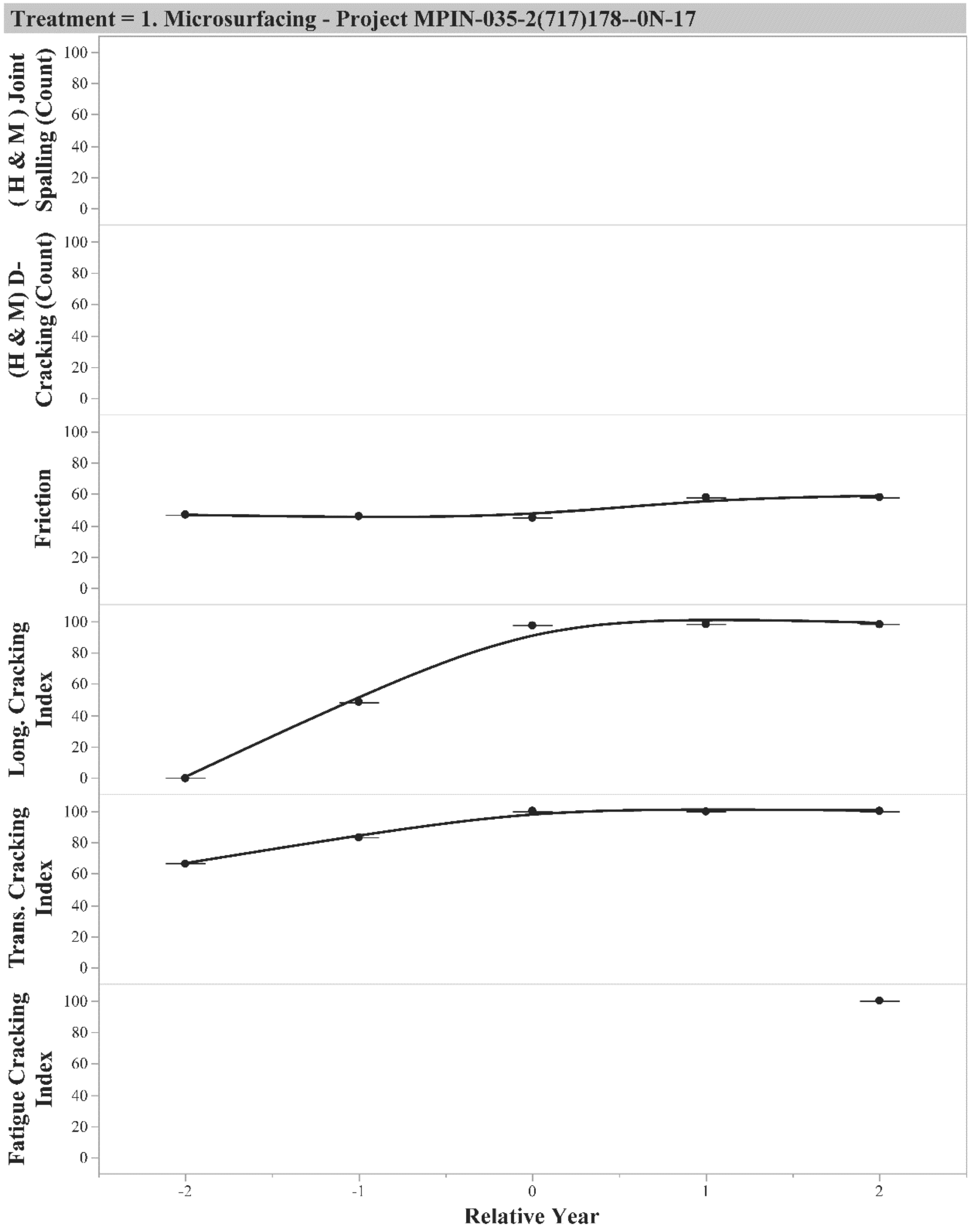


Figure 88. Anecdotal analysis graphs for project MPIN-035-2(717)178—0N-17

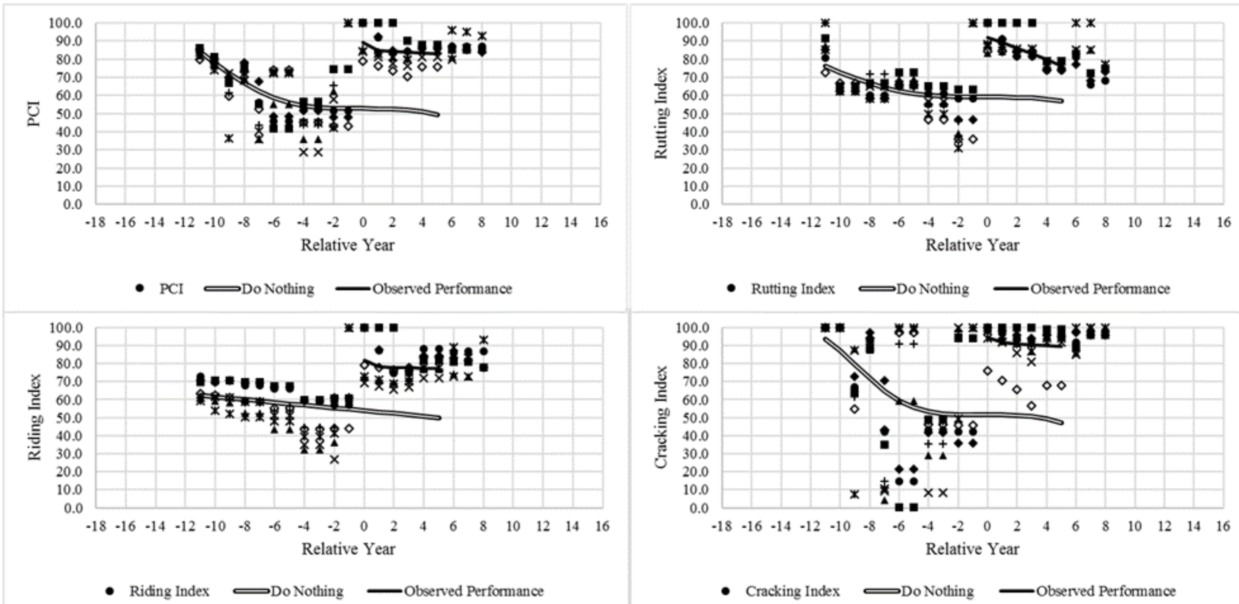


Figure 89. Analytical analysis graphs for project MPIN-035-5(701)33—0N-20

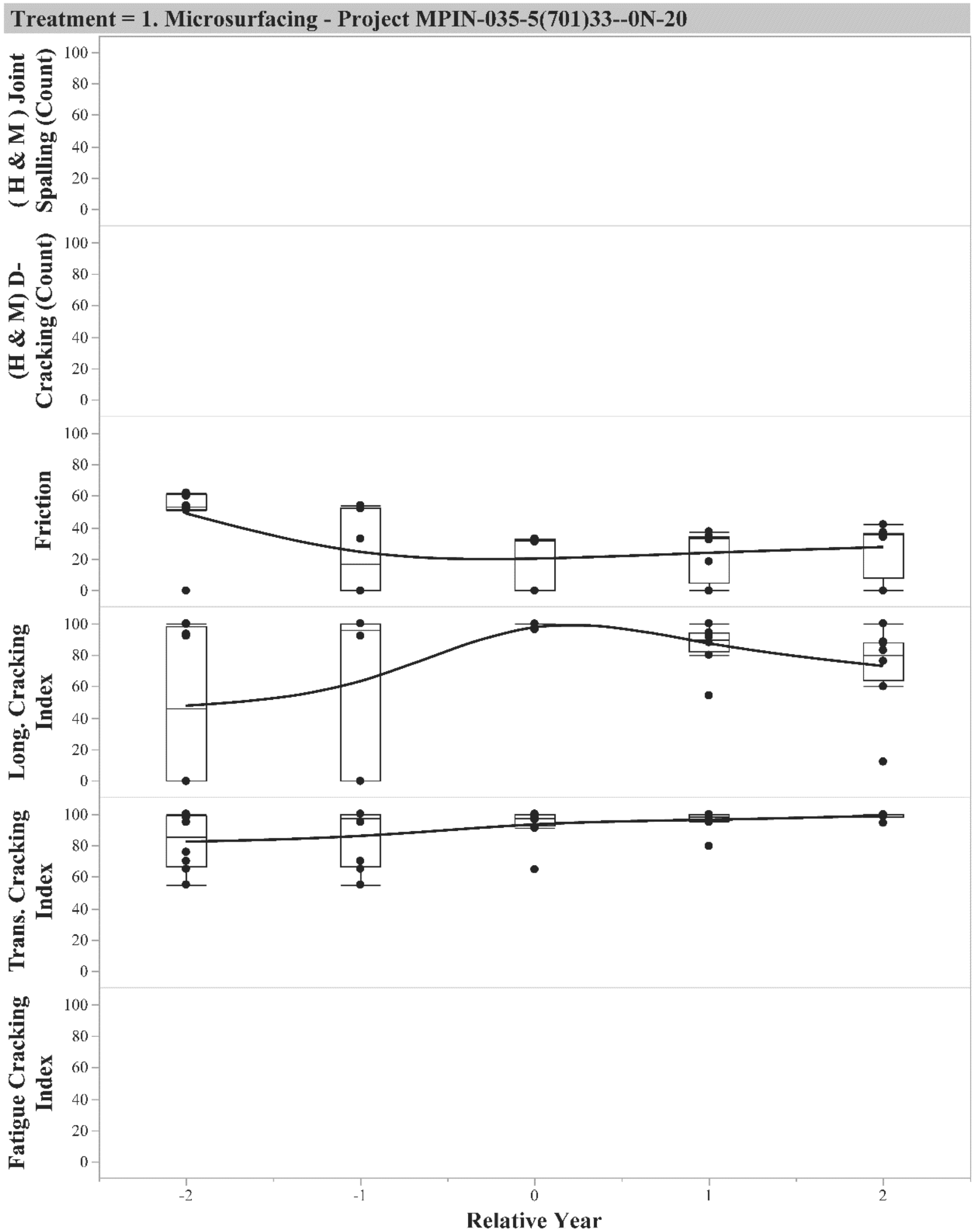


Figure 90. Anecdotal analysis graphs for project MPIN-035-5(701)33—0N-20

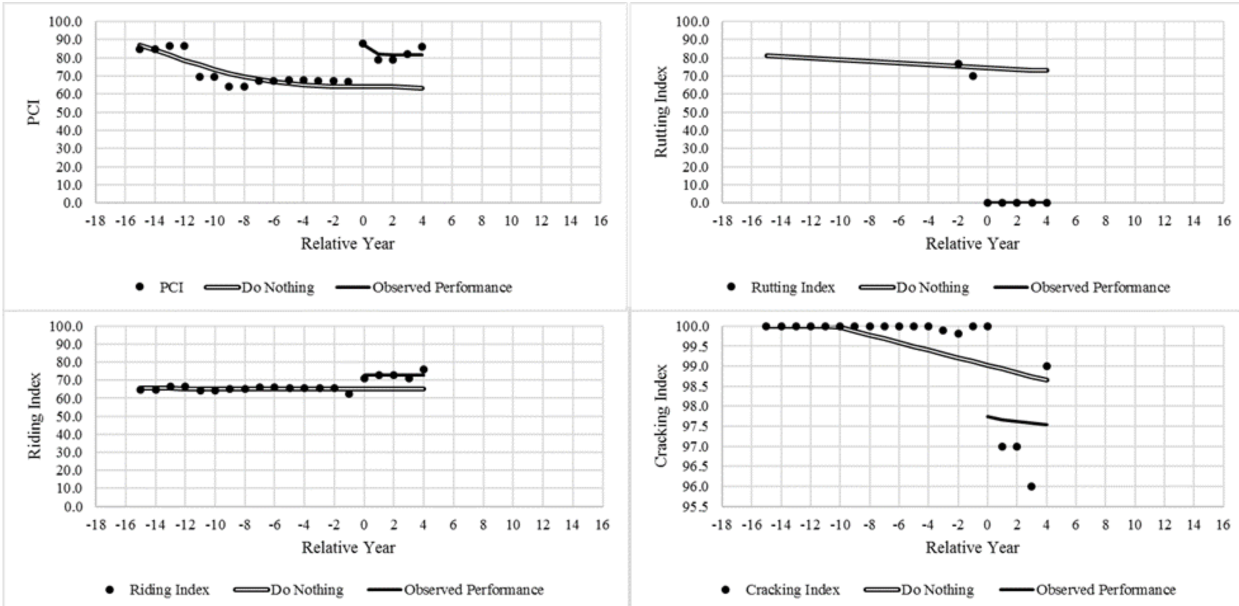


Figure 91. Analytical analysis graphs for project MPIN-080-4(714)40—0N-78

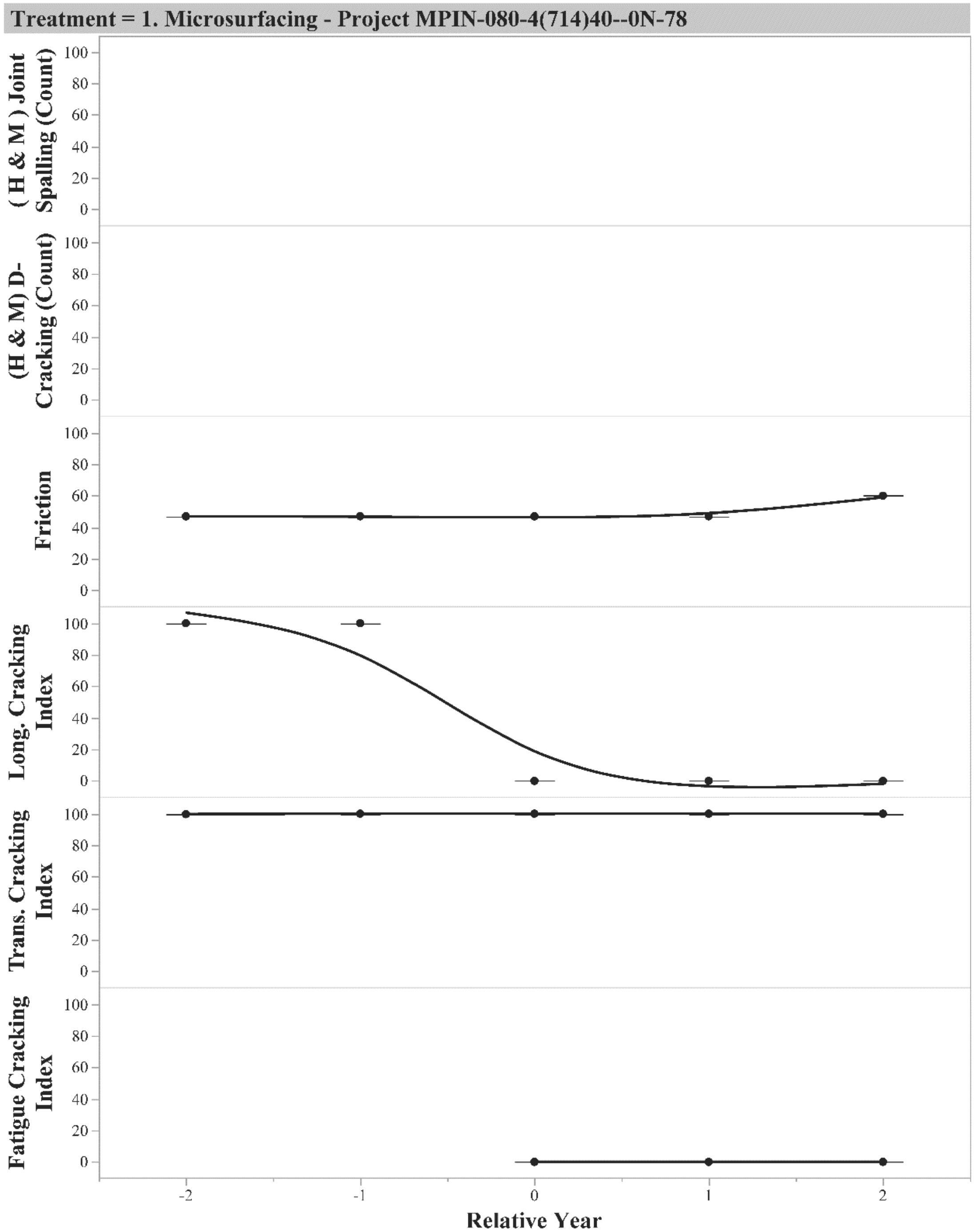


Figure 92. Anecdotal analysis graphs for project MPIN-080-4(714)40—0N-78

Slurry Seal Projects

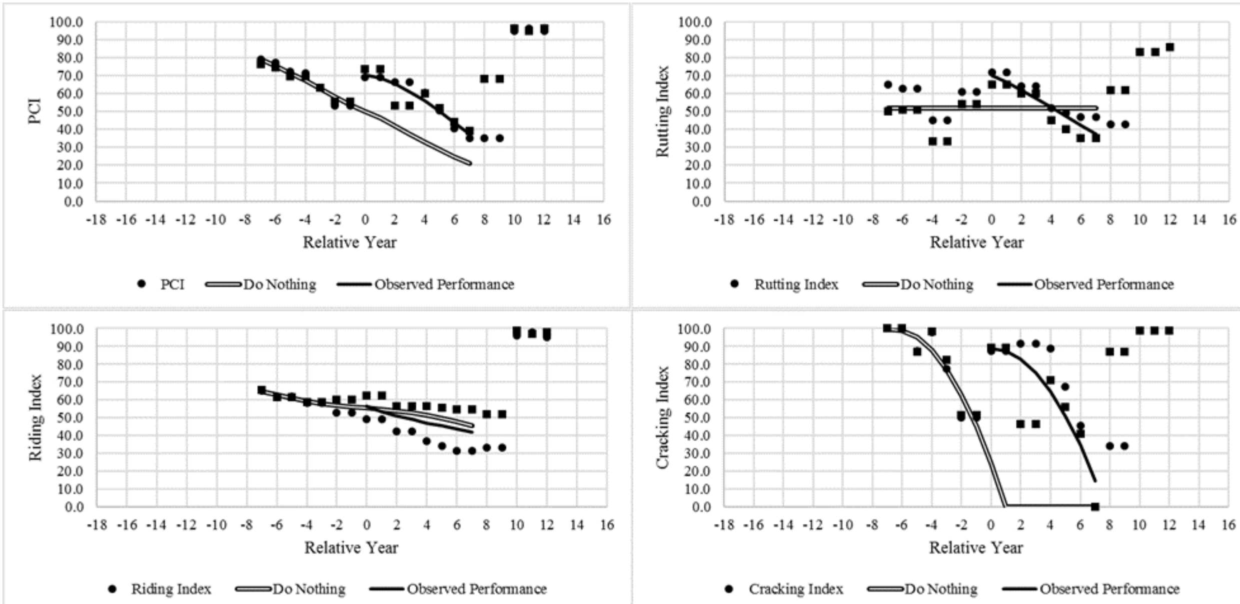


Figure 93. Analytical analysis graphs for project MP-006-6(701)209—76-48 (LS)

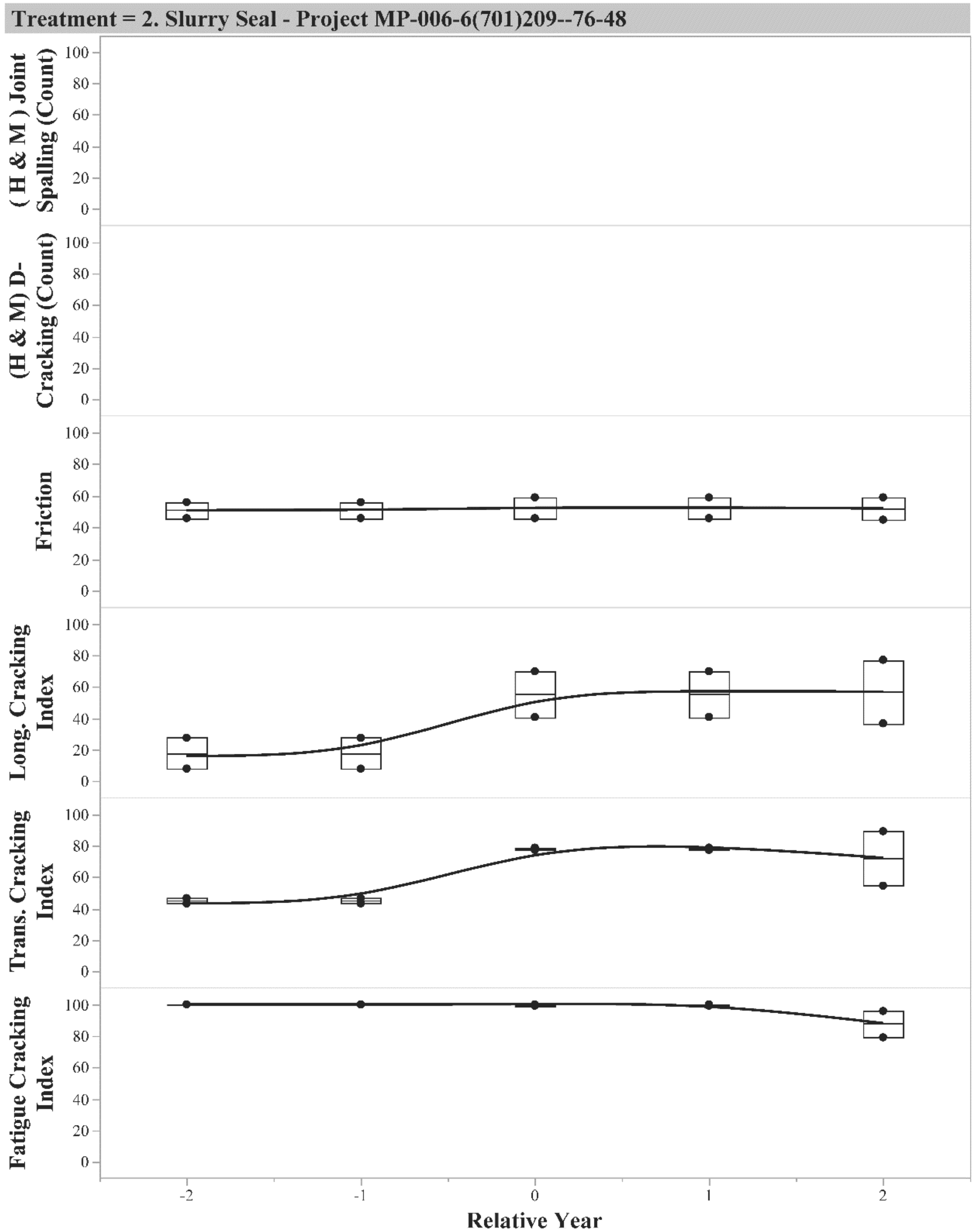


Figure 94. Anecdotal analysis graphs for project MP-006-6(701)209—76-48 (LS)

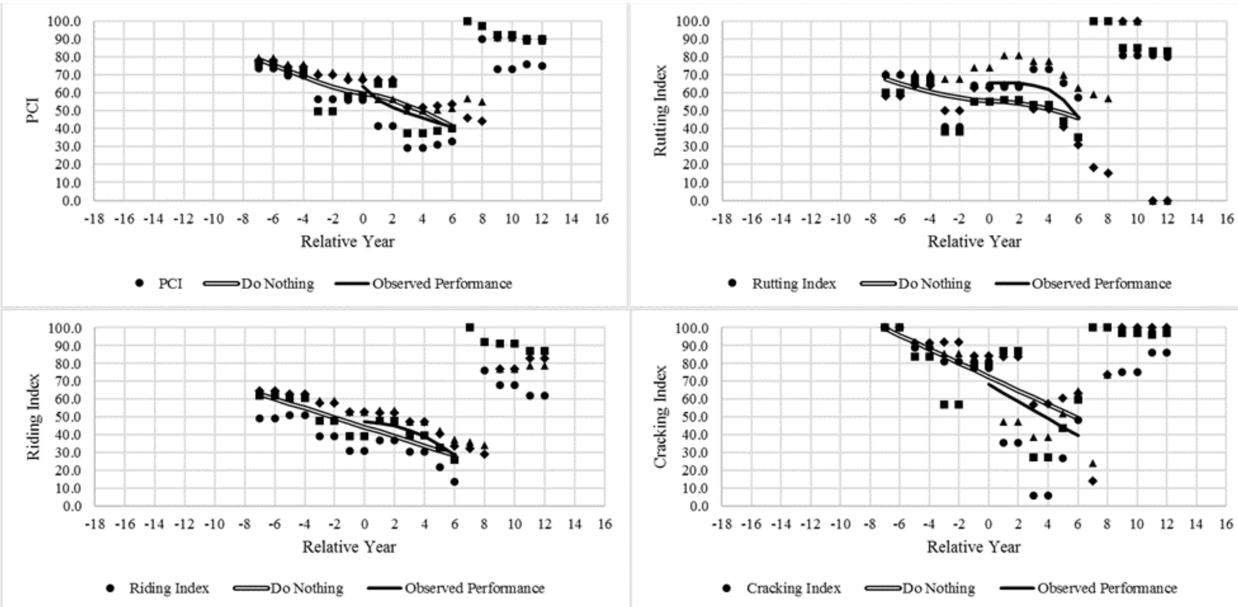


Figure 95. Analytical analysis graphs for project MP-059-3(703)140—76-47 (TL)

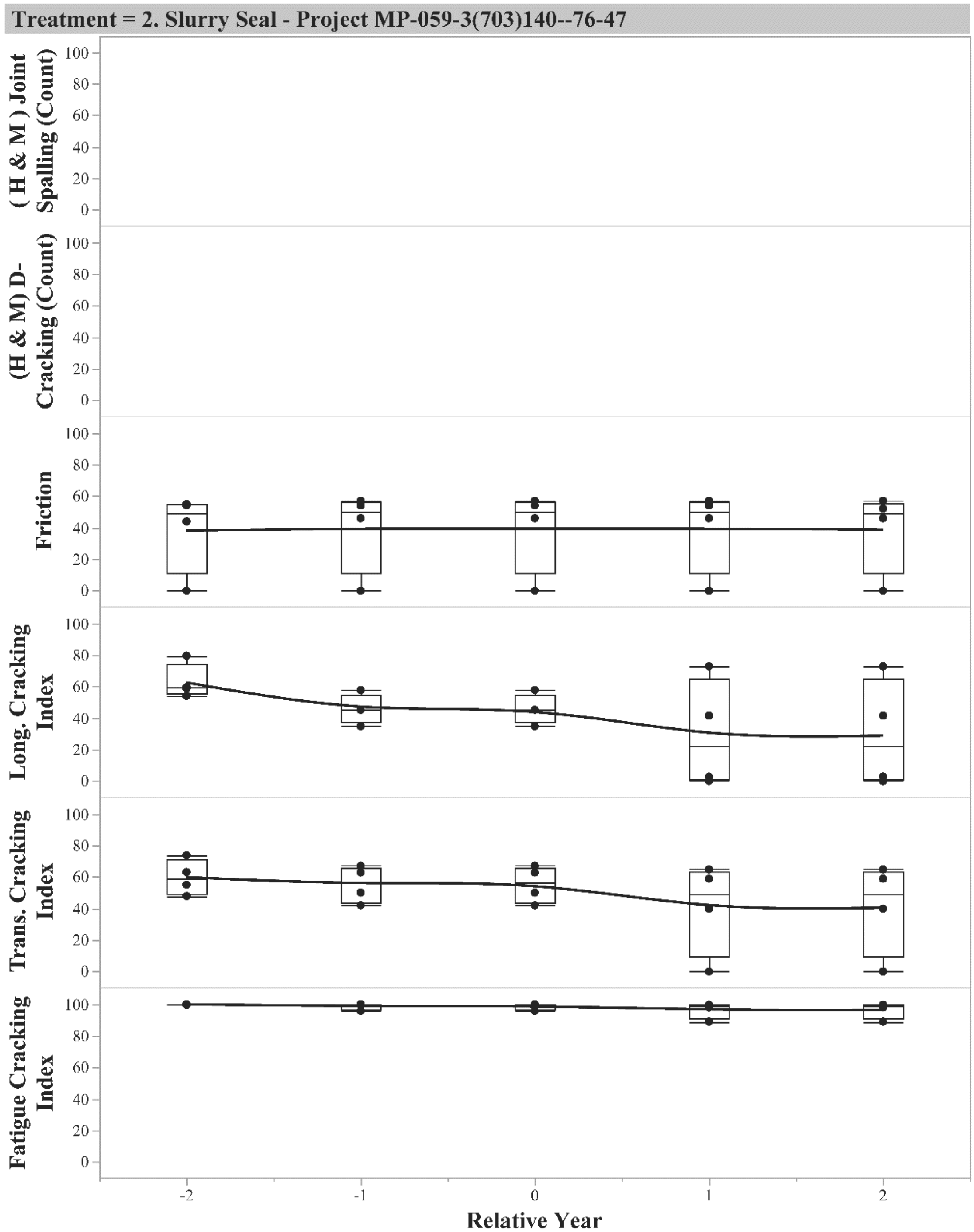


Figure 96. Anecdotal analysis graphs for project MP-059-3(703)140—76-47 (TL)

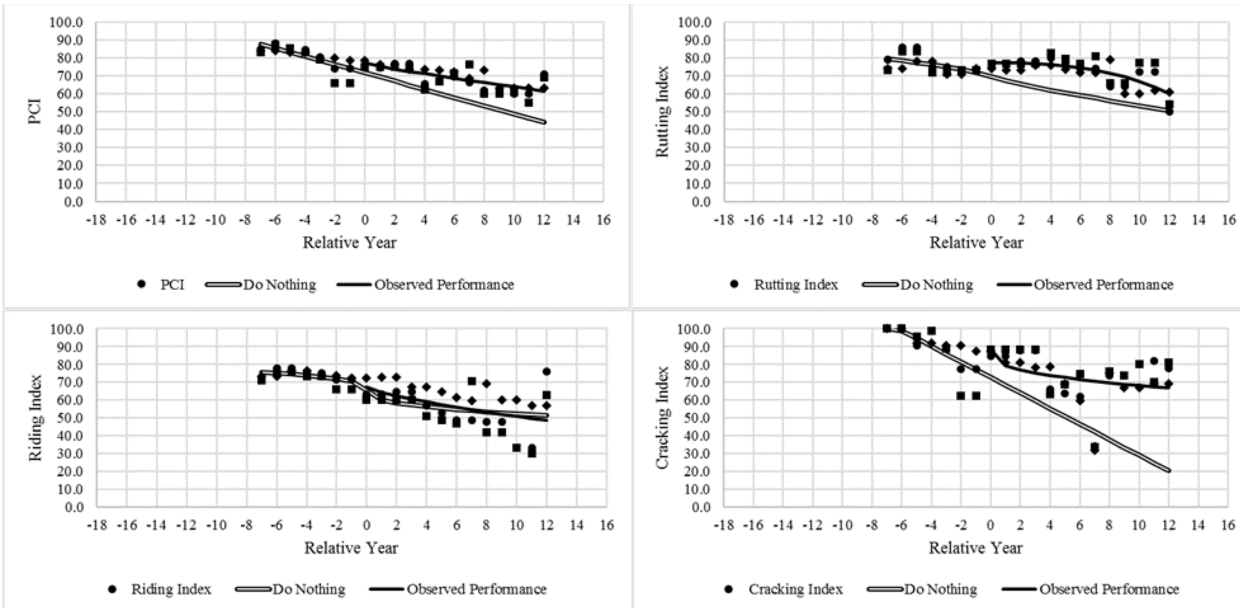


Figure 97. Analytical analysis graphs for project MP-059-4(703)20—76-36 (CL)

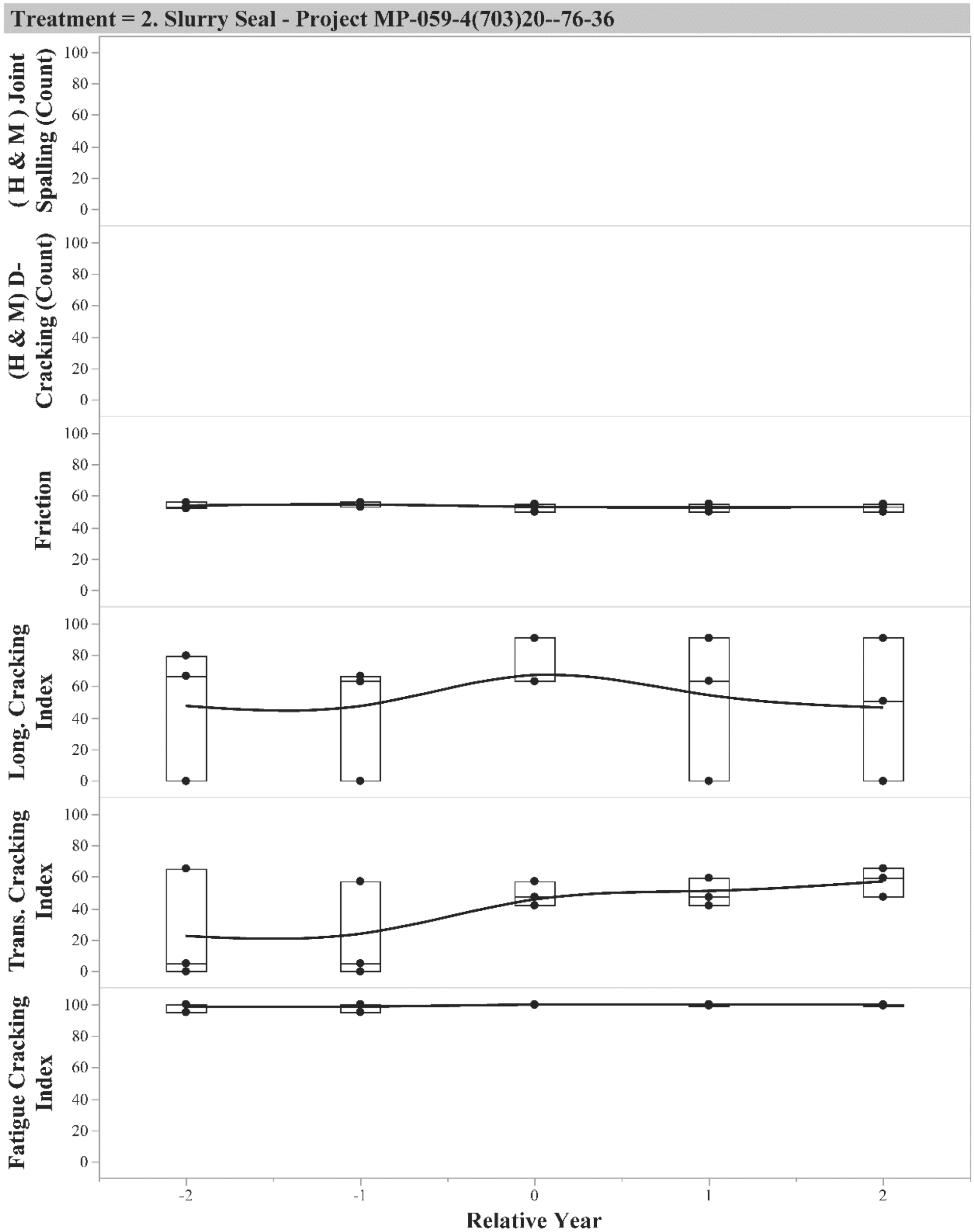


Figure 98. Anecdotal analysis graphs for project MP-059-4(703)20—76-36 (CL)

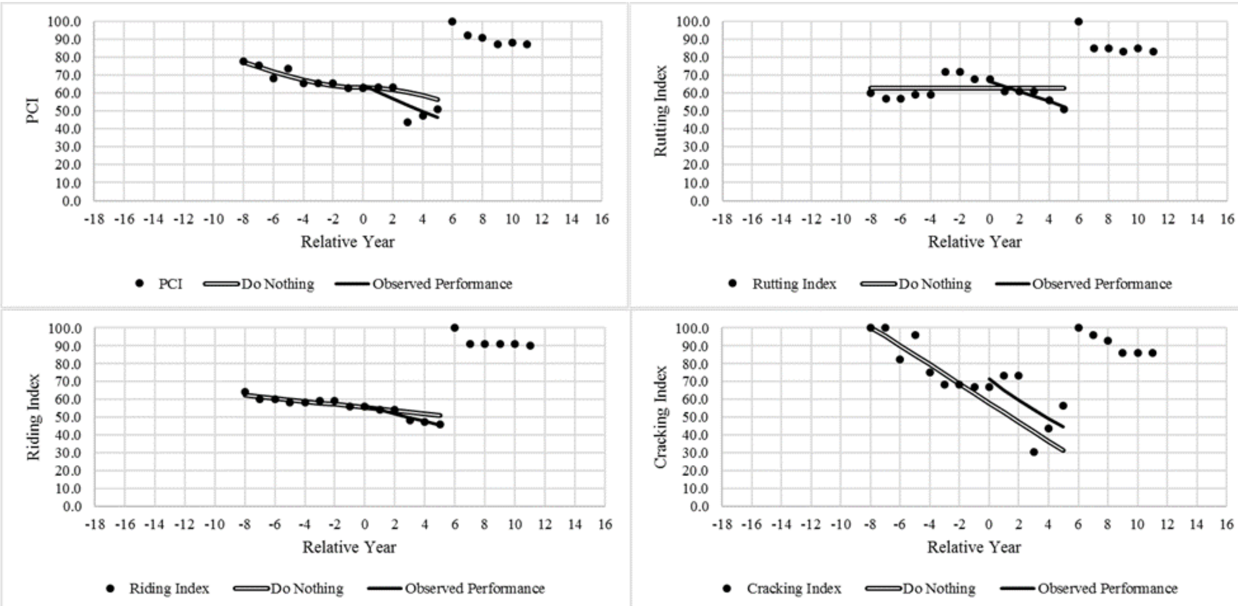


Figure 99. Analytical analysis graphs for project MP-067-6(705)48—76-23 (LS)

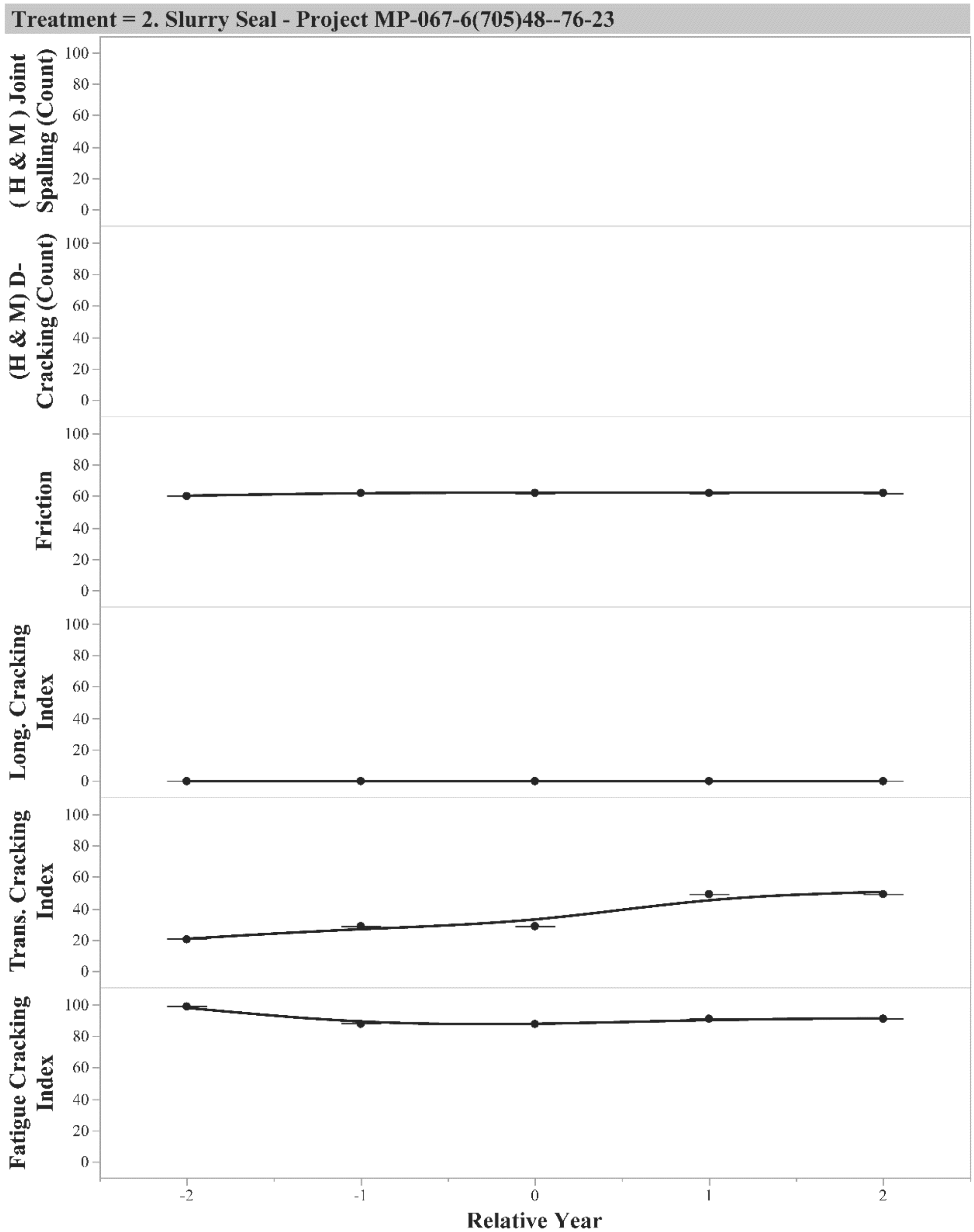


Figure 100. Anecdotal analysis graphs for project MP-067-6(705)48—76-23 (LS)

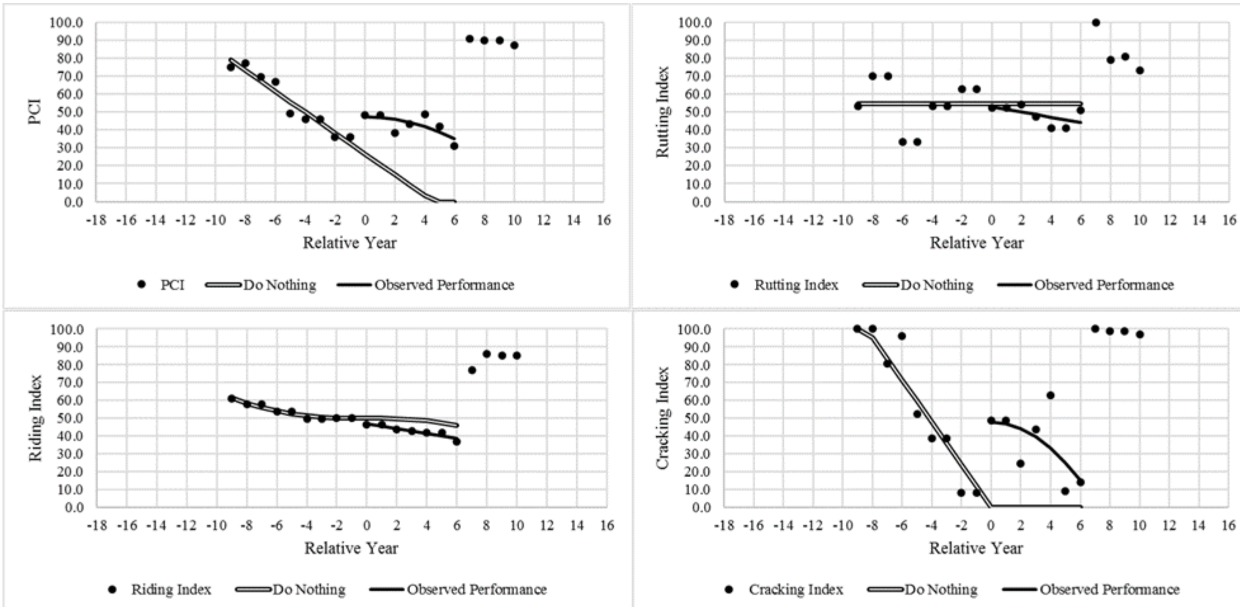


Figure 101. Analytical analysis graphs for project MP-130-6(702)14—76-82 (LS)

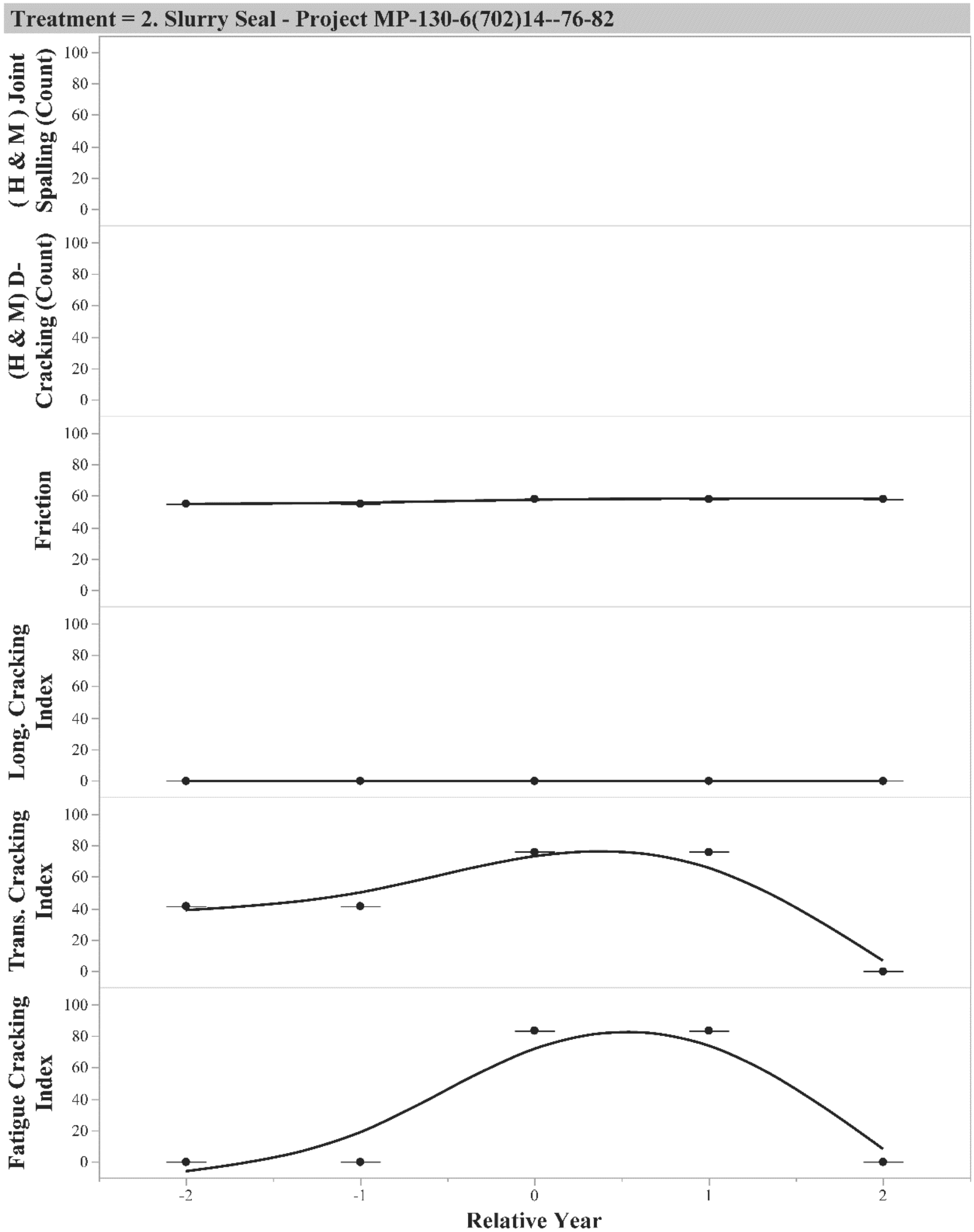


Figure 102. Anecdotal analysis graphs for project MP-130-6(702)14—76-82 (LS)

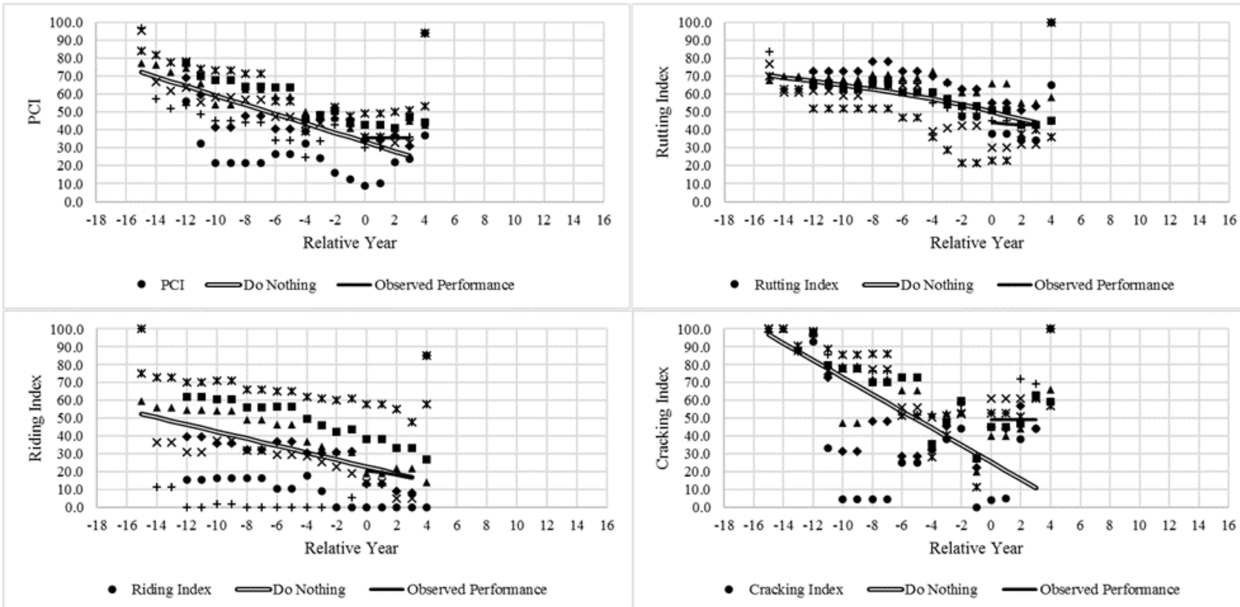


Figure 103. Analytical analysis graphs for project MP-136-6(701)73—76-31 (LS/CL)

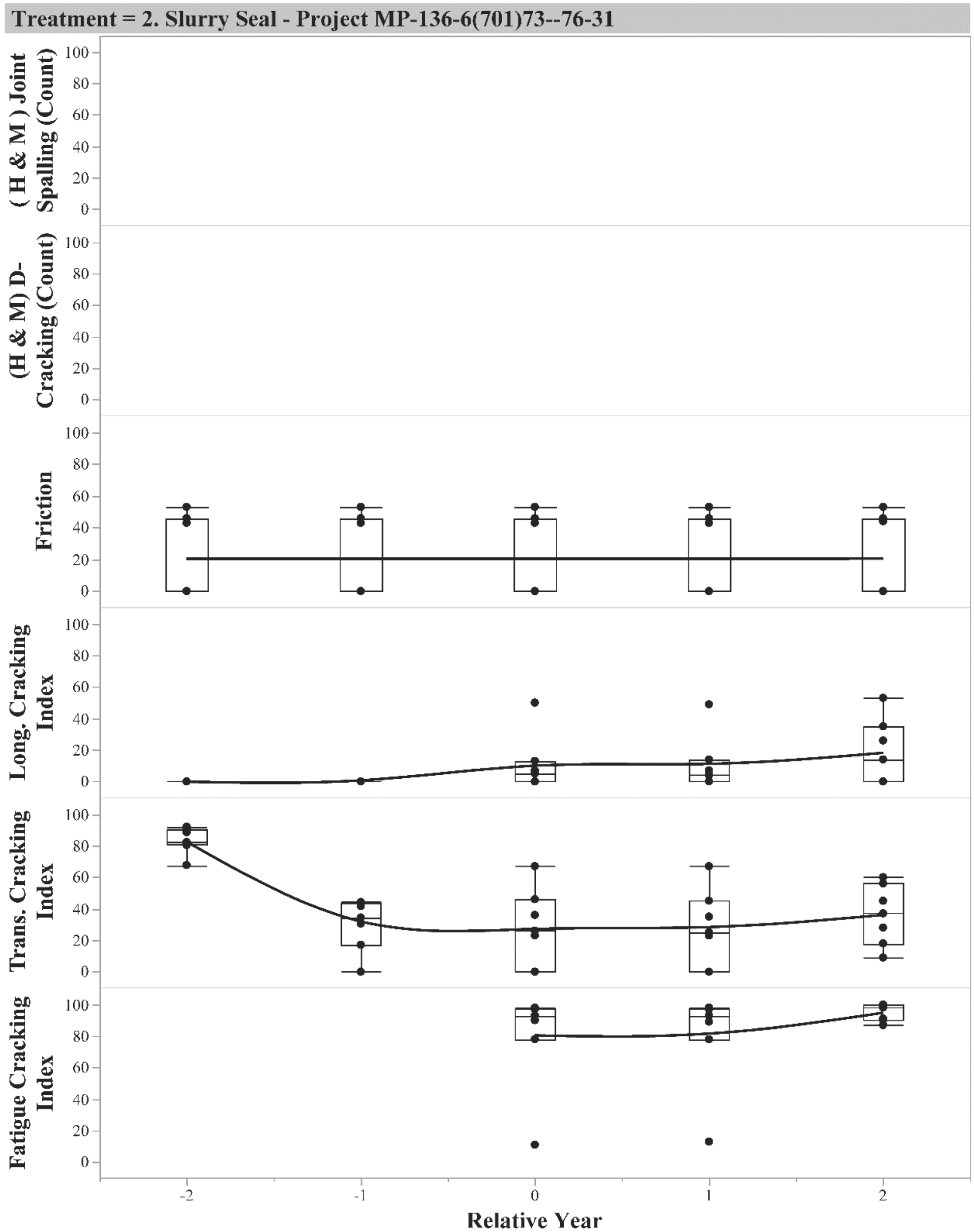


Figure 104. Anecdotal analysis graphs for project MP-136-6(701)73—76-31 (LS/CL)

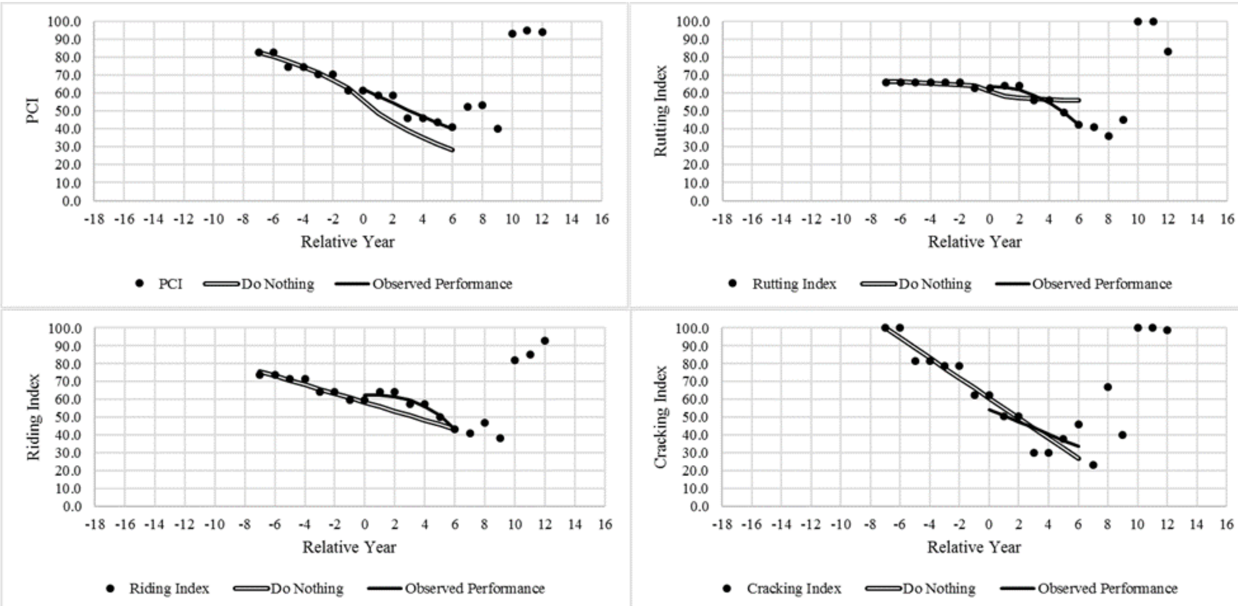
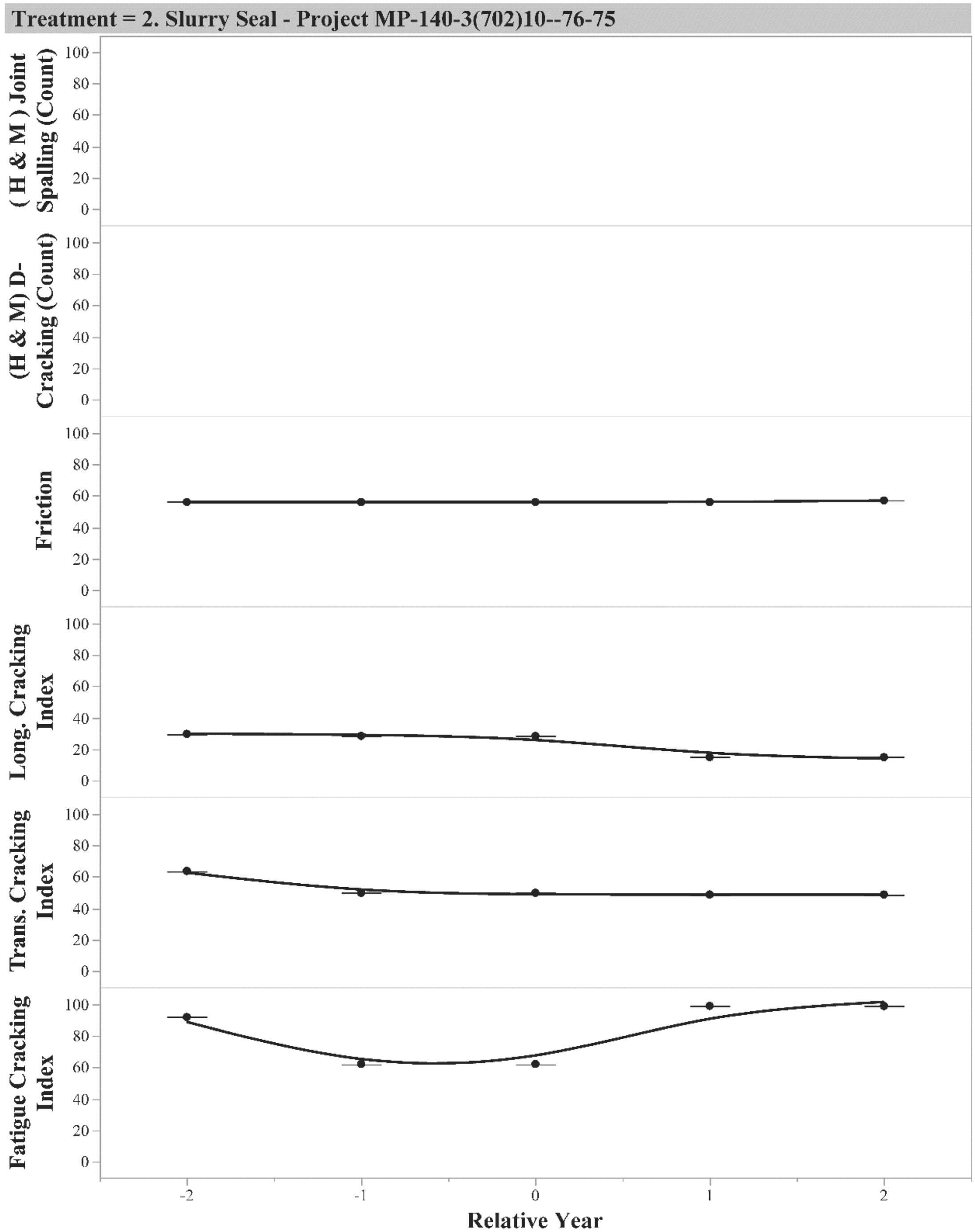


Figure 105. Analytical analysis graphs for project MP-140-3(702)10—76-75 (TL)



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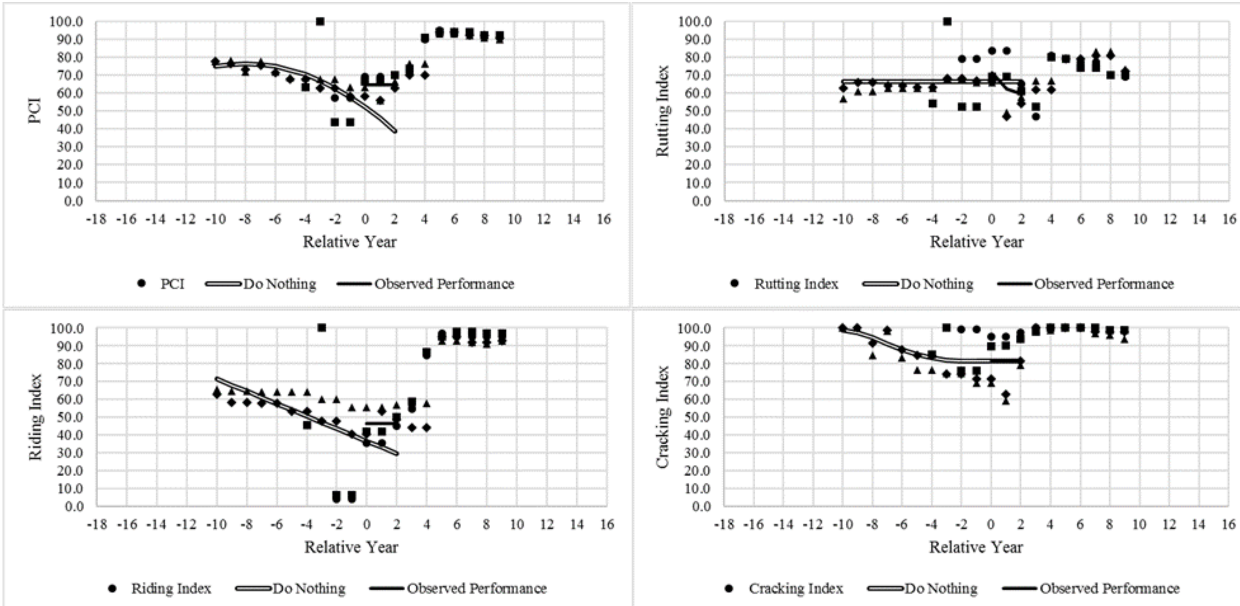


Figure 107. Analytical analysis graphs for project MP-141-4(705)115—76-39 (CL)

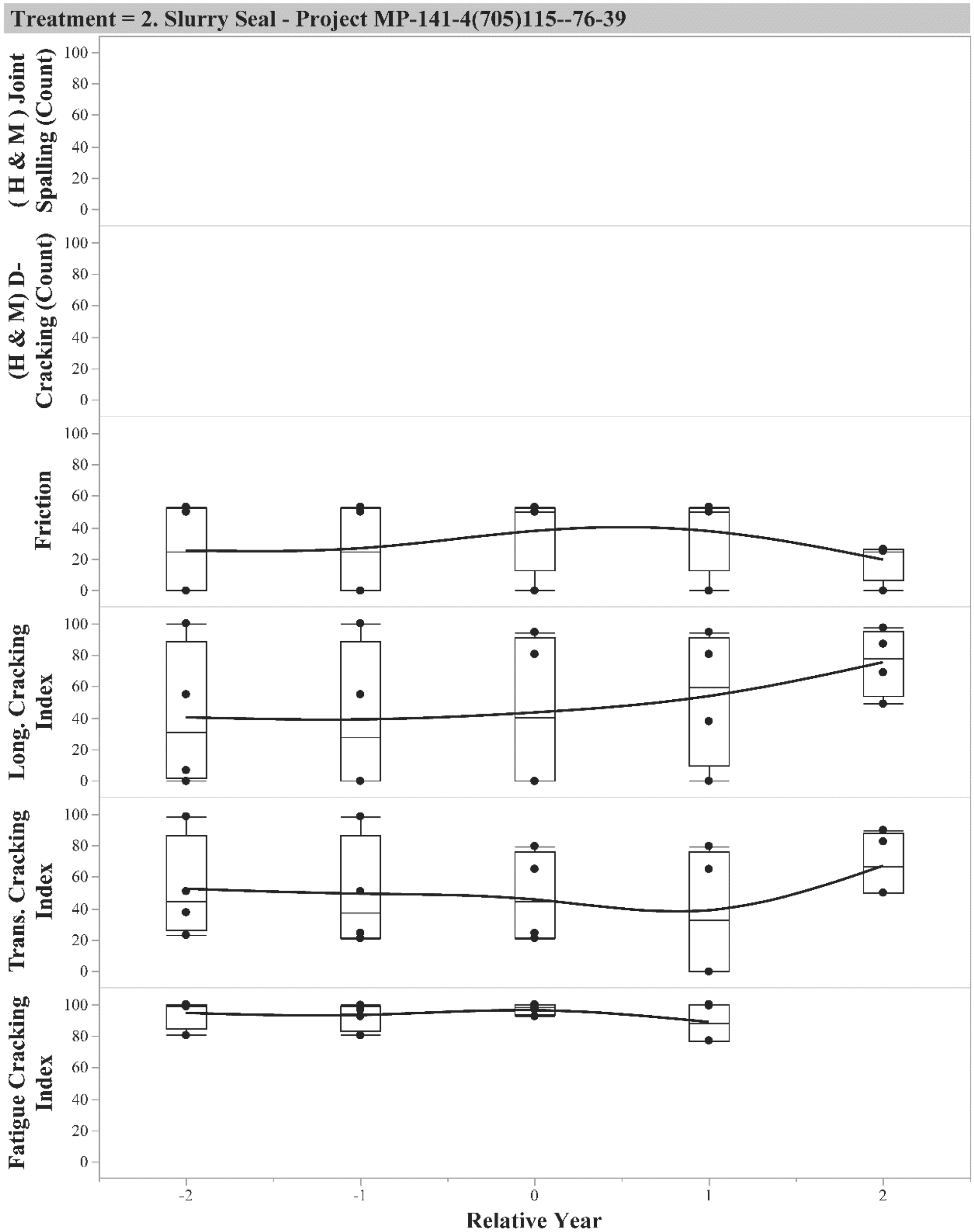


Figure 108. Anecdotal analysis graphs for project MP-141-4(705)115—76-39 (CL)

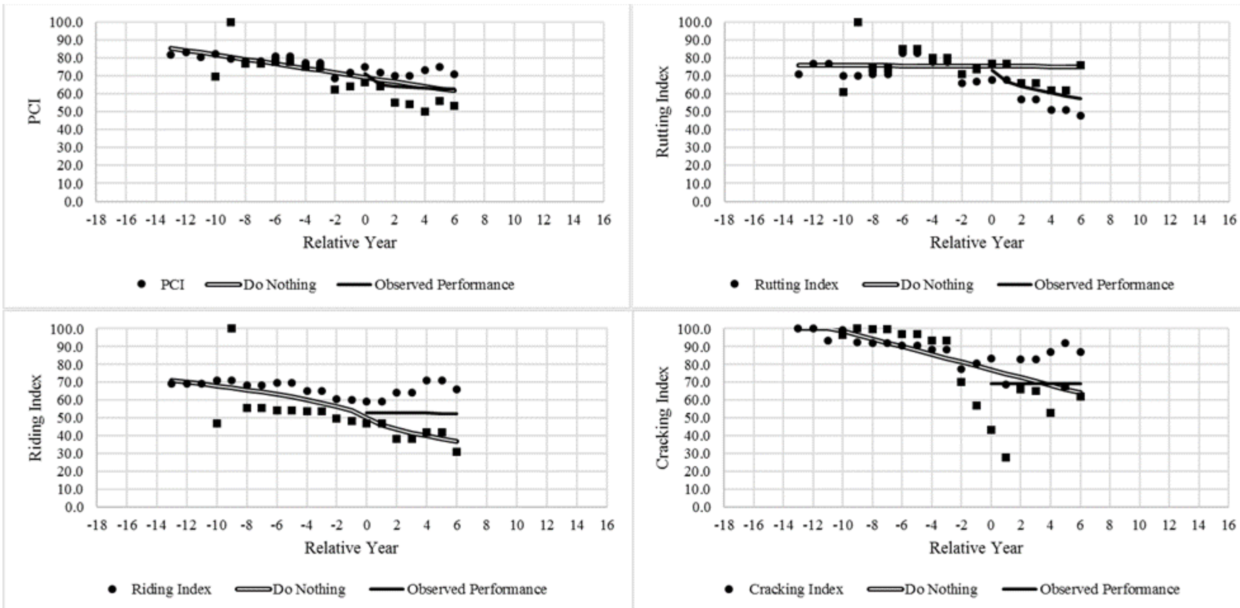
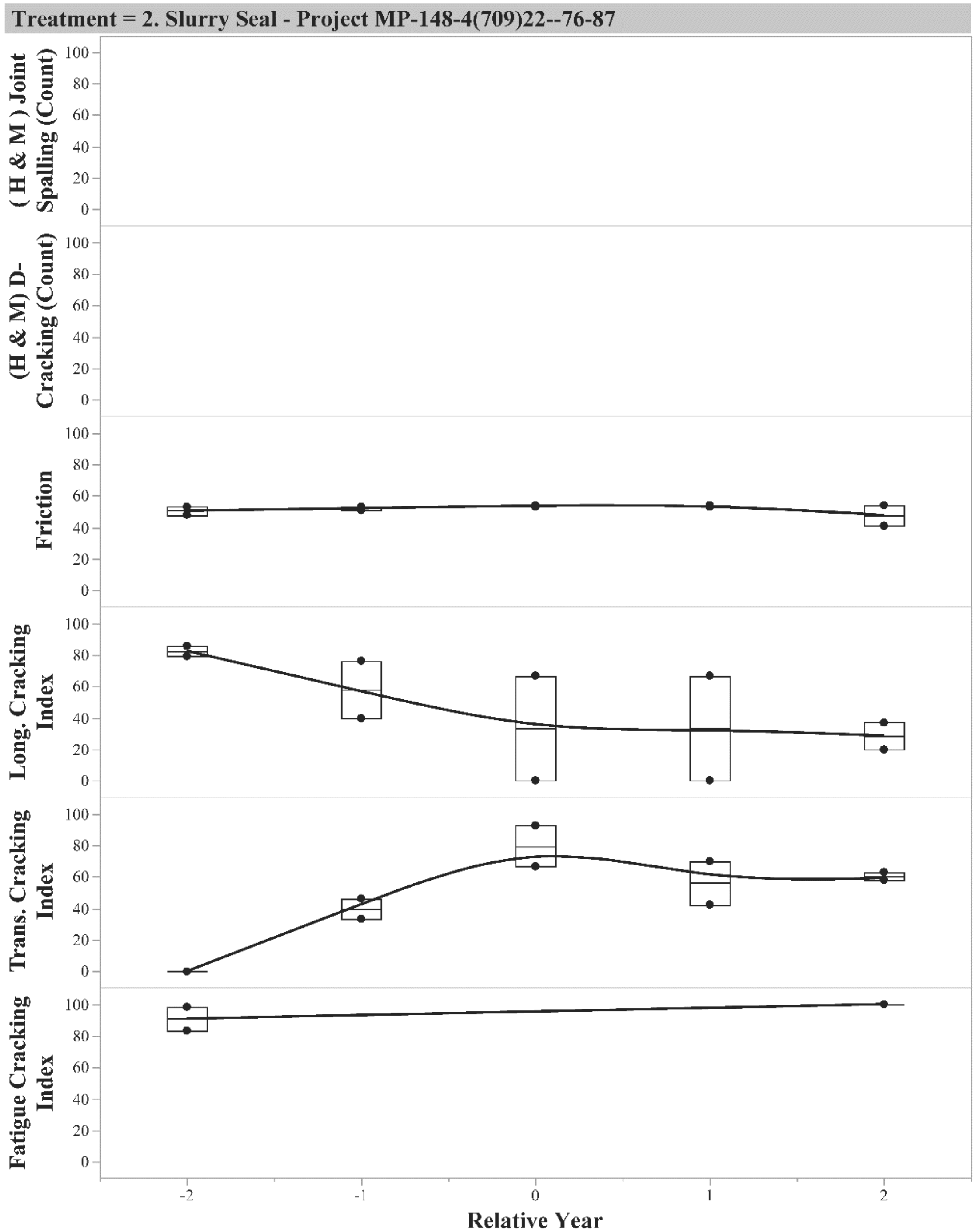


Figure 109. Analytical analysis graphs for project MP-148-4(709)22—76-87 (TL/CL)



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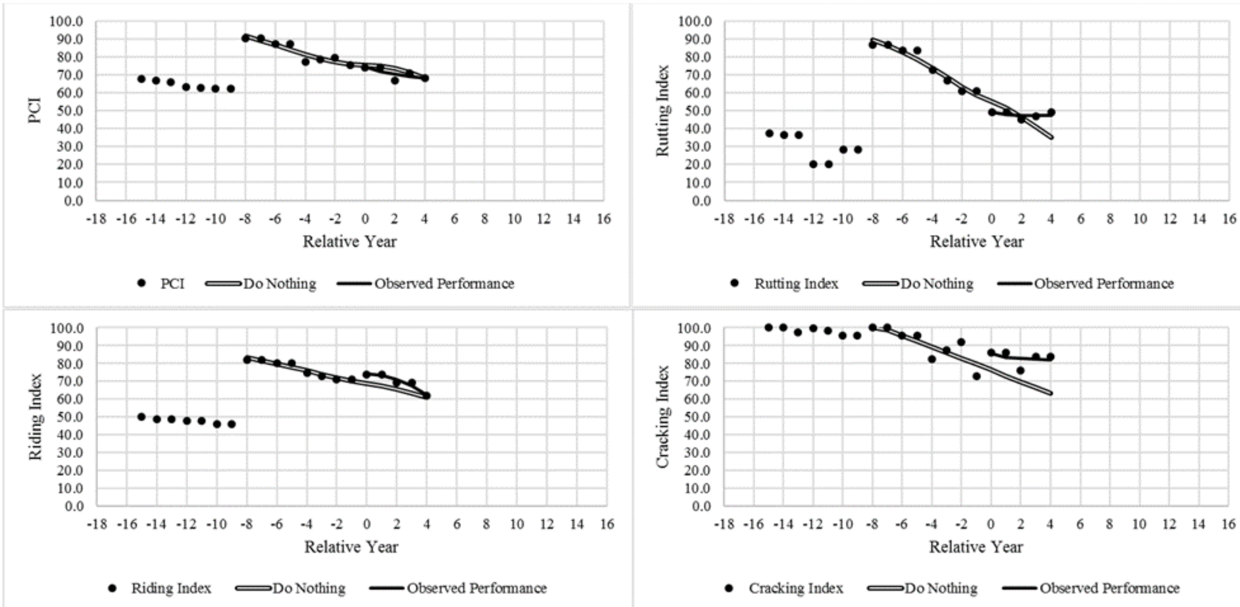
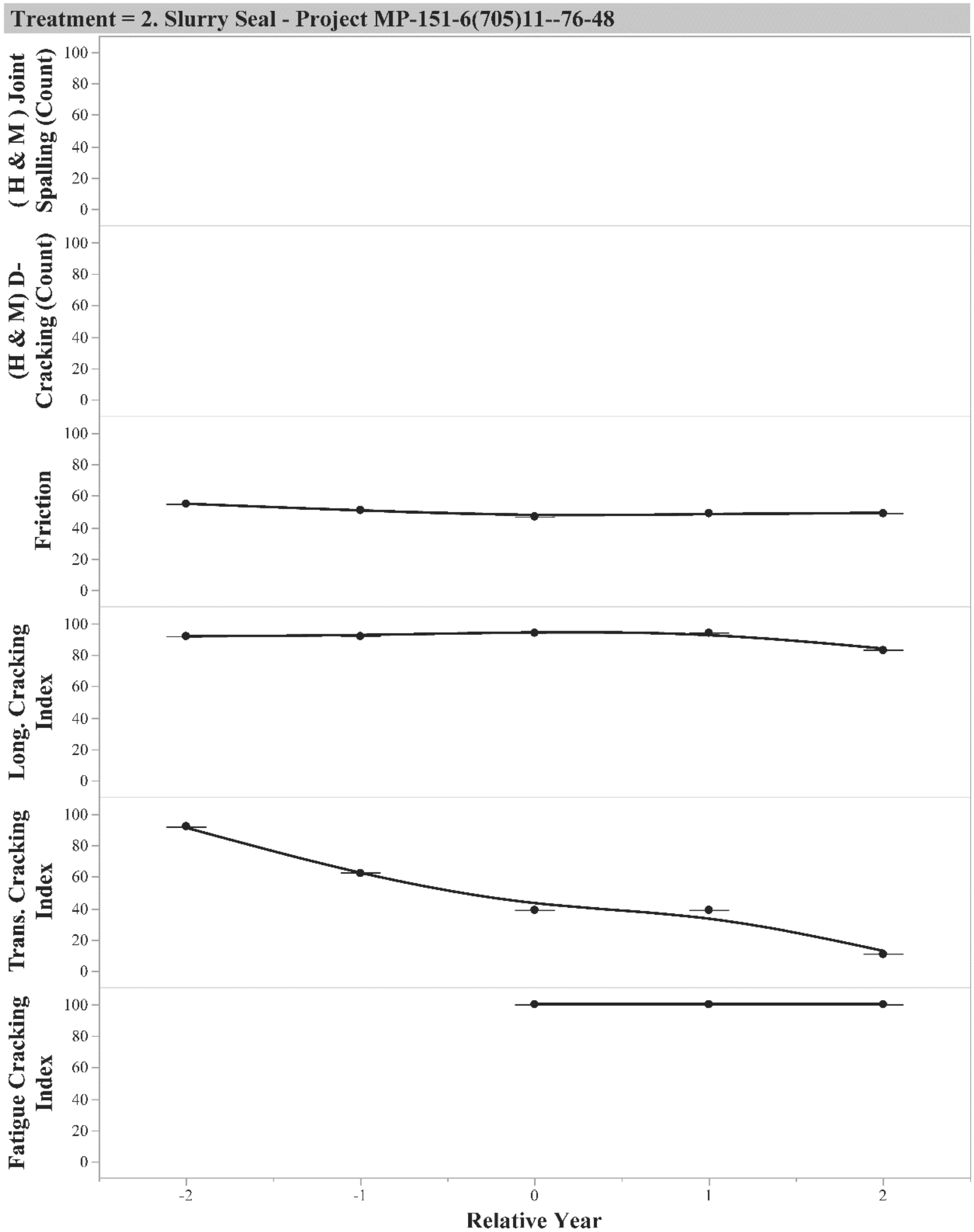


Figure 111. Analytical analysis graphs for project MP-151-6(705)11—76-48 (TL)



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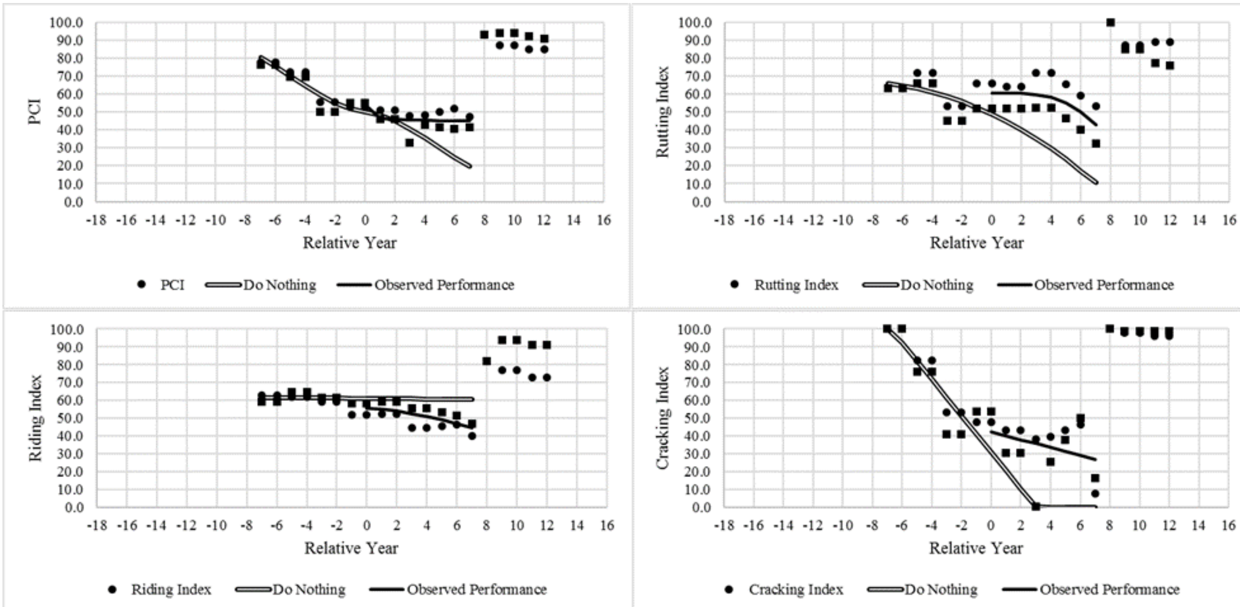


Figure 113. Analytical analysis graphs for project MP-182-3(701)0—76-60 (TL)

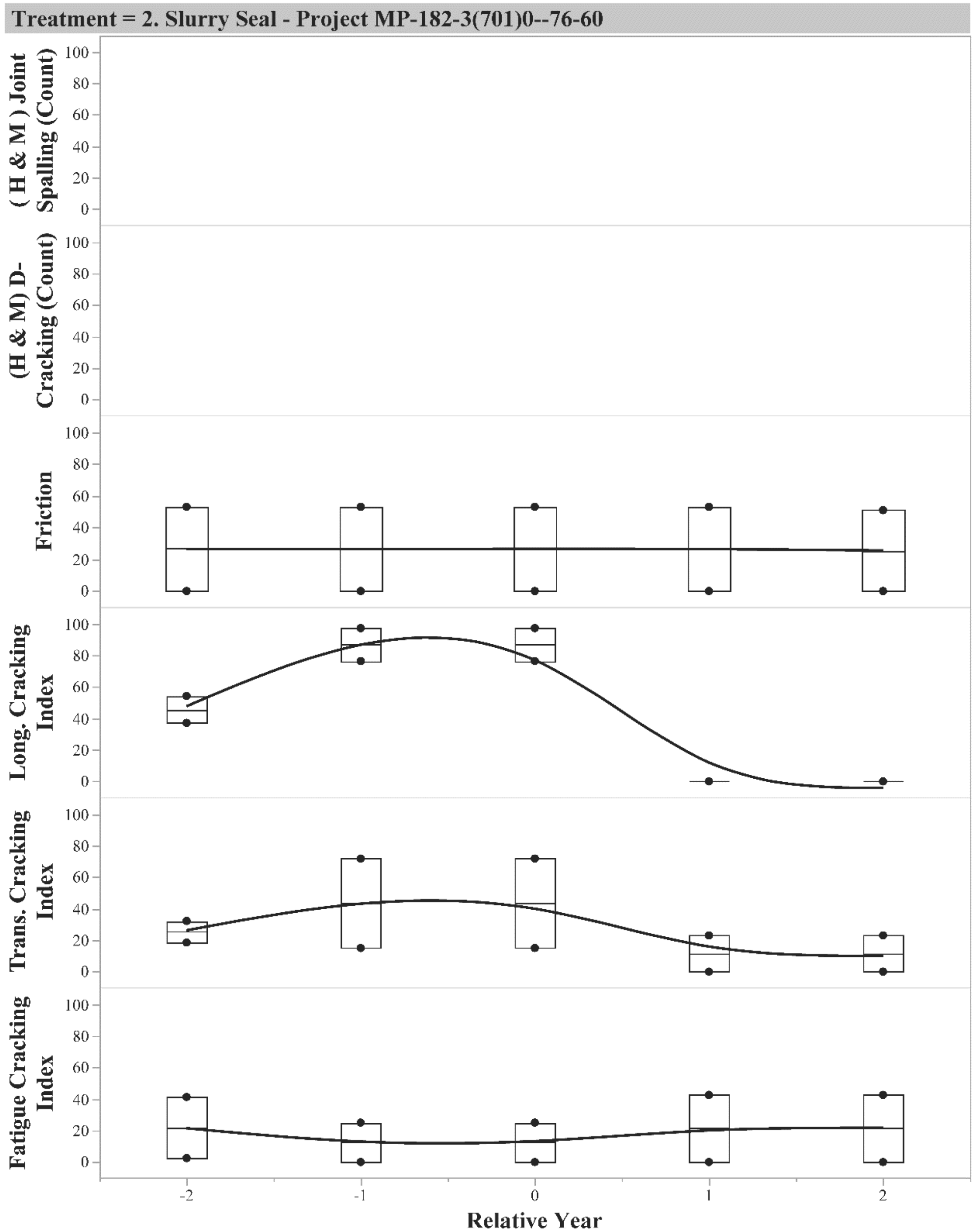


Figure 114. Anecdotal analysis graphs for project MP-182-3(701)0—76-60 (TL)

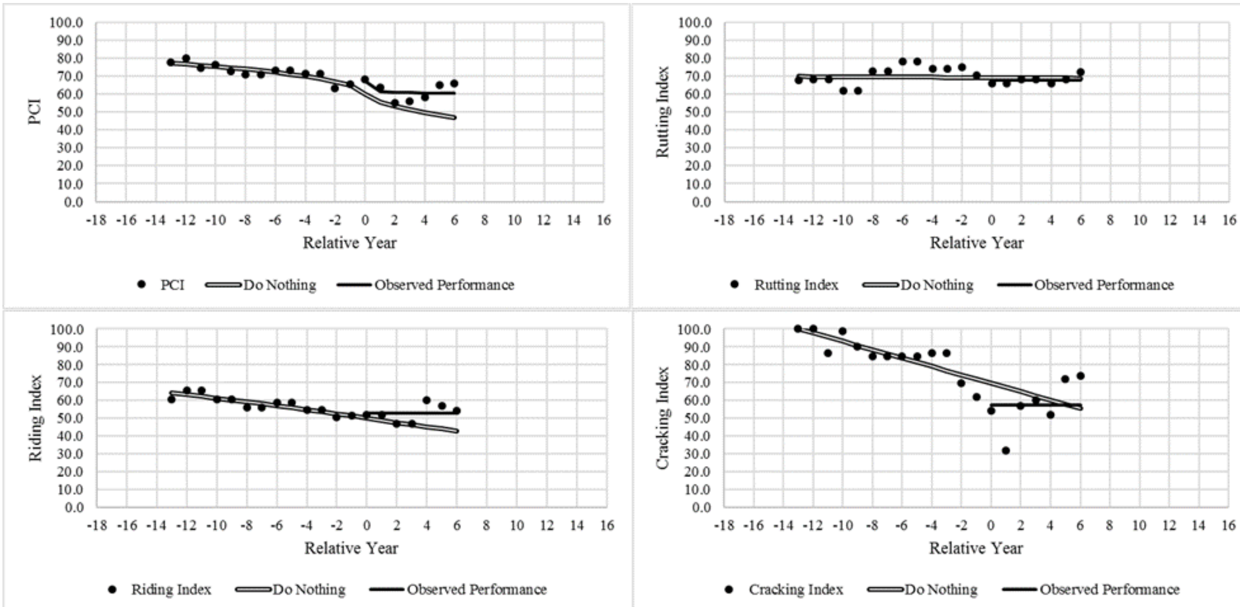
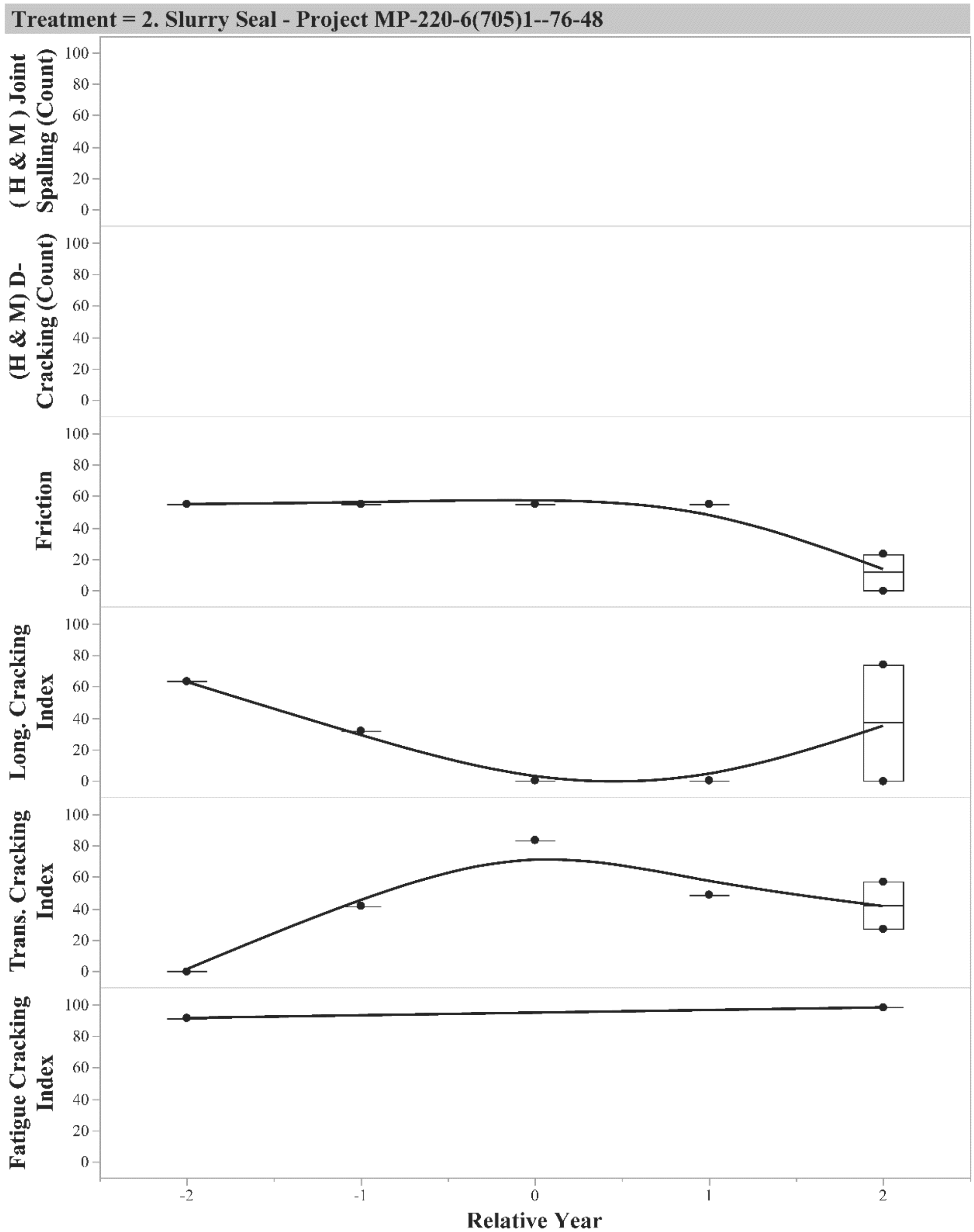


Figure 115. Analytical analysis graphs for project MP-220-6(705)1—76-48 (TL)



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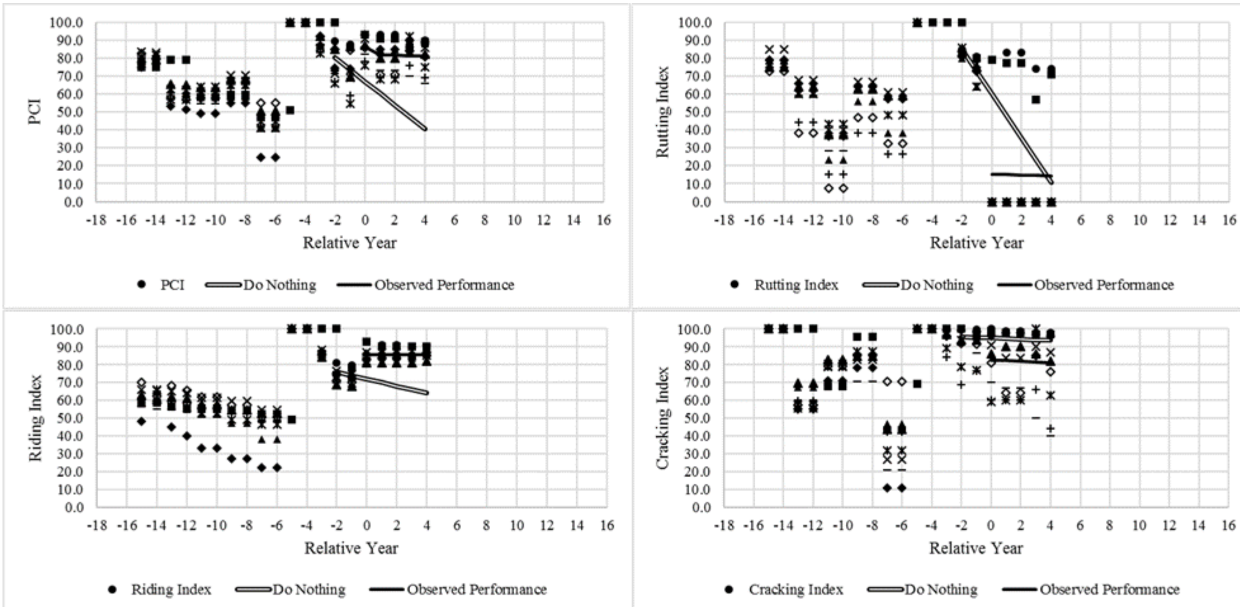


Figure 117. Analytical analysis graphs for project MPIN-029-3(714)106—0N-67 (CL)

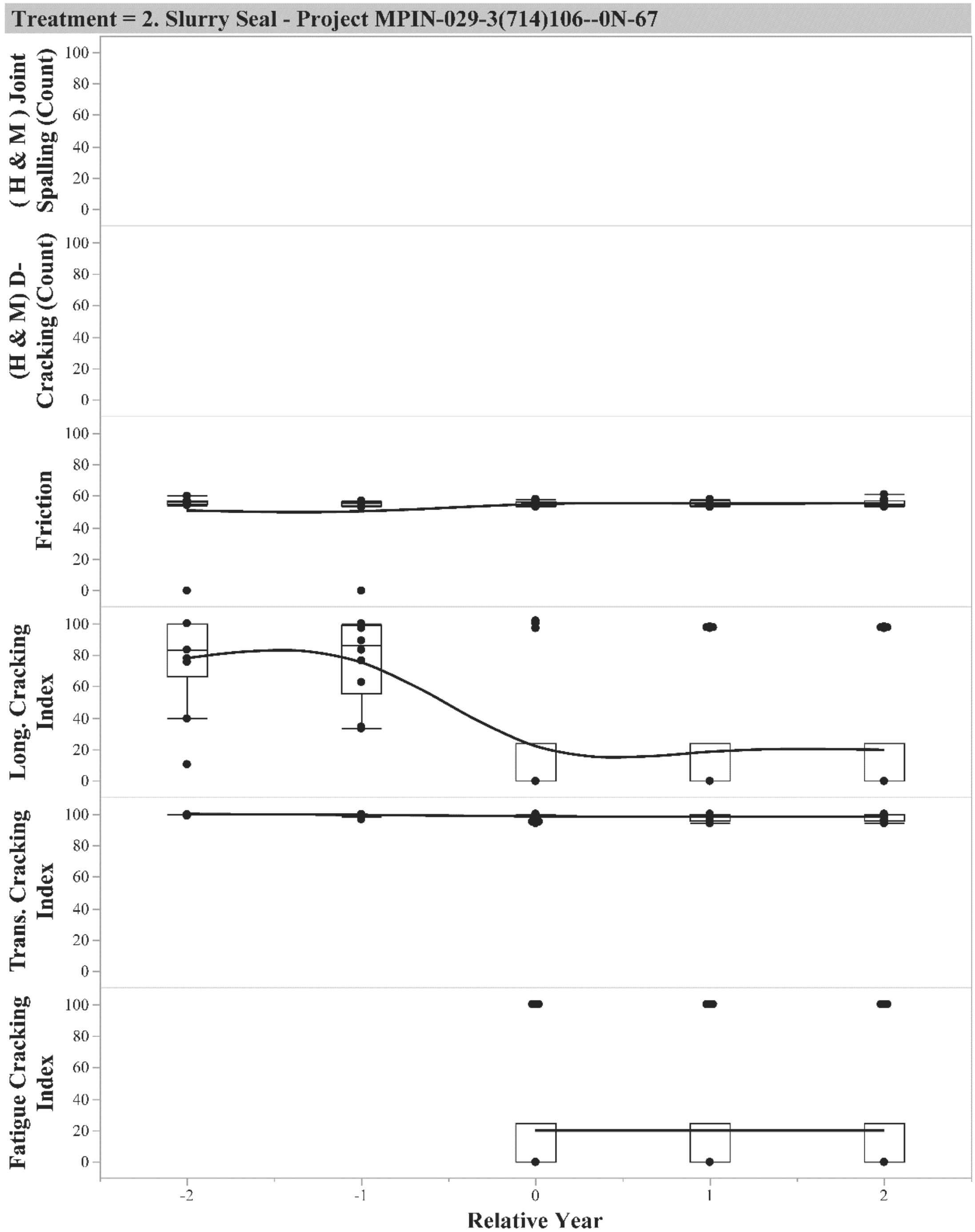


Figure 118. Anecdotal analysis graphs for project MPIN-029-3(714)106—0N-67 (CL)

Patching Projects

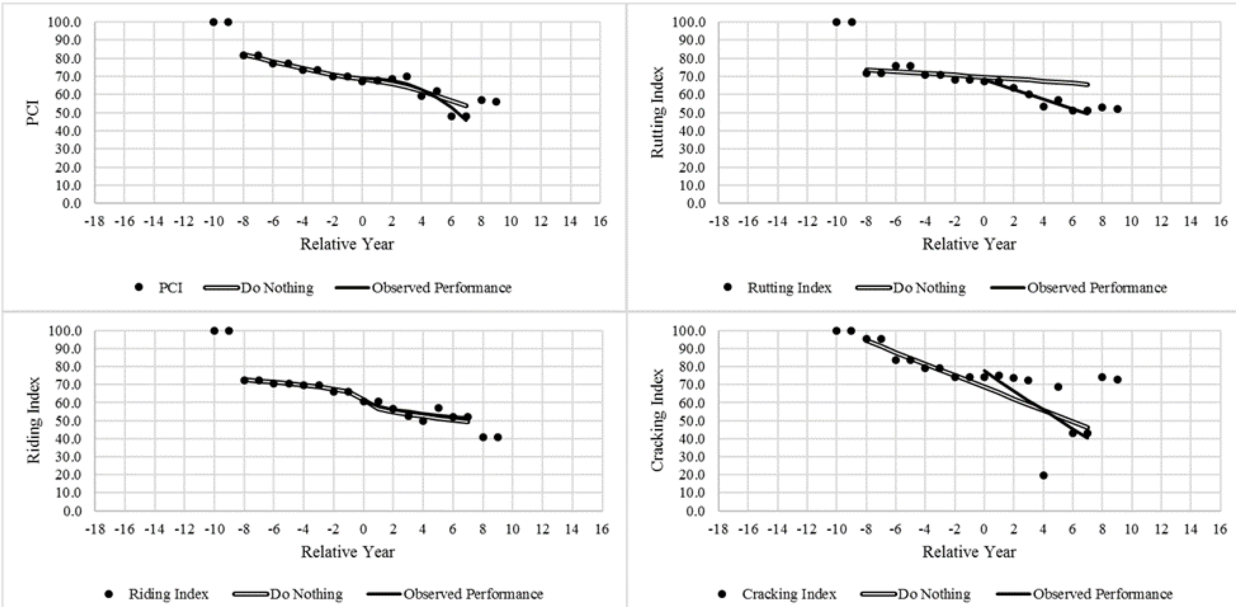
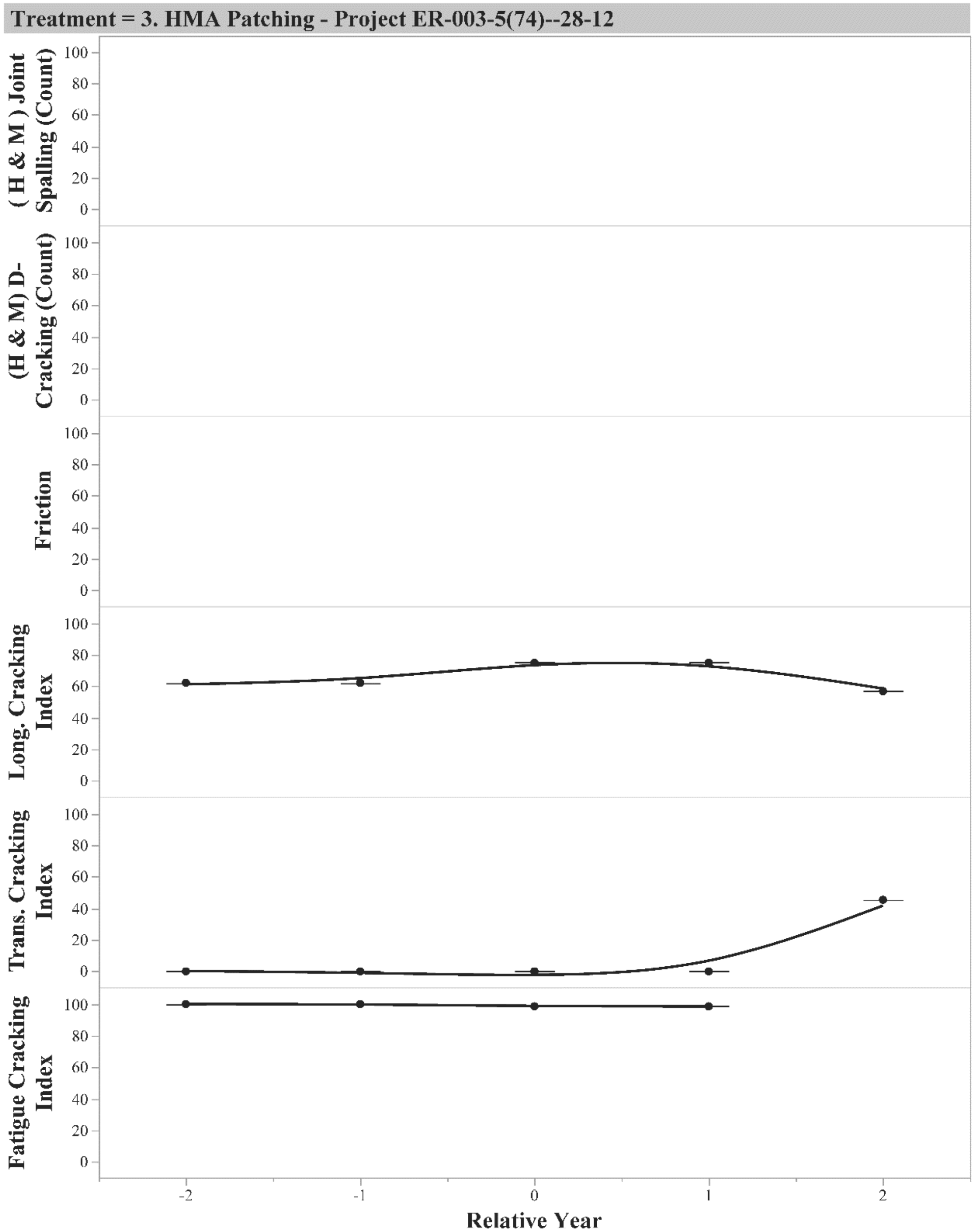


Figure 119. Analytical analysis graphs for project ER-003-5(74)—28-12



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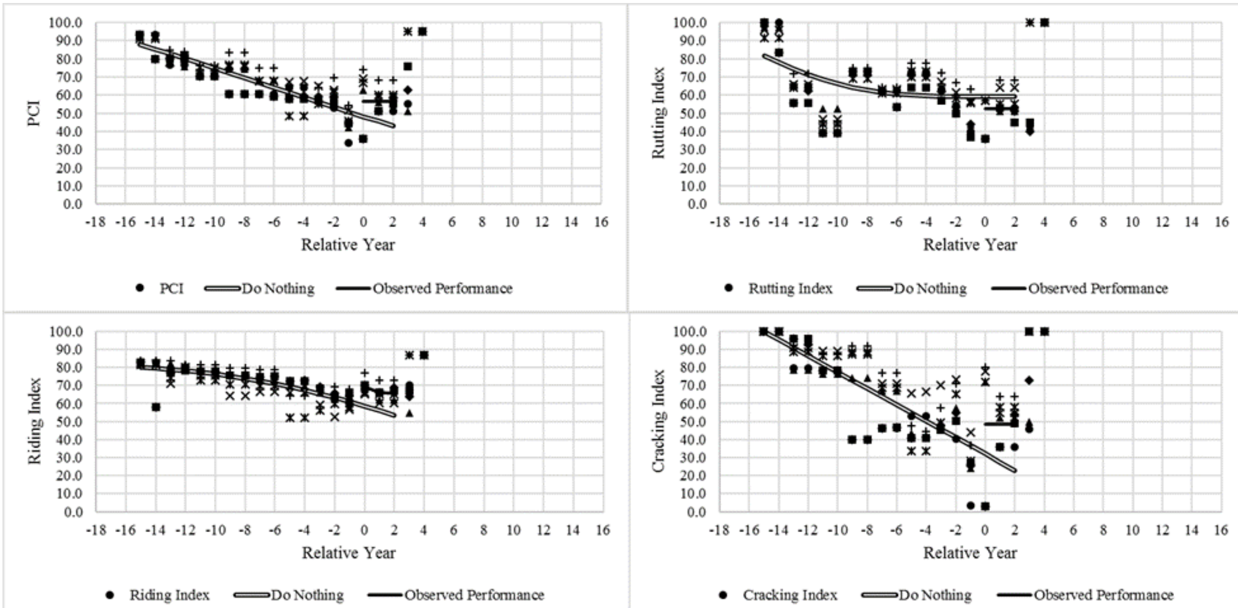
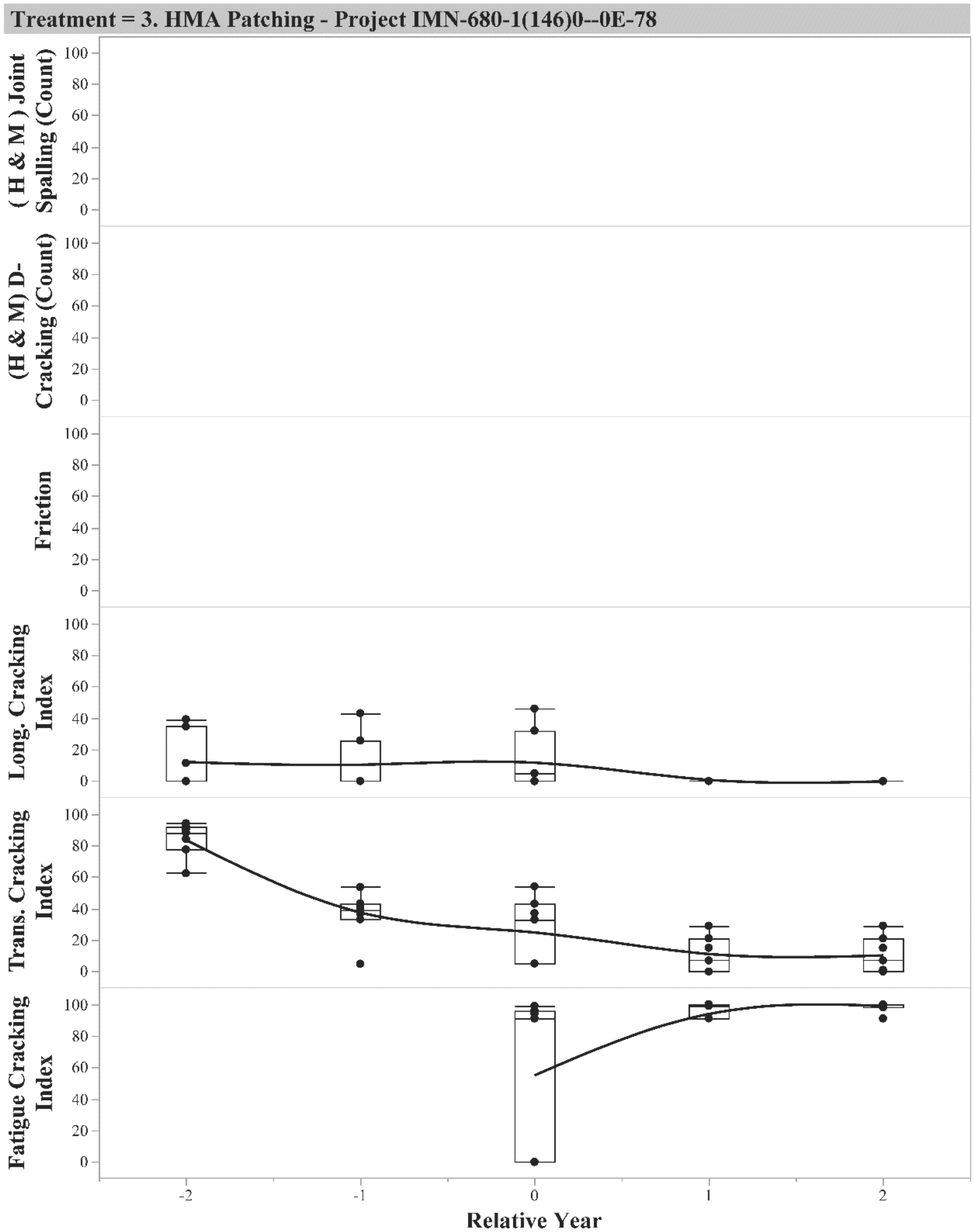


Figure 121. Analytical analysis graphs for project IMN-680-1(146)0—0E-78



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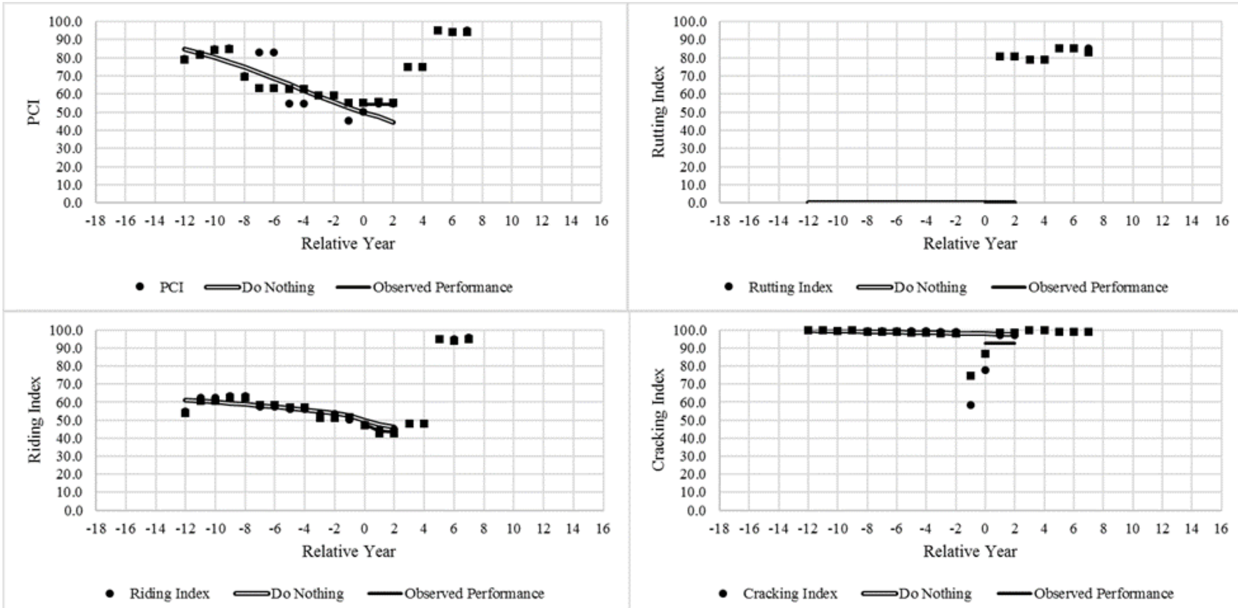
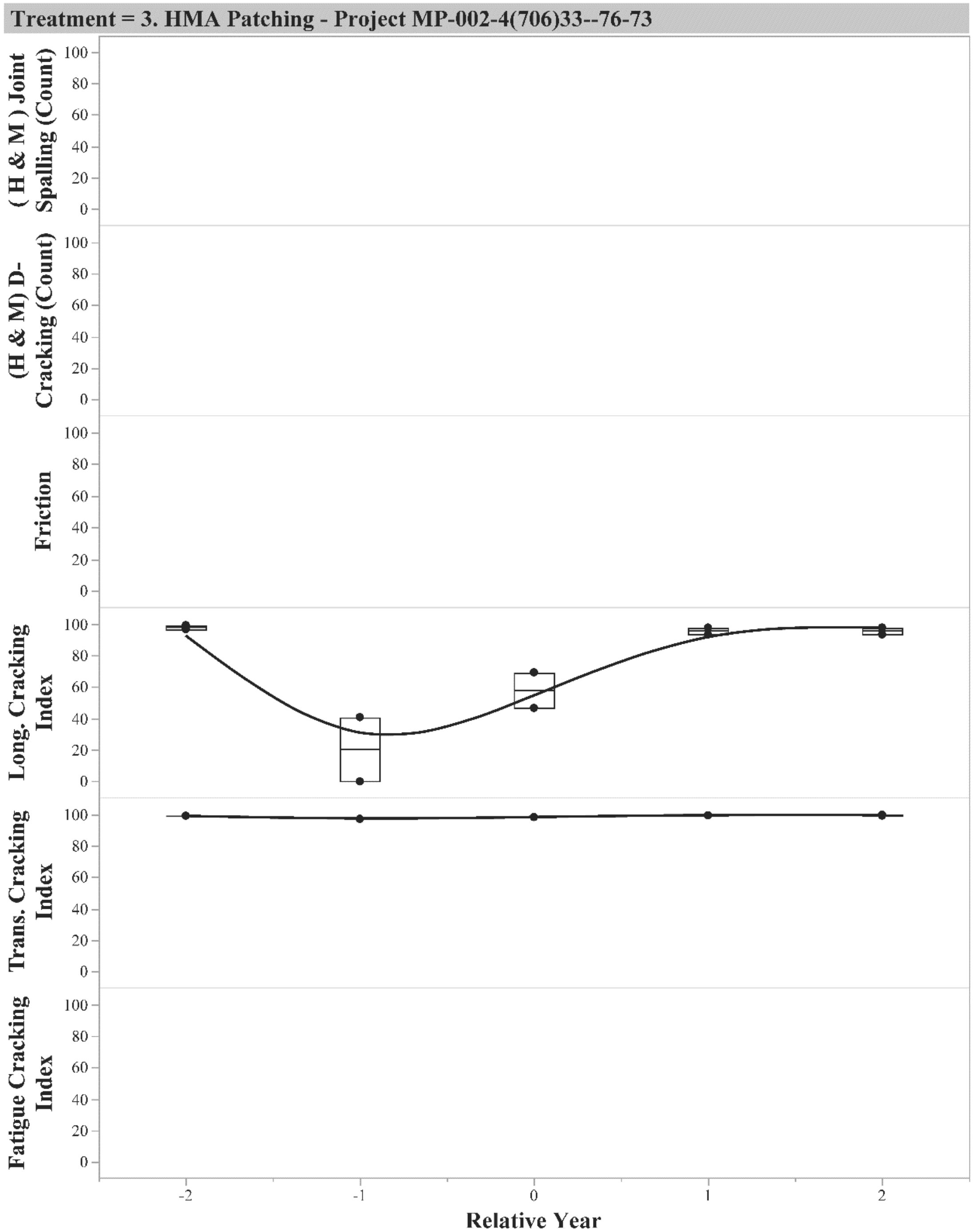


Figure 123. Analytical analysis graphs for project MP-002-4(706)33—76-73



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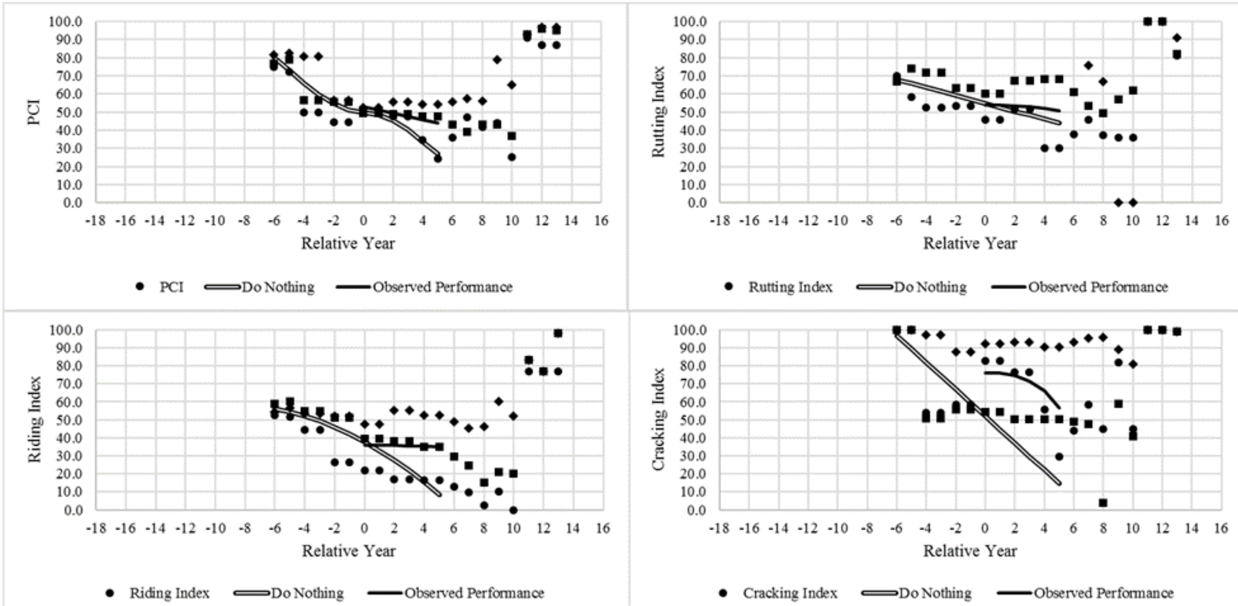
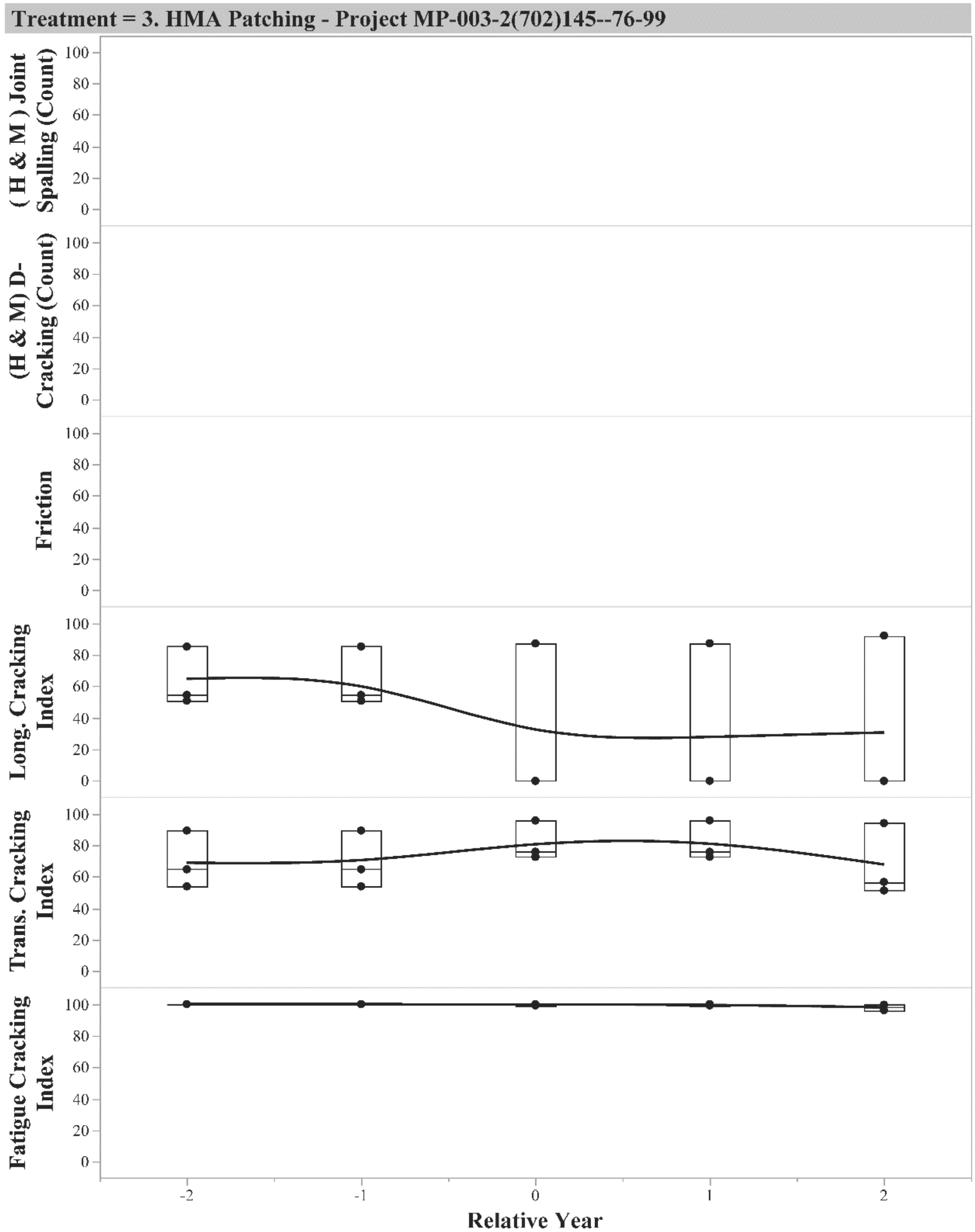


Figure 125. Analytical analysis graphs for project MP-003-2(702)145—76-99



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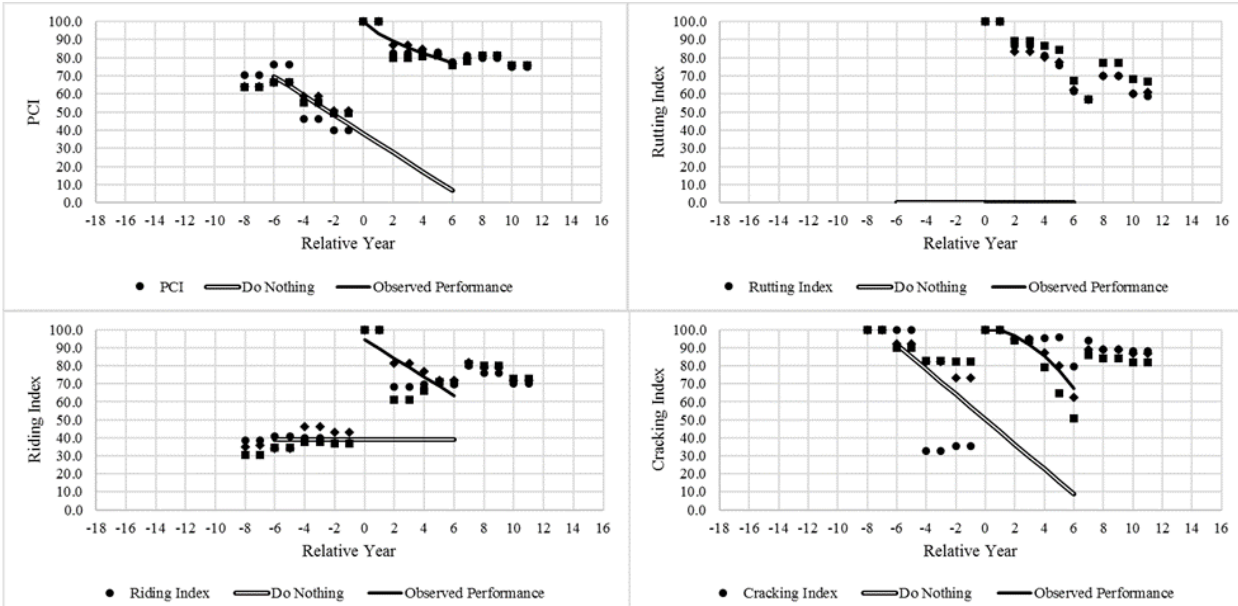
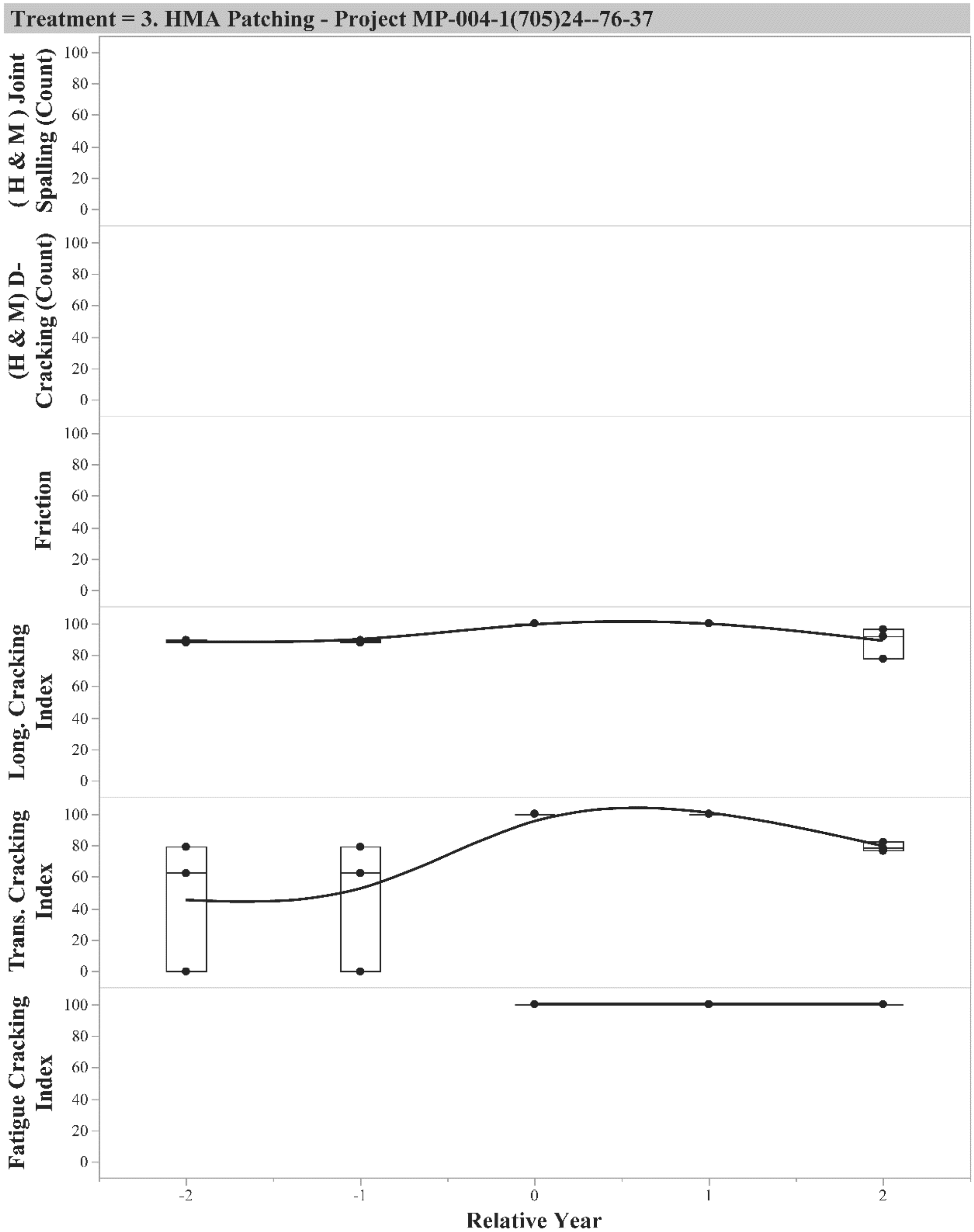


Figure 127. Analytical analysis graphs for project MP-004-1(705)24—76-37



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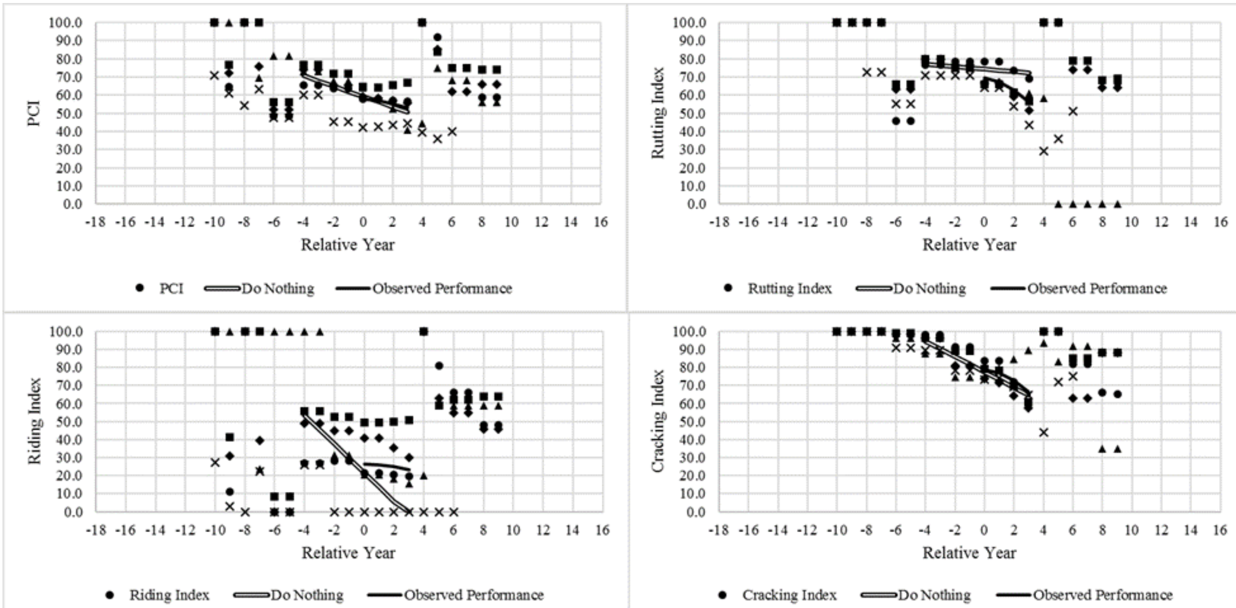
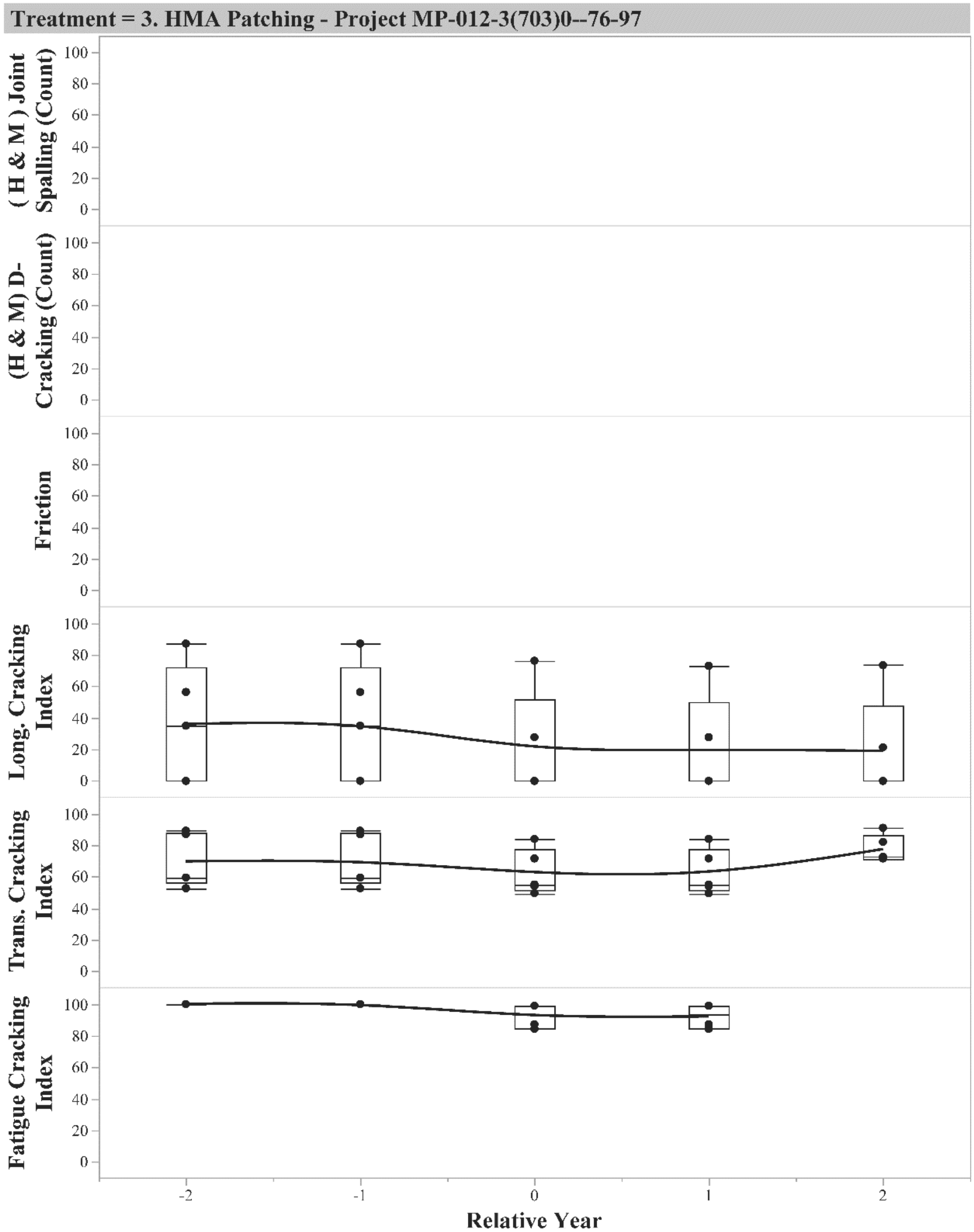


Figure 129. Analytical analysis graphs for project MP-012-3(703)0—76-97



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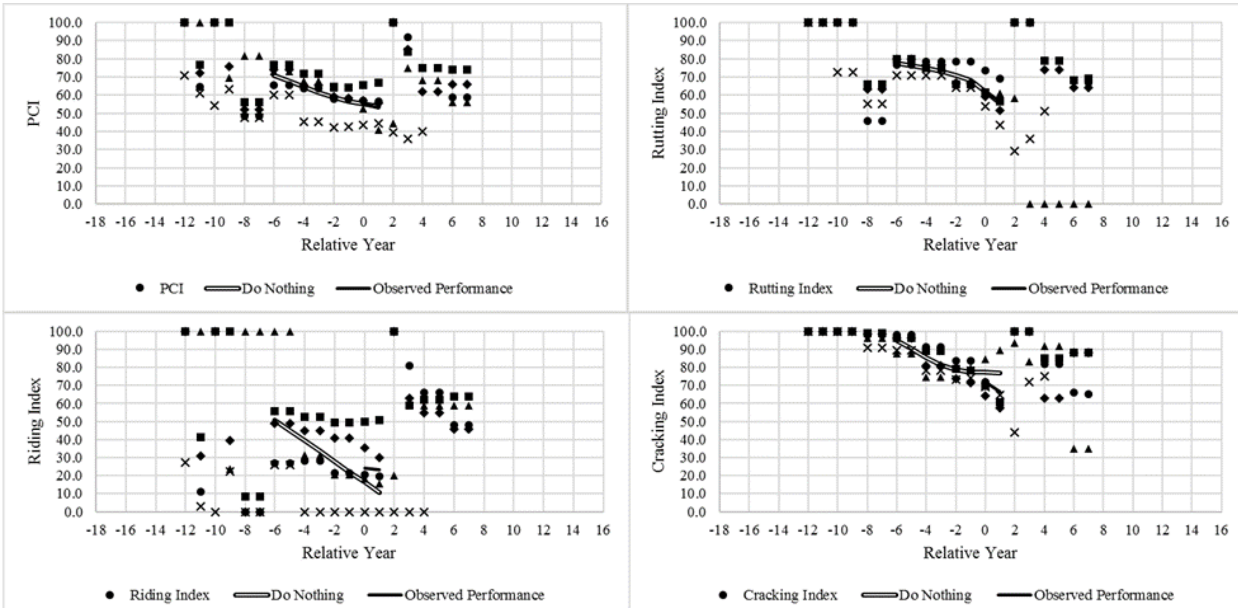

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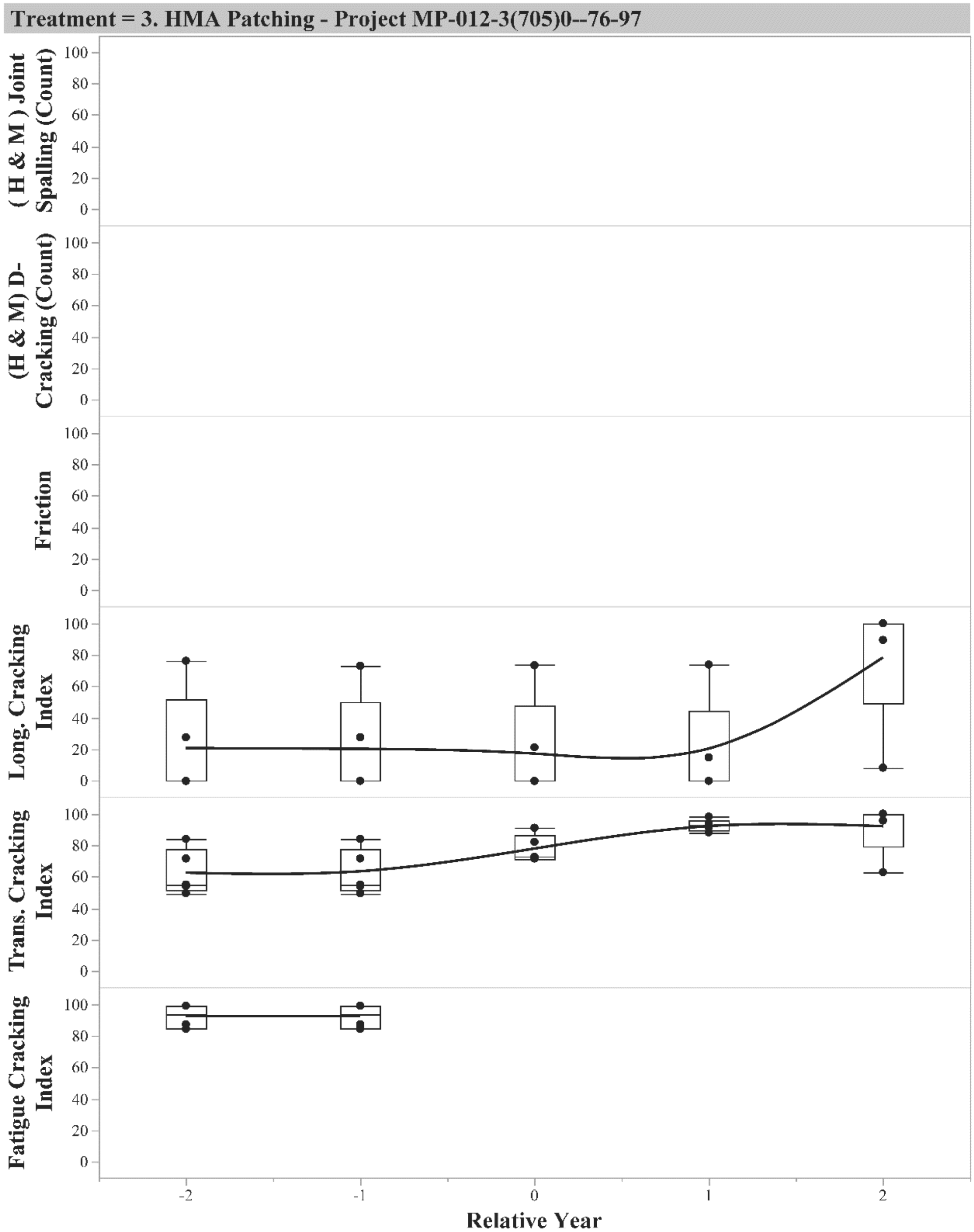


Figure 132. Anecdotal analysis graphs for project MP-012-3(705)0—76-97

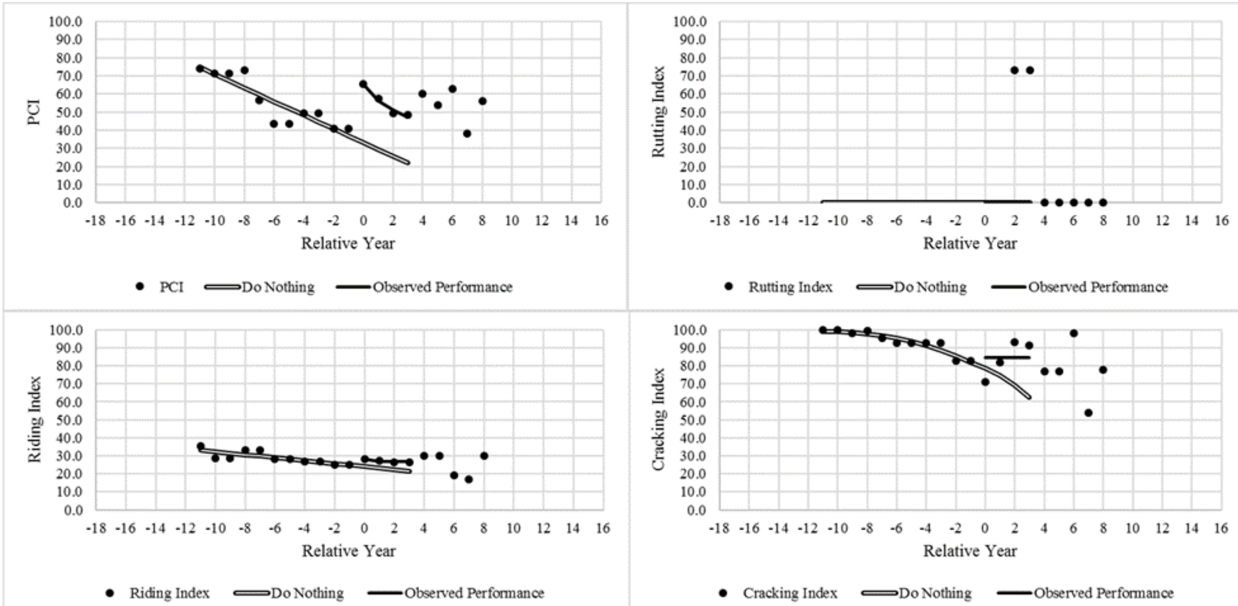
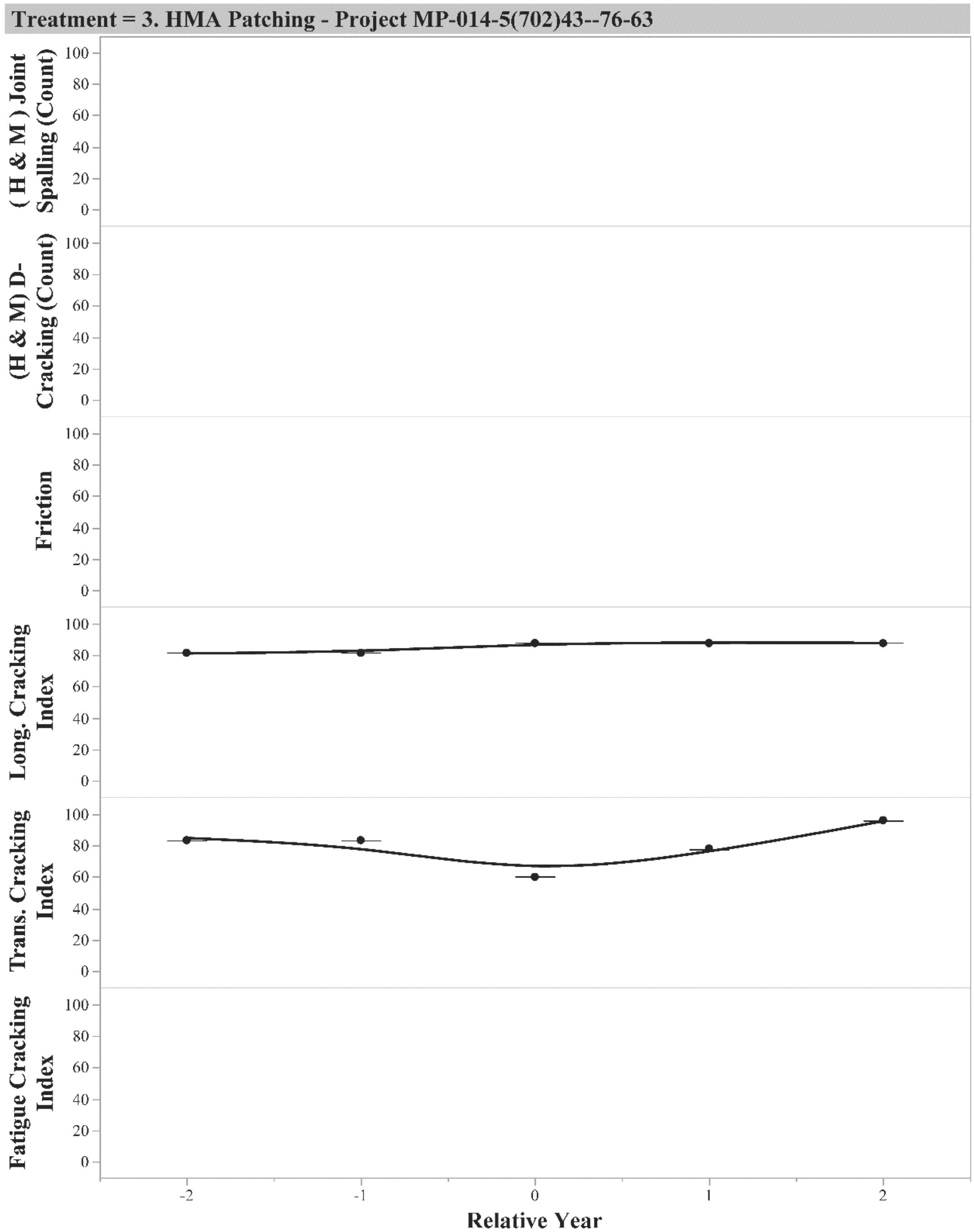


Figure 133. Analytical analysis graphs for project MP-014-5(702)43—76-63



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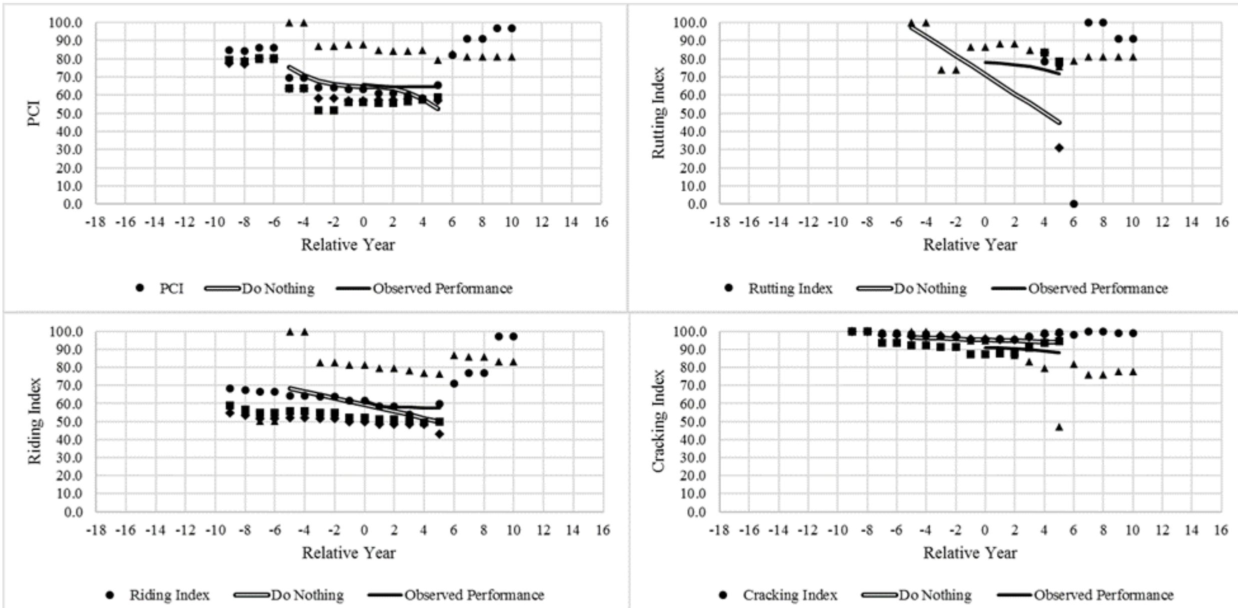


Figure 135. Analytical analysis graphs for project MP-020-1(703)136—76-40

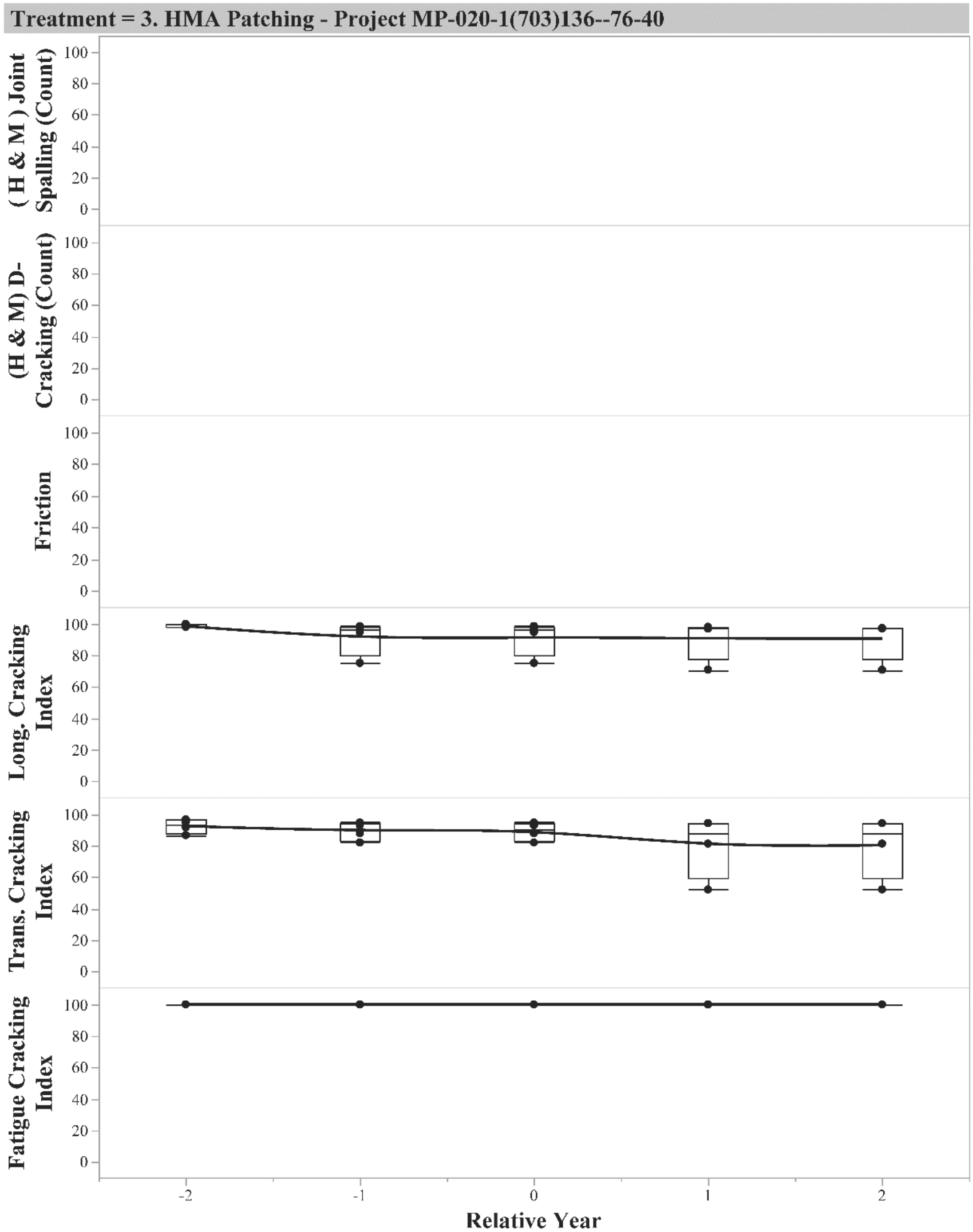


Figure 136. Anecdotal analysis graphs for project MP-020-1(703)136—76-40

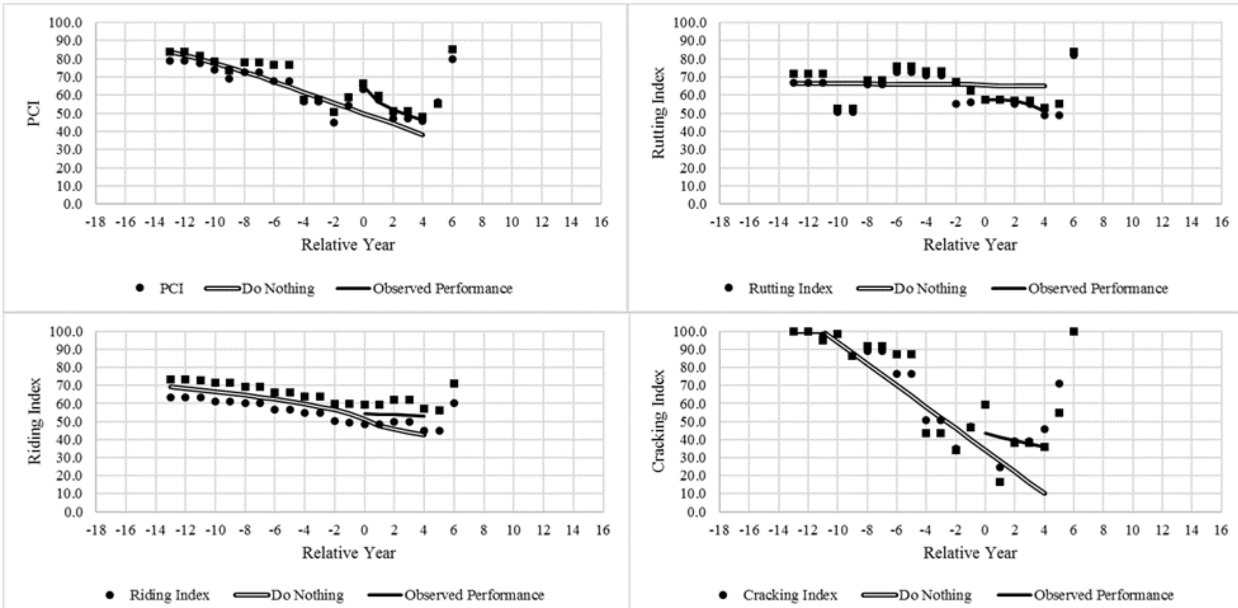
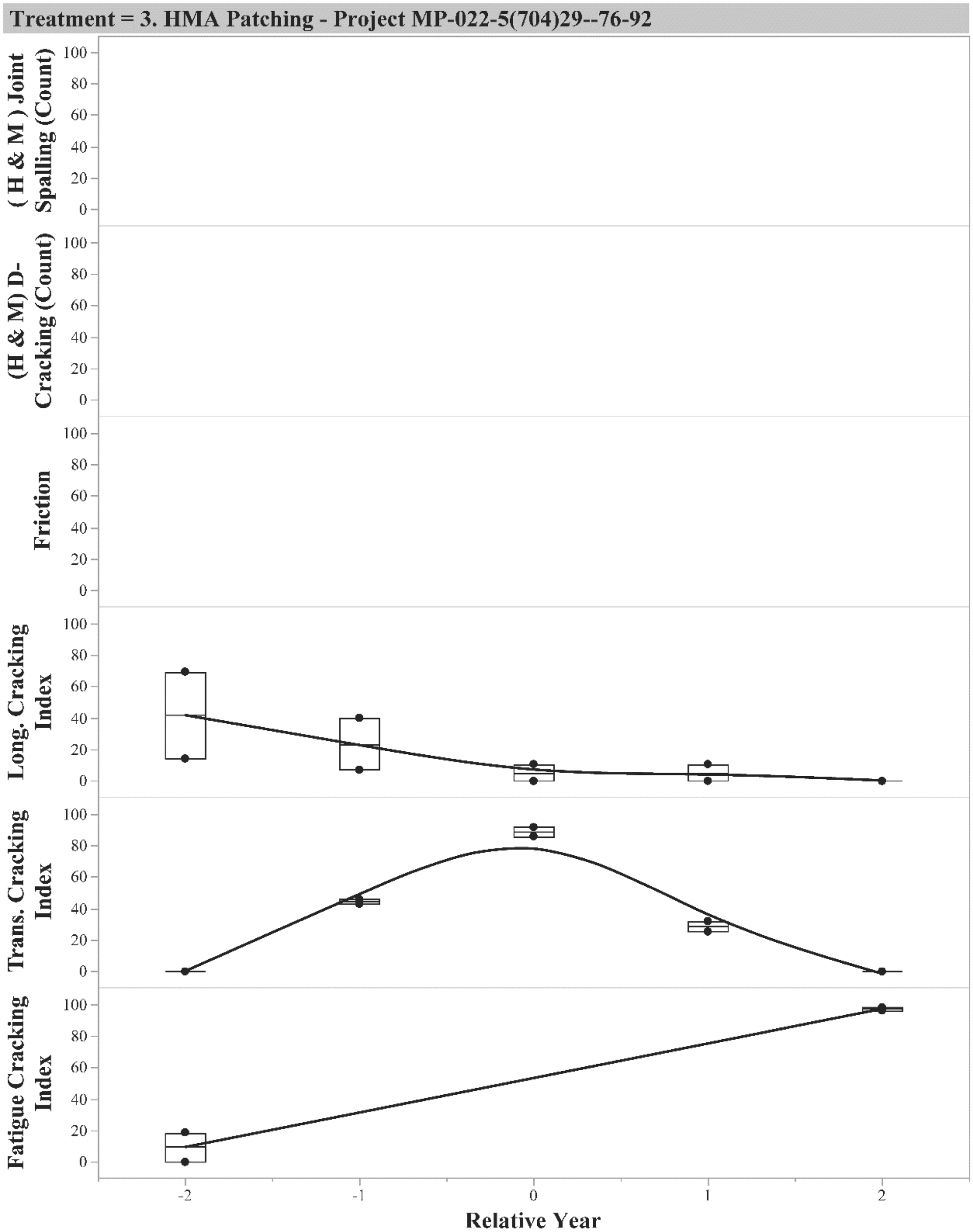


Figure 137. Analytical analysis graphs for project MP-022-5(704)29—76-92



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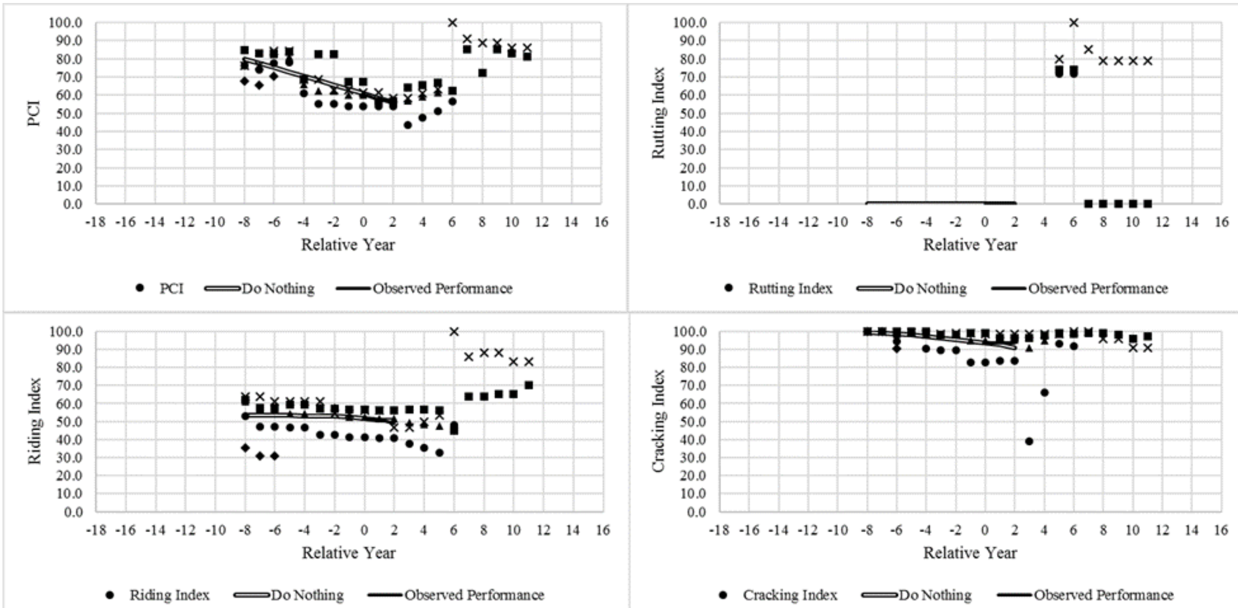
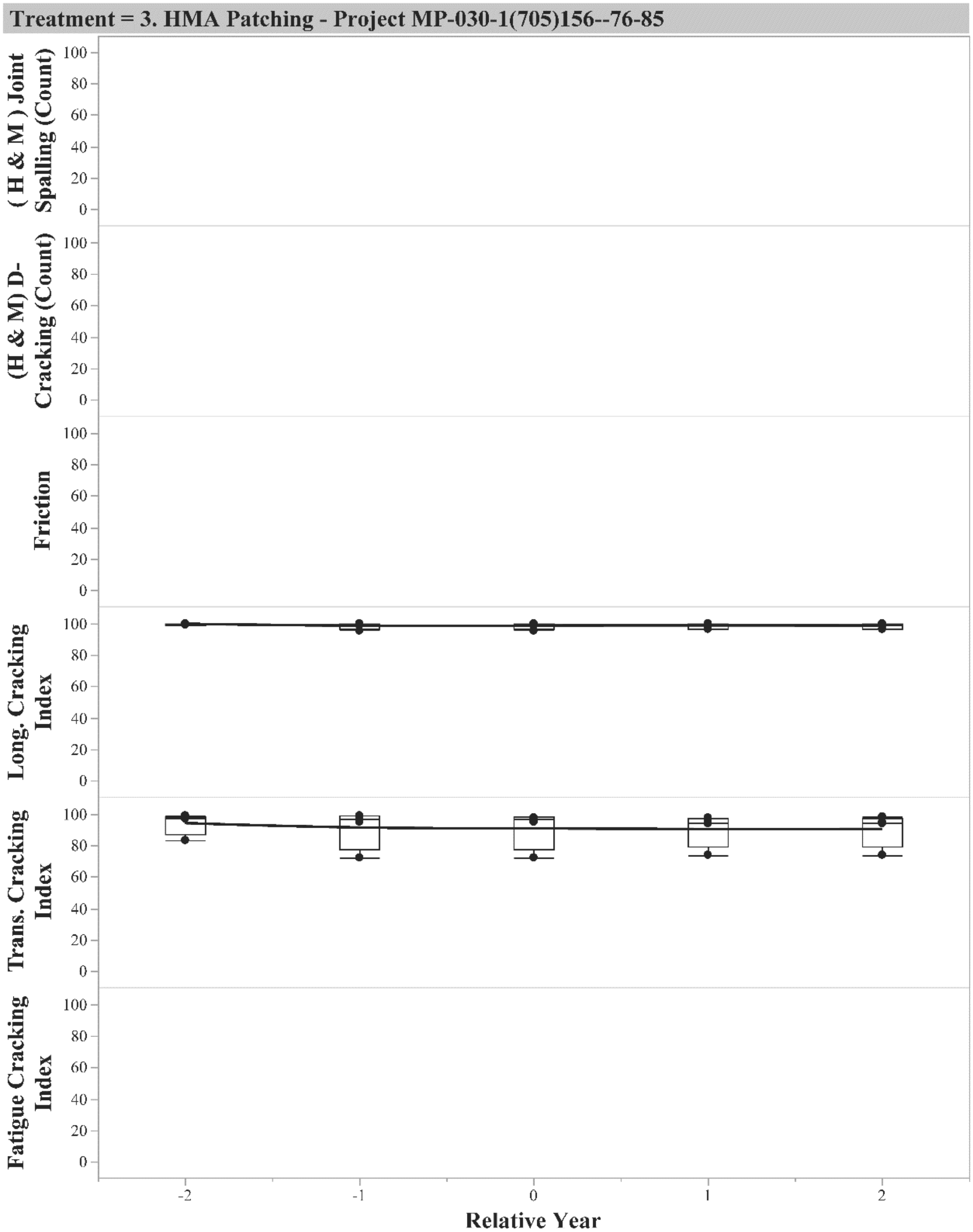


Figure 139. Analytical analysis graphs for project MP-030-1(705)156—76-85



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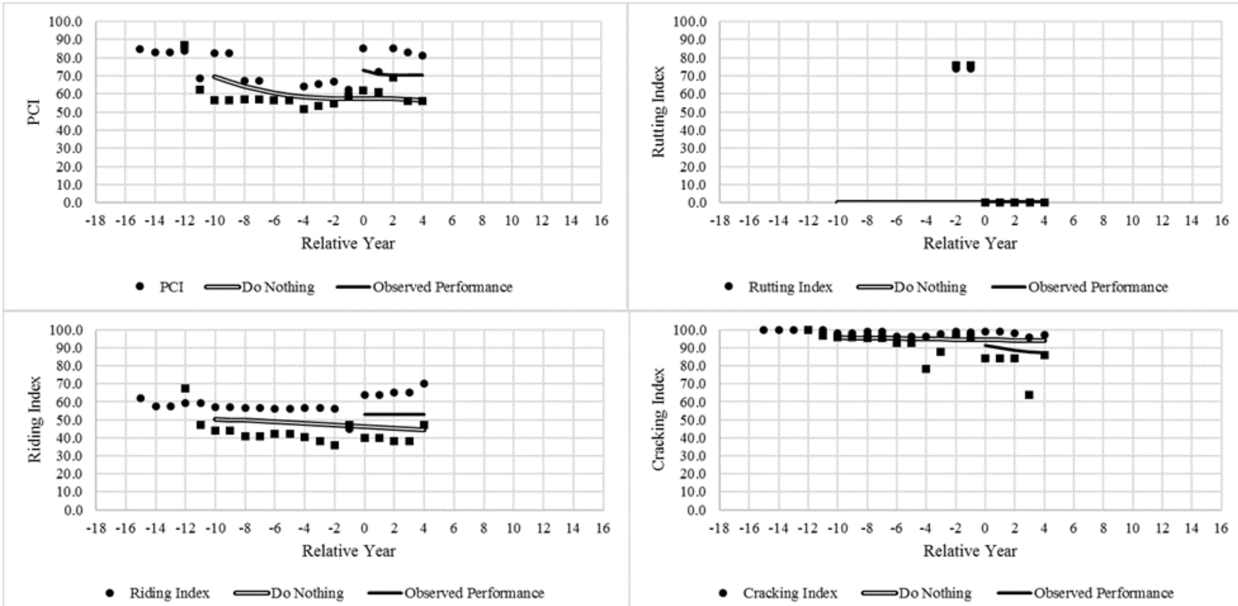


Figure 141. Analytical analysis graphs for project MP-030-1(708)156—76-85

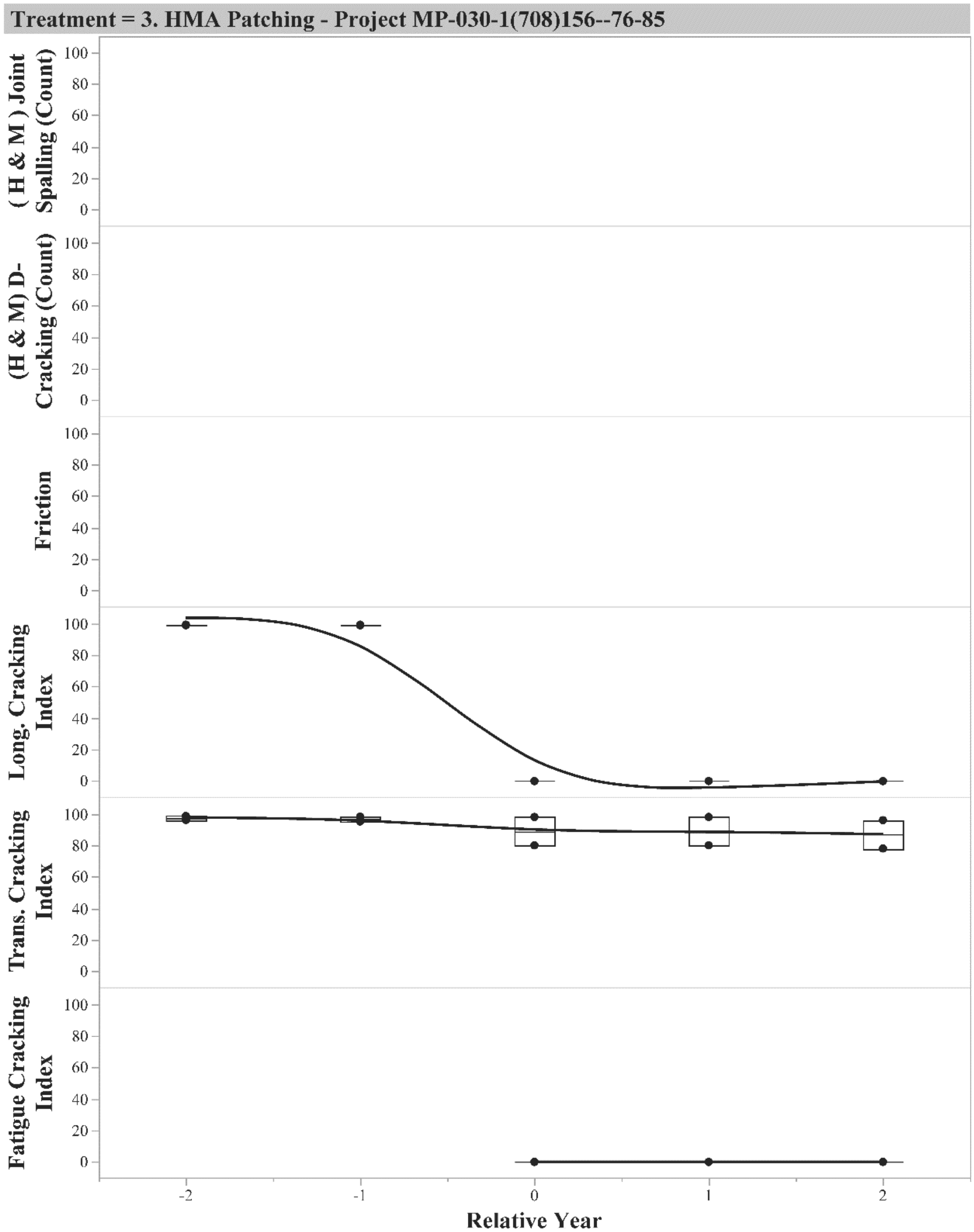


Figure 142. Anecdotal analysis graphs for project MP-030-1(708)156—76-85

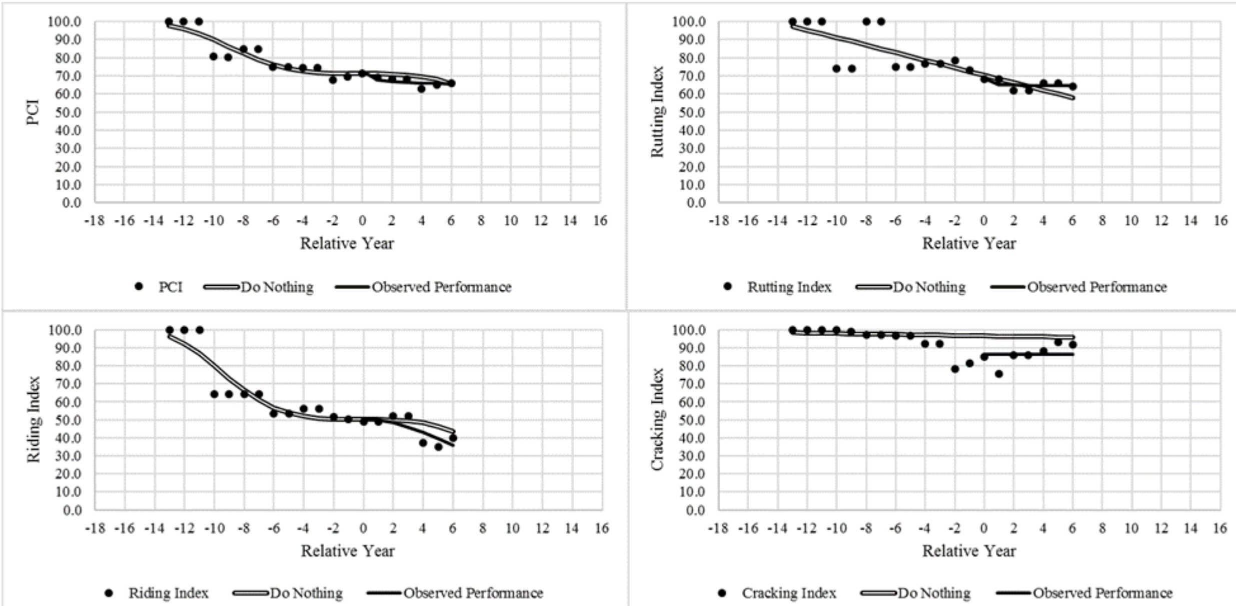


Figure 143. Analytical analysis graphs for project MP-032-6(701)0—76-31

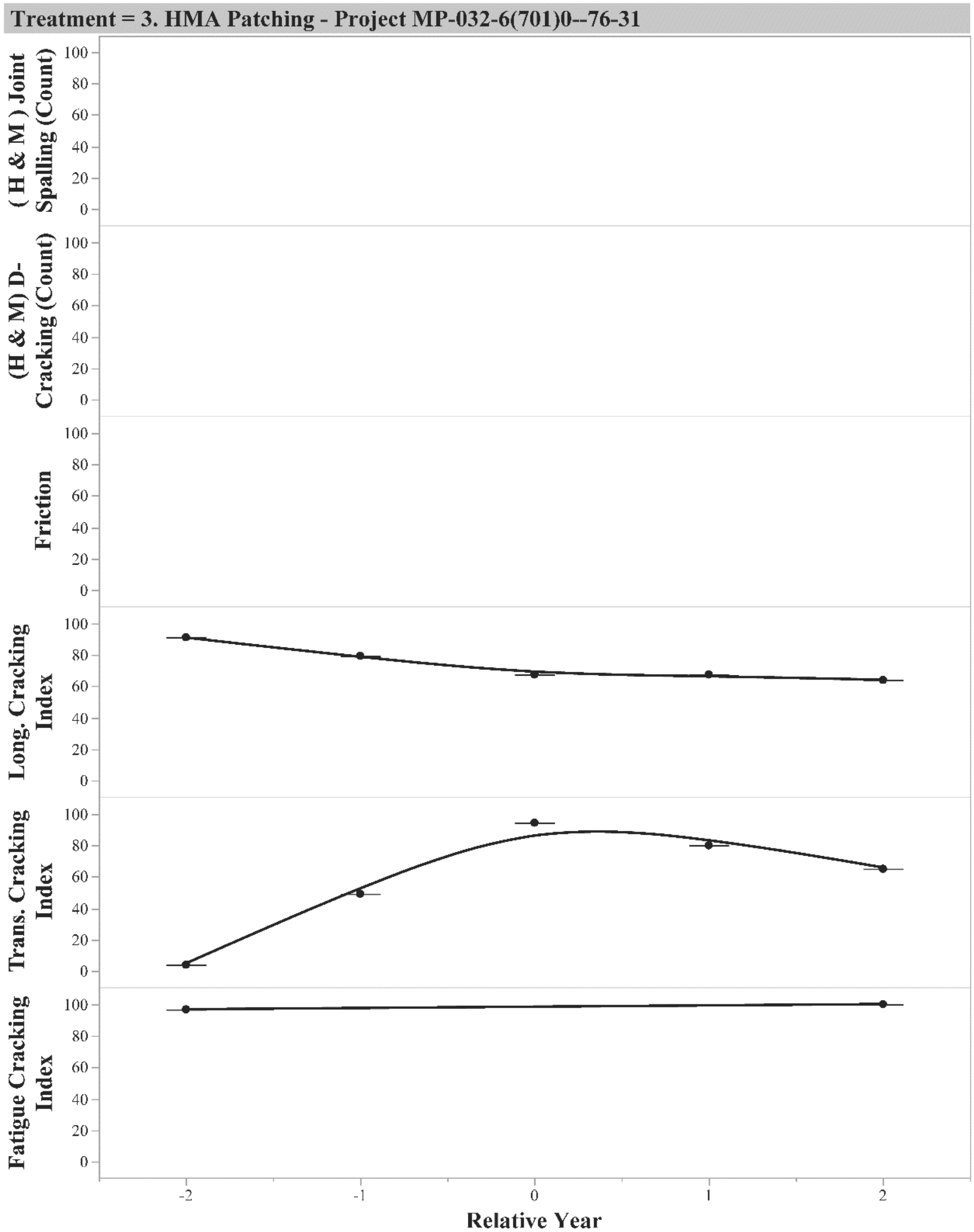


Figure 144. Anecdotal analysis graphs for project MP-032-6(701)0—76-31

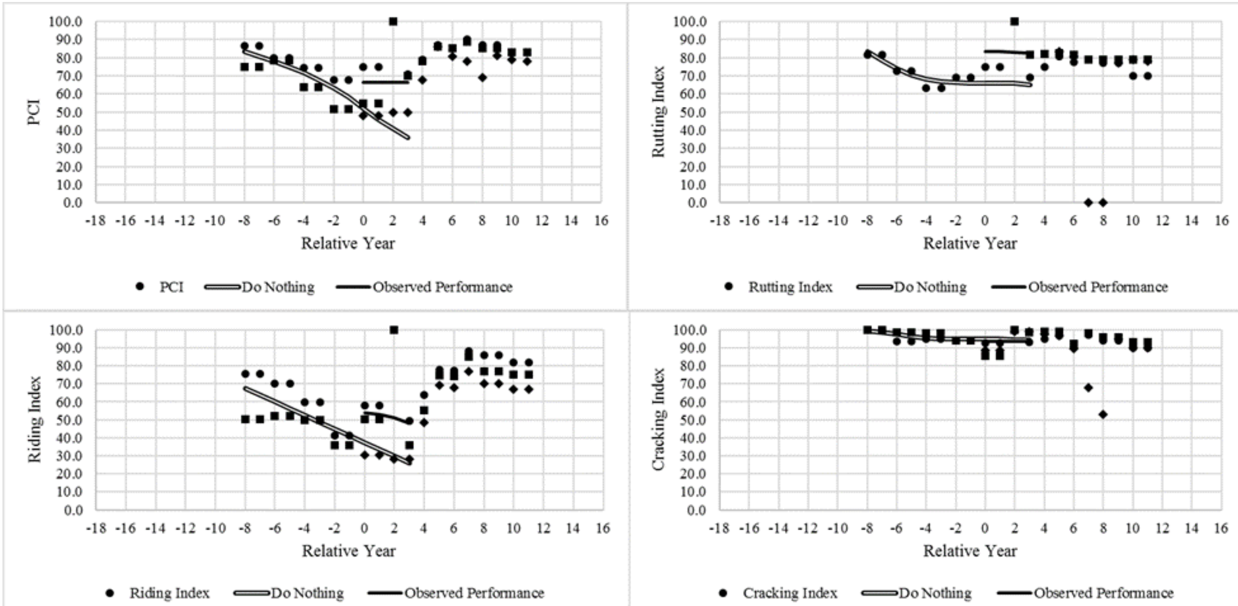


Figure 145. Analytical analysis graphs for project MP-044-4(704)46—76-05

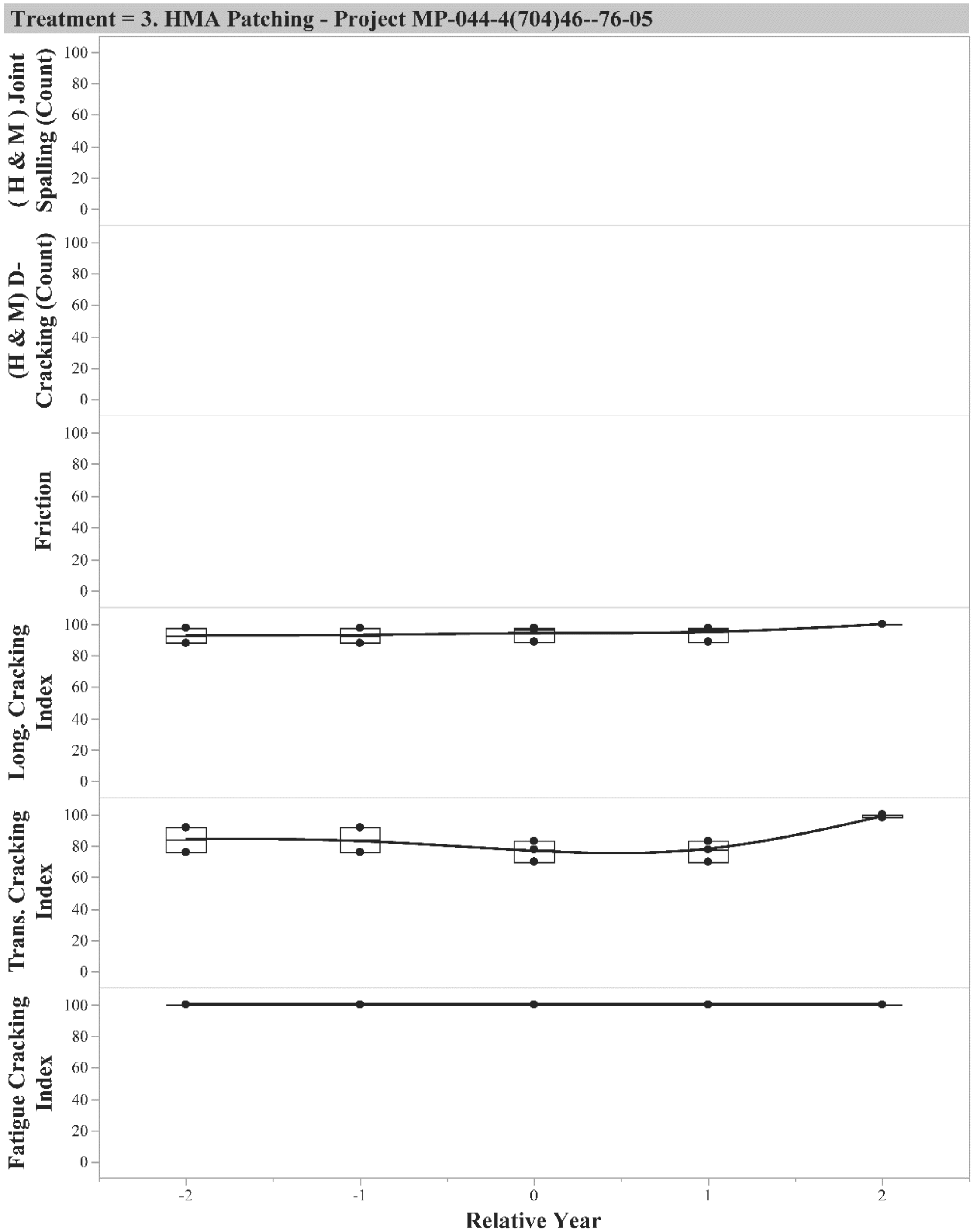


Figure 146. Anecdotal analysis graphs for project MP-044-4(704)46—76-05

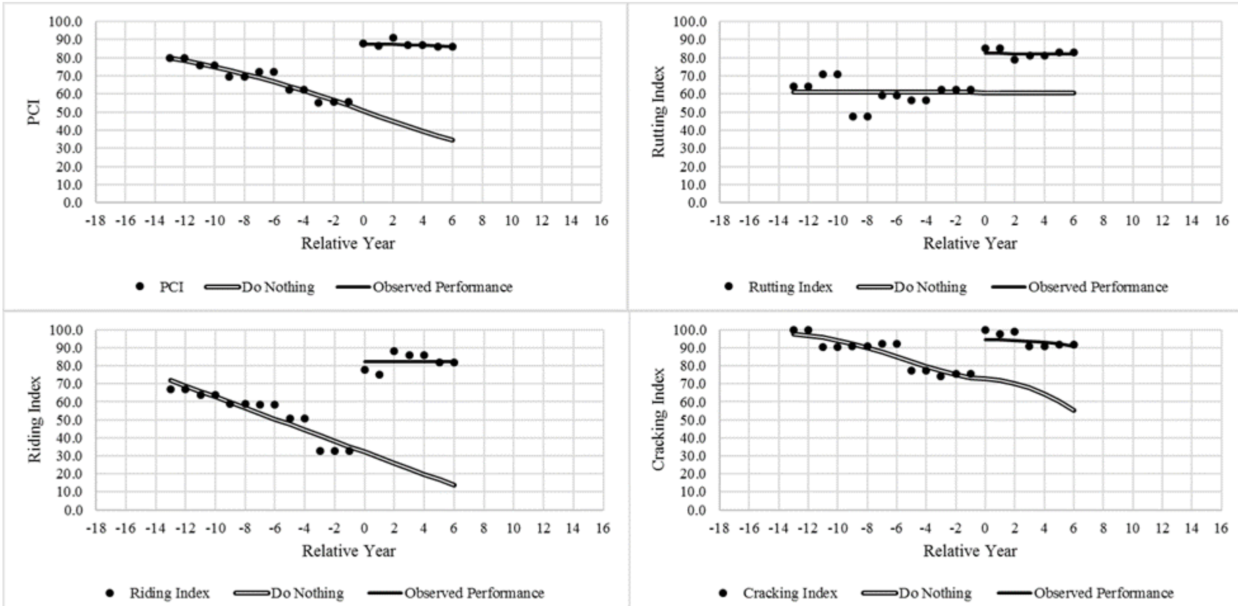


Figure 147. Analytical analysis graphs for project MP-059-3(705)102—76-24

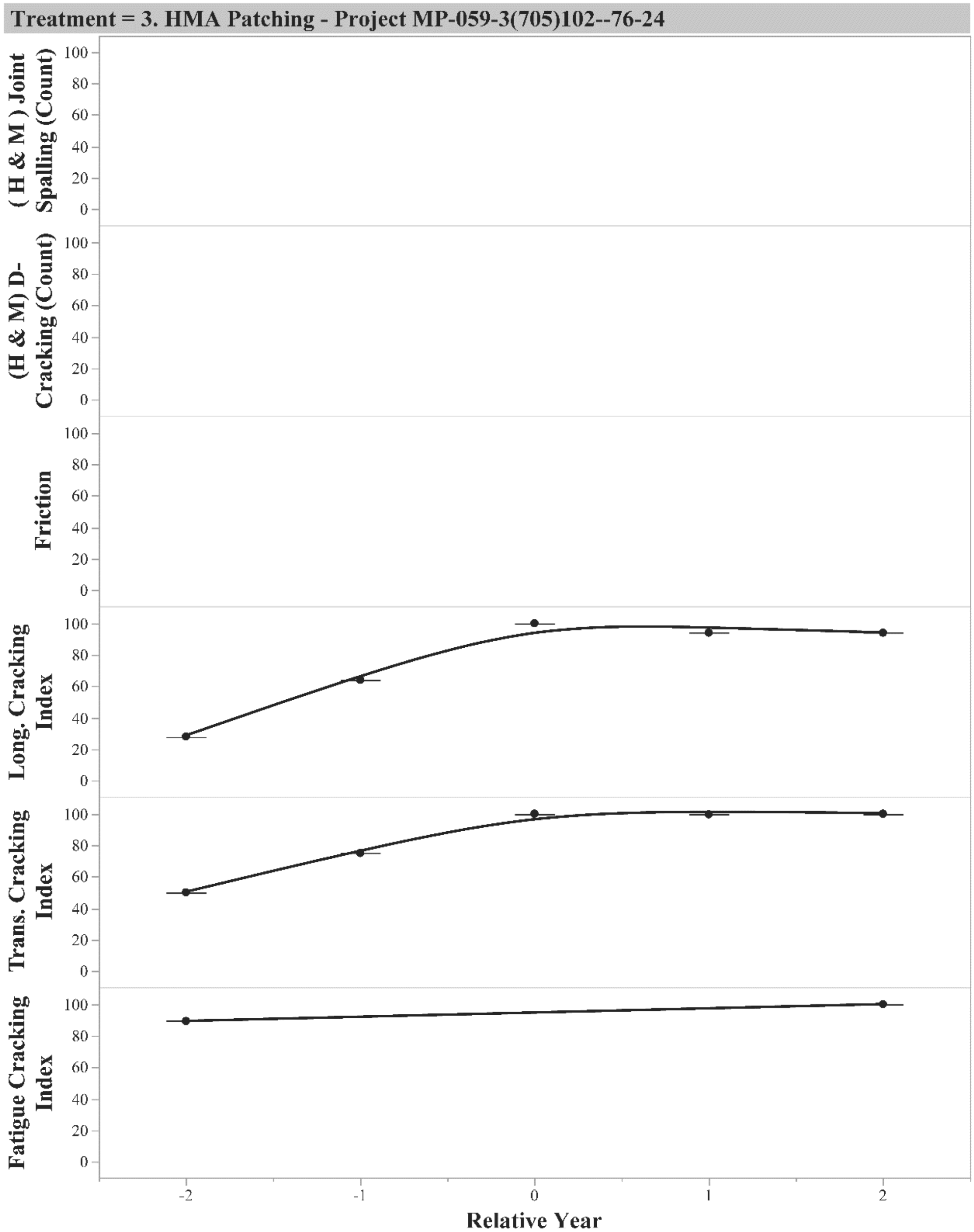


Figure 148. Anecdotal analysis graphs for project MP-059-3(705)102—76-24

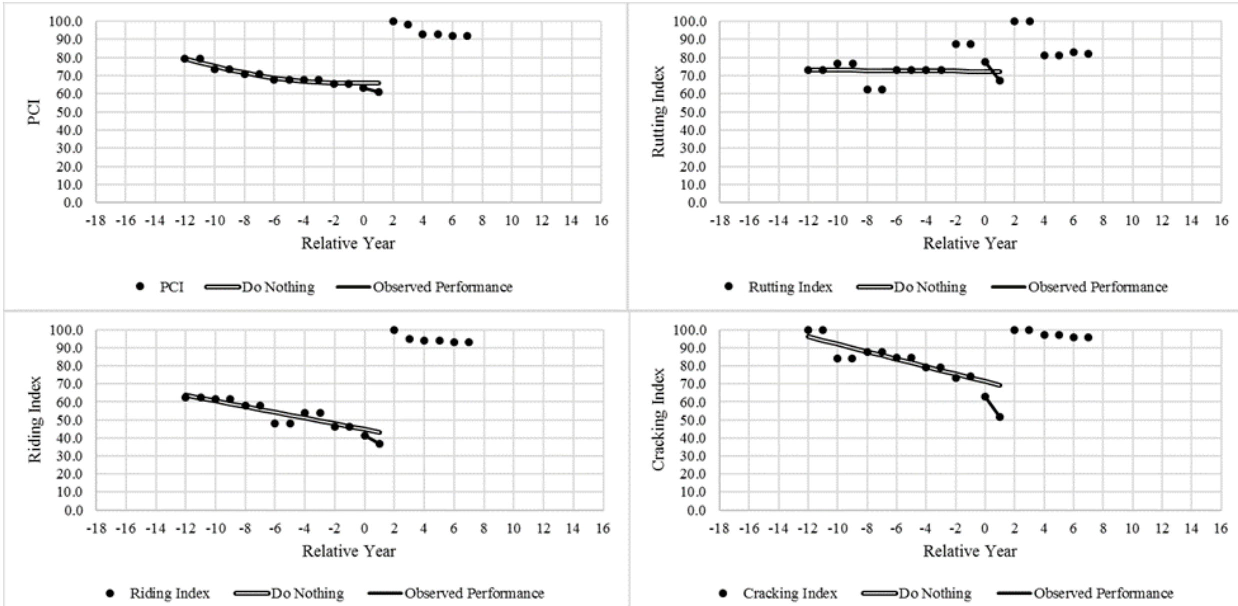


Figure 149. Analytical analysis graphs for project MP-059-3(706)105—76-24

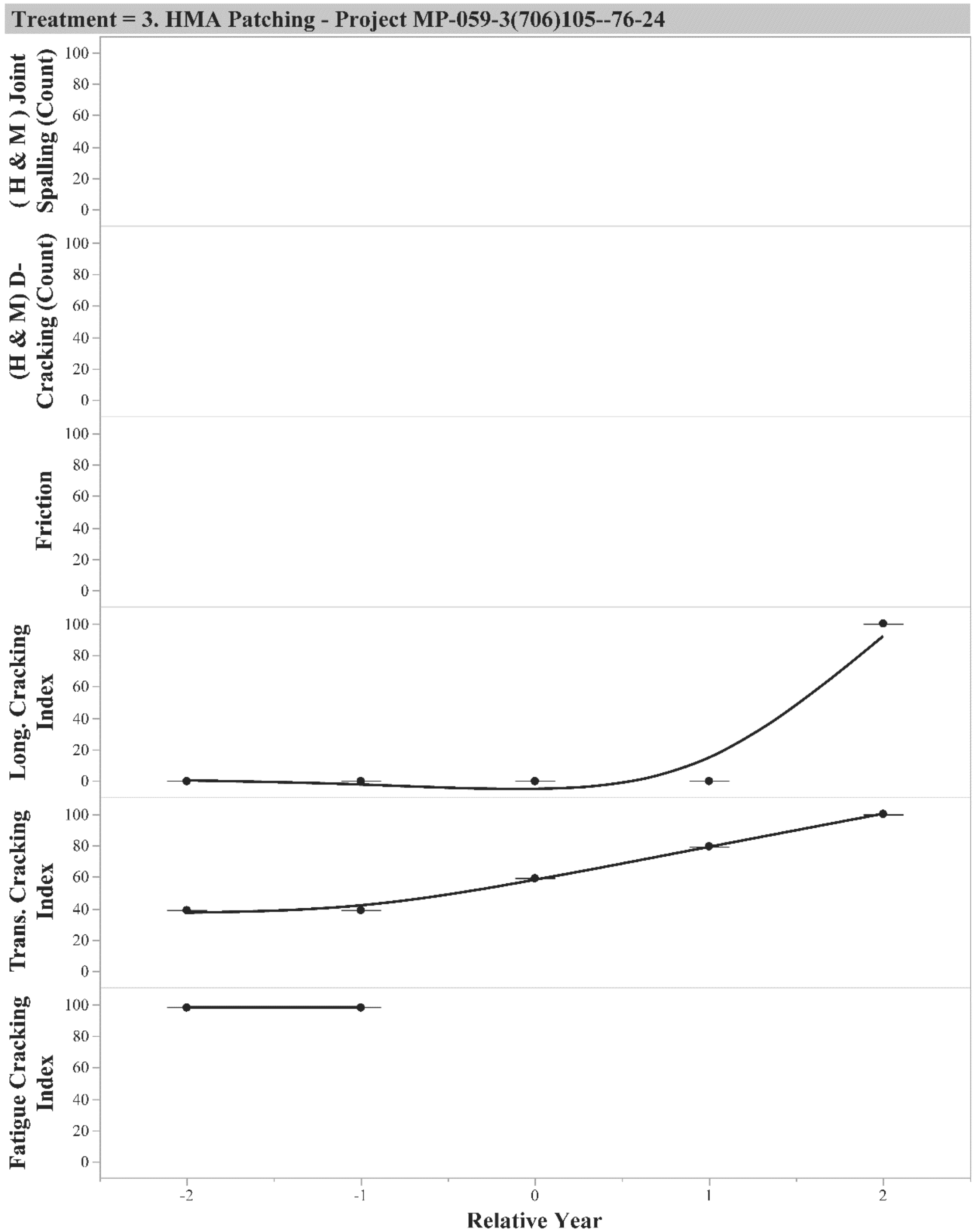


Figure 150. Anecdotal analysis graphs for project MP-059-3(706)105—76-24

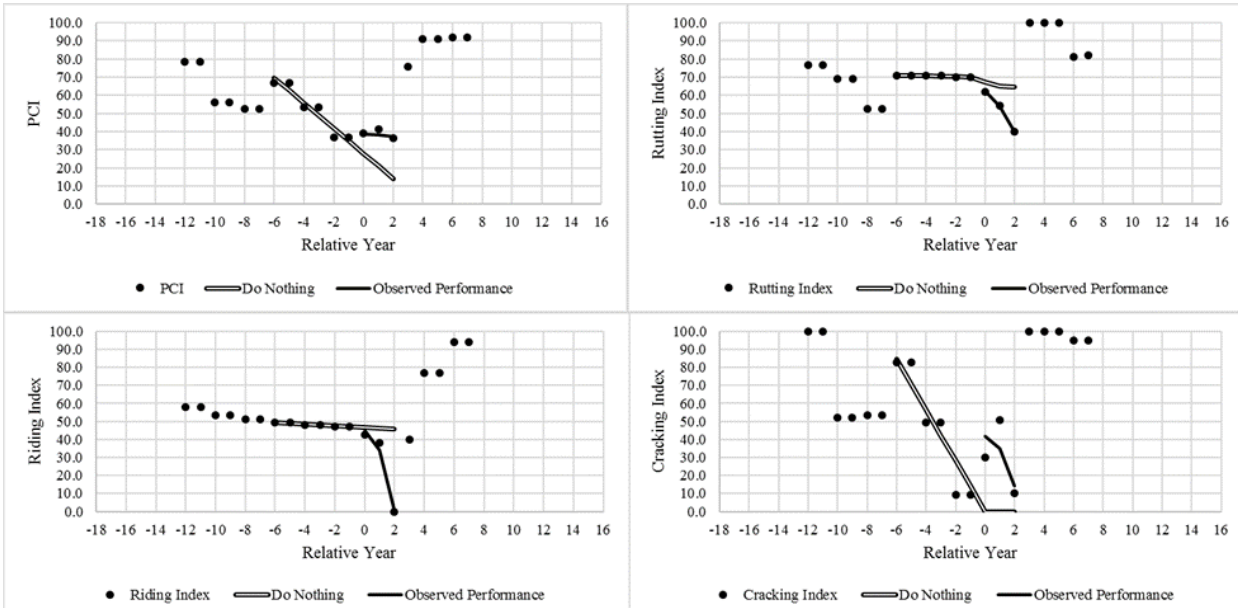


Figure 151. Analytical analysis graphs for project MP-059-3(706)130—76-47

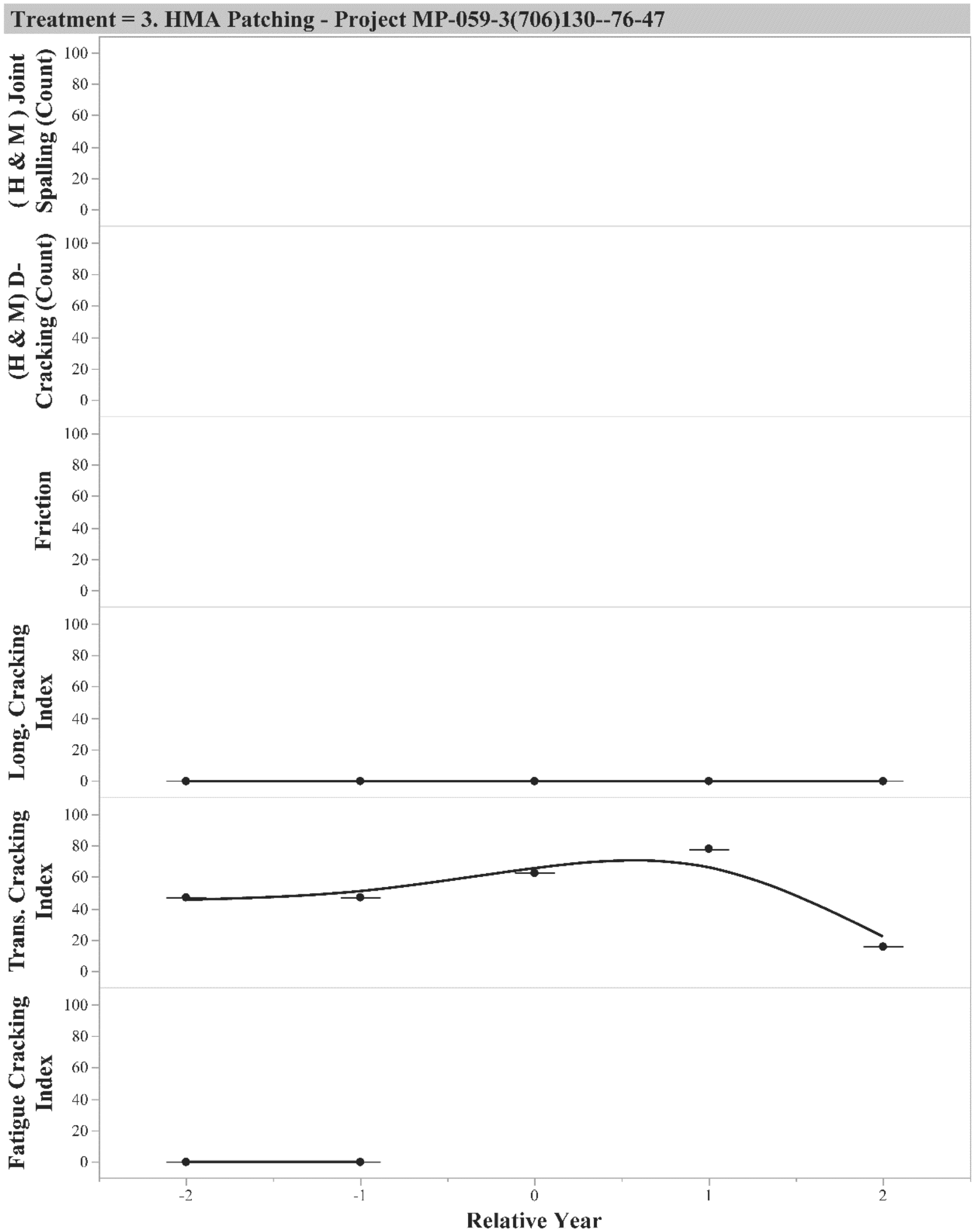


Figure 152. Anecdotal analysis graphs for project MP-059-3(706)130—76-47

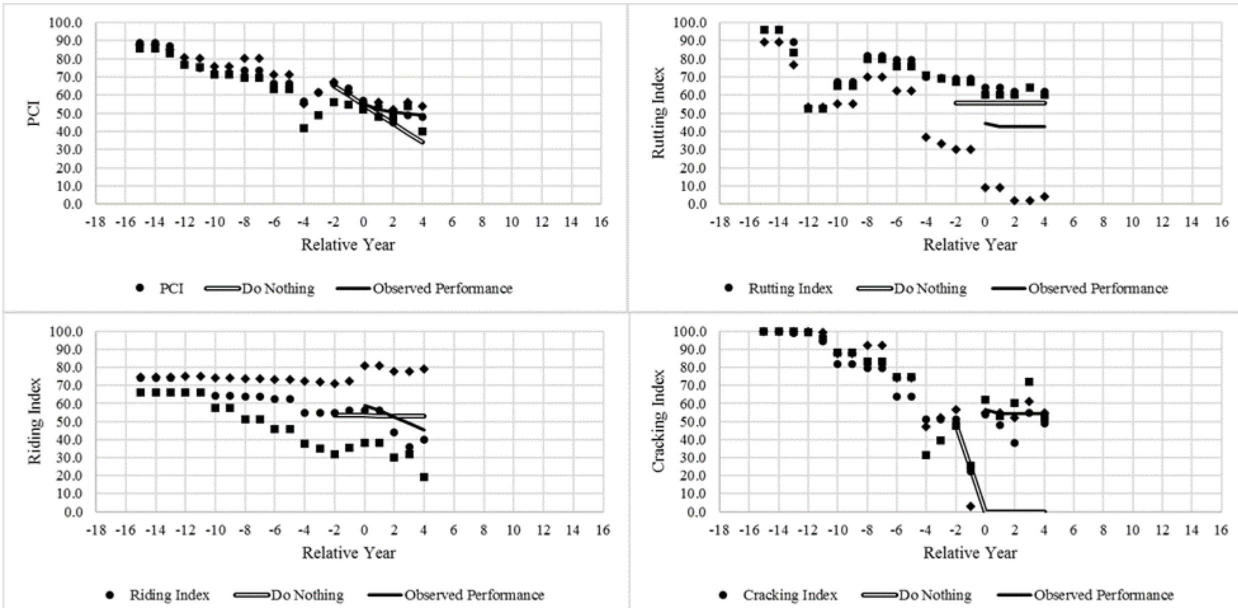


Figure 153. Analytical analysis graphs for project MP-061-5(706)68—76-58

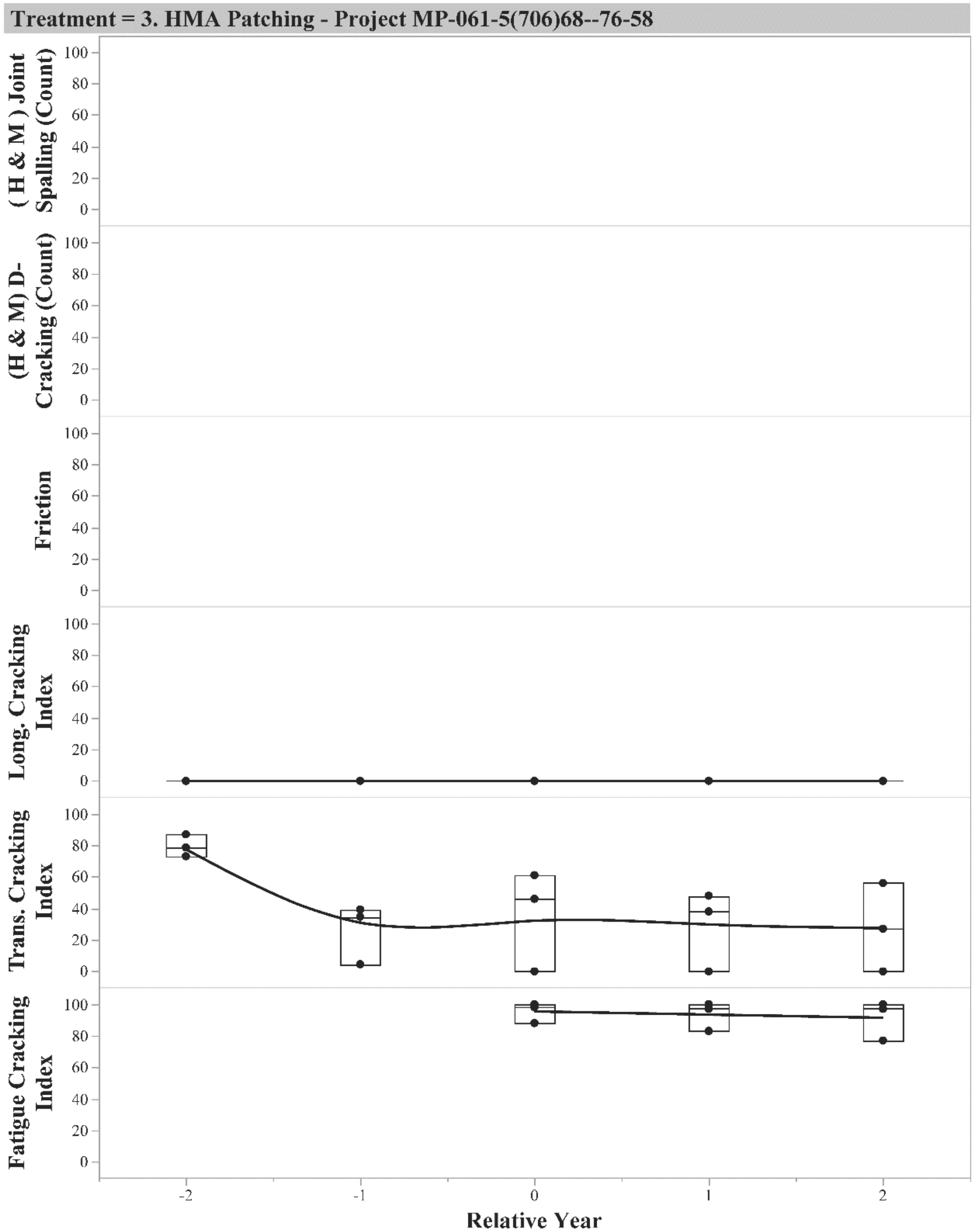


Figure 154. Anecdotal analysis graphs for project MP-061-5(706)68—76-58

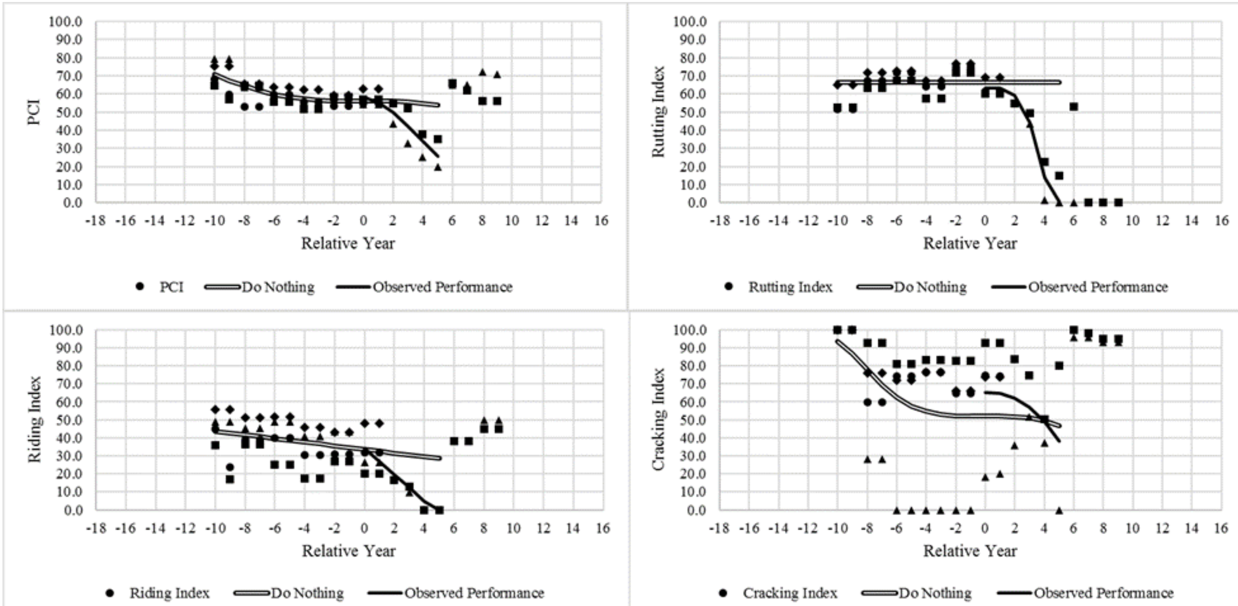


Figure 155. Analytical analysis graphs for project MP-063-2(707)163—76-07

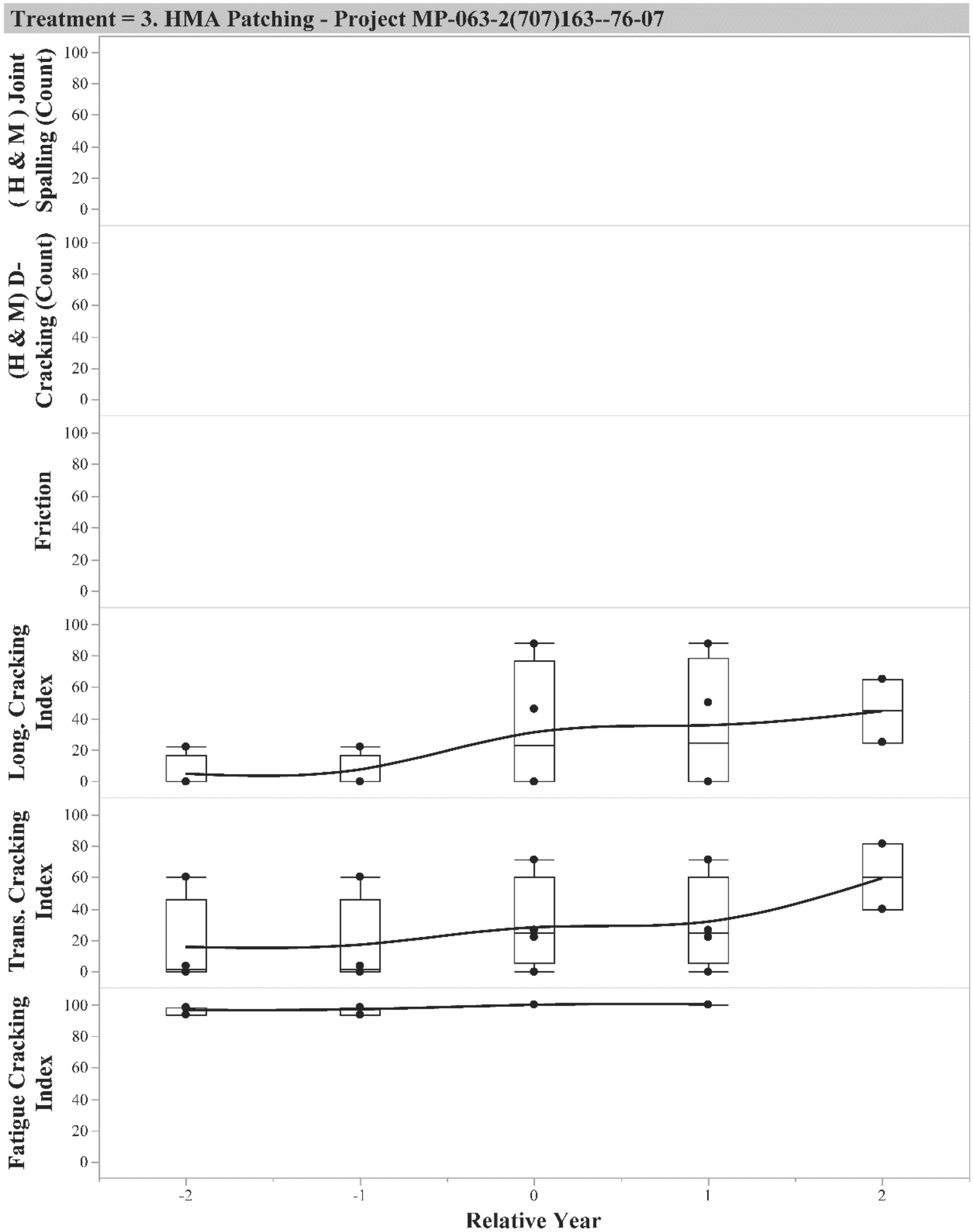


Figure 156. Anecdotal analysis graphs for project MP-063-2(707)163—76-07

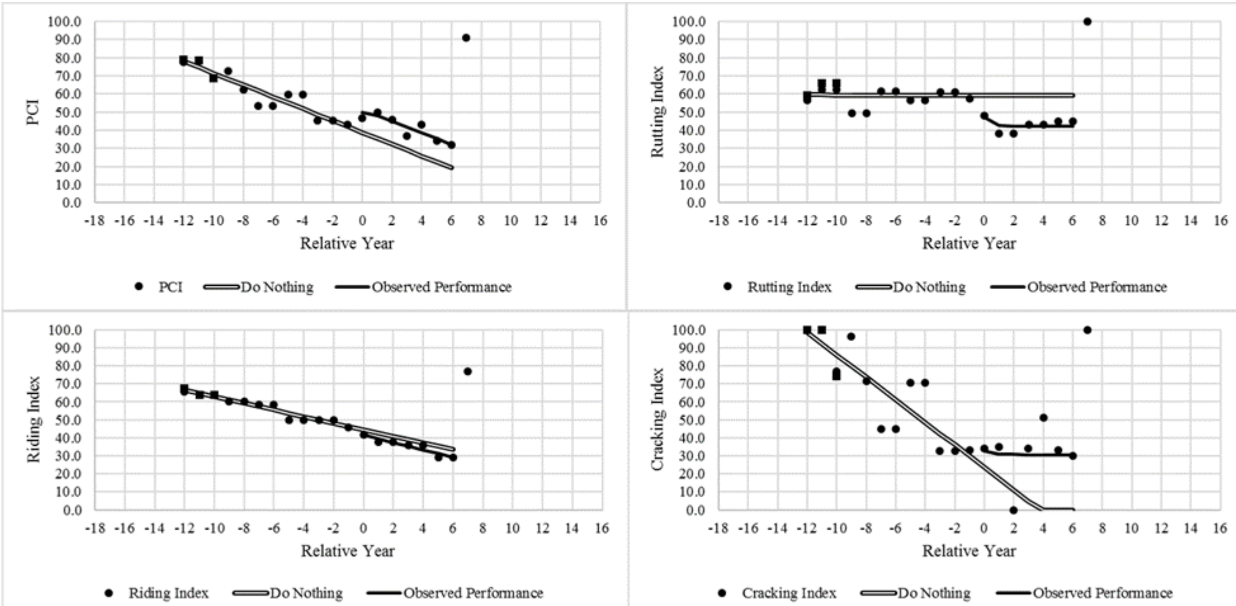


Figure 157. Analytical analysis graphs for project MP-064-6(706)50—76-49

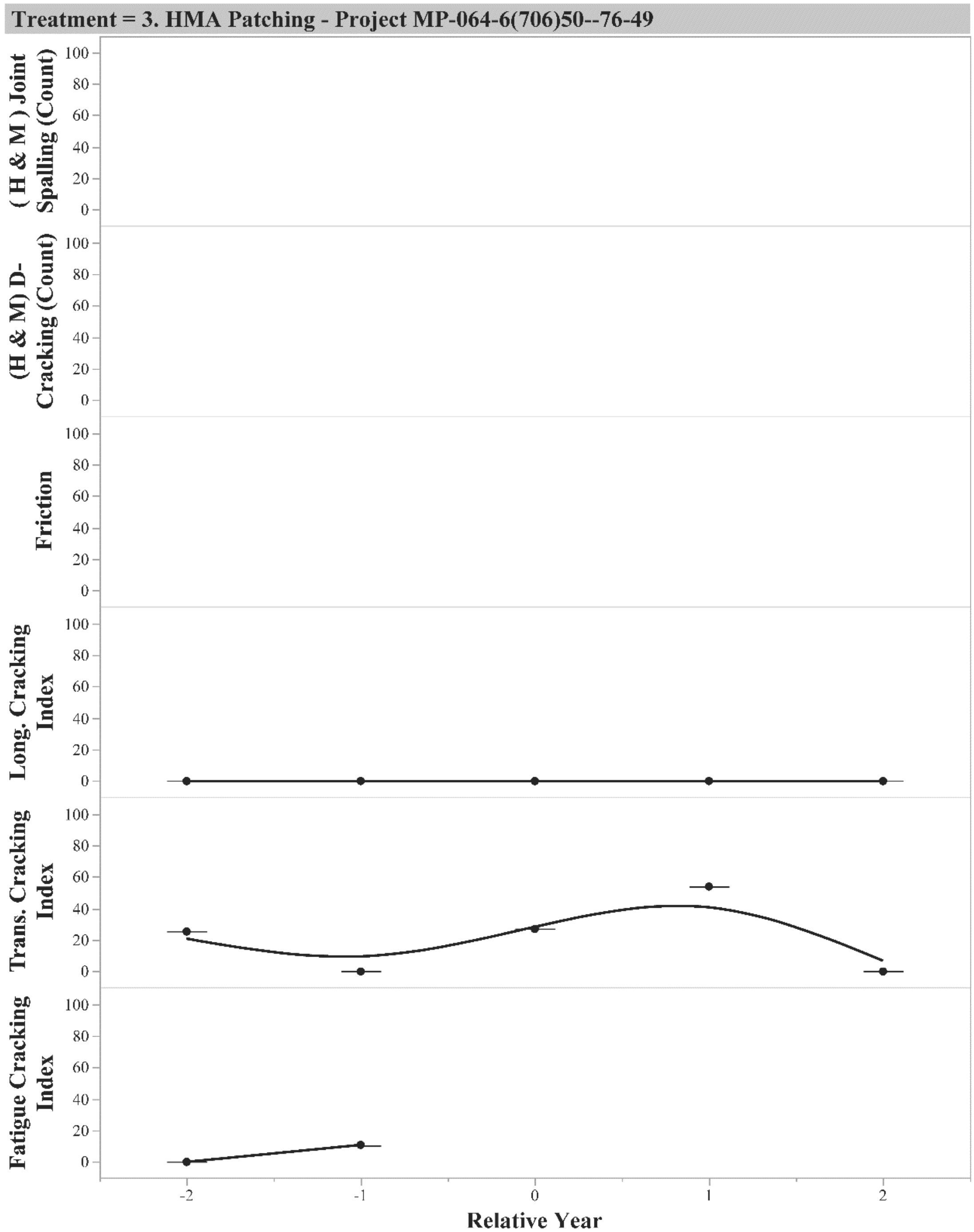


Figure 158. Anecdotal analysis graphs for project MP-064-6(706)50—76-49

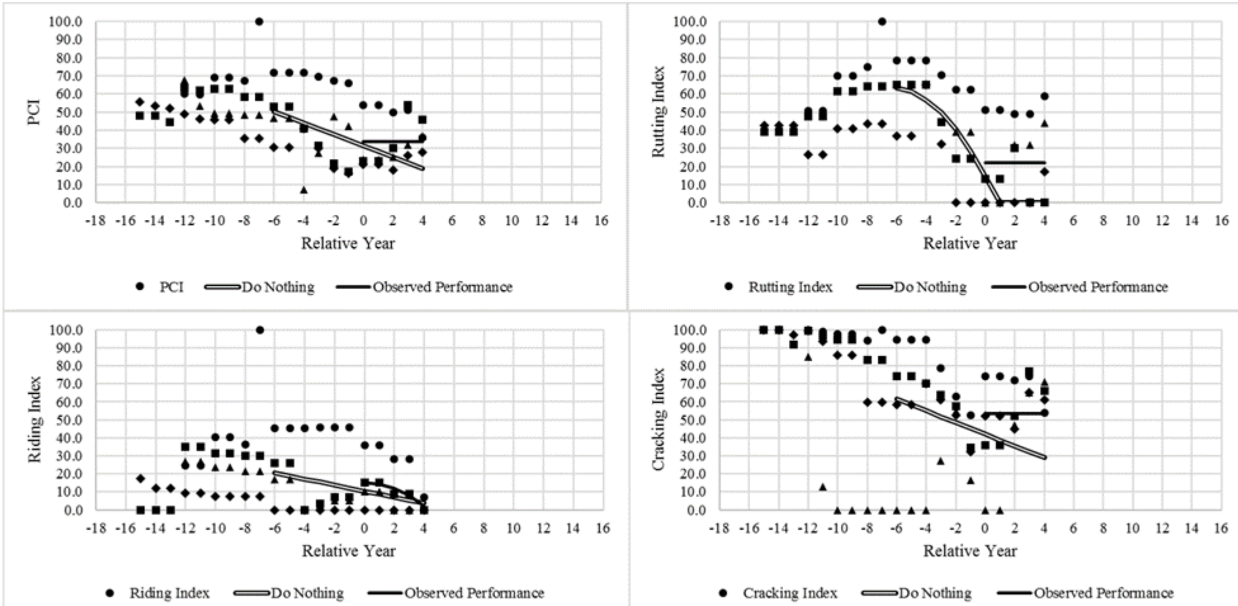


Figure 159. Analytical analysis graphs for project MP-064-6(708)33—76-49

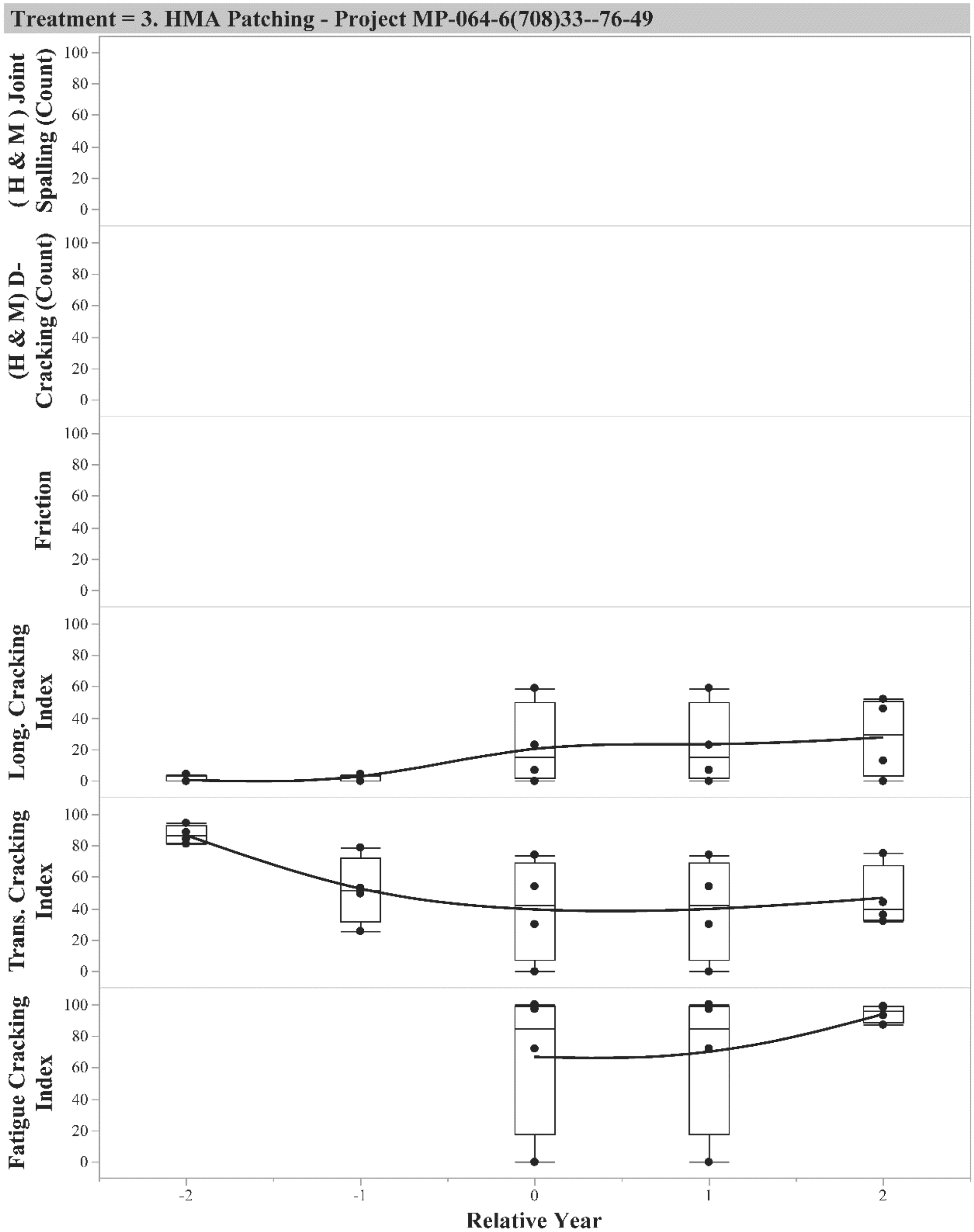


Figure 160. Anecdotal analysis graphs for project MP-064-6(708)33—76-49

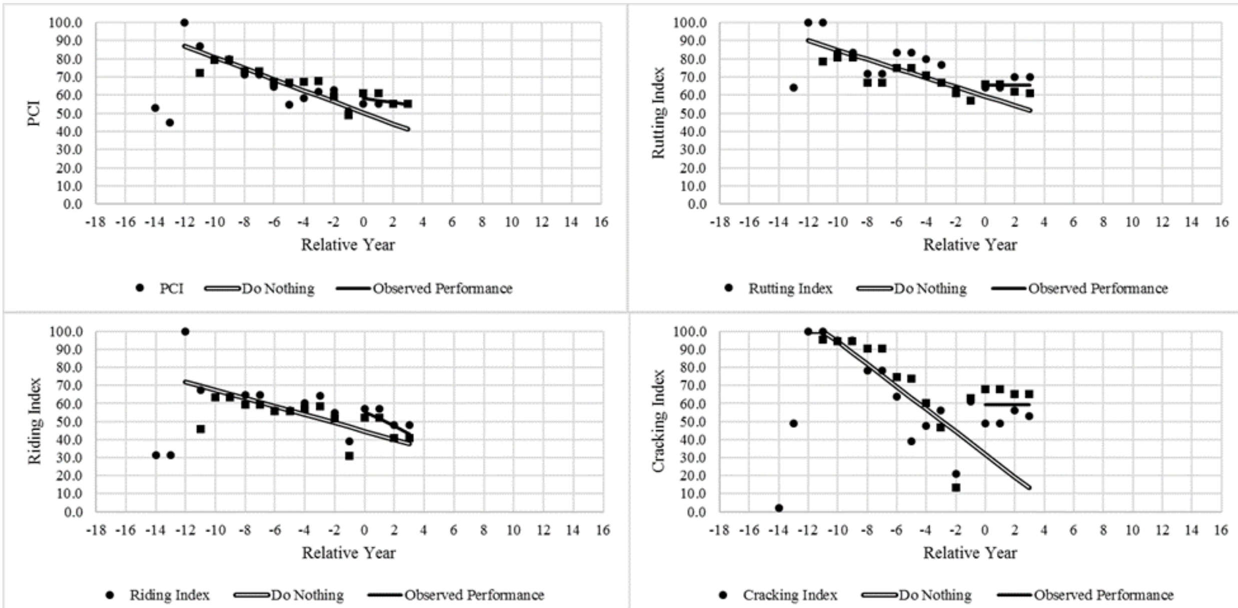


Figure 161. Analytical analysis graphs for project MP-065-1(707)149—76-42

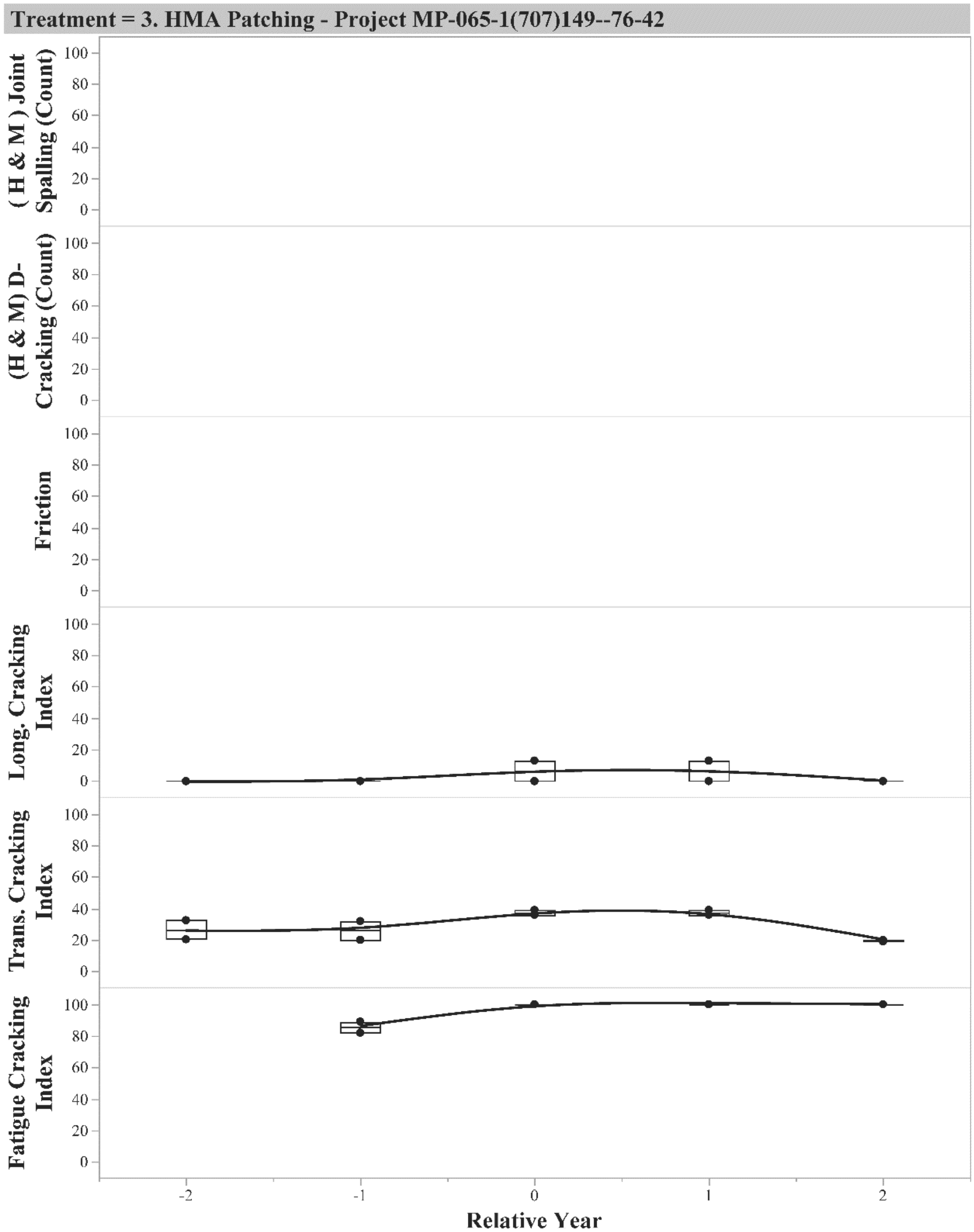


Figure 162. Anecdotal analysis graphs for project MP-065-1(707)149—76-42

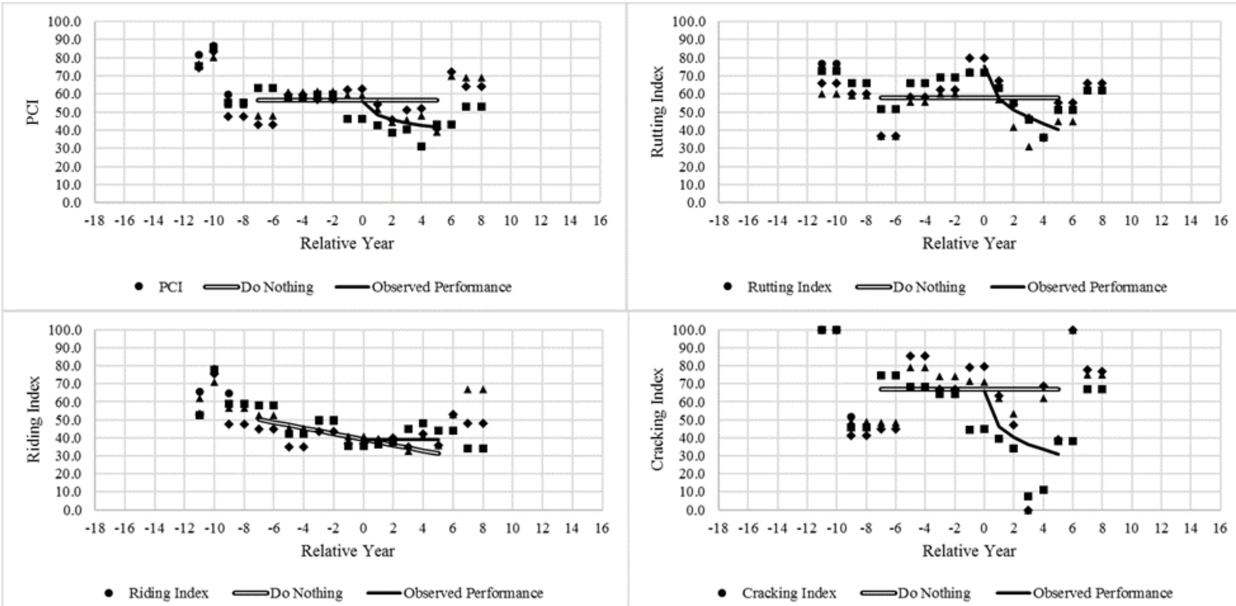


Figure 163. Analytical analysis graphs for project MP-071-3(705)125—76-81

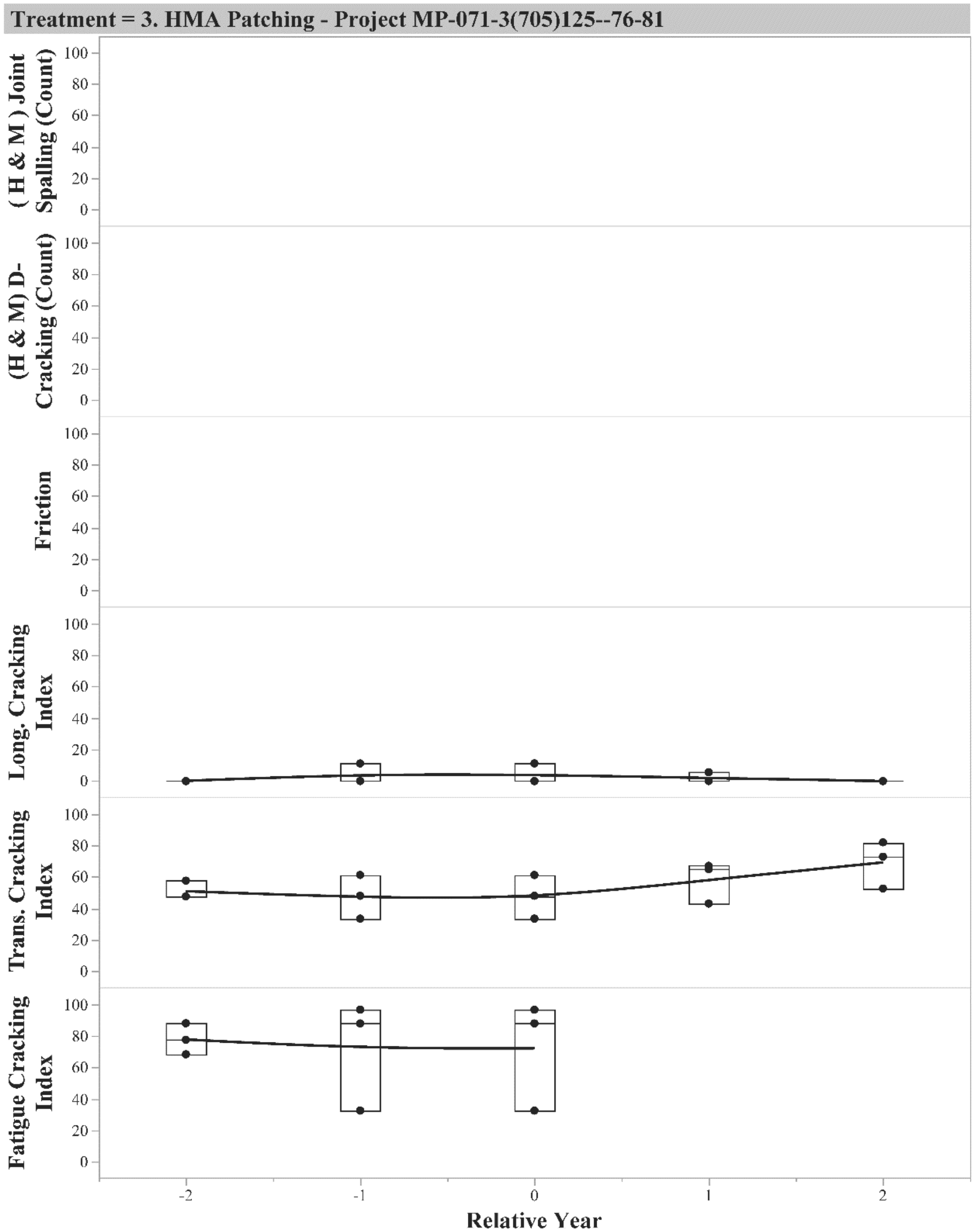


Figure 164. Anecdotal analysis graphs for project MP-071-3(705)125—76-81

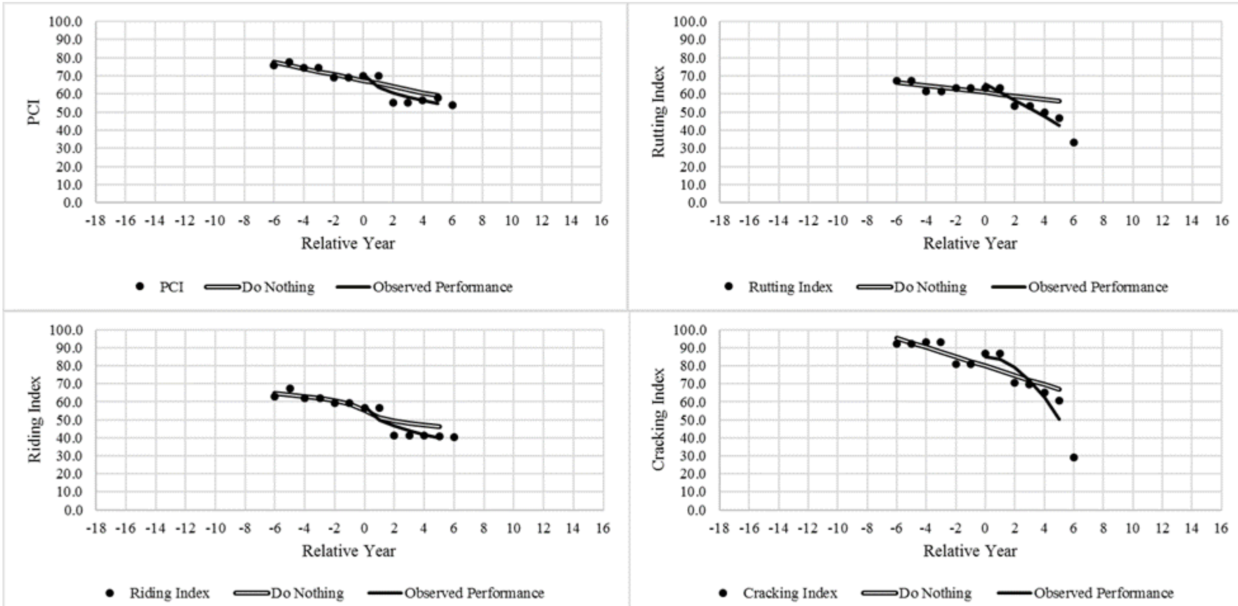


Figure 165. Analytical analysis graphs for project MP-075-3(705)112—76-75

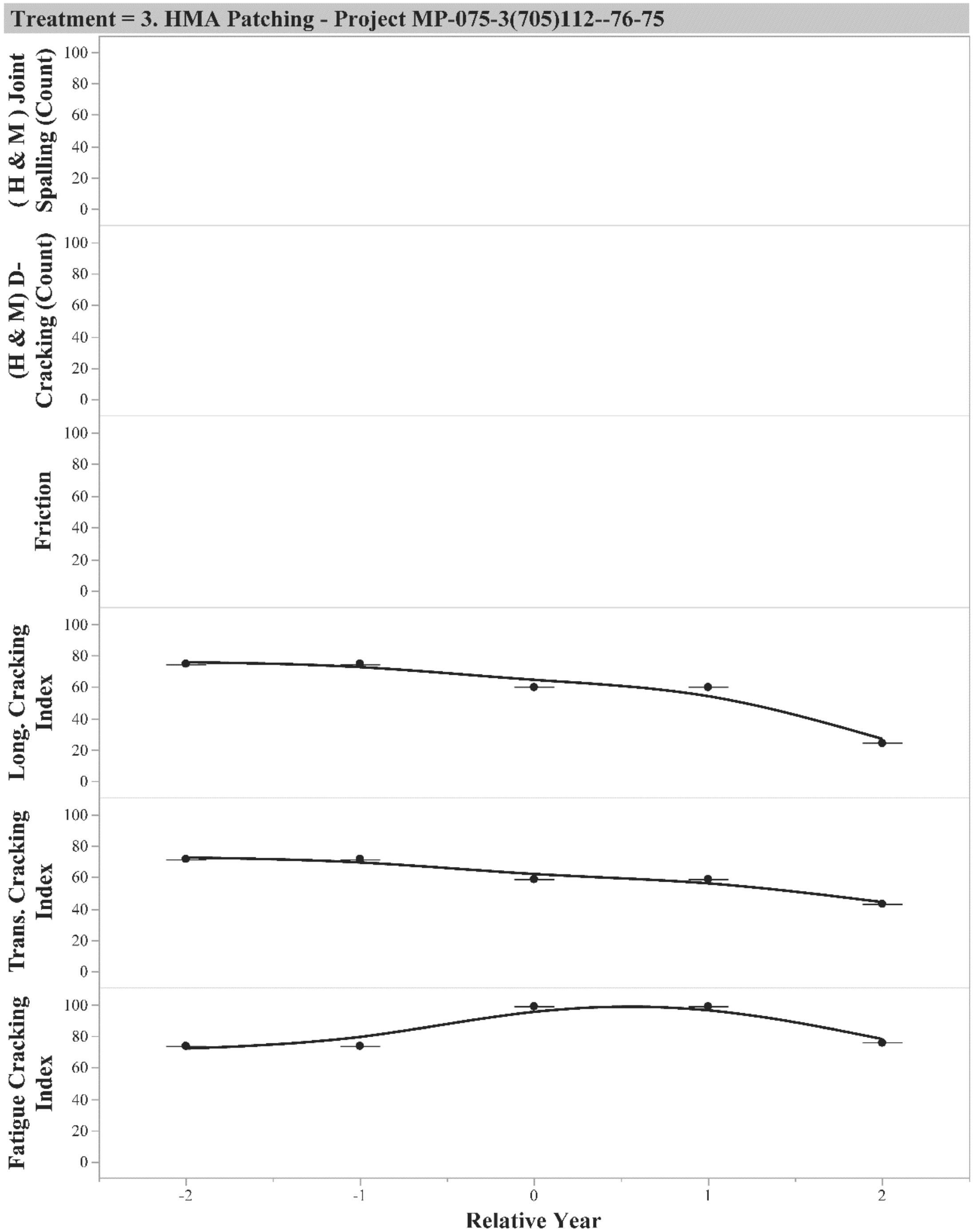


Figure 166. Anecdotal analysis graphs for project MP-075-3(705)112—76-75

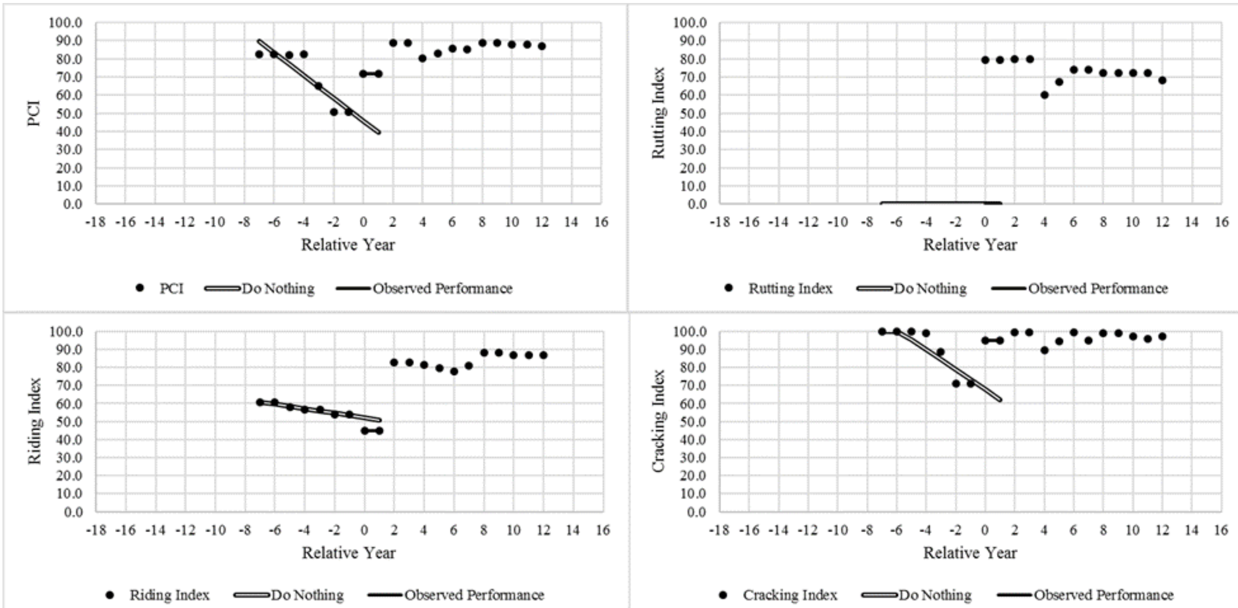


Figure 167. Analytical analysis graphs for project MP-080-6(701)210—76-48

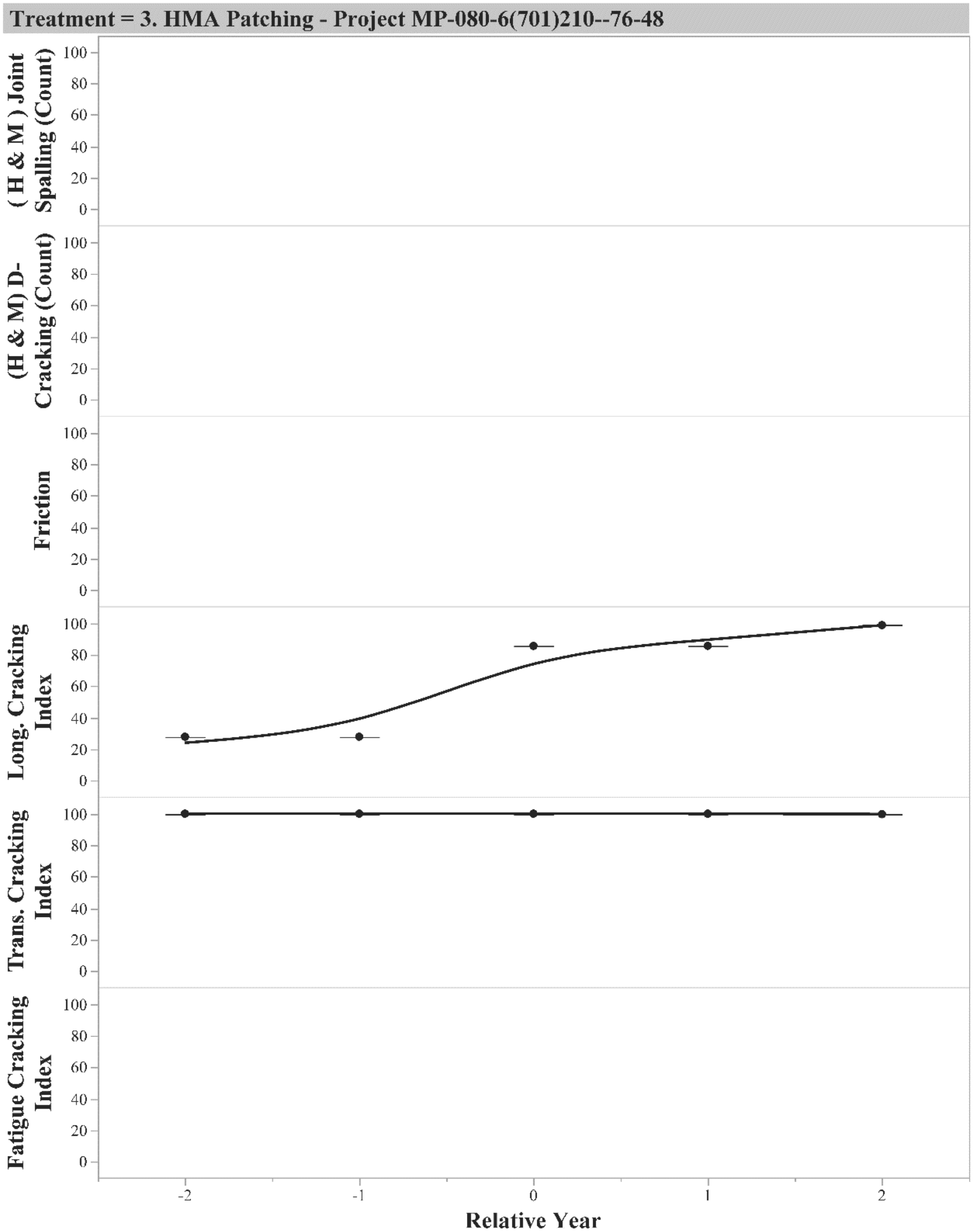


Figure 168. Anecdotal analysis graphs for project MP-080-6(701)210—76-48

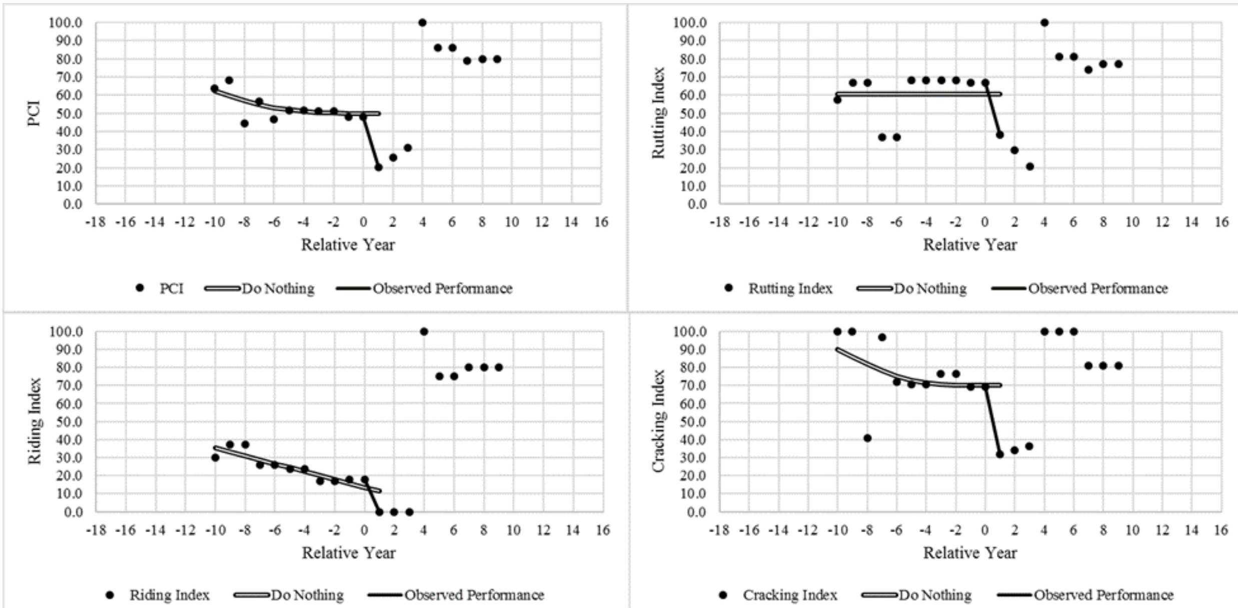


Figure 169. Analytical analysis graphs for project MP-092-5(702)233—76-92

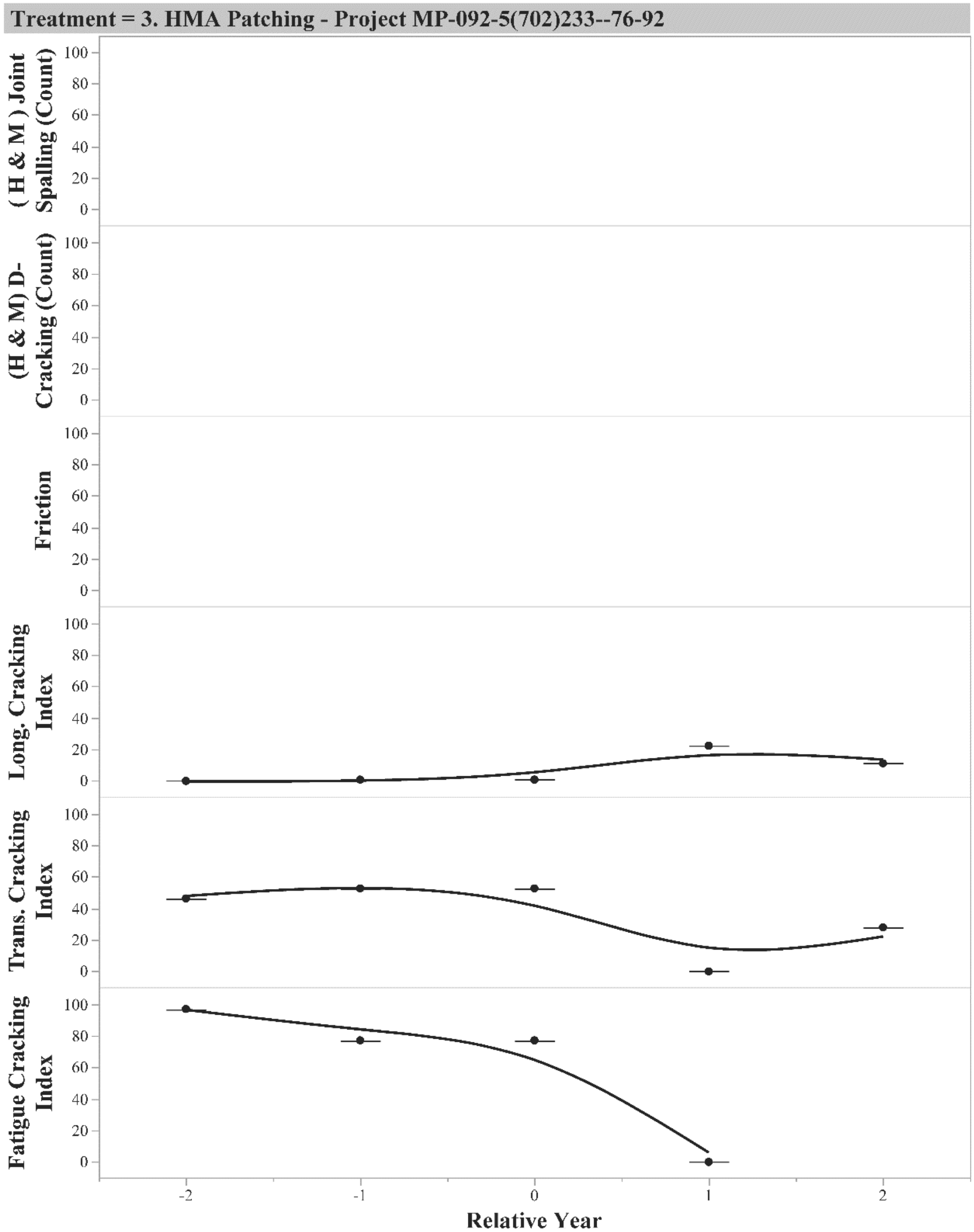


Figure 170. Anecdotal analysis graphs for project MP-092-5(702)233—76-92

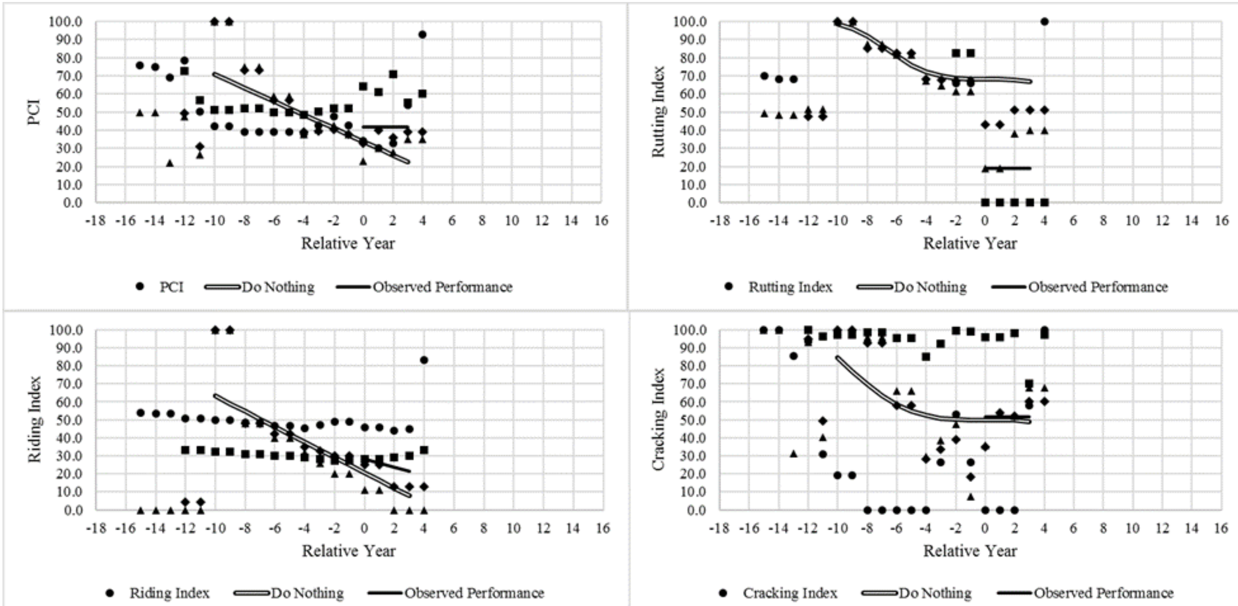


Figure 171. Analytical analysis graphs for project MP-092-5(704)194—76-54

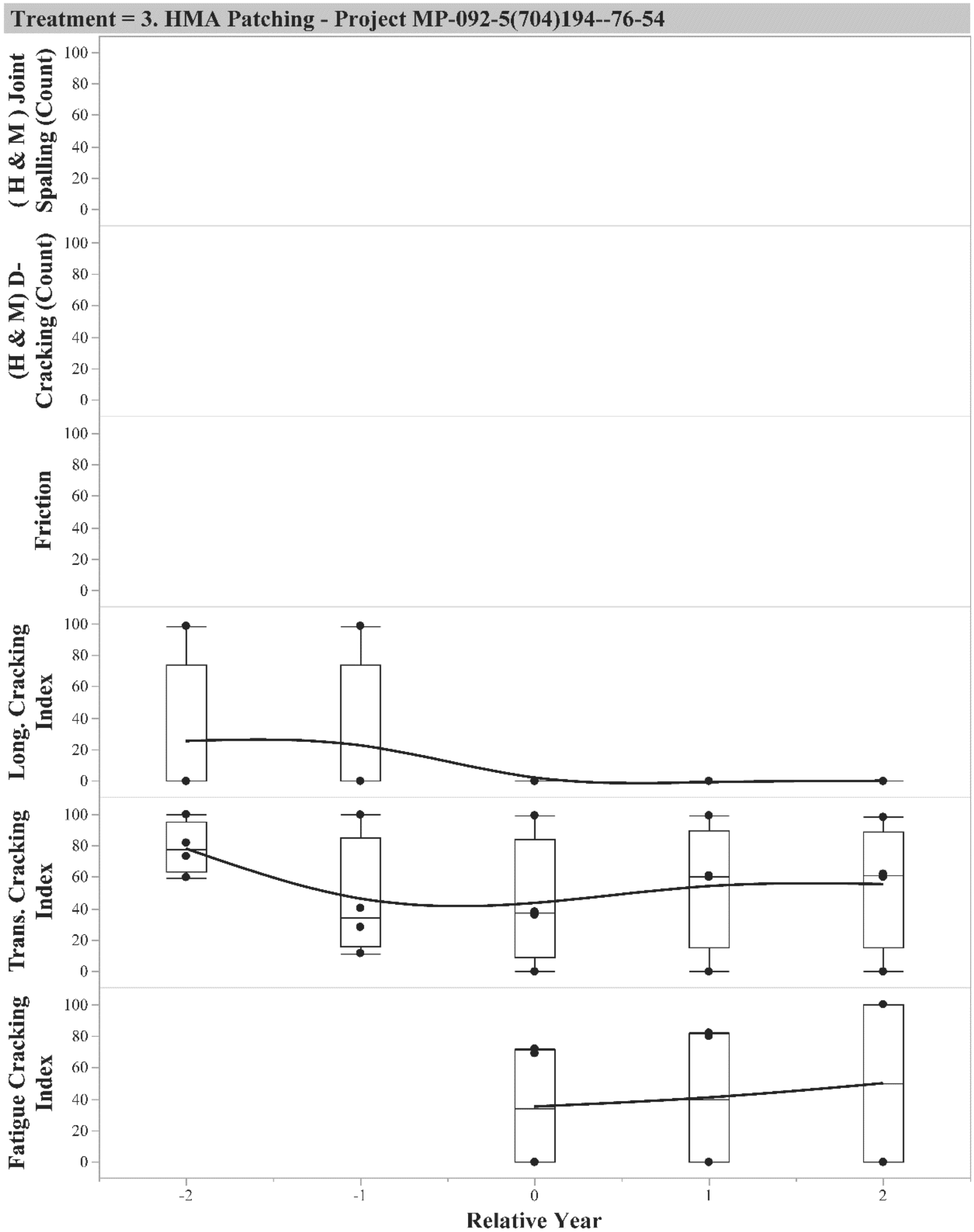


Figure 172. Anecdotal analysis graphs for project MP-092-5(704)194—76-54

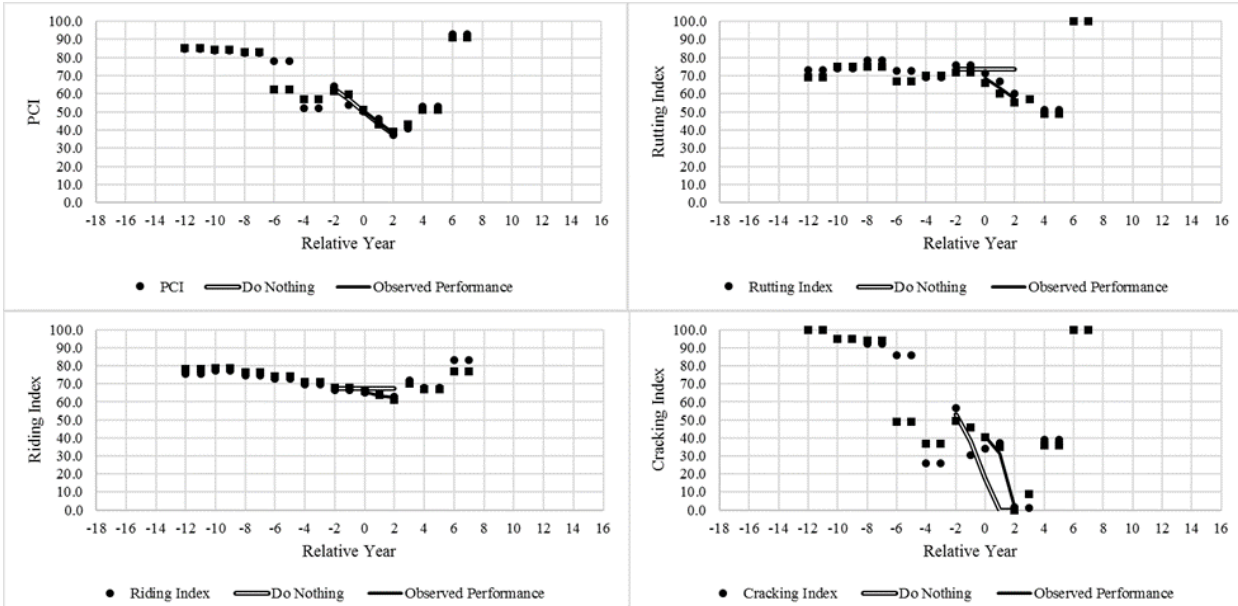


Figure 173. Analytical analysis graphs for project MP-096-1(702)0—76-64

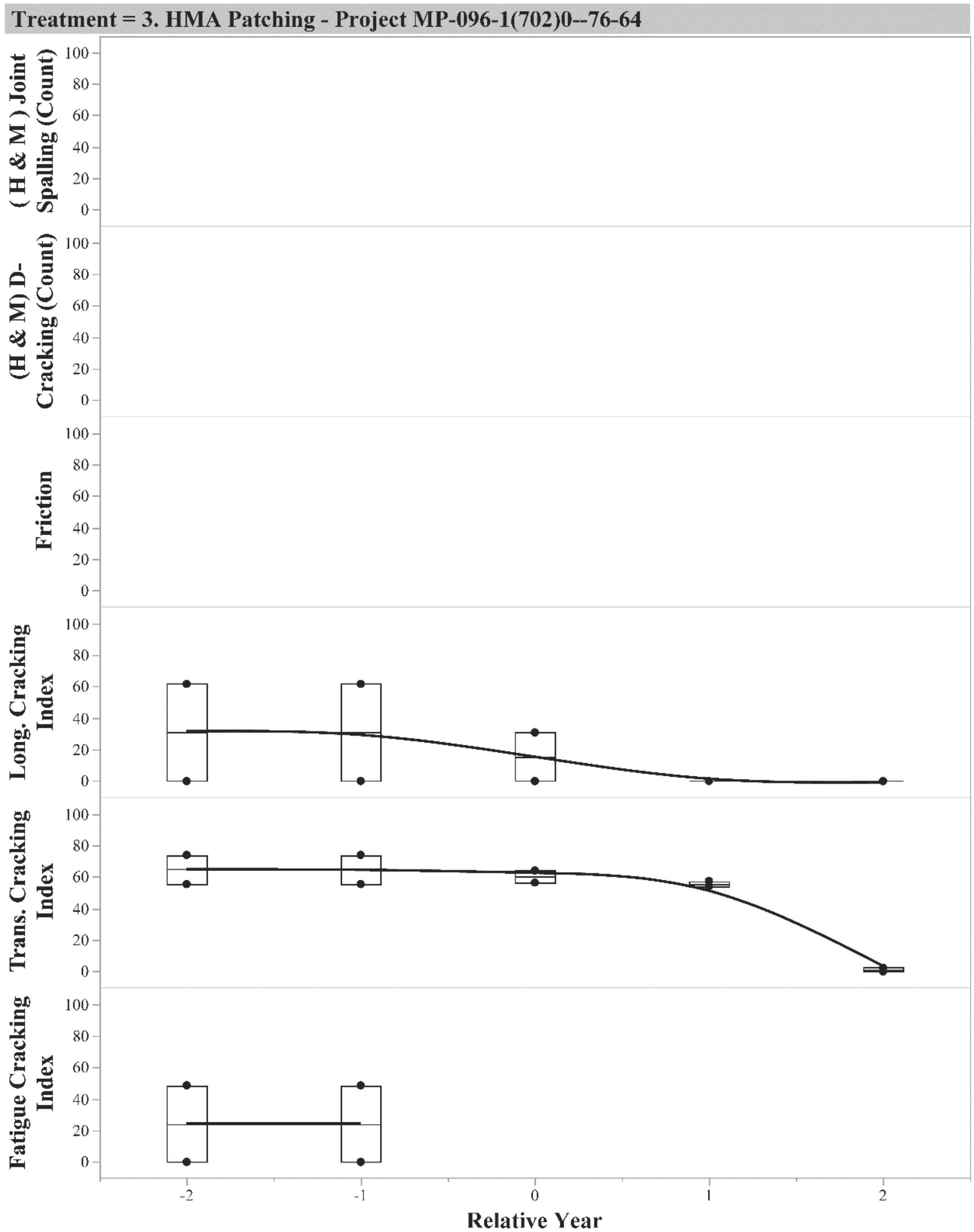


Figure 174. Anecdotal analysis graphs for project MP-096-1(702)0—76-64

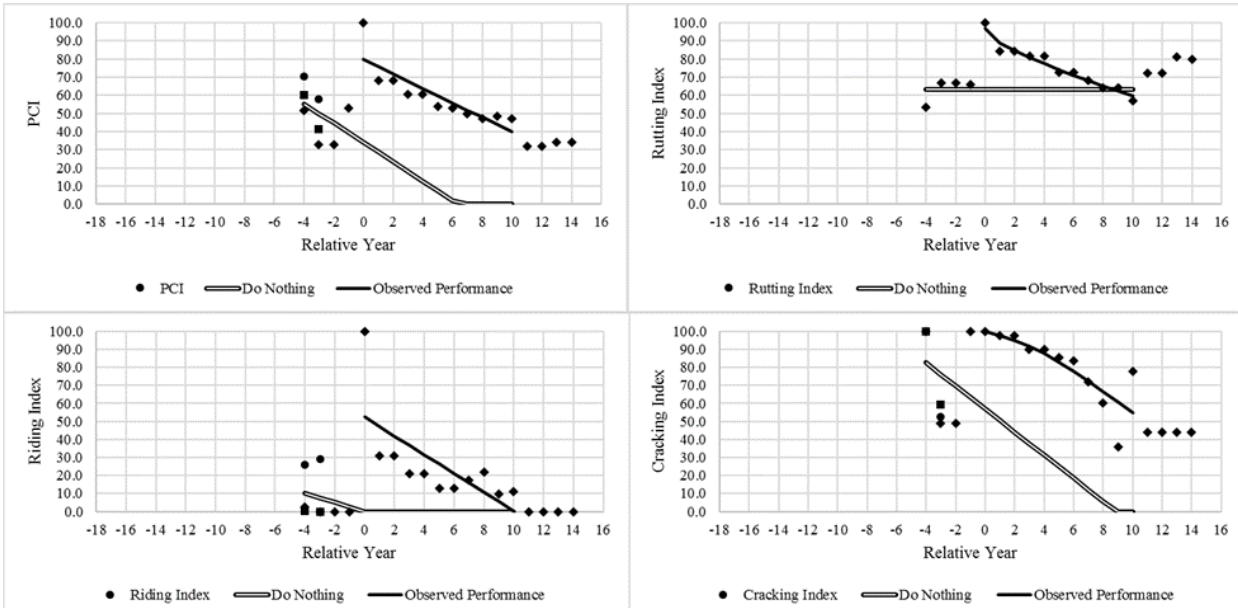


Figure 175. Analytical analysis graphs for project MP-122-2(701)7--76-17

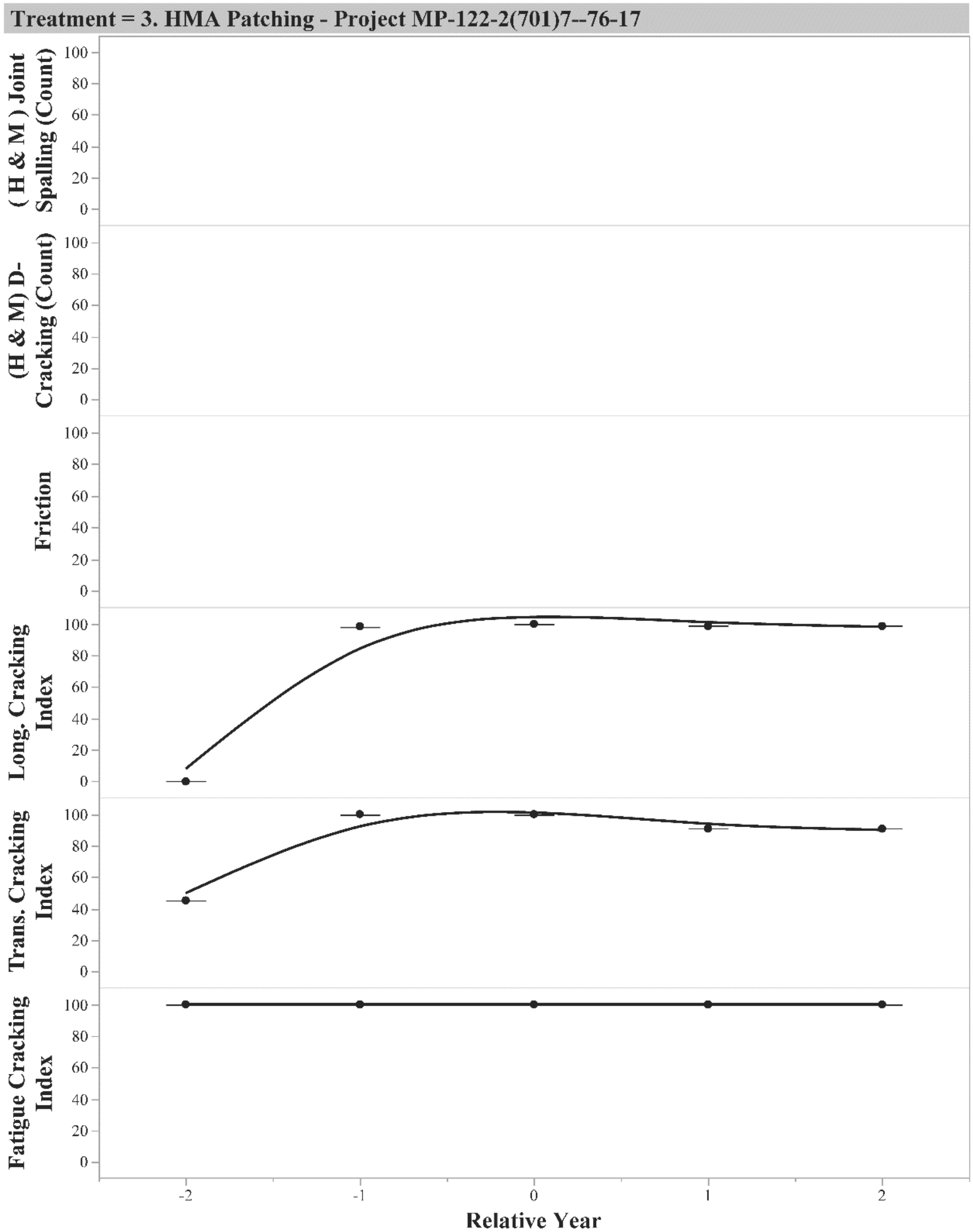


Figure 176. Anecdotal analysis graphs for project MP-122-2(701)7—76-17

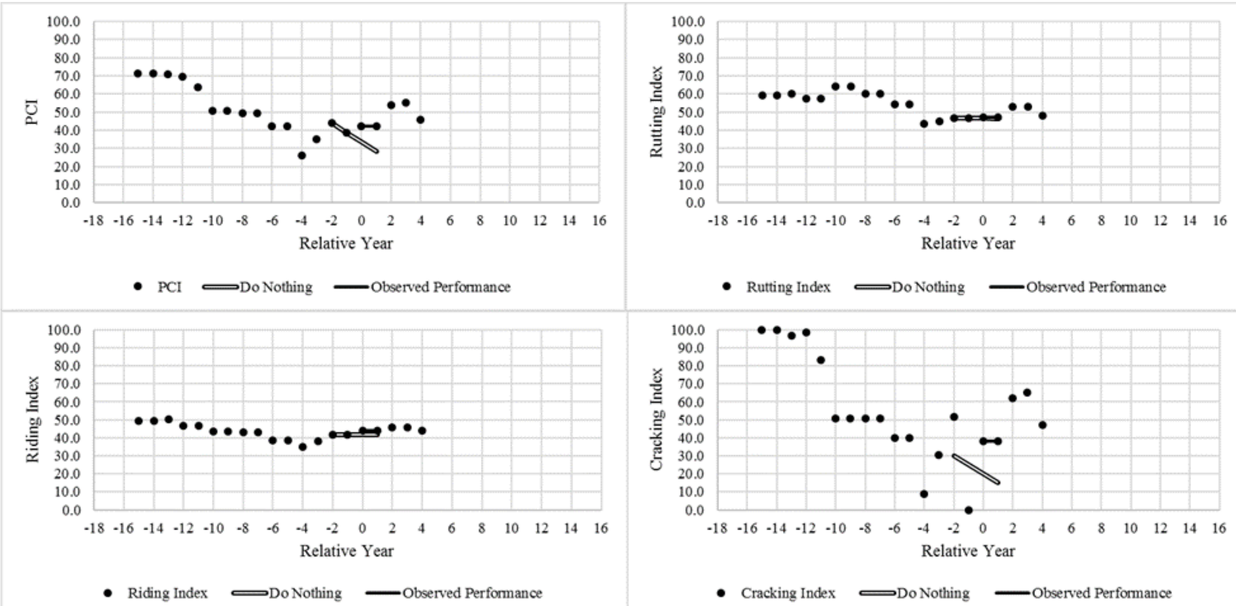


Figure 177. Analytical analysis graphs for project MP-149-6(707)46—76-54

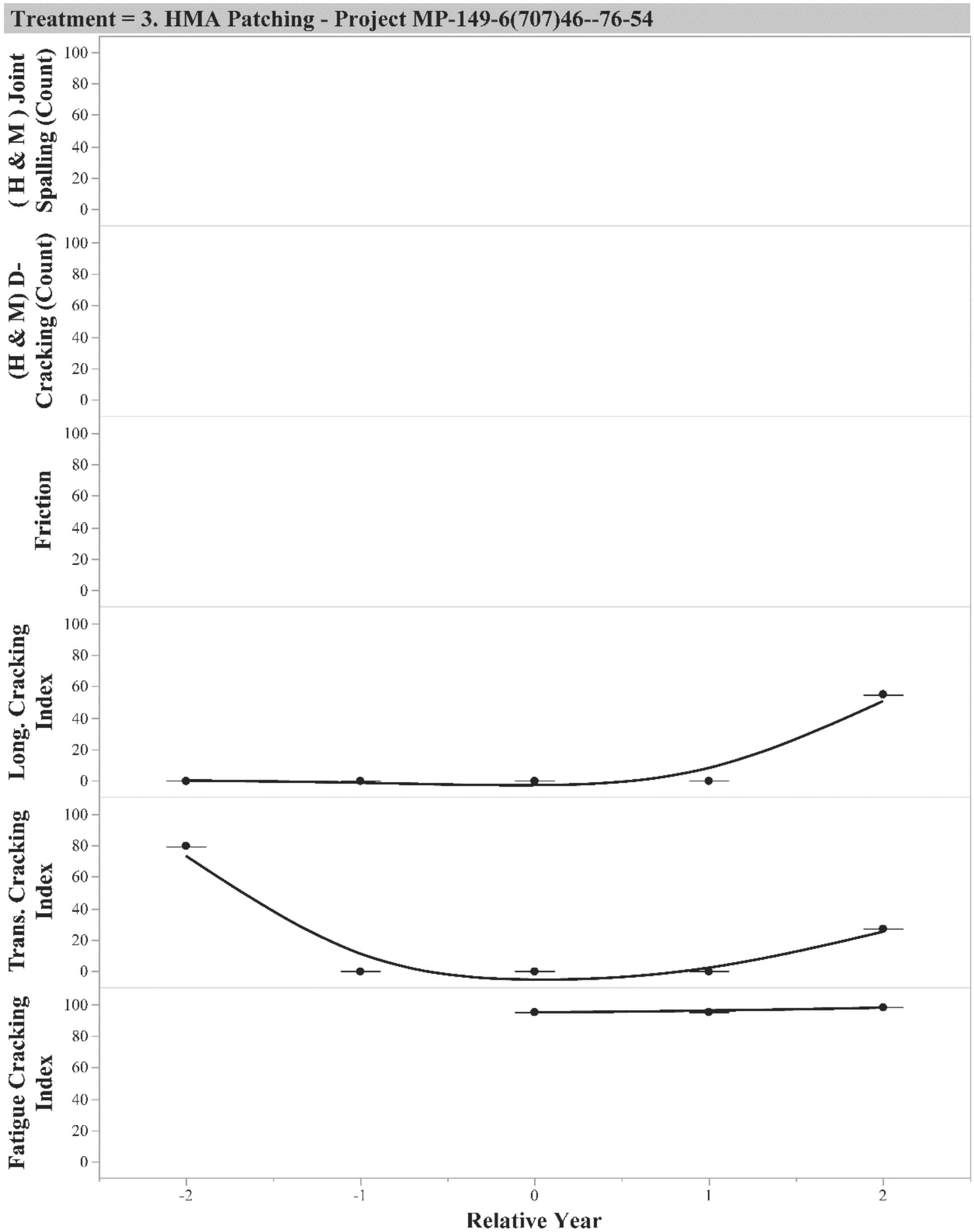


Figure 178. Anecdotal analysis graphs for project MP-149-6(707)46—76-54

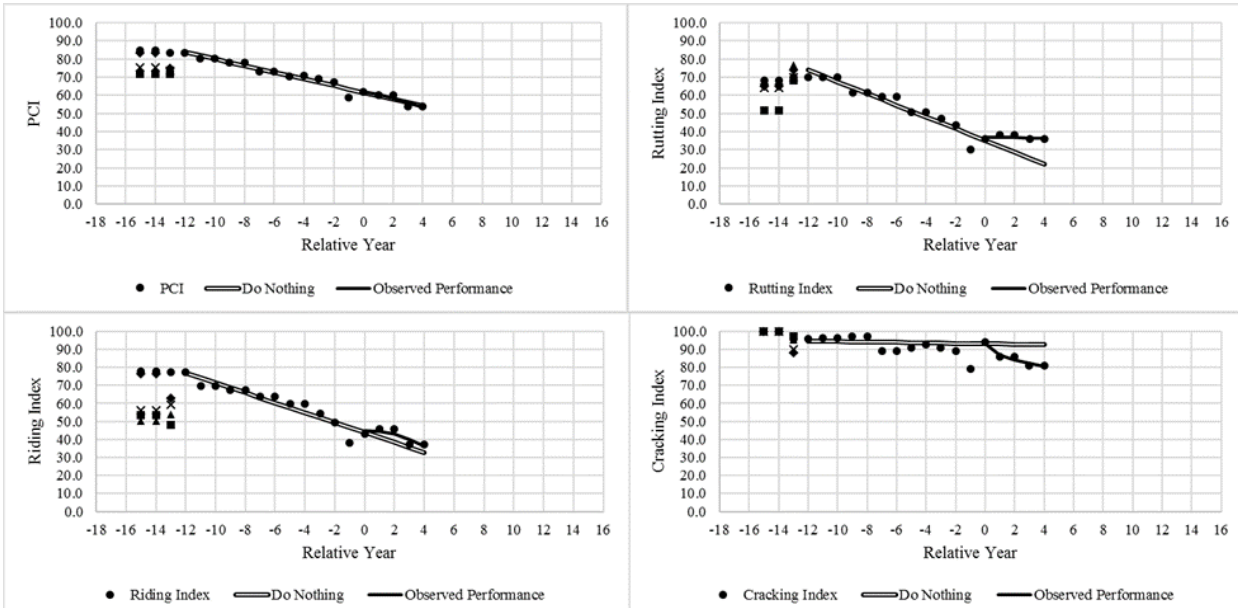
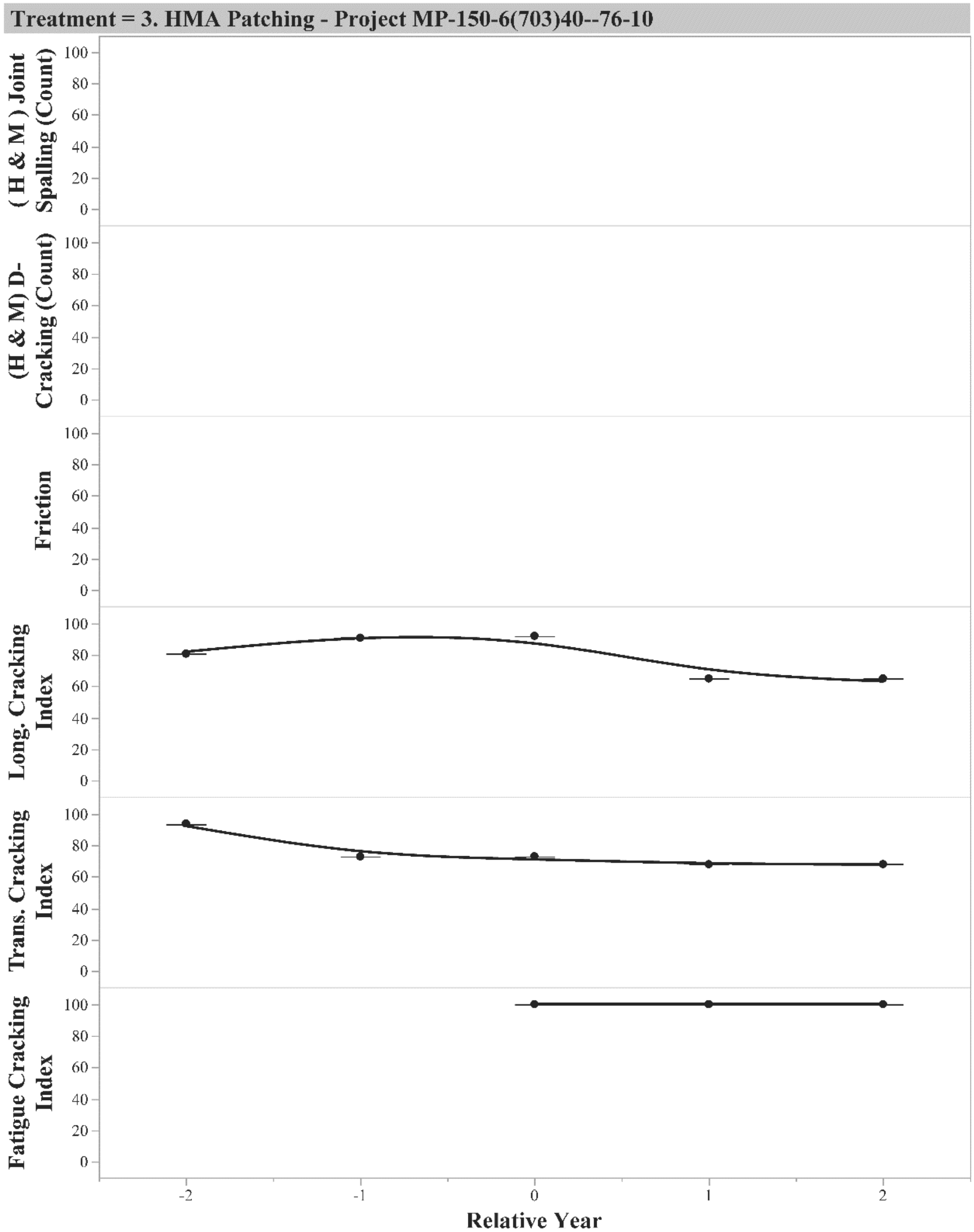


Figure 179. Analytical analysis graphs for project MP-150-6(703)40—76-10



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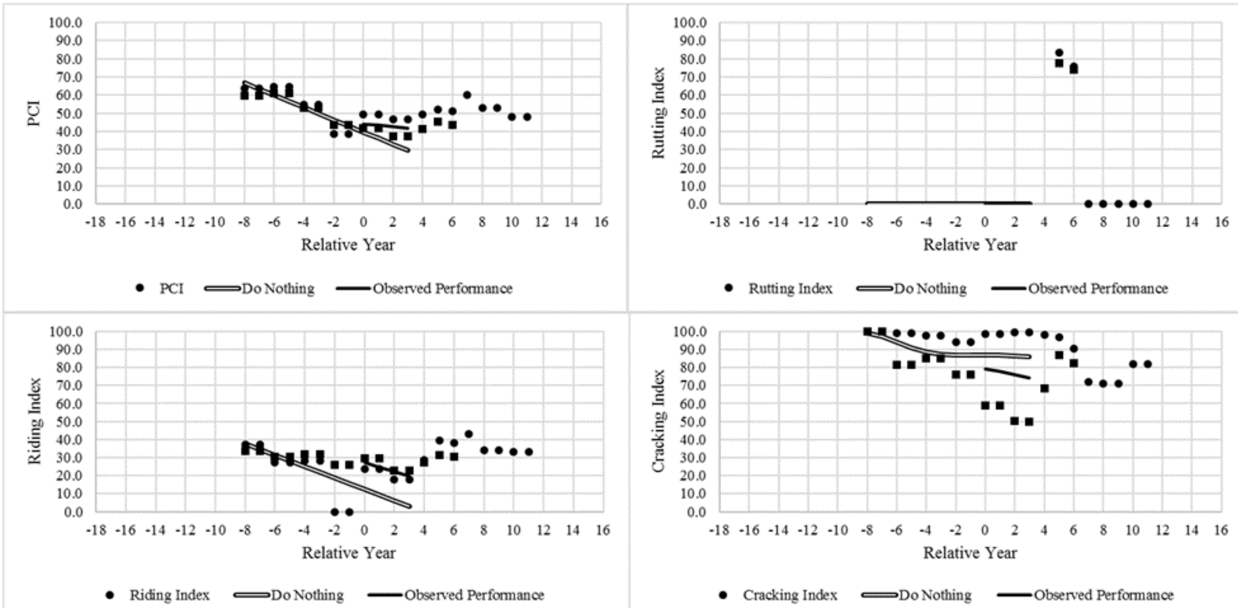


Figure 181. Analytical analysis graphs for project MP-175-1(704)188—76-42

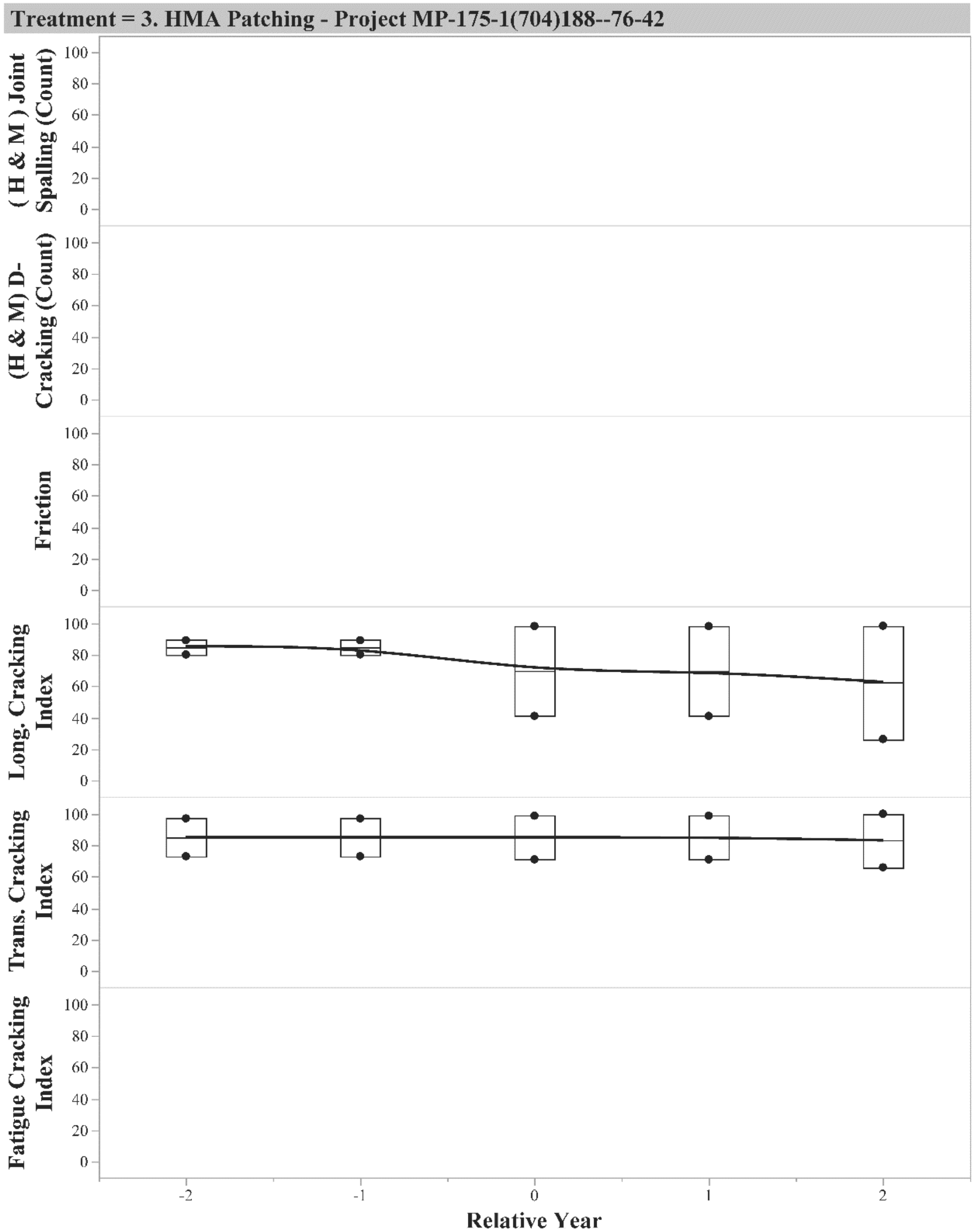


Figure 182. Anecdotal analysis graphs for project MP-175-1(704)188—76-42

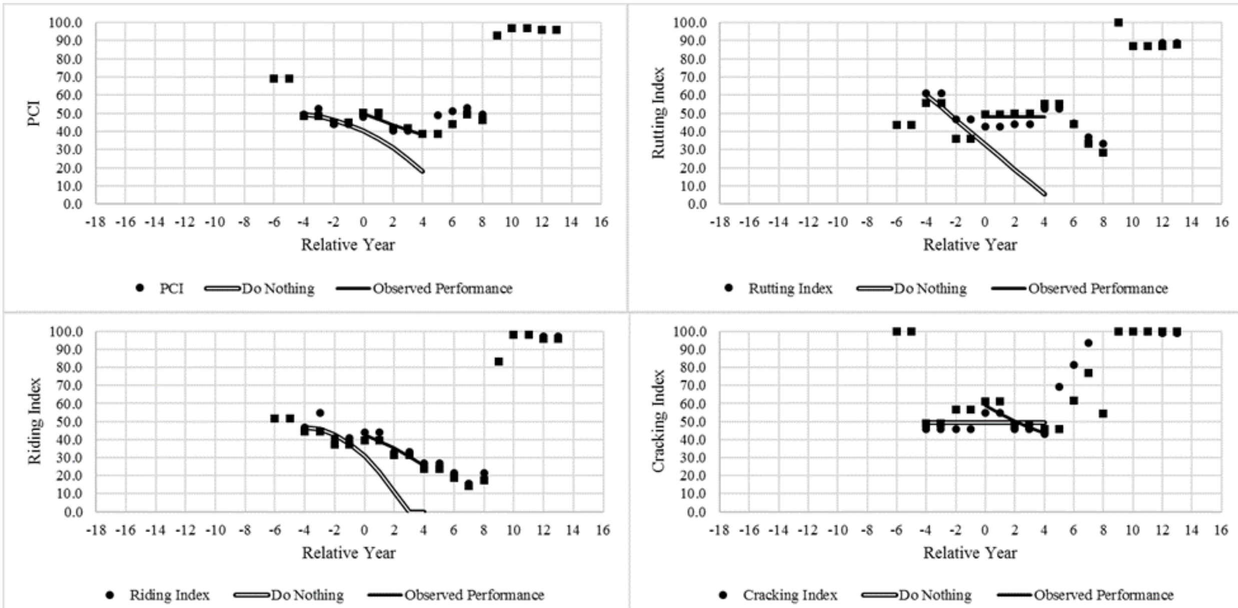
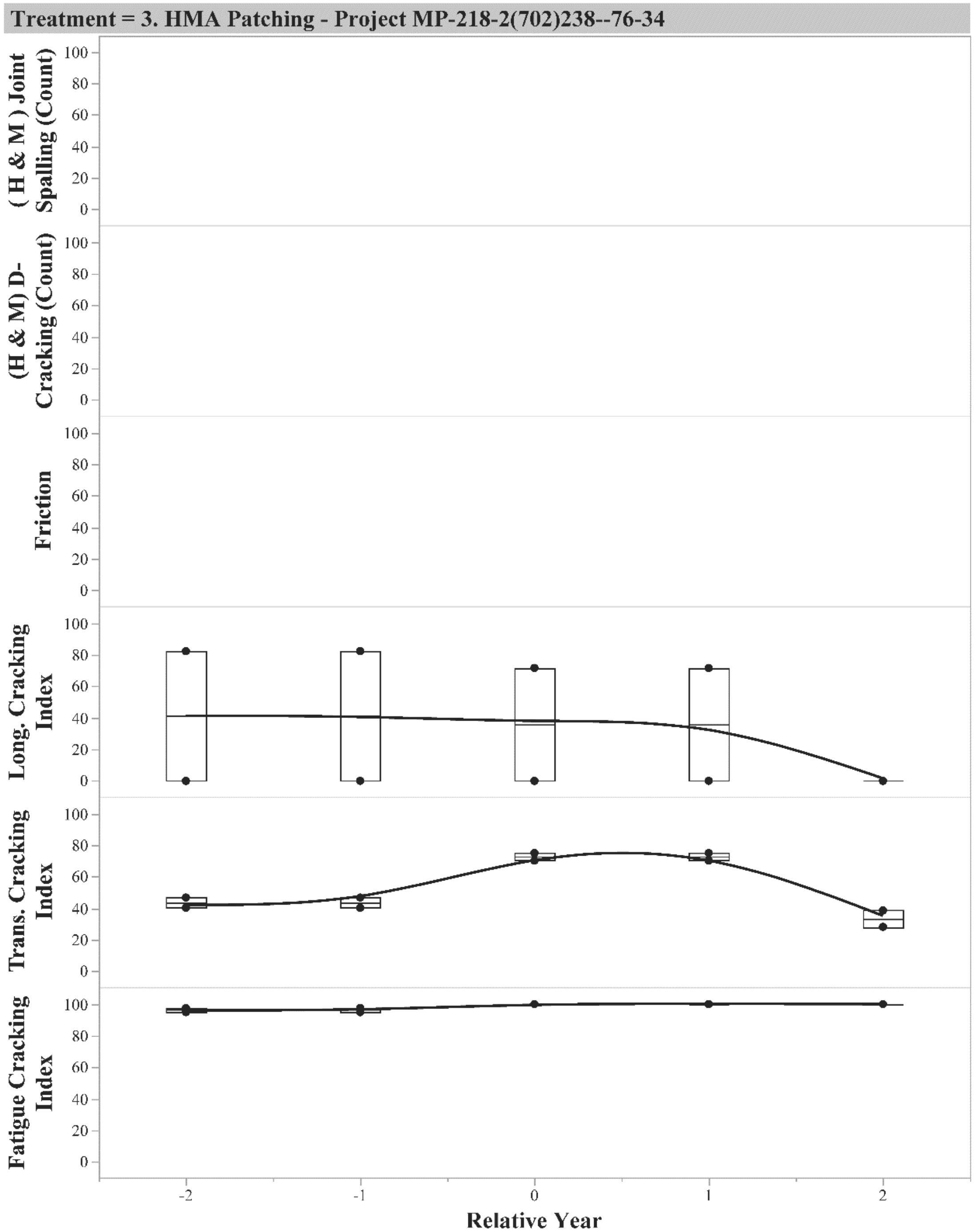


Figure 183. Analytical analysis graphs for project MP-218-2(702)238—76-34



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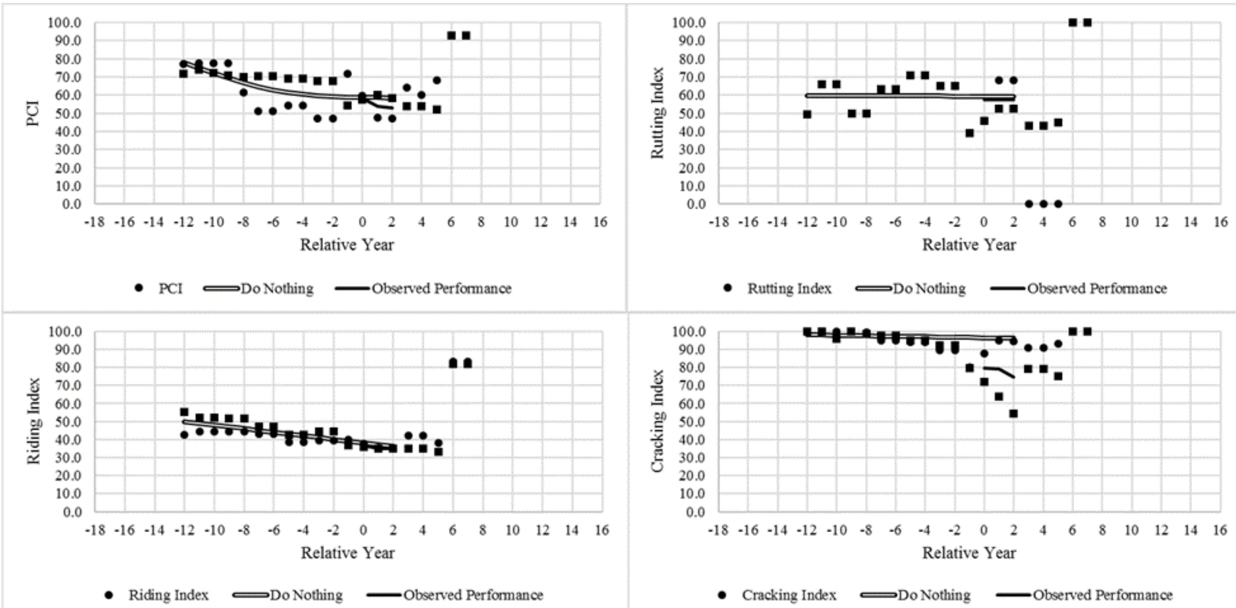


Figure 185. Analytical analysis graphs for project MP-415-1(707)8—76-77

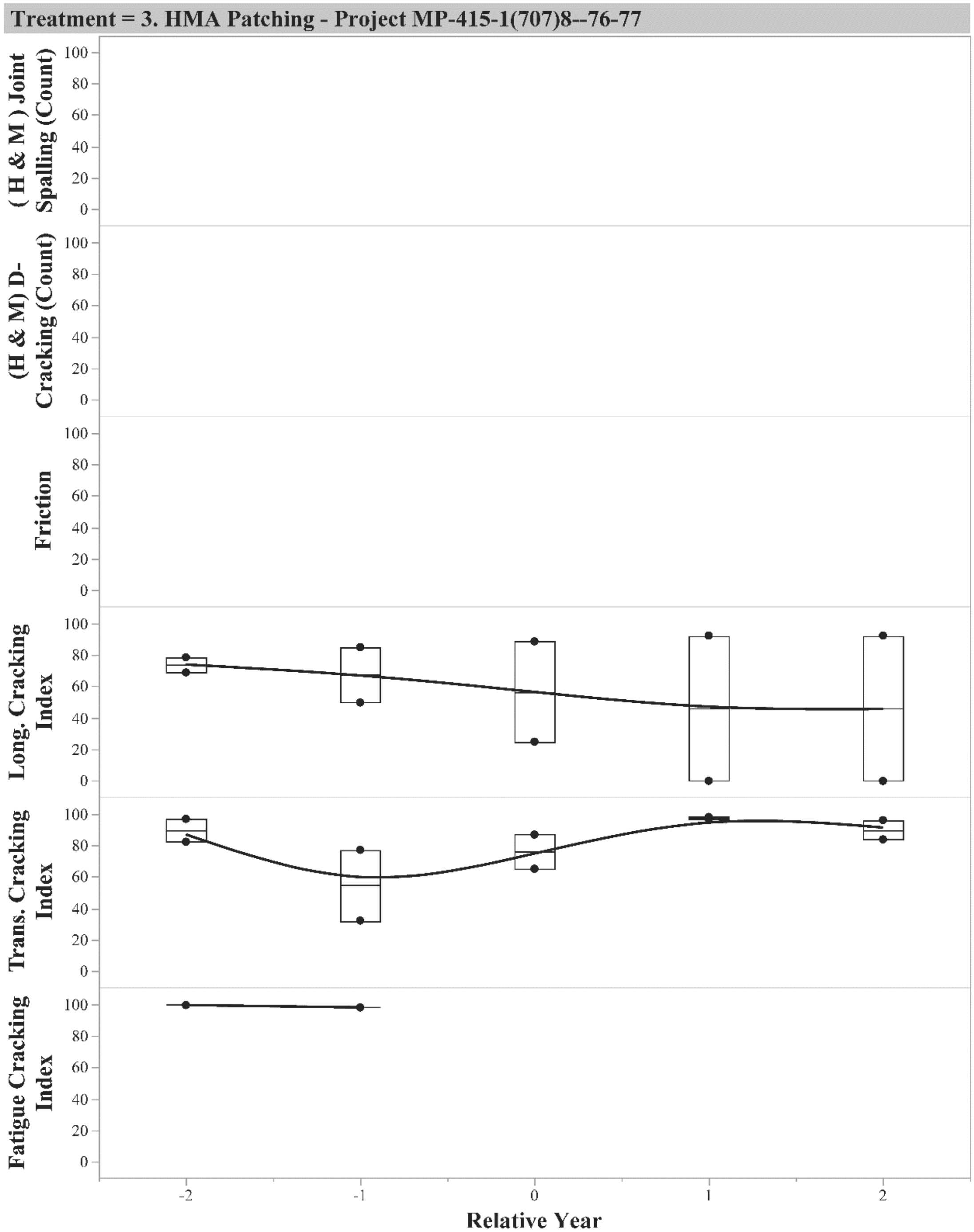


Figure 186. Anecdotal analysis graphs for project MP-415-1(707)8—76-77

Crack Sealing/Filling Projects

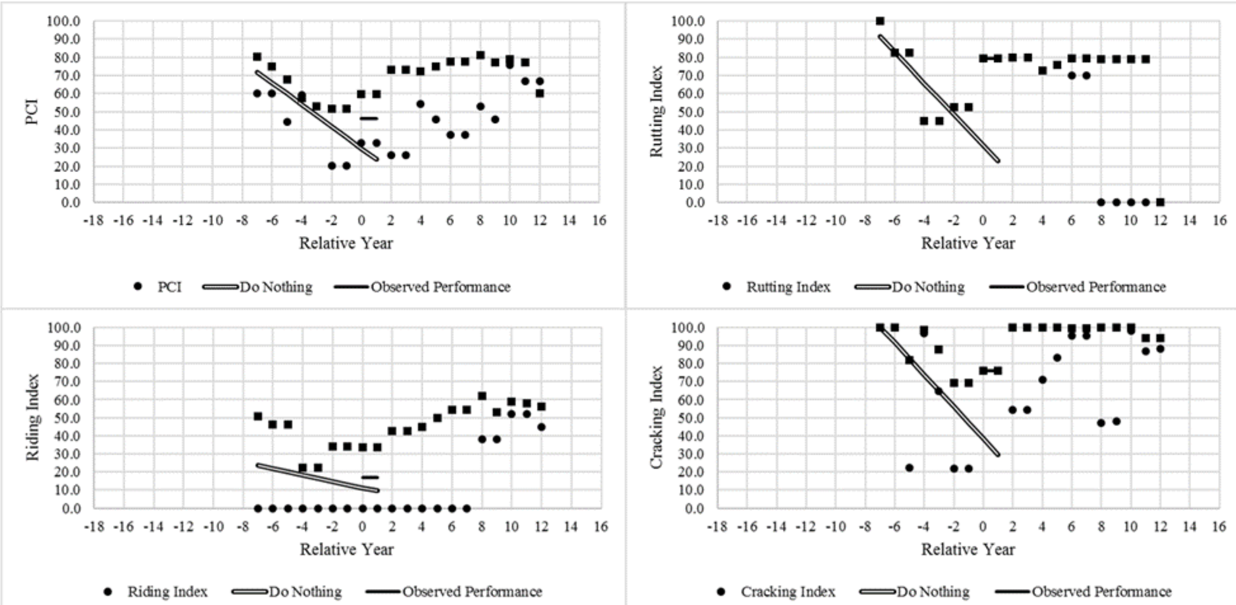
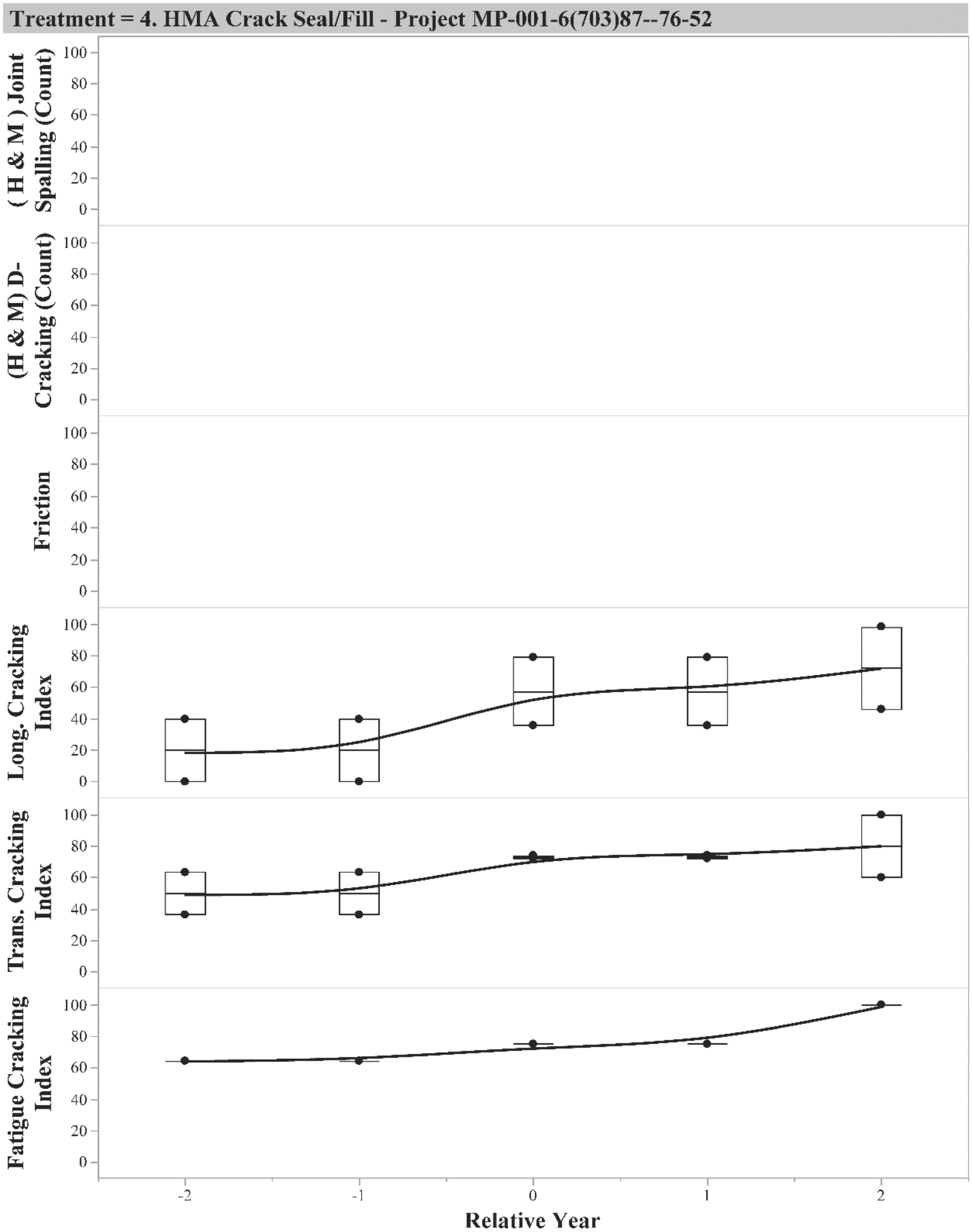


Figure 187. Analytical analysis graphs for project MP-001-6(703)87—76-52



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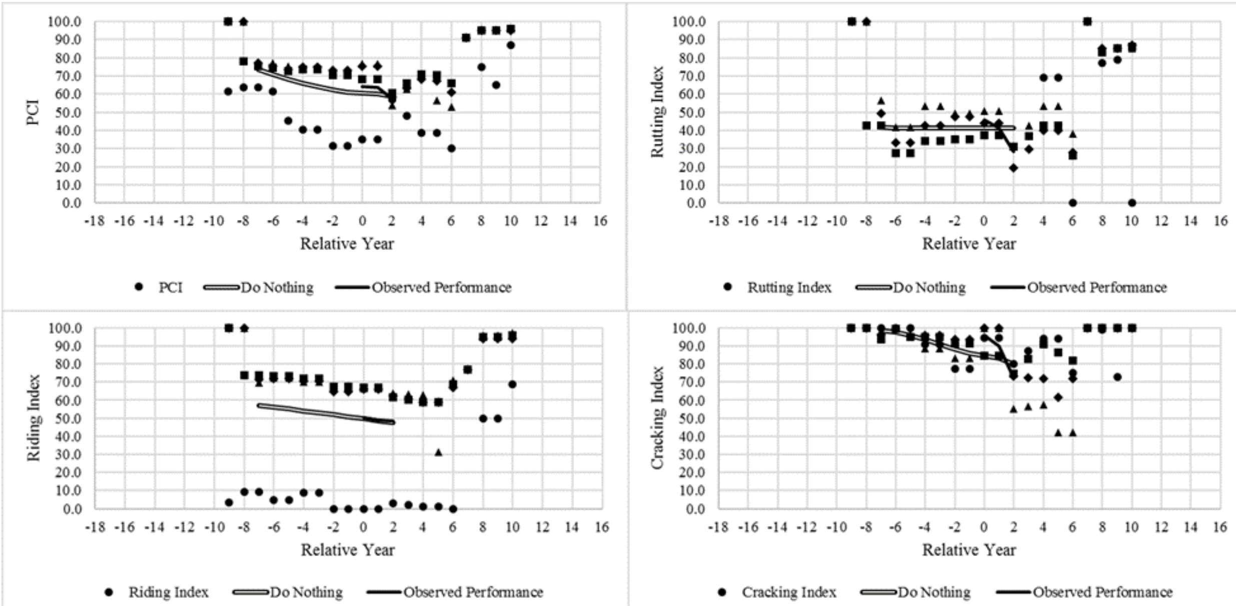


Figure 189. Analytical analysis graphs for project MP-001-6(704)68—76-92

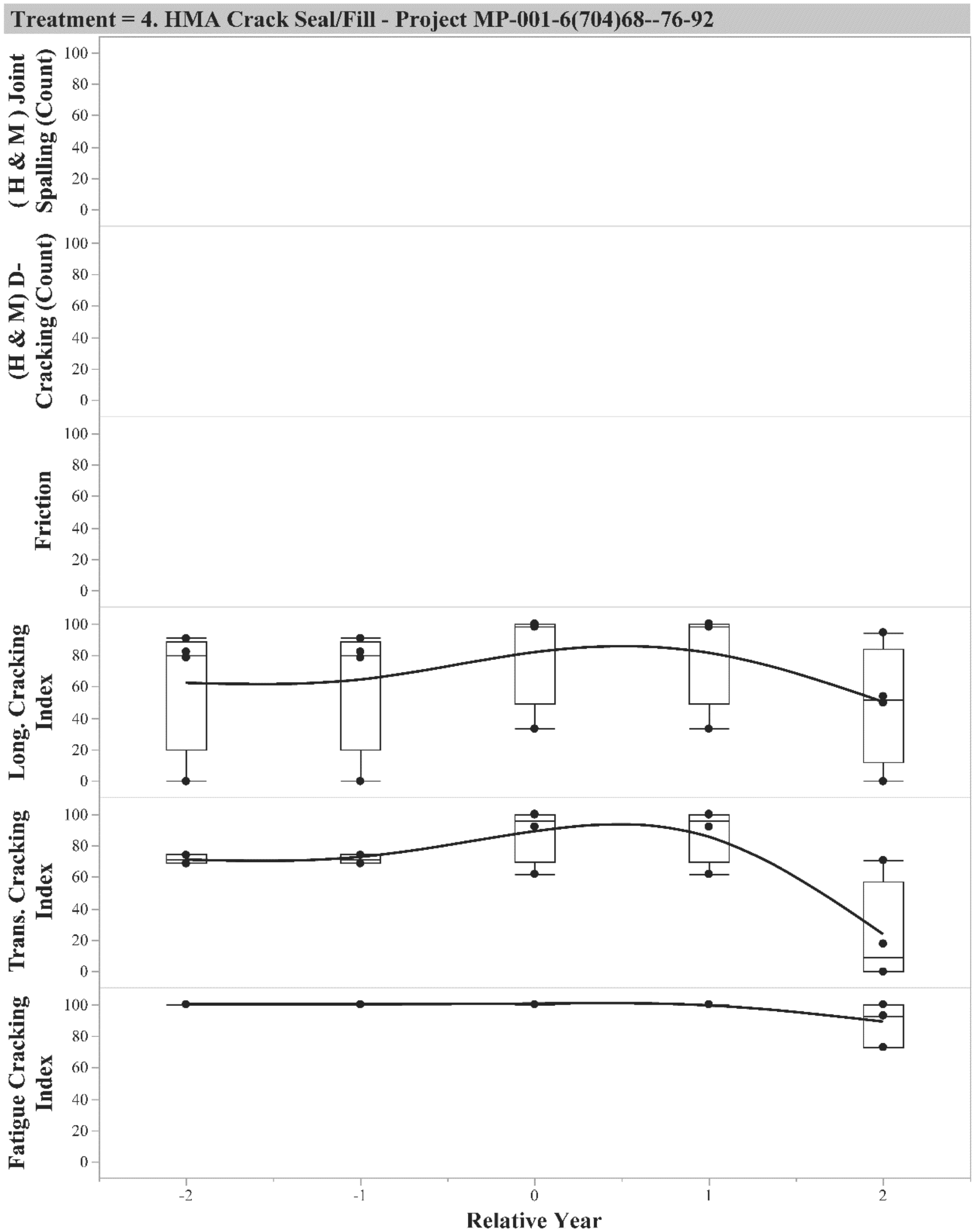


Figure 190. Anecdotal analysis graphs for project MP-001-6(704)68—76-92

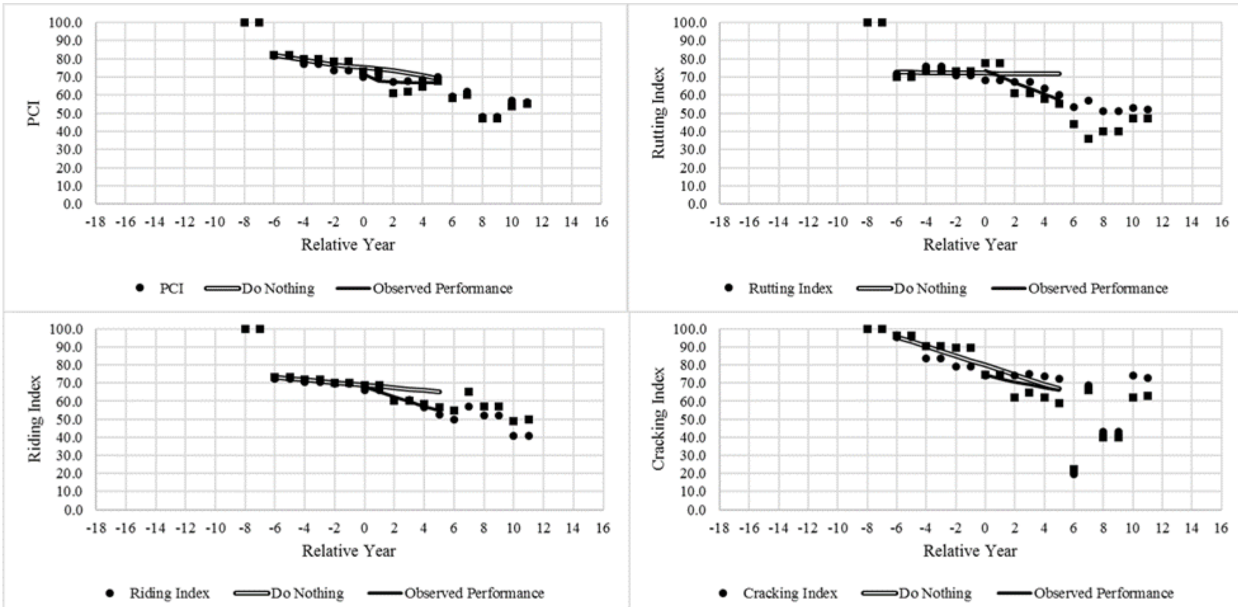


Figure 191. Analytical analysis graphs for project MP-003-2(705)210—76-12

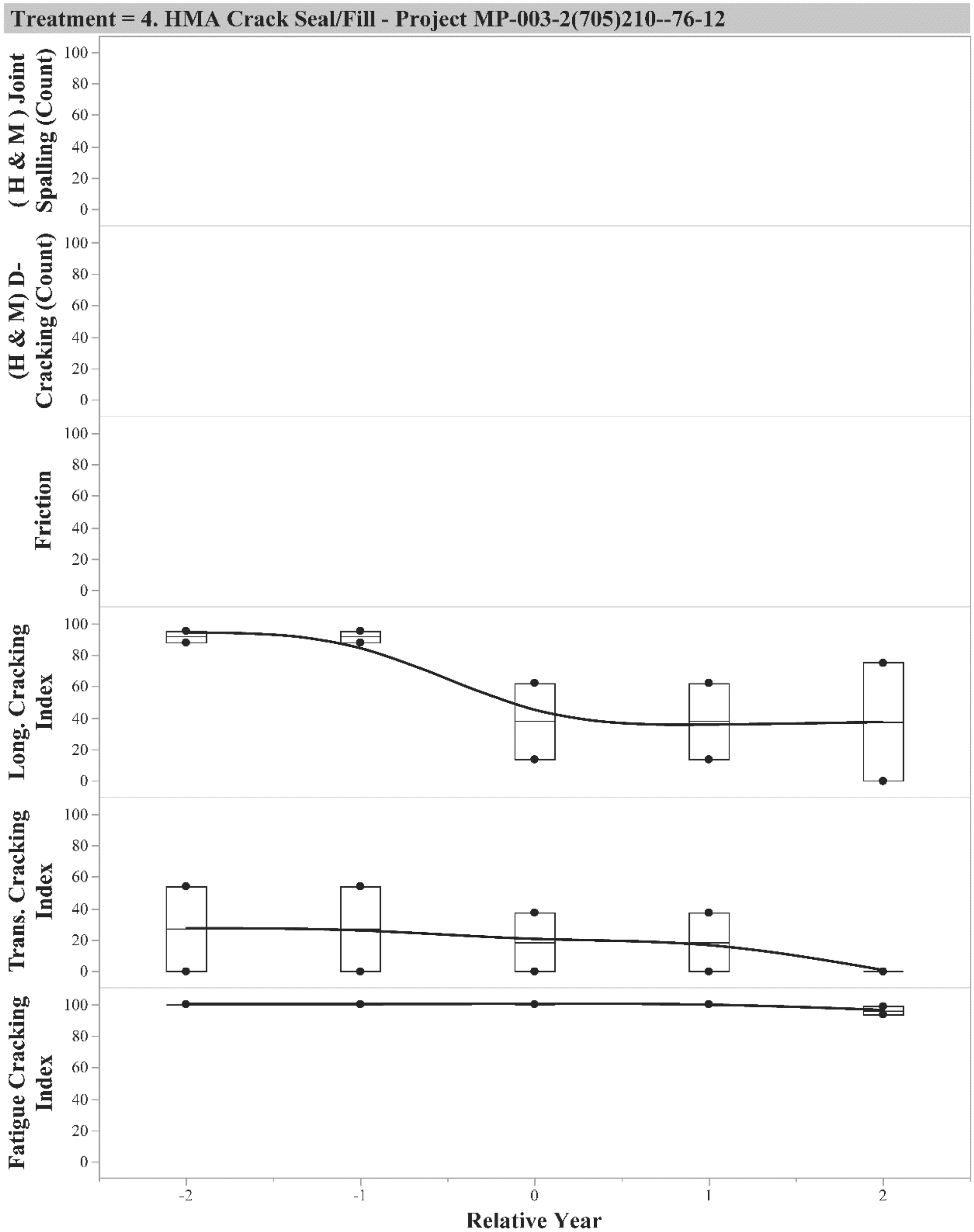


Figure 192. Anecdotal analysis graphs for project MP-003-2(705)210—76-12

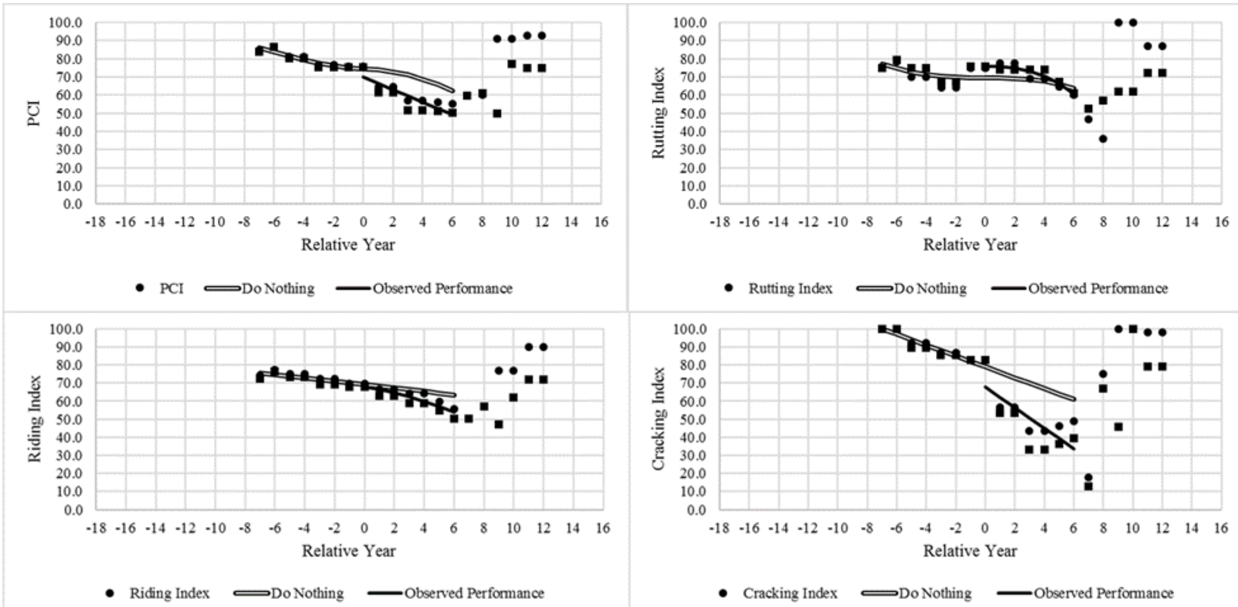
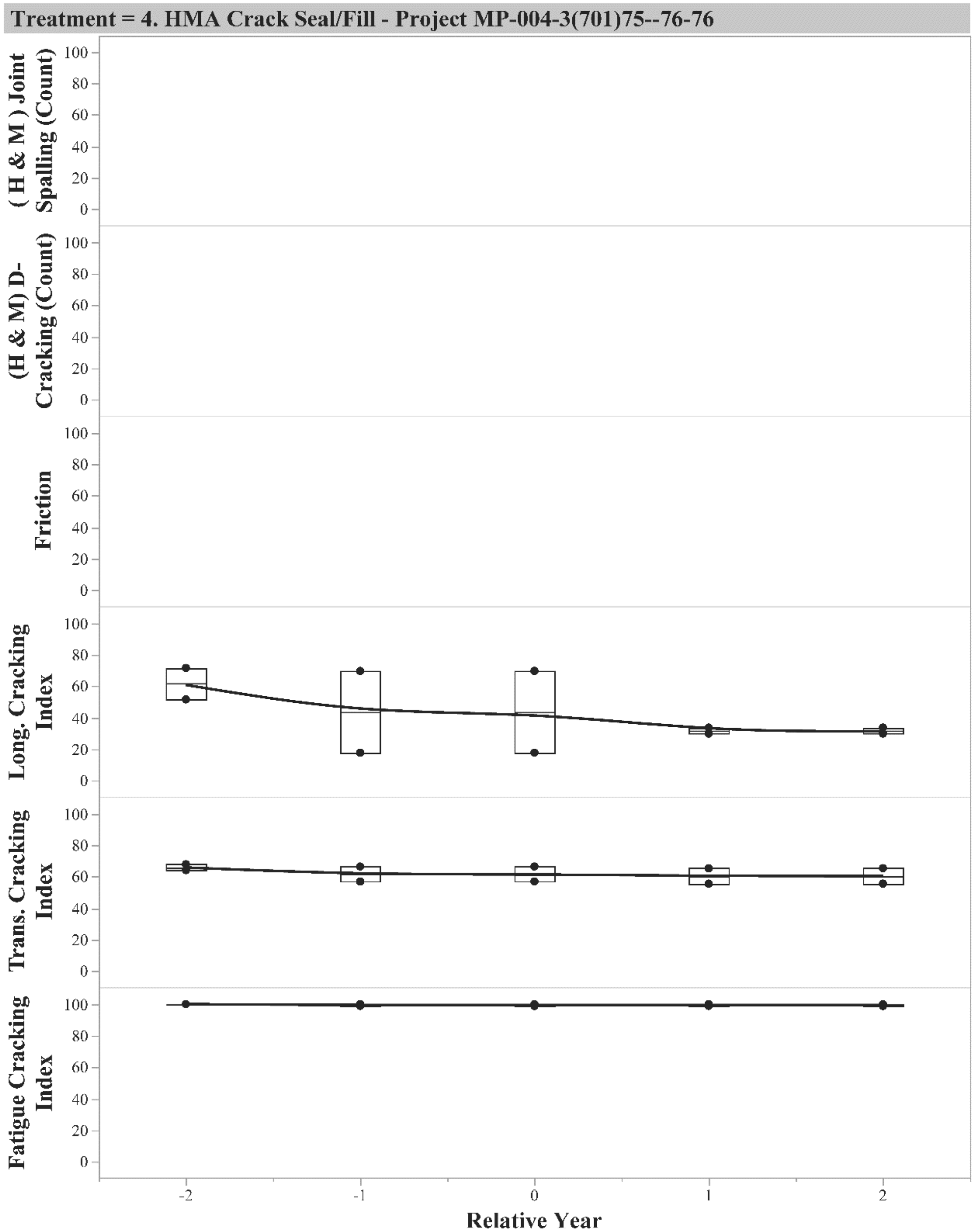


Figure 193. Analytical analysis graphs for project MP-004-3(701)75—76-76



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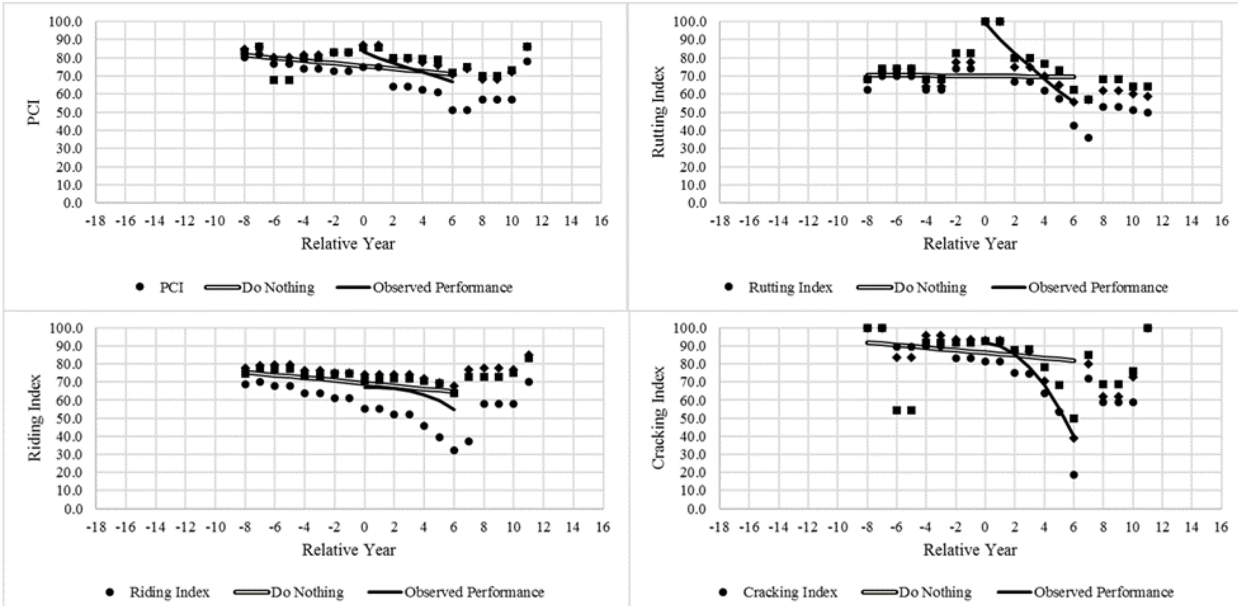
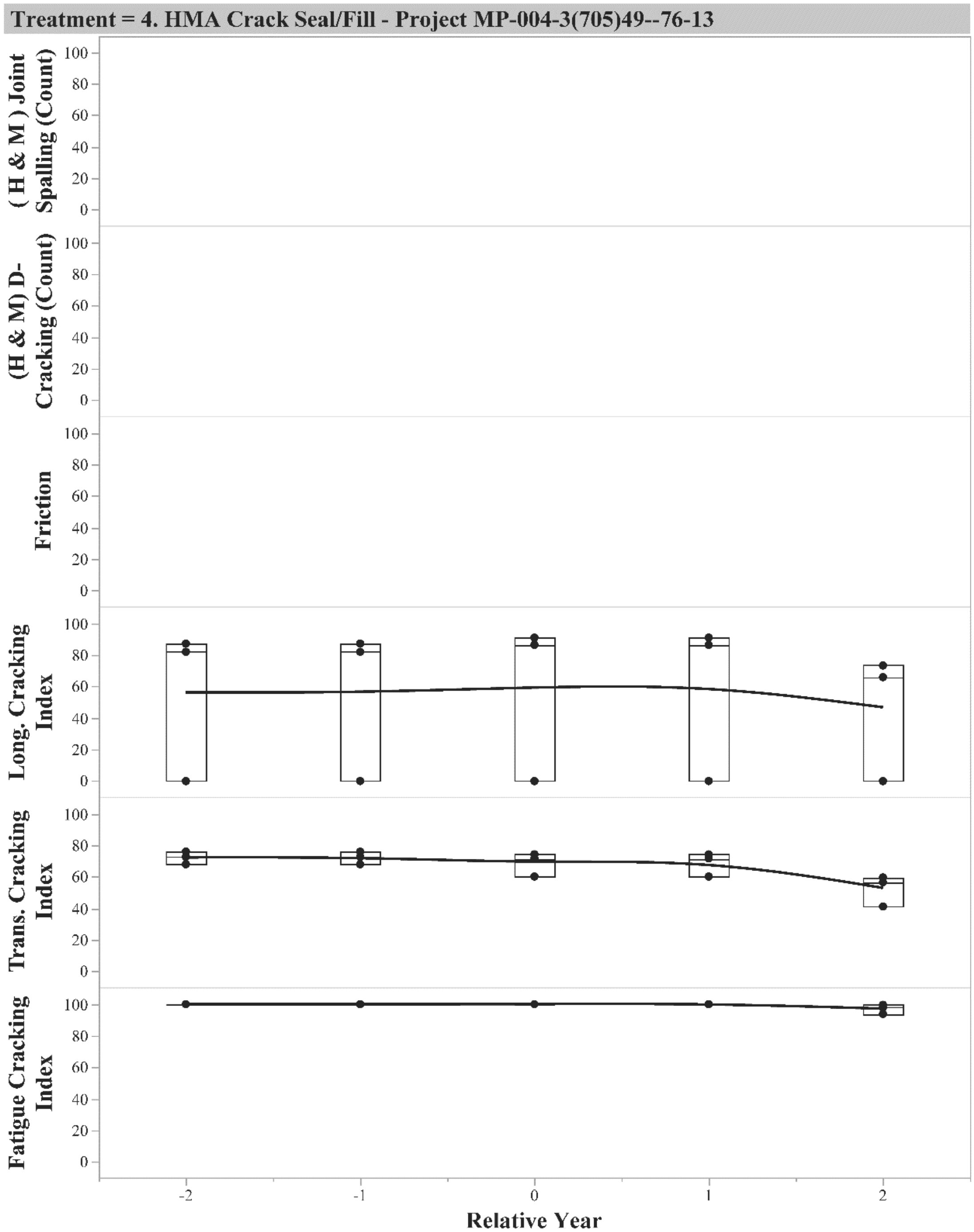


Figure 195. Analytical analysis graphs for project MP-004-3(705)49—76-13



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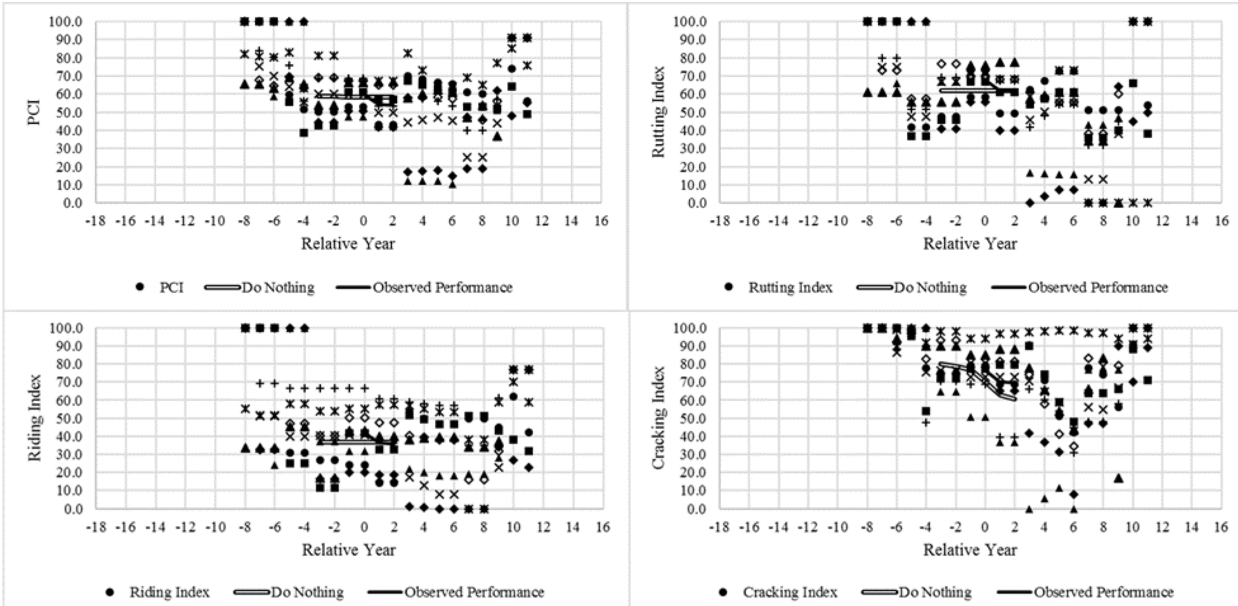
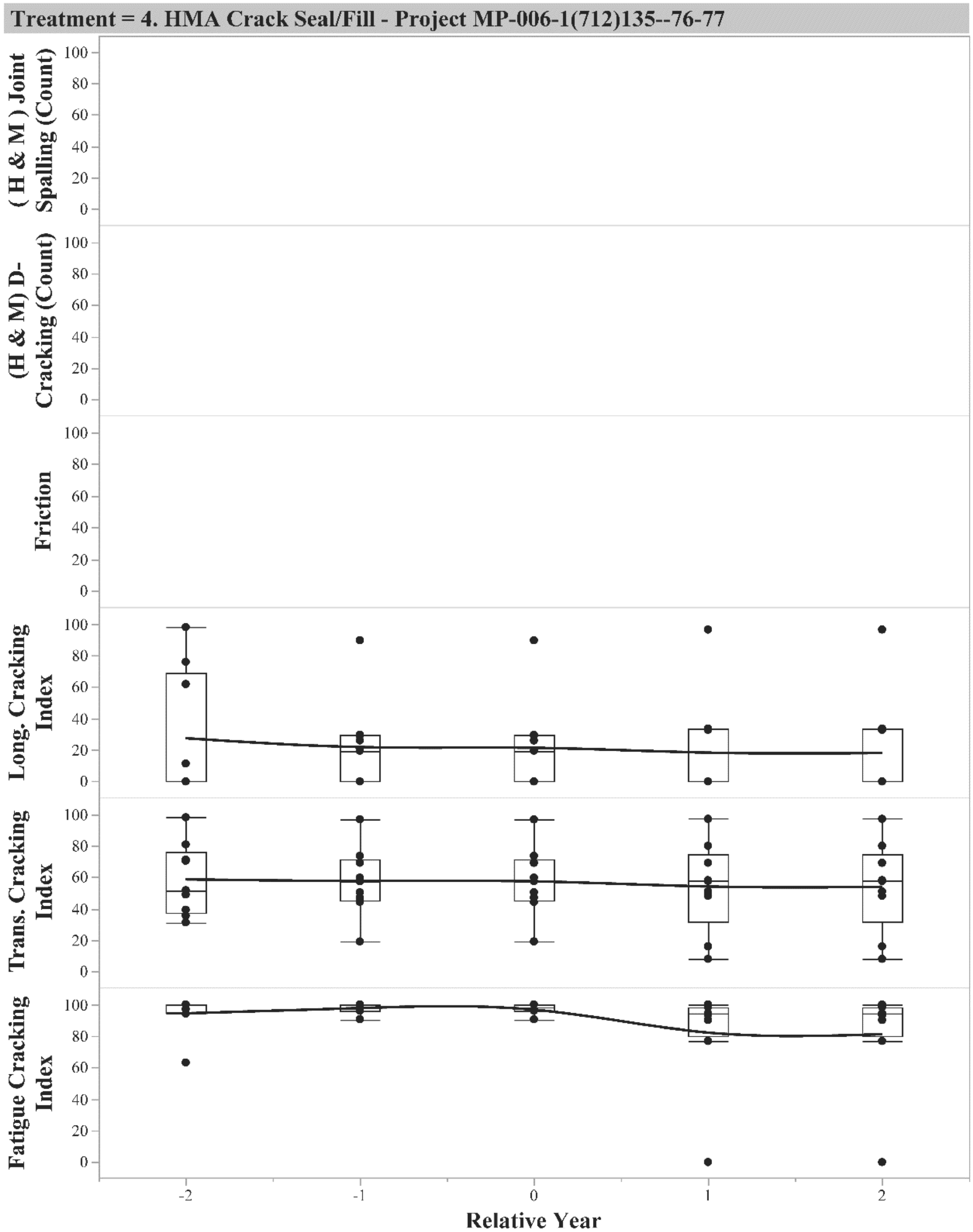


Figure 197. Analytical analysis graphs for project MP-006-1(712)135—76-77



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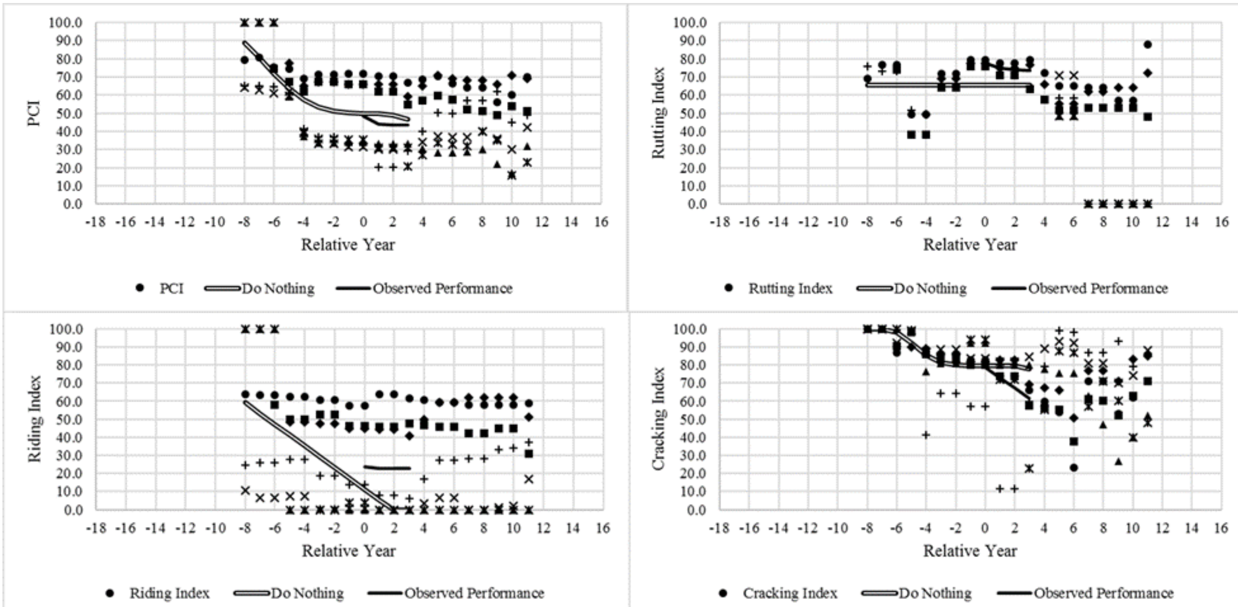
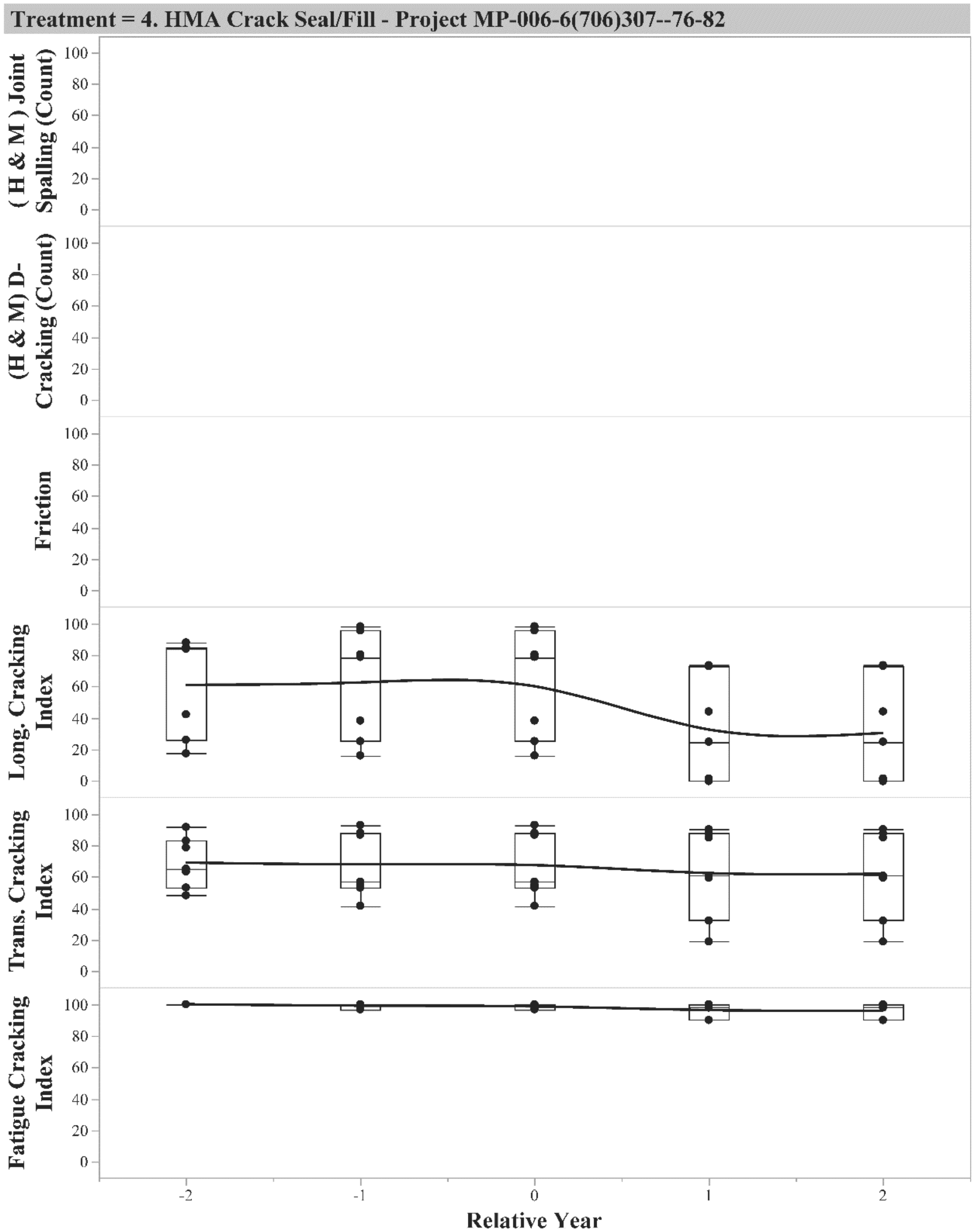


Figure 199. Analytical analysis graphs for project MP-006-6(706)307—76-82



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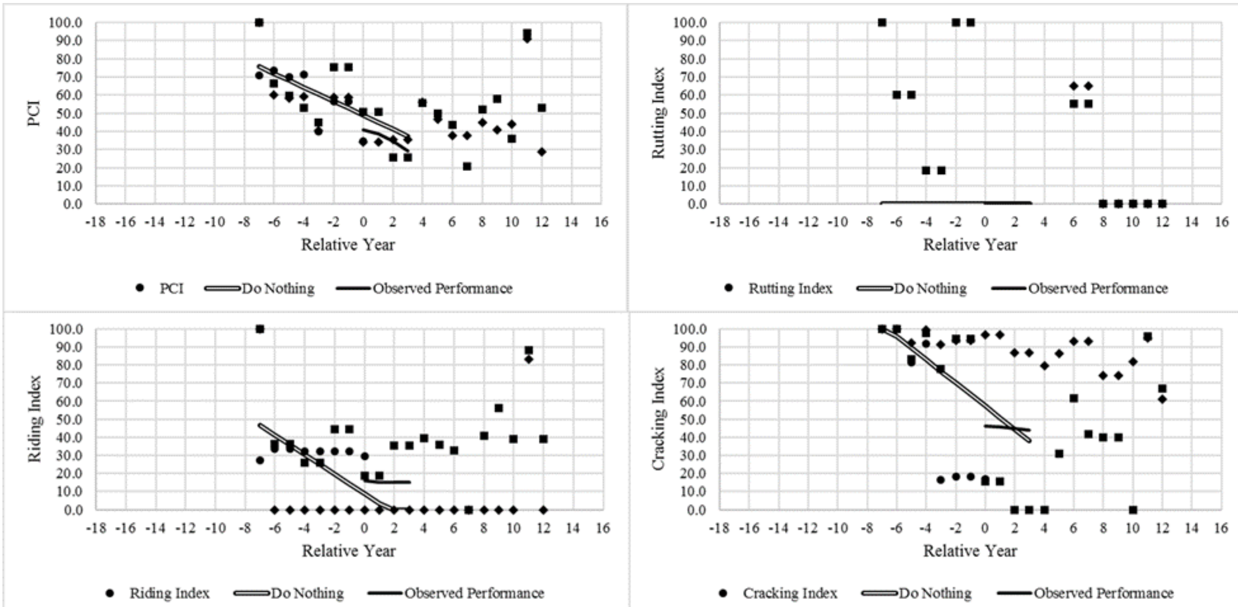


Figure 201. Analytical analysis graphs for project MP-006-6(707)247—76-52

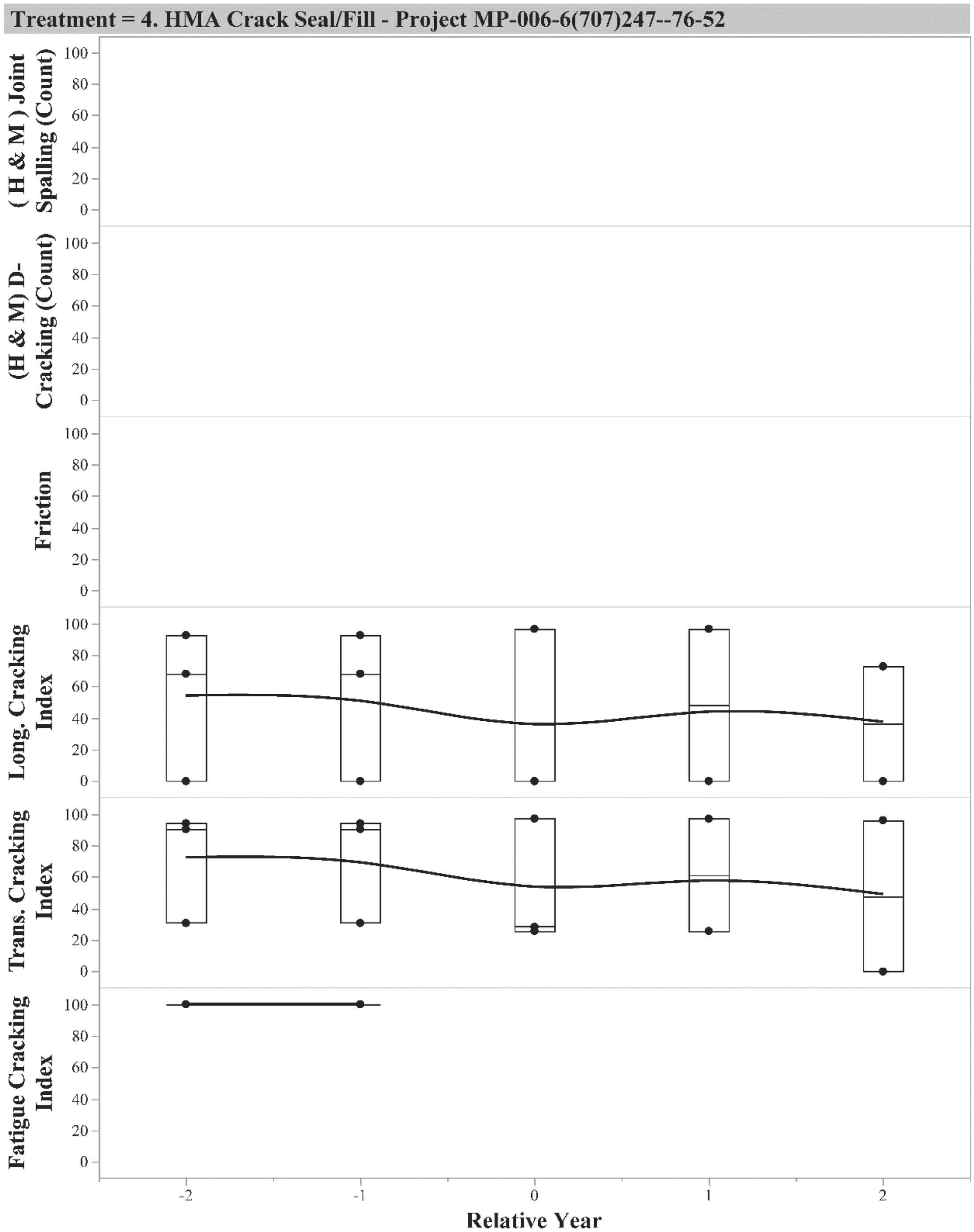


Figure 202. Anecdotal analysis graphs for project MP-006-6(707)247—76-52

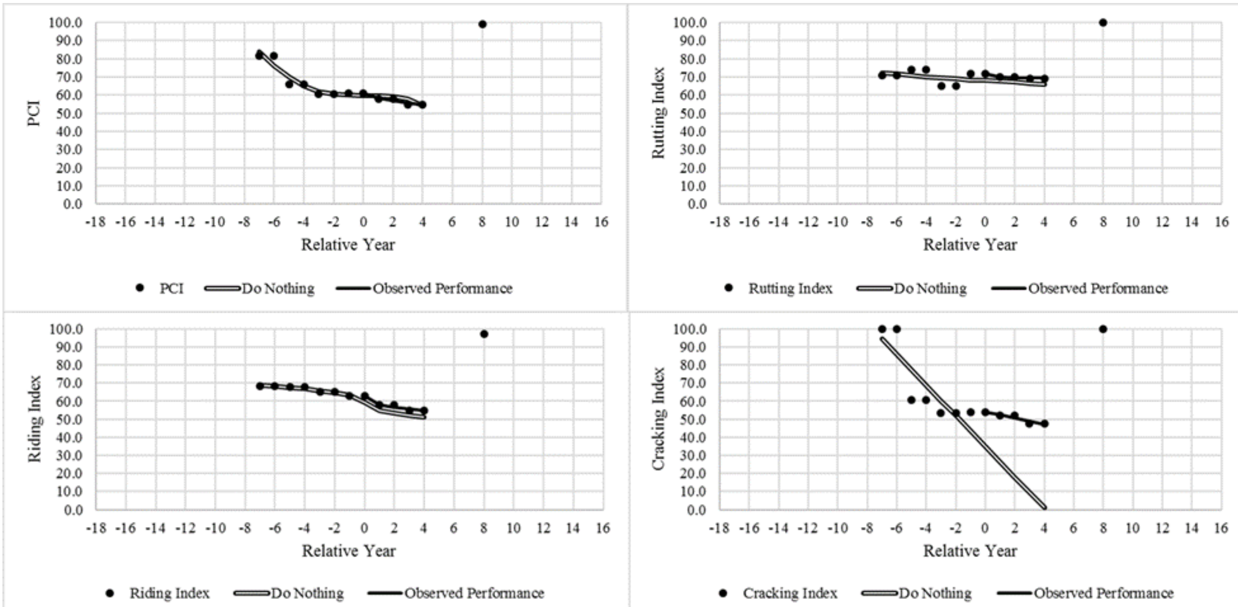


Figure 203. Analytical analysis graphs for project MP-009-2(701)109—76-55

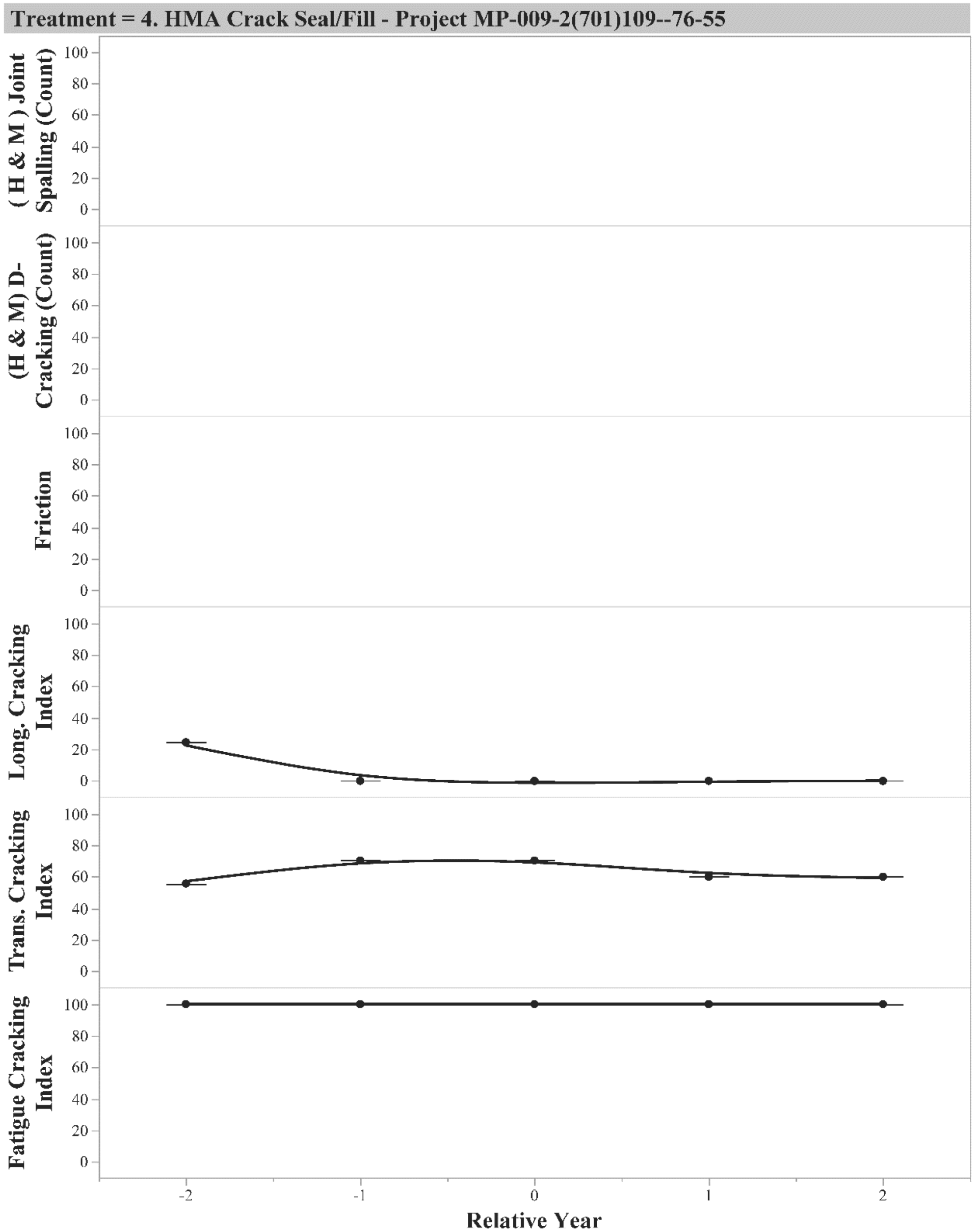


Figure 204. Anecdotal analysis graphs for project MP-009-2(701)109—76-55

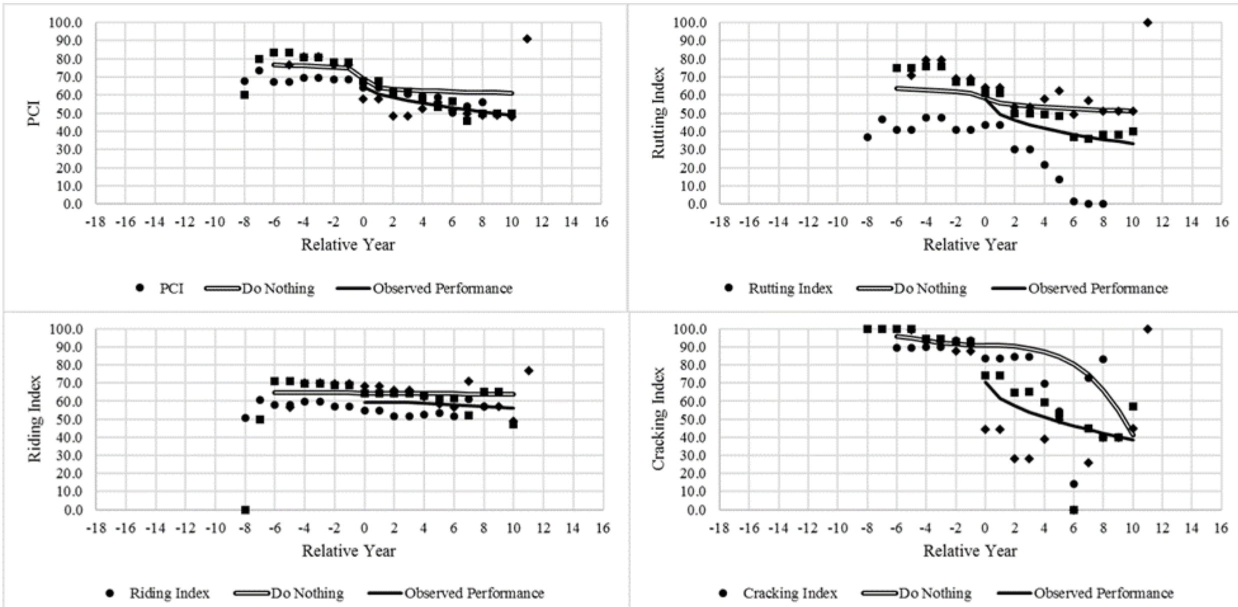


Figure 205. Analytical analysis graphs for project MP-009-2(703)256—76-96

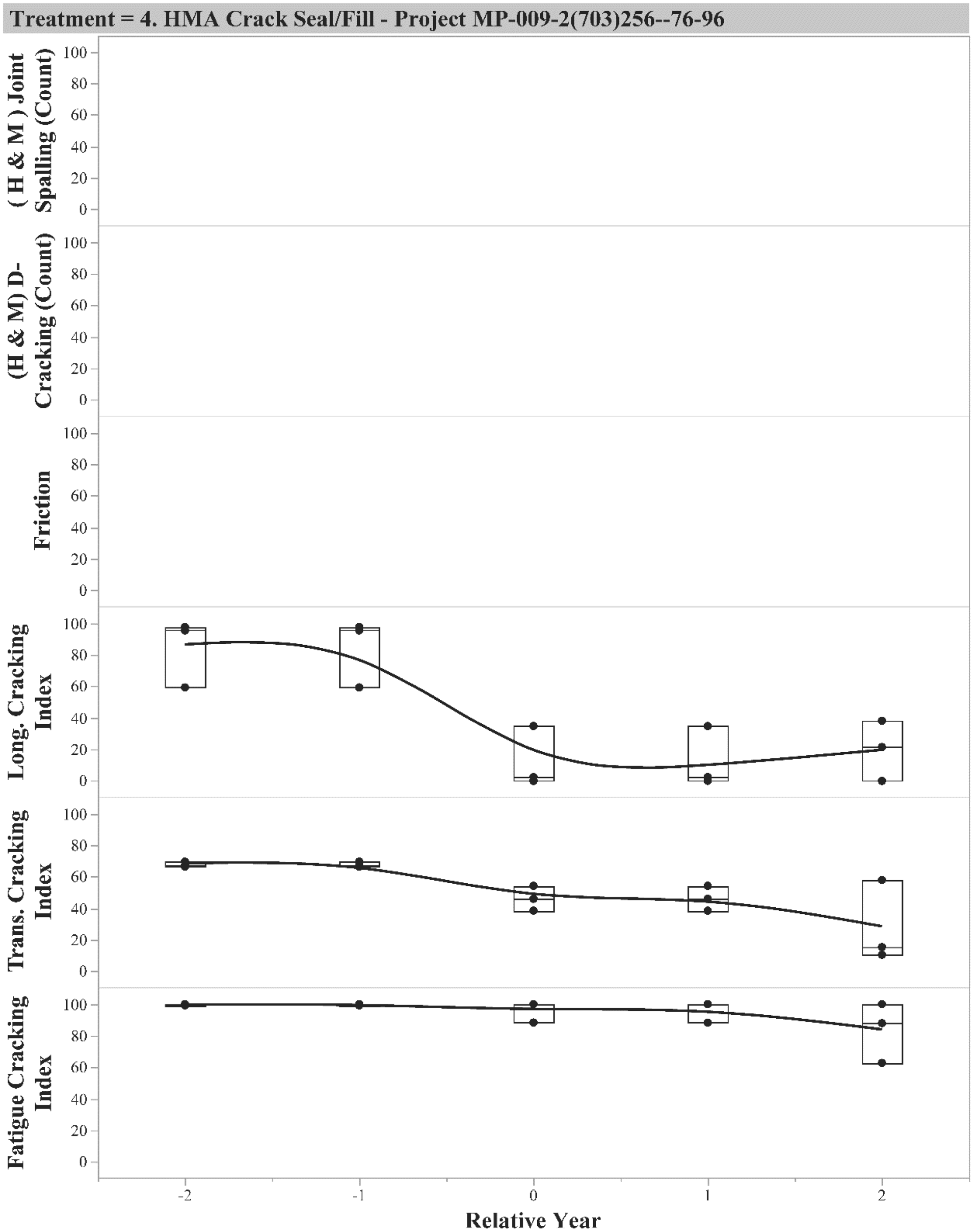


Figure 206. Anecdotal analysis graphs for project MP-009-2(703)256—76-96

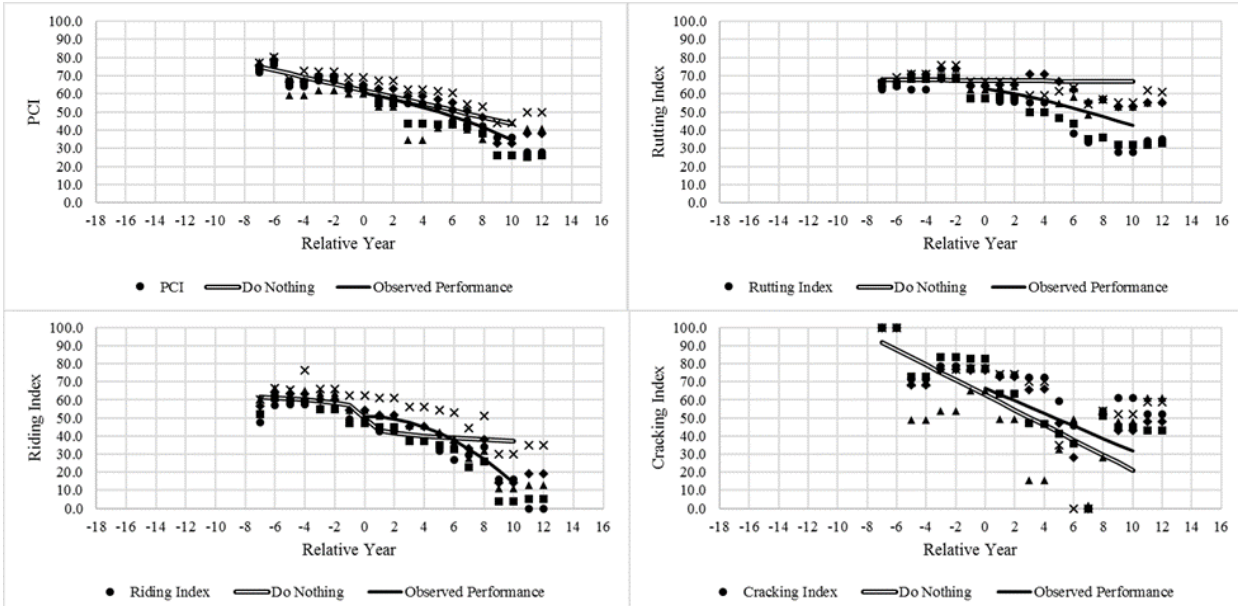


Figure 207. Analytical analysis graphs for project MP-009-2(703)280—76-03

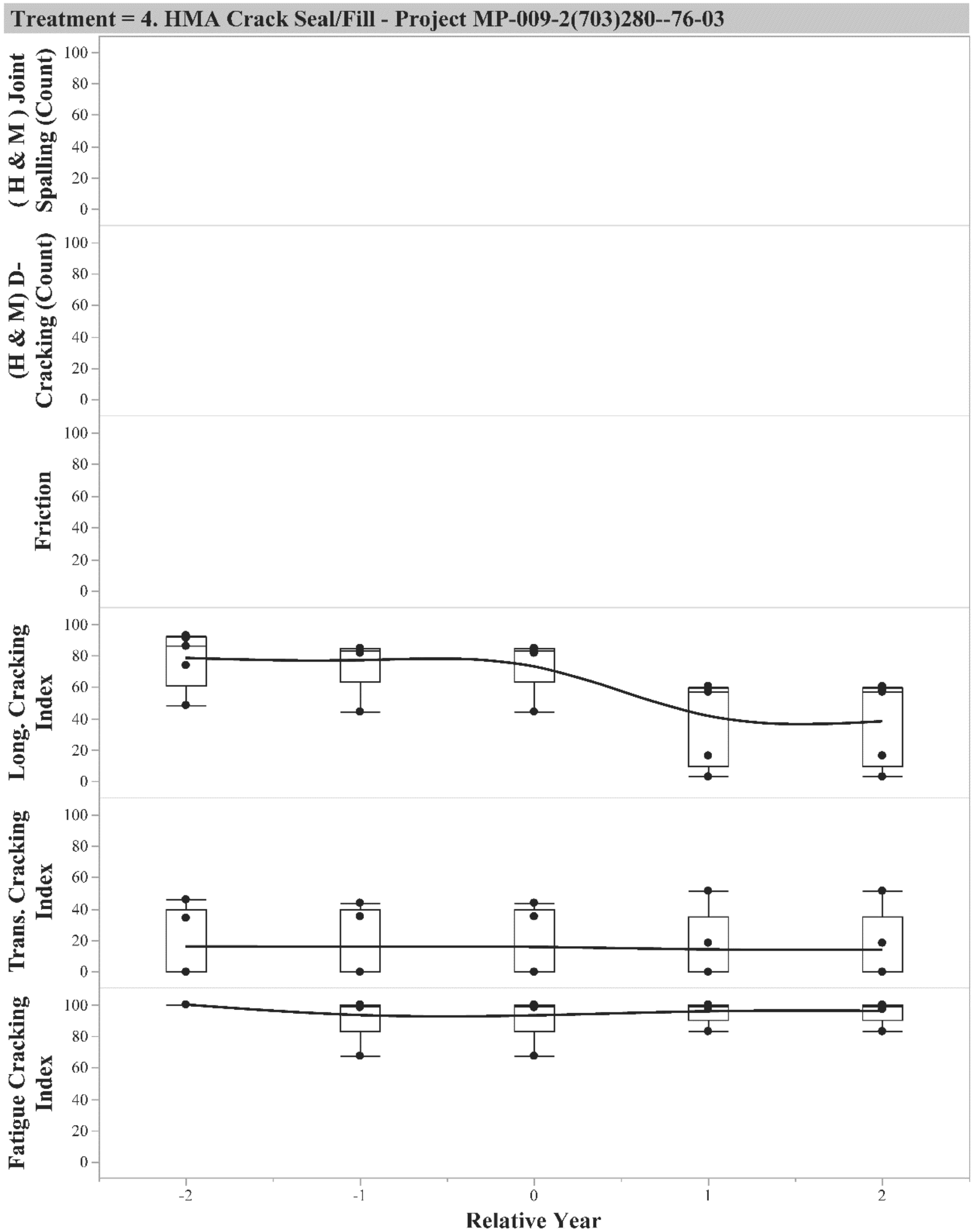


Figure 208. Anecdotal analysis graphs for project MP-009-2(703)280—76-03

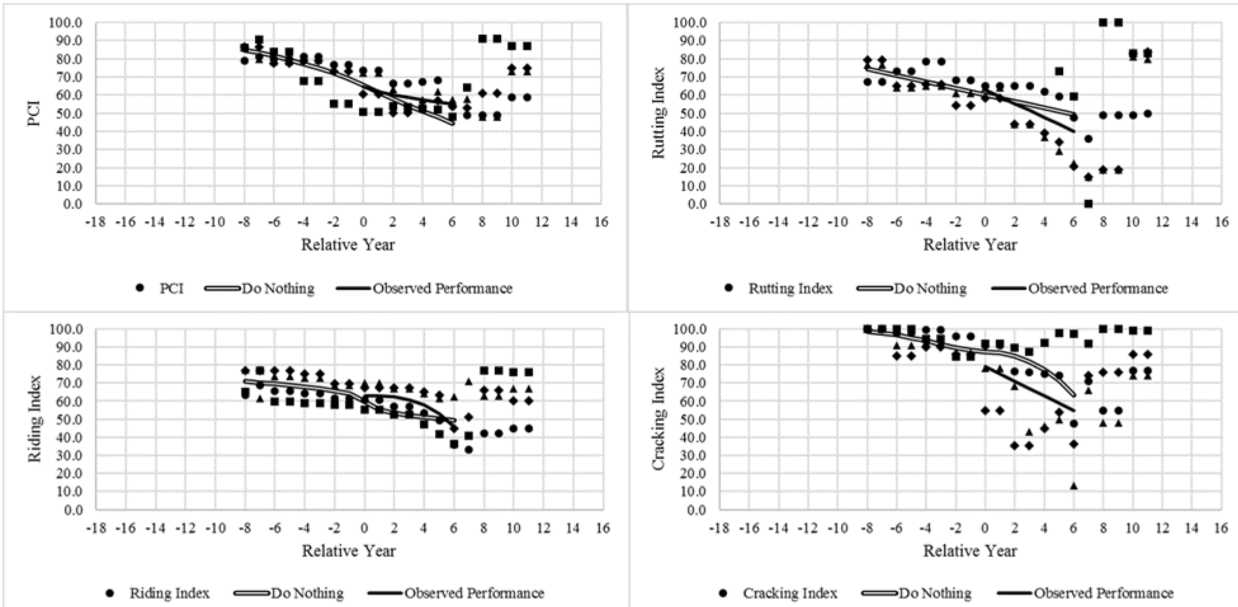
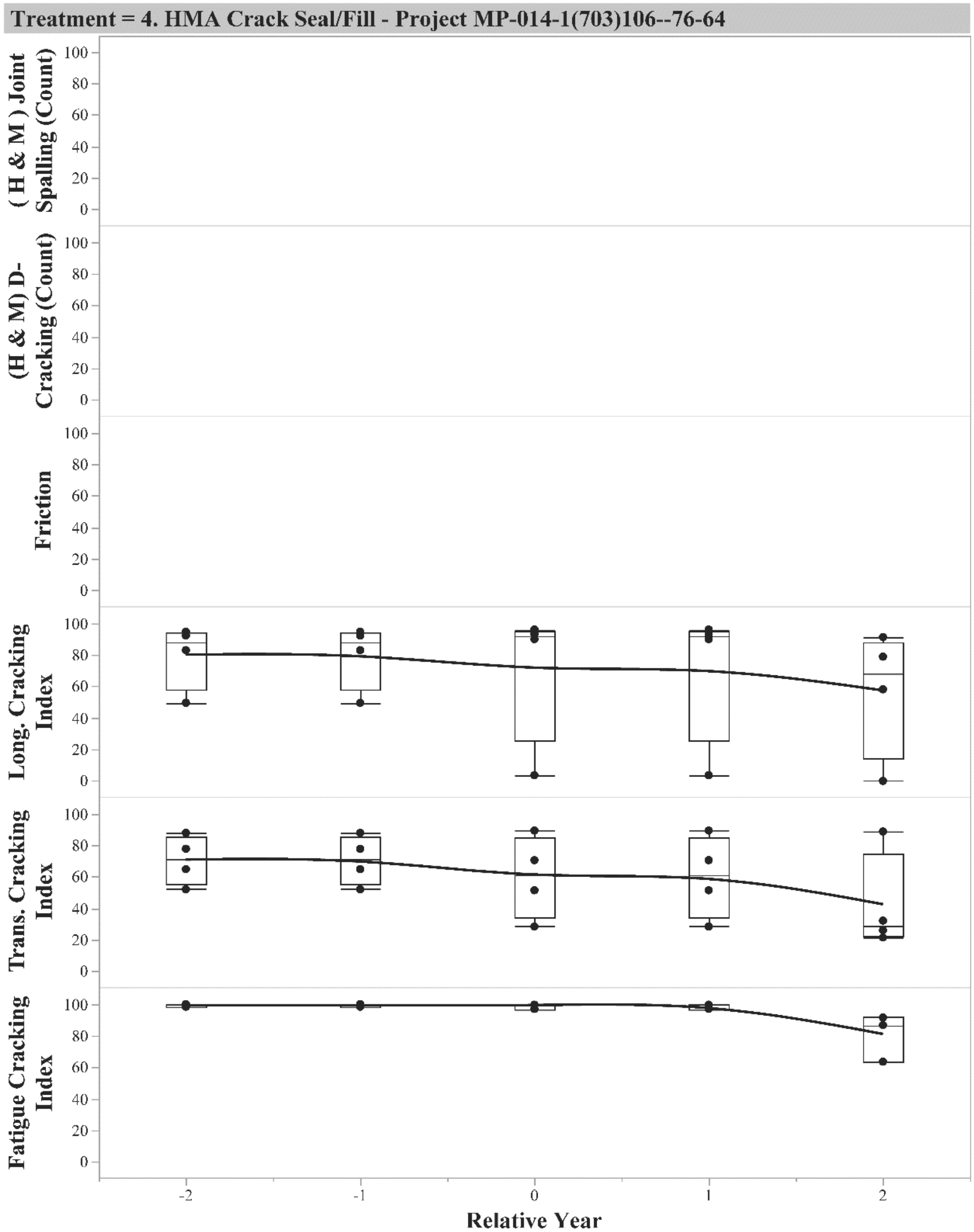


Figure 209. Analytical analysis graphs for project MP-014-1(703)106—76-64



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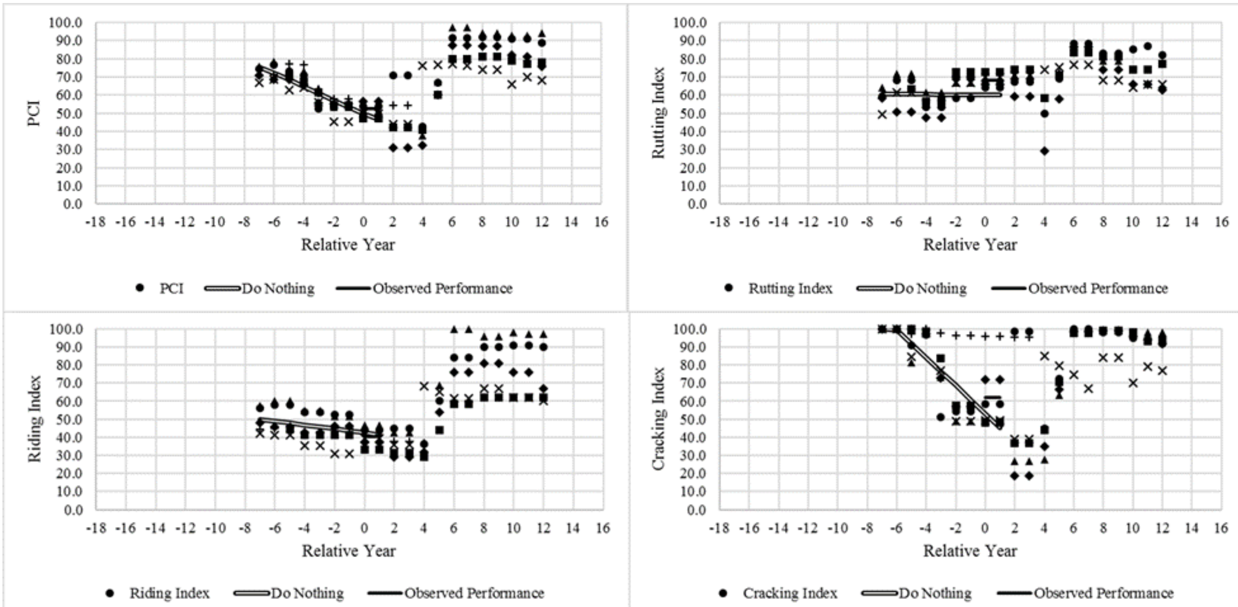
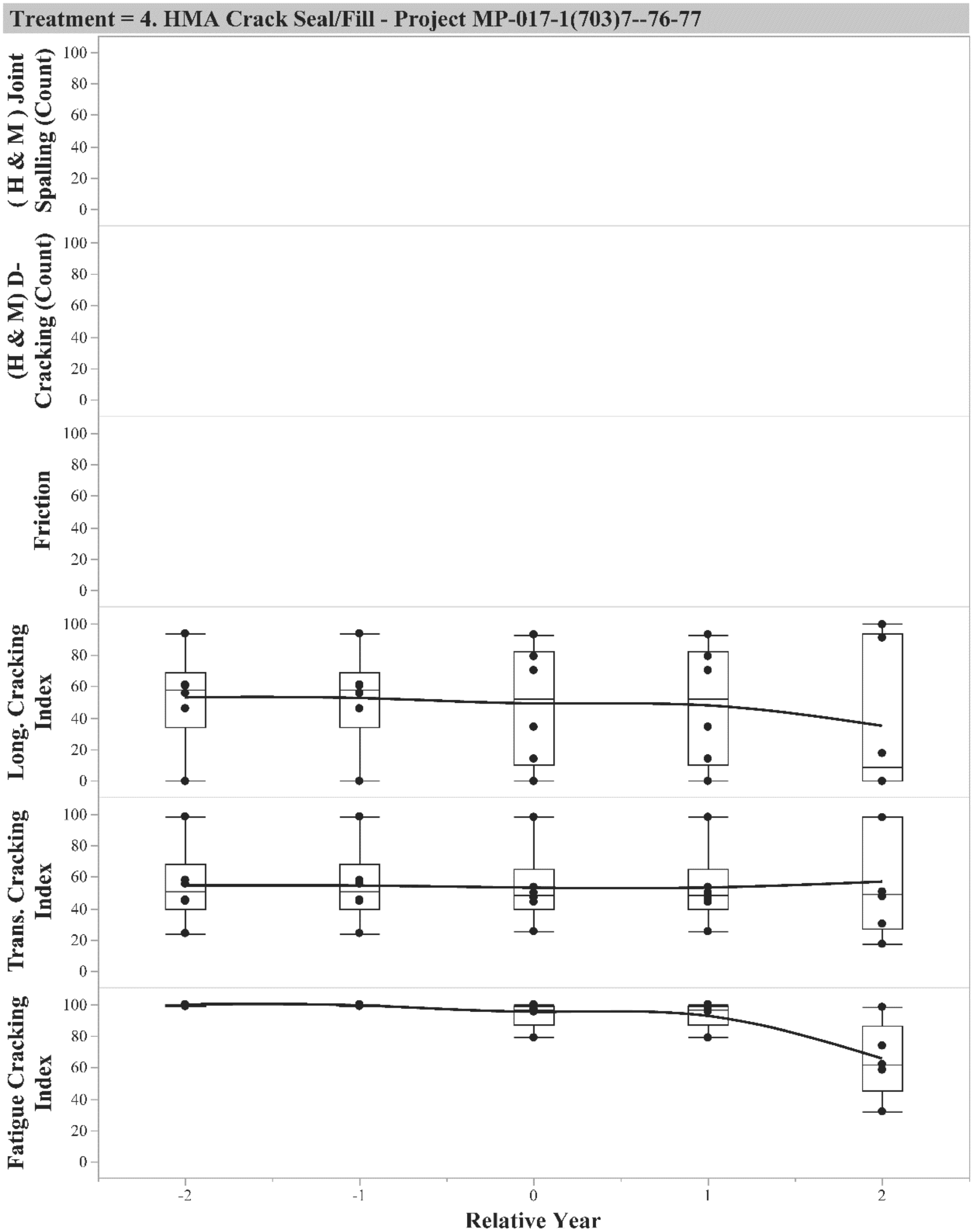


Figure 211. Analytical analysis graphs for project MP-017-1(703)7—76-77



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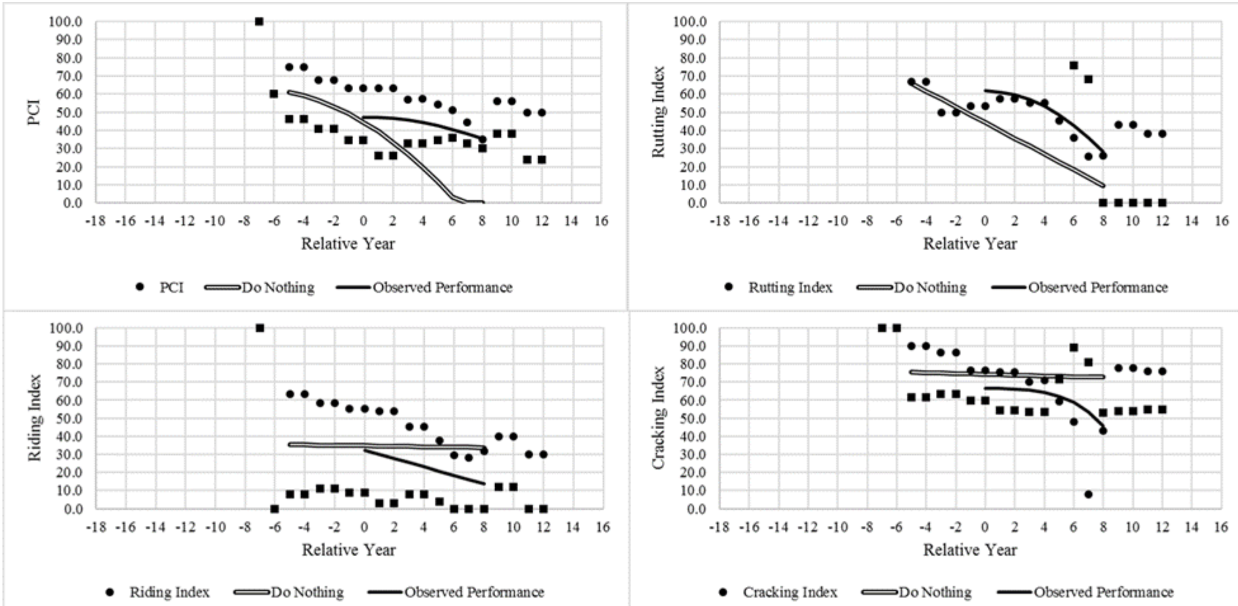


Figure 213. Analytical analysis graphs for project MP-017-2(703)71—76-99

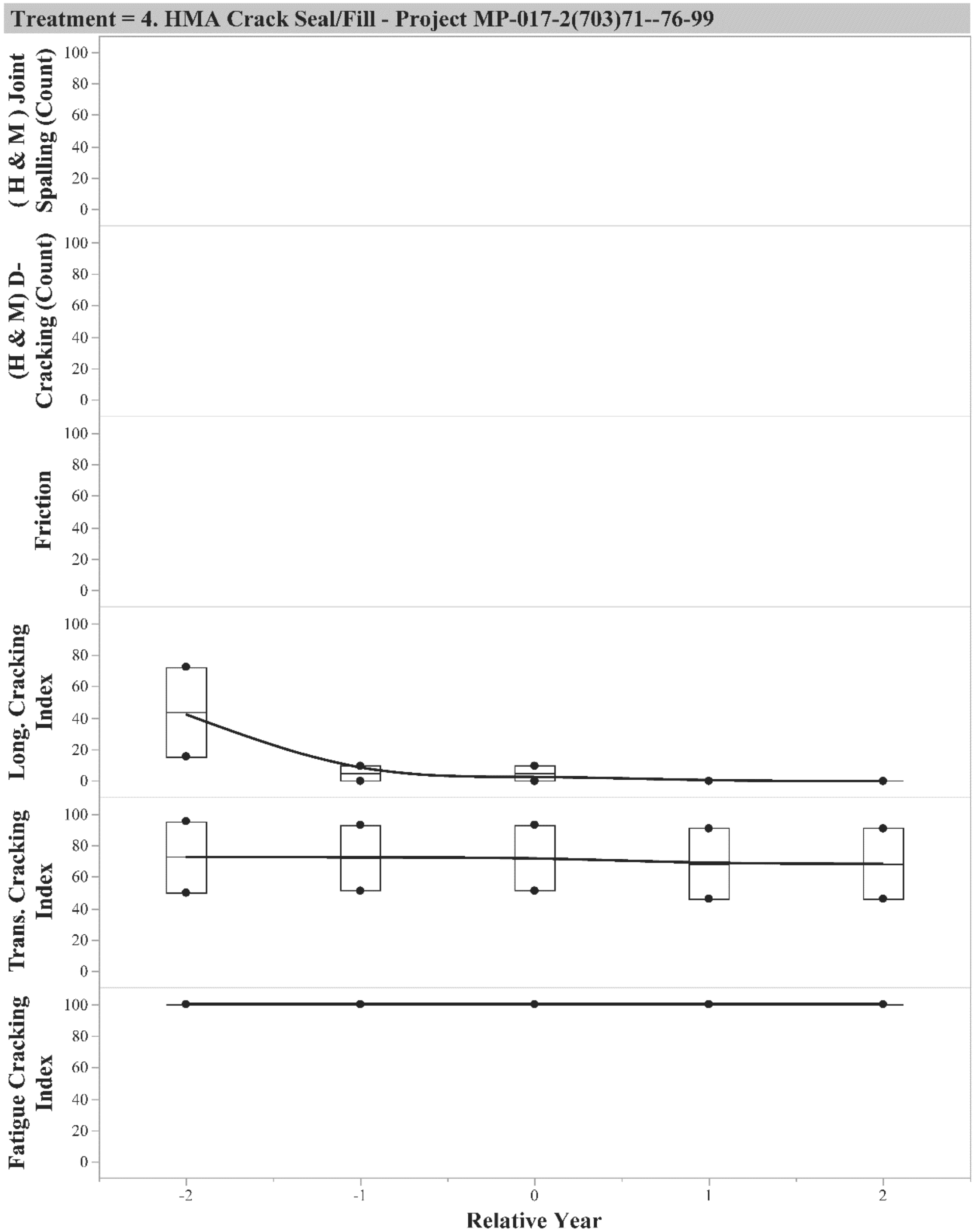


Figure 214. Anecdotal analysis graphs for project MP-017-2(703)71—76-99

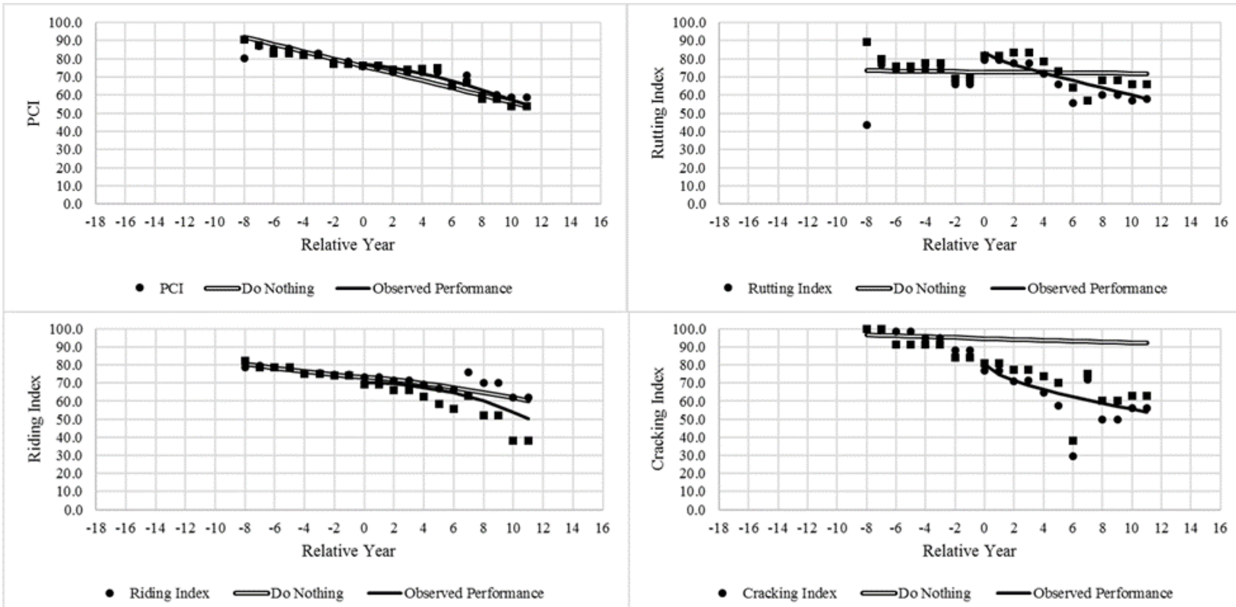
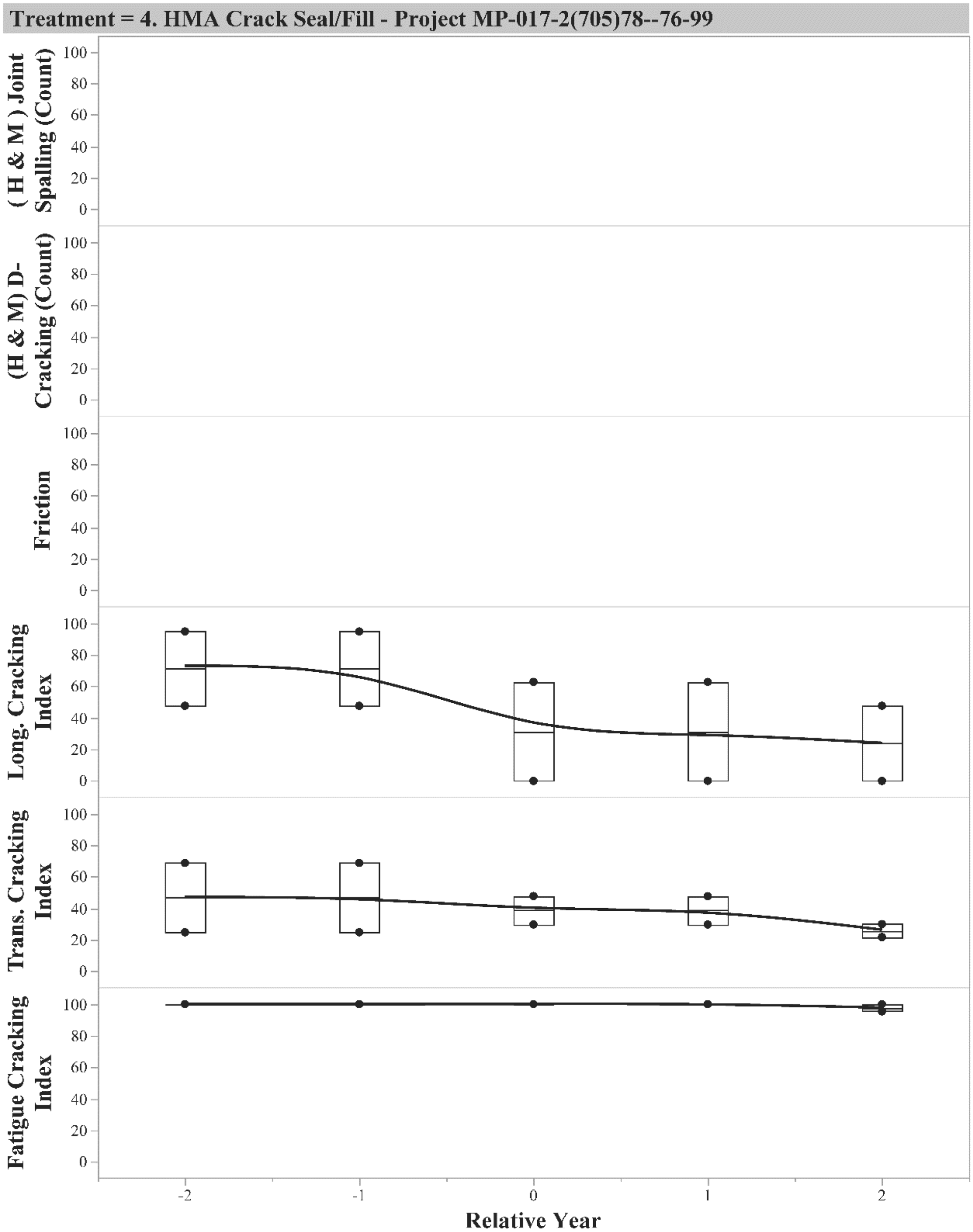


Figure 215. Analytical analysis graphs for project MP-017-2(705)78—76-99



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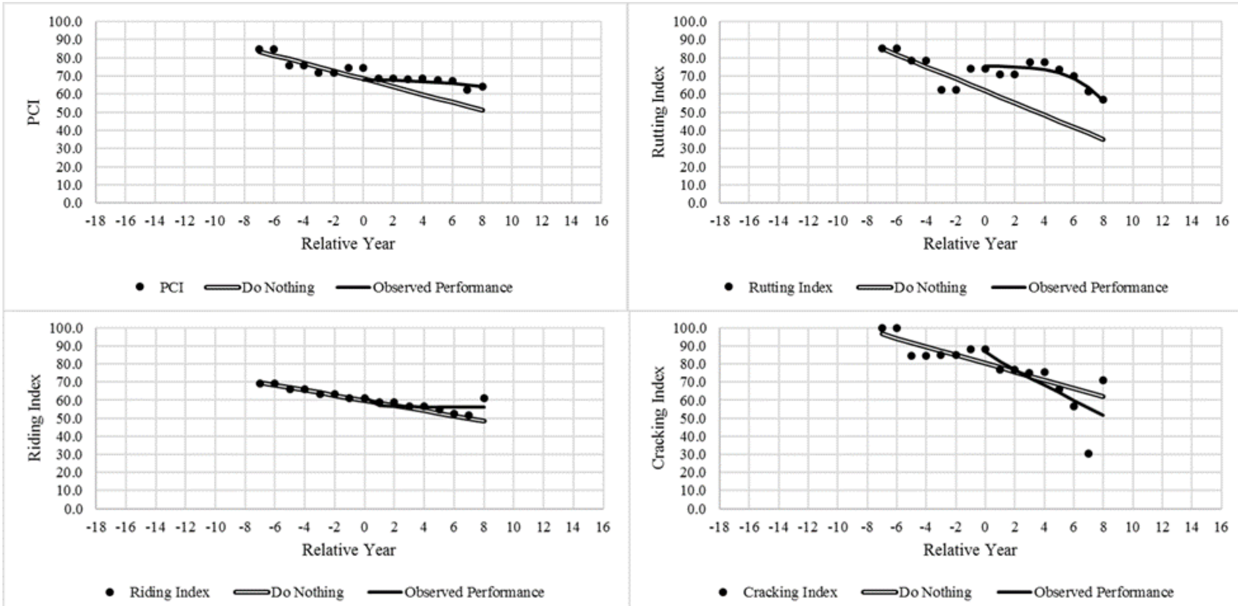

Figure 217. Analytical analysis graphs for project MP-018-2(703)132—76-55

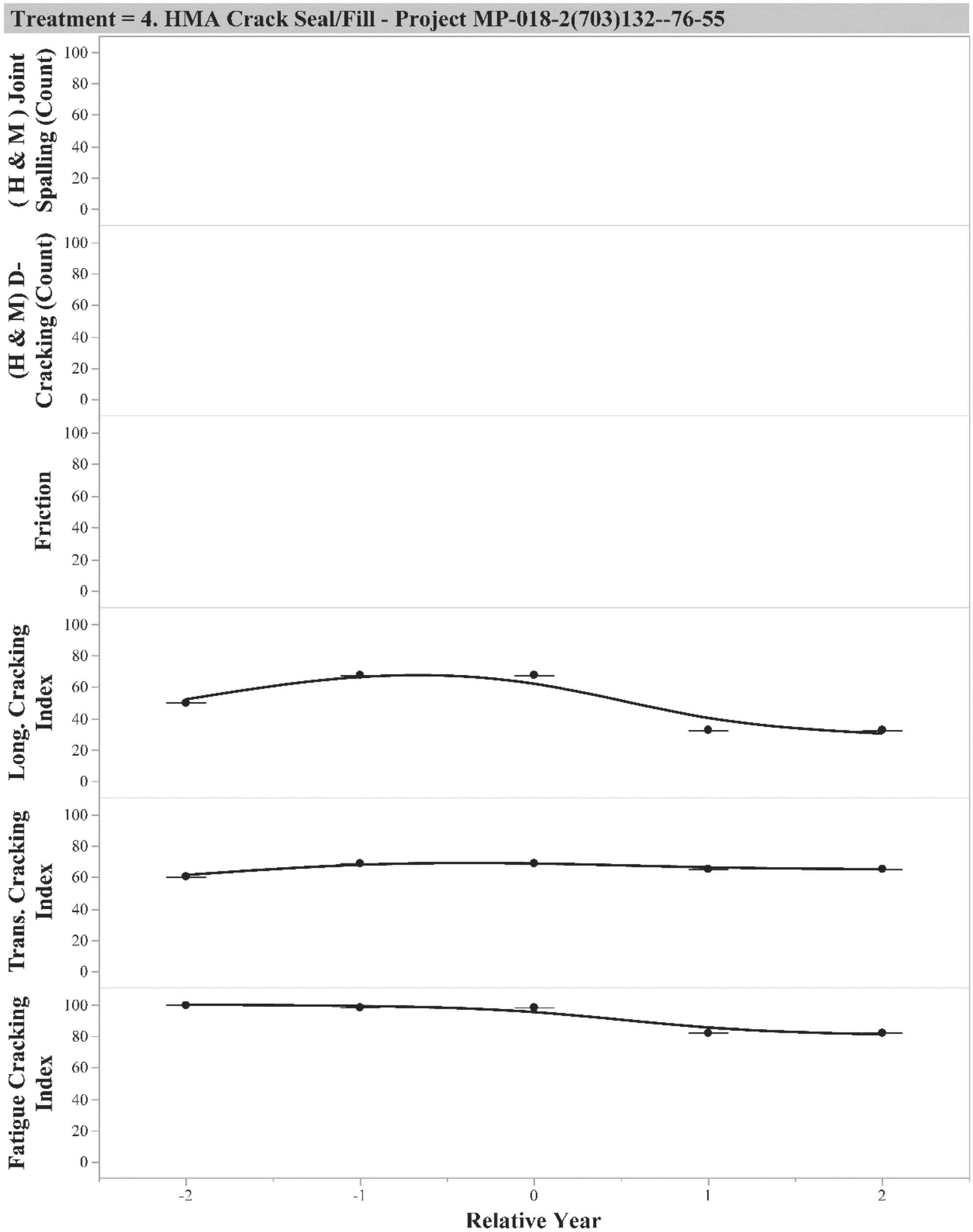

Figure 218. Anecdotal analysis graphs for project MP-018-2(703)132—76-55

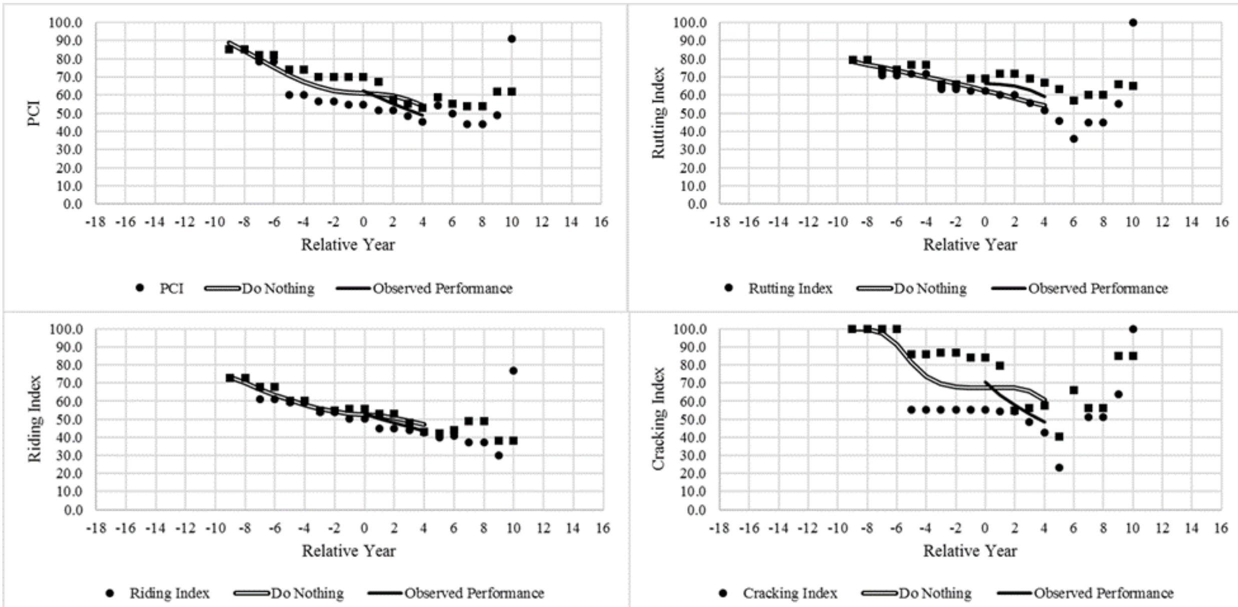

Figure 219. Analytical analysis graphs for project MP-018-2(703)264—76-33

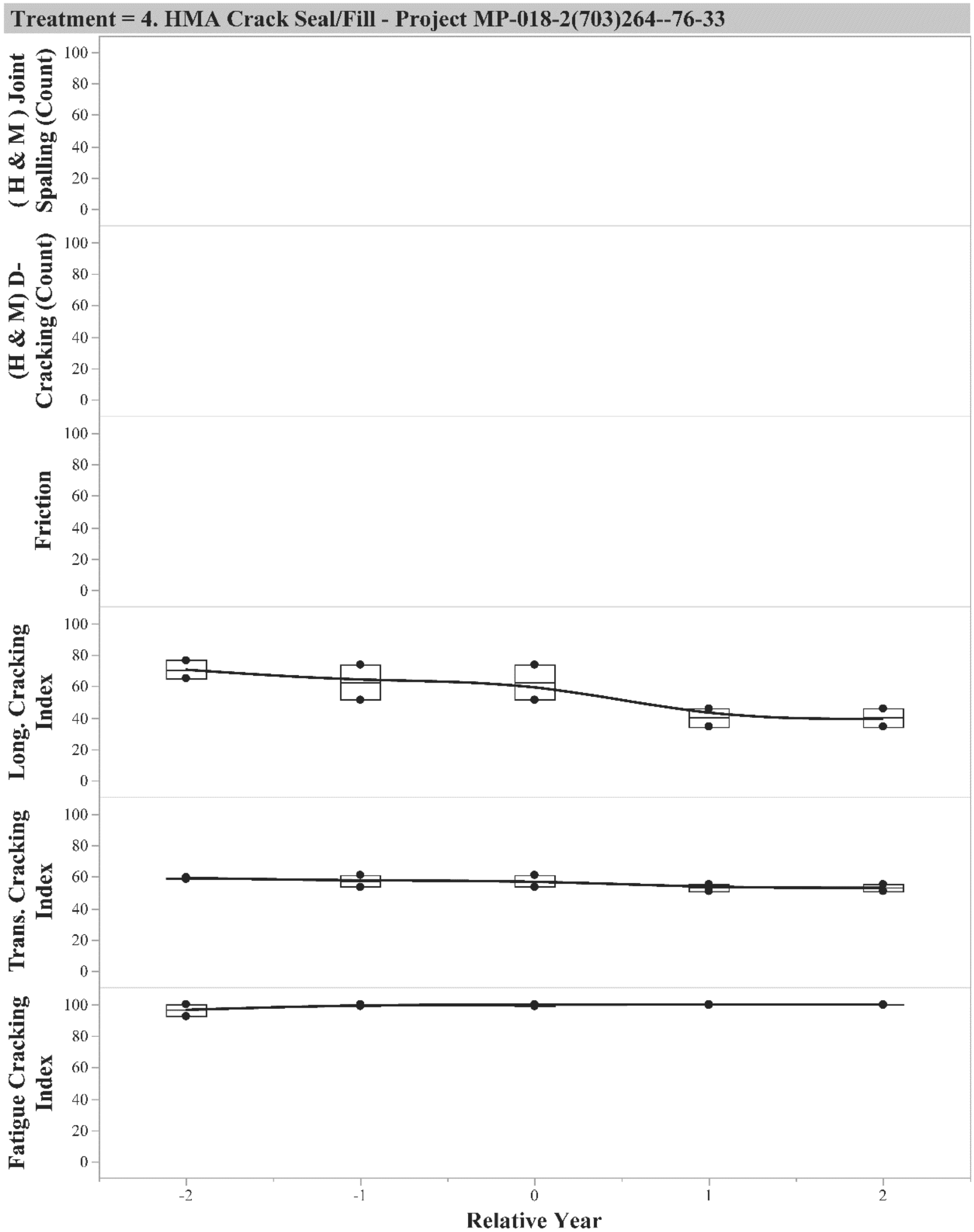

Figure 220. Anecdotal analysis graphs for project MP-018-2(703)264—76-33

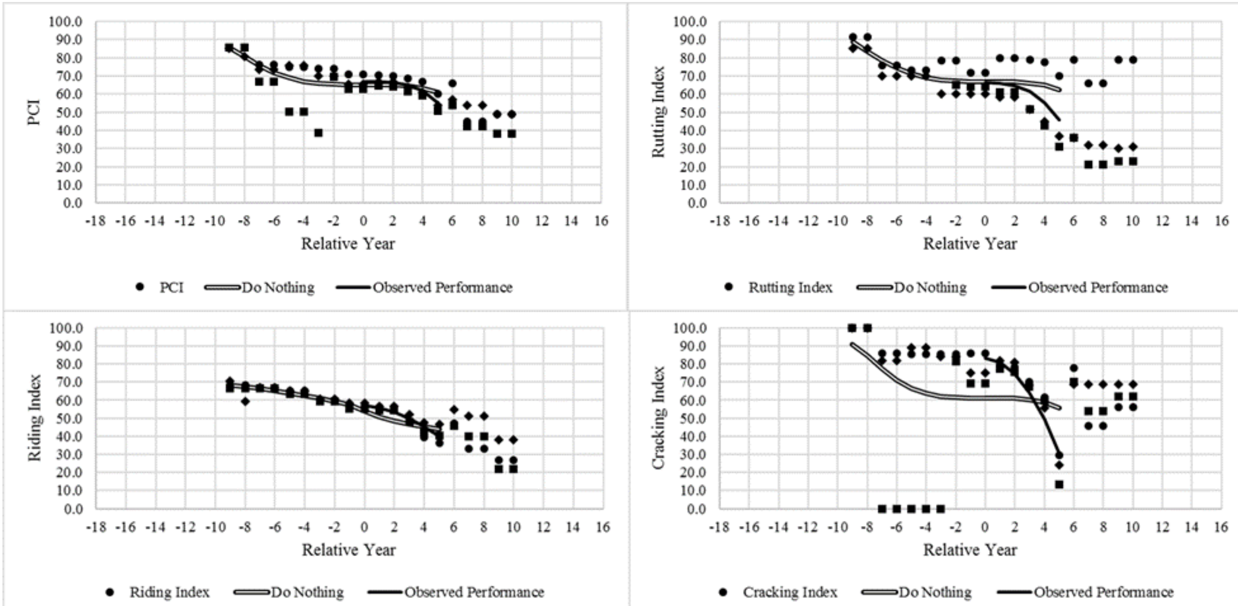

Figure 221. Analytical analysis graphs for project MP-018-2(704)141—76-55

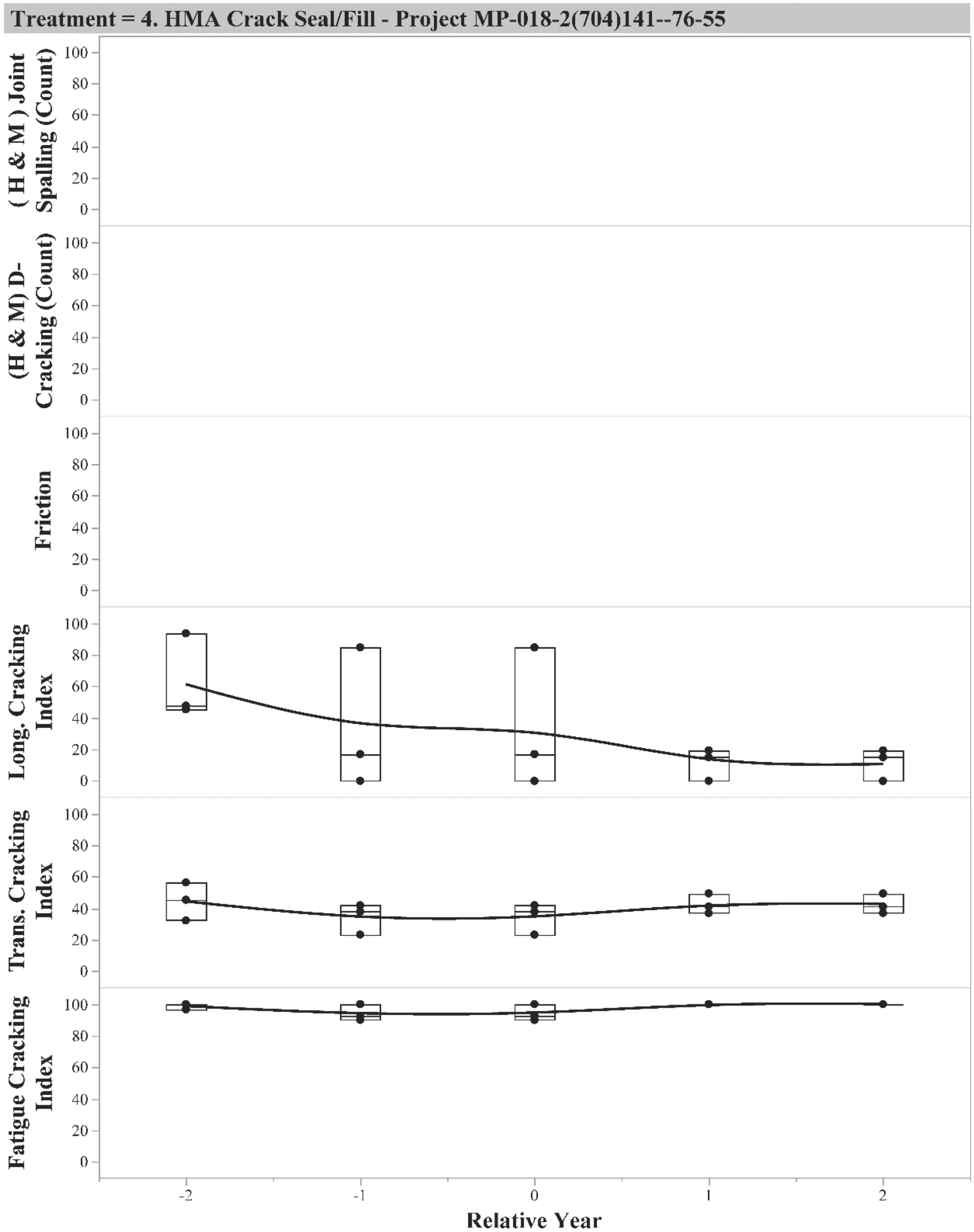

Figure 222. Anecdotal analysis graphs for project MP-018-2(704)141—76-55

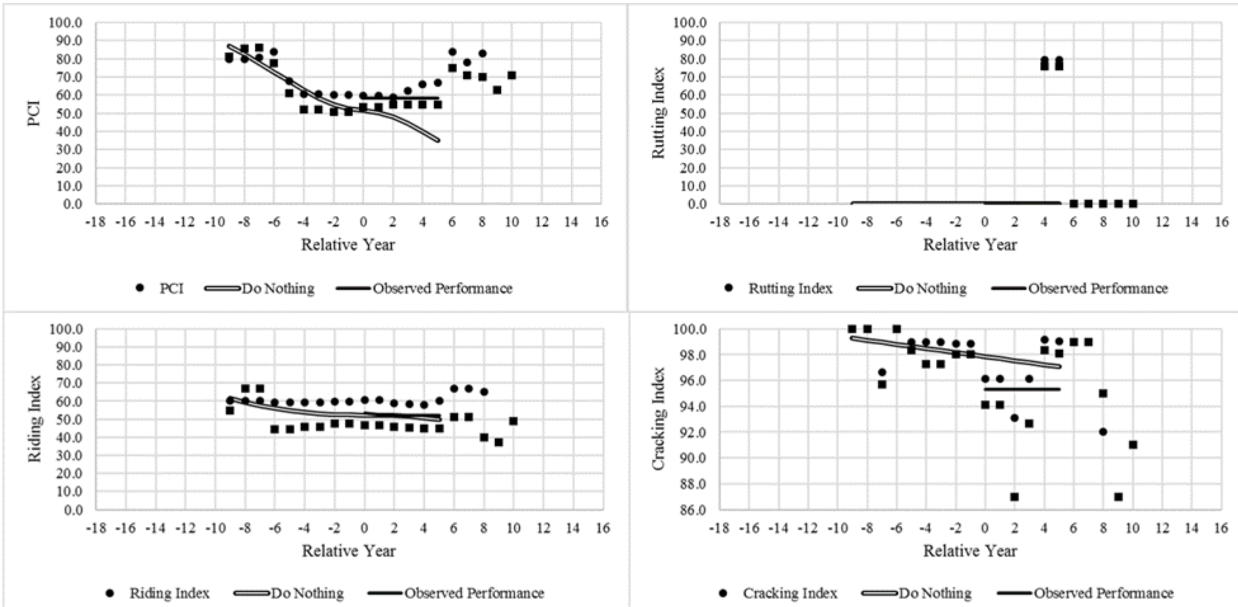

Figure 223. Analytical analysis graphs for project MP-020-6(703)283—76-28

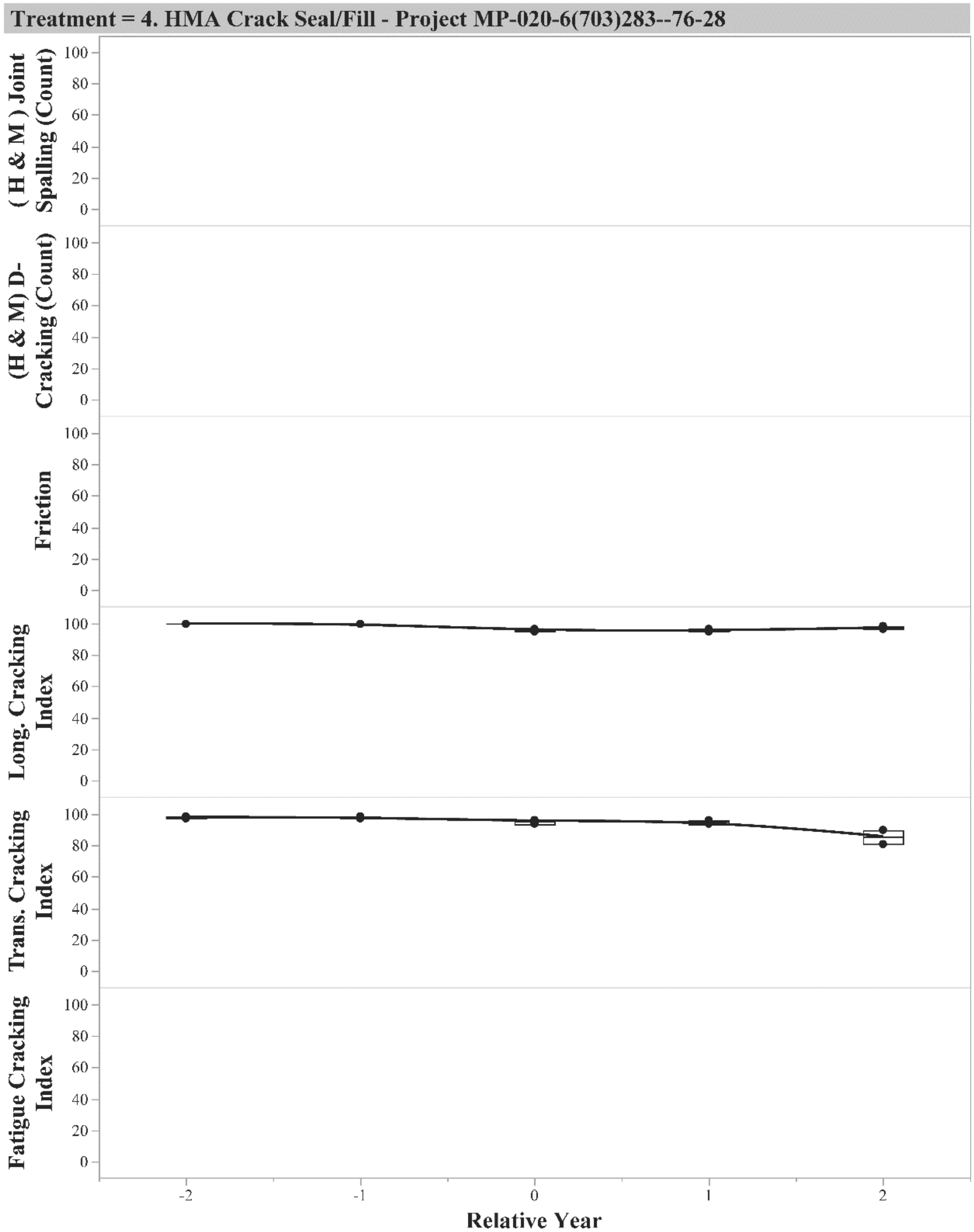

Figure 224. Anecdotal analysis graphs for project MP-020-6(703)283—76-28

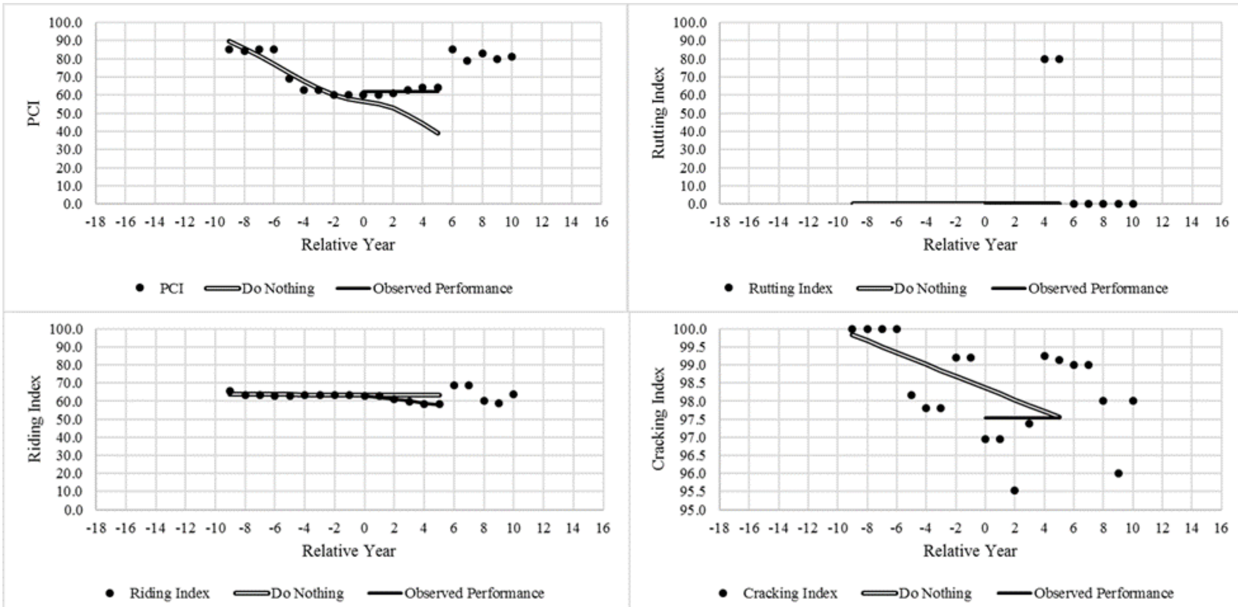

Figure 225. Analytical analysis graphs for project MP-020-6(705)295—76-31

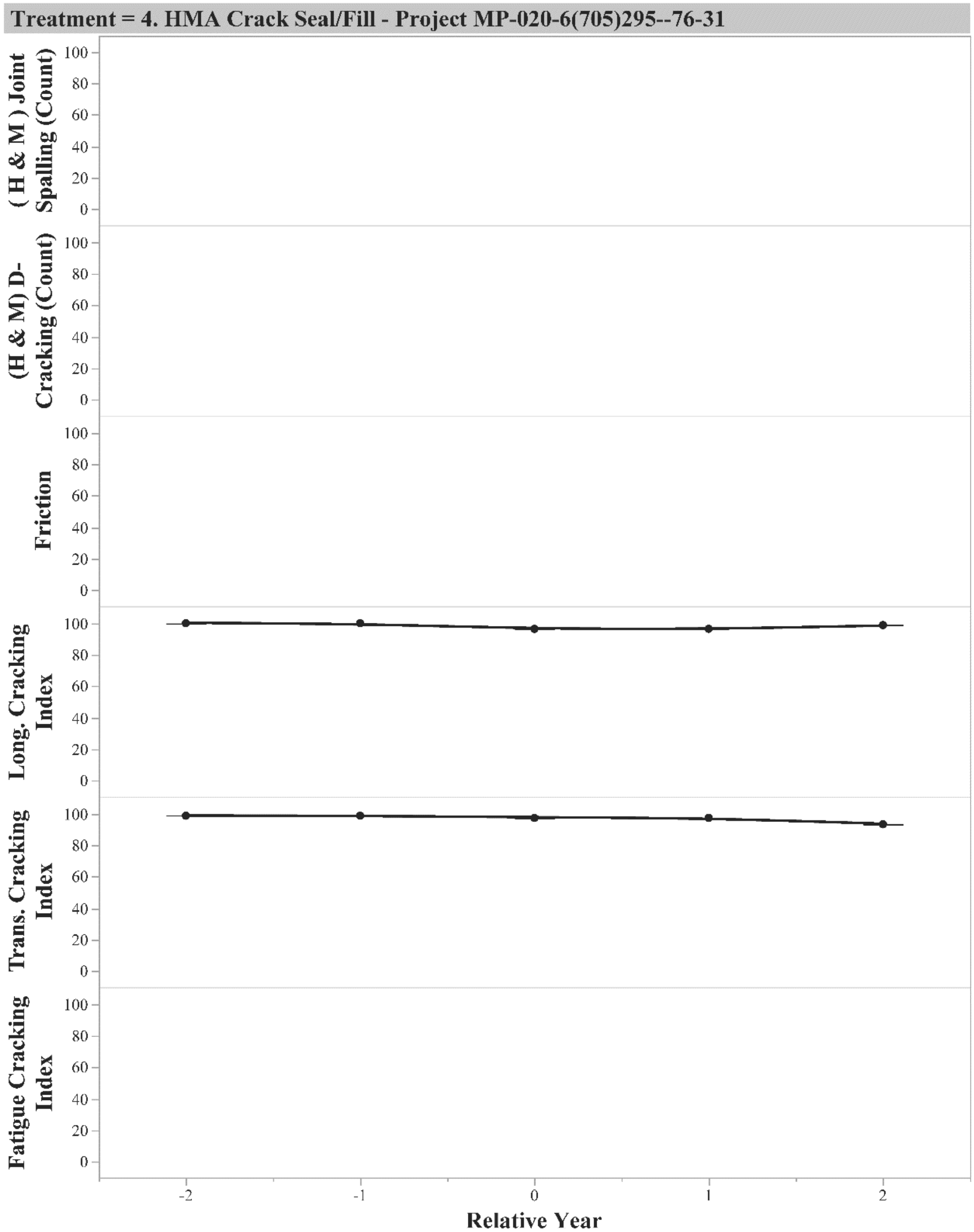

Figure 226. Anecdotal analysis graphs for project MP-020-6(705)295—76-31

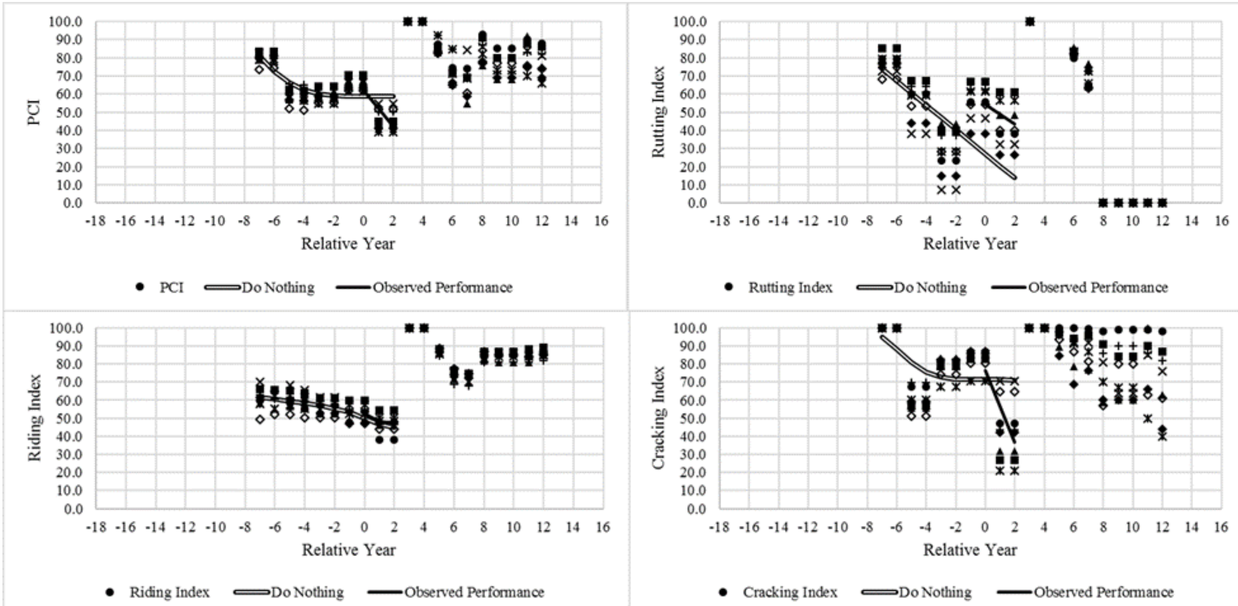

Figure 227. Analytical analysis graphs for project MP-029-3(702)127—76-97

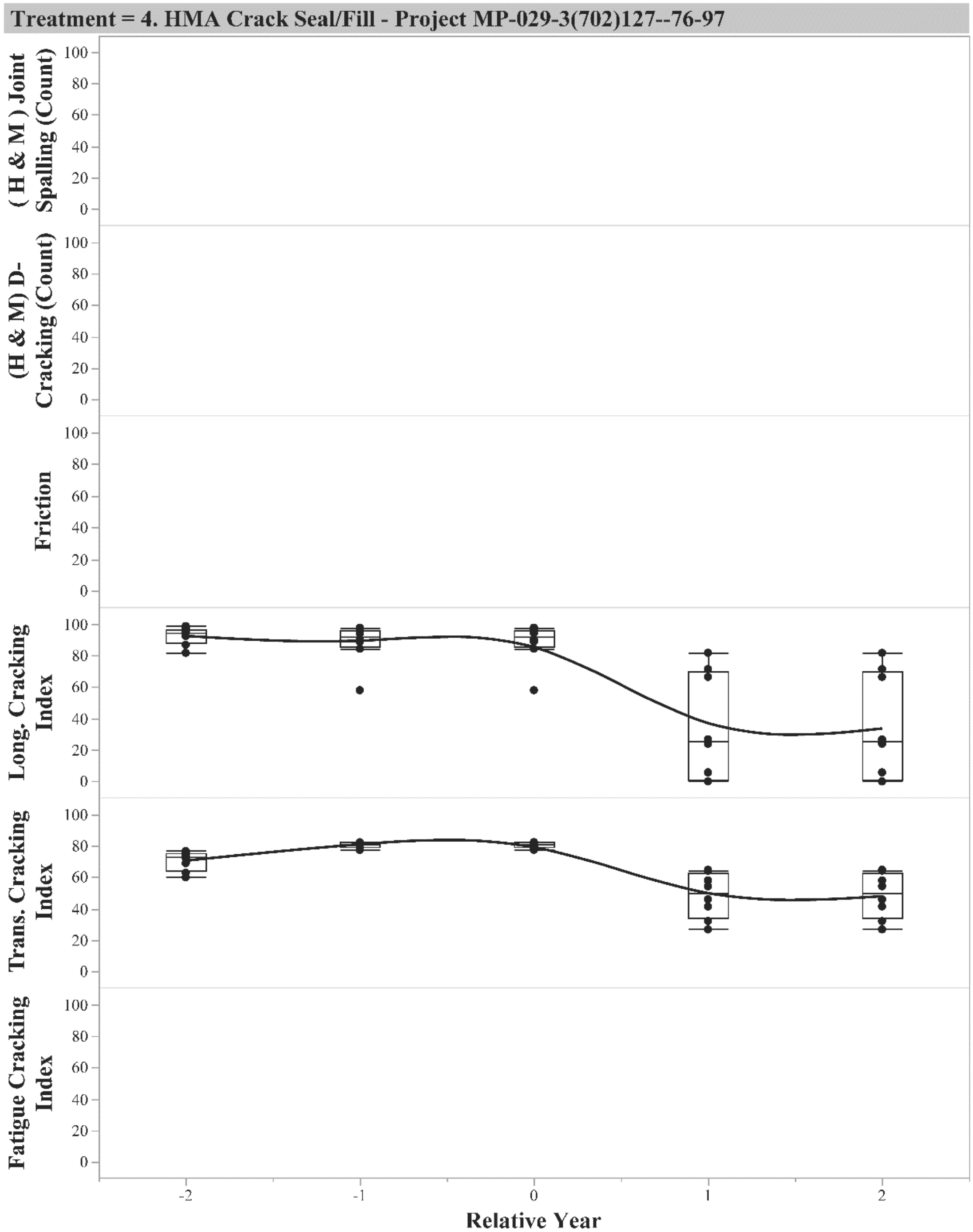

Figure 228. Anecdotal analysis graphs for project MP-029-3(702)127—76-97

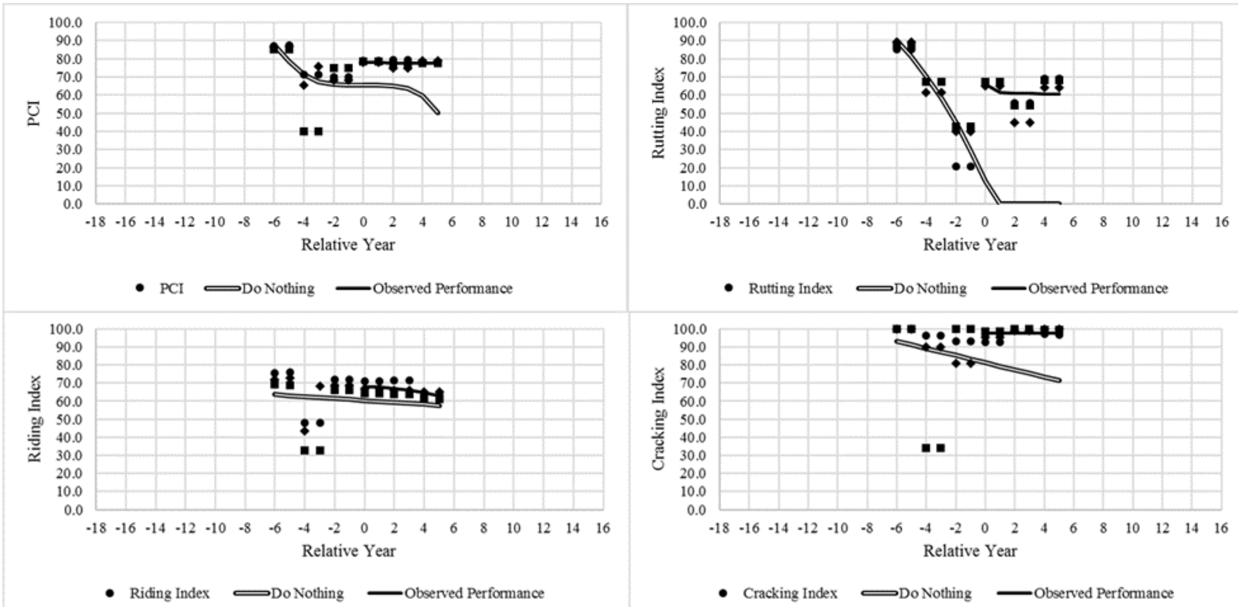

Figure 229. Analytical analysis graphs for project MP-029-3(705)94—76-67

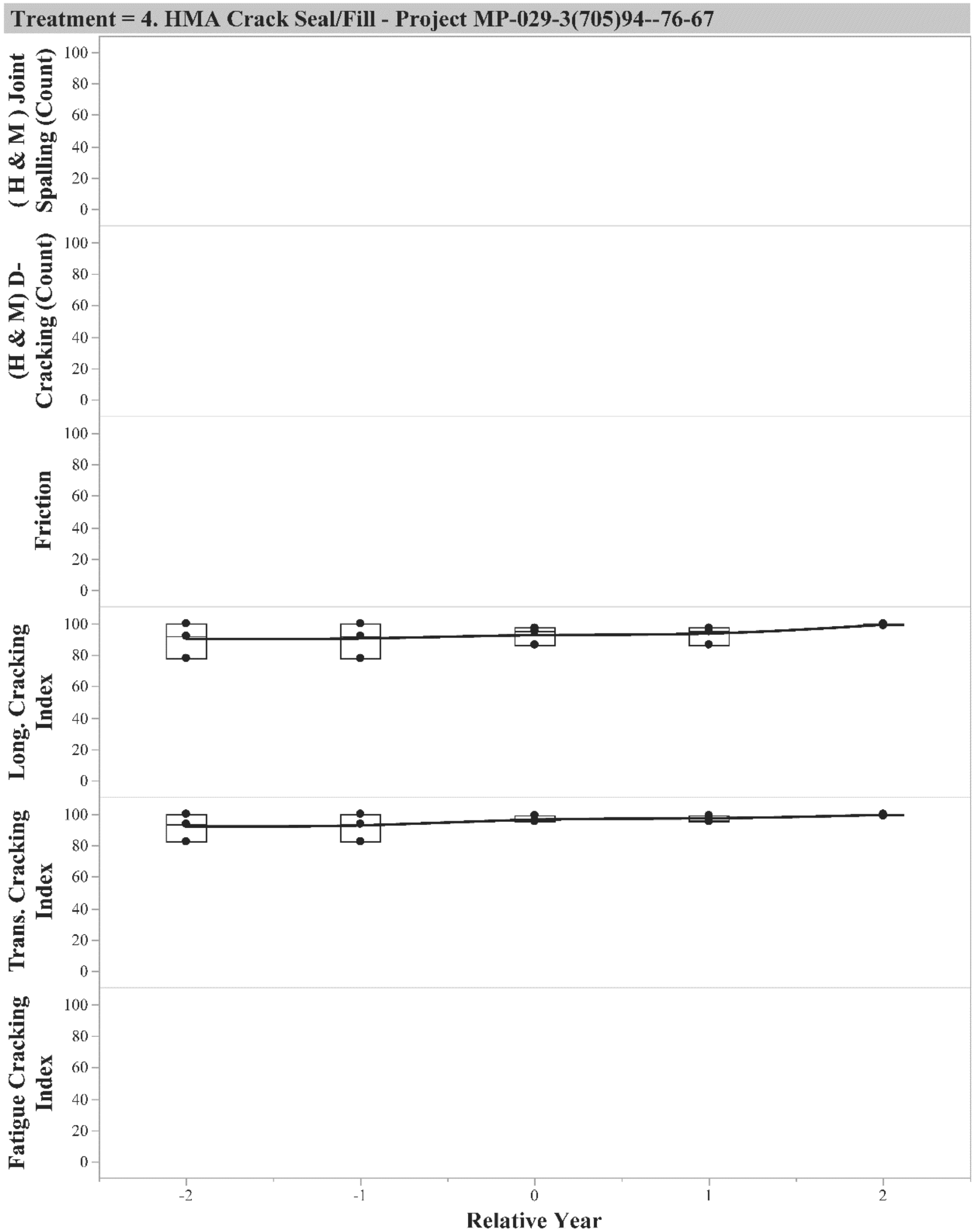

Figure 230. Anecdotal analysis graphs for project MP-029-3(705)94—76-67

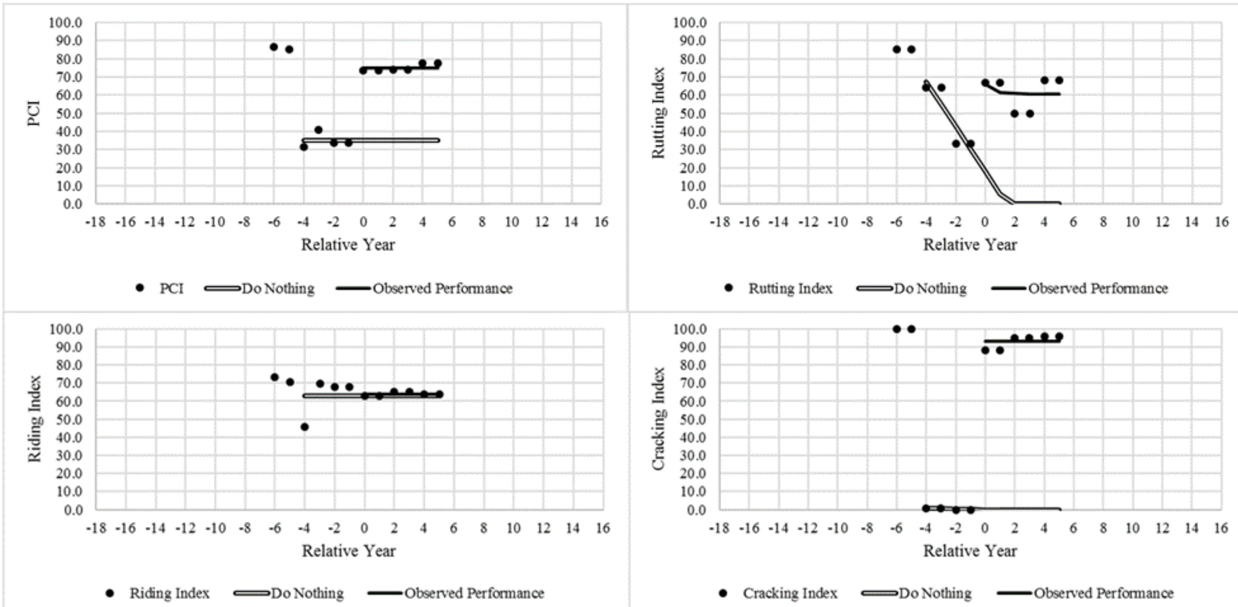

Figure 231. Analytical analysis graphs for project MP-029-3(706)106—76-67

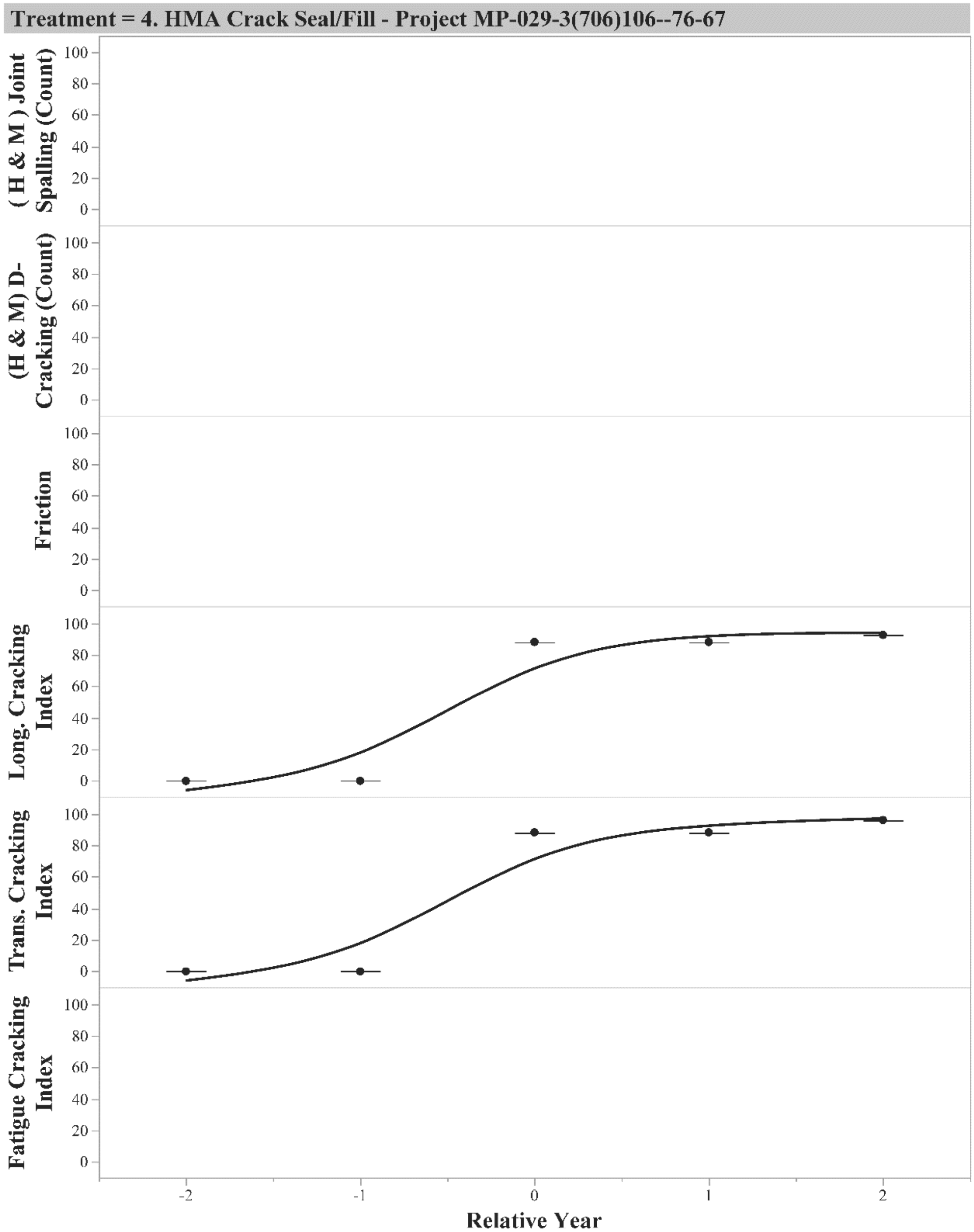

Figure 232. Anecdotal analysis graphs for project MP-029-3(706)106—76-67

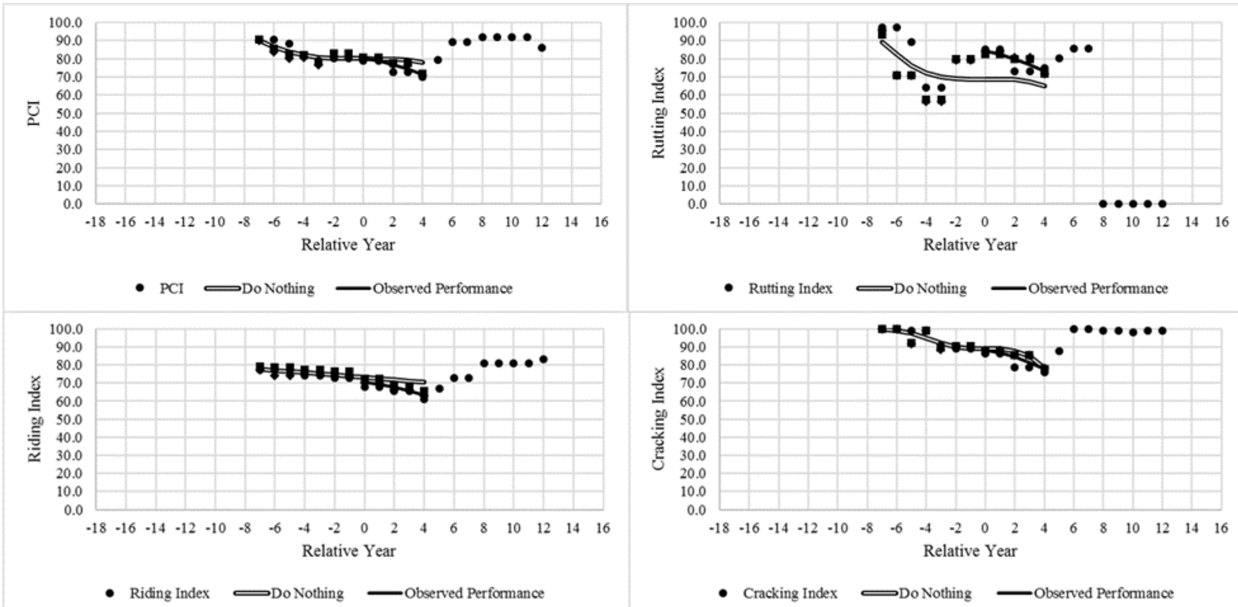

Figure 233. Analytical analysis graphs for project MP-030-1(705)139—76-08

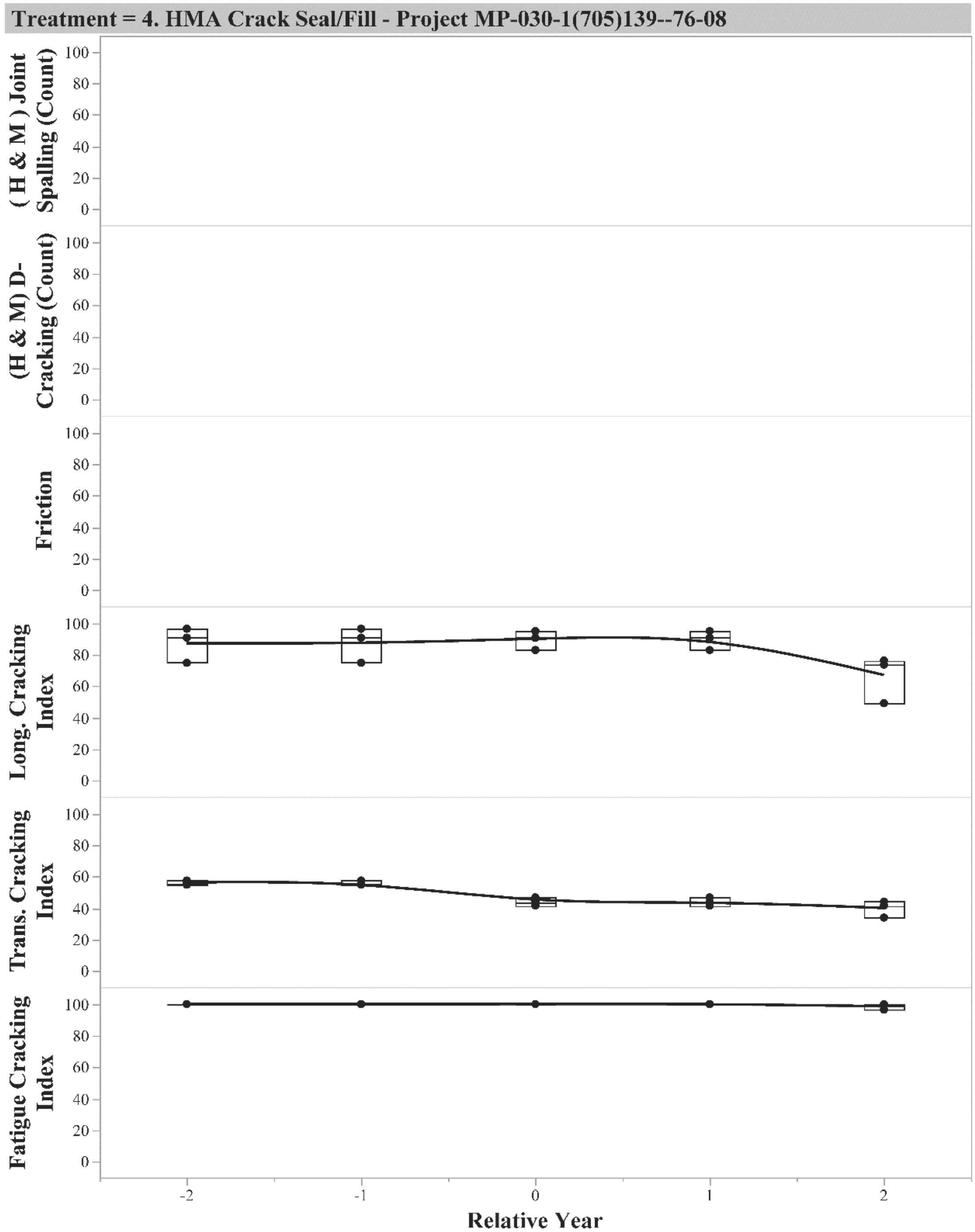

Figure 234. Anecdotal analysis graphs for project MP-030-1(705)139—76-08

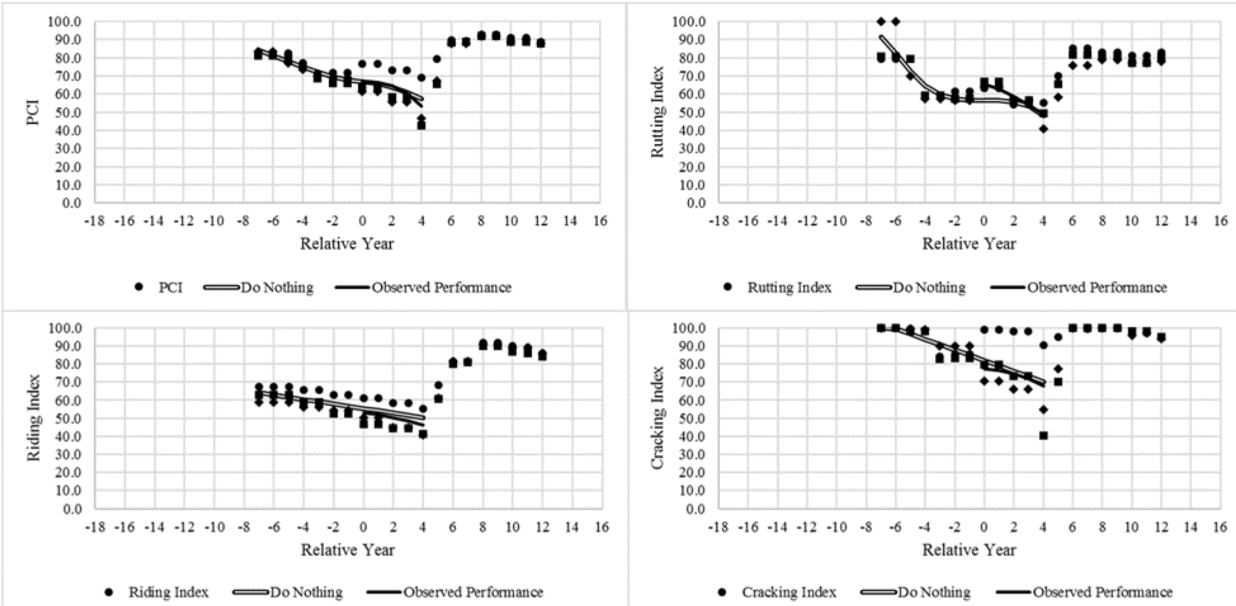

Figure 235. Analytical analysis graphs for project MP-030-6(703)218—76-06

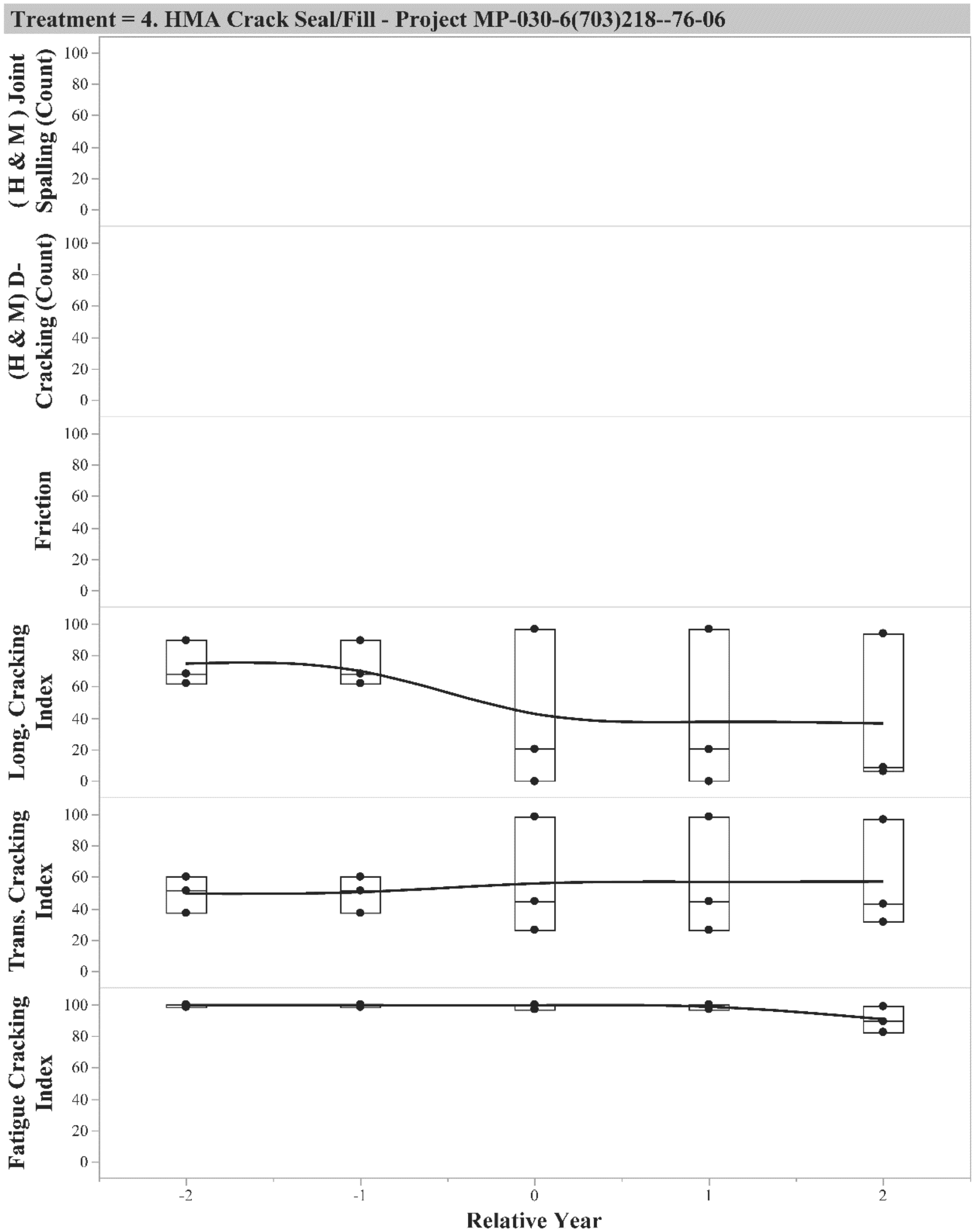

Figure 236. Anecdotal analysis graphs for project MP-030-6(703)218—76-06

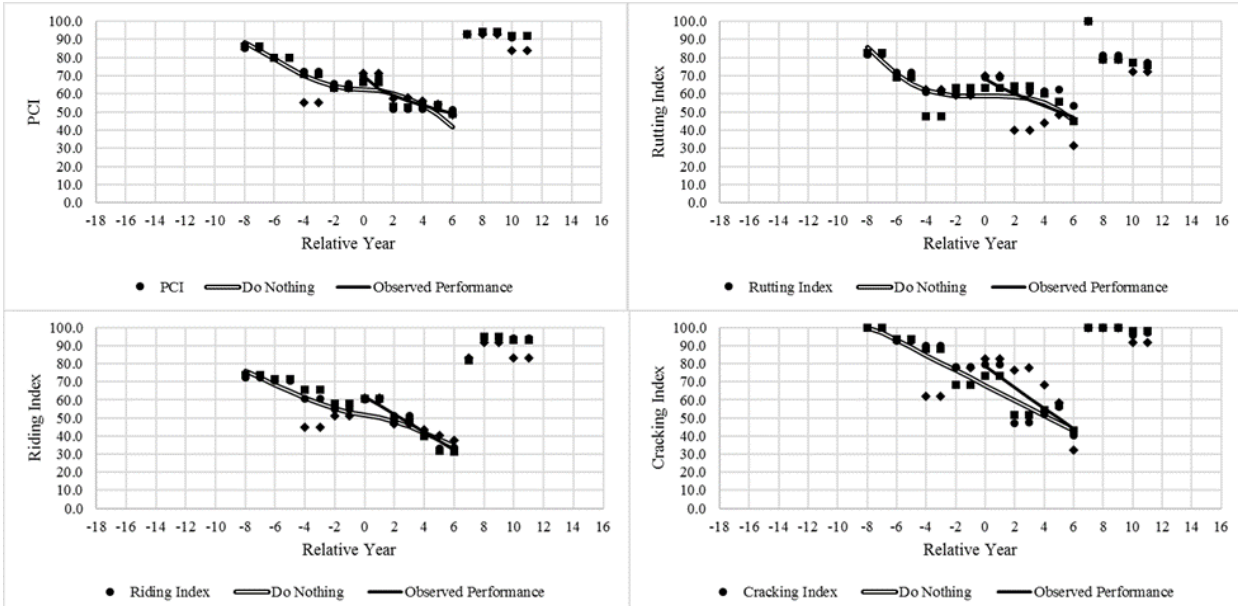

Figure 237. Analytical analysis graphs for project MP-037-3(705)10—76-67

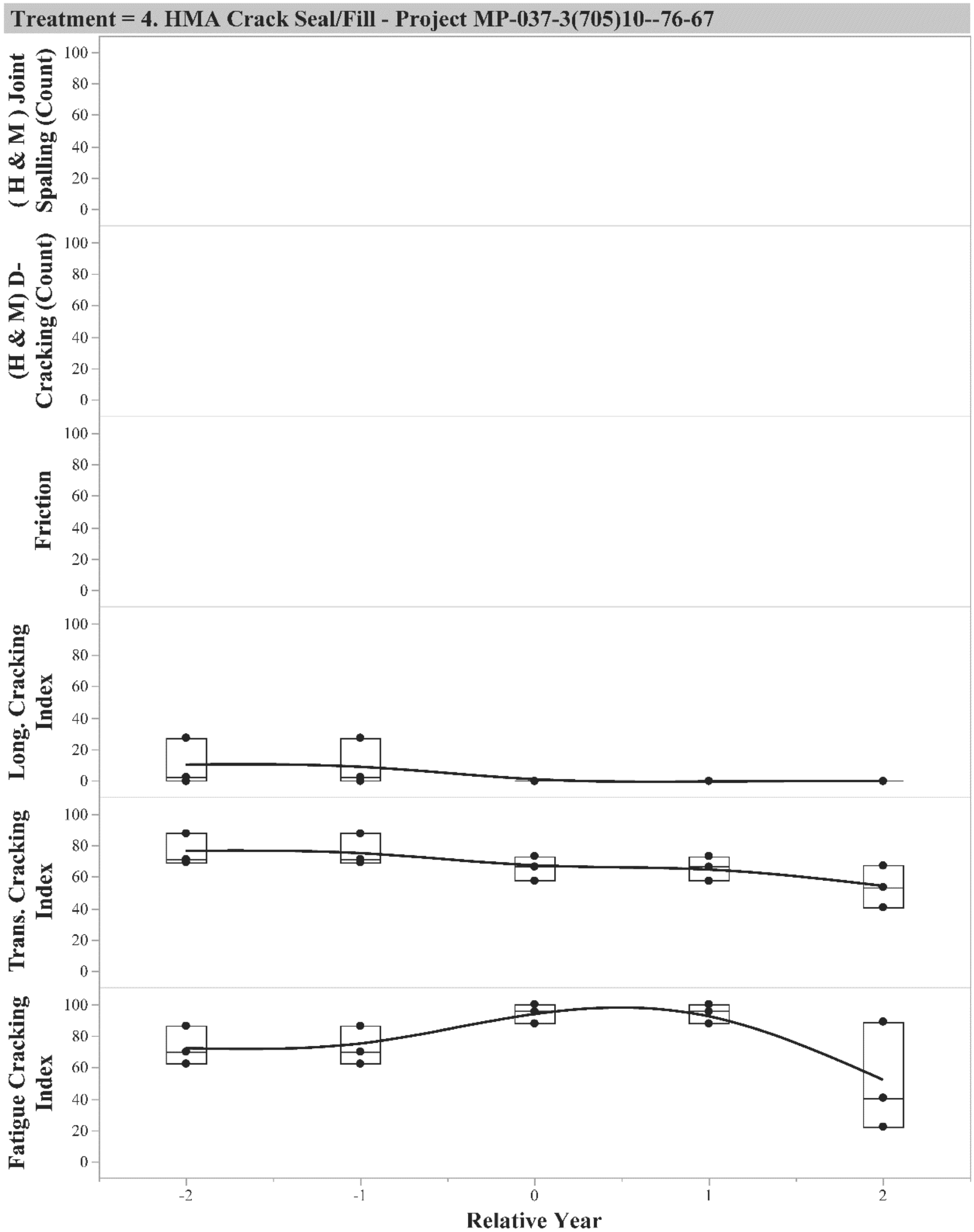

Figure 238. Anecdotal analysis graphs for project MP-037-3(705)10—76-67

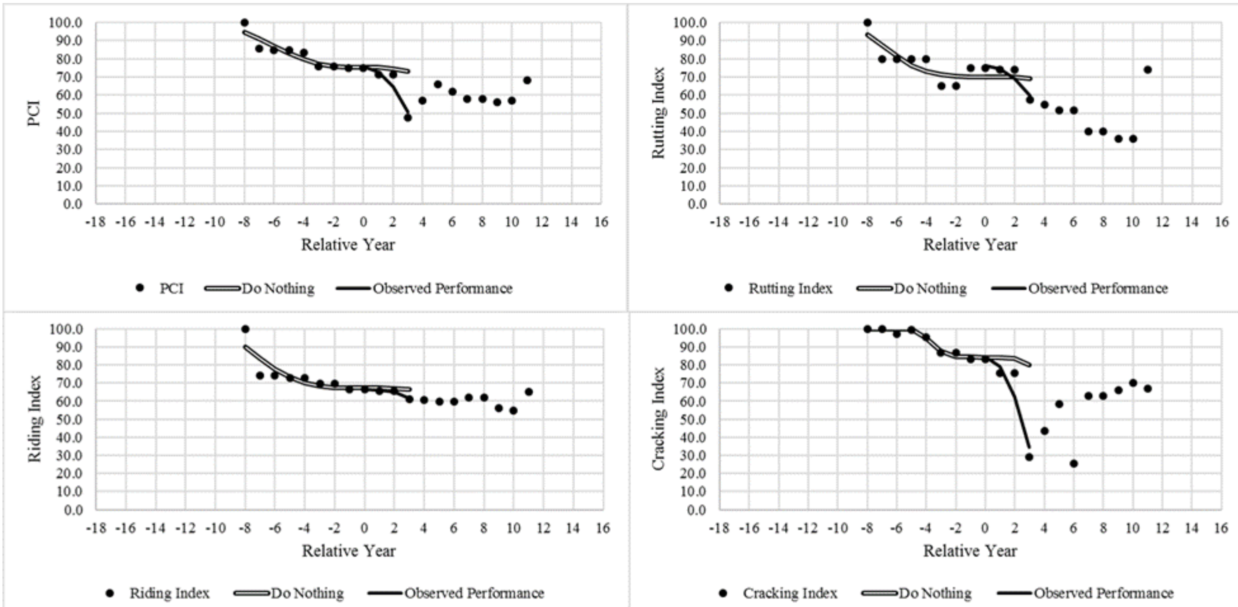

Figure 239. Analytical analysis graphs for project MP-048-4(702)1—76-73

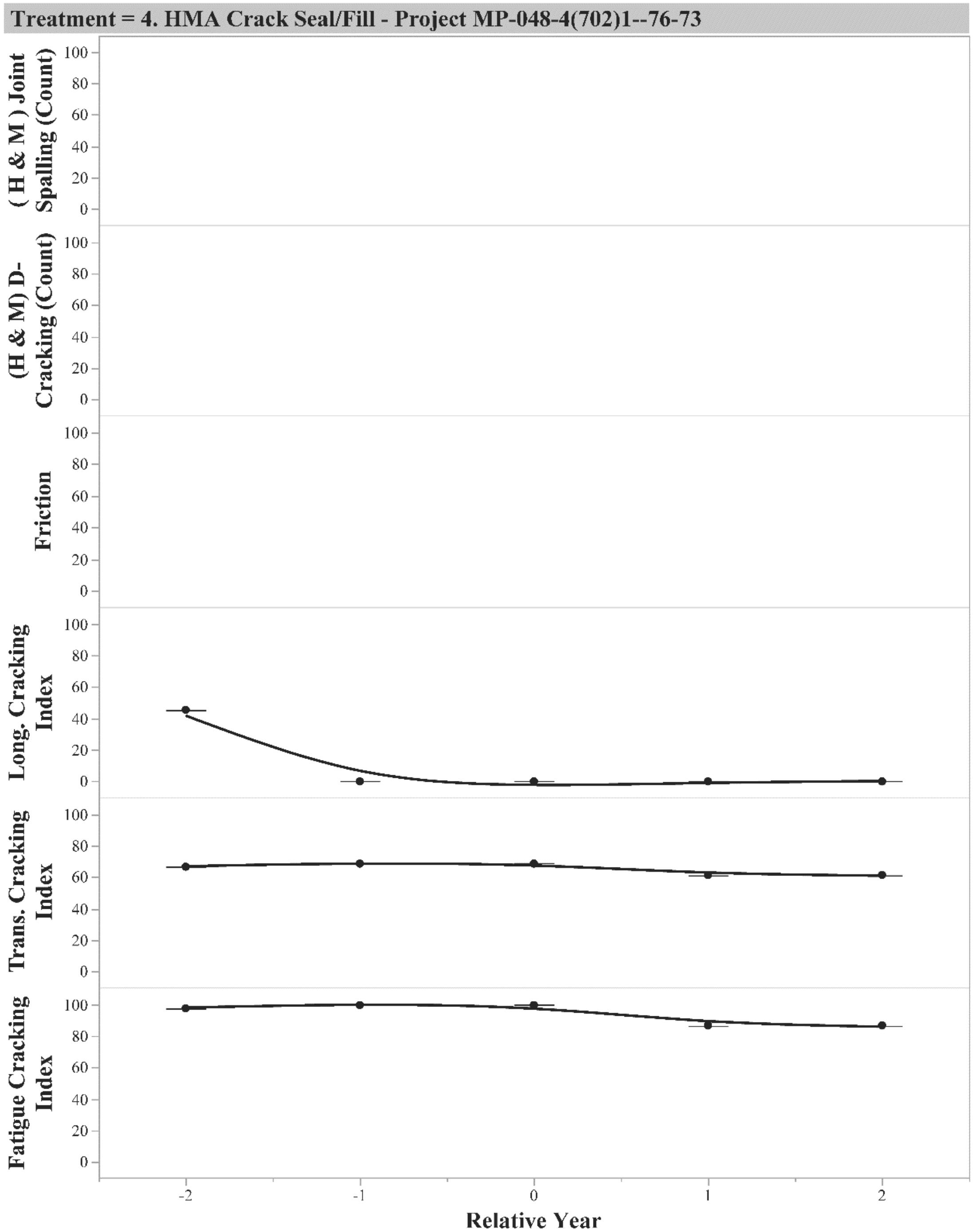

Figure 240. Anecdotal analysis graphs for project MP-048-4(702)1—76-73

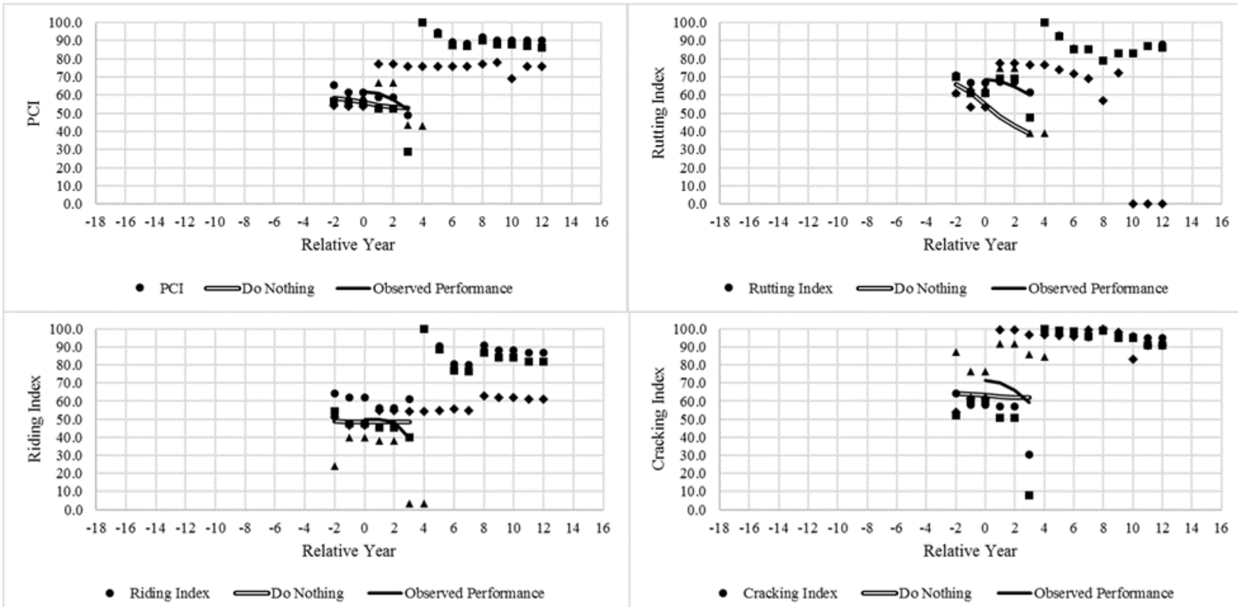

Figure 241. Analytical analysis graphs for project MP-057-2(701)32—76-07

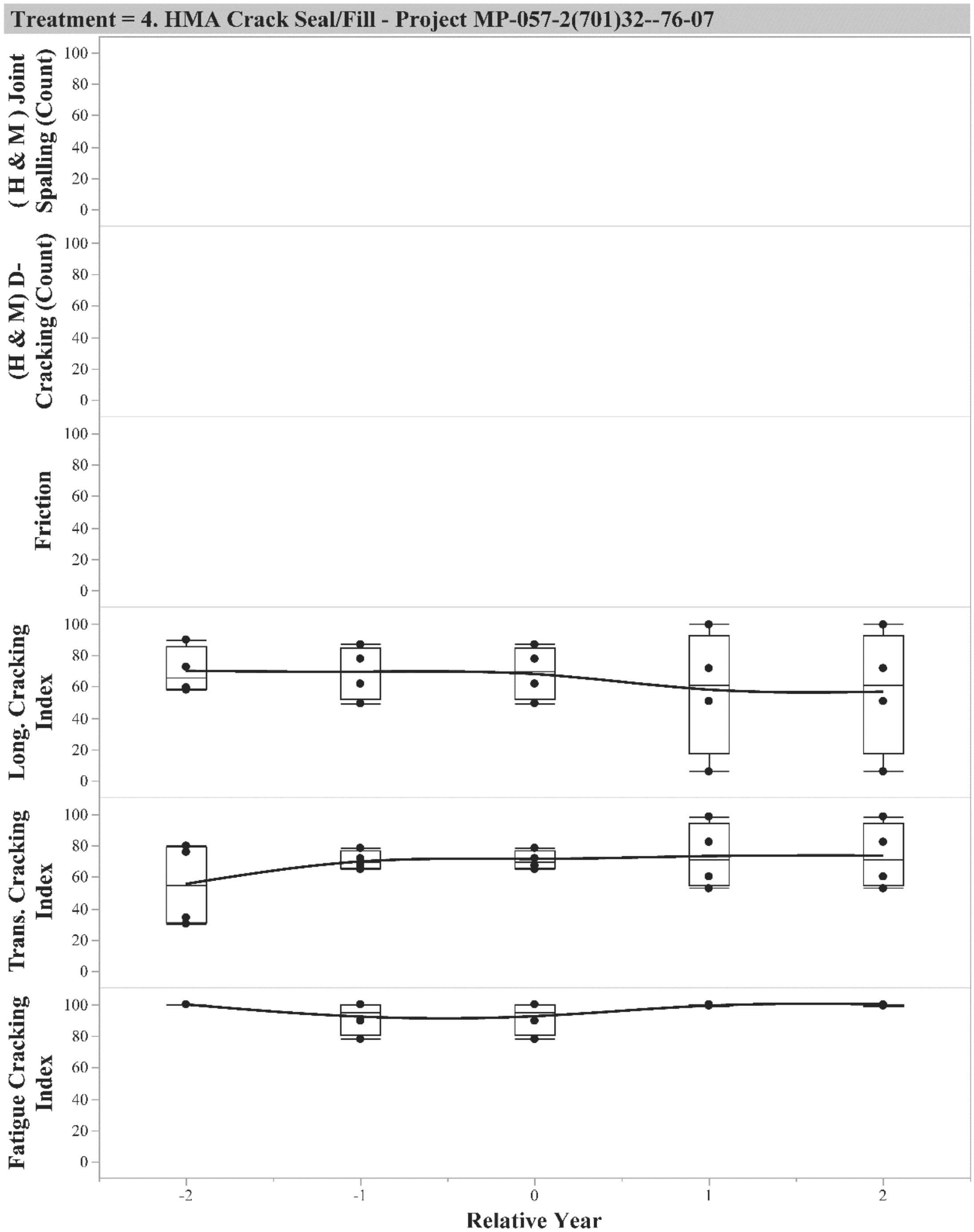

Figure 242. Anecdotal analysis graphs for project MP-057-2(701)32—76-07

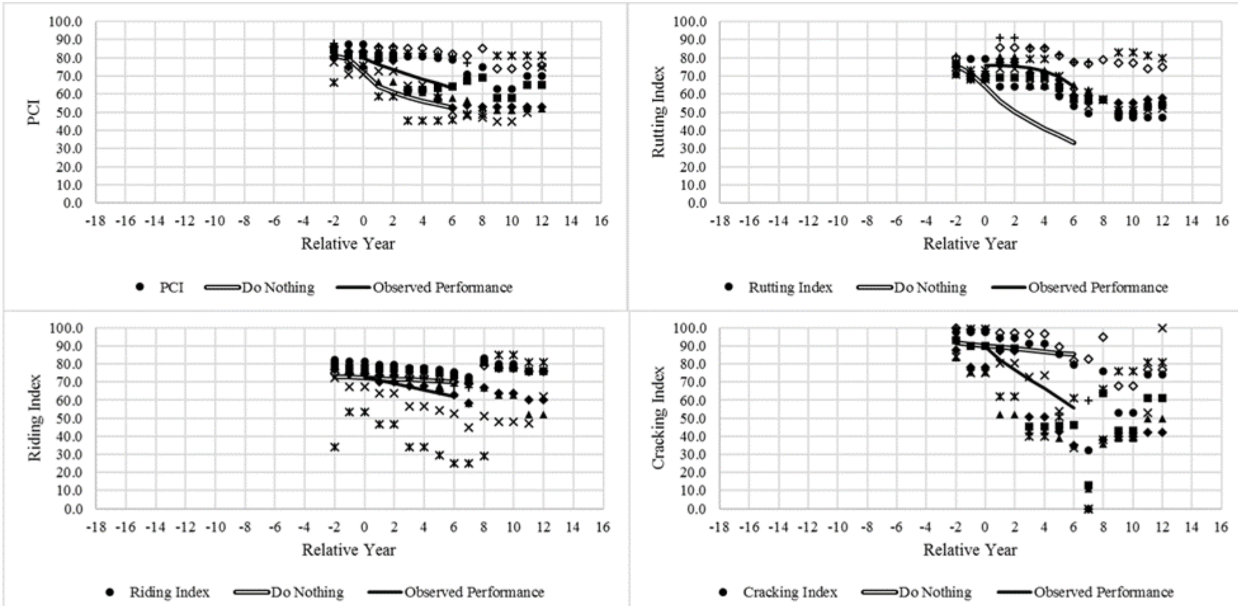

Figure 243. Analytical analysis graphs for project MP-057-2(701)8—76-12

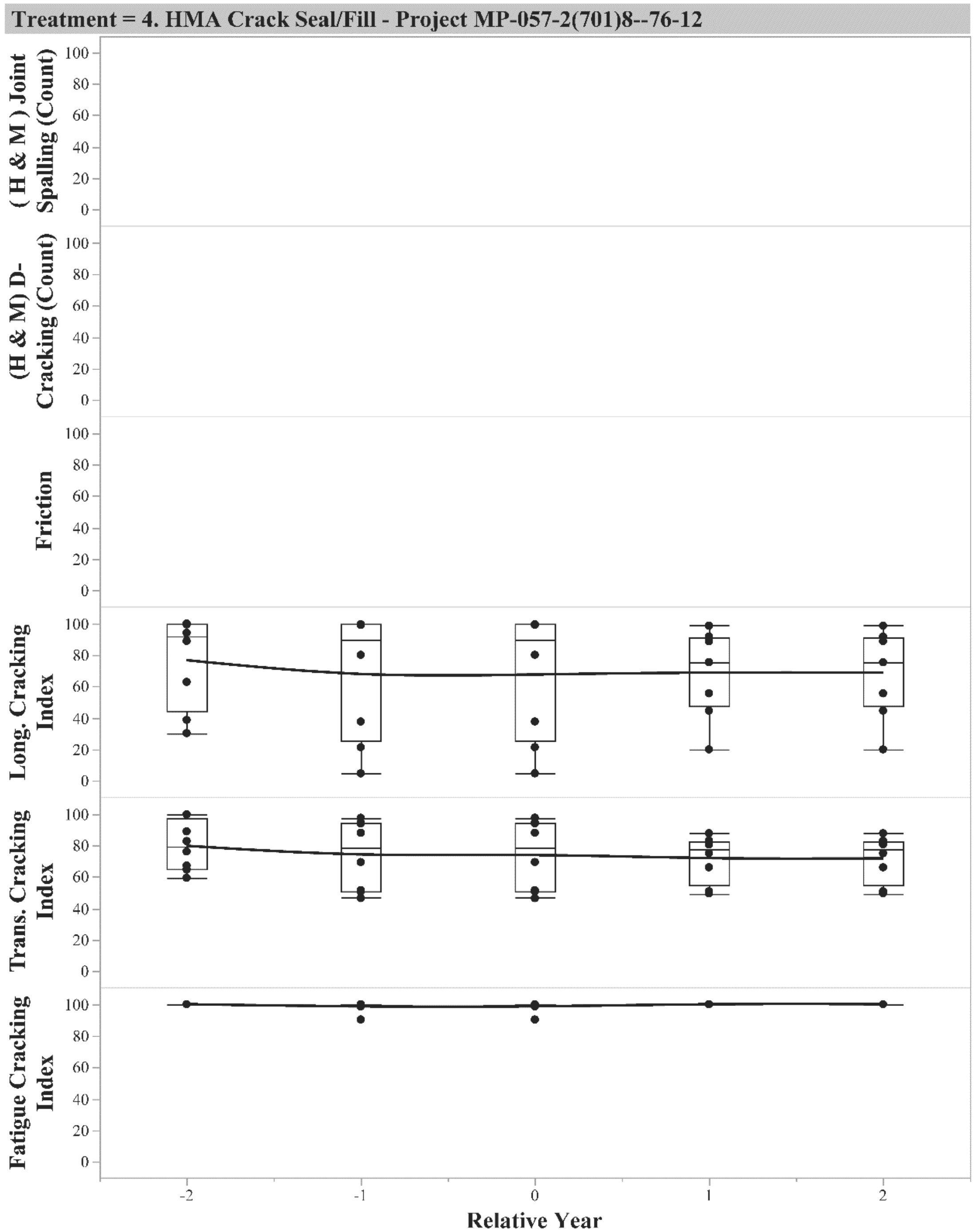

Figure 244. Anecdotal analysis graphs for project MP-057-2(701)8—76-12

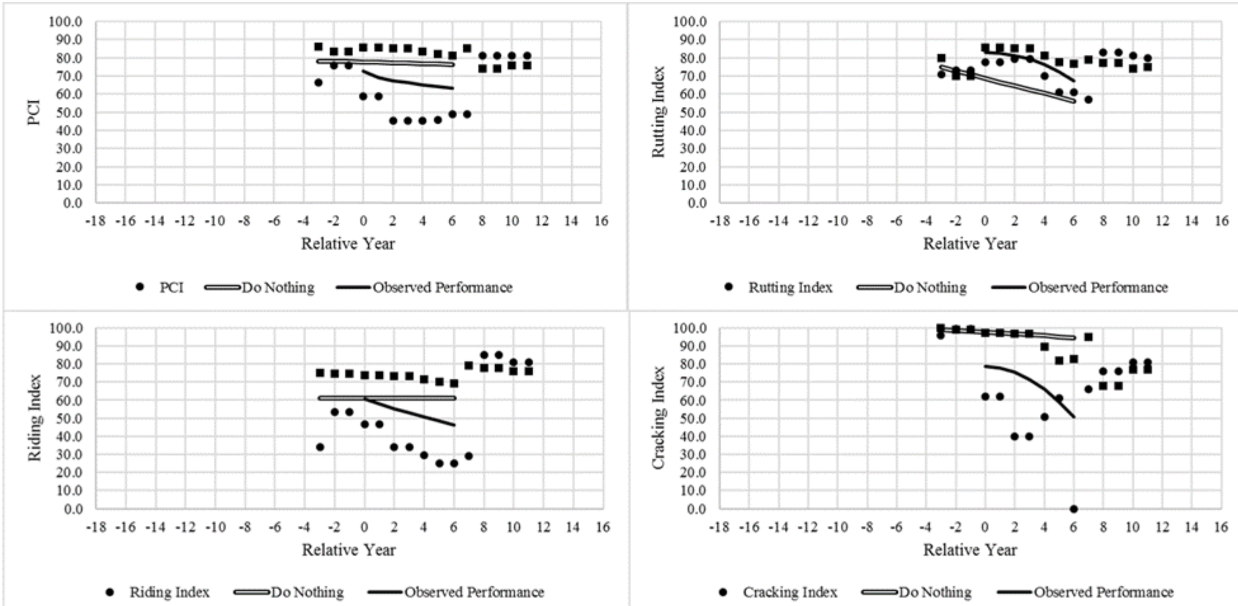

Figure 245. Analytical analysis graphs for project MP-057-2(702)25—76-12

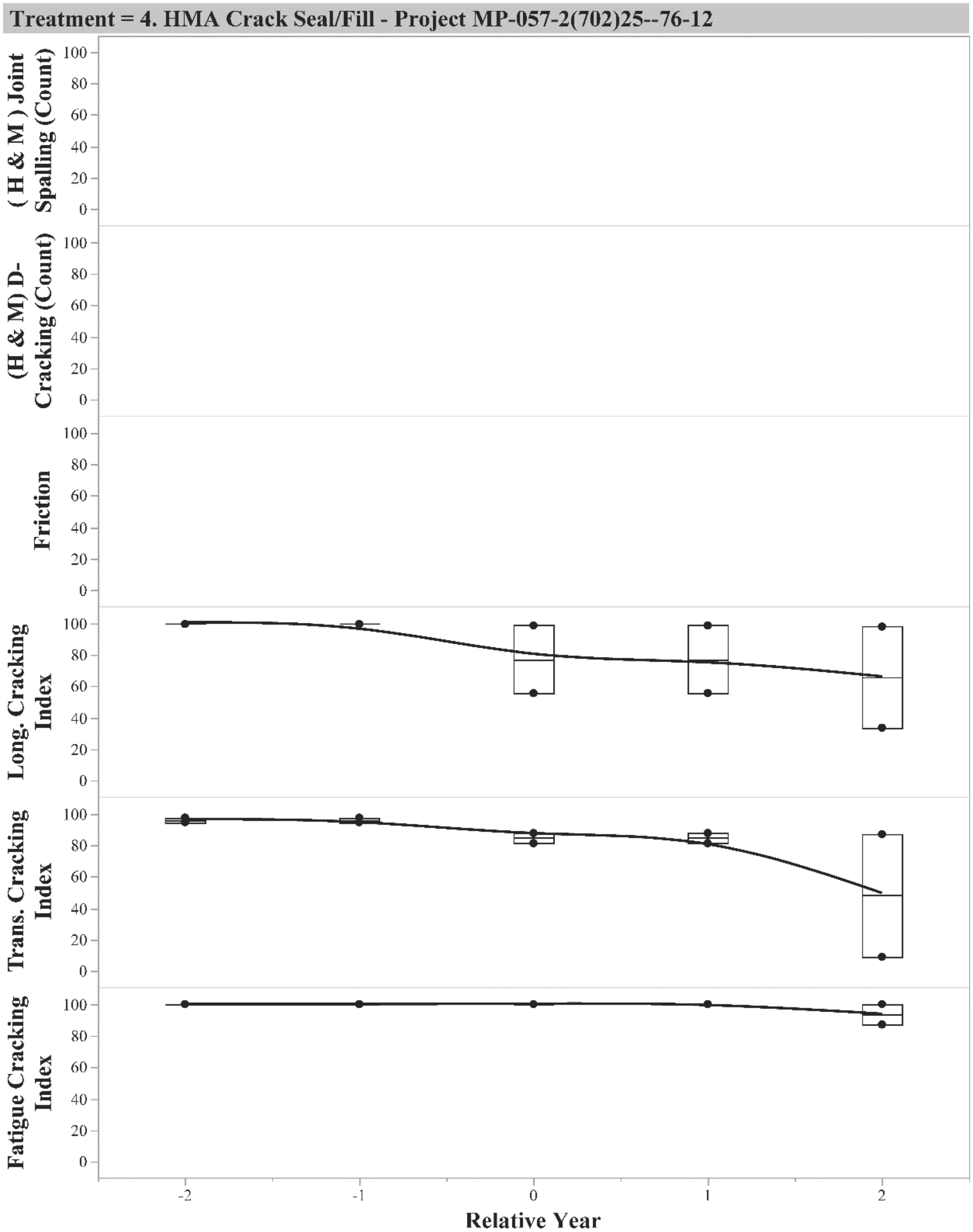

Figure 246. Anecdotal analysis graphs for project MP-057-2(702)25—76-12

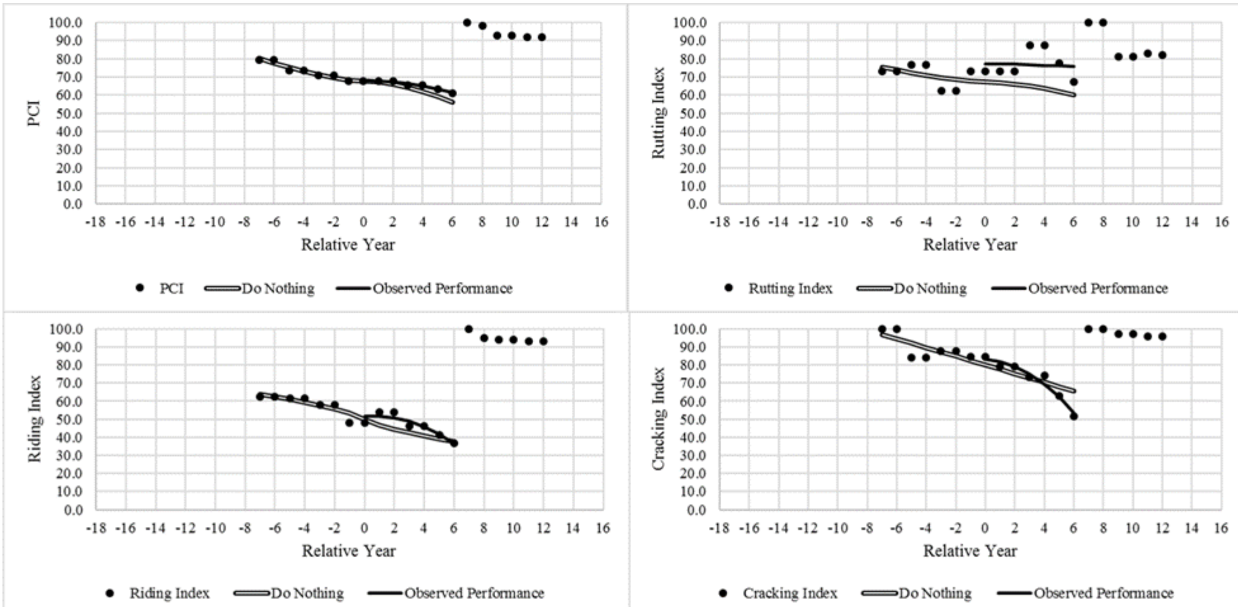

Figure 247. Analytical analysis graphs for project MP-059-3(701)105—76-24

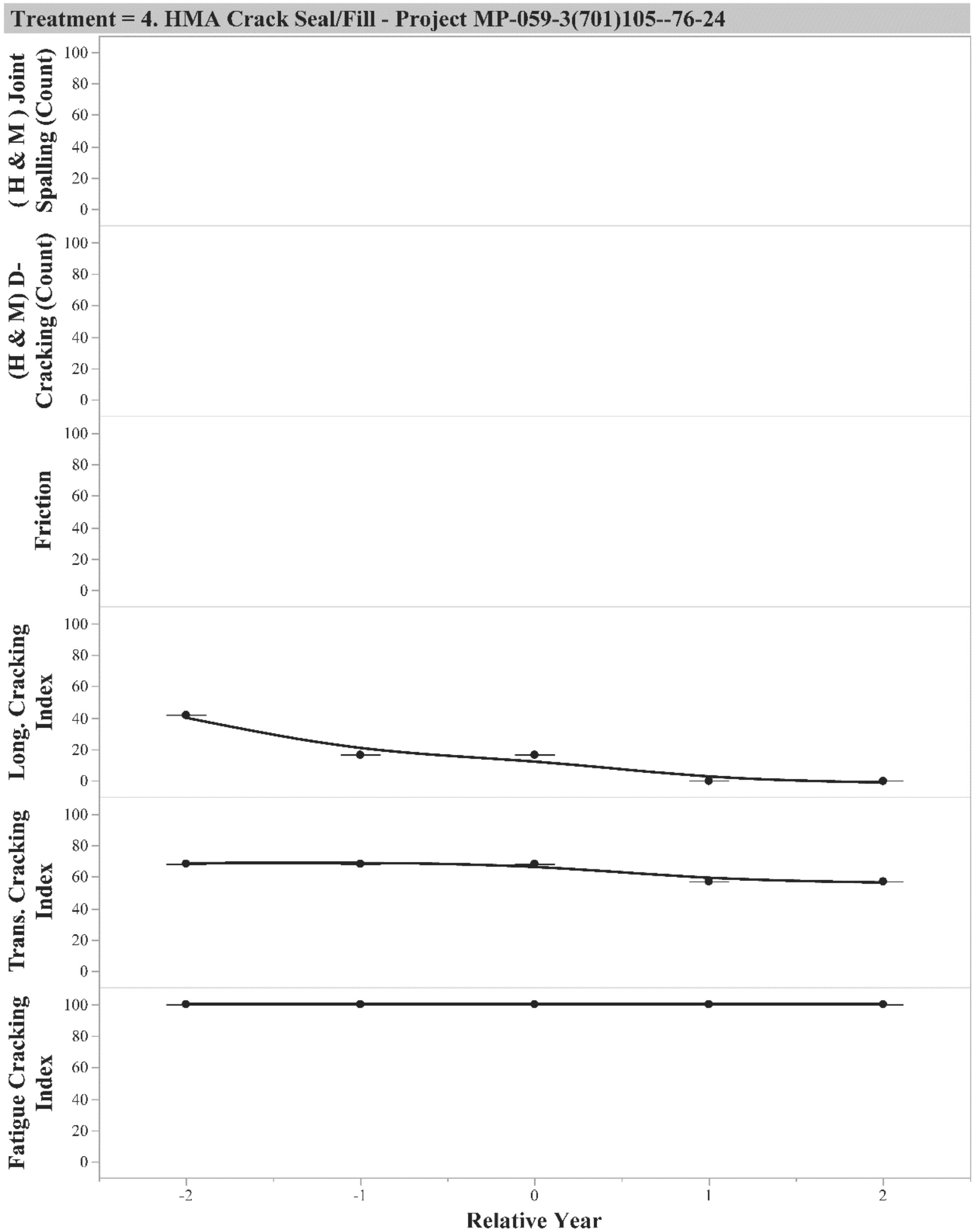

Figure 248. Anecdotal analysis graphs for project MP-059-3(701)105—76-24

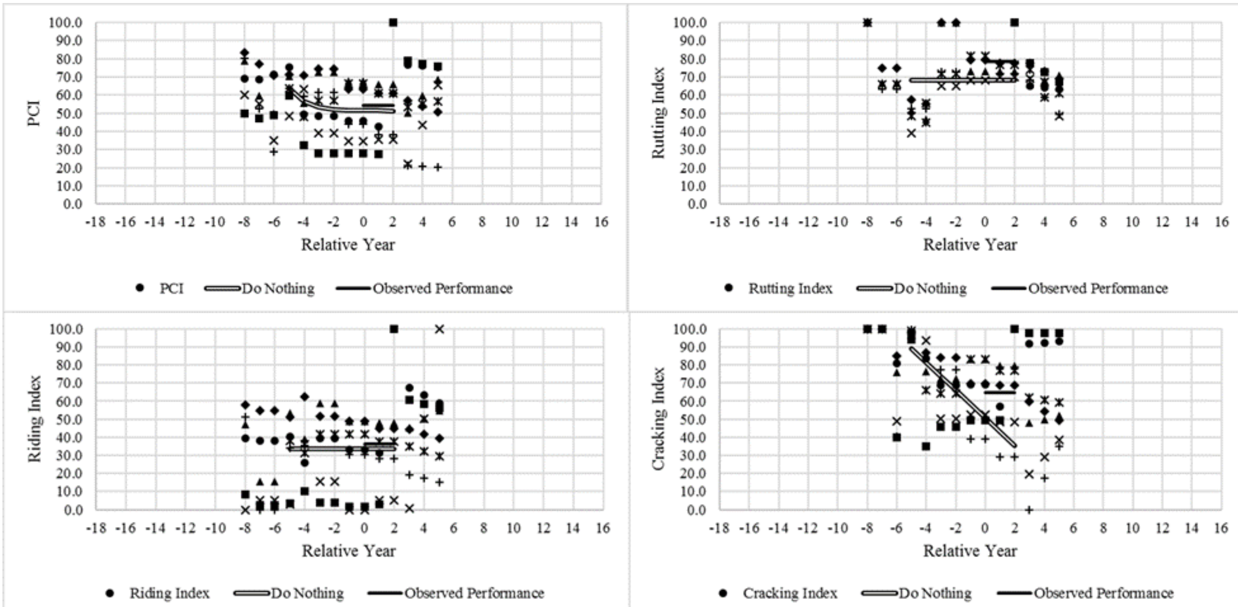

Figure 249. Analytical analysis graphs for project MP-061-6(709)112—76-82

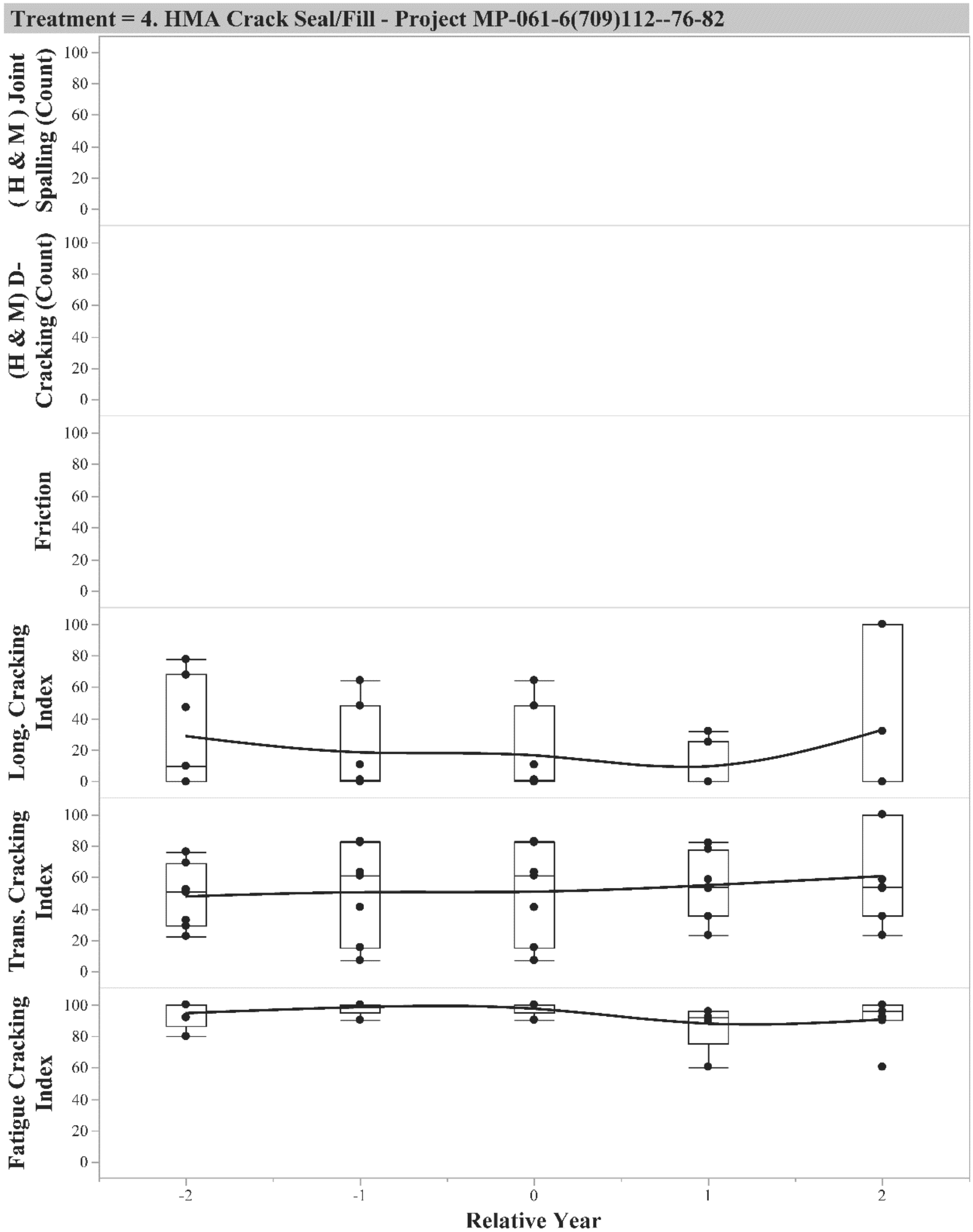

Figure 250. Anecdotal analysis graphs for project MP-061-6(709)112—76-82

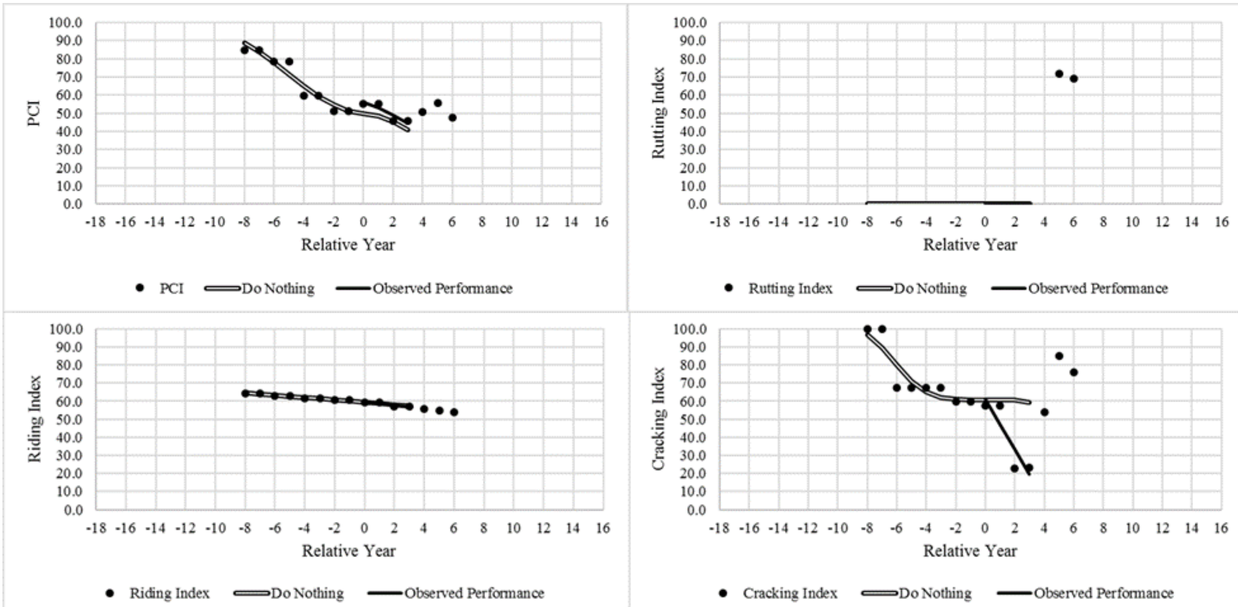

Figure 251. Analytical analysis graphs for project MP-063-2(702)225—76-45

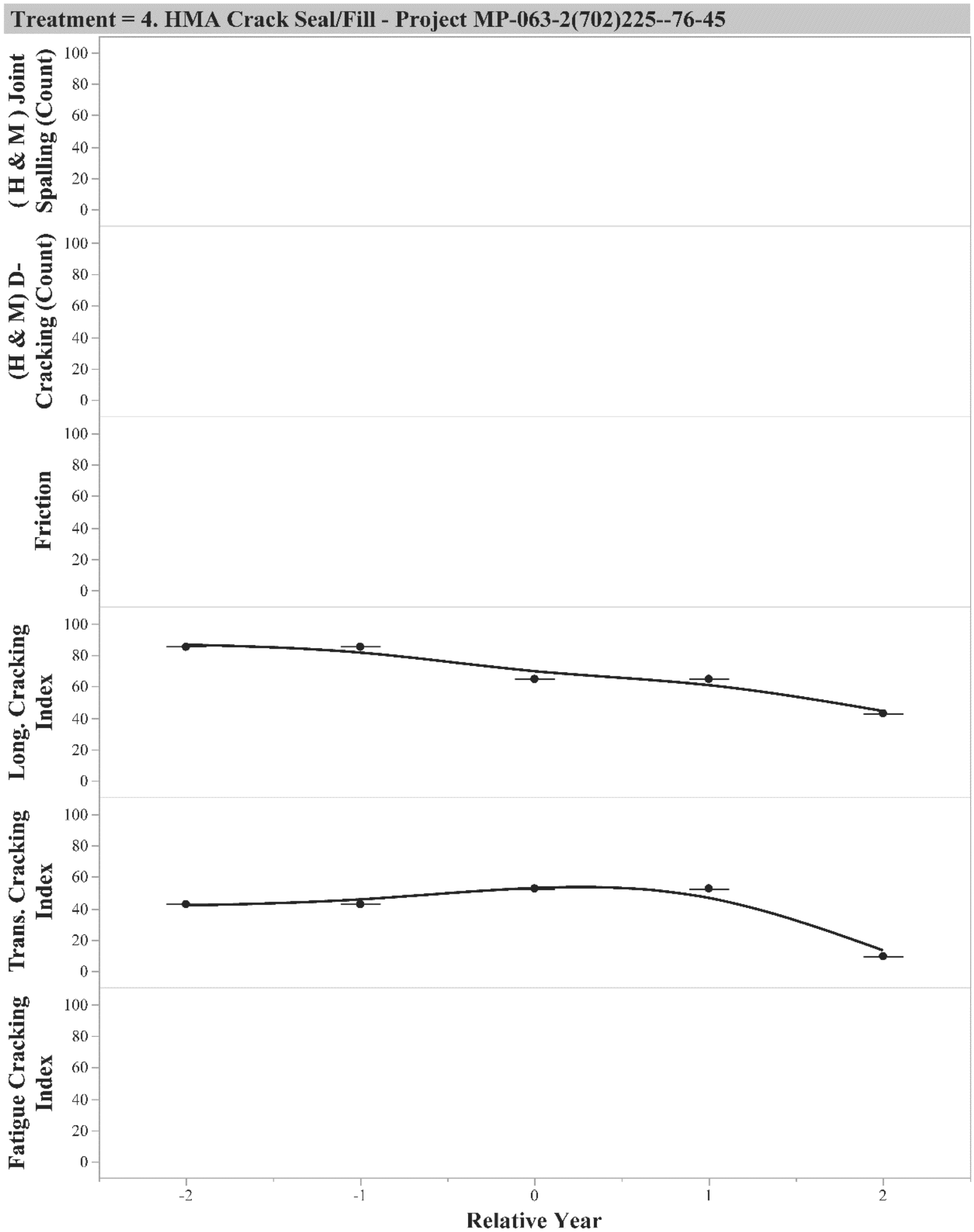

Figure 252. Anecdotal analysis graphs for project MP-063-2(702)225—76-45

APPENDIX C. ANALYTICAL AND ANECDOTAL GRAPHS FOR RIGID PAVEMENT PRESERVATION METHODS

Patching Projects

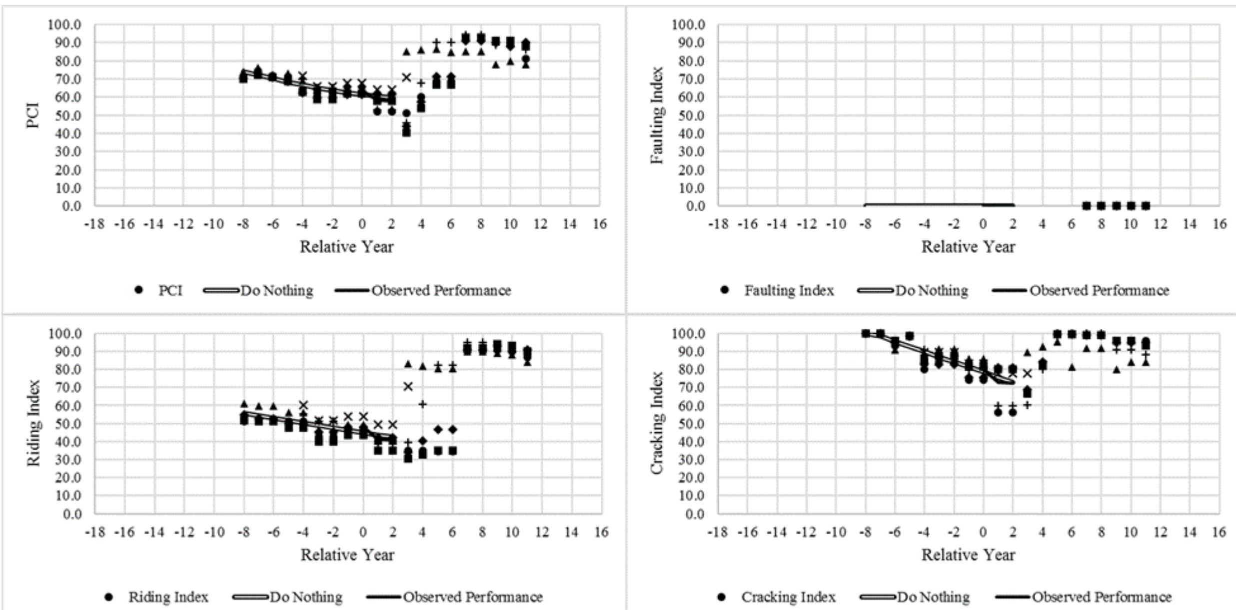

Figure 253. Analytical analysis graphs for project MP-002-4(700)86—76-80

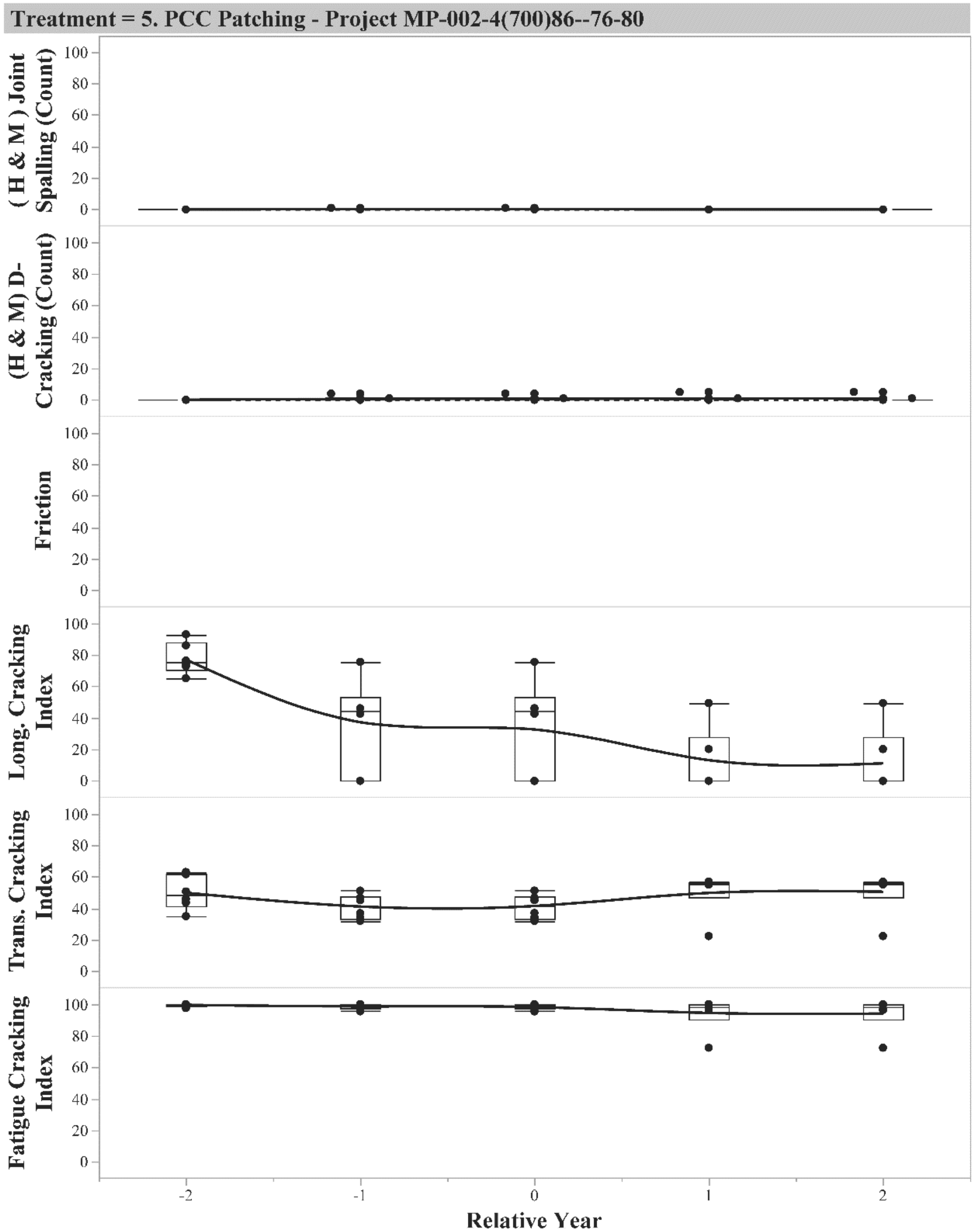

Figure 254. Anecdotal analysis graphs for project MP-002-4(700)86—76-80

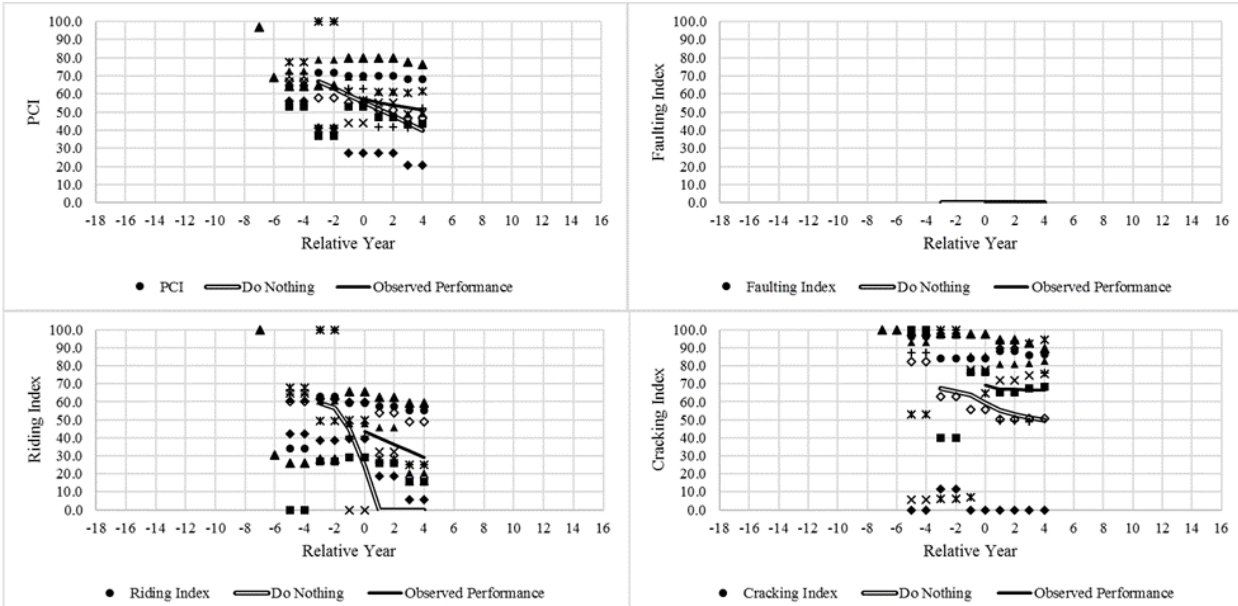

Figure 255. Analytical analysis graphs for project MP-018-2(704)214—76-34

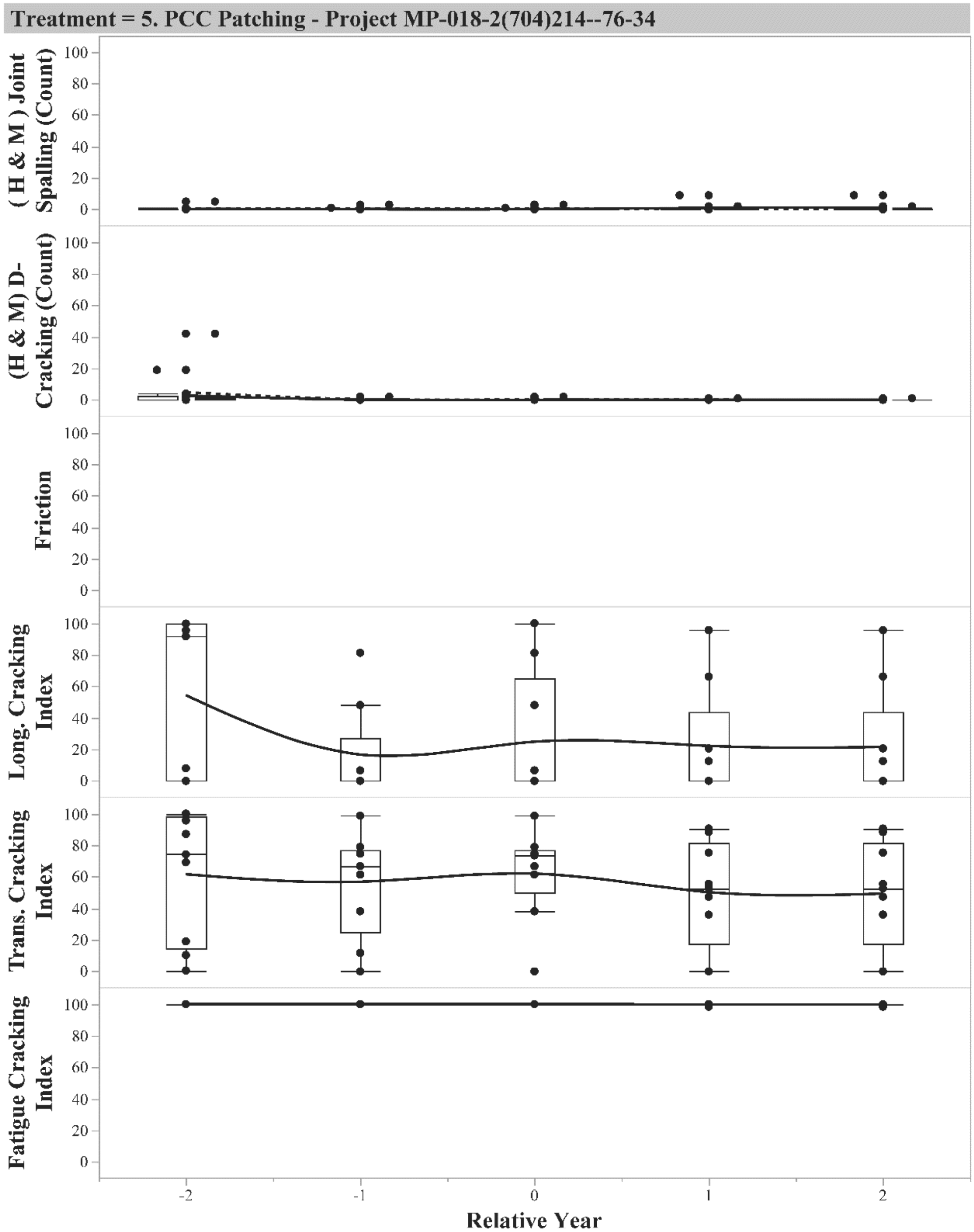

Figure 256. Anecdotal analysis graphs for project MP-018-2(704)214—76-34

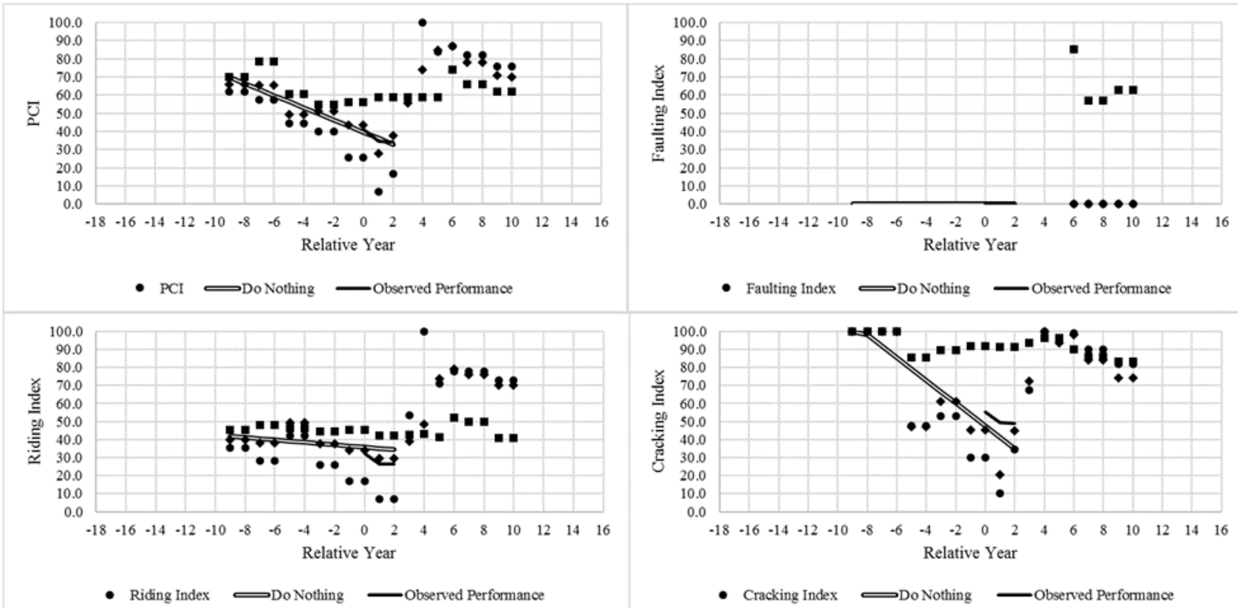

Figure 257. Analytical analysis graphs for project MP-018-3(703)20—76-84

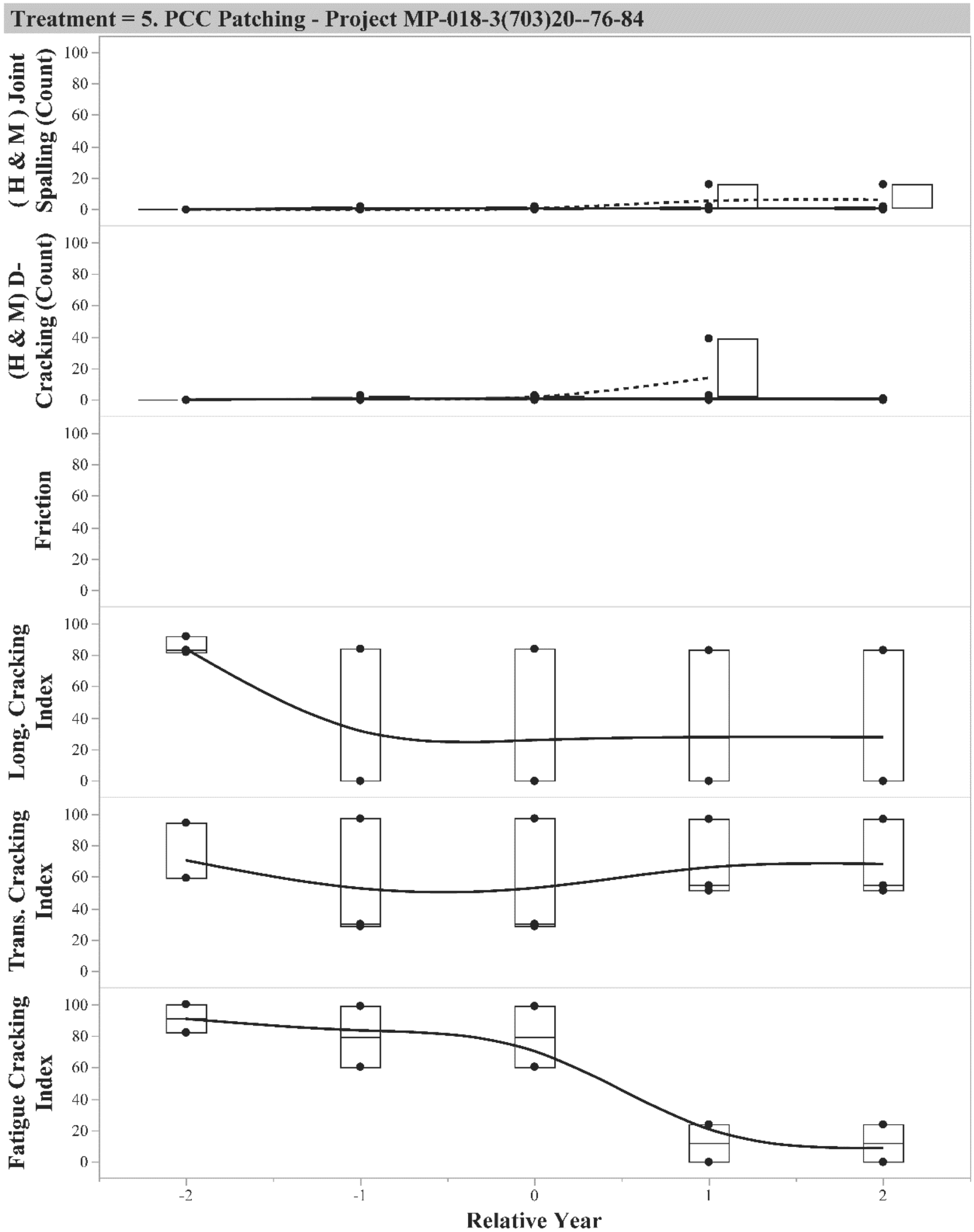

Figure 258. Anecdotal analysis graphs for project MP-018-3(703)20—76-84

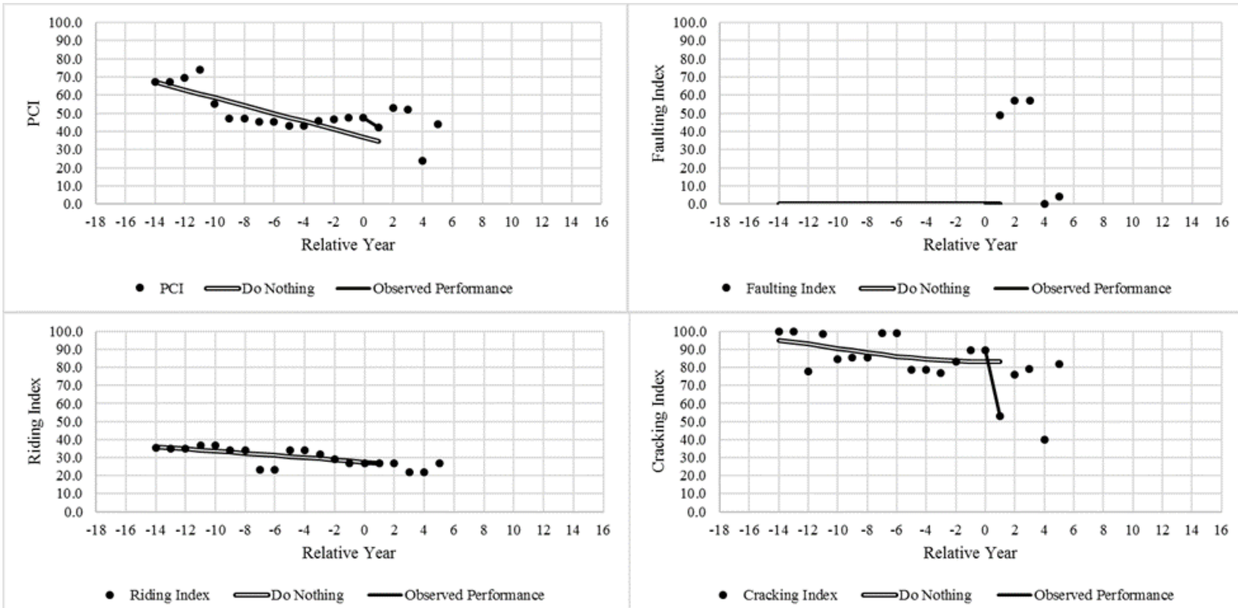

Figure 259. Analytical analysis graphs for project MP-025-4(701)48—76-01

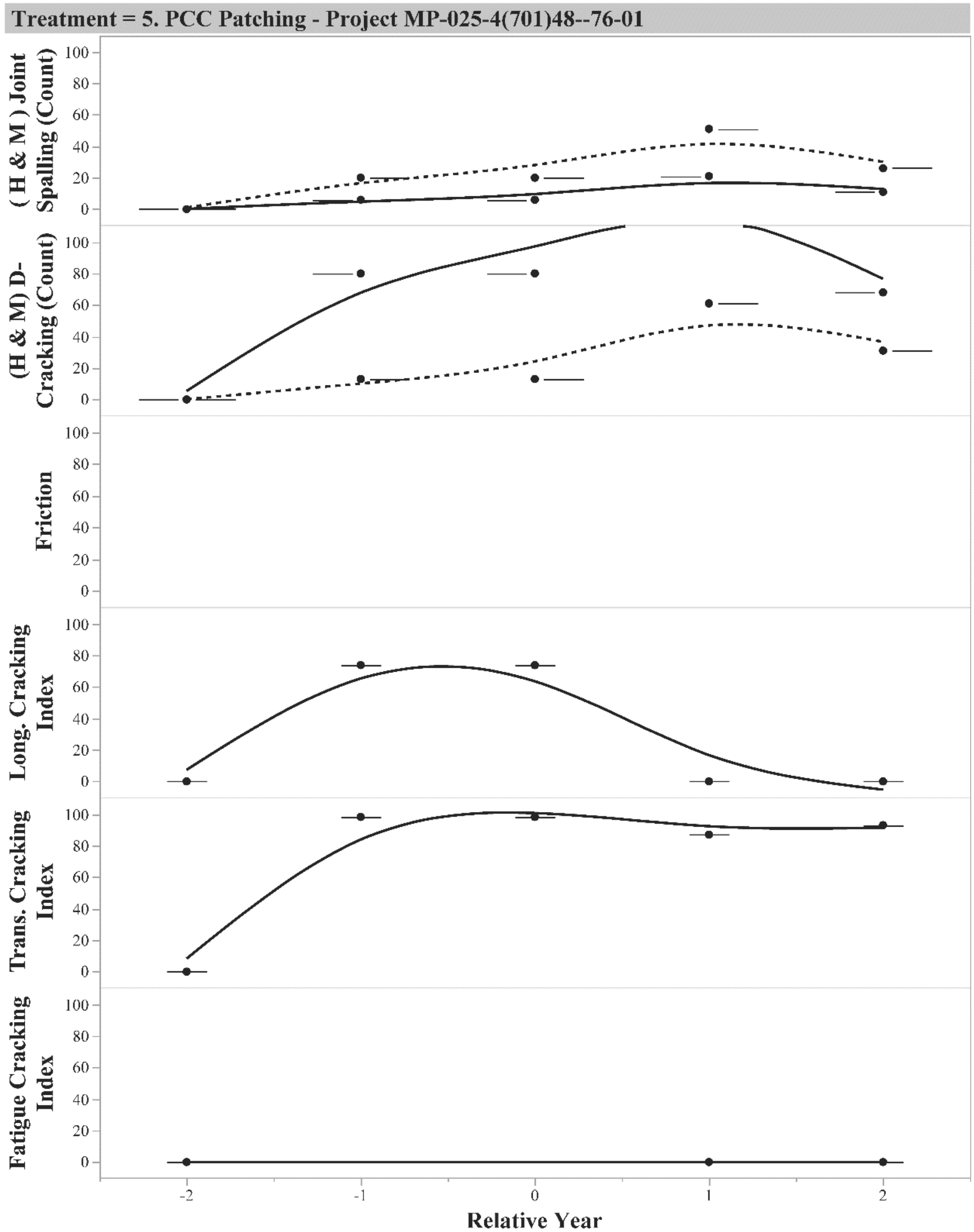

Figure 260. Anecdotal analysis graphs for project MP-025-4(701)48—76-01

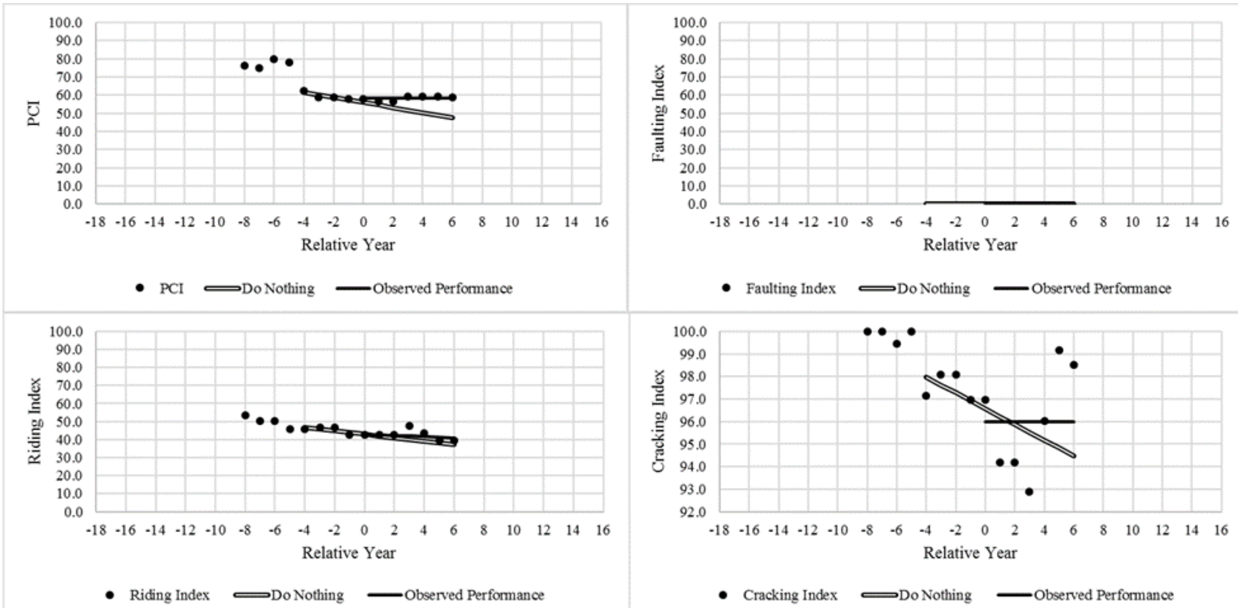

Figure 261. Analytical analysis graphs for project MP-025-4(702)16—76-80

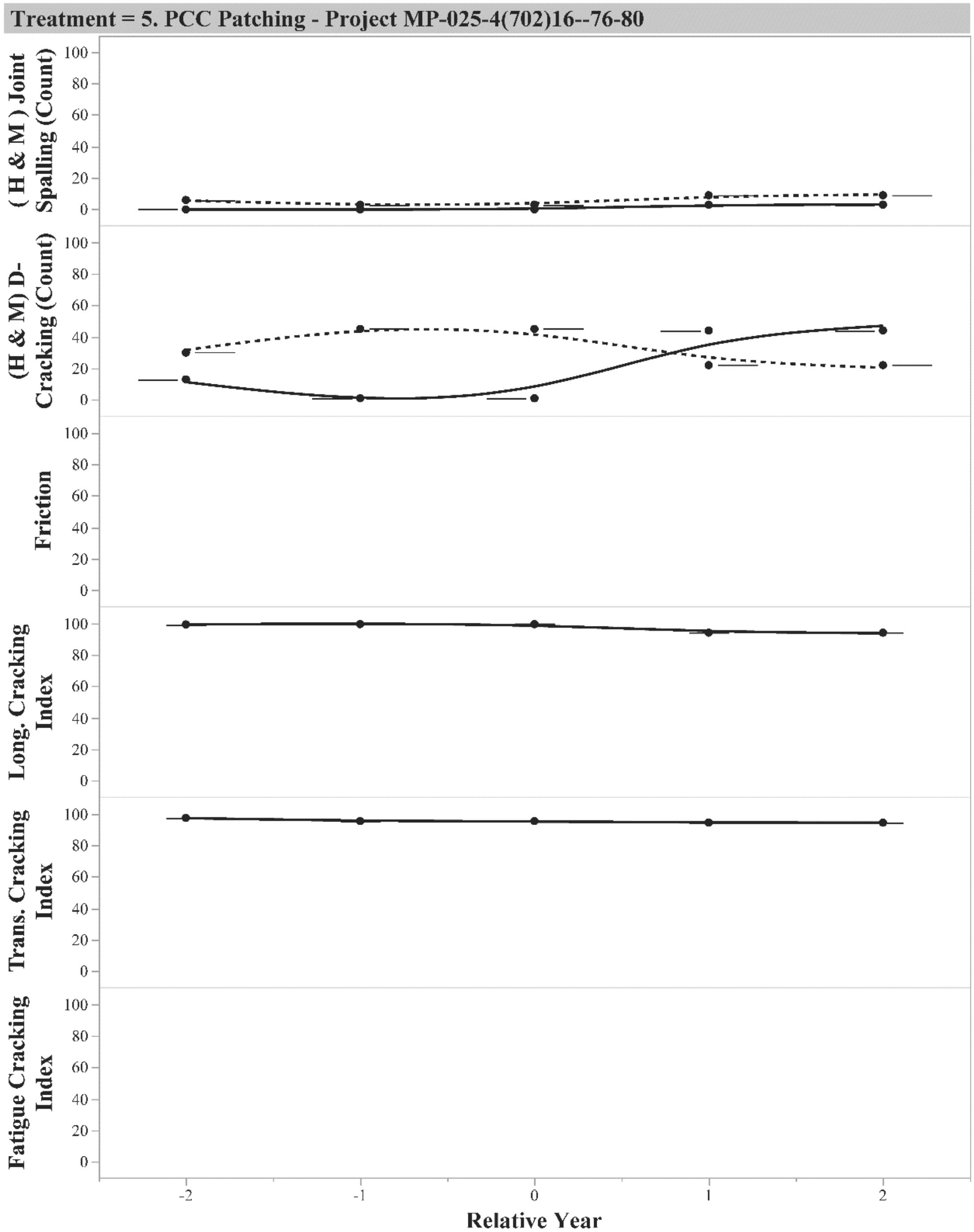

Figure 262. Anecdotal analysis graphs for project MP-025-4(702)16—76-80

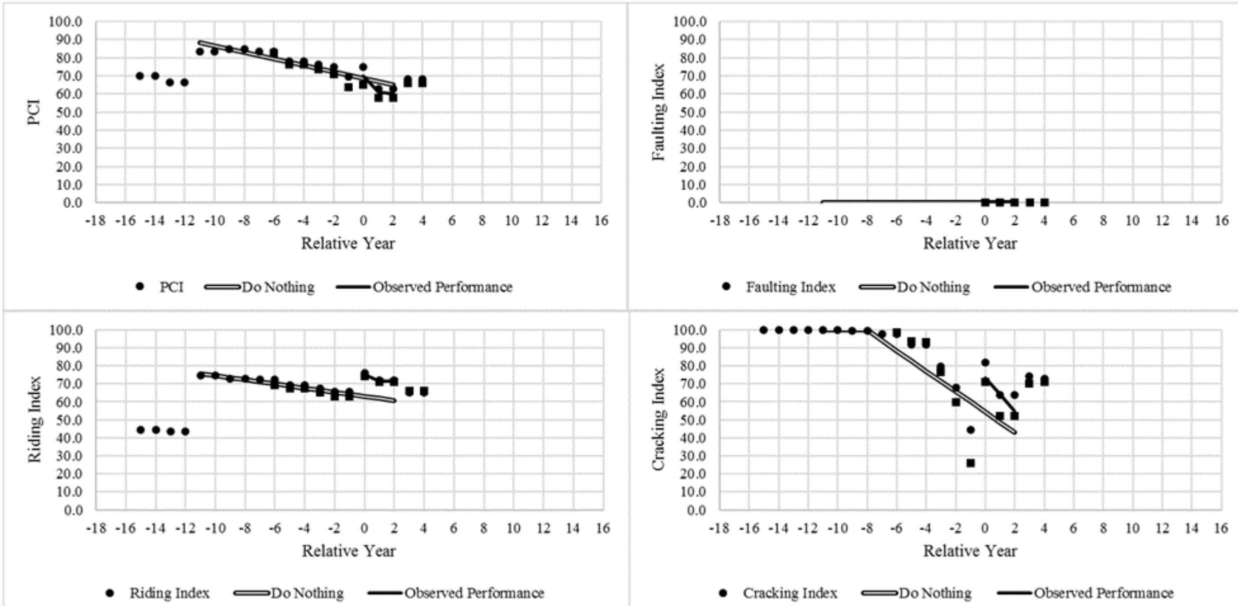

Figure 263. Analytical analysis graphs for project MP-030-4(711)0—76-43

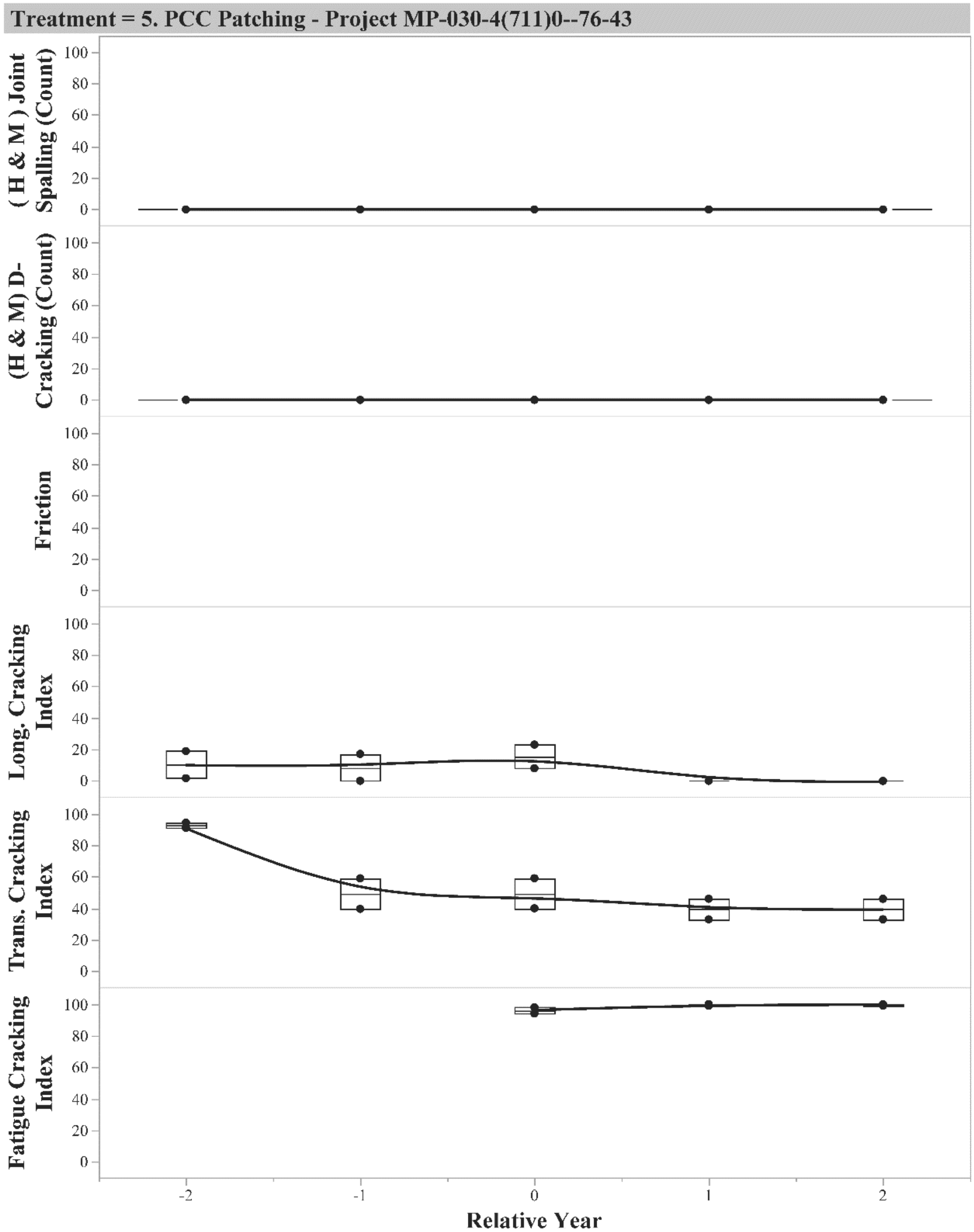

Figure 264. Anecdotal analysis graphs for project MP-030-4(711)0—76-43

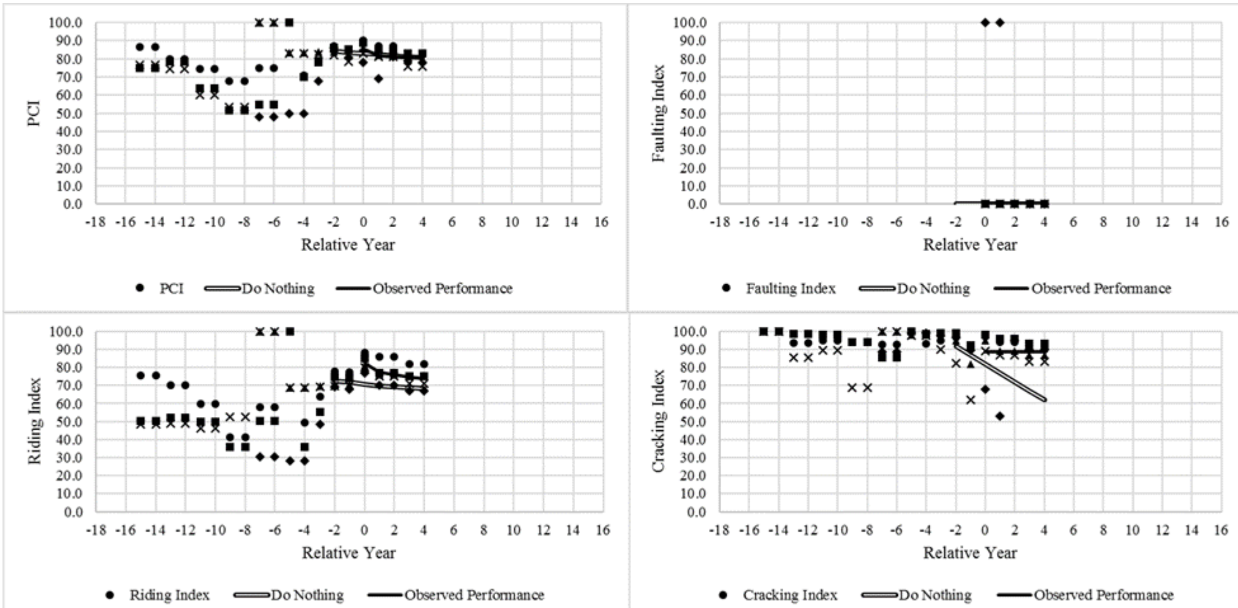

Figure 265. Analytical analysis graphs for project MP-044-4(706)45—76-05

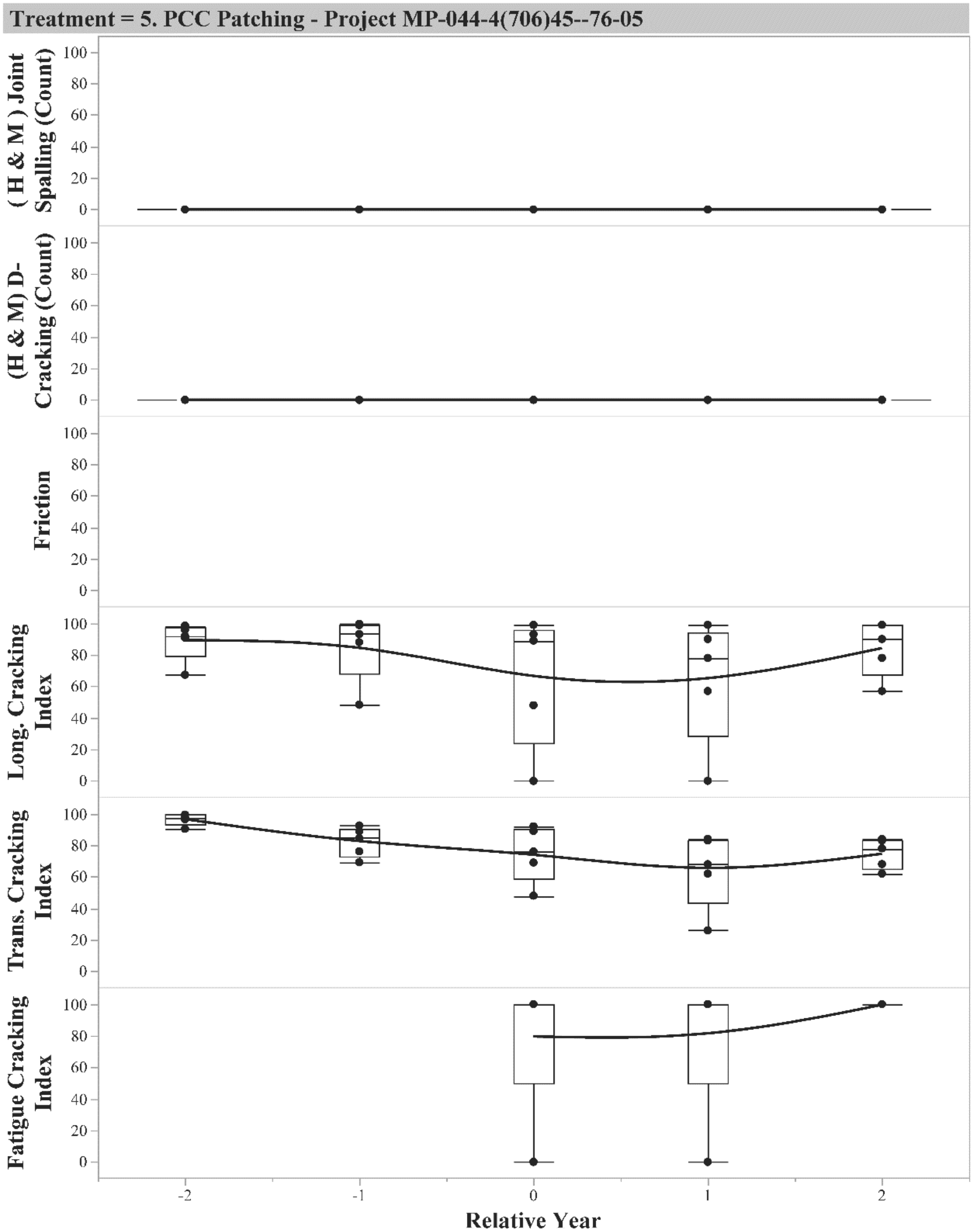

Figure 266. Anecdotal analysis graphs for project MP-044-4(706)45—76-05

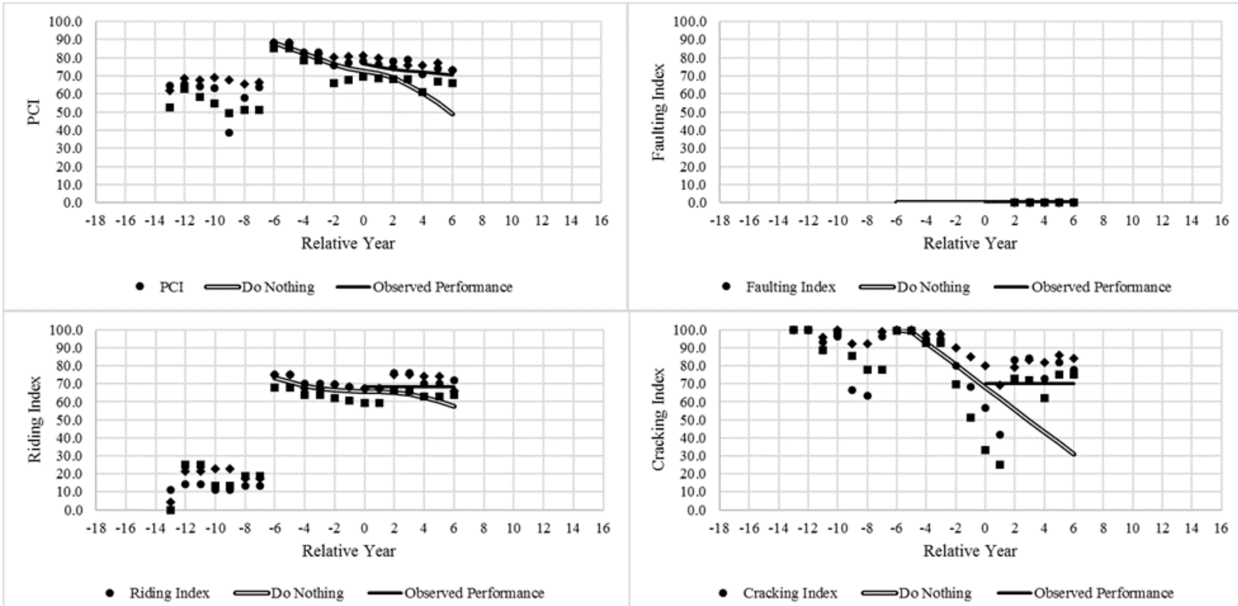

Figure 267. Analytical analysis graphs for project MP-048-4(707)22—76-69

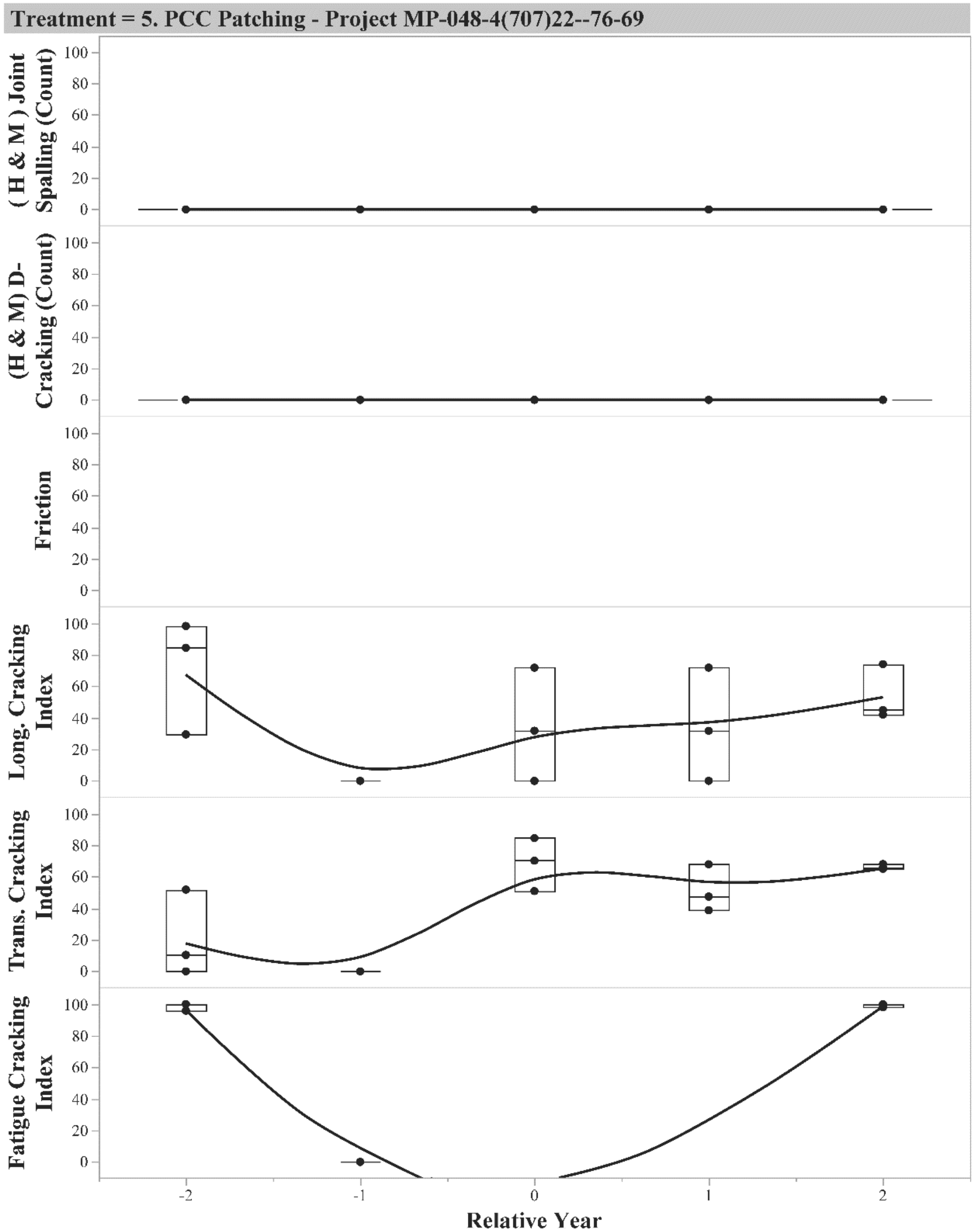

Figure 268. Anecdotal analysis graphs for project MP-048-4(707)22—76-69

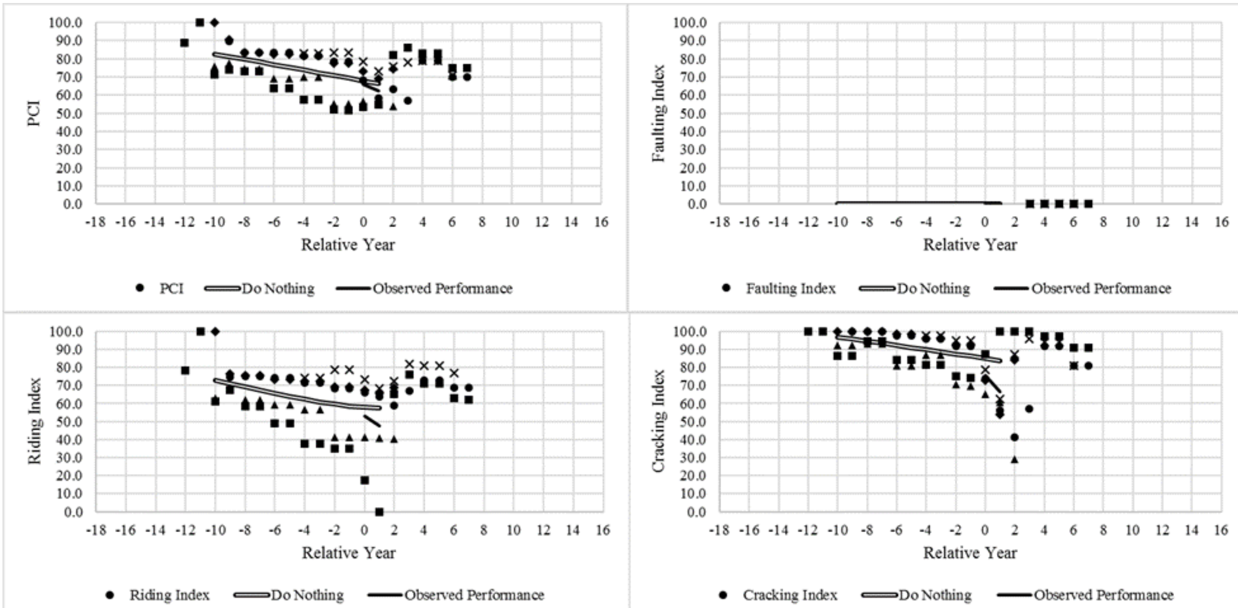

Figure 269. Analytical analysis graphs for project MP-075-3(707)101—76-75

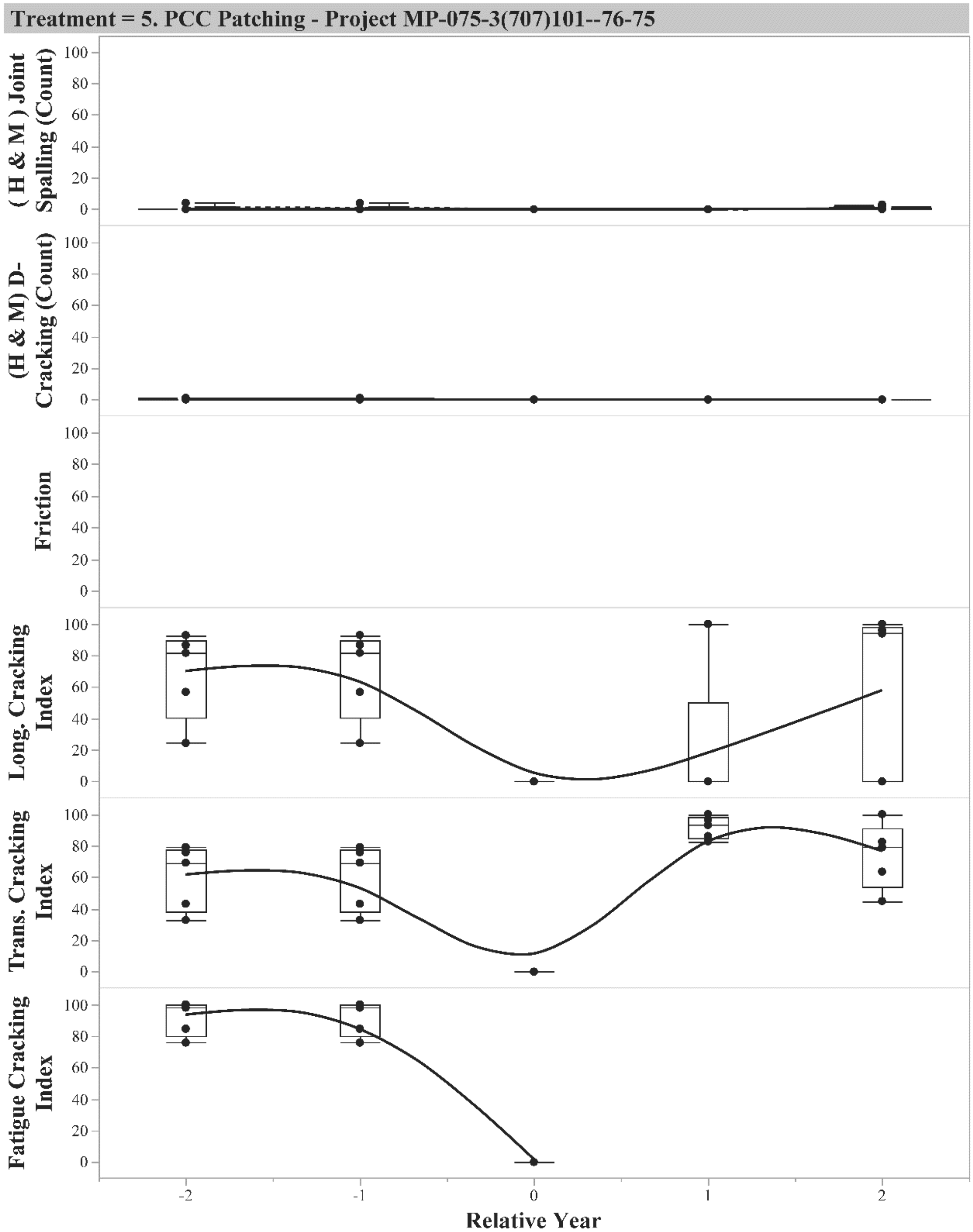

Figure 270. Anecdotal analysis graphs for project MP-075-3(707)101—76-75

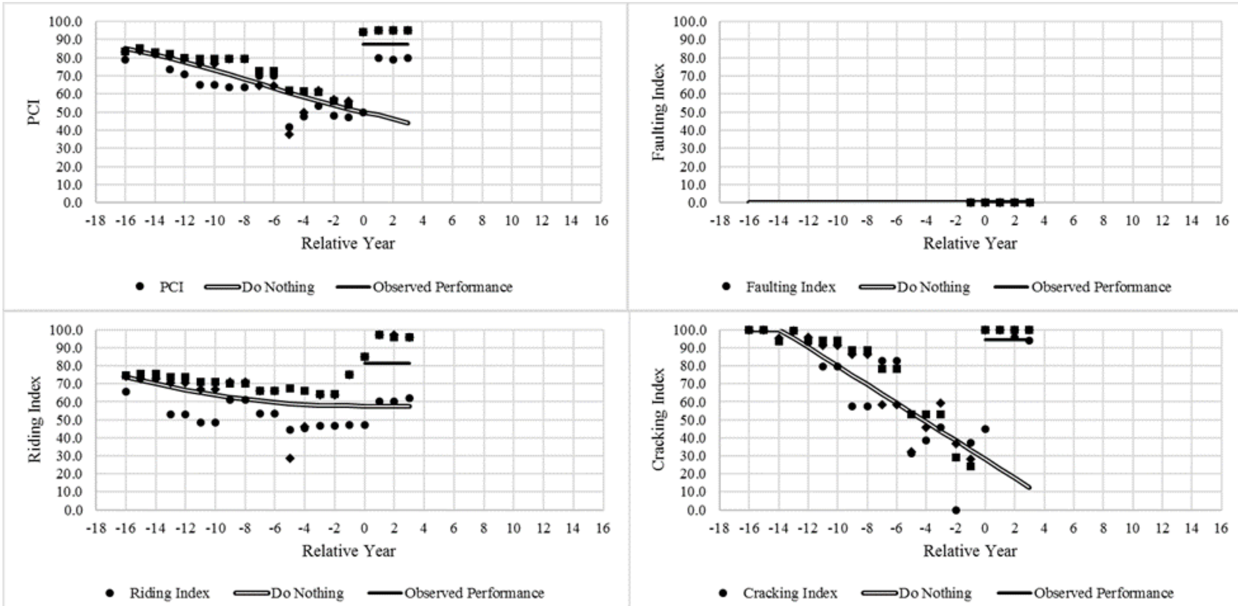

Figure 271. Analytical analysis graphs for project MP-092-4(705)81—76-01

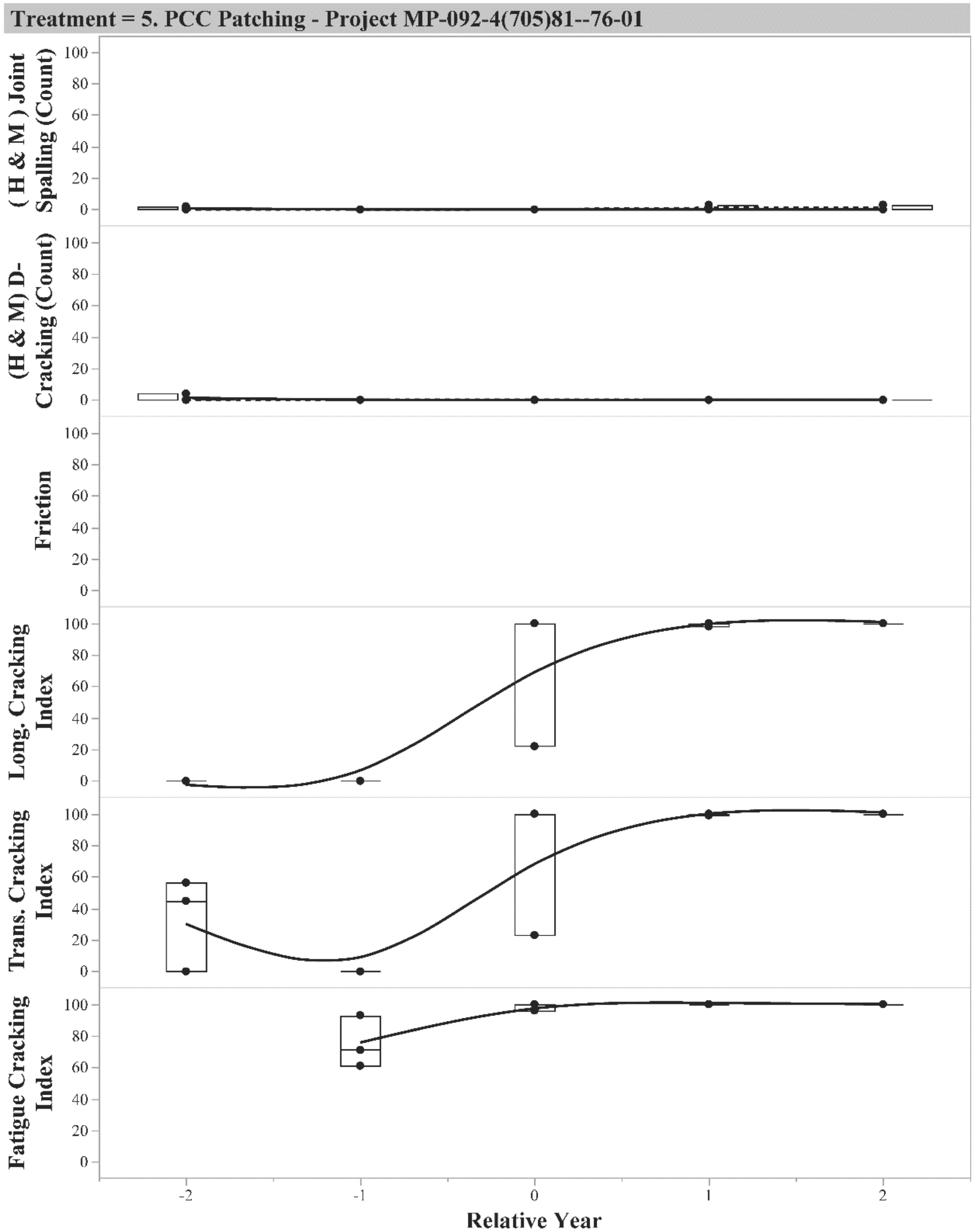

Figure 272. Anecdotal analysis graphs for project MP-092-4(705)81—76-01

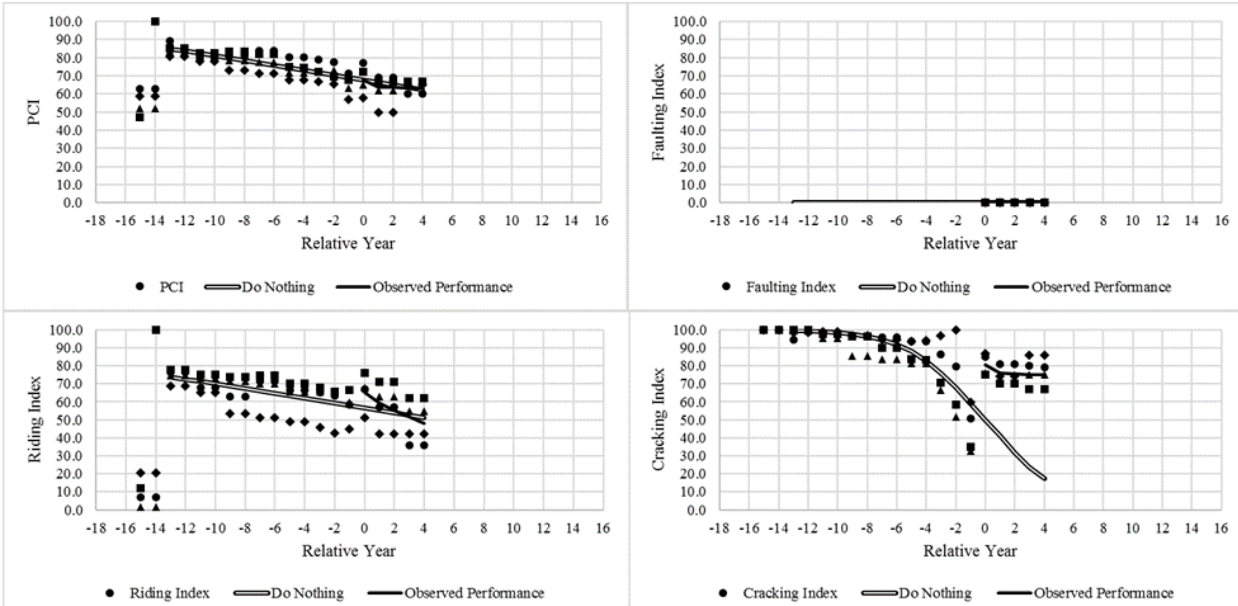

Figure 273. Analytical analysis graphs for project MP-127-4(702)0—76-43

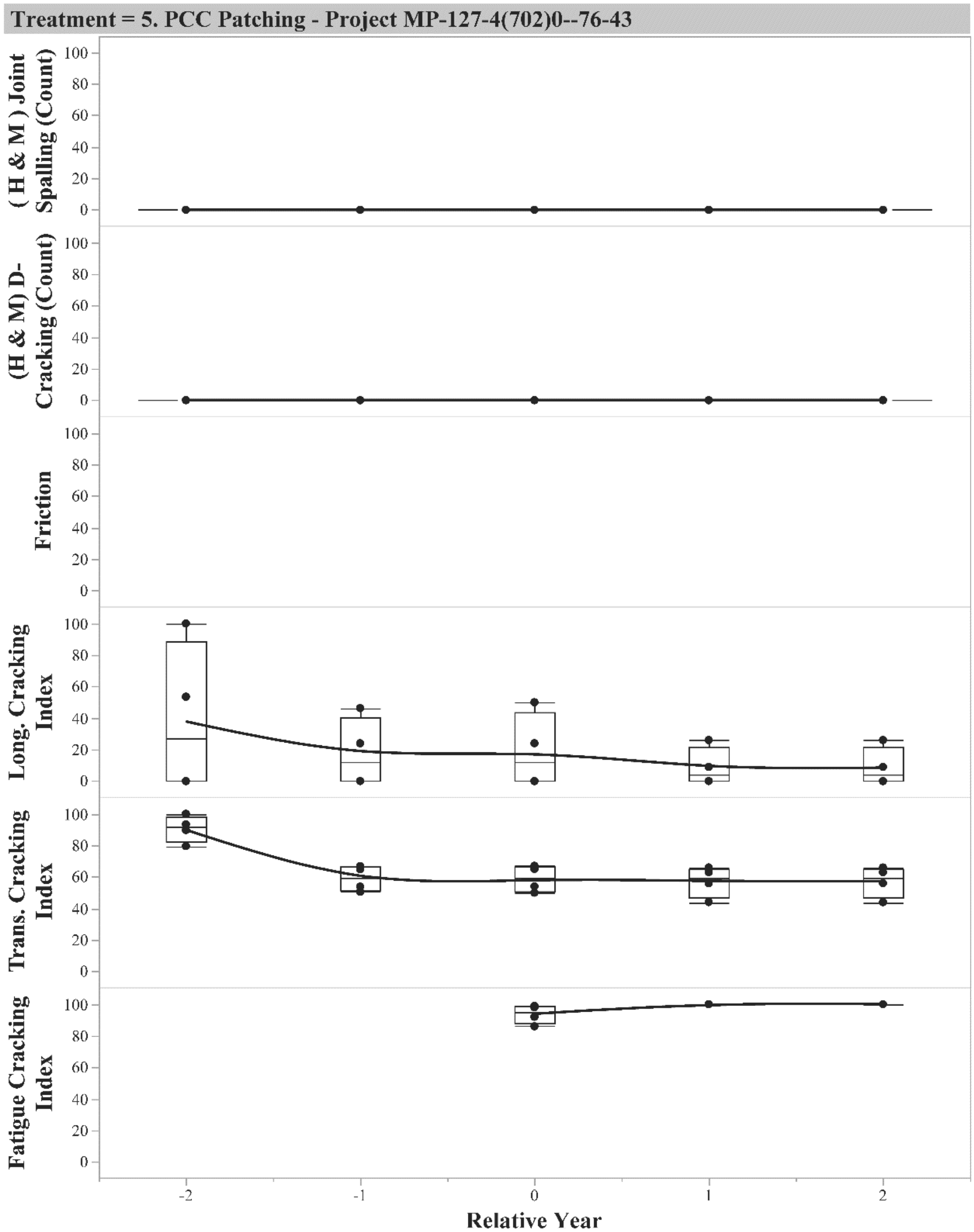

Figure 274. Anecdotal analysis graphs for project MP-127-4(702)0—76-43

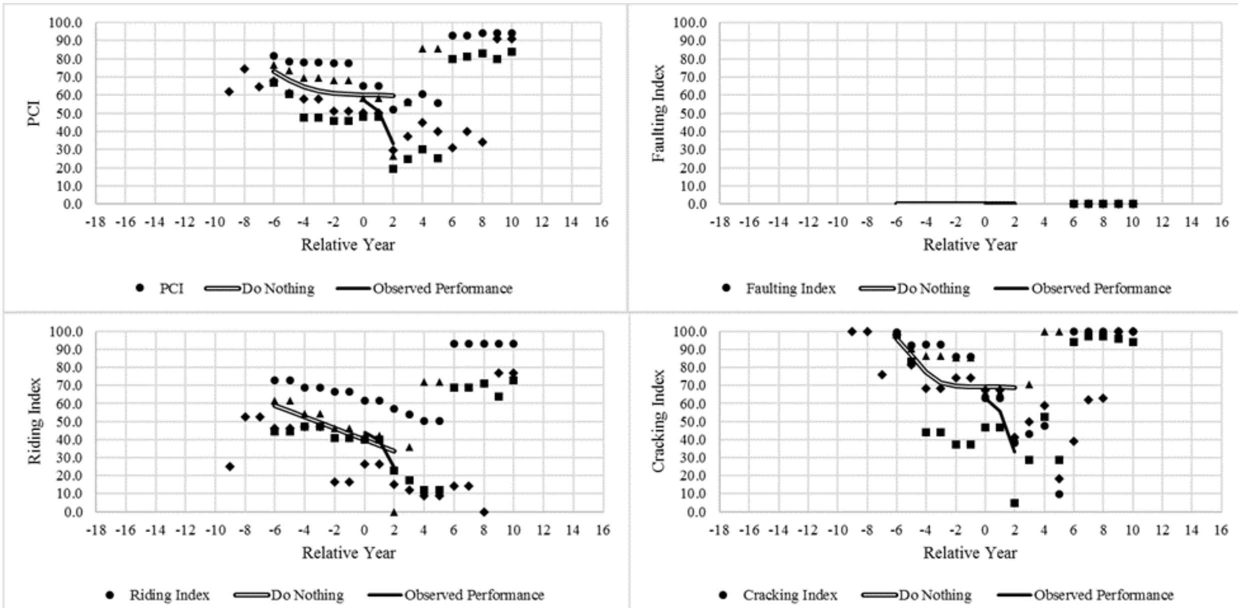

Figure 275. Analytical analysis graphs for project MP-148-4(702)50—76-15

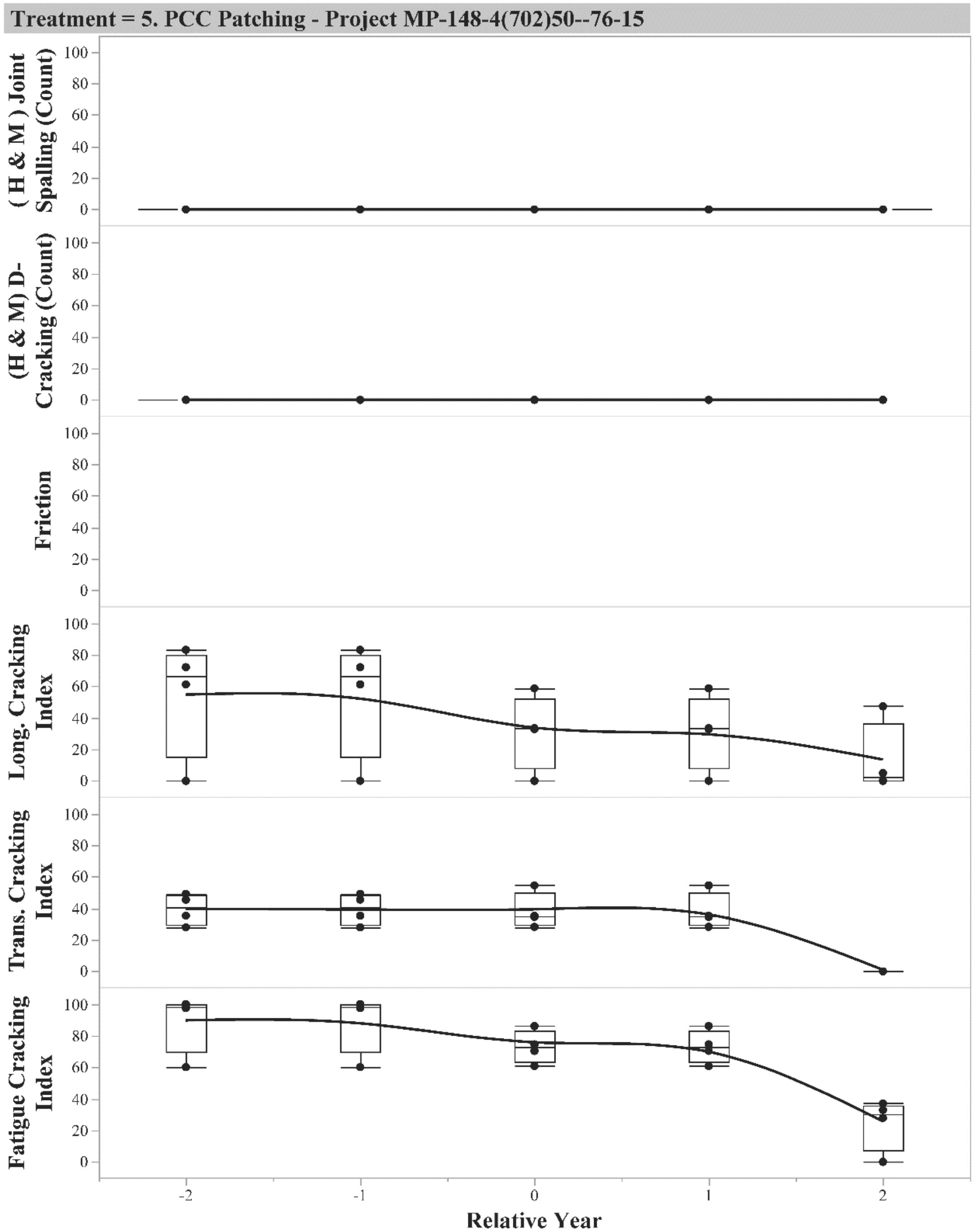

Figure 276. Anecdotal analysis graphs for project MP-148-4(702)50—76-15

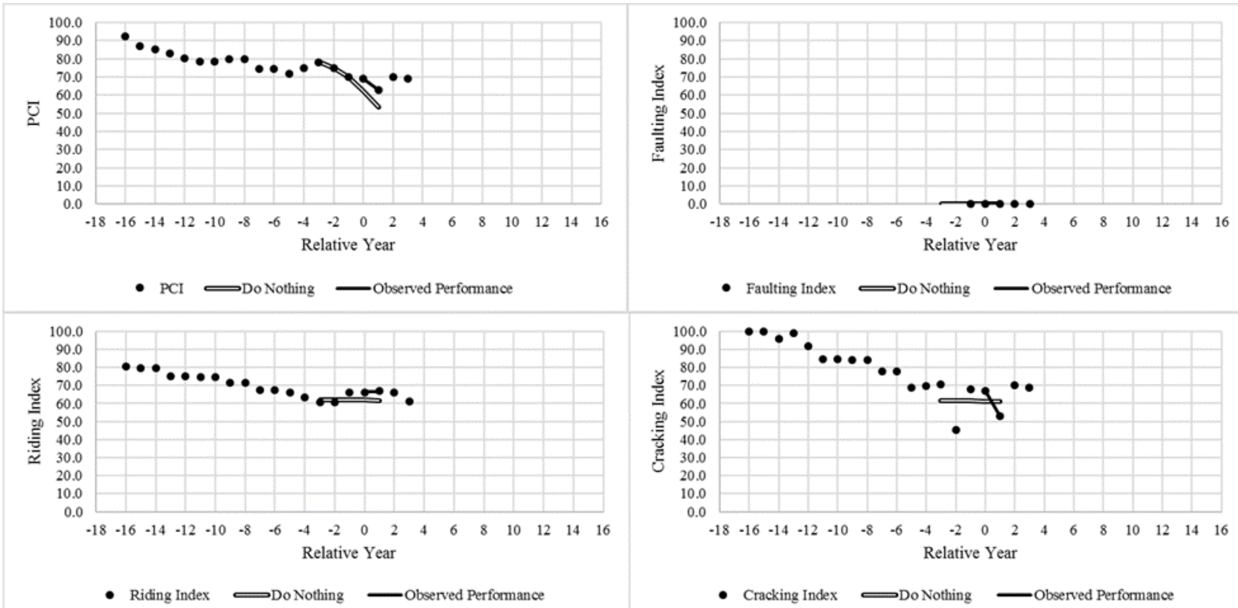

Figure 277. Analytical analysis graphs for project MP-169-4(704)65—76-61

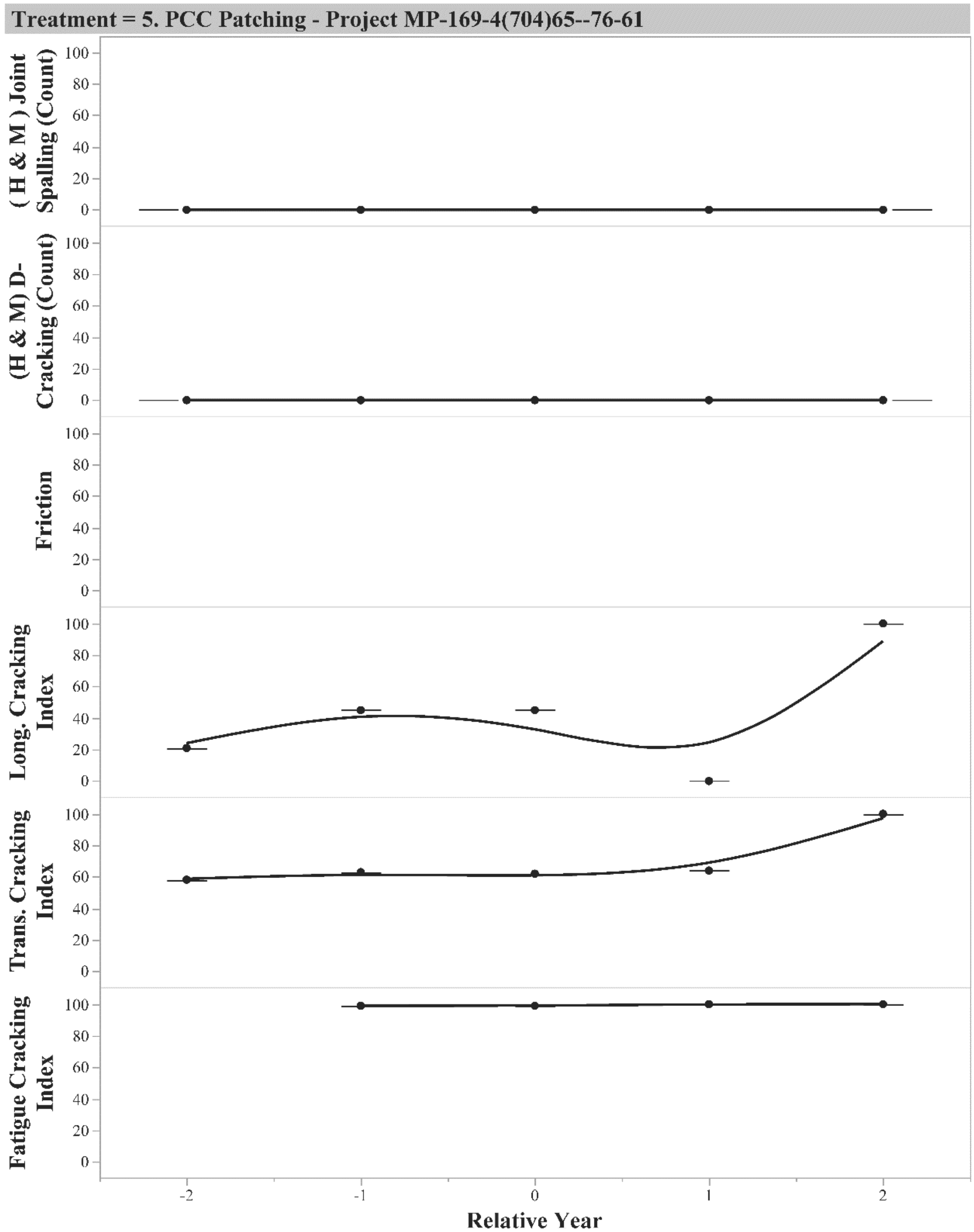

Figure 278. Anecdotal analysis graphs for project MP-169-4(704)65—76-61

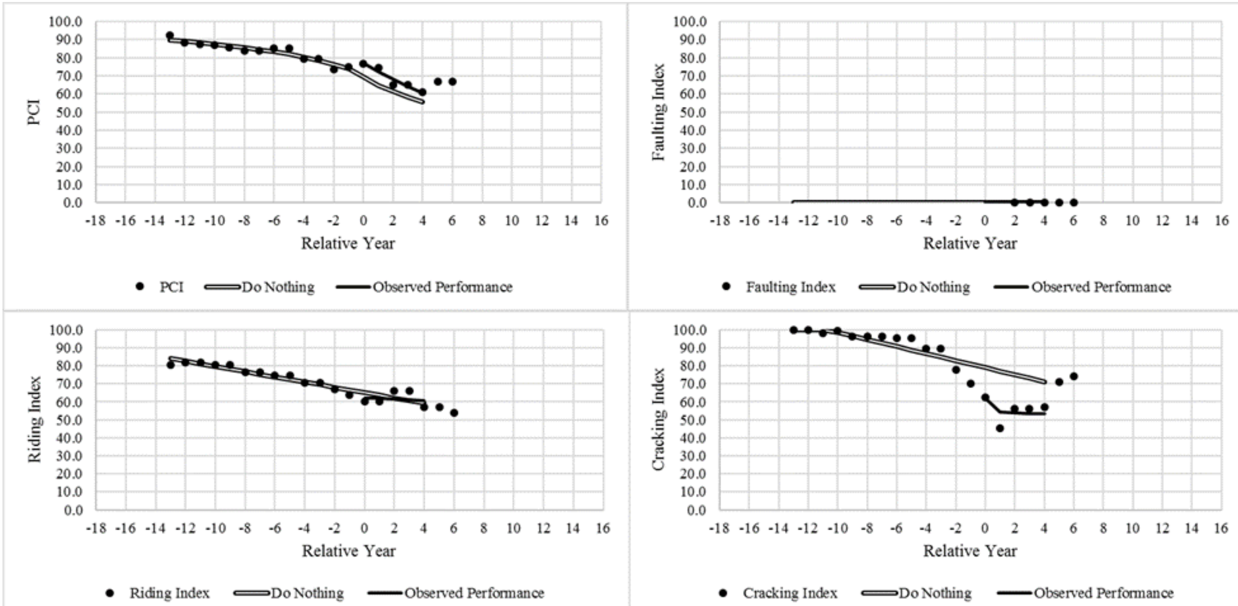

Figure 279. Analytical analysis graphs for project MP-169-4(708)47—76-88

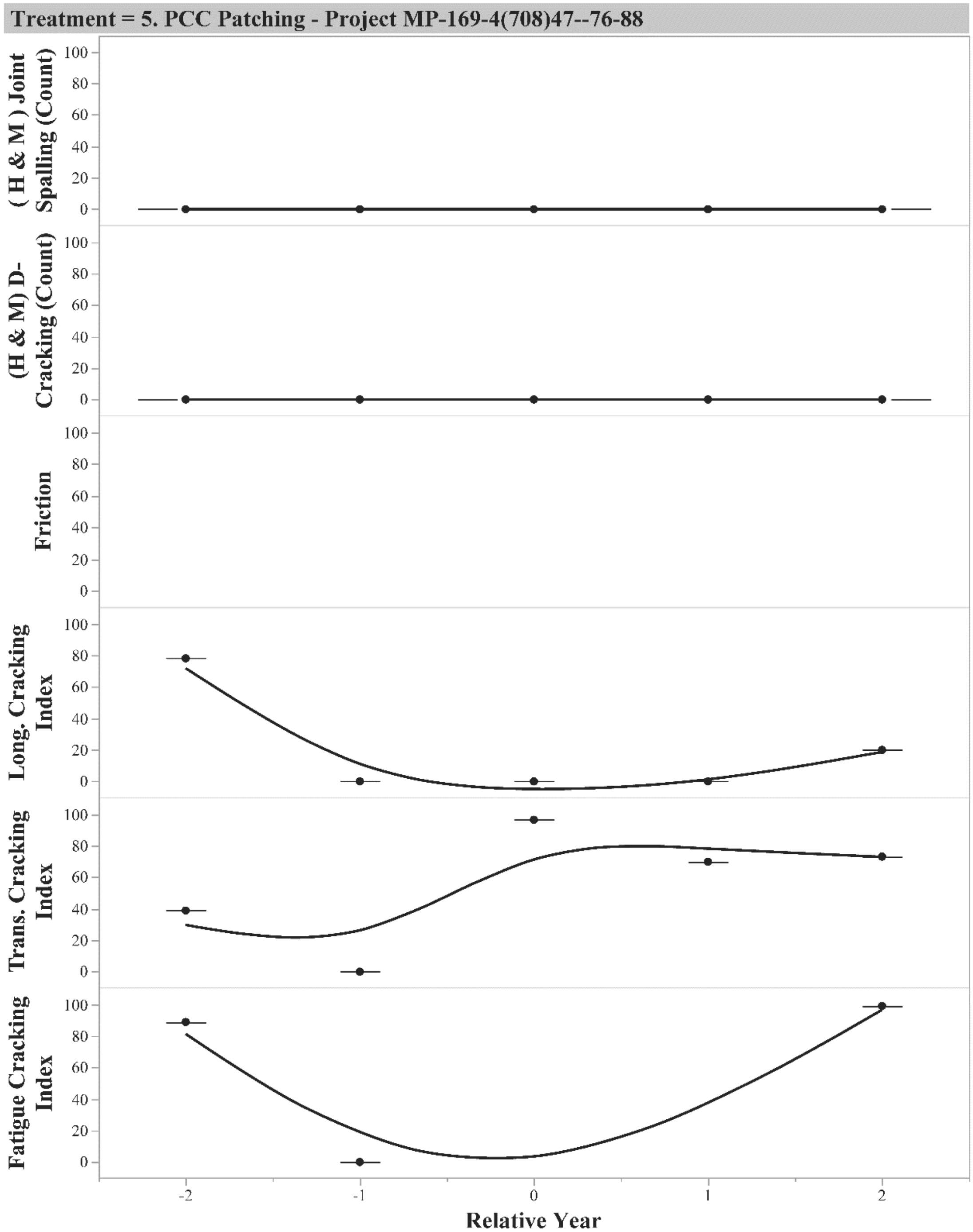

Figure 280. Anecdotal analysis graphs for project MP-169-4(708)47—76-88

Crack Filling and Joint Sealing Projects

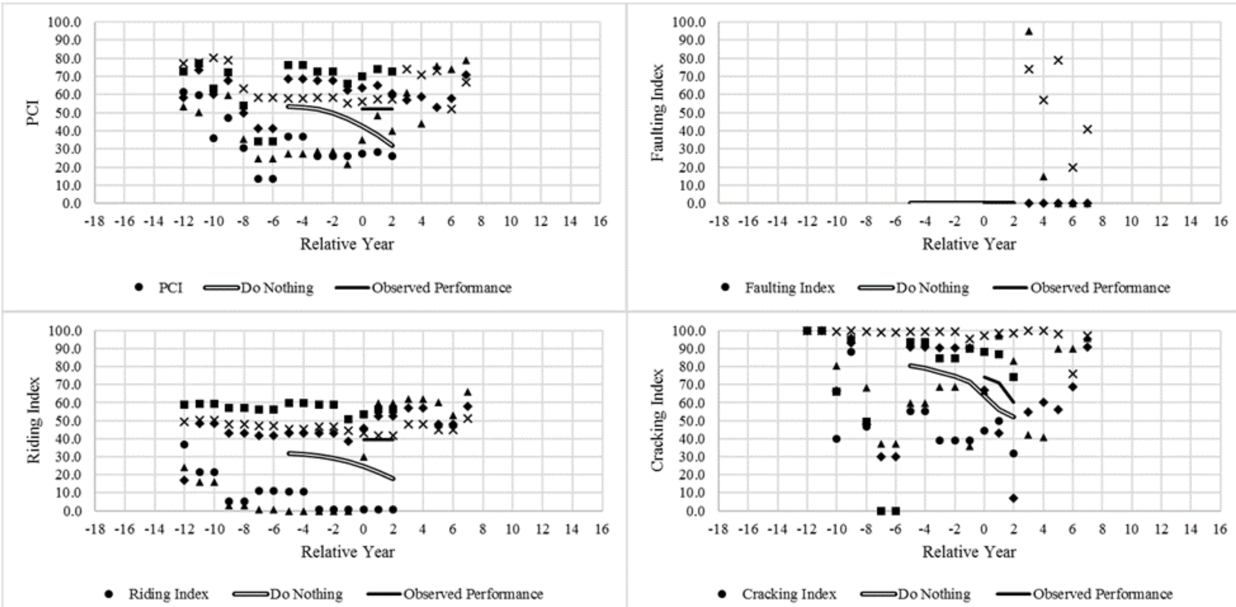

Figure 281. Analytical analysis graphs for project MP-002-4(707)15—76-36

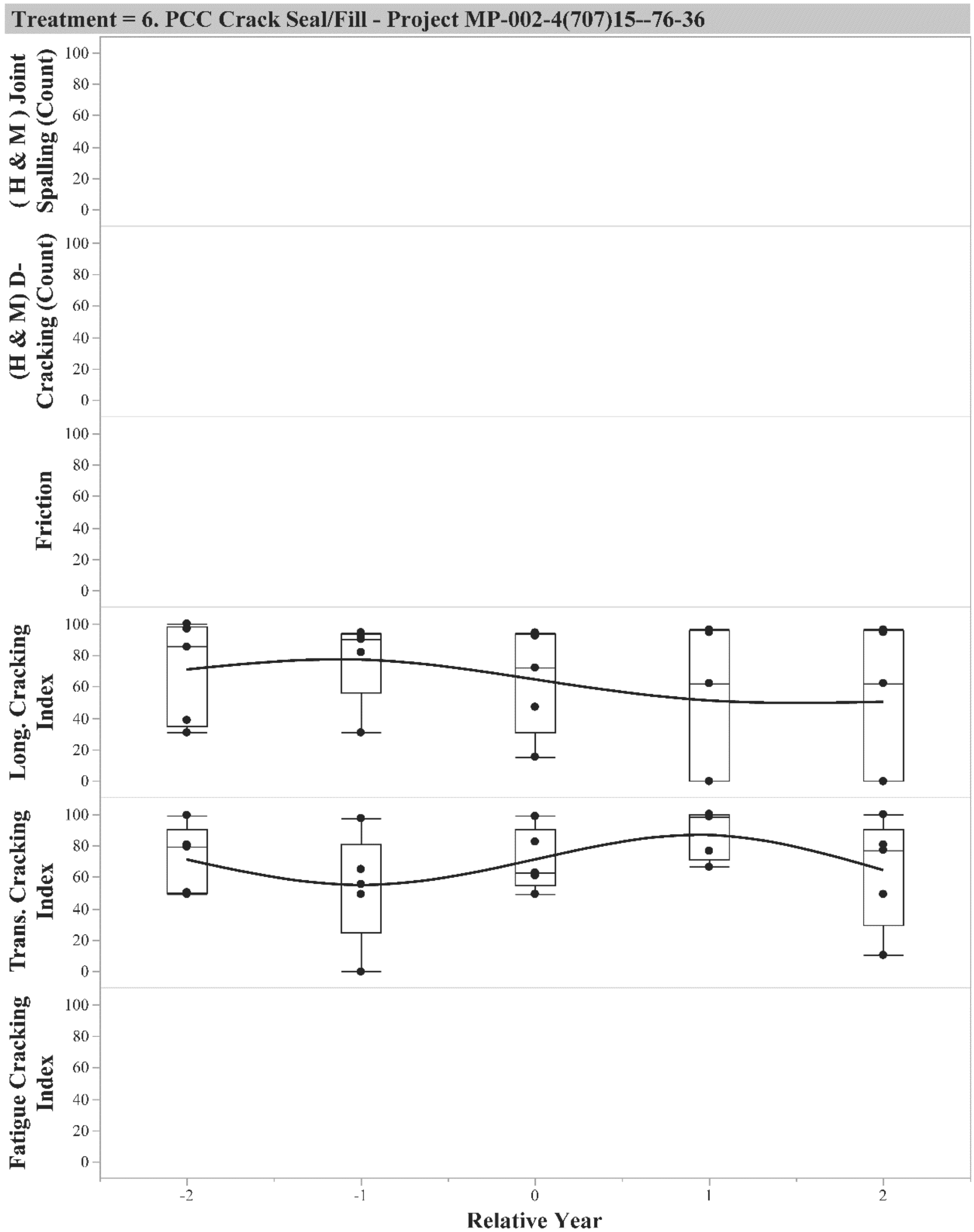

Figure 282. Anecdotal analysis graphs for project MP-002-4(707)15—76-36

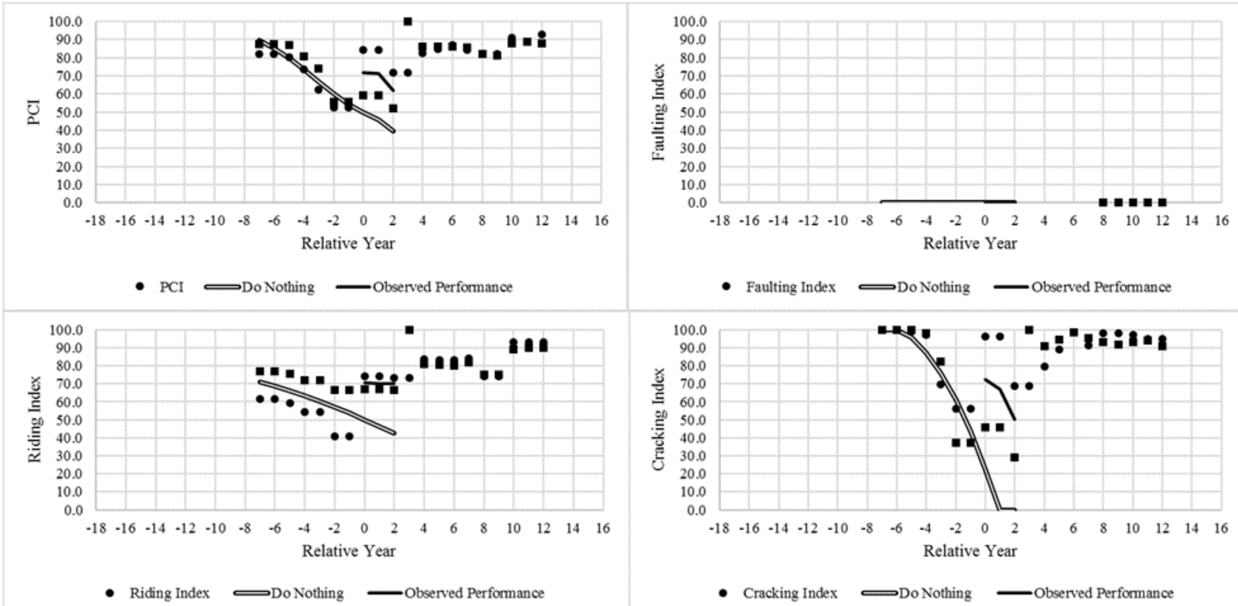

Figure 283. Analytical analysis graphs for project MP-080-4(702)102—76-25

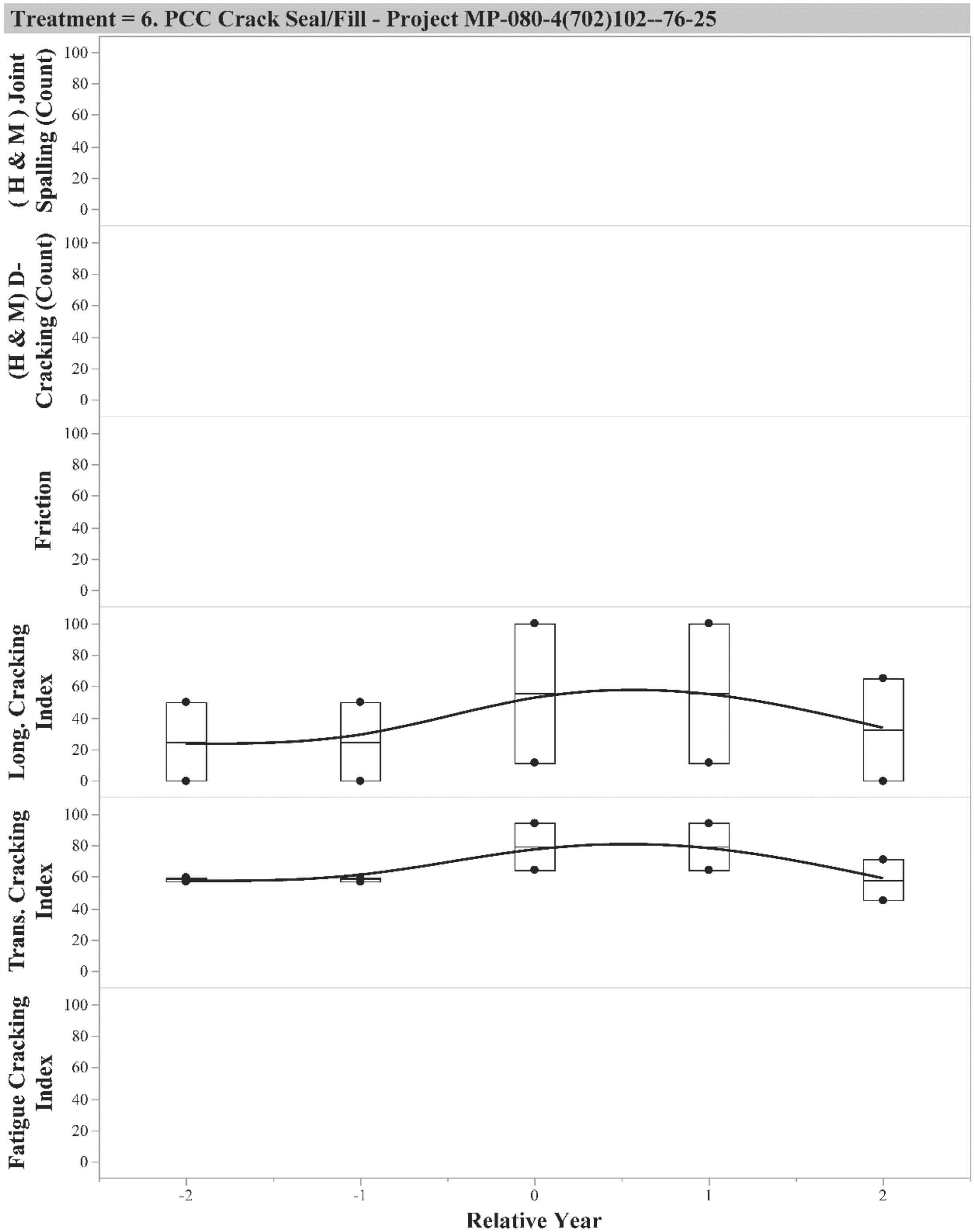

Figure 284. Anecdotal analysis graphs for project MP-080-4(702)102—76-25

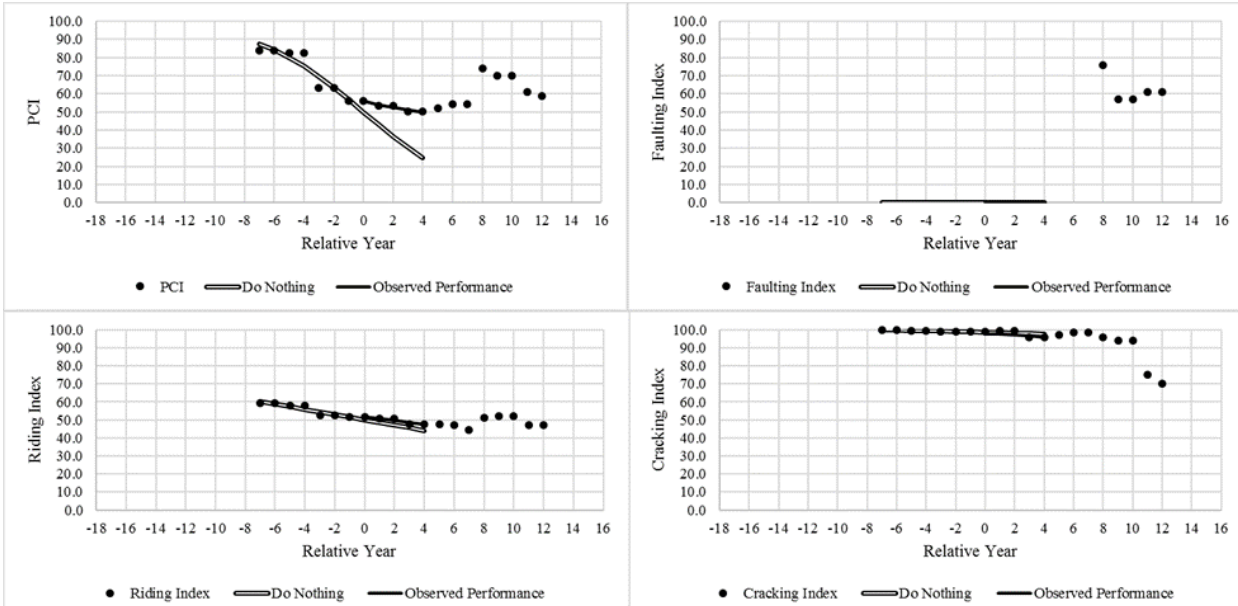

Figure 285. Analytical analysis graphs for project MP-218-2(702)186—76-07

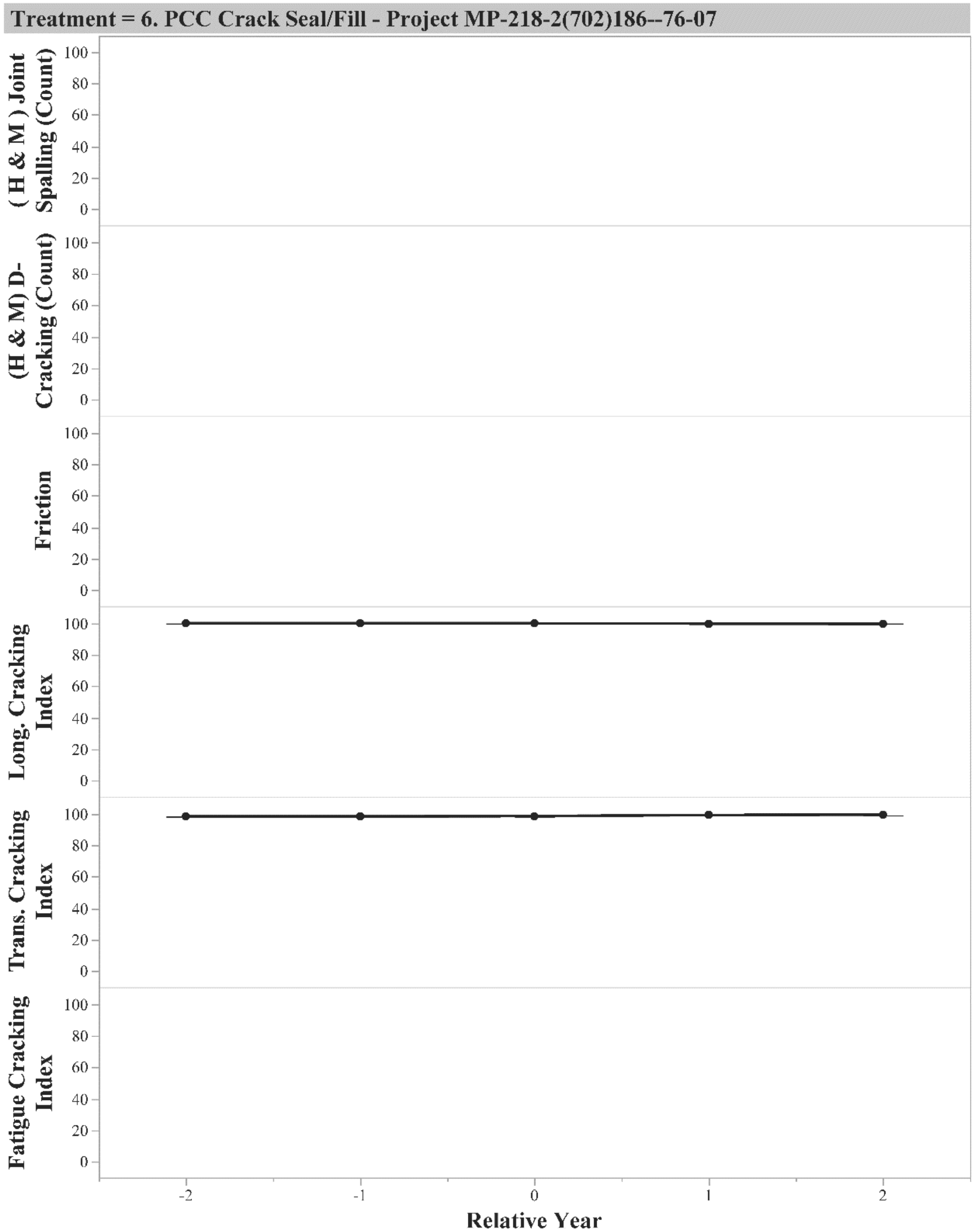

Figure 286. Anecdotal analysis graphs for project MP-218-2(702)186—76-07

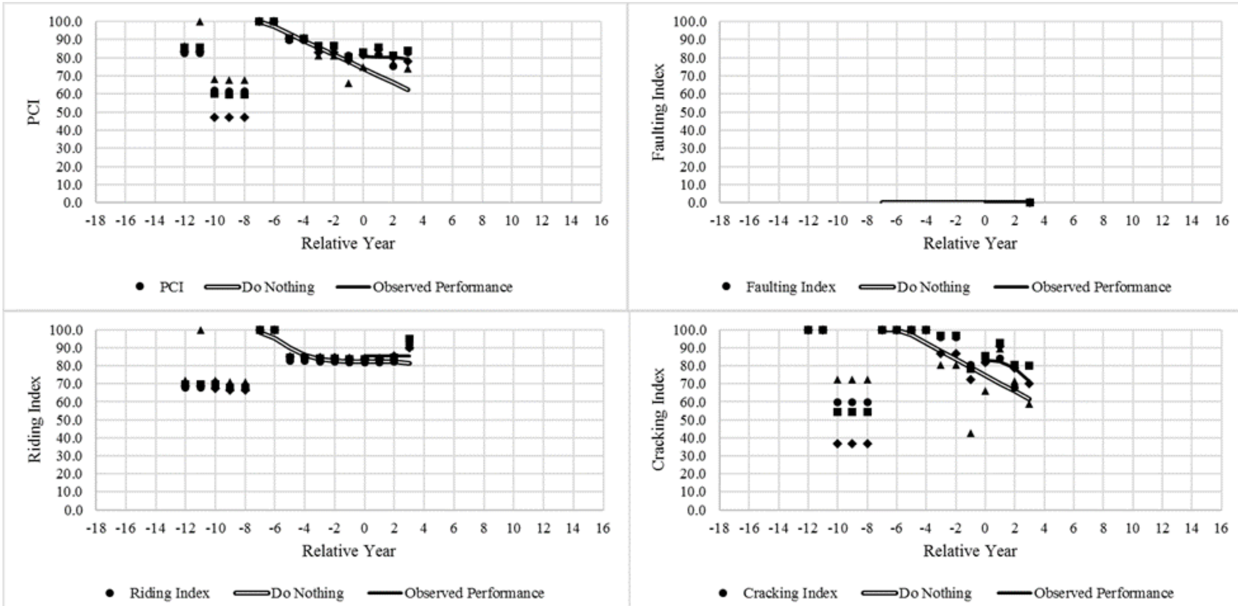

Figure 287. Analytical analysis graphs for project MPIN-035-1(705)113—0N-85

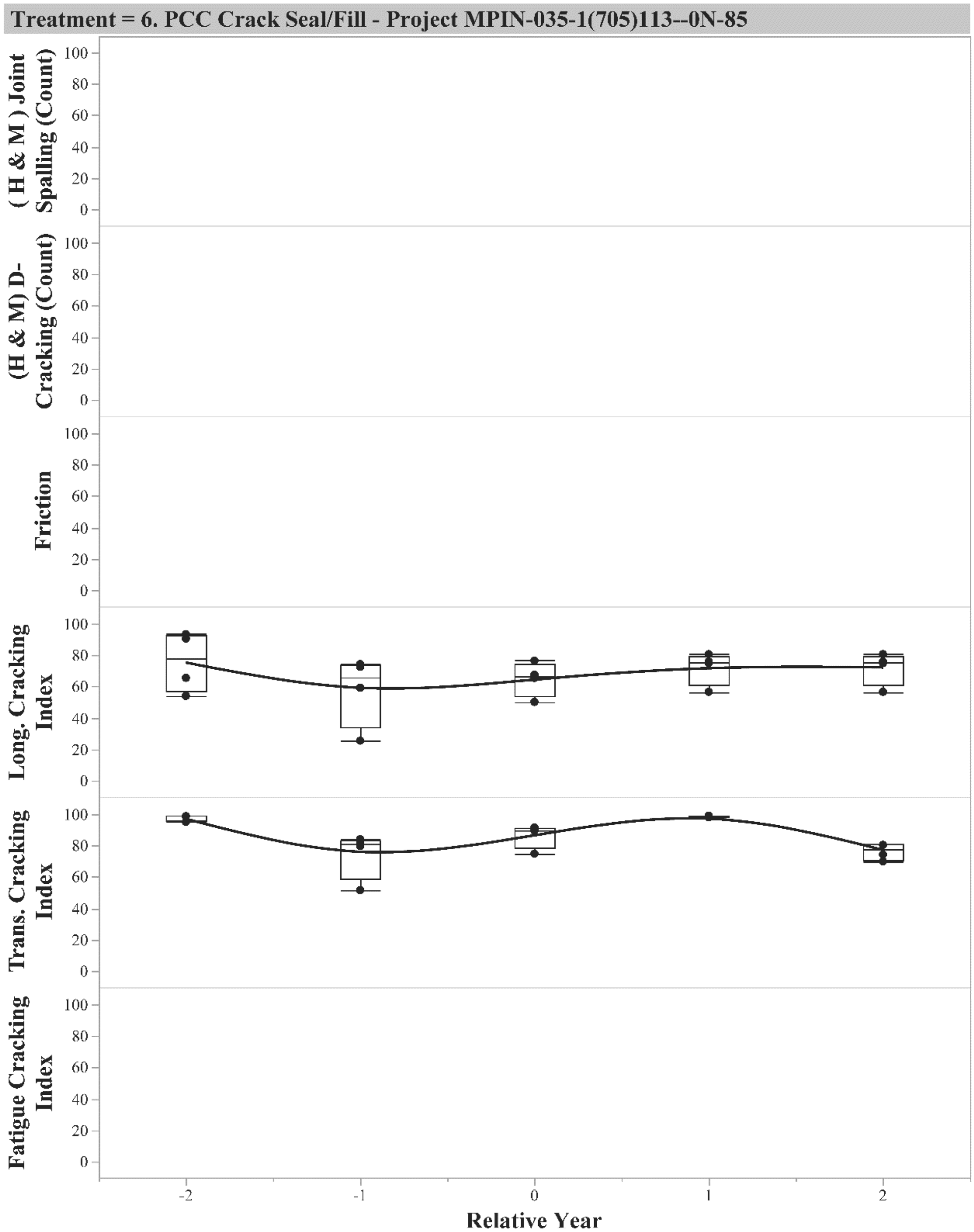

Figure 288. Anecdotal analysis graphs for project MPIN-035-1(705)113—0N-85

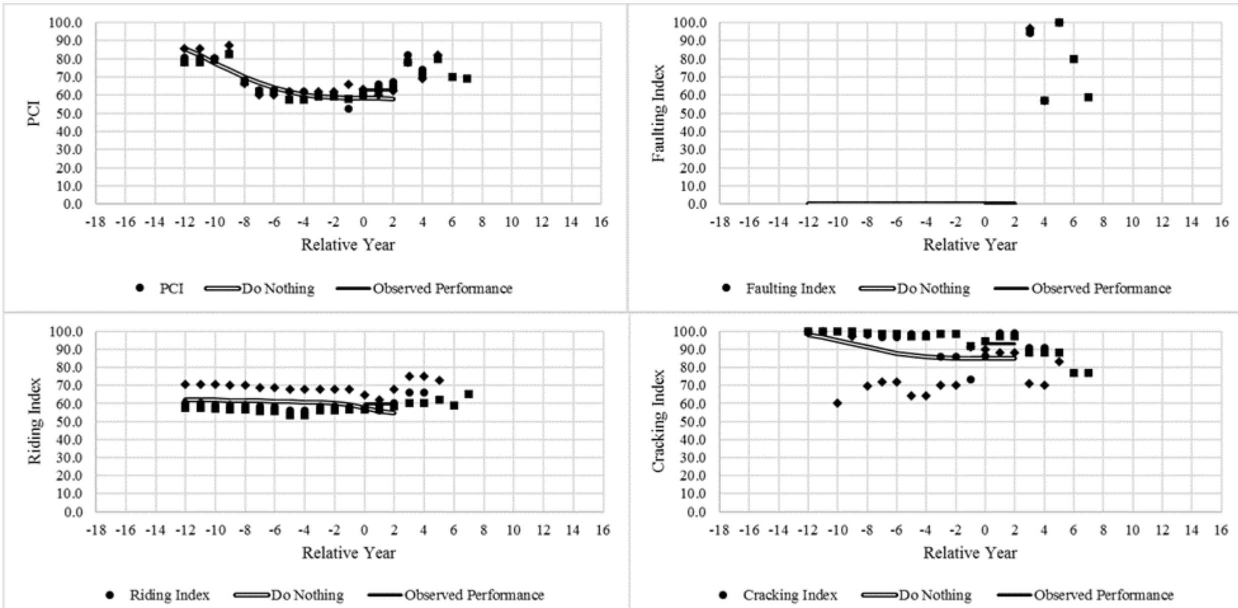

Figure 289. Analytical analysis graphs for project MPIN-080-1(706)142—0N-77

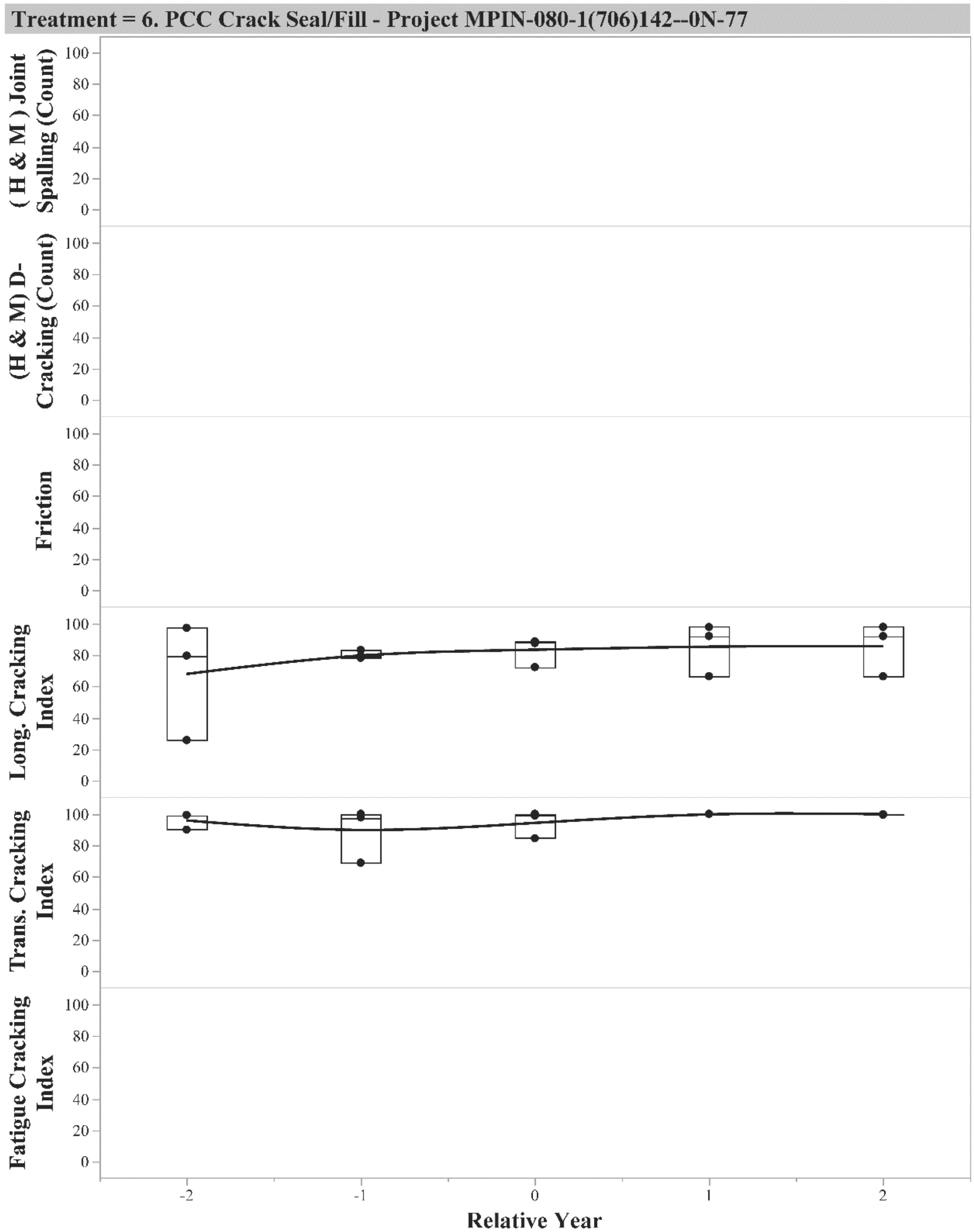

Figure 290. Anecdotal analysis graphs for project MPIN-080-1(706)142—0N-77

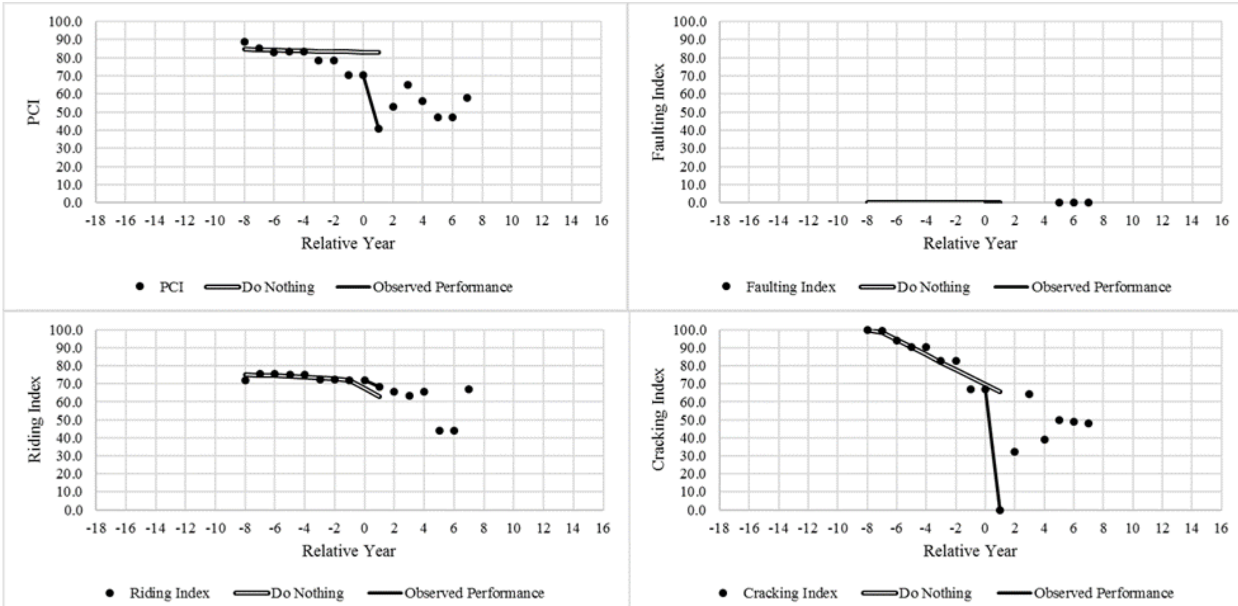

Figure 291. Analytical analysis graphs for project MPIN-080-4(705)111—0N-25

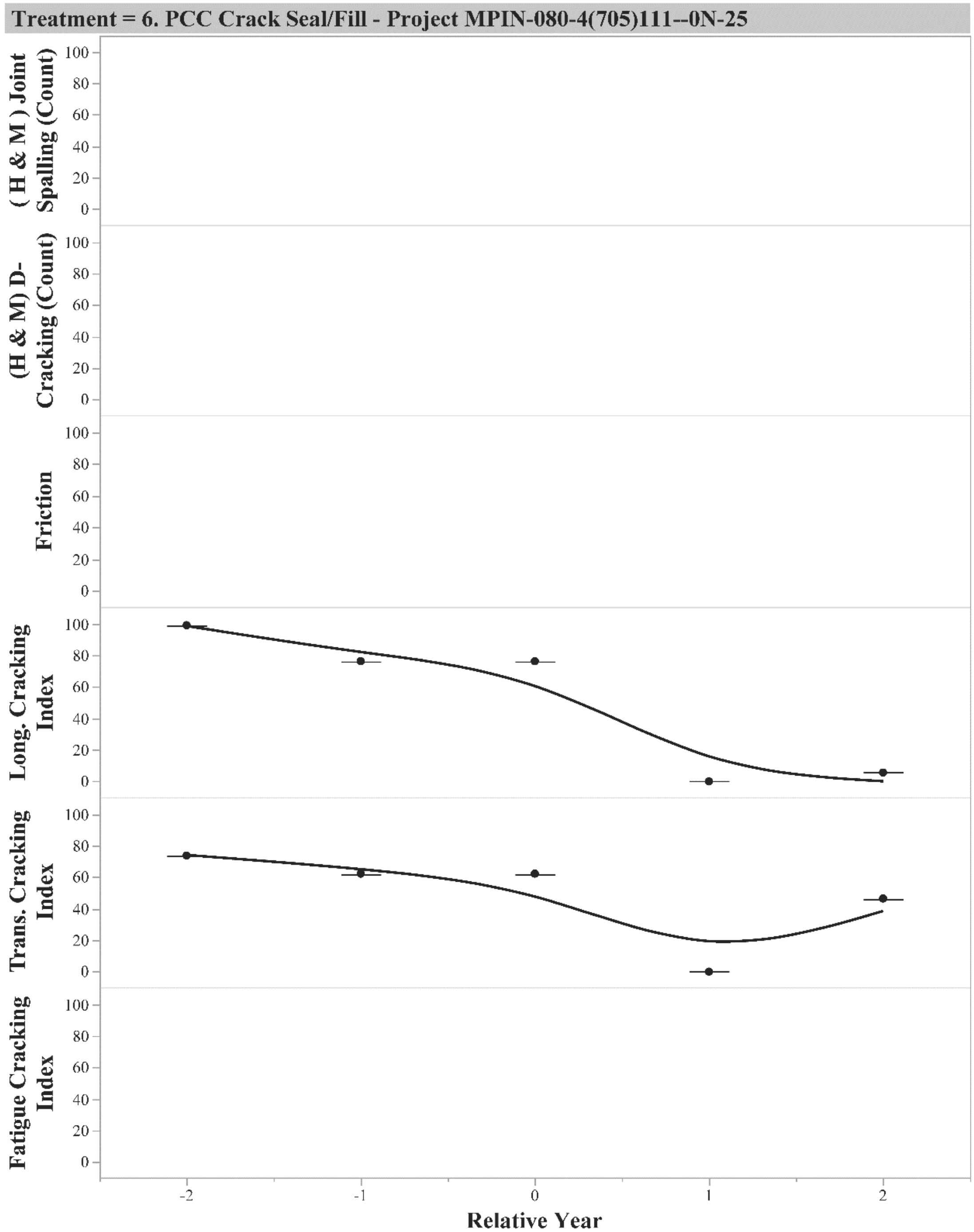

Figure 292. Anecdotal analysis graphs for project MPIN-080-4(705)111—0N-25

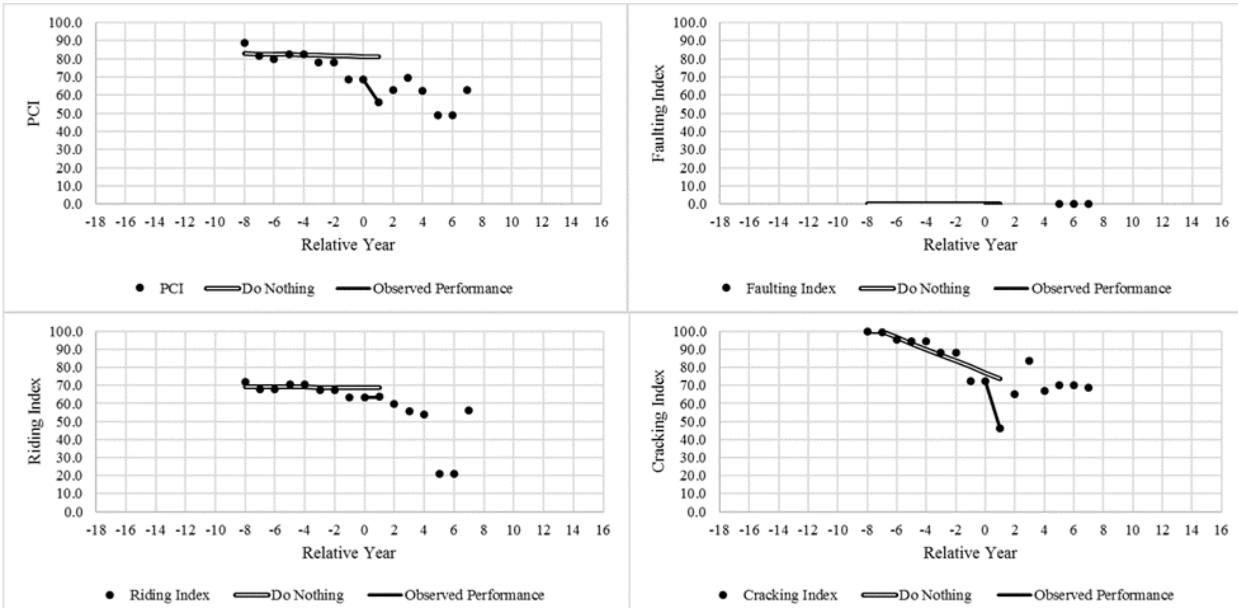

Figure 293. Analytical analysis graphs for project MPIN-080-4(706)119—0N-25

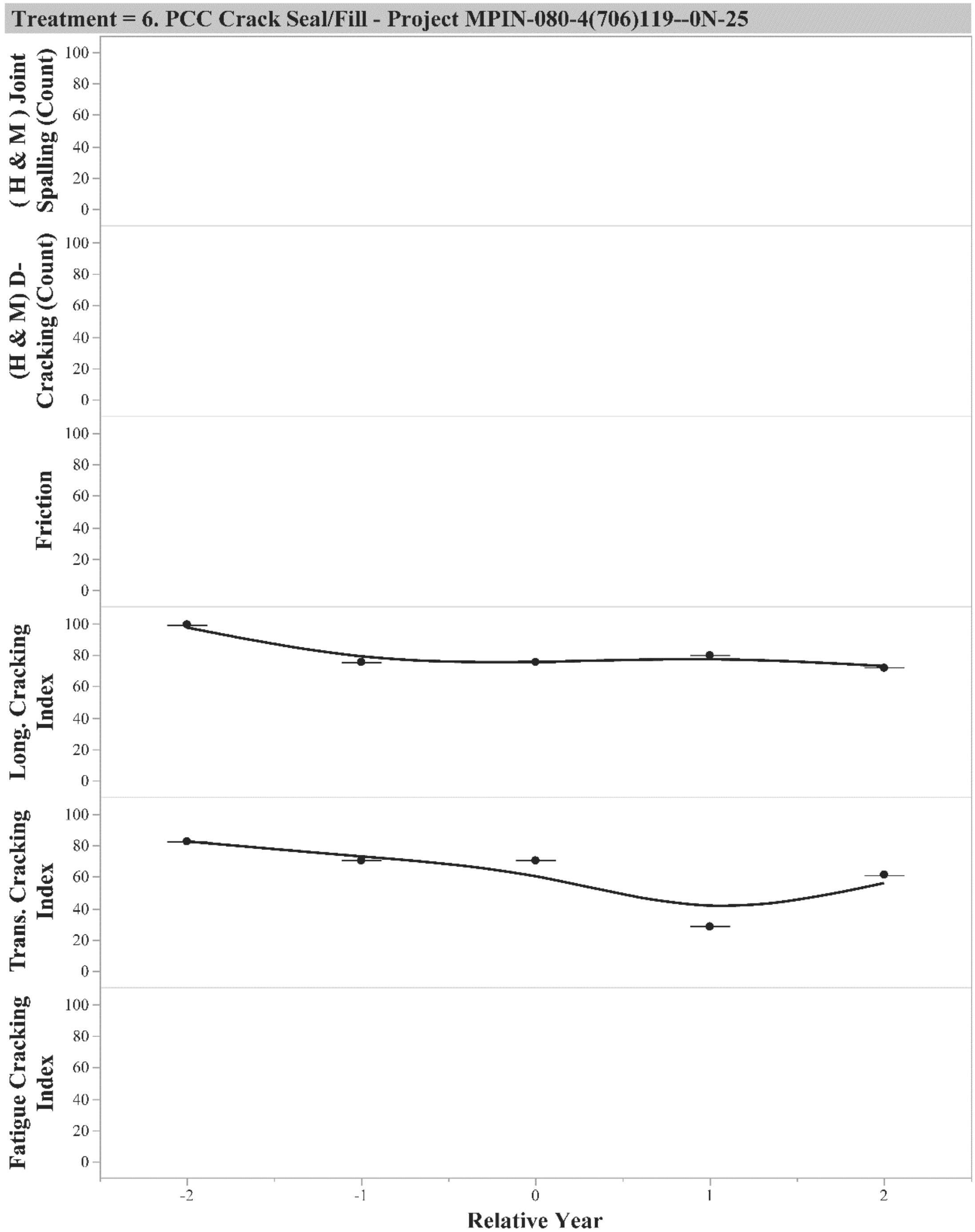

Figure 294. Anecdotal analysis graphs for project MPIN-080-4(706)119—0N-25

Dowel Bar Retrofit and Diamond Grinding Projects

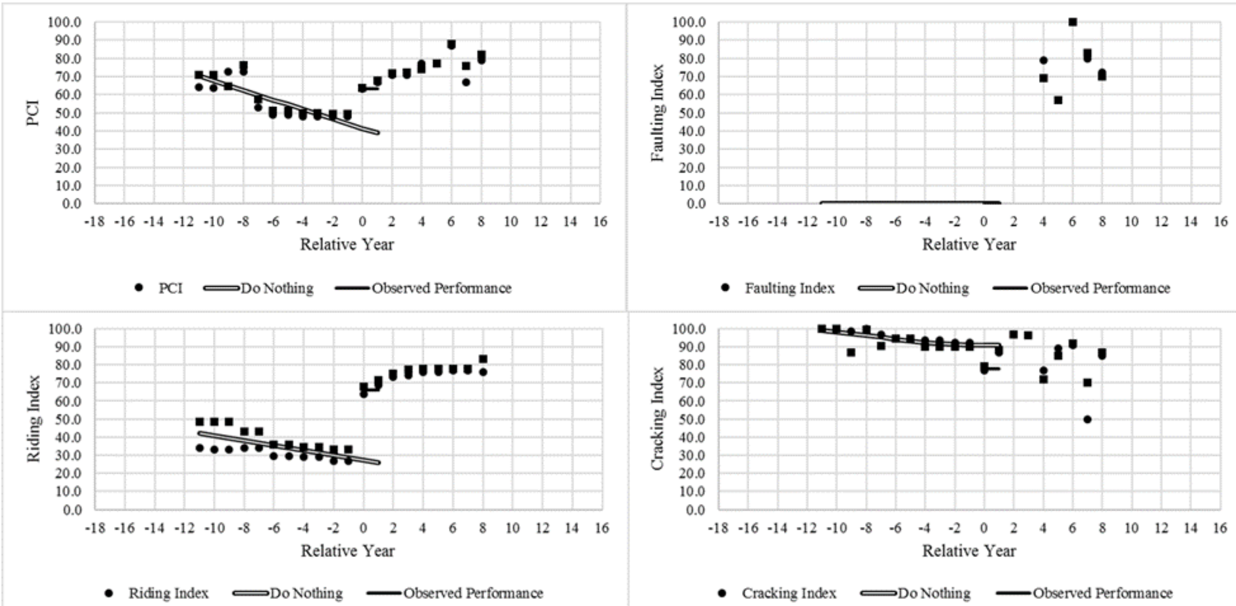

Figure 295. Analytical analysis graphs for project NHSN-16301(176)—2R-77

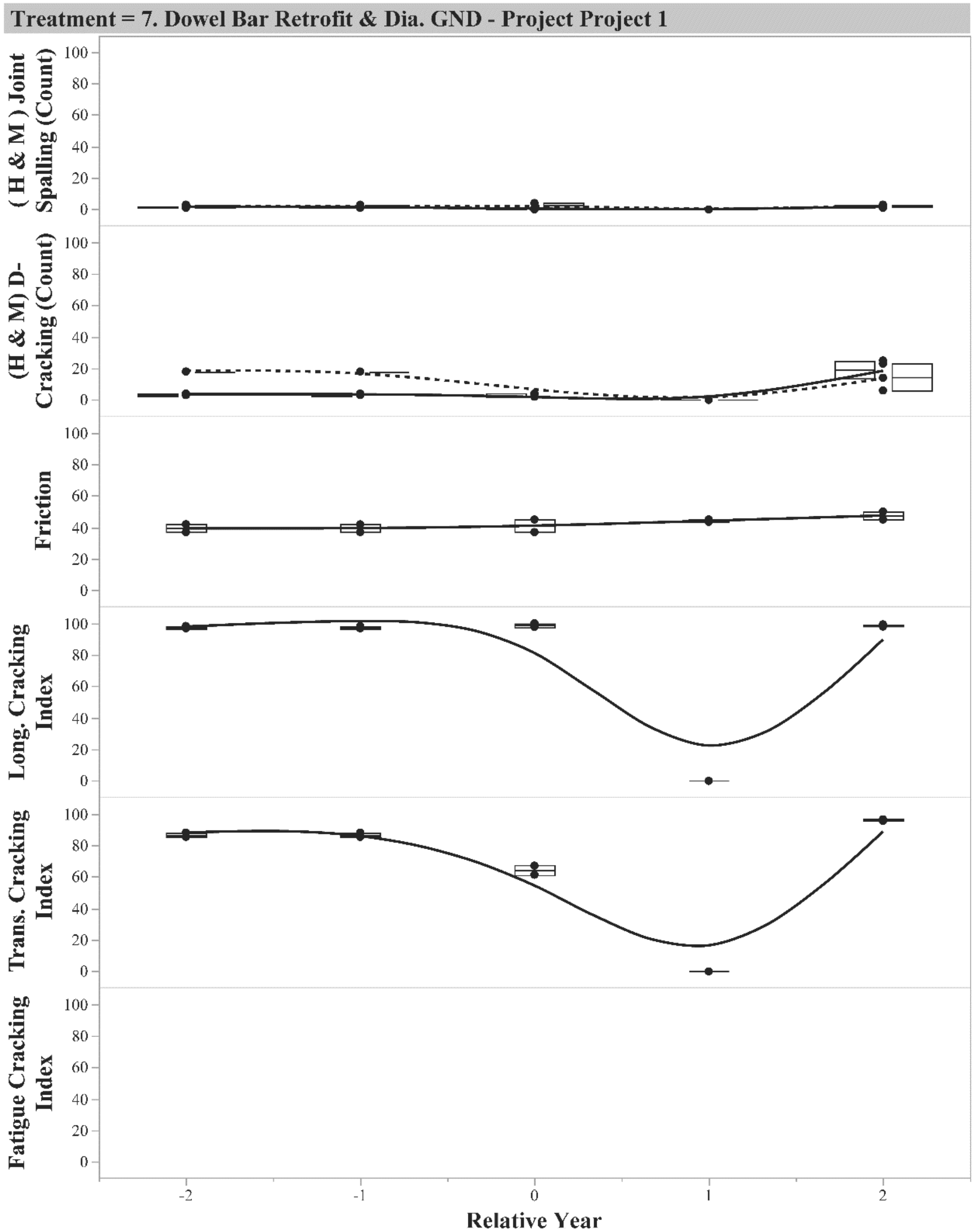

Figure 296. Anecdotal analysis graphs for project NHSN-16301(176)—2R-77

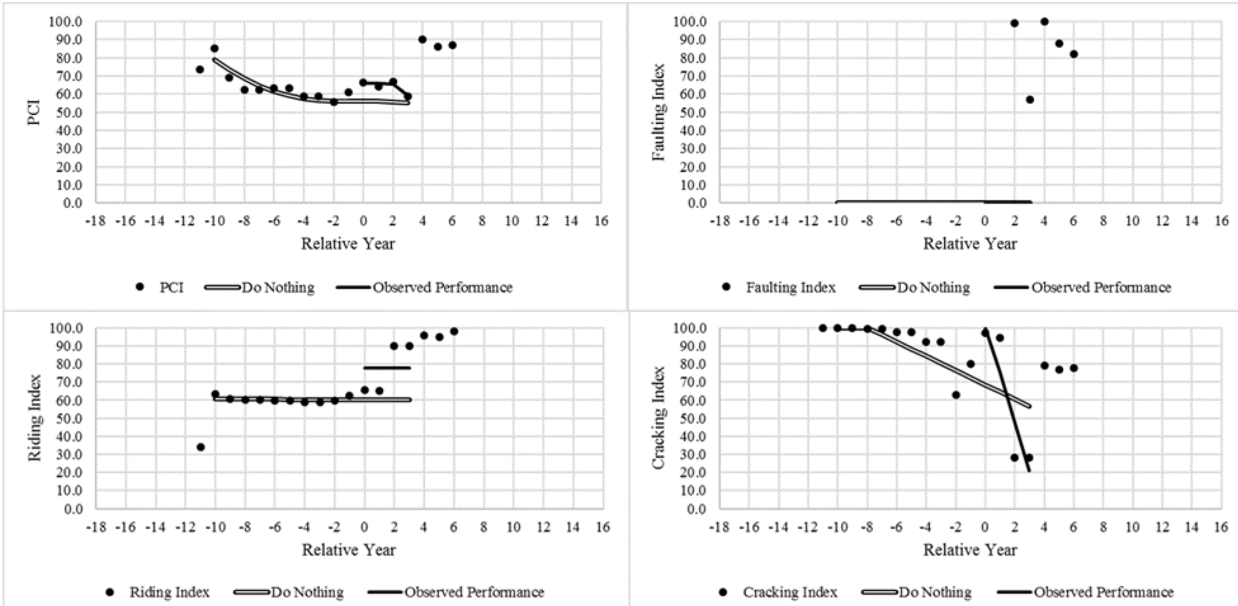

Figure 297. Analytical analysis graphs for project IMN-080-2(226)45—76-01

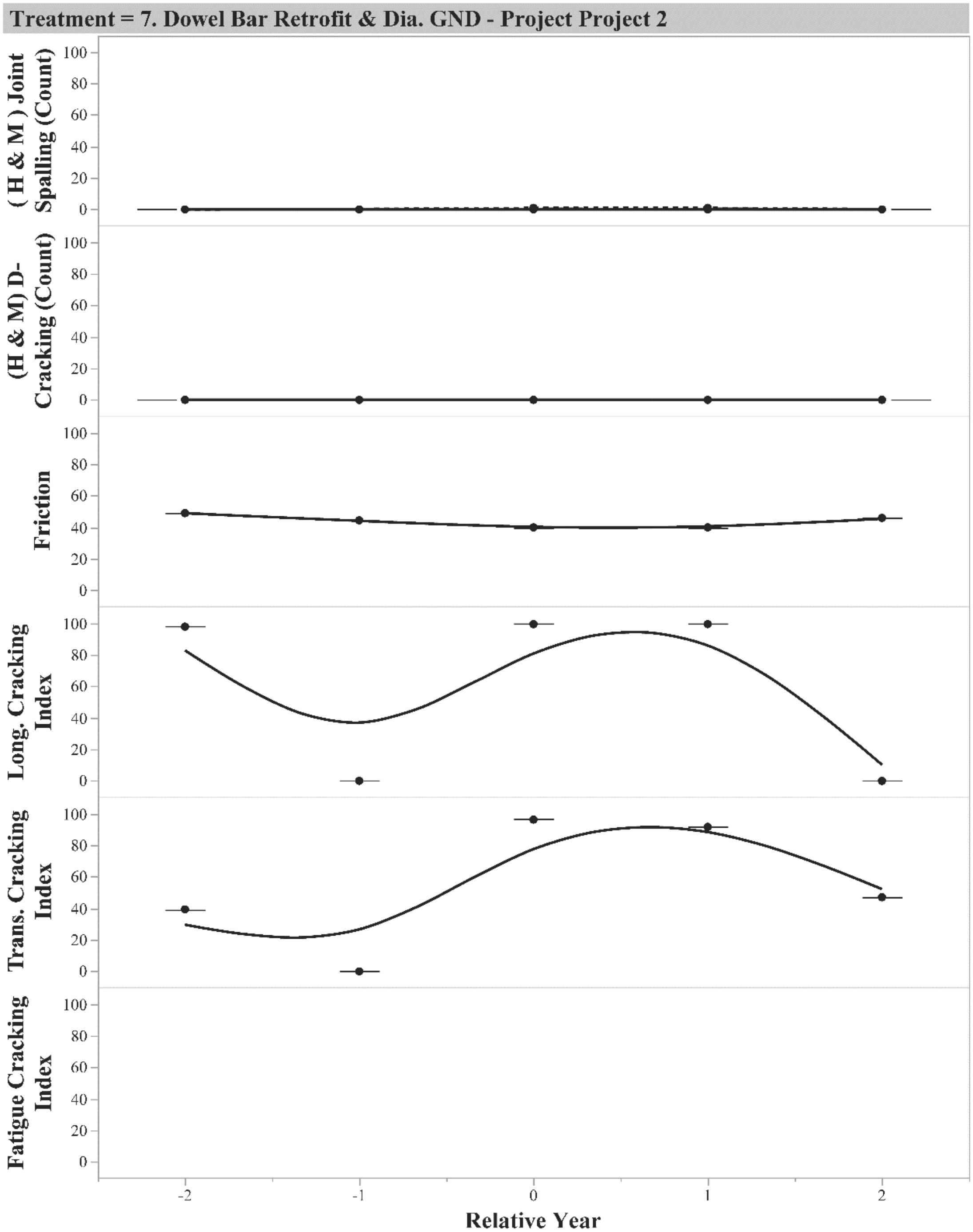

Figure 298. Anecdotal analysis graphs for project IMN-080-2(226)45—76-01

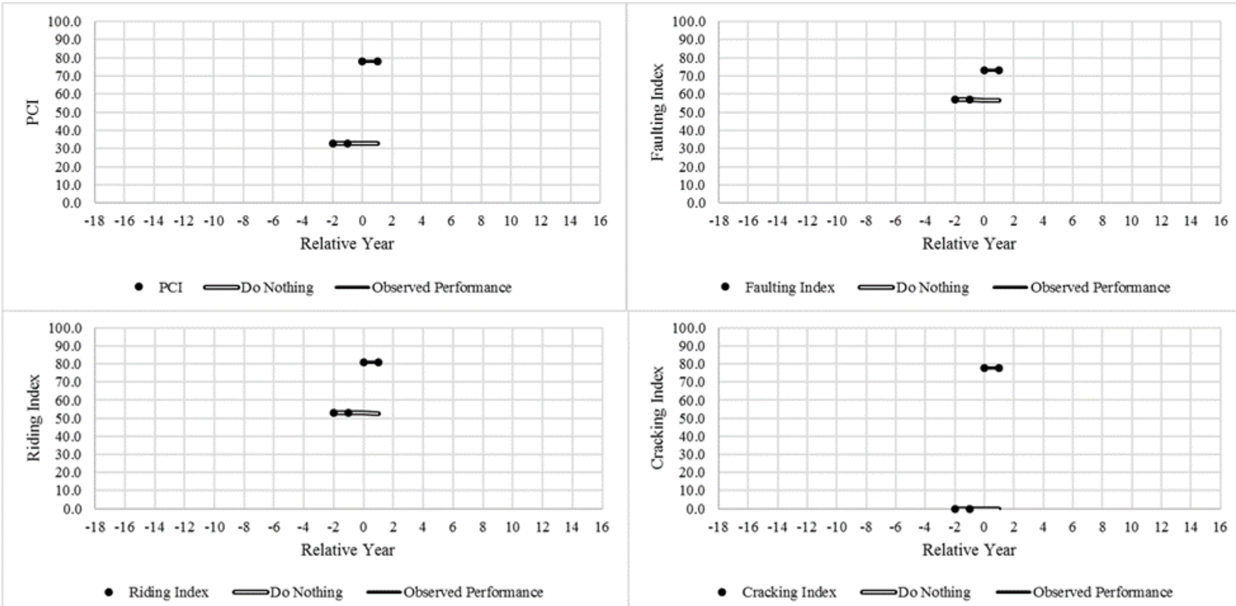

Figure 299. Analytical analysis graphs for project NHSX-020-4(50)—3H-40

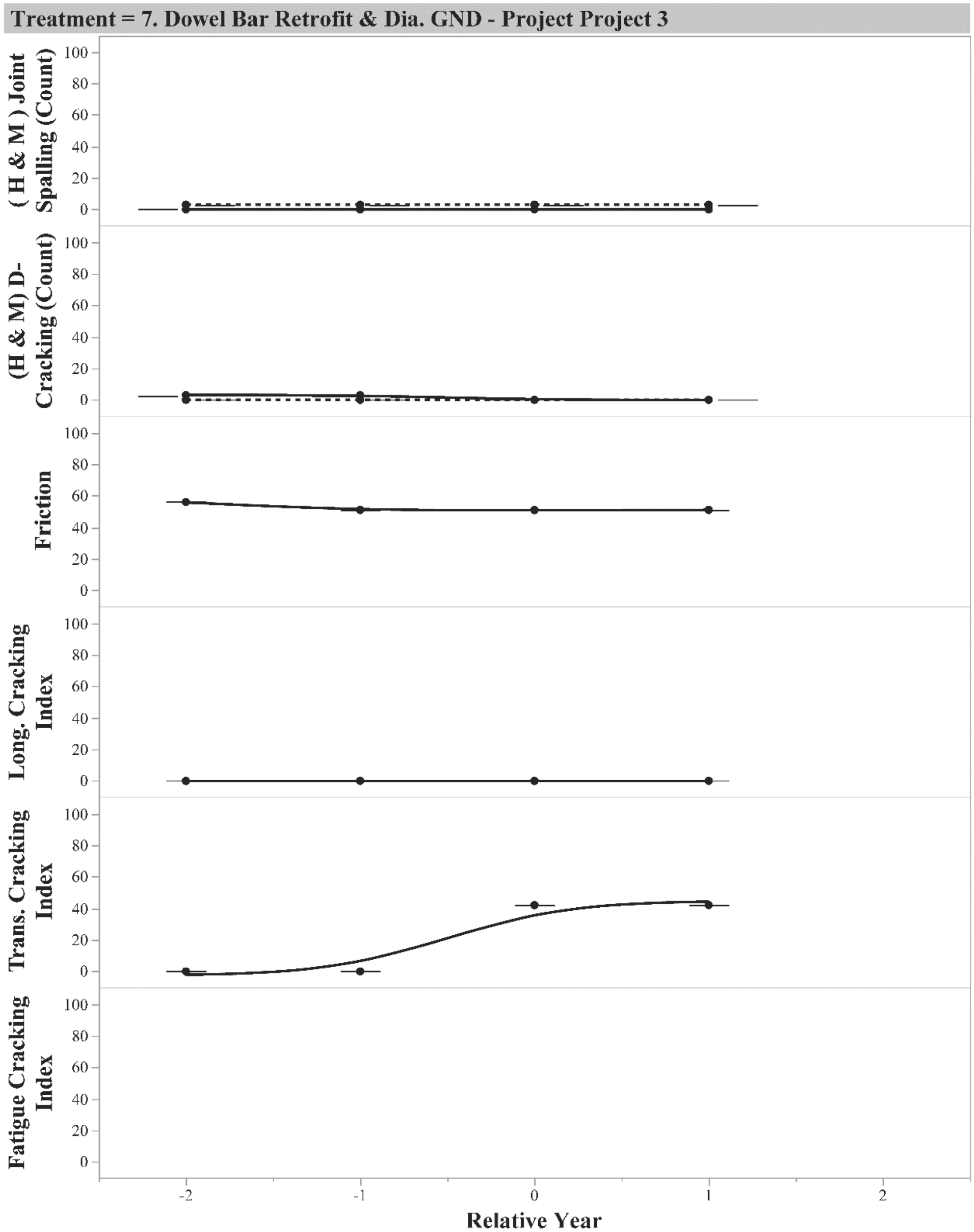

Figure 300. Anecdotal analysis graphs for project NHSX-020-4(50)—3H-40

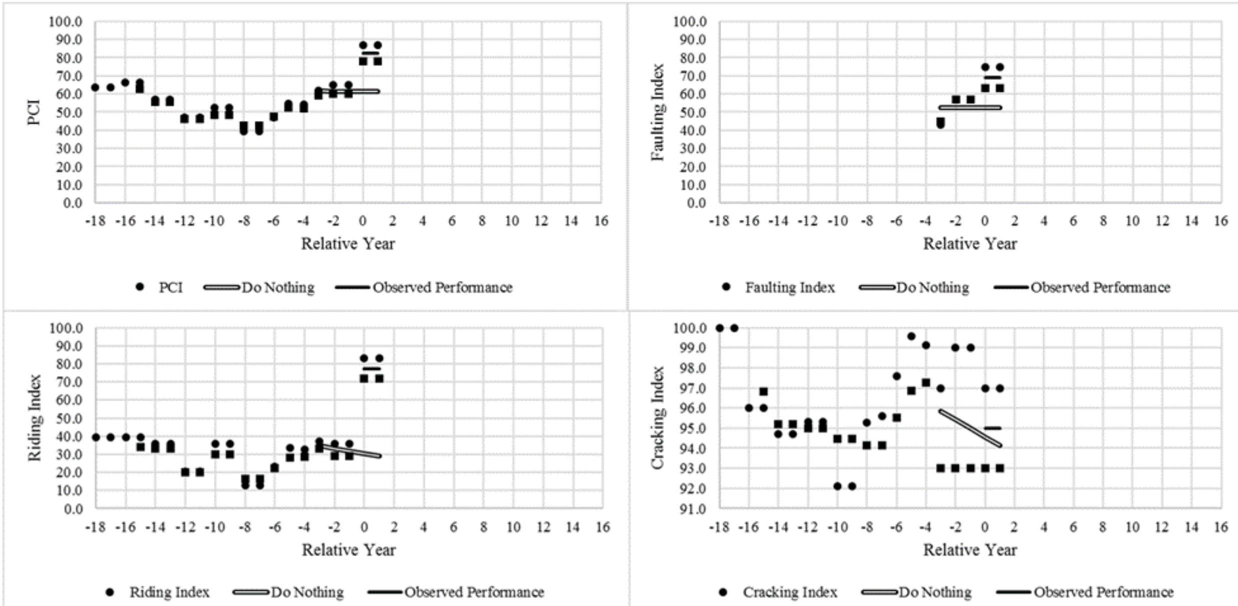

Figure 301. Analytical analysis graphs for project STPN-141-4(28)—2J-14

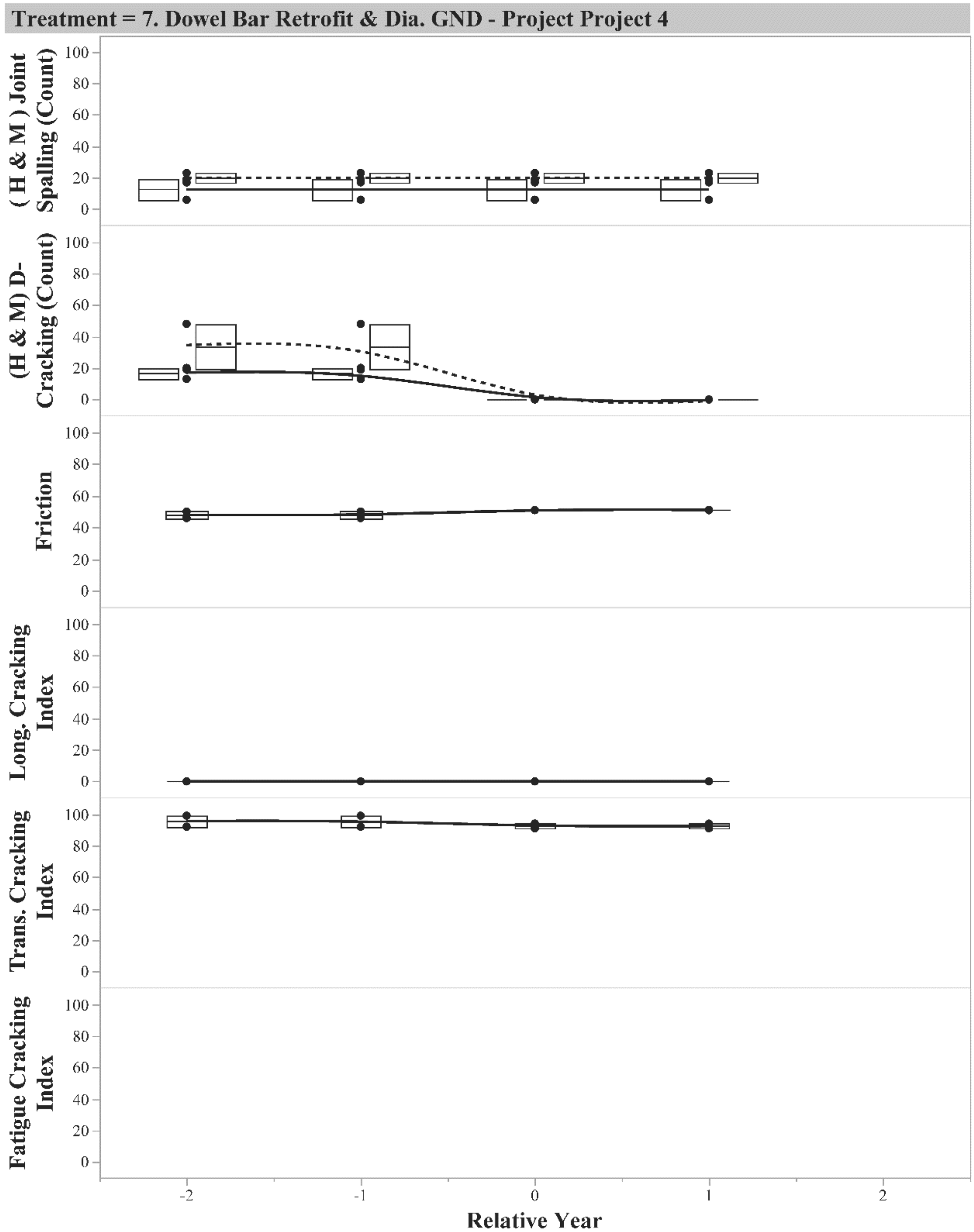

Figure 302. Anecdotal analysis graphs for project STPN-141-4(28)—2J-14

Grinding and Grooving Projects

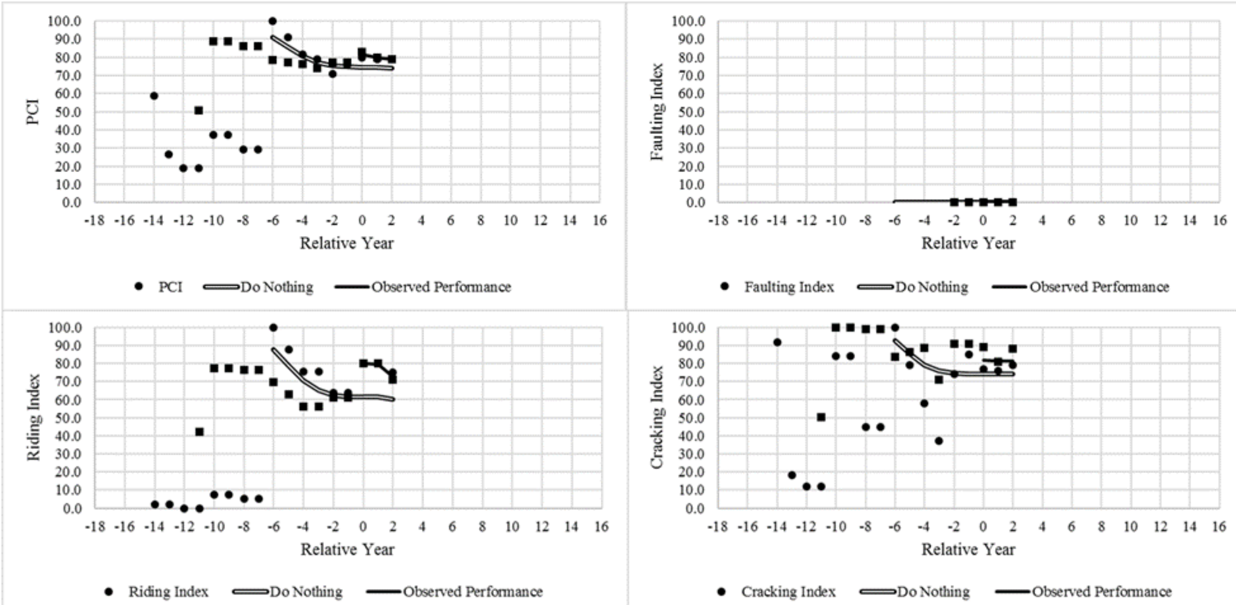

Figure 303. Analytical analysis graphs for project MP-151-6(700)16—76-06

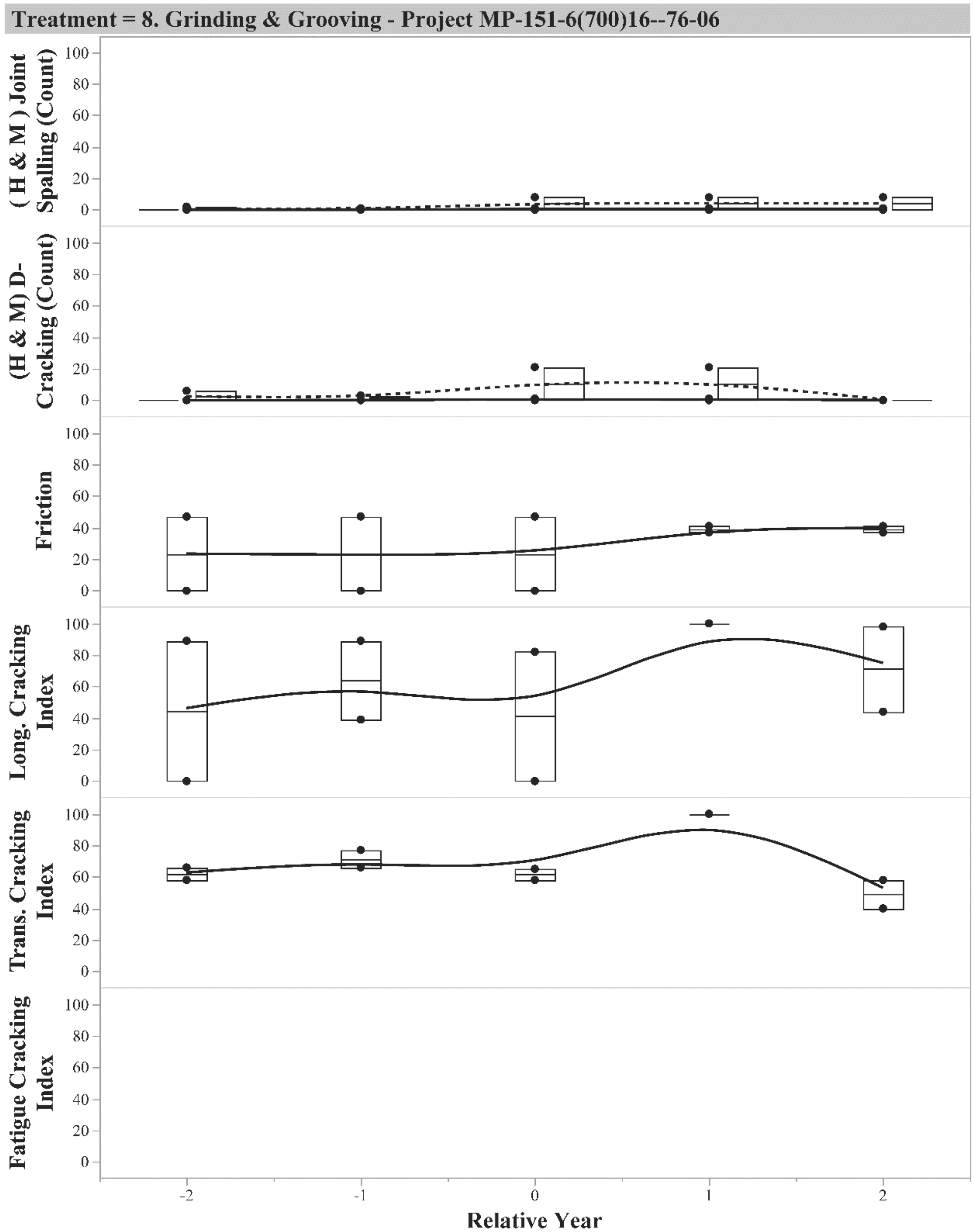

Figure 304. Anecdotal analysis graphs for project MP-151-6(700)16—76-06

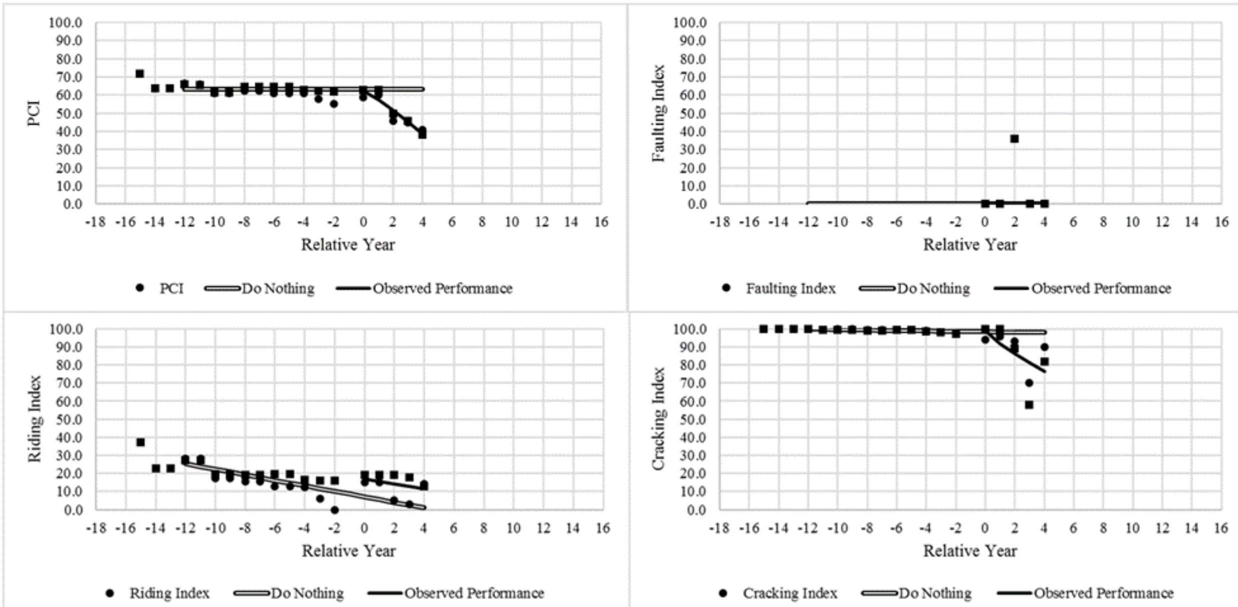

Figure 305. Analytical analysis graphs for project MP-922-6(717)0—76-57

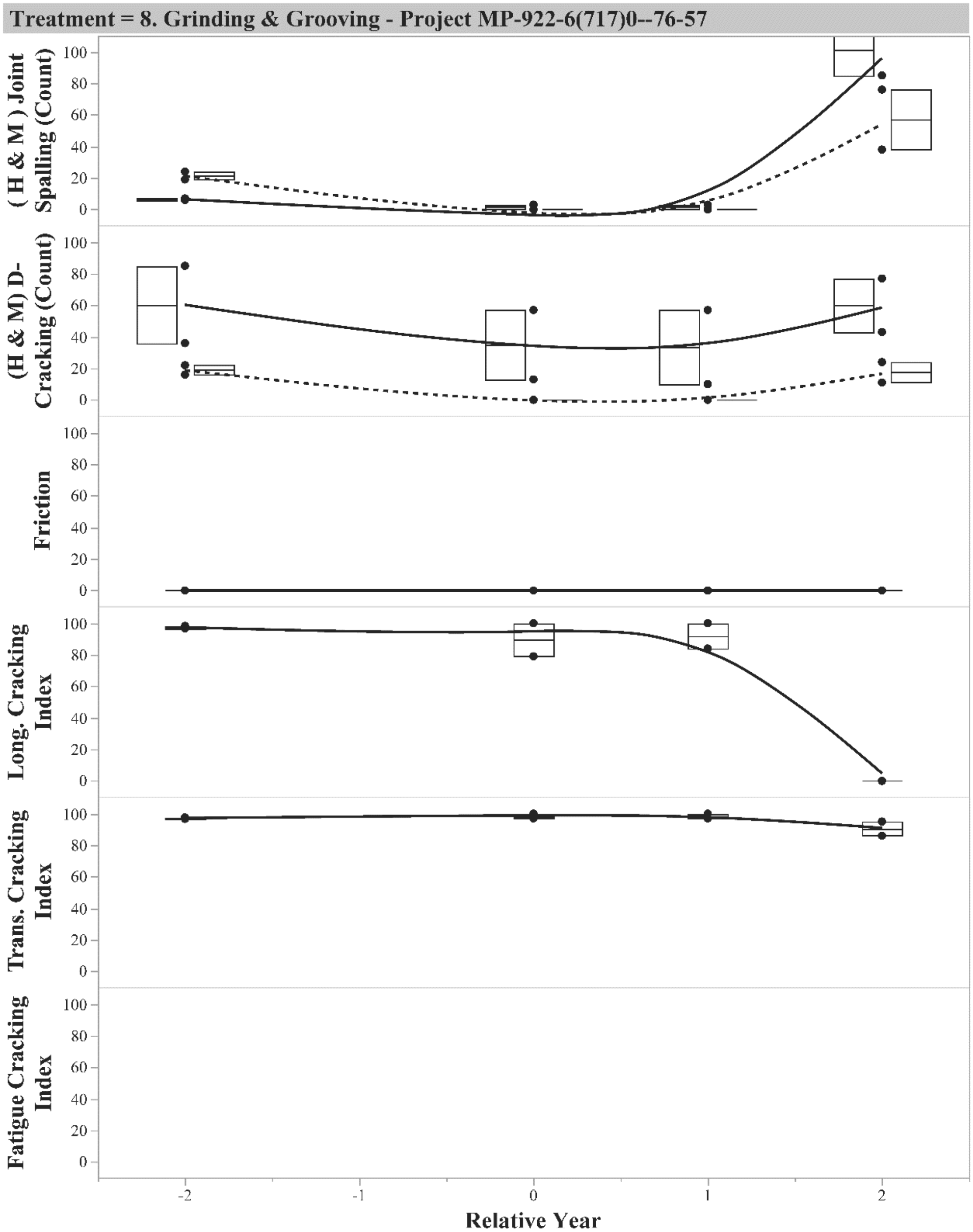

Figure 306. Anecdotal analysis graphs for project MP-922-6(717)0—76-57

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