

# Pavement Evaluation Report

## City of Cincinnati, OH

March 2026



# 1 Table of Contents

- 1 Executive Summary ..... 4
  - 1.1 Condition Results ..... 6
  - 1.2 Budget Scenarios..... 7
- 2 Commonly Used Acronyms ..... 8
- 3 Introduction ..... 9
- 4 Project Scope & Methodology ..... 15
  - 4.1 Pavement Condition Assessment ..... 15
  - 4.2 Pavement Condition Index (PCI) Calculation ..... 18
  - 4.3 International Roughness Index (IRI) Calculation and Analysis..... 18
- 5 Description of Distress Analysis ..... 19
- 6 Results ..... 23
  - 6.1 Pavement Condition Index Results ..... 24
  - 6.2 International Roughness Index Results..... 30
  - 6.3 Distress Breakdown by Severity..... 35
- 7 Sample – Sized Segmentation ..... 38
  - 7.1 Overview of Sample Size Processing..... 38
  - 7.2 Methodology of Sample Size Processing ..... 38
  - 7.3 Sample Size Processing Results..... 38
- 8 Pavement Maintenance/Preservation Funding ..... 41
- 9 Scenarios and Budget Estimates ..... 42
  - 9.1 Deterioration curves ..... 42
  - 9.2 Treatment Activities and Cost..... 42
  - 9.3 Scenarios ..... 44
    - 9.3.1 Do-Nothing..... 44
    - 9.3.2 Unlimited Funding (Fix All) and Distribution of Costs..... 44
    - 9.3.3 Steady State Network PCI (SS PCI) ..... 44
    - 9.3.4 Sample Maintenance Budgets versus PCI Improvement..... 45
- 10 Summary ..... 46
- 11 Appendix I: Distress Definitions (Colorado State University)..... 47
- 12 Appendix II: Automated Data Collection Equipment ..... 48
  - 12.1 Roadway Asset Collection (RAC) Vehicle ..... 48
  - 12.2 Quality Control/Assurance..... 50
  - 12.3 LCMS-2 ..... 51
  - 12.4 Profile..... 52

## List of Figures

Figure 1.1 City of Cincinnati, OH PCI Distribution .....	6
Figure 3.1: Deterioration Curve Example.....	10
Figure 3.2: City of Cincinnati, OH Inspection Breakdown .....	11
Figure 3.3: City of Cincinnati, OH Surface Type Distribution .....	13
Figure 3.4: City of Cincinnati, OH Roadway Network (Collection Status) .....	14
Figure 4.1: City of Cincinnati, OH Network Coverage Map.....	16
Figure 4.2: Right-of-Way Image Example.....	18
Figure 5.1: RAS Pavement Analysis Tool Example .....	20
Figure 5.2: LCMS Post PCI Processing Image .....	21
Figure 5.3: Example of Distress Overlay Images .....	22
Figure 6.1: City of Cincinnati, OH PCI Ranges by Total Miles.....	24
Figure 6.2: City of Cincinnati, OH PCI Ranges by Total Area .....	25
Figure 6.3: City of Cincinnati, OH PCI Ranges by Total Miles (Asphalt) .....	26
Figure 6.4: City of Cincinnati, OH PCI Ranges by Total Miles (Concrete).....	27
Figure 6.5: City of Cincinnati, OH PCI Distribution Map.....	28
Figure 6.6: City of Cincinnati, OH PCI Example Map .....	29
Figure 6.7: City of Cincinnati, OH IRI Category Ranges by Miles.....	30
Figure 6.8: City of Cincinnati, OH IRI Category Ranges by Miles (Asphalt) .....	31
Figure 6.9: City of Cincinnati, OH IRI Category Ranges by Miles (Concrete).....	32
Figure 6.10: City of Cincinnati, OH IRI Distribution Map.....	33
Figure 6.11: City of Cincinnati, OH IRI Example Map .....	34
Figure 6.12: Cincinnati, OH Asphalt Distress Breakdown by Percentage of Segments .....	36
Figure 6.13: Cincinnati, OH Concrete Distress Breakdown by Percentage of Segments.....	37
Figure 7.1: Cincinnati, OH PCI Original Segmentation Example Map .....	40
Figure 7.2: Cincinnati, OH PCI Sample Segmentation Example Map .....	41
Figure 9.1: City of Cincinnati, OH Deterioration Curves with No Maintenance .....	42
Figure 9.2: City of Cincinnati, OH- PCI Trend by Budget Scenario .....	45
Figure 9.3: City of Cincinnati, OH- Predicted 5-Year Pavement Condition Index Outlook .....	46
Figure 12.1: RAS RAC Vehicle.....	49
Figure 12.2: 9-Point Calibration Site Example .....	50
Figure 12.3: LCMS Data Definition .....	53
Figure 9.1: City of Cincinnati, OH PCI Original Segmentation Example Map.....	39
Figure 9.2: City of Cincinnati, OH PCI Sample Segmentation Example Map.....	40

## List of Tables

Table 1.1: City of Cincinnati, OH PCI Ranges by Percent .....	5
Table 3.1: City of Cincinnati, OH Inspection Breakdown .....	12
Table 6.1: City of Cincinnati, OH Condition Scale .....	23
Table 6.2: City of Cincinnati, OH PCI Ranges by Percent (Asphalt) .....	25

Table 6.3: City of Cincinnati, OH PCI Ranges by Percent (Concrete) .....	26
Table 6.4: City of Cincinnati, IRI Category Ranges by Miles.....	30
Table 6.5: City of Cincinnati, OH IRI Category Ranges by Miles (Asphalt) .....	31
Table 6.6: City of Cincinnati, OH IRI Category Ranges by Miles (Concrete).....	32
Table 6.7: Cincinnati, OH Asphalt Distress Breakdown by Percentage of Segments.....	36
Table 6.8: Cincinnati, OH Asphalt Distress Breakdown by Average Density .....	36
Table 6.9: Cincinnati, OH Concrete Distress Breakdown by Percentage of Segments .....	37
Table 7.1: Cincinnati, OH Sample Segmentation PCI Ranges by Percent .....	39
Table 7.2: Cincinnati, OH Sample Segmentation PCI Variance .....	39
Table 9.1: City of Cincinnati, OH- Maintenance Suggestion by PCI Range (Arterials) .....	43
Table 9.2: City of Cincinnati, OH- Maintenance Suggestion by PCI Range (Collectors).....	43
Table 9.3: City of Cincinnati- Maintenance Suggestion by PCI Range (Locals) .....	43
Table 9.4: City of Cincinnati, OH– Fix All Cost per Maintenance Treatment .....	44
Table 9.5: City of Cincinnati, OH- Predicted 5-Year Overall Condition Index Outlook .....	46
Table 9.1: City of Cincinnati, OH Sample Segmentation PCI Ranges by Percent .....	38

## 1 Executive Summary

Roadway Asset Services, LLC (RAS) performed a pavement condition assessment for the City of Cincinnati, OH to provide an accurate assessment of pavement. The pavement data collection started on August 10, 2025, and completed on September 18, 2025. This report provides the processes and procedures for pavement condition data collection and evaluation, assessment of the results, and maintenance recommendations for the City's maintained roadway network.

The pavement condition assessment included an automated mobile data collection, a Pavement Condition Index (PCI) calculated using RAS's pavement analysis tool - Technical Rating Intelligence Program (Road TRIP™), and the delivery of an ESRI file geodatabase. The assessment and conditions rating were performed in general accordance with national standards, where applicable.

The network PCI was determined following the American Society for Testing Materials (ASTM) D6433-11 "Standard Practice for Roads and Parking Lots Pavement Condition Index Surveys" to determine the PCI.

Table 1.1: City of Cincinnati, OH PCI Ranges by Percent

<b>Pavement Condition Index (PCI) Range</b>	<b>Condition Description</b>	<b>Total Area (yd2)</b>	<b>Percent of Total Area (yd2)</b>	<b>Total Distance (Centerline Miles)</b>	<b>Percent of Network Miles</b>
<b>92 - 100</b>	<b>Excellent</b>	<b>1,033,027</b>	<b>5.8%</b>	<b>51.88</b>	<b>5.3%</b>
<b>82 - 91</b>	<b>Very Good</b>	<b>2,264,390</b>	<b>12.6%</b>	<b>122.56</b>	<b>12.4%</b>
<b>68 - 81</b>	<b>Good</b>	<b>4,969,331</b>	<b>27.7%</b>	<b>275.94</b>	<b>28.0%</b>
<b>50 - 67</b>	<b>Fair</b>	<b>4,405,674</b>	<b>24.5%</b>	<b>241.64</b>	<b>24.5%</b>
<b>35 - 49</b>	<b>Poor</b>	<b>2,464,530</b>	<b>13.7%</b>	<b>131.54</b>	<b>13.4%</b>
<b>20 - 34</b>	<b>Very Poor</b>	<b>2,526,213</b>	<b>14.1%</b>	<b>142.54</b>	<b>14.5%</b>
<b>0 - 19</b>	<b>Failed</b>	<b>294,023</b>	<b>1.6%</b>	<b>18.33</b>	<b>1.9%</b>
<b>Total of Rated Segments</b>		<b>17,957,188</b>	<b>100.0%</b>	<b>984.43</b>	<b>100.0%</b>

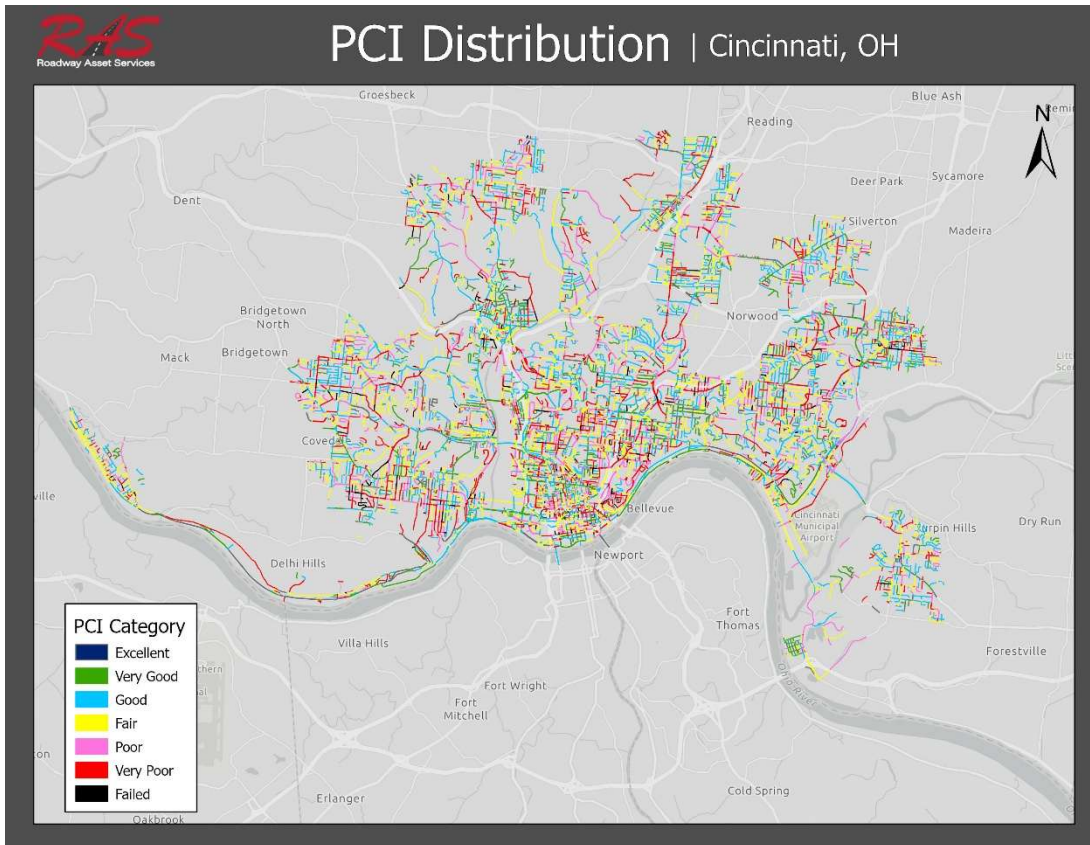


Figure 1.1 City of Cincinnati, OH PCI Distribution

## 1.1 Condition Results

RAS’s pavement analysis tool, Technical Rating Intelligence Program (Road TRIP™), was used to evaluate and classify the distresses, and calculate the PCI. The PCI is a numerical rating of the pavement condition based on the type, severity, and density of distresses observed on the pavement surface. The PCI is a measure of the overall serviceability provided by a pavement to the vehicle driver. The IRI value is normalized to provide a value between 0 and 100. At the time of this evaluation in 2025, the weighted arithmetic average PCI for all roads was **61**. Following the from Table 1.1, the network is in a **“Fair”** condition.

## 1.2 Budget Scenarios

RAS performed several five-year maintenance and preservation program scenarios for the City of Cincinnati, OH that were updated in Fiscal Year 2026/27. Cincinnati has a budget of \$20,350,000 which was run in two forms – with and without preservation treatments. RAS also ran multiple additional scenarios with budgets below and above the City’s annual budget assigned to optimized maintenance and rehabilitation activities. These budgets were applied in the *Budget Optimization Street Selector (BOSS™) software*, for the development of a financially optimized 5-year plan.

Optimization is a broad-based term that has many different definitions. For most pavement management systems, optimization is the ability to prioritize a multi-year rehabilitation plan using several different factors that are important to Cincinnati and based on sound engineering constraints. RAS infuses financial optimization by identifying two key components of a financial analysis:

*Need Year – when a road/segment becomes critical, meaning it is getting closer to dropping into the next more expensive rehabilitation category.*

*Cost of Deferral – identifying the cost of deferral between a road/segment’s current rehabilitation category and its next category.*

Understanding the “Cost of Segment Deferral” allows the analysis to maximize the City’s limited funds in the best manner possible.

Using information provided by the City, RAS pavement management experience, and industry standards, RAS assigned the PCI impact to each maintenance activity and is presented in Tables 9.1 to 9.4.

***A 4% inflation rate per year was applied to the maintenance and rehabilitation activity costs in the 5-year models.***

## 2 Commonly Used Acronyms

<b>AC</b>	Asphalt Concrete
<b>ASTM</b>	American Society for Testing and Materials
<b>BOSS</b>	Budget Optimization Street Selector
<b>BR</b>	Brick
<b>GR</b>	Gravel
<b>GPS</b>	Global Positioning System
<b>IRI</b>	International Roughness Index
<b>LCMS</b>	Laser Crack Measurement System
<b>OCI</b>	Overall Condition Index
<b>PCC</b>	Portland Cement Concrete
<b>PCS</b>	POS Computer System
<b>PCI</b>	Pavement Condition Index
<b>POS</b>	Position and Orientation System
<b>RAC</b>	Roadway Asset Collection vehicle
<b>RAS</b>	Roadway Asset Services
<b>Road TRIP™</b>	Road Technical Rating Intelligence Program
<b>ROW</b>	Right-of-way
<b>UNS</b>	Unsurfaced

### 3 Introduction

The two most common types of paved surfaces are Asphalt and Concrete, or a combination of both. An asphalt pavement surface begins to oxidize and deteriorate from the day it is constructed, while concrete pavements may have longer durability, they also began deteriorating after construction due to exposure to the elements. Many factors affect the deterioration rate, such as, but not limited to, the traffic loads, climatic conditions, age, material durability, subgrade support, damage caused by poor drainage, and construction materials and techniques. These factors cause the deterioration rate to be different for every pavement section. To manage a large pavement network, “family performance” curves are developed from available data to represent the expected performance and to help determine optimal times to apply preventive and rehabilitation treatments. To develop more accurate curves, periodic evaluations and assessment of the pavement condition must be performed to gain a realistic representation of condition versus age of the pavement network.

It is important to note that pavement deterioration is not a linear process. Initial deterioration occurs at a slow rate. After approximately 40% to 50% of a pavement’s service life, a pavement segment reaches an “inflection point” after which pavement condition rapidly deteriorates. Understanding the condition and age at which this rapid drop occurs is imperative in determining the optimal time for maintenance (Figure 3.1). Similarly, properly understanding pavement conditions allow for cost effective preventive maintenance versus reactive maintenance at a much higher cost.

Standard industry practice is to assess a pavement network every three to five years. More frequent assessments will likely not detect significant changes in condition in most pavement segments. More than five years between assessments will likely miss critical changes and will not provide adequate data to define a deterioration curve where preventive maintenance is best applied. RAS recommends assessments every three years for networks greater than 100 miles. Local and residential streets can be delayed to every five years, because they are expected to deteriorate at a slower rate compared to arterial/collector streets. Local street deterioration is based on climatic conditions more than traffic loads. However, if funding is not separated by arterial/collector streets versus local streets, the assessments should be done in the same year to provide equivalent information for the decision process.

In this report, we describe the tools, processes and procedures used to collect and analyze pavement condition data as well as provide a summary of the results obtained from calculating each segment’s PCI.

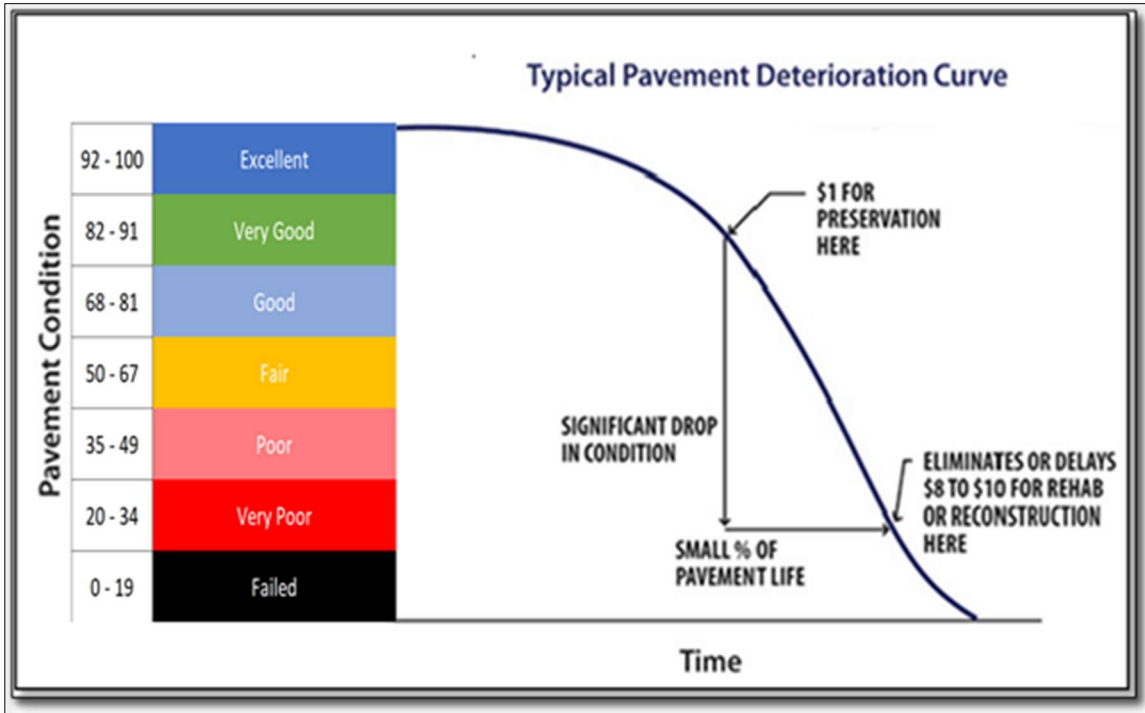


Figure 3.1: Deterioration Curve Example

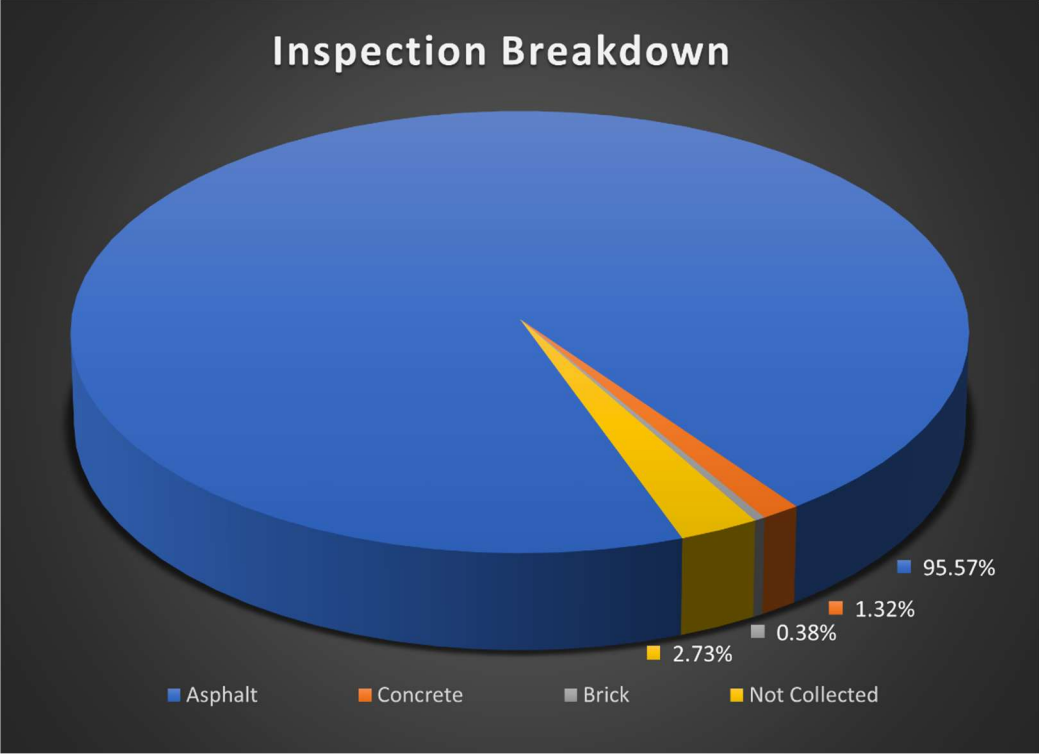


Figure 3.2: City of Cincinnati, OH Inspection Breakdown

Table 3.1: City of Cincinnati, OH Inspection Breakdown

<b>Item</b>	<b>Description</b>	<b>Centerline Miles</b>	<b>Percent of Centerline Miles</b>
<b>1</b>	Asphalt Segments with PCI	967.23	95.57%
<b>2</b>	Concrete Segments with PCI	13.40	1.32%
<b>3</b>	Brick Segments with PCI	3.80	0.38%
<b>4</b>	Not Collected – Not Accessible	17.95	1.77%
<b>5</b>	Not Collected – Gated	3.65	0.36%
<b>6</b>	Not Collected – Construction	1.48	0.15%
<b>7</b>	Not Collected – Does Not Exist	0.95	0.09%
<b>8</b>	Not Collected – Short Segment	0.94	0.09%
<b>9</b>	Not Collected – GIS Error	0.69	0.07%
<b>10</b>	Not Collected – Private	0.21	0.02%
<b>11</b>	Not Collected – Other	0.19	0.02%
<b>12</b>	Not Collected – Bridge	0.19	0.02%
<b>13</b>	Not Collected – Train Tracks	0.11	0.01%
	<b>Total With PCI</b>	984.43	97.27%
	<b>Total Without PCI</b>	27.64	2.73%
	<b>Total</b>	<b>1,012.07</b>	<b>100.00%</b>

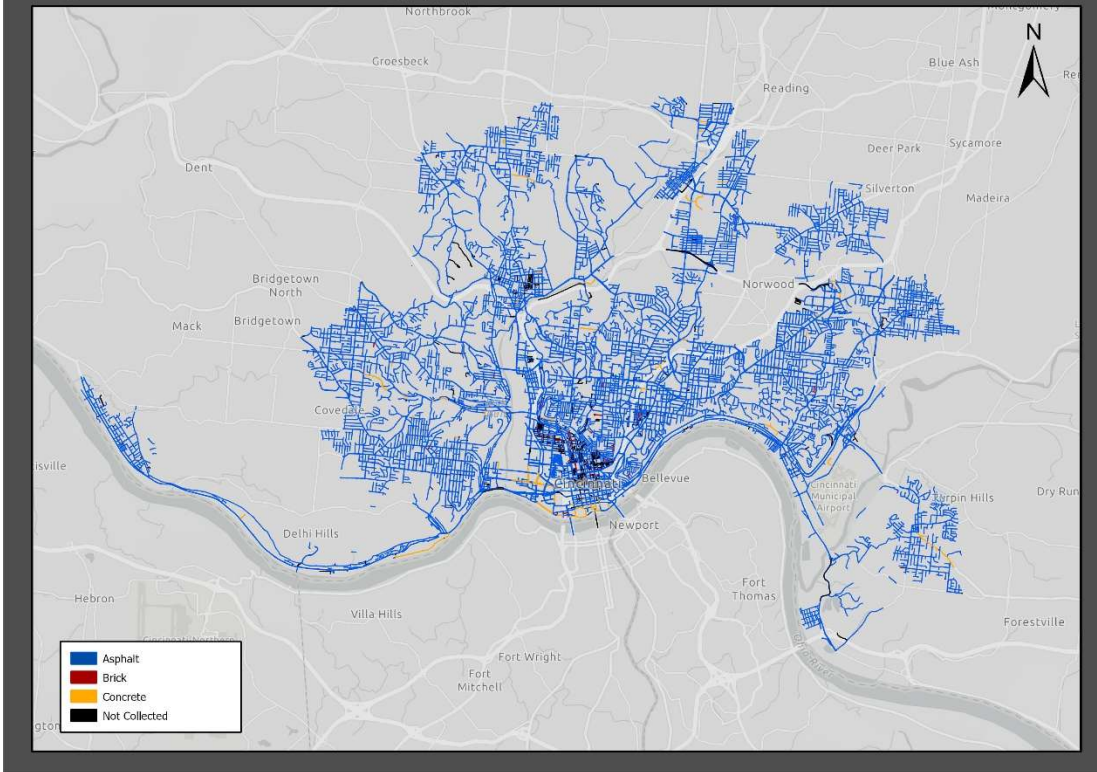


Figure 3.3: City of Cincinnati, OH Surface Type Distribution

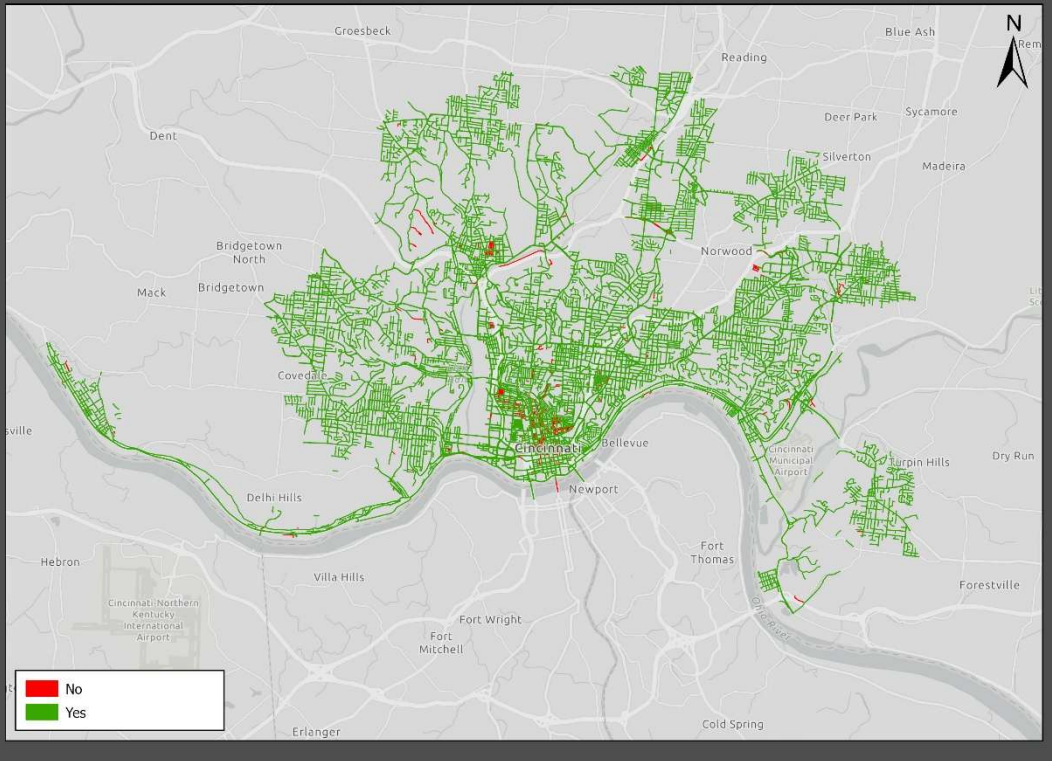


Figure 3.4: City of Cincinnati, OH Roadway Network (Collection Status)

## 4 Project Scope & Methodology

The overall project scope of work contains seven tasks outlined below:

1. Verify City's Street network,
2. Perform mobile image data collection,
3. Determine the Pavement Condition Index (PCI),
4. Determine International Roughness Index (IRI),
5. ODOT Rating of Brick Segments
6. Import of PAVER Data
7. Budget Analysis in RAS's BOSS™ software,
8. Prepare pavement final report.

### 4.1 Pavement Condition Assessment

Roadway Asset Services, LLC (RAS) performed a pavement condition survey for City of Cincinnati, OH beginning August 10, 2025, and completed on September 18, 2025, covering approximately 1,012 centerline miles of roadway. RAS used a Roadway Asset Collection (RAC) vehicle to collect street level ROW images and Laser Crack Measurement System (LCMS-2) pavement images. The collected LCMS-2 pavement images were used to identify street segment pavement distresses and severities through analysis, while the 360-degree panoramic ROW images were used to confirm pavement distresses.

Roadway networks are usually divided into three pavement surface types: asphalt (AC), Portland cement concrete (PCC), and unsurfaced (UNS). Due to the nature and scope of the project, pavement imagery and data were collected on asphalt, concrete, and brick roads.

To determine the general distress characteristics of each roadway segment, RAS utilized a RAC vehicle, which combines multiple engineered technologies to collect real-time pavement data, ROW data, and images at posted speed limits. This eliminates the need to place pavement inspection technicians in the field near vehicle traffic. A detailed listing and description of the RAC equipment is included in Section 12.0 of this report.

Mobile image collection of the City's roadway network was accomplished through coordination with the City's GIS map provided for the survey areas, as displayed in Figure 4.1. Efforts associated with mobile image collection included review of client GIS street centerline file, route planning based on GIS street centerline, and coordination of existing construction projects along the City's streets.

This project applied the ASTM D6433-11 'Standard Practice for Roads and Parking Lots Pavement Condition Index Surveys' pavement condition analysis method on collected LCMS-2 images to determine the road segment and network PCI. The ASTM D6433-11 method covers the process of quantifying pavement conditions and identifies pavement distress types, distress

extent measurements, and distress severity to determine the deduct values for each distress type. ASTM D6433-11 outlines the method of PCI value calculation, which includes determining the deduct values, correcting for number of distresses in each survey, and calculating the PCI value by subtracting the maximum deduct value from one hundred.

The ASTM D6433-11 procedure also outlines how the road network is divided into Sections and Sample Units; first identifying the branches of the pavement with different uses, then dividing each branch into sections based on pavement design, construction history, traffic, and condition. RAS used the sections defined by the city of Cincinnati in their provided GIS database files. These sections typically can then be divided into sample units that are approximately 2,500 square feet in size. However, for this evaluation, RAS used the option to evaluate 100% of the lanes driven by the RAC vehicle. Instead of averaging the number of sample units inspected within each section, RAS provided one PCI score determined by measuring all the distresses within the driven lane to determine the PCI for each section.

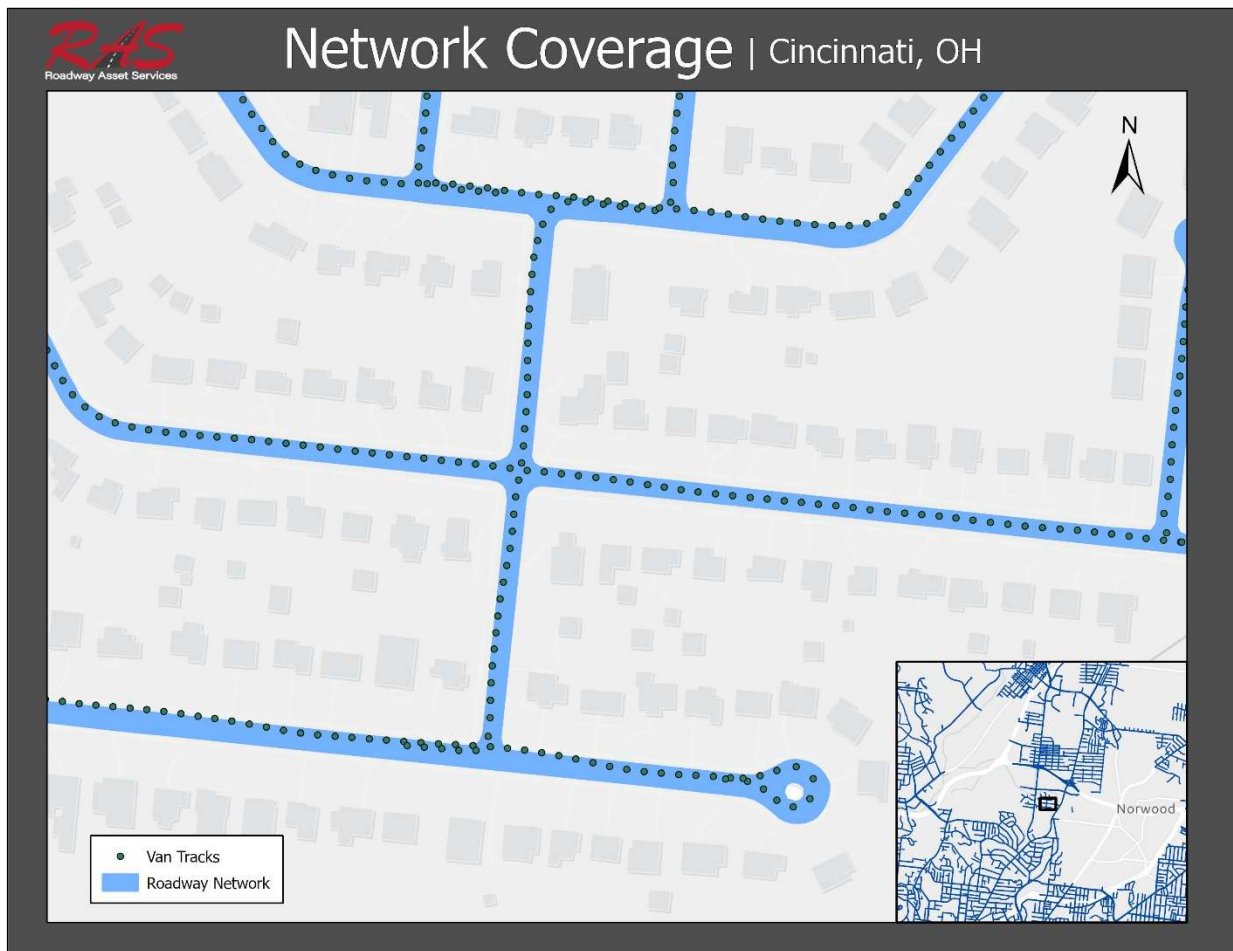


Figure 4.1: City of Cincinnati, OH Network Coverage Map

The RAS RAC vehicle collects pavement and ROW images concurrently, approximately every 25 feet along each street segment. All pavement rating is done automatically through RAS's Road TRIP™ to ensure we accurately capture all the distresses and false positives are minimized using proper sensor settings and logic engineering definitions of each distress.

International Roughness Index (IRI) and longitudinal profiles were collected using an ICC inertial profiling system in accordance with ASTM E950, AASHTO Standard M328-14, AASHTO R43-13, and AASHTO Standard R56-14. For the network collection project, RAS collected IRI data and presented the results in the final database based on the following:

Line lasers were used in each wheel path to increase repeatability of measurements and to reduce variability due to wheel path cracking and concrete tinning. The ICC profiler routinely achieves 98%+ cross-correlations on certification sites, making it one of the most accurate devices available for IRI and profile measurement. The operation and verification of the inertial profiling system shall be expertly conducted in accordance with AASHTO Standard R57-14.

The RAC vehicle is configured with a Point Gray Ladybug 5+ 32MP 360-degree camera to provide a full panoramic image of the ROW, displayed in Figure 4.2. The images were captured at roughly 20-foot intervals and were post-processed using collected inertial and GPS data. This allows for more accurate asset extraction to be completed.

The measuring of pavement width can be accomplished utilizing the calibrated Ladybug imagery in conjunction with the LCMS-2 imagery and inertial GPS data. Using the 360-degree view of the ladybug, RAS can accurately and repeatably measure from edge of pavement to edge of pavement for each road segment. This provides a more accurate area calculation for better budgeting and forecasting. For cul-de-sac sections an average width measurement is taken for the straight portion and the bulb. RAS can also calculate the areas of each segment independently and get a true area of the cul-de-sac section. This is one of the topics that are discussed at the working session prior to data collection. The length of a road segment is determined from the GIS database provided by the City. RAS understands that the GIS is not always 100% accurate. In these cases, after collection is complete, RAS can use the GPS trajectory of the van to determine the true beginning and ending of the road to get a more accurate length and therefore a more accurate area measurement.



Figure 4.2: Right-of-Way Image Example

#### 4.2 Pavement Condition Index (PCI) Calculation

A pavement distress inventory consists of identifying specific pavement surface distress types that are associated with degradation of a pavement surface due to traffic loads, environmental factors, lack of maintenance and other anthropogenic or natural occurrences. The distress type is then assigned a severity rating (low/medium/high), and the extents of the distress type and severity are recorded. For this project, the pavement distress types, causes and measurements were inventoried utilizing the ASTM D6433-11 method. The inspections covered **100% of the length of a section** for the outside lane of travel.

Each street segment's PCI was calculated utilizing Road TRIP™. The calculation tool within Road TRIP™ is based on the ASTM D6433-11 method of calculating a street segment's PCI value using the observed pavement distresses and severities in the inventory database and ASTM D6433-11 deduct curves for each distress type. ASTM D6433-11 is based on a 0 to 100 rating scale where 0 represents a failed roadway condition and 100 represents an excellent roadway condition.

#### 4.3 International Roughness Index (IRI) Calculation and Analysis

As part of this contract, IRI values were collected along the survey segments utilizing a high-speed three laser profiler. The IRI is a general measurement of the ride quality of a street section and was performed in accordance with AASHTO R 43-07 and ASTM E950. IRI indexes were obtained from measured longitudinal road profiles and were processed using a quarter-car model at 52.80-foot intervals (0.010/mi). RAS utilized a three-laser surface profiling system for evaluating the smoothness of the pavement. The profiler uses infrared lasers and precision

accelerometer to obtain accurate and precise profile measurements. The values reported provided to the city are in units of inches per mile. It should be noted that IRI indexes can “spike”, resulting in erroneous data being reported along sections of roads where slow speeds (below 35mph) are involved.

Categorization of IRI indexes can vary from state to state and are typically determined by the agency (e.g., City, DOT, County, etc.). The values for IRI should range from 0 to 700 inches/mile. Any values above 700 inches/mile are flagged and changed to be equal to 700 in/mi as they are caused by several reasons mentioned above. The lower the IRI number, the smoother the ride and conversely, higher values indicate a rougher ride. The national standard in the United States for IRI thresholds for all road classifications range from 96 in/mi to 170 in/mi indicating “acceptable” road segments, and IRI less than 95 in/mi are considered to be “good” road segments.

## 5 Description of Distress Analysis

Fully automated distress reduction methods are used to classify and rate the distress; therefore, acceptance checks are performed by viewing the pavement images. The data collection vehicle includes software programs that overlay the distress ratings directly on the pavement image to allow viewing of the image and ratings together. Checks of distress ratings are a manual process in which samples of data are visually inspected for accuracy of the ratings. Since distress rating checks are very time-consuming, we commonly begin sampling checks before data collection/rating is complete. Because of this overlap, there is an opportunity to promptly re-collect or re-survey any sections with data that do not meet quality criteria. Everything captured in the survey vehicle is GPS-tagged and allows for real time QC to ensure nothing is missed during data collection.

RAS post-processes the pavement and Right-of-Way (ROW) imagery from the RAC vehicle for each day of image collection. A data collection session, which is referred to as a survey, begins when the RAC crew selects “Start” in the collection software on board the RAC vehicle and ends when they select “Stop.” In a single day, RAS will collect multiple survey sets. With a completed day of collection, RAS pavement engineers and GIS analysts use Pavemetrics® Road Inspect Software to generate all the source data used by Road TRIP™. Every survey set is linked to a uniquely identified road segment, which is used as an identifier during the analysis of the sample area, then identification of the distress extent / severity, and ultimately the distress density for each road segment is added to the database.

Figure 5.1 shows a few of the different tool’s RAS utilizes within Road TRIP™ during the QC process. In the upper left corner, we can observe the segment ID, all the images linked to that segment, the rated distresses and exercise the option to manually add a patch area if the Road TRIP™ tool has not identified the patch. RAS utilizes Microsoft® Azure Computer Vision algorithm to identify patches. The algorithm has been specially tested and trained by RAS to produce accurate patch detection. The upper right corner displays the Ladybug images, which the user can toggle between forward, left, right, right-rear, or left-rear facing views. The lower

left corner lists the distresses rated in the segment selected with the severity, quantity, density and how many points are deducted from the PCI based on the ASTM D6433-11 deduct curve values. The lower right corner displays the rutting measured by the Laser Profiler and visually displayed by the LCMS-2 3D data.

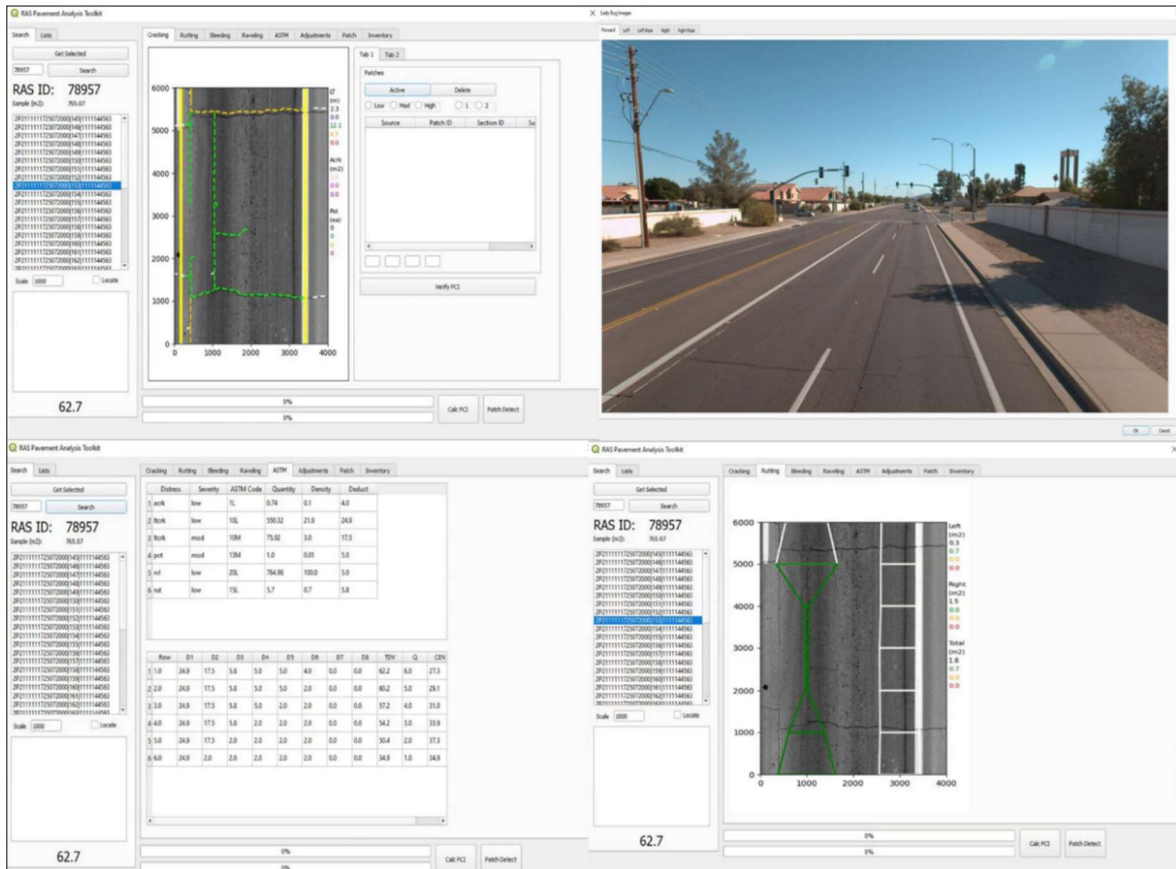


Figure 5.1: RAS Pavement Analysis Tool Example

This method of pavement distress inventory provides a quantifiable and repeatable process to the City. Each street segment, in conjunction with the pavement and ROW imagery, allows pavement engineers to review each road segment, allowing for an open quality control process that is defensible and repeatable.

Road TRIP™ uses the depth map created by the Laser Crack Measurement System (LCMS) to locate the valleys and fissures within the surface of the roadway. These valleys and fissures are then measured and rated. Figures 5.2 and 5.3 display an example of distress overlay images.

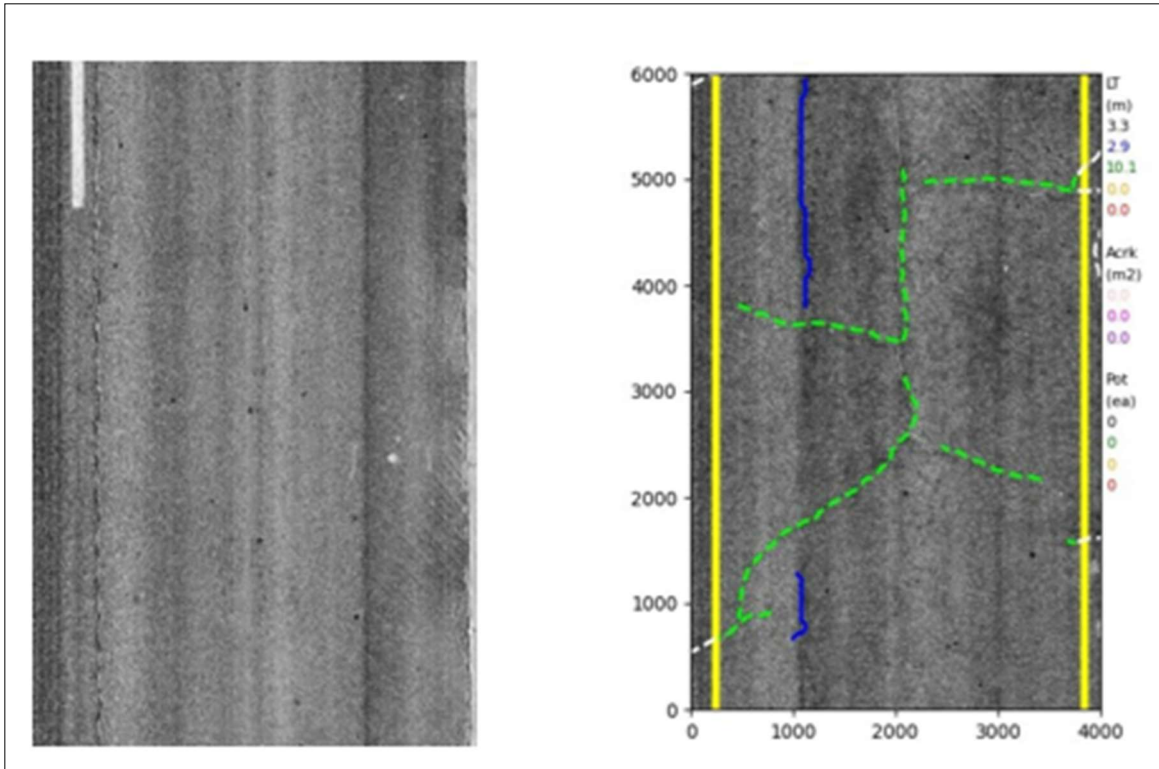


Figure 5.2: LCMS Post PCI Processing Image

The yellow line indicates the boundary of rated sample, green, yellow, and red dotted lines indicate longitudinal and transverse cracking (**LT**) of low, moderate, and high extent. The blue lines are sealed cracks detected by the LCMS and are attributed to the low severity linear crack category. The pink, magenta, and violet lines indicate areas of low, moderate, and high severity alligator cracking that has been filtered because it does not meet minimum length or width requirements. The measurements on the right side of the image are the length for longitudinal / transverse (**LT**) cracking in meters, the area in square meters for alligator cracking (**Acrk**) and the number of potholes (**Pot**) or count.

The LCMS has been set up to follow the ASTM D6433 to determine the severity of each distress. Each distress is defined by ASTM D6433, and the severity levels are presented as measurable attributes of the distress. For example, longitudinal and transverse cracks are defined by the crack width; where non-filled cracks with a width less than 3/8 inch or filled cracks of any width are considered low severity. Moderate severity is defined as non-filled cracks with a width between 3/8 inch and 3 inches. High severity is defined as cracks greater than 3 inches in width or those surrounded by moderate to high severity cracks. The overlay images provide a visual means by which to review the sensor.

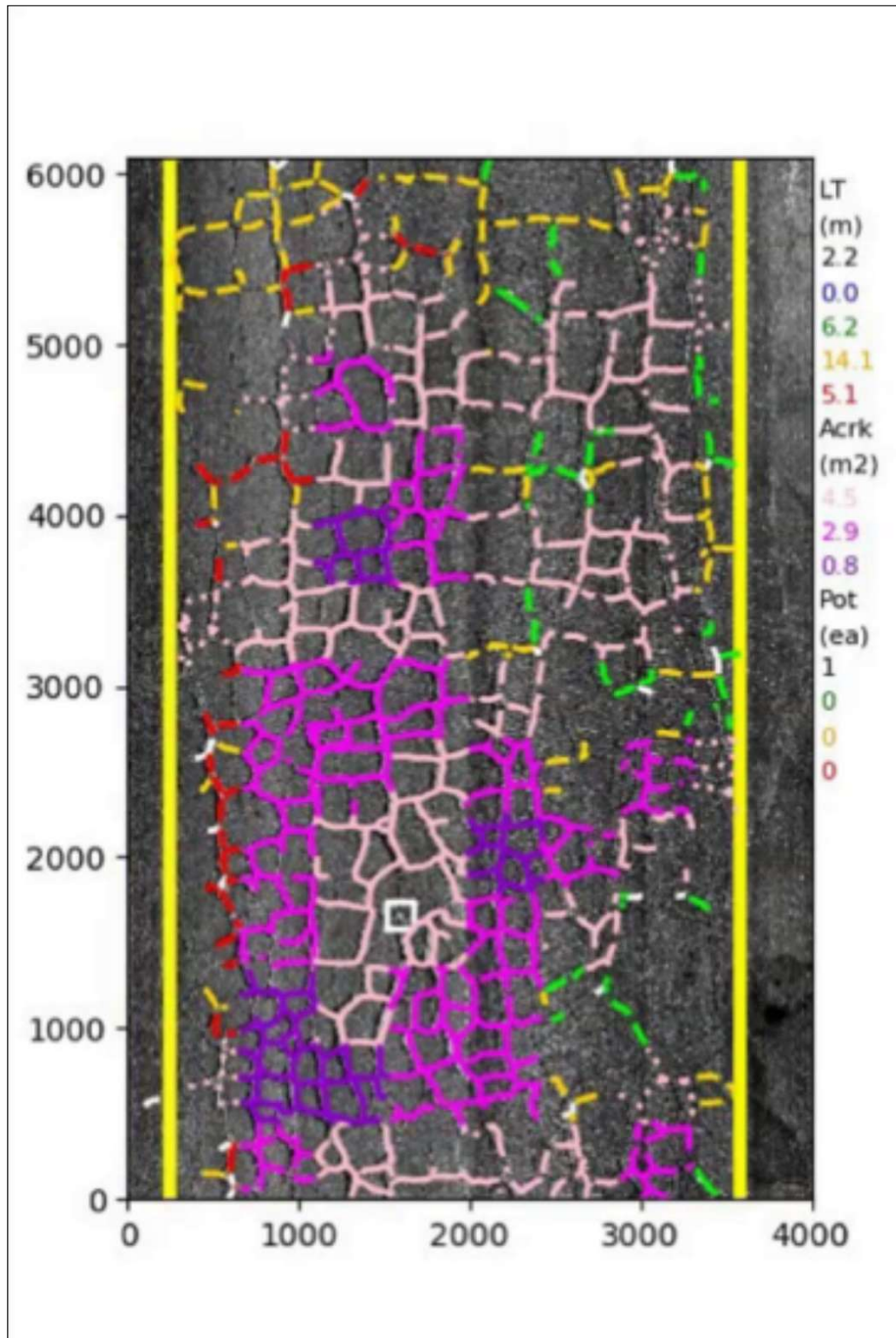


Figure 5.3: Example of Distress Overlay Images

## 6 Results

The overall pavement network health of the City of Cincinnati can be evaluated by examining Figure 6.2 in more detail. This figure illustrates the percentage of the network area that falls within each descriptive condition category. Key observations from this pavement survey include:

- **Shape of Distribution** – the graph illustrates a distribution that is relatively bell-curve shaped and peaks between a PCI of 68 to 81.
- **Average PCI** – The City’s network average PCI score is 61 (as of September, 2025) and is near the averages that are typically seen across the country between a 60 to 65.
- **Good Roads** – Currently 18.4% of the City’s roadways fall into the Very Good and Excellent PCI condition categories, which is above the national average of 15%.
- **Backlog** – these are the roads that fall below a PCI of 40 and land in the Very Poor, Serious, and Failed condition categories. Currently approximately 21.6% of the roadway network falls into this category, which is considered high compared to the national average.

Table 6.1: City of Cincinnati, OH Condition Scale

Pavement Condition Index (PCI)	Condition Description
92 - 100	EXCELLENT
82 - 91	VERY GOOD
68 - 81	GOOD
50 - 67	FAIR
35 - 49	POOR
20 - 34	VERY POOR
0 - 19	FAILED

## 6.1 Pavement Condition Index Results

Table 6.2: City of Cincinnati, OH PCI Ranges by Percent

Pavement Condition Index (PCI) Range	Condition Description	Total Area (Sq. Yd.)	Percent of Total Area (yd <sup>2</sup> )	Total Distance (Centerline Miles)	Percent of Network Miles
92 - 100	Excellent	1,033,027	5.8%	51.88	5.3%
82 - 91	Very Good	2,264,390	12.6%	122.56	12.4%
68 - 81	Good	4,969,331	27.7%	275.94	28.0%
50 - 67	Fair	4,405,674	24.5%	241.64	24.5%
35 - 49	Poor	2,464,530	13.7%	131.54	13.4%
20 - 34	Very Poor	2,526,213	14.1%	142.54	14.5%
0 - 19	Failed	294,023	1.6%	18.33	1.9%
<b>Total of Rated Segments</b>		<b>17,957,188</b>	<b>100.0%</b>	<b>984.43</b>	<b>100.0%</b>

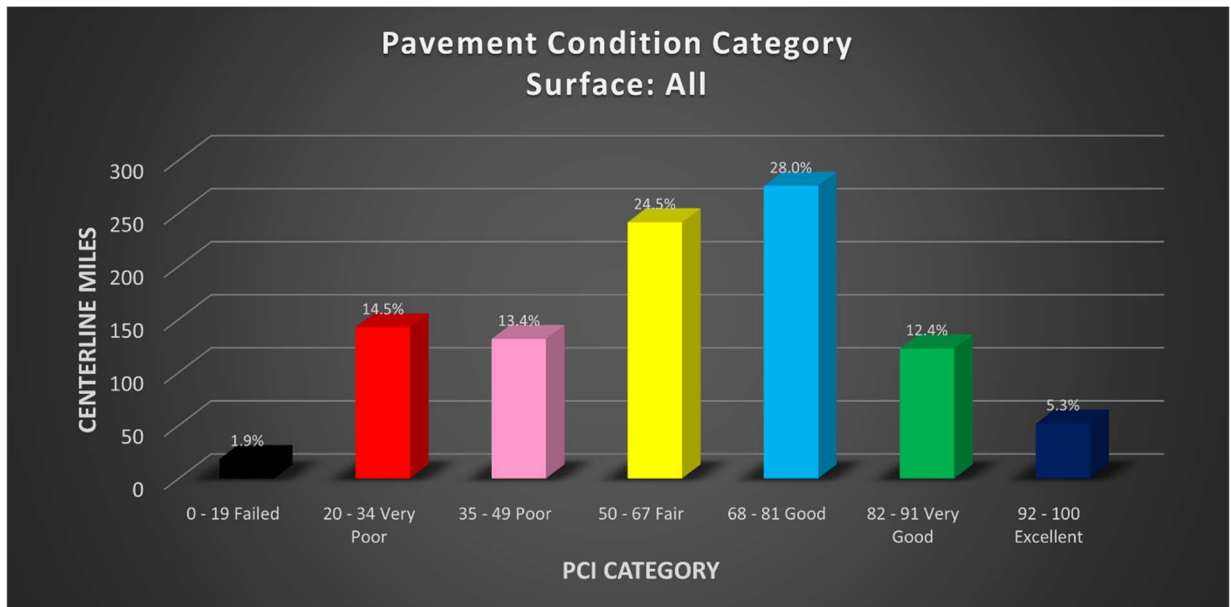


Figure 6.1: City of Cincinnati, OH PCI Ranges by Total Miles

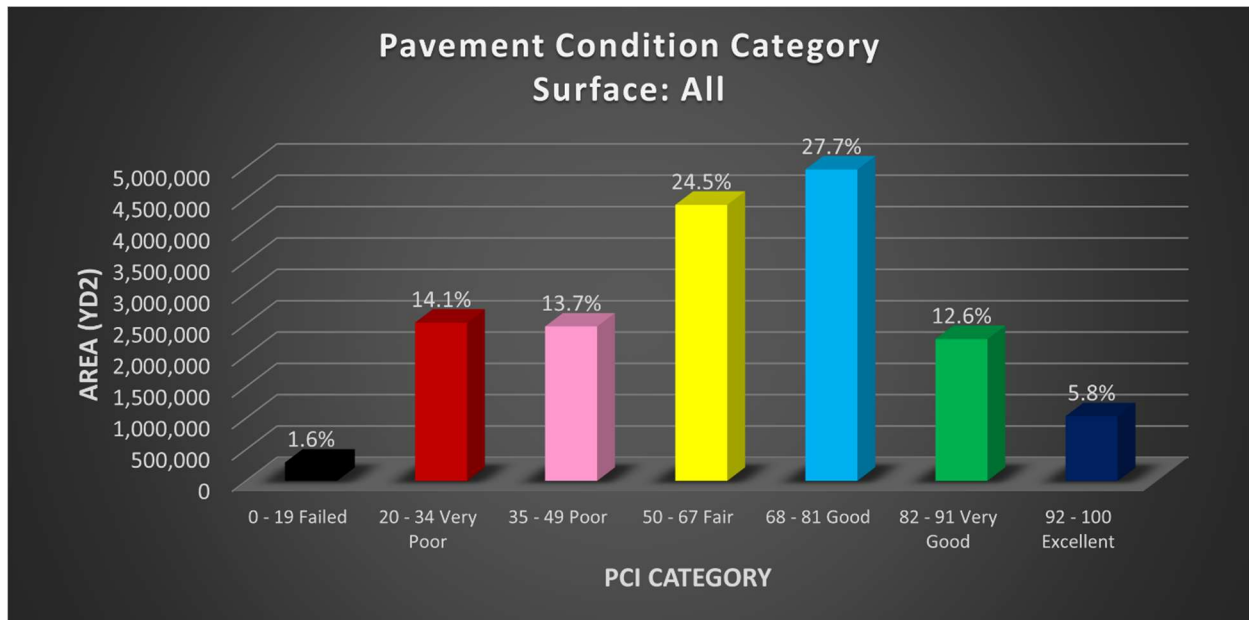


Figure 6.2: City of Cincinnati, OH PCI Ranges by Total Area

The PCI value for each road segment can be viewed in the City’s database. The average of the road segment PCI values for the collected roads within the survey areas was calculated to be **61** at the time of collection. This value indicates the roadway network is in a “**Fair**” condition. The following charts and tables show the PCI ranges for each pavement type.

Table 6.2: City of Cincinnati, OH PCI Ranges by Percent (Asphalt)

Asphalt Pavement Condition Index (PCI) Range	Condition Description	Total Distance (Centerline Miles)	Percent of Network Miles
<b>92 - 100</b>	<b>Excellent</b>	<b>48.28</b>	<b>5.0%</b>
<b>82 - 91</b>	<b>Very Good</b>	<b>117.33</b>	<b>12.1%</b>
<b>68 - 81</b>	<b>Good</b>	<b>269.92</b>	<b>27.9%</b>
<b>50 - 67</b>	<b>Fair</b>	<b>239.5</b>	<b>24.8%</b>
<b>35 - 49</b>	<b>Poor</b>	<b>131.43</b>	<b>13.6%</b>
<b>20 - 34</b>	<b>Very Poor</b>	<b>142.44</b>	<b>14.7%</b>
<b>0 - 19</b>	<b>Failed</b>	<b>18.33</b>	<b>1.9%</b>
<b>Total of Rated Segments</b>		<b>967.23</b>	<b>100.0%</b>

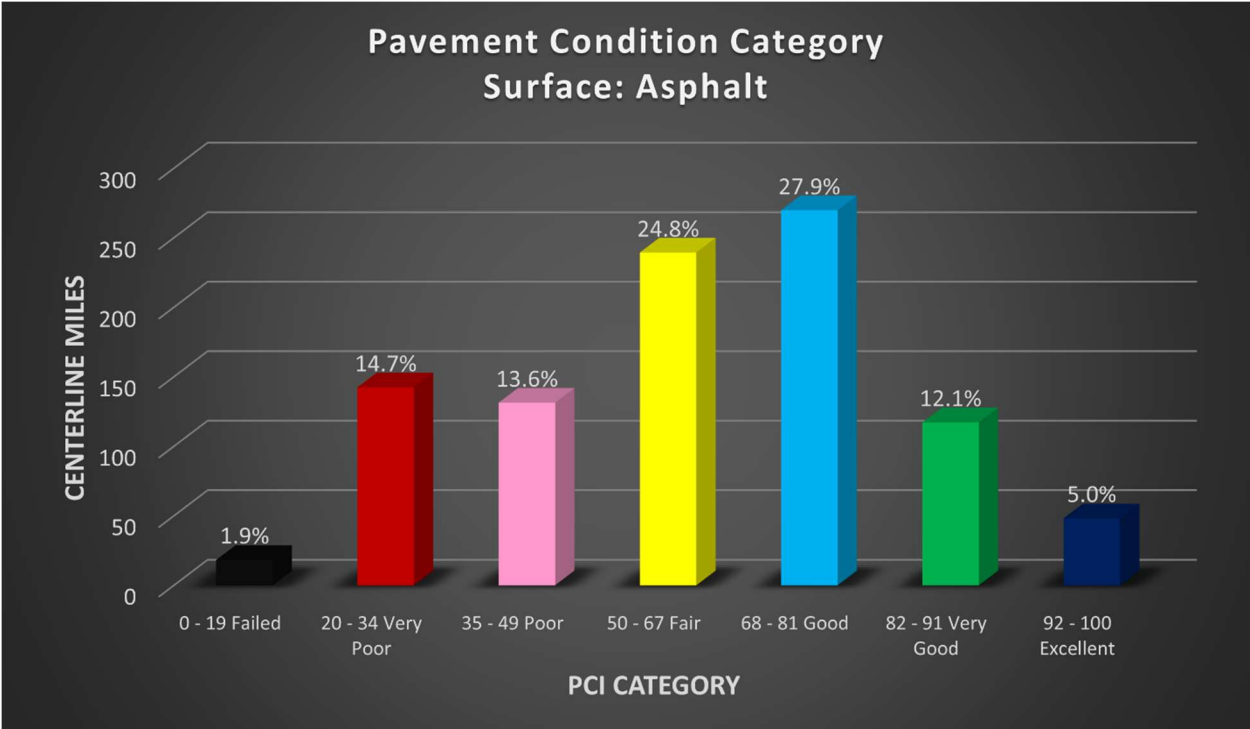


Figure 6.3: City of Cincinnati, OH PCI Ranges by Total Miles (Asphalt)

Table 6.3: City of Cincinnati, OH PCI Ranges by Percent (Concrete)

Concrete Pavement Condition Index (PCI) Range	Condition Description	Total Distance (Centerline Miles)	Percent of Network Miles
<b>92 - 100</b>	<b>Excellent</b>	<b>3.33</b>	<b>24.9%</b>
<b>82 - 91</b>	<b>Very Good</b>	<b>4.36</b>	<b>32.6%</b>
<b>68 - 81</b>	<b>Good</b>	<b>4.53</b>	<b>33.8%</b>
<b>50 - 67</b>	<b>Fair</b>	<b>1.01</b>	<b>7.5%</b>
<b>35 - 49</b>	<b>Poor</b>	<b>0.07</b>	<b>0.5%</b>
<b>20 - 34</b>	<b>Very Poor</b>	<b>0.10</b>	<b>0.7%</b>
<b>0 - 19</b>	<b>Failed</b>	<b>0.00</b>	<b>0.0%</b>
<b>Total of Rated Segments</b>		<b>13.40</b>	<b>100.0%</b>

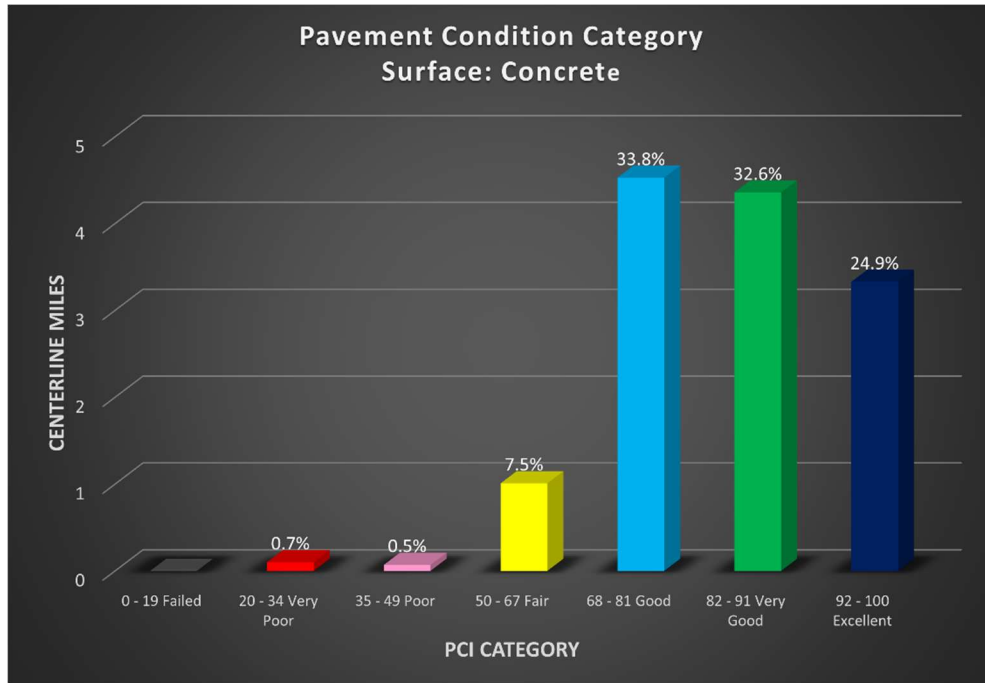


Figure 6.4: City of Cincinnati, OH PCI Ranges by Total Miles (Concrete)

Figure 6.5 displays the Pavement Condition Index distribution throughout the City’s survey area roads. Figure 6.6 displays an example zoomed-in PCI map with the actual PCI values for each roadway section.

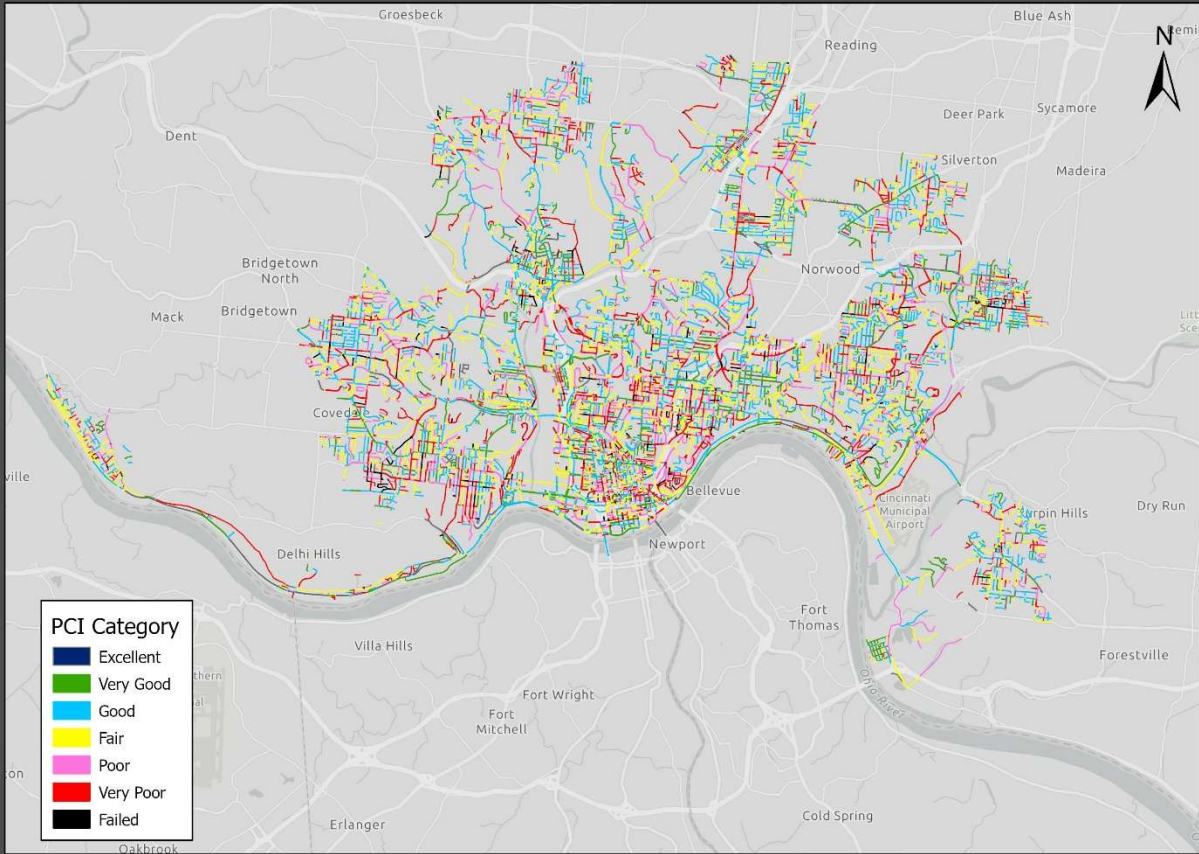


Figure 6.5: City of Cincinnati, OH PCI Distribution Map

# PCI Example | Cincinnati, OH



Figure 6.6: City of Cincinnati, OH PCI Example Map

## 6.2 International Roughness Index Results

Table 6.4: City of Cincinnati, IRI Category Ranges by Miles

Normalized IRI Value	IRI Category	IRI Value (in/mile)	Total Area (Sq. Yd.)	Total Distance (Miles)	Percent of Network (Miles)
92 - 100	Excellent	< 95	80,557	3.64	0.4%
82 - 91	Very Good	96 - 167	2,488,597	106.68	10.8%
68 - 81	Good	168 - 258	5,823,963	293.24	29.8%
50 - 67	Fair	259 - 375	5,668,434	321.36	32.6%
35 - 49	Poor	376 - 472	2,225,603	138.42	14.1%
20 - 34	Very Poor	473 - 570	1,080,064	73.18	7.4%
0 - 19	Failed	> 571	589,970	47.91	4.9%
<b>Total of Rated Segments</b>			<b>17,957,188</b>	<b>984.43</b>	<b>100%</b>

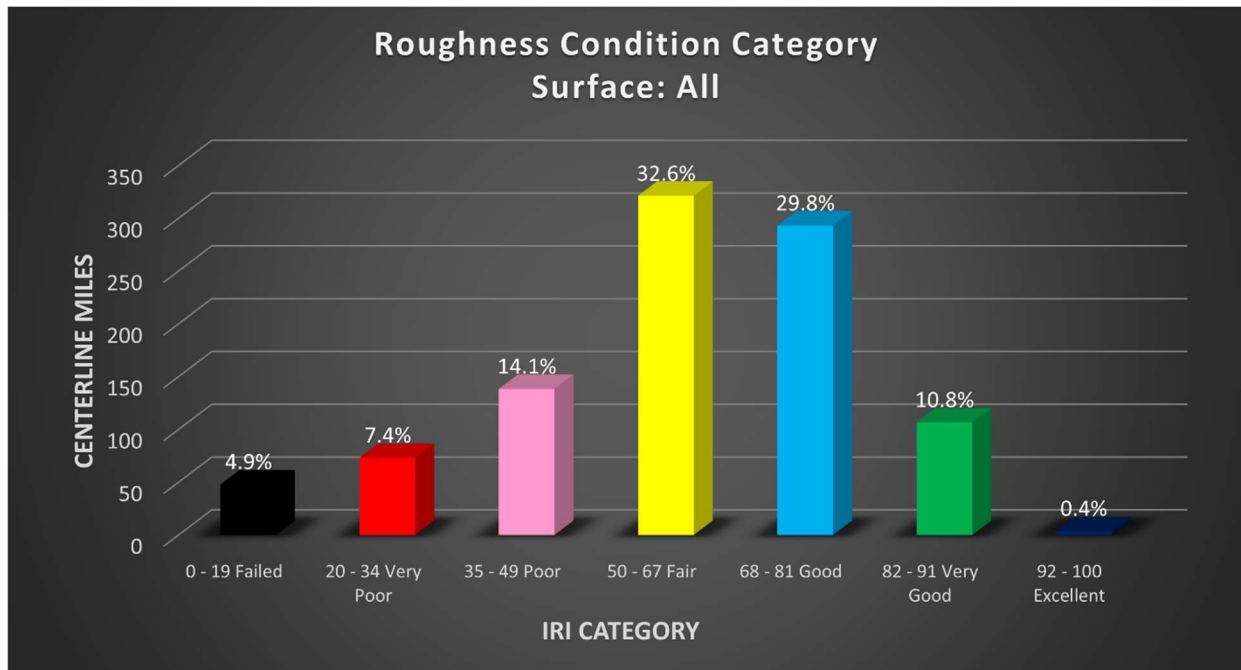


Figure 6.7: City of Cincinnati, OH IRI Category Ranges by Miles

The following figures and tables show the IRI breakdown based on pavement type.

Table 6.5: City of Cincinnati, OH IRI Category Ranges by Miles (Asphalt)

Asphalt Normalized IRI Value	IRI Category	Total Distance (Miles)	Percent of Network (Miles)
92 - 100	Excellent	3.64	0.4%
82 - 91	Very Good	106.36	11.0%
68 - 81	Good	291.87	30.2%
50 - 67	Fair	314.6	32.5%
35 - 49	Poor	135.91	14.1%
20 - 34	Very Poor	71.01	7.3%
0 - 19	Failed	43.84	4.5%
<b>Total of Rated Segments</b>		<b>967.23</b>	<b>100%</b>

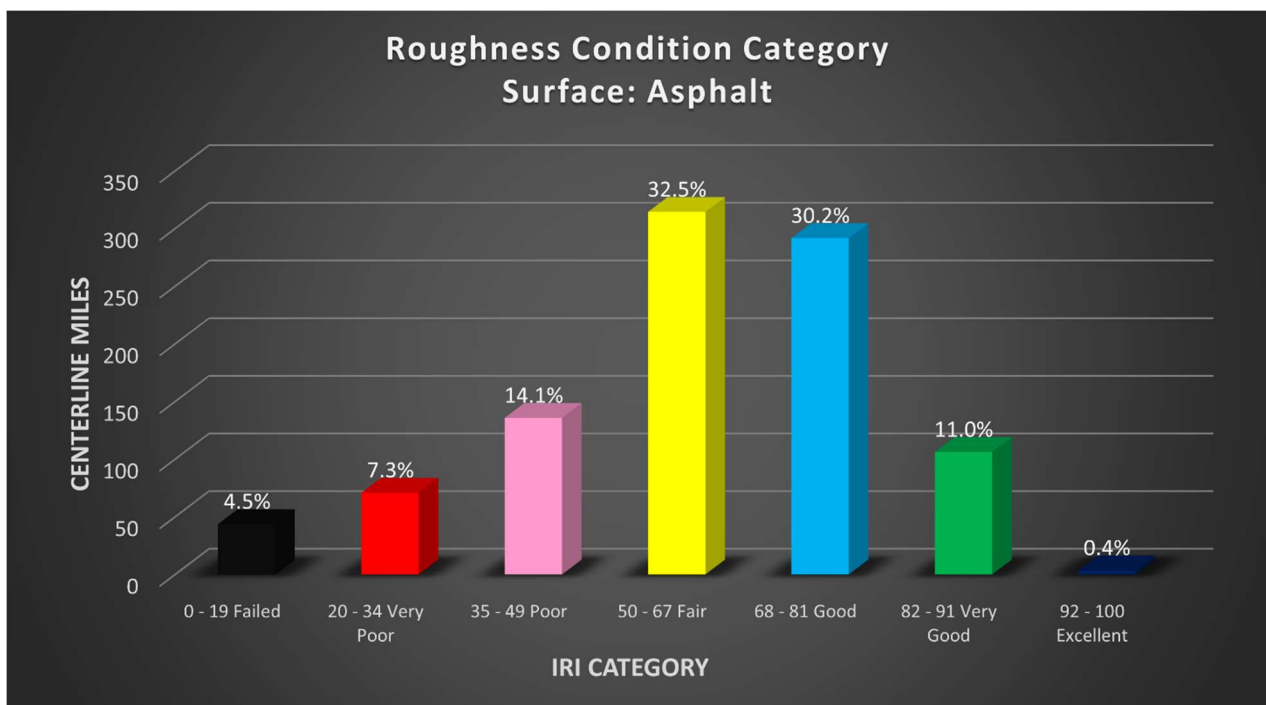


Figure 6.8: City of Cincinnati, OH IRI Category Ranges by Miles (Asphalt)

Table 6.6: City of Cincinnati, OH IRI Category Ranges by Miles (Concrete)

Concrete Normalized IRI Value	IRI Category	Total Distance (Miles)	Percent of Network (Miles)
92 - 100	Excellent	0.0	0.0%
82 - 91	Very Good	0.32	2.4%
68 - 81	Good	1.37	10.2%
50 - 67	Fair	6.46	48.2%
35 - 49	Poor	2.26	16.9%
20 - 34	Very Poor	1.52	11.3%
0 - 19	Failed	1.47	11.0%
<b>Total of Rated Segments</b>		<b>13.40</b>	<b>100%</b>

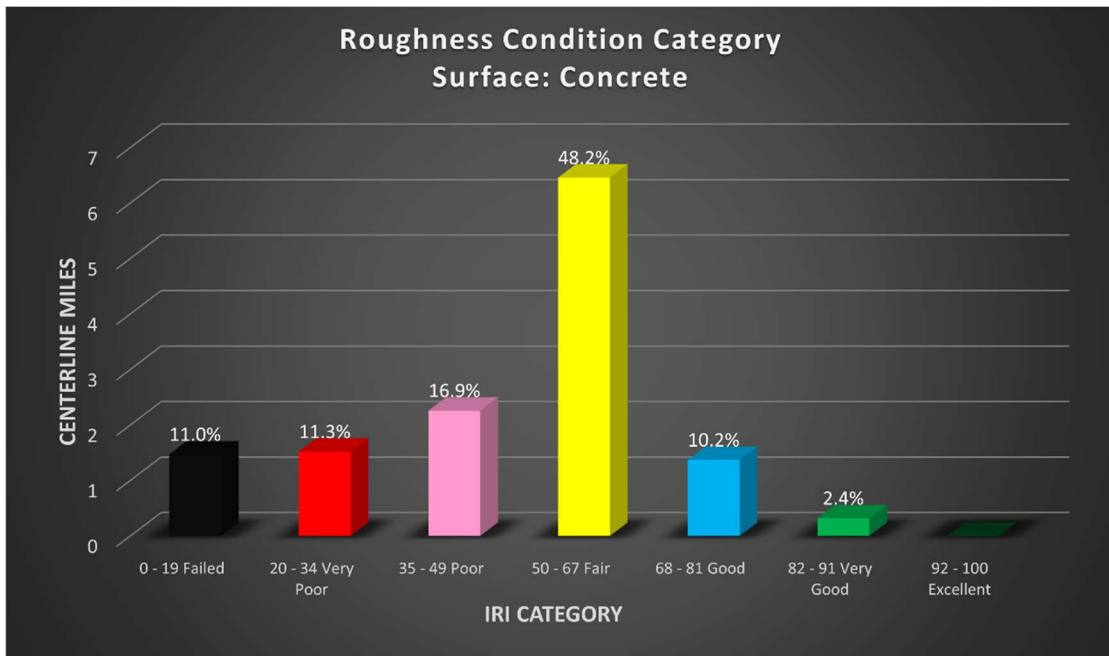


Figure 6.9: City of Cincinnati, OH IRI Category Ranges by Miles (Concrete)

Figure 6.10 displays the International Roughness Index distribution (IRI) throughout the City's survey area roads. Figure 6.11 displays an example zoomed-in IRI map with the Normalized IRI values for each roadway section.

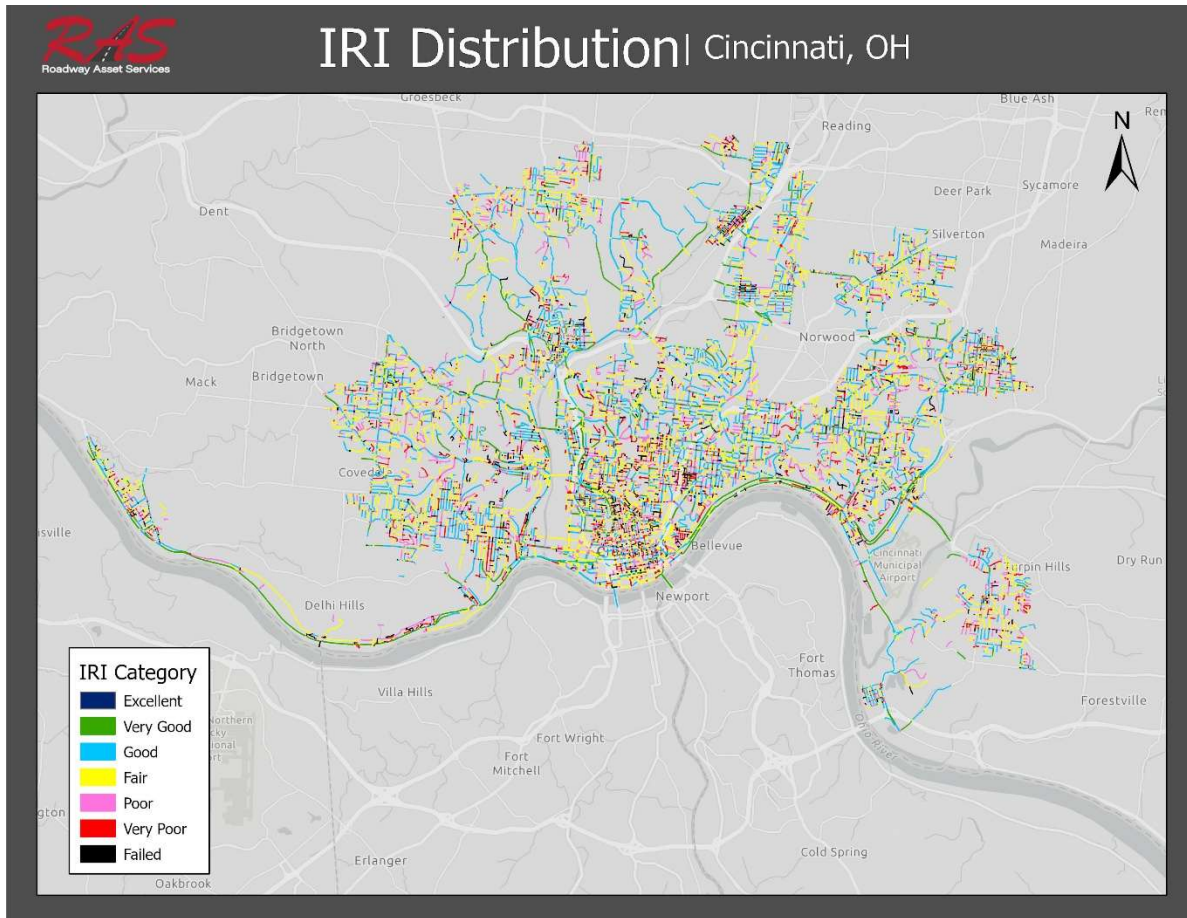


Figure 6.10: City of Cincinnati, OH IRI Distribution Map

# Normalized IRI Example | Cincinnati, OH

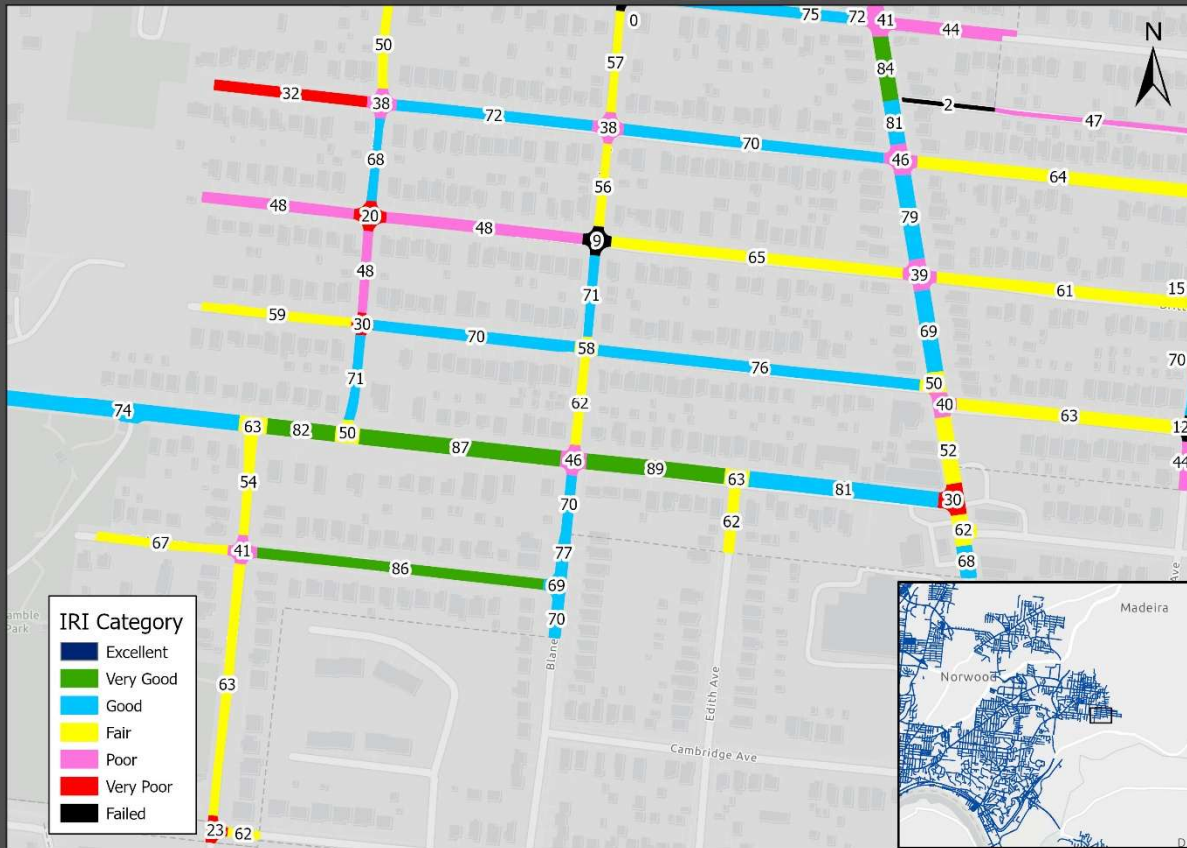


Figure 6.11: City of Cincinnati, OH IRI Example Map

### 6.3 Distress Breakdown by Severity

Figures 6.12 and Tables 6.7 and 6.8 display the types of distresses identified in Cincinnati's asphalt streets. The figures and tables titled "*...Breakdown by Percentage of Segments*" show the percentage of segments that contain each distress type and severity level. Each distress is considered independently, meaning the percentages reflect the presence of a distress within a segment—not the area it covers. For example, if 76% low alligator cracking is reported, it indicates that 76% of the total street segments exhibit some amount of low-severity alligator cracking. Similarly, 41% high alligator cracking means that 41% of all segments contain at least some high-severity alligator cracking.

Tables and figures titled "*...Breakdown by Average Density*" represent the average density of each distress and severity level across all segments. For instance, a value of 2 % low alligator cracking indicates that, on average, 2% of the pavement area in segments containing this distress is affected by low-severity alligator cracking. Therefore, while Table 6.7 shows that 77% of asphalt streets contain some level of low alligator cracking, Table 6.8 reveals that the average density is only 2%, suggesting this distress affects a relatively small portion of the overall network area.

It is also important to note that not all distresses contribute equally to the PCI calculation. For example, a single pothole can have a greater negative impact on PCI than 100% low-severity weathering. As such, the following tables and figures should be used primarily to understand the types and distribution of distresses present within the network, rather than as direct indicators of overall pavement condition.

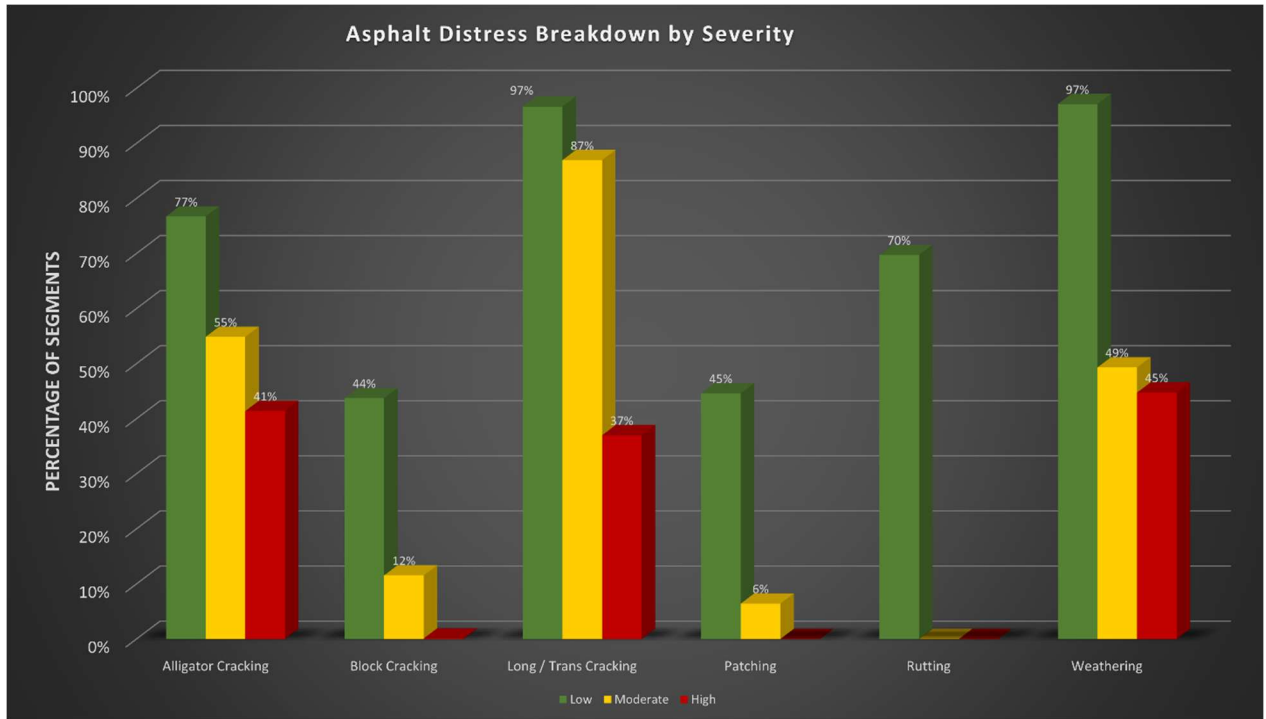


Figure 6.12: Cincinnati, OH Asphalt Distress Breakdown by Percentage of Segments

Table 6.7: Cincinnati, OH Asphalt Distress Breakdown by Percentage of Segments

Asphalt Distress Breakdown by Percentage of Segments			
Type	Low	Moderate	High
Alligator Cracking	76.75%	54.88%	41.41%
Block Cracking	43.75%	11.56%	0.12%
Long / Trans Cracking	96.69%	86.96%	37.00%
Patching	44.62%	6.44%	0.00%
Potholes	0.05%	0.01%	0.00%
Rutting	69.75%	0.00%	0.00%
Weathering	97.14%	49.33%	44.77%

Table 6.8: Cincinnati, OH Asphalt Distress Breakdown by Average Density

Asphalt Distress Breakdown by Average Density			
Type	Low	Moderate	High
Alligator Cracking	2.17%	0.73%	0.66%
Block Cracking	23.93%	15.25%	9.78%
Long / Trans Cracking	9.64%	1.79%	0.38%
Patching	4.44%	1.01%	0.00%
Potholes	0.03%	0.00%	0.00%
Rutting	3.02%	0.00%	0.00%
Weathering	99.57%	0.47%	0.82%

The following charts and figures follow the same logic as the asphalt distresses but show concrete distresses. It is important to note that concrete distresses are measured based on their presence in a slab and thus is not possible to determine the average density of a distress on a road, rather only the presence of that distress.

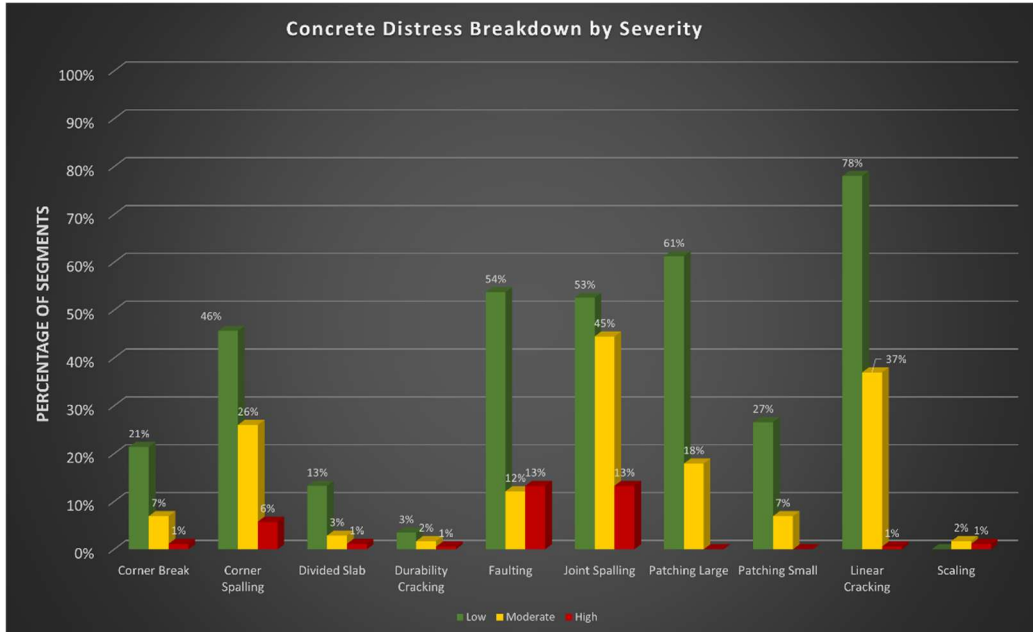


Figure 6.13: Cincinnati, OH Concrete Distress Breakdown by Percentage of Segments

Table 6.9: Cincinnati, OH Concrete Distress Breakdown by Percentage of Segments

Concrete Distress Amounts by Percentage of Segments			
Type	Low	Moderate	High
Corner Break	21.39%	6.94%	1.16%
Corner Spalling	45.66%	26.01%	5.78%
Divided Slab	13.29%	2.89%	1.16%
Durability Cracking	3.47%	1.73%	0.58%
Faulting	53.76%	12.14%	13.29%
Joint Spalling	52.60%	44.51%	13.29%
Patching Large	61.27%	17.92%	0.00%
Patching Small	26.59%	6.94%	0.00%
Linear Cracking	78.03%	36.99%	0.58%
Scaling	0.00%	1.73%	1.16%

## 7 Sample – Sized Segmentation

### 7.1 Overview of Sample Size Processing

In addition to processing the network based on the original segmentation provided by the City, RAS also analyzed the data using 2,500-square-foot sample areas. Depending on the characteristics of a network, some segments can be quite long, sometimes extending over a mile. Segment-level PCI and IRI scores represent the average condition across the entire segment; therefore, the longer the segment, the more variation is averaged together. According to ASTM D6433, each distress type and severity level is associated with a specific deduct curve that depends on the density of that distress within a segment. For long segments, distress densities often appear smaller and may not accurately reflect localized problem areas.

To address this issue, RAS reprocessed the network using 2,500-square-foot samples. This approach provides a more detailed understanding of the types and locations of distresses present, allowing for identification of which direction, lane, or portion of a segment is most affected. The resulting information enables City officials to make more informed decisions regarding targeted maintenance treatments, such as patching or localized repairs.

### 7.2 Methodology of Sample Size Processing

After the initial data was collected and processed, RAS further refined the analysis by dividing the network into 2,500-square-foot samples. The data was reprocessed so that each segment represented, at most, a single pass or direction of a short segment, typically corresponding to a smaller portion of a lane. All data underwent Quality Control review in accordance with ASTM D6433. The processing and rating methodologies used for both the samples and the original segments are identical and are described in detail in Section 3 of this report.

### 7.3 Sample Size Processing Results

Overall, the short segmentation provides greater detail about the specific locations of problem areas and pavement distresses. As a result, many of the PCI category distributions changed when processed at this level. Table 7.1 summarizes the total number of samples within each PCI range following the 2,500-square-foot segmentation.

The results indicate that a larger portion of samples fall within the *Excellent* condition category compared to the original segmentation. Similarly, there is also an increase in the number of samples classified as *Failed*. The percentage of samples in the extreme PCI ranges tells us that the condition of the roads are not uniform and there is potential for isolated road repairs like patching.

Table 7.1: Cincinnati, OH Sample Segmentation PCI Ranges by Percent

Pavement Condition Index (PCI) Range	Condition Description	Percent of Network (Centerline Miles)
<b>92 - 100</b>	<b>Excellent</b>	<b>6.6%</b>
<b>82 - 91</b>	<b>Very Good</b>	<b>13.2%</b>
<b>68 - 81</b>	<b>Good</b>	<b>28.4%</b>
<b>50 - 67</b>	<b>Fair</b>	<b>23.9%</b>
<b>35 - 49</b>	<b>Poor</b>	<b>12.7%</b>
<b>20 - 34</b>	<b>Very Poor</b>	<b>12.8%</b>
<b>0 - 19</b>	<b>Failed</b>	<b>2.4%</b>
<b>Total of Rated Samples</b>		<b>100%</b>

This analysis indicates that a majority of the pavement network is in “good” condition, with a few isolated areas of excellent and failed conditions disproportionately affect the average PCI in the original segmentation. Complete detailed results from the short-segmentation analysis can be accessed through the City’s database.

Following the sample-level PCI processing, each segment was assigned a PCI variance value. The PCI variance represents the difference between the highest and lowest PCI scores within a single segment. Table 7.2 provides a statistical summary of the PCI variances for all segments in the network.

For example, the “Smallest” PCI variance shown in the table represents the lowest variance observed among all segments. A variance value of 0 indicates a completely uniform pavement condition across the segment. The “Average” value represents the mean PCI variance across all segments in the network—higher averages indicate greater variability in pavement condition within segments. The average PCI Variance of 20 points is on the higher end seen by RAS and indicates that the segments are not of a very uniform condition.

Table 7.2: Cincinnati, OH Sample Segmentation PCI Variance

<b>Sample PCI Variance Statistics</b>	
<b>Smallest</b>	<b>0</b>
<b>Largest</b>	<b>83</b>
<b>Average</b>	<b>20</b>
<b>Median</b>	<b>13</b>
<b>Standard Deviation</b>	<b>16</b>

Figure 7.1 illustrates the PCI scores based on the original segmentation provided by the City, while Figure 7.2 displays the PCI scores for the same areas using the sample-level segmentation. By comparing these two maps, it can be observed that although the overall pavement conditions are generally acceptable, there are localized regions with significantly lower PCI values that negatively impact the overall segment scores.

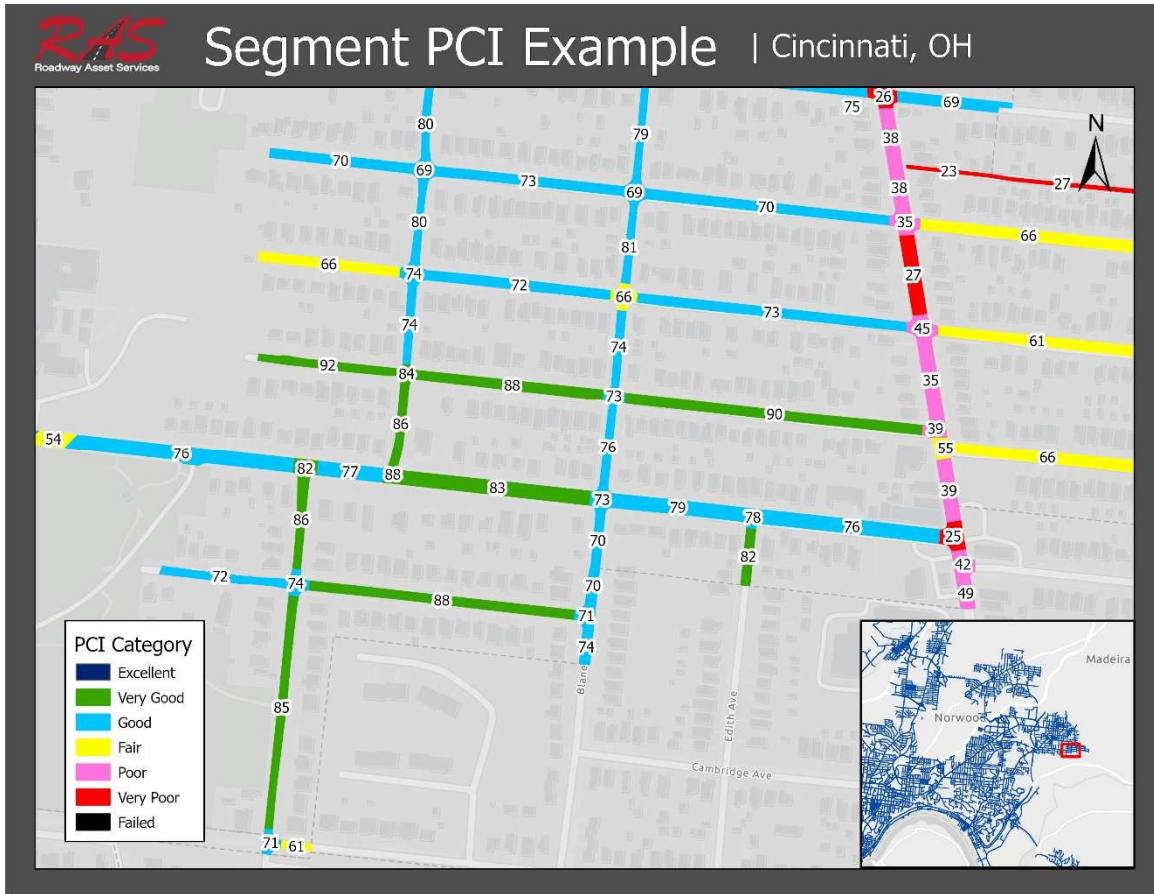


Figure 7.1: Cincinnati, OH PCI Original Segmentation Example Map

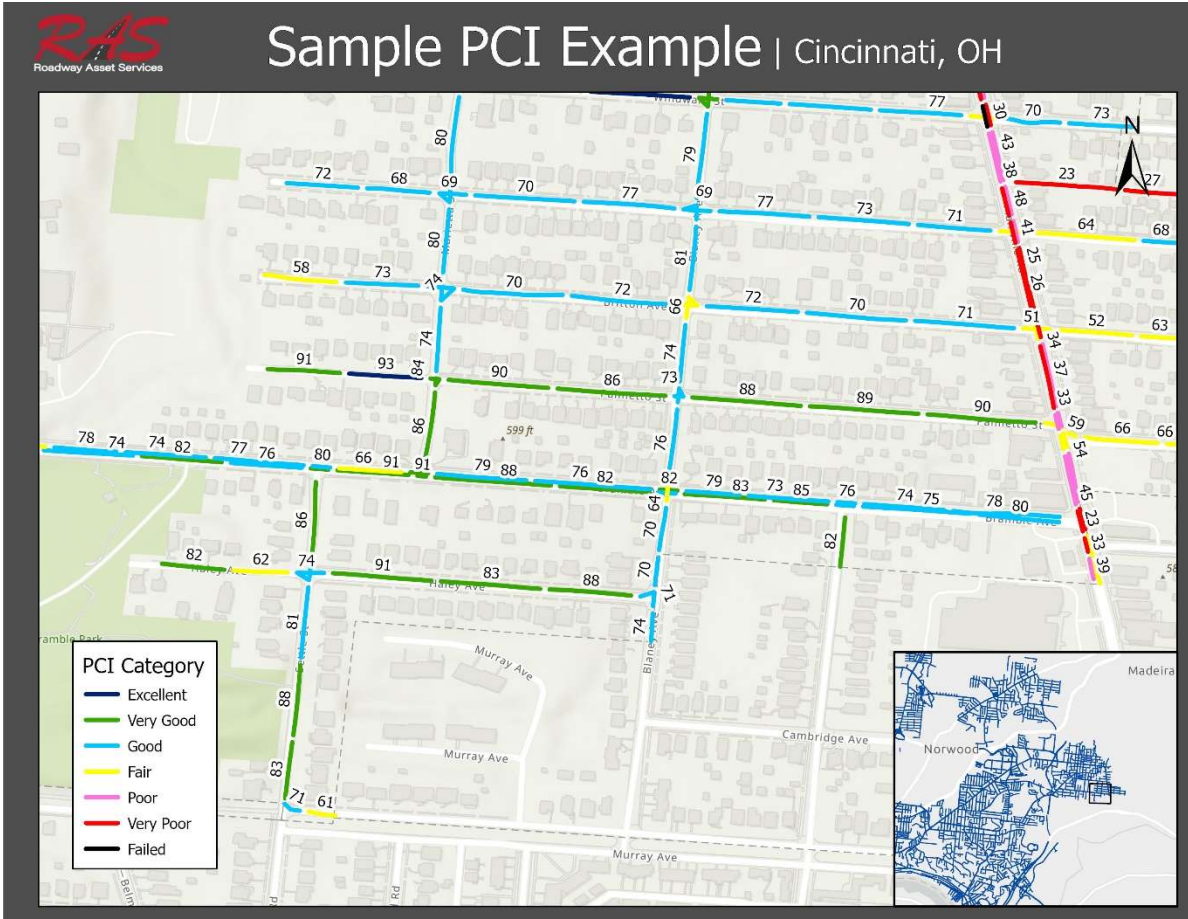


Figure 7.2: Cincinnati, OH PCI Sample Segmentation Example Map

## 8 Pavement Maintenance/Preservation Funding

RAS performed various five-year pavement maintenance and preservation program scenarios for the City's consideration using Budget Optimization Street Selector (BOSS™) software.

The analysis runs a series of profile models for increasing budgets to define how the City's budget will impact network PCI and network backlog. The scenarios include very small budgets, well below current funding and very large scenarios, well above current funding levels. The results from all scenarios are then used to establish a funding level trend. This approach will answer specific funding questions asked at the time of analysis but will also provide a 5-year maintenance and rehabilitation plan. The City's current budget is the only budget that was limited to the use of surface preservation and mill and overlay activities. All other profile models were optimized in an effort to take into consideration segments that are candidates for full-depth reconstruction projects.

## 9 Scenarios and Budget Estimates

### 9.1 Deterioration curves

Deterioration curves were established for each roadway classification (major, intermediate, and local) and follow similar degradation standards as outlined by ASTM D6433 and the US Army Corps of Engineers. In future pavement condition assessments, it is suggested that the consultant conduct a thorough comparison of the current inspection data against the previous condition assessment. Such an analysis will allow for further refinement of the pavement deterioration curves to ensure they reflect reasonable rates of degradation in Cincinnati, OH. Such an analysis should be conducted after every pavement condition update. The pavement deterioration curves were assembled to establish a 100 - 0 deterioration curve for each functional classification as demonstrated in Figure 9.1 below.

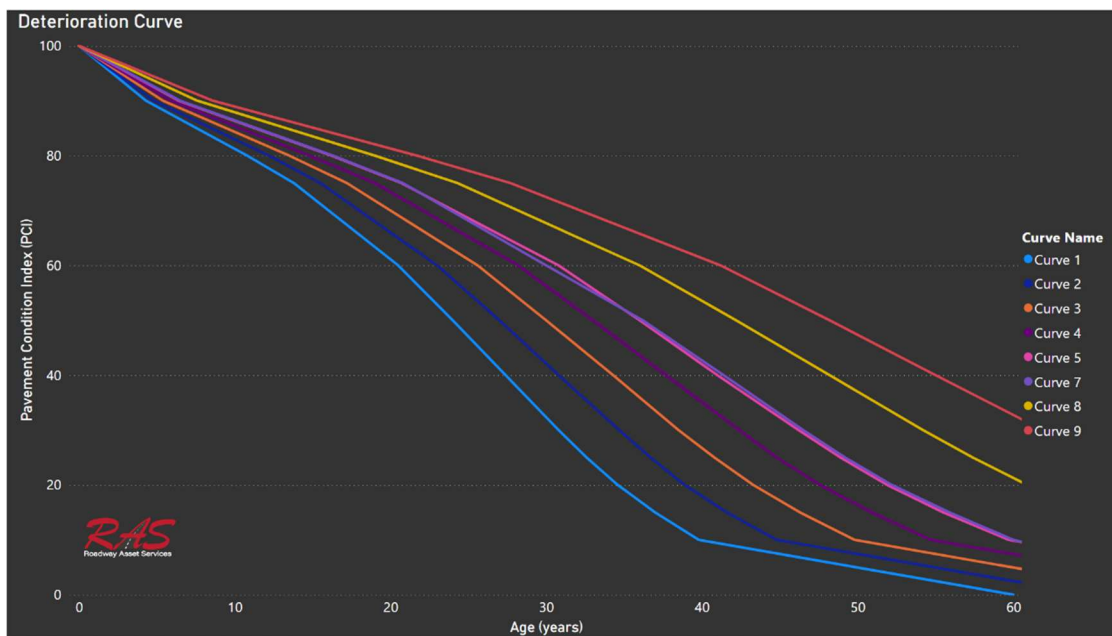


Figure 9.1: City of Cincinnati, OH Deterioration Curves with No Maintenance

These curves represent the deterioration of roads of all surface types and all classifications without maintenance.

Reviewing deterioration rates for unmaintained roads as part of each condition data collection cycle and adjusting deterioration curves is a recommended best practice.

### 9.2 Treatment Activities and Cost

Tables 9.1 to 9.3 summarize the maintenance strategy for roads within a PCI range, the cost of the maintenance per square yard, and the assumed PCI impact for each type of maintenance. The costs displayed in Tables 9.1 to 9.3 show the unit rate for roads with different classifications, with local streets being the only class to receive surface preservation treatments.

Table 9.1: City of Cincinnati, OH- Maintenance Suggestion by PCI Range (Arterials)

Treatment	Min PCI	Critical PCI	Max PCI	Cost per SY	Priority	Reset Value
Do Nothing	60	63	100	\$ 0.00	3	0
Mill & Overlay	20	23	60	\$ 45.00	1	100
Reconstruction	0	15	20	\$ 262.50	2	100

Table 9.2: City of Cincinnati, OH- Maintenance Suggestion by PCI Range (Collectors)

Treatment	Min PCI	Critical PCI	Max PCI	Cost per SY	Priority	Reset Value
Do Nothing	60	63	100	\$ 0.00	3	0
Mill & Overlay	20	23	60	\$ 45.00	1	100
Reconstruction	0	15	20	\$ 262.50	2	100

Table 9.3: City of Cincinnati- Maintenance Suggestion by PCI Range (Locals)

Treatment	Min PCI	Critical PCI	Max PCI	Cost per SY	Priority	Reset Value
Do Nothing	70	80	100	\$ 0.00	5	0
Micro Surfacing	60	63	70	\$ 11.55	4	80
Cape Seal	50	53	60	\$ 14.70	2	90
Mill & Overlay	20	23	50	\$ 45.00	1	100
Reconstruction	0	15	20	\$ 262.50	3	100

Each maintenance strategy has a critical and non-critical PCI range. Streets that are not maintained when they are in the critical range will deteriorate into the next category of maintenance and will become more expensive the following year. The analysis prioritizes segments in the critical PCI range over segments that are in the non-critical PCI range. Given an unlimited budget, the analysis will select all segments in the critical PCI range followed by all segments in the non-critical PCI range.

Each maintenance strategy has a Cost of Deferral Priority which prioritizes selections within the critical PCI range (within 2-4 points of dropping into the next rehabilitation activity) and within

the non-critical PCI range. The priority is sequenced by prioritizing the segments that cost more to defer than segments that cost less to defer, starting with the critical segments first. For example, the cost of deferring a critical cape seal treatment at \$14.70/sqyd to a mill and overlay at \$45.00/sqyd is \$30.30/sqyd. The cost of deferring a critical mill and overlay at \$45.00/sqyd to a full-depth reconstruction at \$262.50/sqyd is \$217.50/sqyd. The financially optimized model will prioritize the critical selections first and if there is funding left over, non-critical selections will then be selected and prioritized using the very same cost of deferral sequencing.

**9.3 Scenarios**

A variety of scenarios have been run to provide an understanding of the relationship between funding levels and the corresponding impact to network PCI and backlog. For this analysis, all roads having a PCI < 40 was considered backlog.

**9.3.1 Do-Nothing**

The Do-Nothing budget models the impact of applying zero maintenance. While it is not a scenario that occurs in practice, the Do-Nothing budget provides an understanding of the rate at which the level of service of the street network will deteriorate without maintenance and ensures the modeling engine is properly applying deterioration over time. In Figure 9.2 the gray line represents the PCI trend if there is zero maintenance applied for the next 5 years. The network PCI would drop to a 51.

**9.3.2 Unlimited Funding (Fix All) and Distribution of Costs**

The Fix All analysis identifies the current maintenance deficiency of the network. Based on the Fix All analysis, the City needs a total budget of \$399,840,055 to treat all of their roads in their current condition. The City’s greatest maintenance need by funding are the mill and overlay activities with 72.98% of the total cost.

Table 9.4: City of Cincinnati, OH– Fix All Cost per Maintenance Treatment

Pavement Type	Treatment	Cost (%)	Cost (\$)	Area (%)	Expected Life
Asphalt	Mill & Overlay	72.98%	\$ 291,786,230.00	74.78%	15
Asphalt	Reconstruction	17.85%	\$ 71,383,405.16	1.62%	30
Asphalt	Micro Surfacing	5.50%	\$ 21,981,294.71	17.41%	8
Asphalt	Cape Seal	3.49%	\$ 13,972,594.69	6.17%	8
Concrete	PCC Overlay	0.18%	\$ 716,531.11	0.02%	15

**9.3.3 Steady State Network PCI (SS PCI)**

The Network PCI is generally accepted as the street networks measure of level of service to the community. The purpose of the Steady State Network PCI analysis is to identify the budget needed to maintain the network PCI as it was surveyed in 2025 and provide a steady level of service to the community.

Approximately \$21,000,000 per year is needed to maintain a Network PCI of ~60.

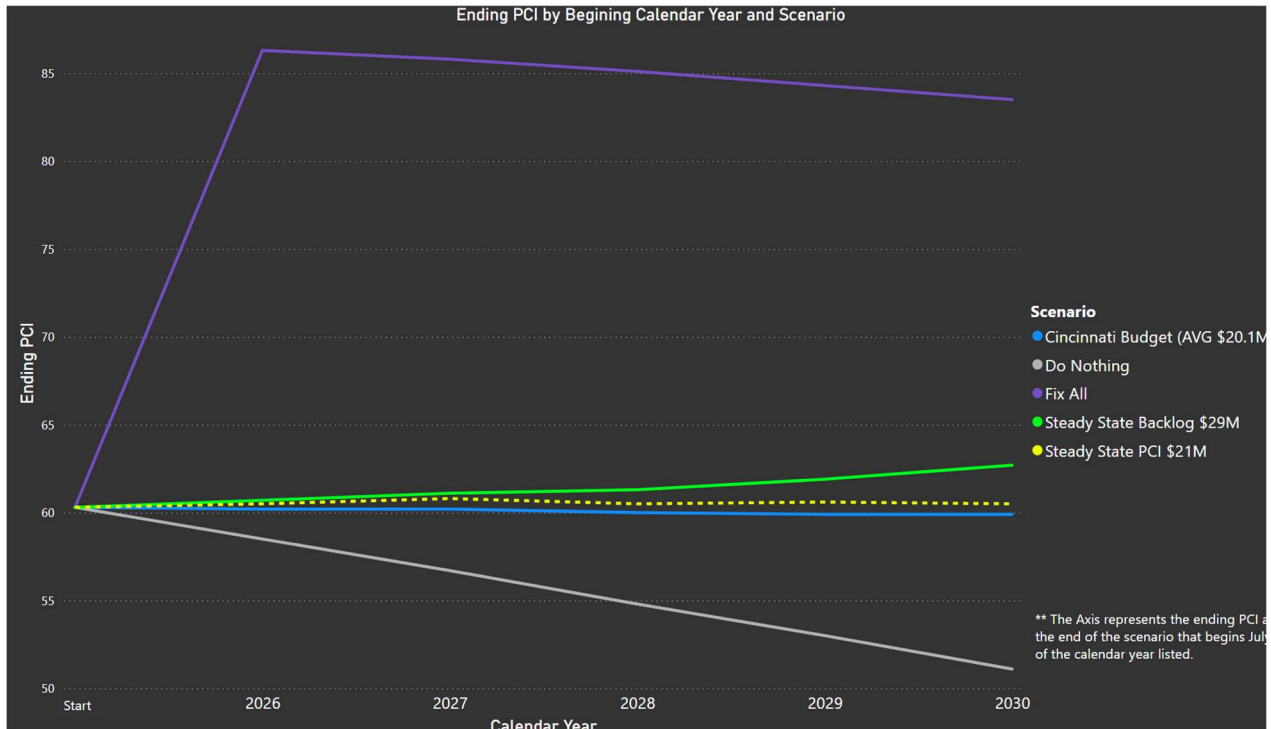


Figure 9.2: City of Cincinnati, OH- PCI Trend by Budget Scenario

### 9.3.4 Sample Maintenance Budgets versus PCI Improvement

Nine sample maintenance budgets were run to define the relationship between budget levels and network PCI. The 5-year budget scenario is set to start in the year 2025 and end in 2030. A majority of the available funds in the first year of the analysis are dedicated to planned work projects already determined by the City.

The network PCI in 2025 was 60.3. With the City’s current budget of ~\$21M annually, the network’s condition will decrease to a PCI of 59.9. Figure 9.3 indicates that a **optimized** budget of approximately \$21,000,000 per year is needed to maintain a network PCI of 60.3 and maintain a consistent level of service to the community. It is important to note that the forced selected of planned work and only selecting certain treatments will have an impact on the ending results. Figure 9.3 can be used to answer and predict the network PCI at any funding level between \$10M per year and \$30M per year. Figure 9.3 was used to predict the PCI at the following budgets in Table 9.5.

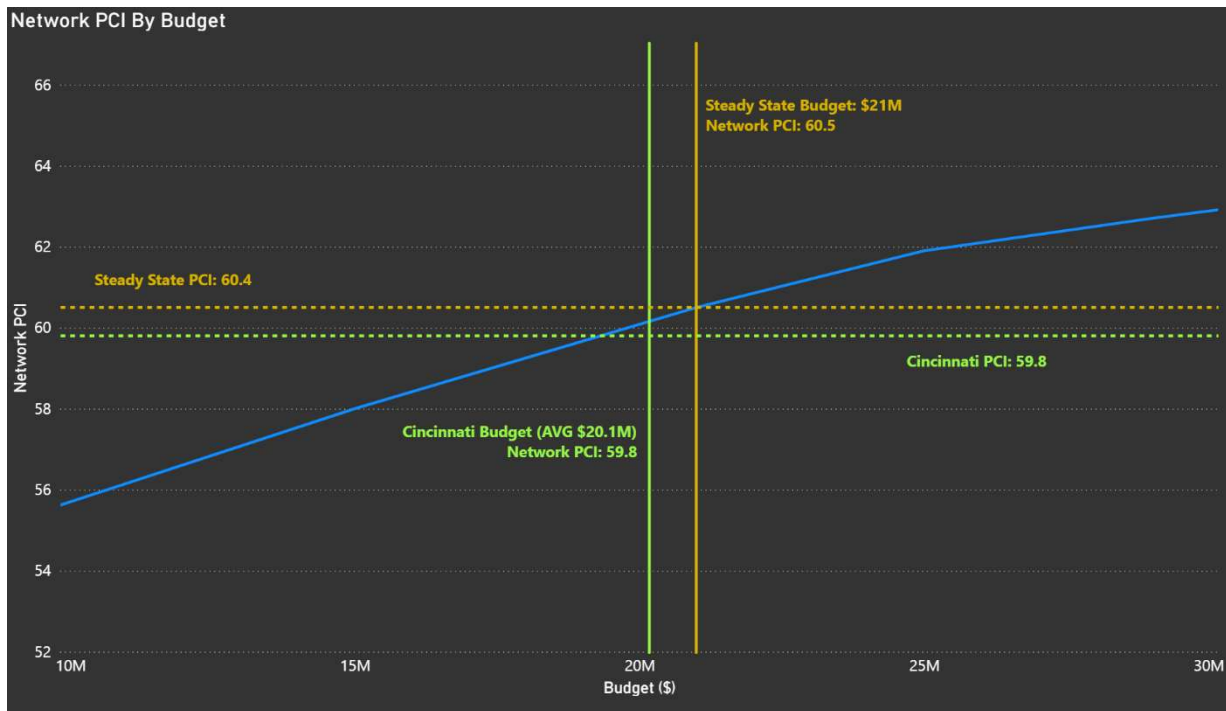


Figure 9.3: City of Cincinnati, OH- Predicted 5-Year Pavement Condition Index Outlook

Table 9.5: City of Cincinnati, OH- Predicted 5-Year Overall Condition Index Outlook

Budget	Network PCI
\$0	51
\$10,000,000	56
\$15,000,000	58
\$25,000,000	62
\$40,000,000	65
\$50,000,000	68

## 10 Summary

In conclusion, Cincinnati’s pavement is in **Fair** condition, with a network average PCI of 61. Pavement management is a complex topic that involves many factors, including the types of distresses found across the network, the desired level of service, and the network’s size and age. For this reason, it is important to consider results from multiple perspectives. In addition to PCI, backlog is a critical metric when assessing the overall condition of a pavement network. Backlog amounts can quickly become unmanageable for most agencies, so maintaining a healthy backlog is essential. The current backlog sits at **21.6%**, which is considered high. Backlogs above 15% can become unmanageable and require additional bond funding to stabilize the issue. RAS recommends repeating pavement condition surveys every 3-5 years to best analyze pavement conditions over time.

## 11 Appendix I: Distress Definitions (Colorado State University)

AC Bleeding & Pumping (ft<sup>2</sup>) represents excessive use of bituminous binder in the asphalt mix. AC Fatigue (Alligator) Cracking (ft<sup>2</sup>) is associated with fatigue due to traffic loading and visually looks like interconnected cracks forming small pieces ranging in size from about 1" to 6" typically in the wheel path.

AC Block Cracking (ft<sup>2</sup>) usually intersect at nearly right angles and range from one foot to 10' or more across. The closer spacing indicates more advanced aging caused by shrinking and hardening of the asphalt over time.

AC Edge Cracking (ft) is parallel to and usually within 1.5 feet of the outer edge of the pavement. This distress is accelerated by traffic loading and can be caused by frost-weakened base or subgrade near the edge of the pavement.

AC/PCC Lane/Shoulder Drop-off (ft) is a difference in elevation between the pavement edge and the shoulder. This distress is caused by shoulder erosion, shoulder settlement, or by building up the roadway without adjusting the shoulder level.

AC Linear Cracking (trans/long) (ft) typically occurs in overlays where the crack is reflected through the overlaying asphalt surface.

AC Patching (ft<sup>2</sup>) is an area of pavement that has been replaced with new material to repair existing pavement.

AC Potholes (count) are small, usually less than 30 inches in diameter, bowl-shaped depressions in the pavement surface. Generally, have sharp edges and vertical sides near the top of the hole.

AC Raveling & Weathering (ft<sup>2</sup>) is loss of pavement material from the asphalt surface. Typically raveling is caused by stripping of the bituminous film from the aggregate or hardening of asphalt due to aging. Poor compaction, especially in cold weather construction, or insufficient asphalt content can also cause raveling.

AC Slippage Cracking (ft<sup>2</sup>) are crescent half-moon shaped cracks, usually transverse to the direction of travel. They are produced when braking or turning wheels cause the pavement to slide or deform.

AC Rutting (ft<sup>2</sup>) is a surface depression in the wheel paths.

PCC Corner Break (slab count) is a crack that intersects the joints. Load repetition combined with loss of support and curling stresses usually cause corner breaks.

PCC Divided Slab (slab count) is when a slab is divided into four or more pieces due to overloading, or inadequate support.

PCC Durability "D" Cracking (slab count) is caused by freeze-thaw expansion of the large aggregate, which gradually breaks down the concrete. Usually appears as a pattern of cracks running parallel and close to a joint or linear crack.

PCC Joint Sealant Damage (slab count) is any condition that enables soil or rocks to accumulate in the joints or allows significant water infiltration.

PCC Linear Cracking (trans/long) (slab count) divide the slab in two or three pieces and are usually caused by a combination of repeated traffic loading, thermal gradient curling and repeated moisture loading.

PCC Patching, Large/Utility Cut (slab count) is an area where the original pavement has been removed and replaced by new pavement.

PCC Patching, Small (slab count) is an area where the original pavement has been removed and replaced by filler material.

PCC Polished Aggregate (slab count) is caused by repeated traffic applications. There are no rough or angular aggregate particles to provide good skid resistance.

PCC Popouts (slab count) are small pieces of pavement that break loose from the surface due to freeze-thaw action, combined with expansive aggregates. Usually range in diameter from 1 to 4 inches and in depth from ½ to 2 inches.

PCC Punchout (slab count) is a localized area of the slab that is broken into pieces. This distress is caused by heavy repeated loads, inadequate slab thickness, loss of foundation support or localized concrete construction deficiency.

PCC Scaling/Map Cracking/Crazing (slab count) is a network of shallow, fine or hairline cracks that extend only through the upper surface of the concrete. Usually caused by concrete over-finishing and may lead to scaling, which is the breakdown of the slab surface to a depth of ¼ to ½ in.

PCC Shrinkage Cracks (slab count) are hairline cracks usually less than 6 feet long and do not extend across entire slab. They are formed during the setting and curing of the concrete and do not extend through the depth of the slab.

PCC Spalling, Corner (slab count) is the breakdown of the slab within 1.5 feet of the corner. Usually caused by traffic loading or infiltration of incompressible materials, weak concrete and/or water accumulation and freeze-thaw action.

PCC Spalling, Joint (slab count) is the breakdown of the slab edges within 1.5 feet of the joint. Usually caused by traffic loading or infiltration of incompressible materials, weak concrete and/or water accumulation and freeze-thaw action.

## 12 Appendix II: Automated Data Collection Equipment

### 12.1 Roadway Asset Collection (RAC) Vehicle

To determine the general distress characteristics of each roadway segment, RAS utilized one of our RAC vehicles, presented in Figure 12.1, to collect street level (ROW) imagery and downward (LCMS-2) pavement imagery.

The RAC vehicle components include:

#### Navigation System

- **Inertial Measurement Unit (IMU):** Generates a true representation of vehicle motion in all three axes; producing continuous, accurate position and orientation information.
- **PCS:** Applanix POS/LV Computer System with DGPS (Provides accurate GPS coordinates for each subsystem) enables raw GPS data from as few as one satellite to be processed directly into the system, to compute accurate positional information in areas of intermittent, or no GPS reception.
- **GPS Receivers:** Embedded GPS receivers provide heading aiding to supplement the inertial data.

- **GPS Antennas:** Two GPS antennas generate raw observables data.
- **Sub-meter accuracy:** The system is rated to get 0.3 m accuracy in the X, Y position and 0.5 m in the Z position.

#### **Distance Measuring Indicator (DMI)**

- Computes wheel rotation information to aid vehicle positioning and collect high-resolution imagery at posted speeds.

#### **Cameras**

- Point Gray Ladybug 5+ 32MP 360 camera (Utilized for accurate ROW asset capture and extraction). This system is far superior to multiple mounted independent HD cameras others use.

#### **Pavement Imaging System**

- Second-generation Pavemetrics Laser Crack Measurement System (LCMS-2) provides 1mm resolution pavement imagery for automatic and continuous measuring of pavement cracking, texture, rutting geometrics, and other pavement distresses.
- LCMS-2 camera is a laser array providing images used to evaluate data that conforms with ASTM D6433 protocols and provides a detailed array of data using two 1-millimeter resolution line scan cameras. A 1mm resolution is equivalent to over 4,000 laser points across the driven lane.
- Allows fully illuminated pavement image collection even in heavy shadow/canopy areas.

#### **Pavement Ride Quality**

- An inertial profiler with line lasers (Used to capture International Roughness Index (IRI) measurements).



Figure 12.1: RAS RAC Vehicle

## 12.2 Quality Control/Assurance

All subsystems for the RAS vans are integrated using International Cybernetics Corporation’s (ICC) collection core with tight synchronization between all data streams on the truck in real-time, referenced to both time and distance. All sensor locations are calibrated to the vehicle, together with the GPS and IMU, using 3D translations and rotations. This allows for the rapid calculation of the precise location of all sensor data. The RAC vehicle has received independent inertial profiler certification for accuracy and repeatability from the National Center for Asphalt Technology at Auburn University.

RAS RAC image collection includes a daily check of the on-board systems. This vehicle component check includes a calibration site survey of a nine-point grid in state plane coordinates (Figure 12.2). Each morning and afternoon, before and after a day’s image collection, the RAC vehicle drives over the surveyed location. The RAC technician then extracts each point’s location to verify the location of the point extracted was within approximately three feet of the surveyed points. RAS’ QA/QC manual includes further details regarding RAC quality control procedures.



Figure 12.2: 9-Point Calibration Site Example

Calibration of the laser profiling system includes laser sensor checks and block tests to ensure the accuracy of the height sensors, accelerometer calibration “bounce tests” to verify proper functioning of the height sensors and accelerometers and distance calibration to ensure accuracy of the DMI. Calibration of the DMI and some accelerometers occurs during field testing, and each is checked and recalibrated on a regular basis.

During image collection, the RAC technician reviews the images collected on-screen as they are collected and any issue with image clarity requires the collection run to end and the image quality issue to be resolved. This provides real-time verification that the equipment is operating correctly. Once resolved, the collection run begins from the beginning for the road segment collected. The RAC technician also monitors GPS reception during collection. If GPS reception is lost measured using positional dilution of precision (PDOP), the RAC technician stops the collection and resolves the GPS reception issue. Collection begins again once the GPS reception issue is resolved. The RAC technician will check each camera's exposure rate, image quality and GPS and IMU operation to ensure the RAC system is recording the image, GPS, DMI and IMU data and that the GPS location is within the stated project tolerance.

Each day's image and road data collection are recorded on a RAC server. Each night, the day's collection data is backed up to an external hard drive. The external hard drives are then mailed back to RAS' project office where the data is placed on a production server for post-processing of images and data, quality control review and pavement distress inventory.

The QC program for pavement condition data collection typically includes random sample audits, inter-rater reproducibility and data checks for accuracy and repeatability of the results. For this survey project random samples of the pavement condition data were selected and checked by the lead rater or QC personnel. If the pavement condition ratings did not meet quality standards, corrective action was taken, and the entire section was reviewed.

#### **Cameras**

- High-definition cameras with precision lenses allow for accurate asset extraction and video log recording, but with lower frame rate: 15 images per second, with lower 1936x1456 color resolution.

#### **Pavement Imaging System**

- Two line-scan cameras and lasers configured to image 4m transverse road sections with 1 mm resolution (4000 pixel) at speeds that can reach 100 km/h, upgraded to the 3D imagery of the LCMS-2 camera system.

The QC program for pavement condition data collection typically includes random sample audits, inter-rater reproducibility and data checks for accuracy and repeatability of the results. For this survey project random samples of the pavement condition data were selected and checked by the lead rater or QC personnel. The QC selection process includes but is not limited to random sampling at ten-point PCI range increments with a minimum of 10% per range, a complete verification for any road with a 'Poor', "Very Poor", or "Failed" PCI (0-40 PCI), a review of all high-density distresses, and a spatial review of neighboring PCI's. If the pavement condition ratings did not meet quality standards, corrective action was taken, and the entire section was reviewed.

### **12.3 LCMS-2**

Downward-facing LCMS-2 pavement imagery is collected for use in quantifying distress type, severity, and extents present on segments of road. The resolution of the imagery allows for

distresses to be easily identified and measured during the analysis portion of the contract. Pavemetrics' Laser Crack Measurement System (LCMS) is a high-speed and high-resolution transverse profiling system. Capable of acquiring full 4-meter width 3D profiles of a highway lane. At normal traffic speed, the system uses two laser profilers that acquire the shape of the pavement. Both the resolutions and acquisition rate of the LCMS are high enough to perform automatic cracking detection, macro-texture evaluation, rutting measurements, and much more. Custom optics and high-power pulsed laser line projectors allow the system to operate in full daylight or in nighttime conditions. Road profile data are collected onboard the inspection vehicle.

#### 12.4 Profile

A road profile is a set of (X,Z) data points captured along the transversal axis of the road. A profile is captured each time the LCMS controller receives a trigger signal from the vehicle's odometer<sup>1</sup>. Typically, the LCMS system can capture one road profile every few millimeters (5 mm at 100km/h). Each profile consists of up to 4160 data points. This value will be referred to later in this document as being the number of points per profile.

The longitudinal profile of the road is generated by measuring its shape along an imaginary line in the direction of travel or longitudinal axis of the road. The longitudinal profile can then be used to compute various roughness indexes such as the IRI (International Roughness Index). The following guidelines should be followed to ensure proper readings from the Roughness subsystem:

- Maintain the recommended tire pressure.
- Ensure the wheels are balanced.
- Drive at speeds between 15.5 mph and 60 mph.
- Avoid quick accelerations and decelerations and sudden changes in direction.

A road section is a set of consecutive profiles that are merged and saved in a common file. A road section can be seen as a set of 3D coordinates (X, Y ,Z), where X is the coordinate along the transversal axis of the road, Y along the longitudinal axis, and Z is the depth axis, as displayed in Figure 12.3. The road section length is configurable and is set by the user before starting the acquisition. A typical road section length is between 5 to 10 meters.

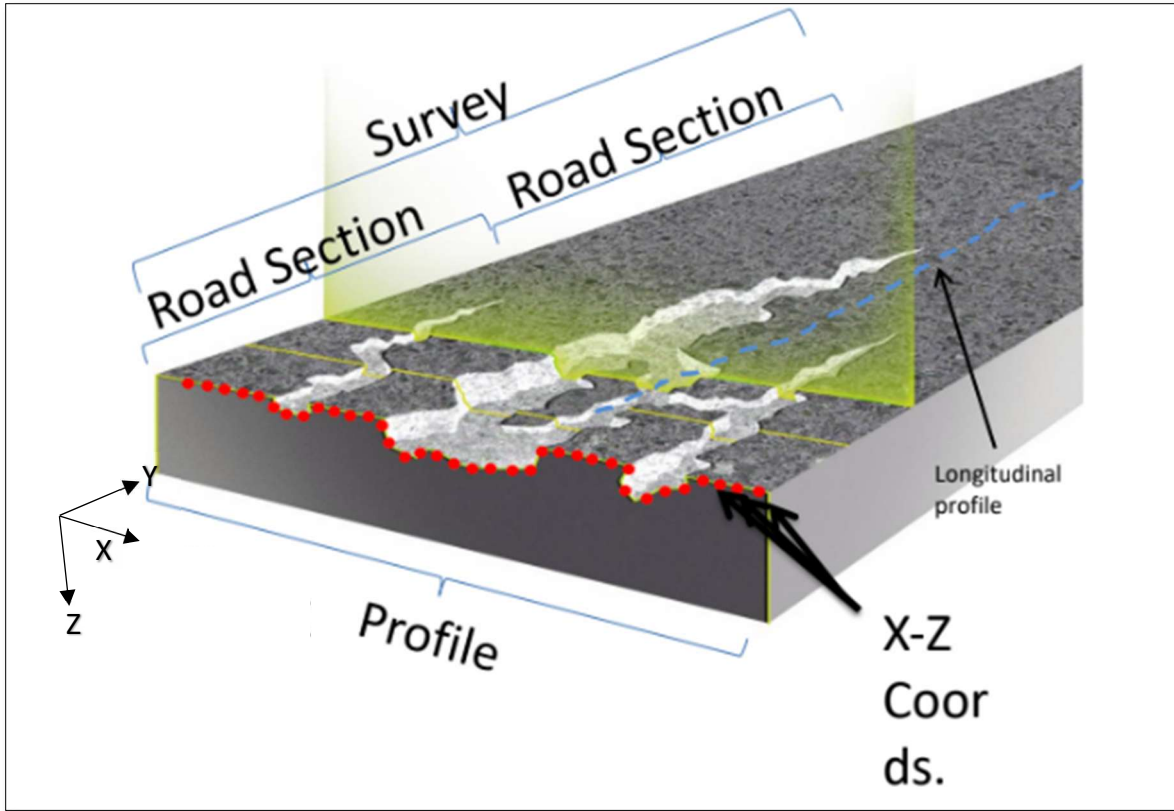


Figure 12.3: LCMS Data Definition