Survival Analysis of Concrete Overlay Performance in Iowa

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Overview

- Concrete Overlays in Iowa
- Study Motivation and Methodology
- Key Findings
- Conclusions

Concrete Overlays in Iowa

County Highways in Iowa

- Iowa ranks 26th among U.S. states in land area and 31st in population, but it ranks 5th in centerline miles of rural roadways
- While many of these roadways are unpaved and relatively low volume roads, many are paved and carry significant traffic loads

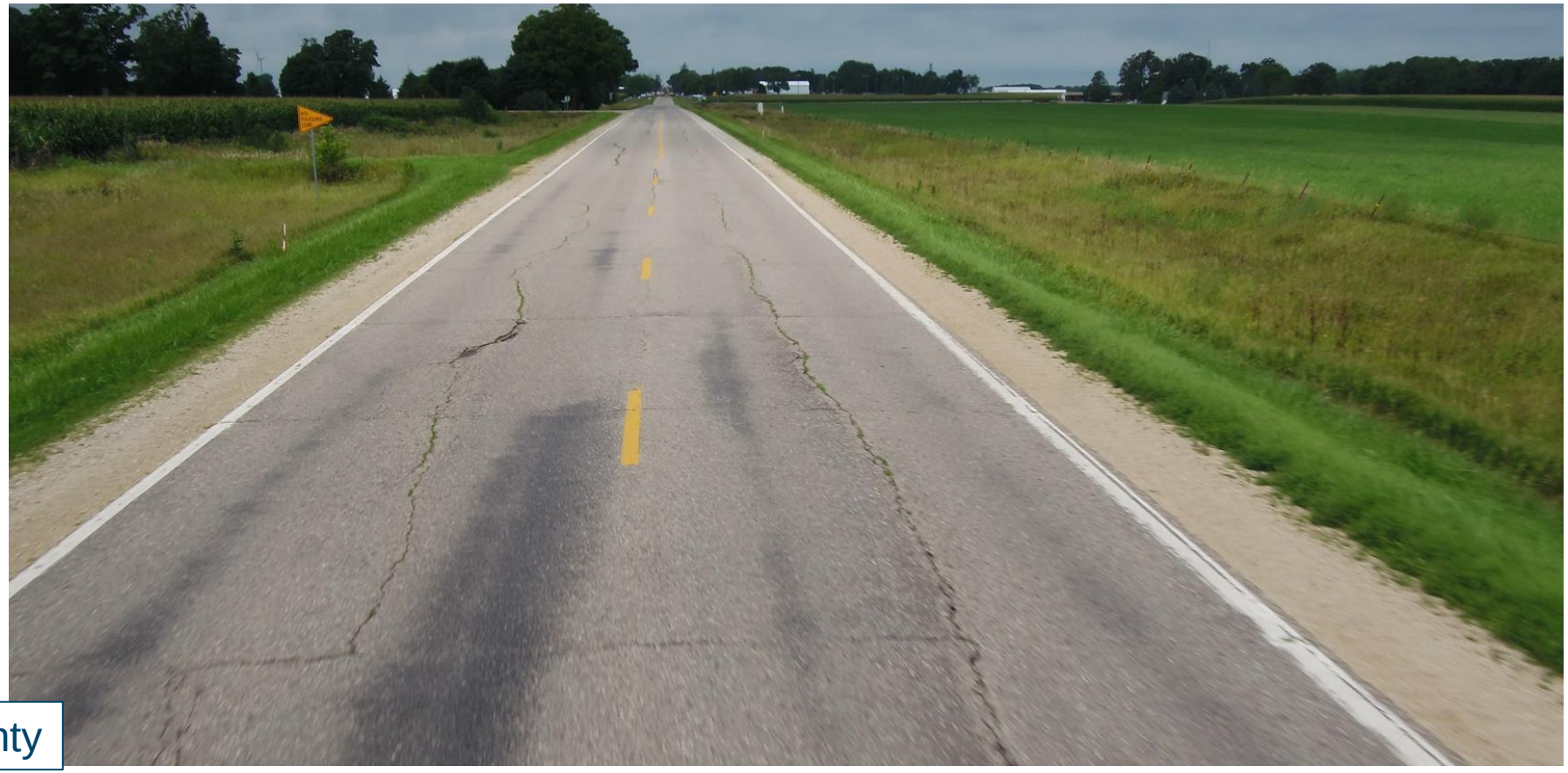
Wapello County

County Highways in Iowa

- Iowa stands out from many states in its extensive use of concrete pavements on county highways
  - 9,100 centerline miles of concrete-surfaced roads in total
    - 2nd-most in the U.S. (TX)
  - 7,200 of those miles are classified as rural
    - No other state has more than 1,200 such miles
- Many of the concrete pavements on Iowa's rural roadways are concrete overlays

What is a Concrete Overlay?

- Extending the life of an existing pavement with an overlay of a new concrete surface



Mitchell County

Image: Rich Brumm, Mitchell County

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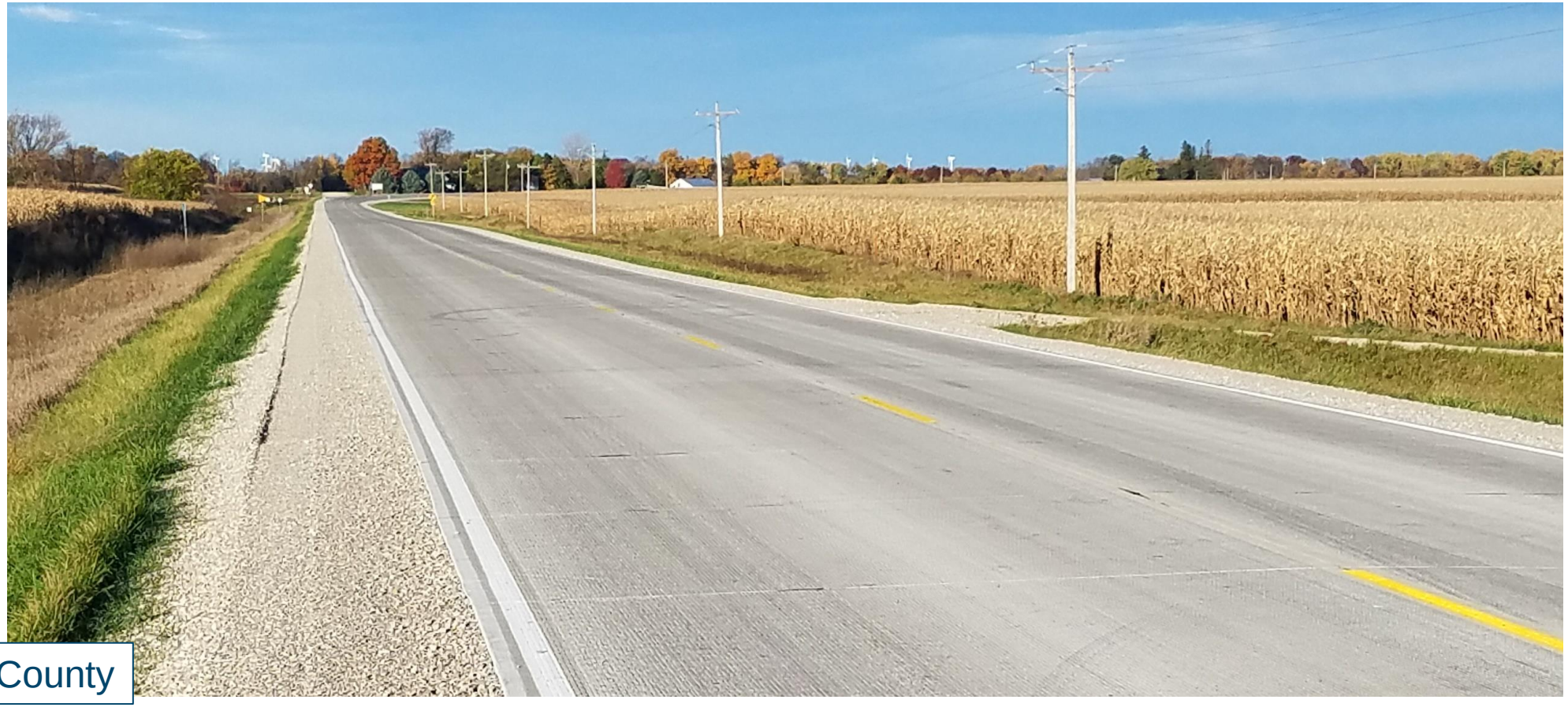


Mitchell County

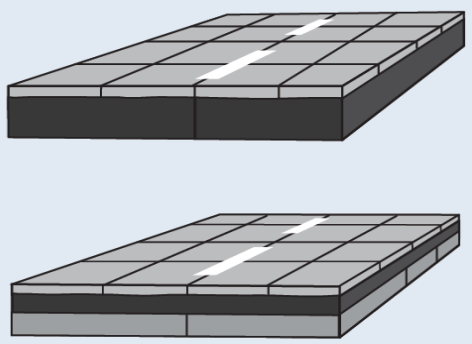
What is a Concrete Overlay?

- Concrete overlays are primarily classified based on the existing pavement type and the bonding condition

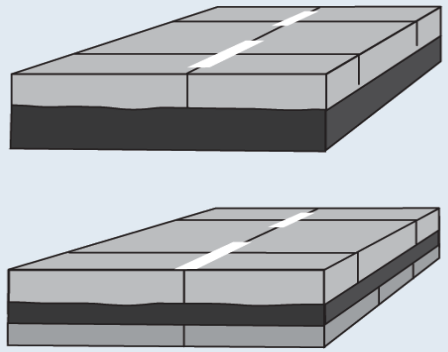
Concrete on Asphalt

Concrete on asphalt (COA) overlays can be designed to address a broad range of existing pavement conditions on both composite and full-depth asphalt pavements. Both bonded (COA–B) and unbonded (COA–U) options enable designs to cost-effectively match the condition of the existing asphalt—from deteriorated to good—as well as geometric parameters.

COA–B (Full Depth and Composite)



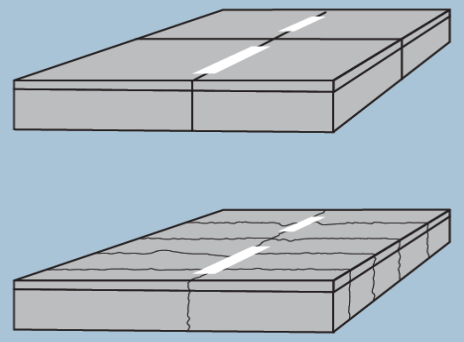
COA–U (Full Depth and Composite)



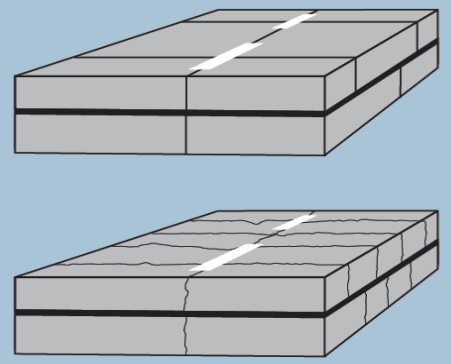
Concrete on Concrete

Concrete on concrete (COC) overlays can be designed for applications on both existing jointed plain concrete pavement (JPCP) and continuously reinforced concrete pavement (CRCP). The predominance of COC overlay designs are unbonded (COC–U) systems; however, bonded (COC–B) applications can be successful, provided the existing pavement is in good condition.

COC–B (JPCP and CRCP)

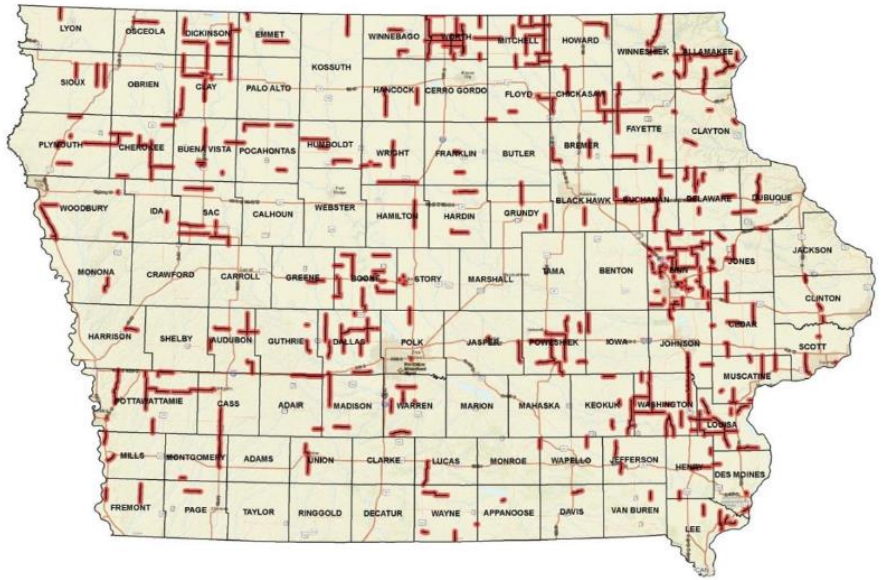


COC–U (JPCP and CRCP)



Iowa's Concrete Overlays

- There are over 2,000 centerline miles of concrete overlays in Iowa (#1 in the U.S.), mainly on the county highway system
  - 81/99 of Iowa's counties have built a concrete overlay
  - 96/595 projects were constructed before 1990
  - Includes all types of concrete overlays



Study Motivation and Methodology

Concrete Overlay Performance in Iowa

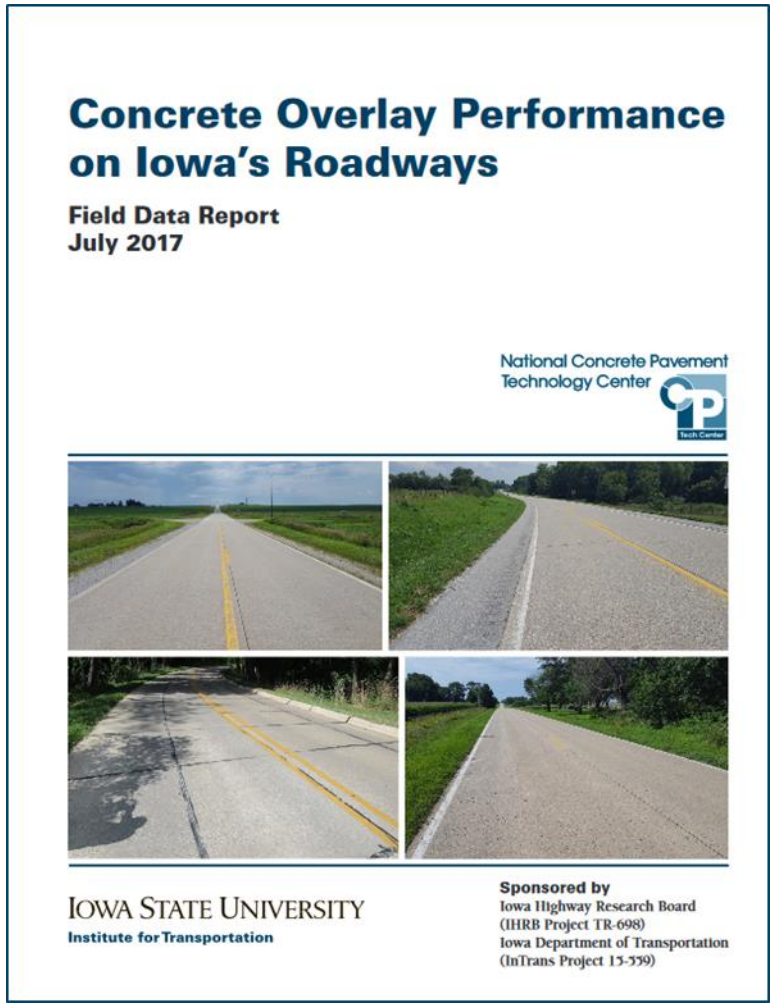
- With increasing use of concrete overlays, agencies want to know:
  - What kind of performance and service life can we expect?
  - What has been successful in design, materials, and construction? What hasn't worked?

Boone County
Constructed 1977
Pictured 2016

Dallas County
Constructed 1992
Pictured 2016

Concrete Overlay Performance in Iowa

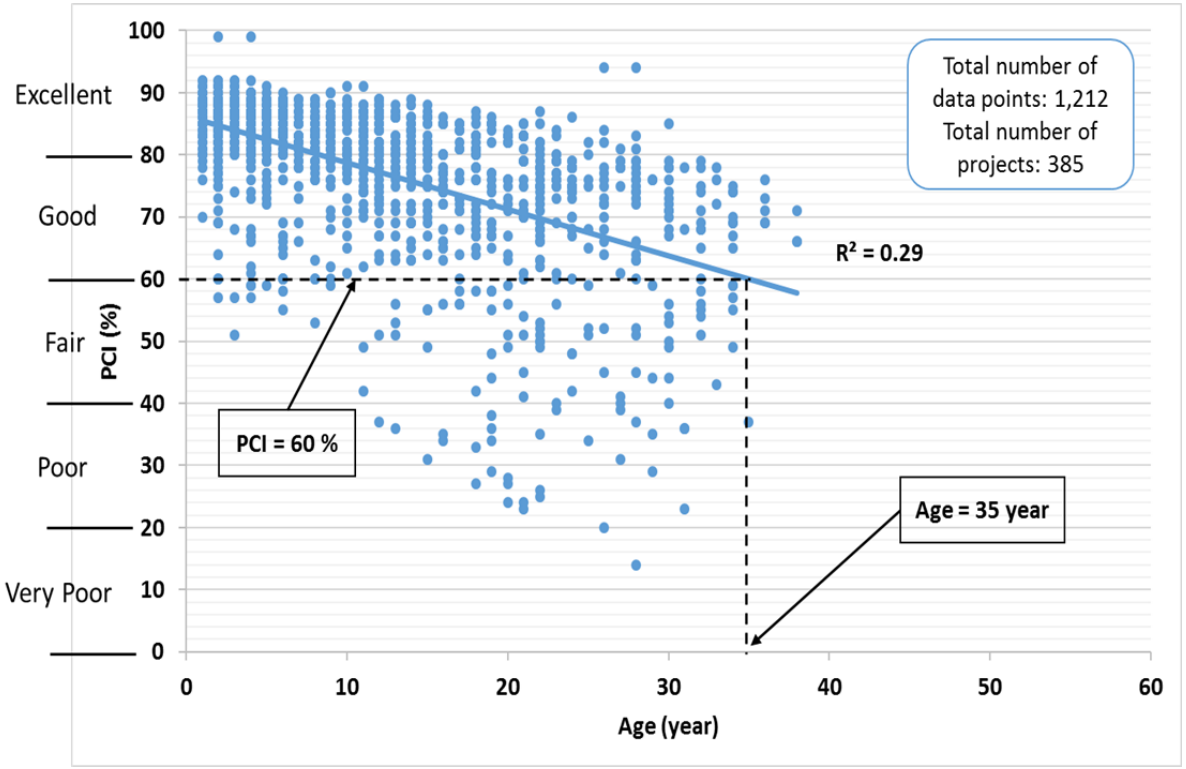
- Iowa has a comprehensive data set of concrete overlays, including older projects
- A CP Tech Center study from 2017 used Iowa Pavement Management Program (IPMP) data to analyze concrete overlay performance

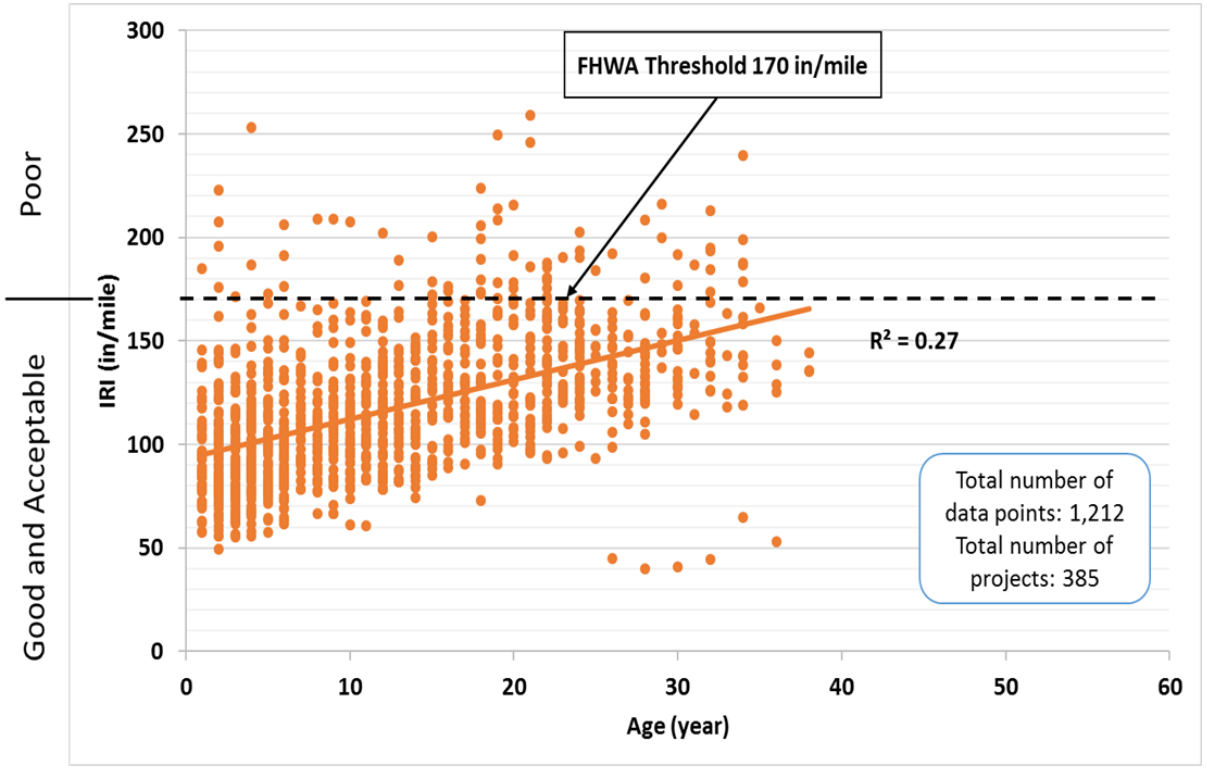


Source: Gross et al. (2017)

Concrete Overlay Performance in Iowa

- The 2017 study found good performance overall, with an average concrete overlay service life of about 35 years based on a regression analysis of different performance measures





Images: Gross et al. (2017)

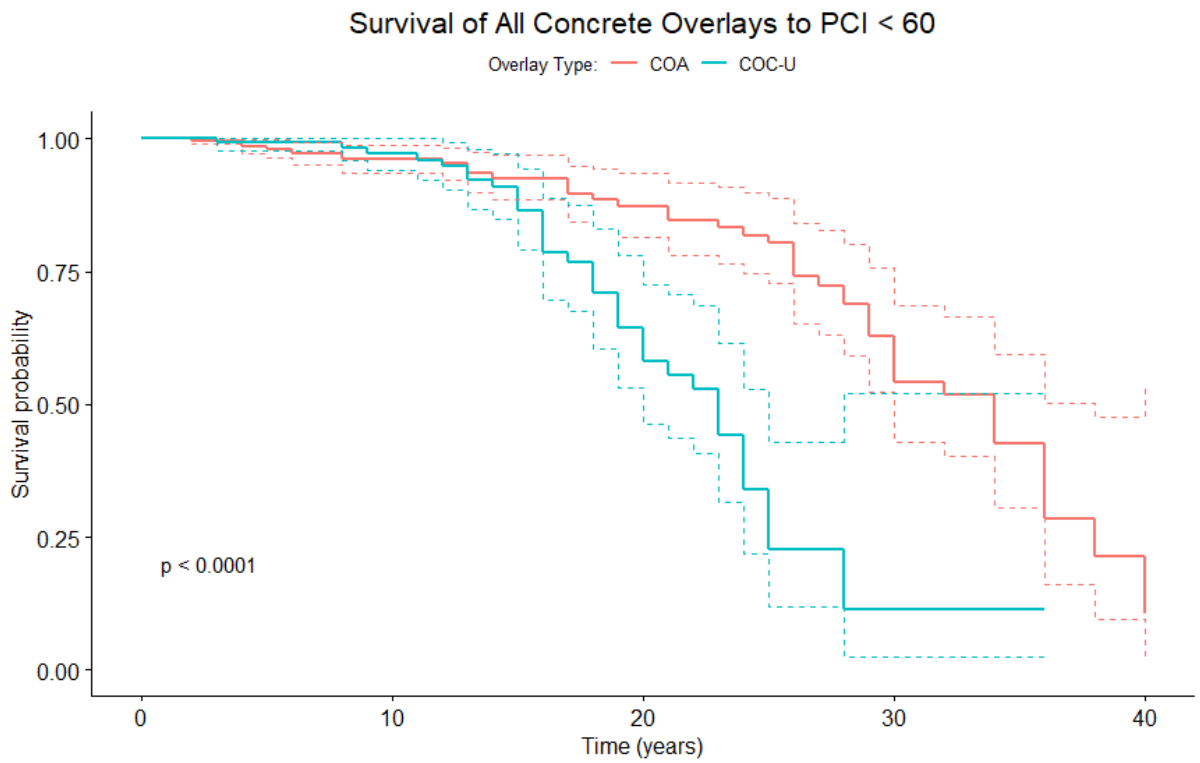
Concrete Overlay Performance in Iowa

- Motivations for new study:
  - Continuing interest in concrete overlays in Iowa and nationwide
  - Opportunity to update the Iowa project data set (+4 years)
    - New projects and additional data for older projects

Le Mars

Survival Analysis of Concrete Overlays

- Survival analysis was identified as an alternative methodology for this study
  - Evaluates the expected amount of time before an event or outcome occurs and factors that influence the occurrence
  - Can estimate survival probability at a given time, *t*, as well as median survival time (*t* when survival probability ≤ 50%)



Survival Analysis of Concrete Overlays

- Kaplan-Meier estimator used to create survival curves for Iowa's concrete overlays
  - *S(t)* = probability of pavement survival beyond time *t*
  - *t* = time (pavement age)
  - n_i = number of pavements at risk at time t_i
  - d_i = number of pavements observed to fail at time t_i
- Data from pavements that haven't yet failed are removed from the denominator (censored) after the time *t* (pavement age) that they last appear in the study

$$S(t) = \prod_{t_i \leq t} \left(1 - \frac{d_i}{n_i}\right)$$

Survival Analysis of Concrete Overlays

- Three different survival conditions were analyzed:
  - Time until major rehabilitation or reconstruction
  - Time until Pavement Condition Index (PCI) < 60%
  - Time until International Roughness Index (IRI) > 170 in/mi
- Log-rank tests were used to compare multiple survival curves

$$PCI = 100 - 35\left(\frac{IRI}{253}\right) - 25\left(\frac{D - cracking}{8}\right) - 15\left(\frac{joint\ spalling}{9}\right) - 25(\frac{transverse\ cracking}{14}\right)$$

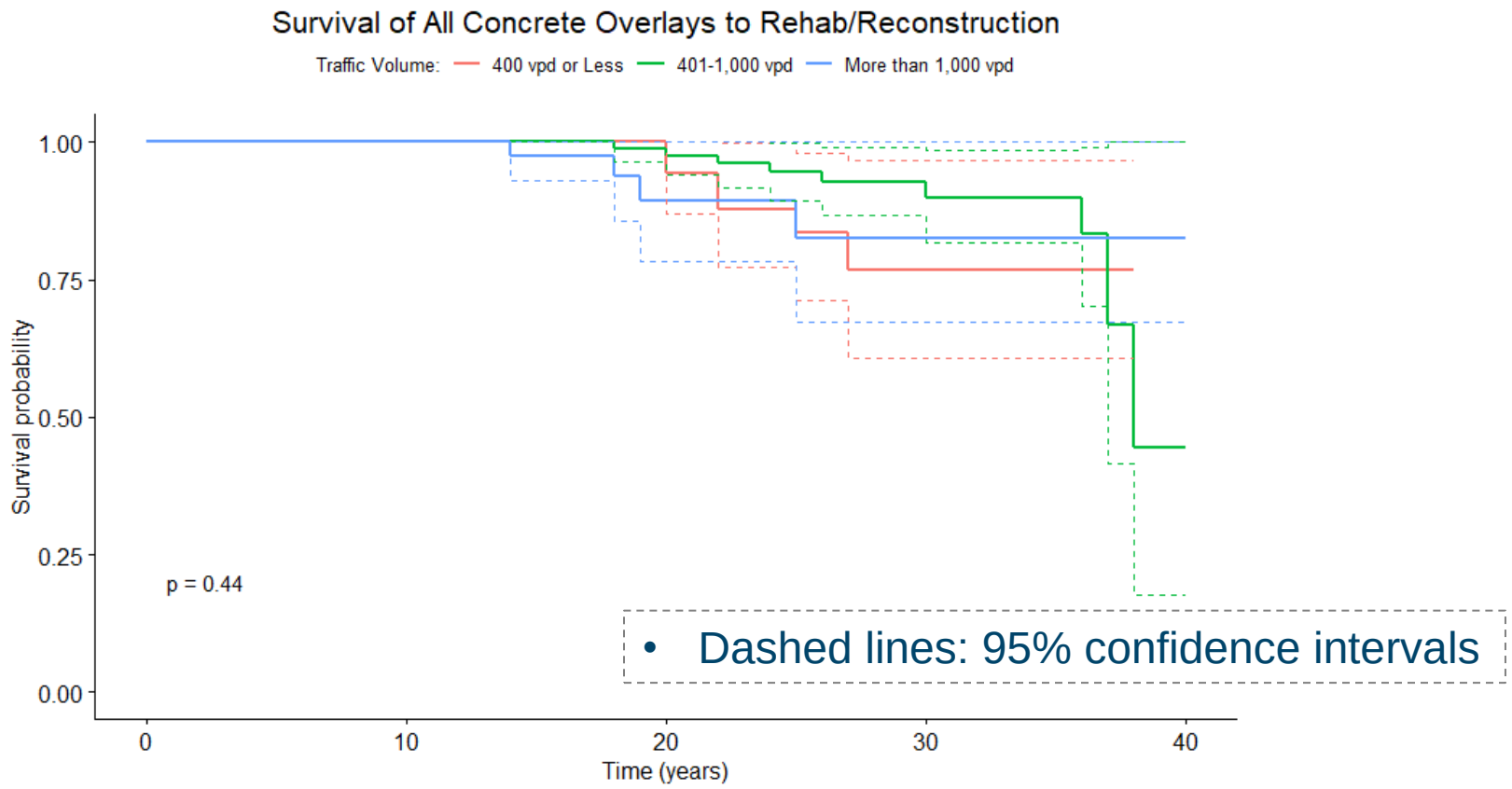
Survival Analysis of Concrete Overlays

- Data were broken down into different subsets to look at the impacts of different variables on survival probability
  - Failure mode (PCI vs. IRI)
  - Traffic level
  - Overlay type (COA vs. COC–U)
  - Thickness
  - Joint spacing

Results and Discussion

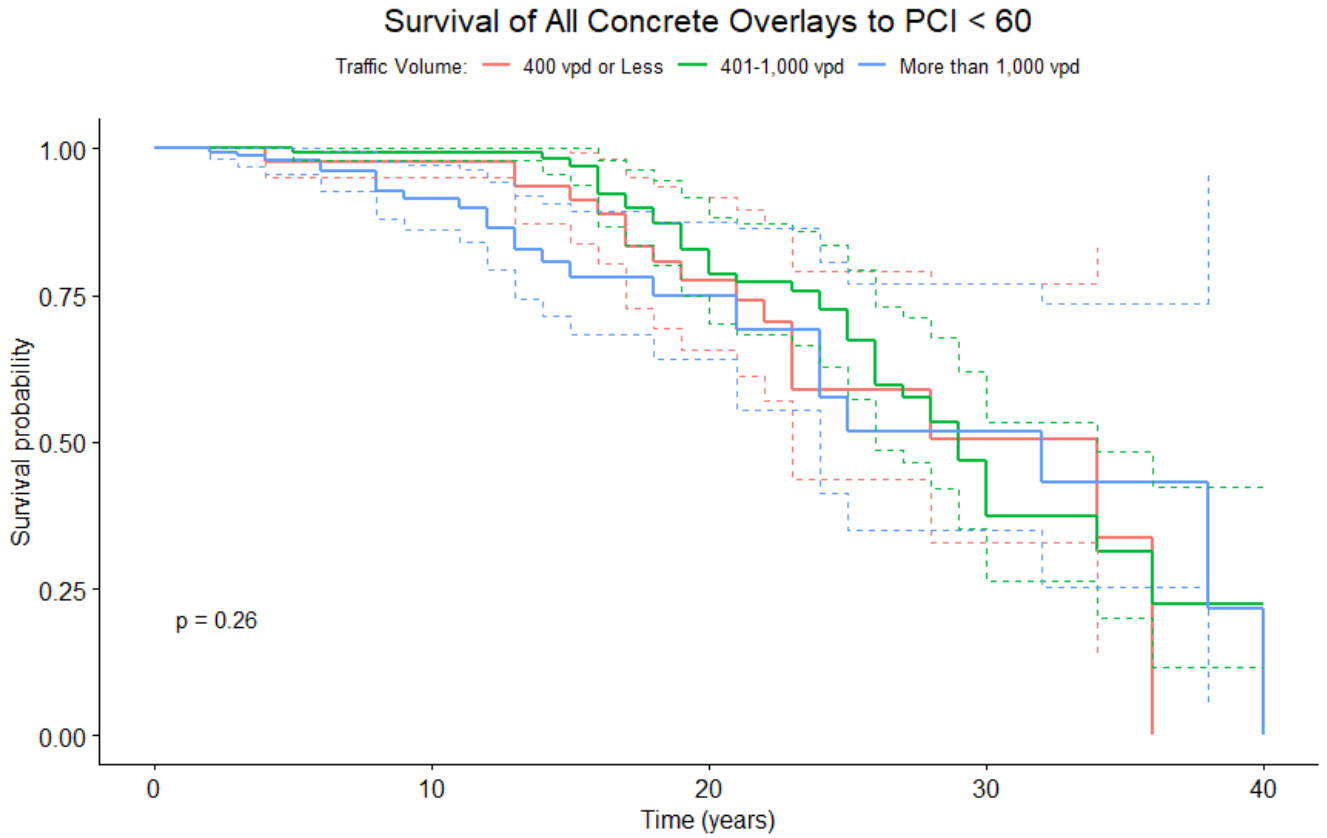
Key Findings – Overall

- 30 year survival probability = 85.3% for all projects to rehab/reconstruction
- Similar results for all traffic levels



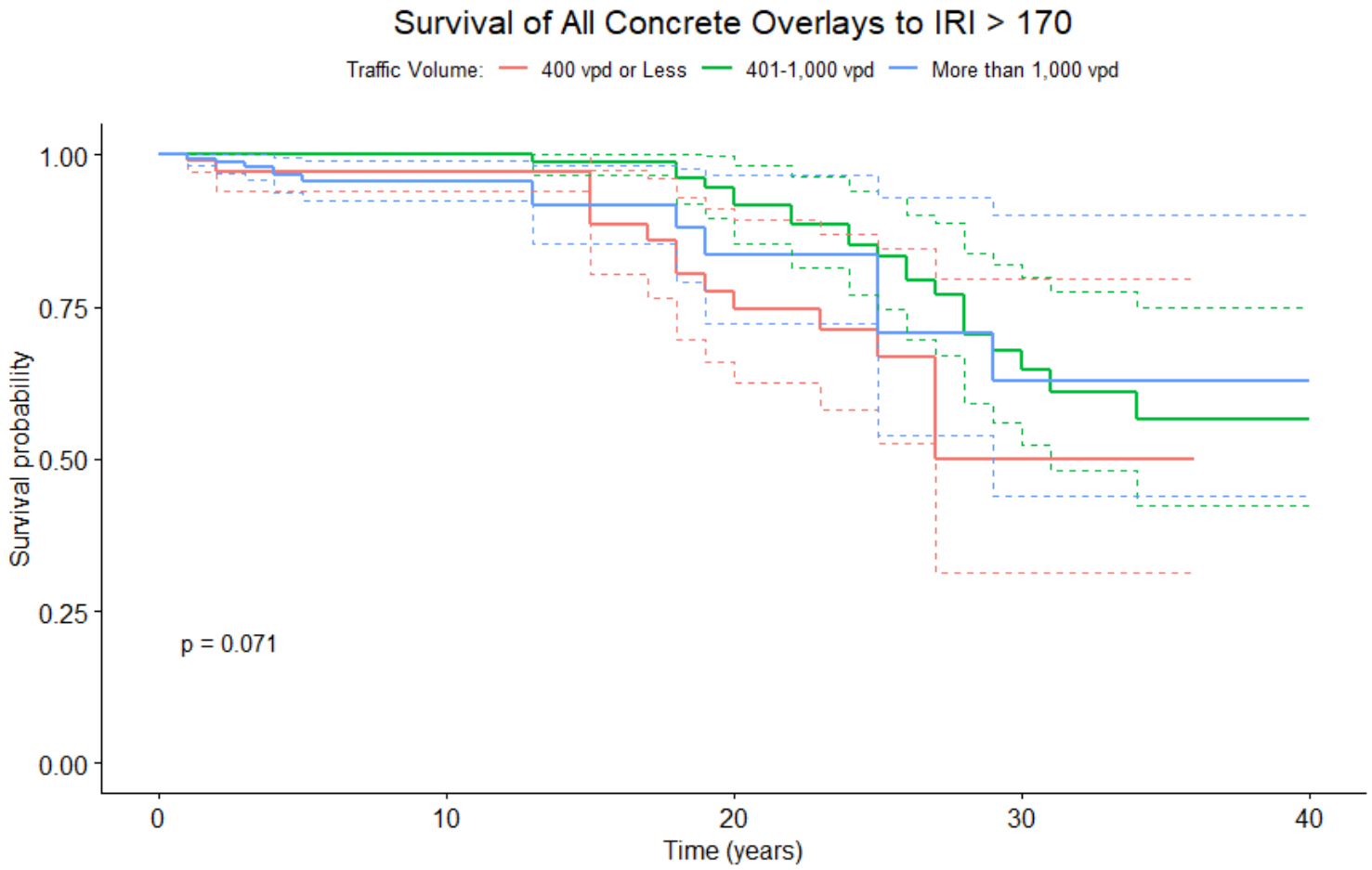
Key Findings – Survival Condition (PCI)

- 30-year survival probability = 41.1% for all projects to PCI < 60
- Median survival age = 29 years for all projects to PCI < 60



Key Findings – Survival Condition (IRI)

- 30-year survival probability = 60.0% for all projects to IRI > 170 in/mi

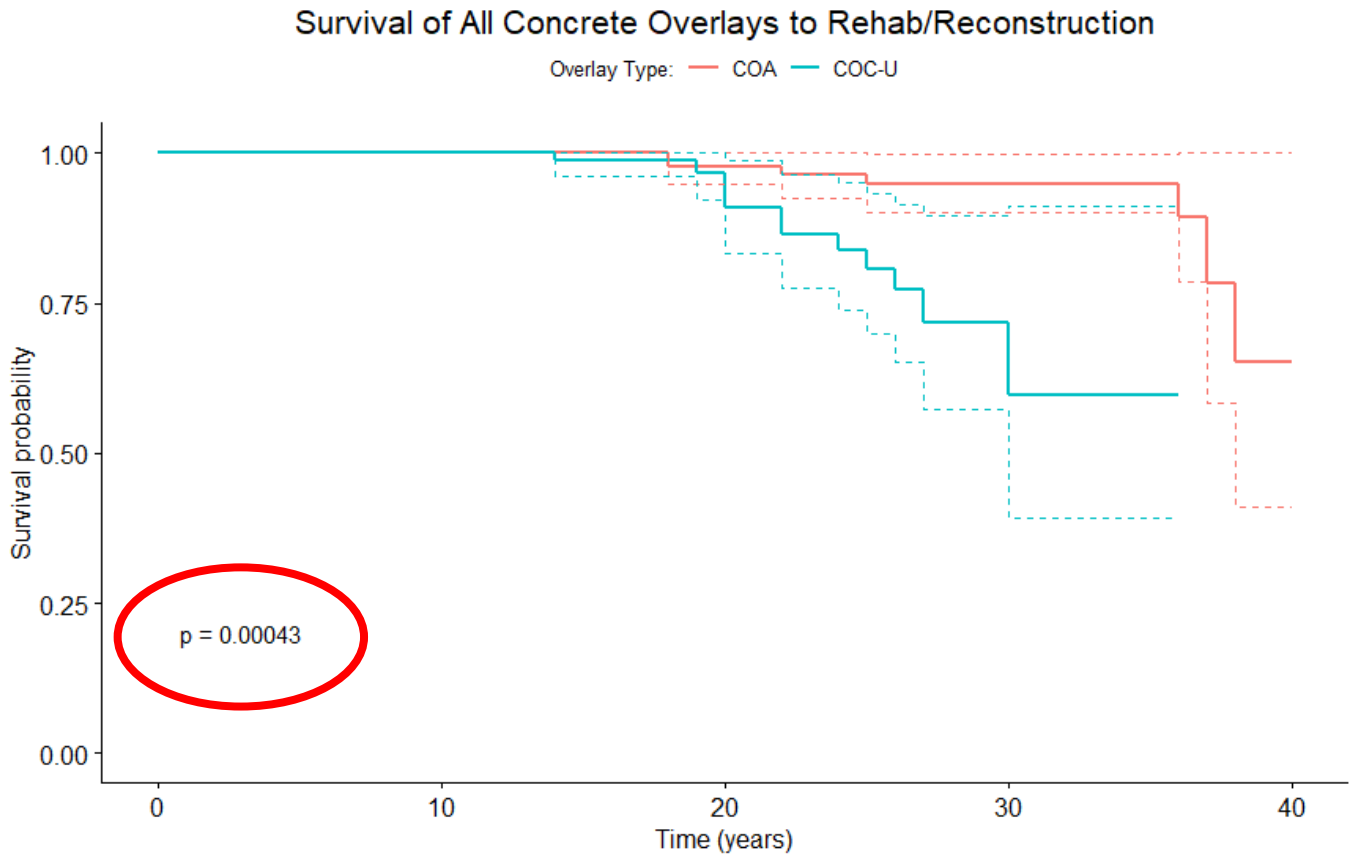


Key Findings – Survival Condition

- A greater number of projects failed in terms of the PCI survival condition (84) compared to the IRI condition (50) or the rehab/reconstruction condition (19)
  - D-cracking, joint spalling, and transverse cracking may be larger issues for concrete overlays than ride quality/smoothness
  - Is PCI < 60 the right threshold for “survival” given that these pavements remain in service for longer periods of time?

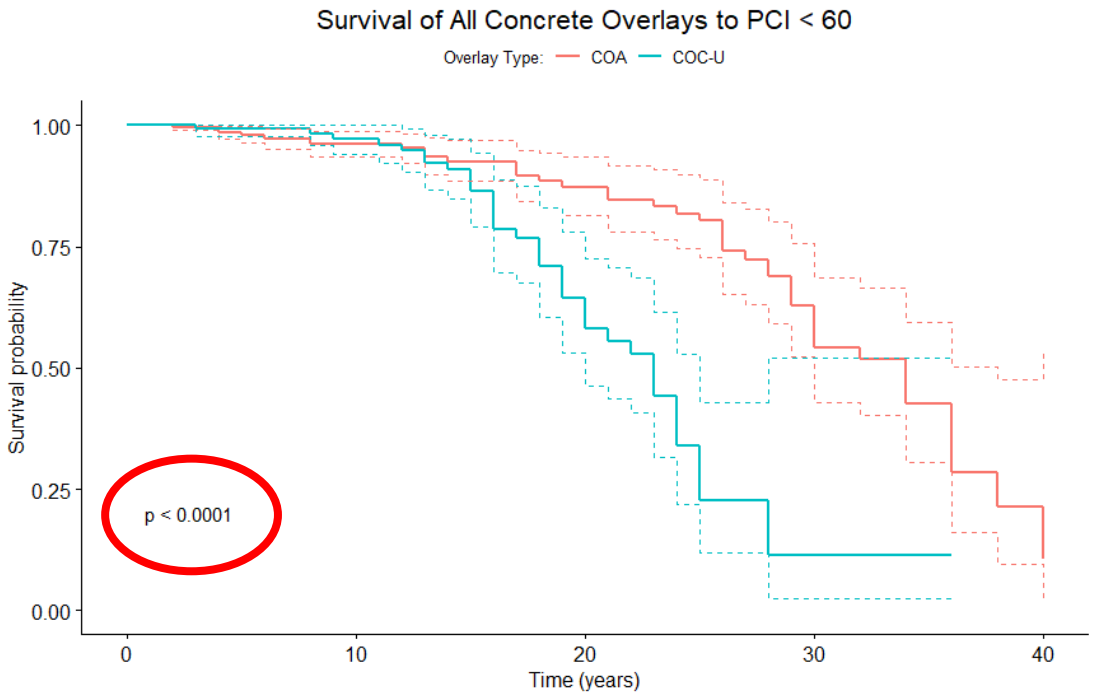
Key Findings – Overlay Type

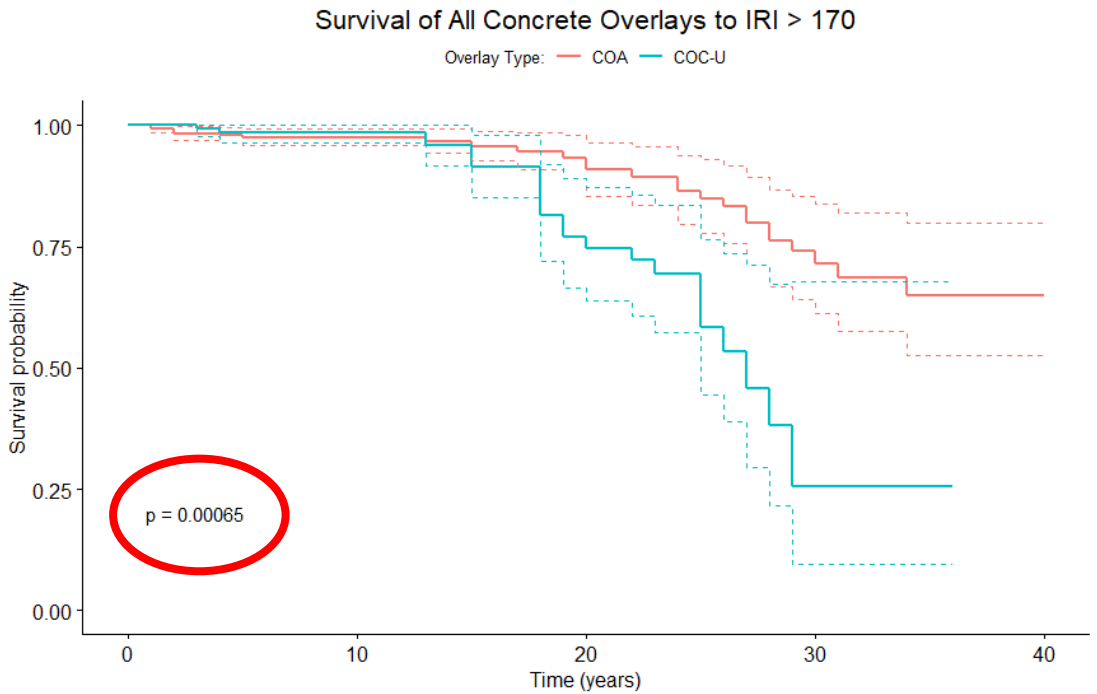
- 30-year survival = 95.0% for COA overlays to rehab/reconstruction
- 30-year survival = 59.8% for COC – U overlays to rehab/reconstruction



Key Findings – Overlay Type

- This disparity holds when analyzing the PCI and IRI survival conditions for COA and COC–U overlays





- Median survival age = 34 years for COA
- Median survival age = 23 years for COC–U

- 30-year survival probability = 71.6% for COA
- 30-year survival probability = 25.5% for COC–U

Key Findings – Overlay Type

- Significant differences were observed between COA and COC–U overlays for all survival conditions
  - Better performance for COA overlays
- Questions for further investigation:
  - Are Iowa's COC–U overlays under-designed relative to its COA overlays?
  - How much do COA overlays benefit from bond to the underlying asphalt, even when they are not designed to bond?

Key Findings – Thickness and Joint Spacing

- Thickness and joint spacing did not appear to have much of an impact on time to failure to any of the survival conditions
  - The lack of any trends could be a sign that overlay thickness tends to be designed properly according to truck traffic
- Joint spacing: limited long-term sample size of shorter panels
  - e.g. 6 ft x 6 ft

Conclusions

Conclusions

- Overall, the findings of this survival analysis are broadly consistent with the findings of the 2017 study, and provided some additional insights into failure mode and overlay type
- Properly designed and constructed, concrete overlays are capable of good long-term performance and extended service life
  - 30-year survival probability of 85.3% for all projects
- More failures were observed when survival condition was defined in terms of the PCI and IRI performance thresholds

Conclusions

- More projects reached the PCI failure threshold than the IRI one
  - May indicate that cracking and spalling are more significant performance issues than deterioration of ride quality
- Considering all projects, COA overlays had longer survival lives and greater 30-year survival probabilities than COC–U overlays
  - Warrants further investigation into typical designs and the effect of bond on COA overlay performance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