EXTENDED SUPPLEMENTAL MATERIALS: SOCIAL EQUITY OF BRIDGE MANAGEMENT

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CODE, DATA, AND ADDITIONAL INFORMATION

The final panel dataset, code used to prepare the panel from raw data, code to run the models (including the robustness checks) and produce Latex tables, and more detailed data descriptions, are available from the Carnegie Mellon University KiltHub Repository (Gandy et al. 2022).

PANEL PREPARATION DETAILED DESCRIPTION

Identifying Unique Bridge Structures

We constructed a time-series panel of bridge inspections using the National Bridge Inventory (NBI) delimited ASCII files published from 1992 through 2020 containing inspection data collected from 1990 through 2020 (Federal Highway Administration 2021). Each structure was associated with a unique identifier field created by concatenating the “State Code," “Structure Number,” “Record Type (5A),” and “Year Built” fields from the NBI record and partially hand-checked for unique identifier consistency across record years (Federal Highway Administration 1995). When constructing the unique identifiers for each structure, we incorporated FHWA records of "Structure Number" changes to maximize the number of record years available for each structure. Due to the size of the merged records, the “data.table” package for R was used for fast reading, manipulation, and queries (Dowle et al. 2021). As shown in Table 2 in the main paper, the initial panel contained over 20 million records from over 1.3 million unique structures, to include culverts, on-ramps, and bridge sections.

Censoring Records without Required Attributes

Age, defined as the difference between the inspection year and year of construction or reconstruction in the NBI record, is essential for understanding the rate of condition deterioration (Kale et al. 2021; Saeed et al. 2017). Records missing both the construction and reconstruction year data were omitted. Records that were missing the inspection year were assigned the NBI record year as a proxy measure and retained. Any inspection records with a resulting age of over 100 years was eliminated from the panel so that our models represent a typical bridge life-cycle.

This study analyzes changes in NBI deck, superstructure, and substructure component condition ratings because they underpin the FHWA’s bridge management strategy (Parker 2018). Thus, bridges without component condition ratings could not be used in the panel data regression. Bridges that do not carry a National Highway System (NHS) route, but bridge over an NHS route (Route Type, item 005A is 2 or A-Z) do not need to have component condition inspections (Federal Highway Administration 1995). Component condition inspections are also not required for culverts and specifically deck component condition ratings are not required for filled archways (Federal Highway Administration 1995). Of the nearly 6.4 million records missing condition information, 40% did not carry an NHS route and 58% were culverts or filled archways carrying an NHS route.

Validating Bridge Coordinates

The NBI contains geospatial identifiers (GEOID) for the state, county, and place (if applicable) in which the bridge is located, but tract-level socioeconomic data is more appropriate for equity assessments (Jones and Armanios 2020; Desai and Armanios 2018; Council on Environmental Quality 2020; Kang et al. 2022). Therefore, we spatially joined the coordinates listed in the NBI record with census tracts and climate zones for additional resolution. Coordinates for each unique bridge structure were taken from the most recent record overall under the assumption that these will be the most accurate. The coordinates should have been recorded to the nearest hundredth of a second (eight-digit Degree-Minutes-Seconds-Decimal Seconds latitude and nine-digit Degree-Minutes-Seconds-Decimal Seconds longitude) (Federal Highway Administration, 1995, p.9) , but many records did not contain this level of precision because the coordinates were entered with excess leading or trailing zeros (see Table 2). After removing records with insufficient digits in the coordinates, we removed records with illogical coordinates, specifically, if numbers in the latitude degrees bin were not 0-90 degrees or the numbers in the longitude degrees bin were not 0-180 degrees. Moreover, the NBI Recording and Coding Guide does not permit negative (-) designations in the coordinates, but they are still present in some records (Federal Highway Administration 1995).

The valid bridge coordinates were converted to decimal degrees and spatially joined to Census TIGER/LINE shapefiles for tracts using “tigris” and “sf” packages for R (Pebesma et al. 2021; Walker and Rudis 2022). We used the 2000, 2010, and 2020 tract boundaries to conduct spatial joins with the bridge coordinates and remove records that were not joined to the same state and county listed in the NBI record as summarized in Figure 1 and Table 2 in the main paper (U.S. Census Bureau ; Kang et al. 2022). Given our focus on demography, we eliminated bridges joined to tracts with zero population or zero income, typically water bodies and industrial zones, for any of the Decennial or ACS periods.

We recognize that even among the records with a coordinate within the state and county listed in the NBI record, there may be inaccuracies that affect our associations with census tracts. A previous study found that 461 NBI coordinates in Texas and Oklahoma were between 101 and 1235 meters from the nearest roadway (Din and Tang 2016). We reviewed one hundred bridge coordinates (two randomly selected in each state) and verified that these locations had a bridge visible in the available imagery and were coincident with the features or location information in the NBI record. Only one coordinate in the sample was off by just over one hundred meters from the feature intersection and the imagery. This is consistent with previous work that finds about 1% of bridge coordinates were not in the listed county (Kang et al. 2022). Given that census tracts are often defined by highways and the waterways that bridges span, a potential improvement to our point intersection spatial joins would be to summarize the demography of all tracts within a radius of the bridge coordinate, but the improvement in accuracy and retention of additional records comes at the expense of precision depending on the size of the circular buffer used (Jones and Armanios 2020; Kang et al. 2022). From our cursory review, we found that coordinates were often defined at "the beginning of the bridge in the direction of inventory" (Federal Highway Administration, 1995, p.9) for longer bridges and in the middle of the span of relatively short bridges. Inconsistency in the surveying of bridge locations would thus impact the accuracy of circular buffers for bridges of different lengths. That said, per our random check and noted limitations aside, we felt adequately confident to proceed with joining bridge points to census and climate polygons by intersection. This is especially true given that our aim here is to influence more national-level strategic decision-making and not decision-making tailored to any specific local government where such inaccuracies may be more consequential.

Balancing the Panel

Bridges are typically inspected less than annually, resulting in duplicate records of the same bridge and age that cannot be included in the panel data regression. Therefore, we included only the most recent record for each bridge and inspection year. Then, unique bridges with less than three unique inspection records with condition data were eliminated from the panel to improve the balance of the time-series panel (Ahrens and Pincus 1981). We selected a minimum threshold of three records per unique bridge after comparing two measures of panel unbalance (γ and ν) from Ahrens and Pincus (1981) with the number of bridges retained at each threshold, as shown in Figure S1. For an unbalanced panel of N unique bridges by Q total inspection records, where n is the index for an individual bridge, q_n is the number of records for an individual bridge, and $\bar{q}$ is the average number of inspections per bridge:

$$\gamma = \frac{N}{\bar{q} \sum_{n=1}^{N} \frac{1}{q_n}} \tag{1}$$

Source: (Ahrens and Pincus 1981)

$$\nu = \frac{1}{N \sum_{n=1}^{N} (\frac{q_n}{Q})^2} \tag{2}$$

Source: (Ahrens and Pincus 1981)

The majority of unique bridge structures with only one or two inspection records were either first inspected after 2015 (13%), were re-coded or eliminated after their first entry in 1990-1992 (35%), or were re-coded or eliminated in 2012-2013 (24%). We note that previous work found significant changes in NBI geospatial accuracy in 2013 (Kang et al. 2022) and that this period is coincident with the publication of the Bridge Inspector's Reference Manual (Ryan et al. 2012). For the subset of 192,335 bridges with less than three observations, differences in condition and other explanatory variables are significant at the 99.9% because of the size of the samples, but we do not find that the mean values are appreciably different (see Table S2).

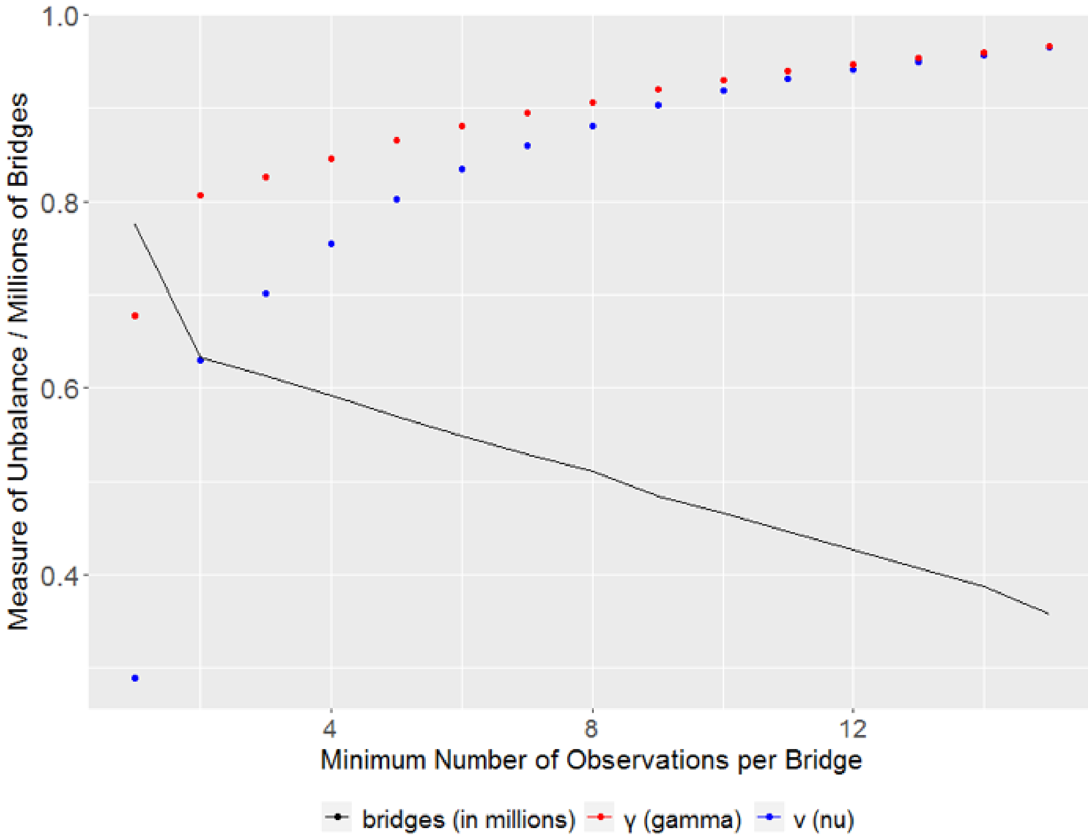

Fig. S1. Measures of Panel Unbalance (γ and ν) and Millions of Bridges Retained by Minimum Number of Observations per Bridge in the Panel

DESCRIPTIVE STATISTICS AND EXPLORATORY ANALYSIS

Comparing the Initial Records to the Final Panel

In addition to the data censoring steps detailed in Table 2 of the article we reviewed the distribution of the retained records by state and the mean values (by unique inspection records, not unique bridges) of the main variables used in the analysis. Table S1 shows the distribution by state of the 6.4 million records retained in the final panel after processing the original set of over 20 million NBI inspection records dated from 1990 to 2020 (Federal Highway Administration 2021). The poorest retention rate was 15% in North Dakota. Over half of the records in Ohio and South Carolina were retained.

Table S1. Initial NBI Records and Final Panel by State

State Code	State Name	NBI Records	Panel Records	Percent Retained
01	Alabama	493,913	143,880	29.13
02	Alaska	40,439	11,623	28.74
04	Arizona	241,995	43,297	17.89
05	Arkansas	405,051	123,739	30.55
06	California	940,411	264,791	28.16
08	Colorado	266,804	91,565	34.32
09	Connecticut	153,693	39,074	25.42
10	Delaware	35,075	6,704	19.11
11	District of Columbia	10,318	2,105	20.40
12	Florida	425,062	130,387	30.67
13	Georgia	485,486	131,967	27.18
15	Hawaii	33,690	11,901	35.33
16	Idaho	131,987	60,554	45.88
17	Illinois	855,107	270,135	31.59
18	Indiana	589,504	239,583	40.64
19	Iowa	749,009	178,969	23.89
20	Kansas	766,577	241,994	31.57
21	Kentucky	448,391	127,087	28.34
22	Louisiana	407,201	152,646	37.49
23	Maine	81,000	24,590	30.36
24	Maryland	172,199	29,660	17.22
25	Massachusetts	163,549	63,363	38.74
26	Michigan	400,244	101,909	25.46
27	Minnesota	555,277	167,086	30.09
28	Mississippi	518,959	181,317	34.94
29	Missouri	768,915	305,706	39.76
30	Montana	170,119	63,085	37.08
31	Nebraska	468,375	145,715	31.11
32	Nevada	56,690	14,264	25.16
33	New Hampshire	100,611	38,855	38.62
34	New Jersey	268,014	77,882	29.06
35	New Mexico	127,373	33,364	26.19
36	New York	634,279	224,171	35.34
37	North Carolina	628,884	197,011	31.33
38	North Dakota	137,697	20,076	14.58
39	Ohio	937,769	530,988	56.62
40	Oklahoma	726,787	236,663	32.56
41	Oregon	240,340	83,266	34.65
42	Pennsylvania	812,608	266,651	32.81
44	Rhode Island	28,494	8,885	31.18
45	South Carolina	292,430	148,852	50.90

46	South Dakota	185,774	70,380	37.88
47	Tennessee	651,929	118,595	18.19
48	Texas	1,610,301	418,391	25.98
49	Utah	106,733	29,673	27.80
50	Vermont	86,821	37,855	43.60
51	Virginia	481,032	148,530	30.88
53	Washington	261,724	104,566	39.95
54	West Virginia	238,241	83,407	35.01
55	Wisconsin	466,637	109,659	23.50
56	Wyoming	96,656	39,752	41.13

On average, the final panel is slightly more conservative than the original records in terms of component conditions as shown in Table S2. Necessarily, this excludes the 6.4 million records that did not contain component condition data in both sets (see main paper Table 2). There are also slightly less urban and interstate bridges and slightly more bridges with steel structures and bridges over waterways in the final panel. Both the mean of Average Daily Traffic (ADT) and the percentage of truck traffic decreased from the original set to the final panel. We did not compare the initial and final panel in terms of the demographic or climate variables because many of the NBI records were censored because of coordinate issues (see main paper Table 2). All differences are significant at the 99.9% level due to the number of records in each sample (20 and 6.4 million respectively).

Table S2. Mean of NBI Variables from Uncensored Panel and Final Panel, All Differences are Significant at the 99.9% Level due to the Number of Records in each Sample

Variable	Source	Mean, All Records	Mean, Final Panel
Deck Condition	NBI Item 58	6.59	6.56
Superstructure Condition	NBI Item 59	6.65	6.63
Substructure Condition	NBI Item 60	6.51	6.49
Urban indicator	NBI Item 26	0.297	0.285
Interstate indicator	NBI Item 26	0.121	0.112
Average Daily Traffic (ADT)	NBI Item 29	9370	8330
% ADT trucks	NBI Item 109	8.16	7.92
Detour length, kilometers	NBI Item 19	19.8	19.8
Deck protection indicator	NBI Item 108C	0.477	0.352
Steel structure indicator	NBI Item 43B	0.0751	0.0969
Over waterway indicator	NBI Item 42B	0.739	0.779

Table S3. Summary of Explanatory Variables, Mean over Unique Bridge Inspection Records

Variables	Source	Mean
Age, years	NBI Items 27, 90, 106	33.07
Urban indicator	NBI Item 26	0.29
Interstate indicator	NBI Item 26	0.11
Average Daily Traffic (ADT)	NBI Item 29	8326
% ADT trucks	NBI Item 109	7.92
Detour length, kilometers	NBI Item 19	19.84
Deck protection indicator	NBI Item 108C	0.35
Steel structure indicator	NBI Item 43B	0.1
Over waterway indicator	NBI Item 42B	0.78
Average temperature > 18 deg C	Liao et al.. (2022)	0.16
Freeze-thaw cycles > 60	Liao et al.. (2022)	0.7
Annual precipitation > 127 cm	Liao et al.. (2022)	0.23
% Minority > average (42%)	2020 Decennial Census	0.2
% Minority > average (36%)	2010 Decennial Census	0.2
% Minority > average (31%)	2000 Decennial Census	0.19
% Minority > 50%	2020 Decennial Census	0.15
% Minority > 50%	2010 Decennial Census	0.13
% Minority > 50%	2000 Decennial Census	0.11
% Minority > 60%	2020 Decennial Census	0.11
% Minority > 60%	2010 Decennial Census	0.09
% Minority > 60%	2000 Decennial Census	0.08
Black or African American > average (13%)	2020 Decennial Census	0.19
Black or African American > average (13%)	2010 Decennial Census	0.19
Black or African American > average (13%)	2000 Decennial Census	0.18
Black or African American > 50%	2020 Decennial Census	0.05
Black or African American > 50%	2010 Decennial Census	0.05
Black or African American > 50%	2000 Decennial Census	0.05
Black or African American > 60%	2020 Decennial Census	0.03
Black or African American > 60%	2010 Decennial Census	0.03
Black or African American > 60%	2000 Decennial Census	0.03
Hispanic or Latino > average (19%)	2020 Decennial Census	0.13
Hispanic or Latino > average (16%)	2010 Decennial Census	0.13
Hispanic or Latino > average (13%)	2000 Decennial Census	0.11
Hispanic or Latino > 50%	2020 Decennial Census	0.04
Hispanic or Latino > 50%	2010 Decennial Census	0.03
Hispanic or Latino > 50%	2000 Decennial Census	0.02
Hispanic or Latino > 60%	2020 Decennial Census	0.02
Hispanic or Latino > 60%	2010 Decennial Census	0.02
Hispanic or Latino > 60%	2000 Decennial Census	0.02
Median household income (USD)	2016-2020 ACS	31,372
Median household income (USD)	2006-2010 ACS	24,869
Median household income (USD)	2000 Decennial Census	39,467
Disadvantaged community	CEJST Ver 1.0 (2022)	0.27

Comparing Regional Subsets of the Final Panel

Table S4 breaks down the mean of all of the variables included in the final panel by census region (U.S. Census Bureau 2010). On average, bridge characteristics are relatively consistent across all regions with the exception that the mean detour length in the Western region is over double the mean detour length in the other regions. Almost all of the bridges in the Northeast and the Midwest experience over 60 freeze-thaw cycles and have an average area temperature less than or equal to 18 degrees Celsius (64 degrees Fahrenheit). Additionally, the Midwest has very few bridges that experience over 127 centimeters (50 inches) of precipitation based on our interpolation of climate data. The Western region has very few bridges associated with a tract with over 50Black or African American population and had little variation in the logarithm of median household income across all records.

Table S4. Mean of Main Analysis Variables for Bridges in each Census Region, All Differences are Significant at the 99.9% Level due to the Number of Records in each Sample

Variable	U.S.	Northeast	South	Midwest	West
Deck Condition	6.56	6.21	6.6	6.65	6.51
Superstructure Condition	6.63	6.23	6.61	6.74	6.76
Substructure Condition	6.49	6.07	6.39	6.67	6.66
Age, years	33.1	35.3	32.6	32.4	34.4
Urban indicator	0.285	0.463	0.278	0.211	0.352
Interstate indicator	0.112	0.139	0.104	0.0885	0.178
Average Daily Traffic (ADT)	8330	11400	8090	5120	15100
% ADT trucks	7.92	7.08	8.02	7.51	9.59
Detour length, kilometers	19.8	16.2	17.9	15.9	39.6
Deck protection indicator	0.352	0.364	0.393	0.381	0.142
Steel structure indicator	0.0969	0.0962	0.0981	0.0711	0.166
Over waterway indicator	0.779	0.671	0.798	0.817	0.716
Average temperature > 18 deg C	0.163	0	0.38	0	0.159
Freeze-thaw cycles > 60	0.701	0.996	0.369	0.998	0.525
Annual precipitation > 127 cm	0.226	0.187	0.503	0.0154	0.0756
% Minority > 50%	0.152	0.093	0.237	0.0414	0.279
Black or African American > 50%	0.0451	0.0144	0.0981	0.0182	0.00022
Hispanic or Latino > 50%	0.0373	0.0188	0.0452	0.00346	0.127
Median income (USD)	31400	36200	28500	32200	32700
Disadvantaged community	0.273	0.124	0.434	0.151	0.305

Alternate Socioeconomic Variables

We sourced the main analysis demographic variables from the 2020 Decennial Redistricting Data (PL 94-171) table P2: "Hispanic or Latino, and Not Hispanic or Latino by Race" and 2016-2020 American Community Survey (ACS) table B19025 for median household income (U.S. Census Bureau 2020; U.S. Census Bureau 2021). Alternatively, we could have used the 2000 Decennial census data or the 2010 Decennial census with 2006-2010 ACS data. For each census year that we collected data, we find that the bridge inspection records coincident with a tract that met the 50% threshold criteria for each demographic variable were positively correlated with the variables derived from an alternate census year (Tables S5, S6, S7, S8). Referring back to the national averages for each variable in Table S3, the total panel records that met this criteria expanded in this period.

Table S5. Correlation between Census Years for Minority Population Over 50% Indicator Variable

	2000	2010	2020
2000	1.00	0.84	0.74
2010	0.84	1.00	0.85
2020	0.74	0.85	1.00

Table S6. Correlation between Census Years for Black or African American Population Over 50% Indicator Variable

	2000	2010	2020
2000	1.00	0.86	0.77
2010	0.86	1.00	0.86
2020	0.77	0.86	1.00

Table S7. Correlation between Census Years for Hispanic or Latino Population Over 50% Indicator Variable

	2000	2010	2020
2000	1.00	0.80	0.72
2010	0.80	1.00	0.86
2020	0.72	0.86	1.00

Table S8. Correlation between Census Years for Median Household Income (USD) Variable

	2000	2010	2020
2000	220651721.80	101651189.44	114082416.01
2010	101651189.44	67179932.01	68962395.36
2020	114082416.01	68962395.36	106914097.24

The distribution of tracts by percent White of one race is bimodal with most tracts having either a high or very low percentage. Instead of transforming the demographic variables which have this bimodal distribution, we included categorical variables for whether the tract intersecting with each bridge had over a certain percentage minority population threshold (any race besides White of one race, not Hispanic or Latino), Black or African American (individuals that identify as Black or African American of any number of races, not Hispanic or Latino), and Hispanic or Latino of any race (U.S. Census Bureau 2021). We created and evaluated models for demographic indicator variables based on three thresholds: over the tract national average, over 50%, and over 60% for each demographic variable.

Table S3 summarizes the sources variable sources and means (by unique inspection records in the panel, not unique structures). For the different census years available, we find that records associated with our race or ethnicity indicator variables increased 0-4% of the panel from the 2000 to the 2020 census data and the tracts that meet this criteria are at least 70% correlated (Tables S6 and S7). The average of the median household income associated with each record varied less predictably, decreasing from the 2000 Decennial Census to the 2006-2010 ACS and then increasing again to the 2016-2020 ACS value.

Naturally, increasing the threshold percentage for assigning the race or ethnicity indicator decreased the number of records associated with the indicator. From Table S3, increasing the threshold from a 50% to a 60% majority resulted in a 2% drop in the records associated with the Black or African American and Hispanic or Latino indicator variables. The 60% threshold resulted in only 3% of bridge records meeting the criteria for Black or African American majority tracts and only 2% of bridge records meeting the criteria for Hispanic or Latino majority tracts. Therefore, we did not attempt increasing the threshold past 60% and further limiting the tracts associated with our indicator variables. Our main analysis uses race and ethnicity thresholds of over 50% for "majority" variable definition, but we also conducted regressions with thresholds of the national average (Table S10) and 60% (Table S11) as robustness checks.

ORDERED PROBIT MODEL WITH RANDOM EFFECTS

By using an ordered model, we implicitly assume that there are latent variables that describe bridge component conditions on a continuum and the discrete ratings recorded by bridge inspectors are indirect measures of this unobserved variable, V. (Washington et al. 2011; Saeed et al. 2017). We incorporate bridge-specific individual effects (η) into the ordered probit model to account for cross-sectional heterogeneity in the panel. (Washington et al. 2011; Lu et al. 2019). Therefore, for each unique bridge structure (n) in each inspection year (t), the latent variable (V_{nt}) for each component is estimated as the linear combination of the regressors ($\mathbf{x}_{nt}$) multiplied by the estimated regression coefficients ($\boldsymbol{\beta}_{nt}$), a bridge-specific individual effect (η_n), and an idiosyncratic error term (ϵ_{nt}) (Saeed et al. 2017).

$$V_{nt} = \boldsymbol{\beta}^T \mathbf{x}_{nt} + \eta_n + \epsilon_{nt} \tag{3}$$

Sources: (Saeed et al. 2017; Croissant and Millo 2018)

We used a probit model under the assumption that the cumulative distribution of the idiosyncratic term is normally distributed (Croissant and Millo 2018; Washington et al. 2011).

$$F(\epsilon) = \int_{-\infty}^{\epsilon} \frac{1}{\sqrt{2\pi}} e^{-0.5t^2} dt \tag{4}$$

Source: (Croissant and Millo 2018)

To replicate previously refined methods and reduce computational requirements, we changed our dependent variable from the 0-9 condition ratings in the NBI to four condition states: state one - failed to fair (0-5), state two - satisfactory (6), state three - good or very good (7-8), and state four - excellent (9), identical to prior work (Saeed et al. 2017). For each unique bridge structure (n) in each inspection year (t), the unobserved latent variable (V_{nt}) is mapped into these four discrete condition states (y_{nt}) in relation to a vector of threshold parameters $\mu = (\mu_0, \mu_1, \mu_2)$.

$$\begin{aligned} P(y_{nt} = 1) &= P(V_{nt} \leq \mu_0) = F(\mu_0 - V_{nt}) \\ P(y_{nt} = 2) &= P(\mu_0 < V_{nt} \leq \mu_1) = F(\mu_1 - V_{nt}) - F(\mu_0 - V_{nt}) \\ P(y_{nt} = 3) &= P(\mu_1 < V_{nt} \leq \mu_2) = F(\mu_2 - V_{nt}) - F(\mu_1 - V_{nt}) \\ P(y_{nt} = 4) &= P(\mu_2 < V_{nt}) = 1 - F(\mu_2 - V_{nt}) \end{aligned} \tag{5}$$

Sources: (Saeed et al. 2017; Croissant and Millo 2018)

Incorporating the definition of the continuous latent variable (V_{nt}) in Equation 3 into Equation 5, the conditional probability that bridge n with individual effect η_n is in condition state y_n for all (T) inspection years and all ($J = 4$) condition states is represented by Equation 6.

$$P(y_n|\eta_n) = \prod_{t=1}^{T} \sum_{j=1}^{J} (y_{nt} = j)[F(\mu_{j-1} - \boldsymbol{\beta}^T \mathbf{x}_{nt} - \eta_n) - F(\mu_{j-2} - \boldsymbol{\beta}^T \mathbf{x}_{nt} - \eta_n)] \tag{6}$$

Source: (Croissant and Millo 2018)

We make the assumption that the bridge-specific individual effects (η_n) are normally distributed with mean zero based on the large number of bridges sampled (Saeed et al. 2017). Assuming random effects is necessary for including time-independent explanatory variables in the model (all explanatory variables other than age and condition) (Washington et al. 2011). Assuming that η is normally distributed with standard deviation σ_η, the unconditional probability used in the ordered probit model becomes:

$$P(y_n) = \int_{-\infty}^{+\infty} \prod_{t=1}^{T} \sum_{j=1}^{J} (y_{nt} = j)[F(\mu_{j-1} - \boldsymbol{\beta}^T \mathbf{x}_{nt} - \eta) - F(\mu_{j-2} - \boldsymbol{\beta}^T \mathbf{x}_{nt} - \eta)] \frac{1}{\sigma_\eta \sqrt{2\pi}} e^{-0.5(\frac{\eta}{\sigma_\eta})^2} d\eta \tag{7}$$

Source: (Croissant and Millo 2018)

This integral cannot be evaluated analytically, so we use a change of variable $\omega = \frac{\eta}{\sigma_\eta \sqrt{2}}$, to get the equation in an appropriate form for approximation with Gauss-Hermite quadrature (Blevins 2022):

$$P(y_n) = \frac{1}{\sqrt{\pi}} \int_{-\infty}^{+\infty} \prod_{t=1}^{T} \sum_{j=1}^{J} (y_{nt} = j)[F(\mu_{j-1} - \boldsymbol{\beta}^T \mathbf{x}_{nt} - \sigma_\eta \omega \sqrt{2}) - F(\mu_{j-2} - \boldsymbol{\beta}^T \mathbf{x}_{nt} - \sigma_\eta \omega \sqrt{2})] e^{-\omega^2} d\omega \tag{8}$$

Source: (Croissant and Millo 2018)

The Gauss-Hermite quadrature approximation, yields:

$$P(y_n) \approx \frac{1}{\sqrt{\pi}} \sum_{r=1}^{R} \prod_{t=1}^{T} \sum_{j=1}^{J} (y_{nt} = j)[F(\mu_{j-1} - \boldsymbol{\beta}^T \mathbf{x}_{nt} - \sigma_\eta \omega_r \sqrt{2}) - F(\mu_{j-2} - \boldsymbol{\beta}^T \mathbf{x}_{nt} - \sigma_\eta \omega_r \sqrt{2})] e^{-\omega_r^2} d\omega \tag{9}$$

Source: (Croissant and Millo 2018)

There are four condition states, $j \in (1, 2, 3, 4)$ and we set $\mu_0 = 0$ (the threshold between states one and two) without loss of generality because our regressors ($\mathbf{x}_{nt}$) contain an intercept (Washington et al. 2011). As defined in Equation 5, the condition cannot be lower than state one ($\mu = -\infty$) or higher than state four ($\mu = +\infty$). Thus, only the interior thresholds between states two and three (μ_1) and between states three and four (μ_2) are estimated by the model in conjunction with the regression coefficients ($\boldsymbol{\beta}$) (Saeed et al. 2017). We implemented this method using the Panel Generalized Linear Models "pglm" package for R (Croissant 2021).

$$\begin{aligned} P(y_n) \approx \frac{1}{\sqrt{\pi}} \sum_{r=1}^{R} \prod_{t=1}^{T} [(y_{nt} = 1) F(-\boldsymbol{\beta}^T \mathbf{x}_{nt} - \sigma_\eta \omega_r \sqrt{2}) \\ +(y_{nt} = 2)[F(\mu_1 - \boldsymbol{\beta}^T \mathbf{x}_{nt} - \sigma_\eta \omega_r \sqrt{2}) - F(-\boldsymbol{\beta}^T \mathbf{x}_{nt} - \sigma_\eta \omega_r \sqrt{2})] \\ +(y_{nt} = 3)[F(\mu_2 - \boldsymbol{\beta}^T \mathbf{x}_{nt} - \sigma_\eta \omega_r \sqrt{2}) - F(\mu_1 - \boldsymbol{\beta}^T \mathbf{x}_{nt} - \sigma_\eta \omega_r \sqrt{2})] \\ +(y_{nt} = 4)[1 - F(\mu_2 - \boldsymbol{\beta}^T \mathbf{x}_{nt} - \sigma_\eta \omega_r \sqrt{2})]] e^{-\omega_r^2} d\omega \end{aligned} \tag{10}$$

Sources: (Croissant and Millo 2018; Saeed et al. 2017)

ROBUSTNESS CHECKS

Replication of Saeed et al. (2017, Table 5)

Our methodology follows from an ordered probit with random effects model used to analyze Indiana bridges with records from 1992 to 2014 (Saeed et al. 2017). To check our implementation of their methodology, we replicated all aspects of Saeed et al. (2017) with the exception of the high-freeze thaw cycle variable and intervention variables for past repairs, rehabilitations, and replacements based on the history of component conditions improving. Table S9 displays the results of replicating Saeed et al.'s (2017) models by subsetting our final panel to Indiana State Highway bridges (NBI variable 21: Maintenance Authority) inspected before 2015, changing the temperature threshold to 11 degrees Celsius (52 degrees Fahrenheit), and omitting the intervention and freeze-thaw cycle variables. In contrast with previous results from Saeed et al. (2017, Table 5), we did not have consistent and robust results for urban bridges across all models and we obtained positive coefficients for steel bridges and bridges over waterways. From our replication, we conclude that our selection of physical and environmental variables and our model specification is robust and consistent with previous work.

Table S9. Replication of Saeed et al. (2017, Table 5), Panel Subset of 1990-2014 Inspections of State Highway Bridges in Indiana, Comparison of Ordered Probit Random Effects Models, Component Condition States 1-4, Warm Region Indicator Changed to 52 degrees Fahrenheit (50% of Subset). Excludes Freeze-thaw Cycles > 60 (100% of Subset) and Excludes Maintenance Intervention Indicators.

	Deck	Superstructure	Substructure
Intercept	$2.112\ (0.025)^{***}$	$2.461\ (0.025)^{***}$	$2.473\ (0.028)^{***}$
Age, years	$-0.046\ (0.001)^{***}$	$-0.045\ (0.001)^{***}$	$-0.041\ (0.001)^{***}$
Interstate indicator	$-0.112\ (0.020)^{***}$	$-0.039\ (0.020)$	
Urban indicator	$-0.059\ (0.017)^{***}$	$0.084\ (0.019)^{***}$	$0.038\ (0.022)$
Average temperature > 11 deg C	$0.376\ (0.016)^{***}$	$0.193\ (0.016)^{***}$	$0.186\ (0.018)^{***}$
Deck protection indicator	$0.459\ (0.017)^{***}$		
Steel structure indicator		$0.152\ (0.047)^{**}$	
Bridge over waterway indicator		$0.170\ (0.019)^{***}$	$0.093\ (0.021)^{***}$
μ_1	$1.298\ (0.009)^{***}$	$1.172\ (0.009)^{***}$	$1.336\ (0.011)^{***}$
μ_2	$4.447\ (0.020)^{***}$	$4.679\ (0.022)^{***}$	$5.064\ (0.024)^{***}$
σ_η	$1.035\ (0.010)^{***}$	$1.078\ (0.011)^{***}$	$1.284\ (0.010)^{***}$
Log Likelihood	−45789.852	−40364.698	−35250.950
AIC	91597.703	80749.396	70517.900

$^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$

Models with Alternate Threshold Socioeconomic Variables

We chose a 50% threshold to determine whether a tract had a minority of White individuals, a majority of Black or African American individuals, or a majority of Hispanic or Latino individuals. Alternatively, we considered lowering the threshold to the national average so that more tracts meet the criteria or increasing the threshold to sixty percent which stabilizes the measure across the 2000, 2010, and 2020 Decennial census years. We replicated the models shown in Table 4 of the article using the national average threshold and find that the negative effect size is larger for the Black or African American indicator and the positive effect size is smaller for the Hispanic or Latino indicator (Table S10). Using a sixty percent threshold (Table S11), we find a somewhat smaller negative effect size for the Black or African American indicator and a similar positive effect size for the Hispanic or Latino indicator when compared to the 50% threshold variables in Table 4. In summary, for the full panel, the results for the race and ethnicity indicators are robust and consistent in direction even when the threshold for selecting these binary indicators is changed from the national average to sixty percent of the tract population.

Table S10. National Average Threshold for Race and Ethnicity Indicators, Comparison of Ordered Probit Random Effects Models, Component Condition States 1-4, 2020 Income, Race, and Ethnicity Indicators

	Deck	Superstructure	Substructure
Intercept	1.641 (0.043)***	1.744 (0.044)***	1.469 (0.047)***
Age, years	-0.038 ($5 \cdot 10^{-5}$)***	-0.041 ($5 \cdot 10^{-5}$)***	-0.037 ($5 \cdot 10^{-5}$)***
Urban indicator	-0.118 (0.003)***	-0.039 (0.003)***	0.033 (0.004)***
Interstate indicator	-0.116 (0.005)***	-0.107 (0.005)***	-0.091 (0.006)***
Average Daily Traffic (ADT)	$-2 \cdot 10^{-6}$ ($7 \cdot 10^{-8}$)***	$-4 \cdot 10^{-6}$ ($8 \cdot 10^{-8}$)***	$-3 \cdot 10^{-6}$ ($1 \cdot 10^{-7}$)***
% ADT trucks	-0.009 ($2 \cdot 10^{-4}$)***	-0.003 ($2 \cdot 10^{-4}$)***	$3 \cdot 10^{-4}$ ($2 \cdot 10^{-4}$)
Detour length, kilometers	-0.002 ($2 \cdot 10^{-5}$)***	-0.001 ($2 \cdot 10^{-5}$)***	$4 \cdot 10^{-4}$ ($2 \cdot 10^{-5}$)
Deck protection indicator	0.218 (0.002)***		
Steel structure indicator		0.016 (0.004)***	0.099 (0.005)***
Bridge over waterway indicator		-0.071 (0.004)***	-0.131 (0.004)***
Average temperature > 18 deg C	0.139 (0.004)***	0.106 (0.004)***	0.052 (0.005)***
Annual freeze-thaw cycles > 60	-0.080 (0.004)***	-0.137 (0.004)***	-0.113 (0.004)***
Annual precipitation > 127 cm	0.020 (0.003)***	-0.064 (0.003)***	-0.074 (0.003)***
Logarithm of median income	0.103 (0.004)***	0.122 (0.004)***	0.124 (0.005)***
Black or African American > 13%	-0.108 (0.003)***	-0.120 (0.003)***	-0.175 (0.004)***
Hispanic or Latino > 19%	0.035 (0.004)***	0.076 (0.004)***	0.099 (0.004)***
μ_1	0.899 (0.001)***	0.863 (0.001)***	0.905 (0.001)***
μ_2	3.300 (0.001)***	3.306 (0.001)***	3.282 (0.001)***
σ_η	1.255 (0.001)***	1.293 (0.001)***	1.313 (0.001)***
Log Likelihood	-4991078	-4707984	-4766942
AIC	9982191	9416003	9533921

$^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$

Table S11. Sixty Percent Threshold for Race and Ethnicity Indicators, Comparison of Ordered Probit Random Effects Models, Component Condition States 1-4, 2020 Income, Race, and Ethnicity Indicators

	Deck	Superstructure	Substructure
Intercept	$1.286\ (0.042)^{***}$	$1.330\ (0.044)^{***}$	$0.942\ (0.044)^{***}$
Age, years	$-0.038\ (5 \cdot 10^{-5})^{***}$	$-0.041\ (5 \cdot 10^{-5})^{***}$	$-0.039\ (4 \cdot 10^{-5})^{***}$
Urban indicator	$-0.133\ (0.003)^{***}$	$-0.052\ (0.003)^{***}$	$0.017\ (0.003)^{***}$
Interstate indicator	$-0.122\ (0.005)^{***}$	$-0.111\ (0.005)^{***}$	$-0.097\ (0.005)^{***}$
Average Daily Traffic (ADT)	$-1 \cdot 10^{-6}\ (7 \cdot 10^{-8})^{***}$	$-4 \cdot 10^{-6}\ (9 \cdot 10^{-8})^{***}$	$-3 \cdot 10^{-6}\ (9 \cdot 10^{-8})^{***}$
% ADT trucks	$-0.012\ (2 \cdot 10^{-4})^{***}$	$-0.003\ (2 \cdot 10^{-4})^{***}$	$-0.026\ (2 \cdot 10^{-4})^{***}$
Detour length, kilometers	$-0.002\ (2 \cdot 10^{-5})^{***}$	$-0.001\ (2 \cdot 10^{-5})^{***}$	$-1 \cdot 10^{-6}\ (2 \cdot 10^{-5})$
Deck protection indicator	$0.215\ (0.002)^{***}$		
Steel structure indicator		$0.018\ (0.004)^{***}$	$0.101\ (0.004)^{***}$
Bridge over waterway indicator		$-0.065\ (0.004)^{***}$	$-0.121\ (0.004)^{***}$
Average temperature > 18 deg C	$0.138\ (0.004)^{***}$	$0.105\ (0.004)^{***}$	$0.053\ (0.004)^{***}$
Annual freeze-thaw cycles > 60	$-0.059\ (0.004)^{***}$	$-0.116\ (0.004)^{***}$	$-0.082\ (0.004)^{***}$
Annual precipitation > 127 cm	$0.003\ (0.003)$	$-0.085\ (0.003)^{***}$	$-0.104\ (0.003)^{***}$
Logarithm of median income	$0.134\ (0.004)^{***}$	$0.160\ (0.004)^{***}$	$0.196\ (0.004)^{***}$
Black or African American > 60%	$-0.029\ (0.008)^{***}$	$-0.035\ (0.008)^{***}$	$-0.086\ (0.008)^{***}$
Hispanic or Latino > 60%	$0.087\ (0.008)^{***}$	$0.184\ (0.008)^{***}$	$0.215\ (0.009)^{***}$
μ_1	$0.897\ (0.001)^{***}$	$0.863\ (0.001)^{***}$	$0.965\ (0.001)^{***}$
μ_2	$3.297\ (0.001)^{***}$	$3.305\ (0.001)^{***}$	$3.367\ (0.001)^{***}$
σ_η	$1.256\ (0.001)^{***}$	$1.293\ (0.001)^{***}$	$1.296\ (0.001)^{***}$
Log Likelihood	−4994105	−4709581	−4732726
AIC	9988243	9419198	9465489

$^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$

Models with Alternate Census Year Socioeconomic Variables

From Tables S8, S6, and S7, the socioeconomic variables are not perfectly correlated in census years 2000, 2010, and 2020. We assumed that this is mostly due to national trends and would not affect the overall distribution of these indicators. To test this assumption, we compared models with 2000 Decennial census data, 2010 Decennial census and 2006-2010 ACS data, and 2020 Decennial census and 2016-2020 ACS data for deck (Table S24), superstructure (Table S25), and substructure (S26) condition. We find that the coefficients for logarithm of median household income and majority Hispanic or Latino tracts are consistently positive and the coefficients for majority Black or African American tracts are consistently negative across census years and bridge components.

Table S12. Comparison of Census Years, Ordered Probit Random Effects Models, Deck Condition States 1-4

	2000	2010	2020
Intercept	1.403 (0.040)***	1.390 (0.042)***	1.336 (0.043)***
Age, years	-0.038 $(5 \cdot 10^{-5})^{***}$	-0.038 $(5 \cdot 10^{-5})^{***}$	-0.038 $(5 \cdot 10^{-5})^{***}$
Urban indicator	-0.131 (0.003)***	-0.131 (0.003)***	-0.132 (0.003)***
Interstate indicator	-0.119 (0.005)***	-0.120 (0.005)***	-0.121 (0.005)***
Average Daily Traffic (ADT)	$-1 \cdot 10^{-6}$ $(7 \cdot 10^{-8})^{***}$	$-1 \cdot 10^{-6}$ $(7 \cdot 10^{-8})^{***}$	$-1 \cdot 10^{-6}$ $(7 \cdot 10^{-8})^{***}$
% ADT trucks	-0.011 $(2 \cdot 10^{-4})^{***}$	-0.011 $(2 \cdot 10^{-4})^{***}$	-0.012 $(2 \cdot 10^{-4})^{***}$
Detour length, kilometers	-0.002 $(2 \cdot 10^{-5})^{***}$	-0.002 $(2 \cdot 10^{-5})^{***}$	-0.002 $(2 \cdot 10^{-5})^{***}$
Deck protection indicator	0.214 (0.002)***	0.215 (0.002)***	0.215 (0.002)***
Average temperature > 18 deg C	0.143 (0.004)***	0.138 (0.004)***	0.137 (0.004)***
Annual freeze-thaw cycles > 60	-0.063 (0.004)***	-0.062 (0.004)***	-0.061 (0.004)***
Annual precipitation > 127 cm	0.002 (0.003)	0.005 (0.003)	0.006 (0.003)
Logarithm of median income	0.121 (0.004)***	0.127 (0.004)***	0.130 (0.004)***
Black or African American > 50%	-0.073 (0.006)***	-0.074 (0.007)***	-0.056 (0.007)***
Hispanic or Latino > 50%	0.043 (0.008)***	0.067 (0.007)***	0.076 (0.007)***
μ_1	0.897 (0.001)***	0.898 (0.001)***	0.897 (0.001)***
μ_2	3.296 (0.001)***	3.298 (0.001)***	3.297 (0.001)***
σ_η	1.256 (0.001)***	1.256 (0.001)***	1.256 (0.001)***
Log Likelihood	-4994542	-4992546	-4993917
AIC	9989119	9985125	9987868

$^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$

Table S13. Comparison of Census Years, Ordered Probit Random Effects Models, Superstructure Condition States 1-4

	2000	2010	2020
Intercept	$1.263\ (0.041)^{***}$	$1.386\ (0.042)^{***}$	$1.330\ (0.043)^{***}$
Age, years	$-0.041\ (5 \cdot 10^{-5})^{***}$	$-0.041\ (5 \cdot 10^{-5})^{***}$	$-0.041\ (5 \cdot 10^{-5})^{***}$
Urban indicator	$-0.054\ (0.003)^{***}$	$-0.052\ (0.003)^{***}$	$-0.053\ (0.003)^{***}$
Interstate indicator	$-0.110\ (0.005)^{***}$	$-0.110\ (0.005)^{***}$	$-0.111\ (0.005)^{***}$
Average Daily Traffic (ADT)	$-4 \cdot 10^{-6}\ (8 \cdot 10^{-8})^{***}$	$-4 \cdot 10^{-6}\ (9 \cdot 10^{-8})^{***}$	$-4 \cdot 10^{-6}\ (8 \cdot 10^{-8})^{***}$
% ADT trucks	$-0.004\ (2 \cdot 10^{-4})^{***}$	$-0.003\ (2 \cdot 10^{-4})^{***}$	$-0.003\ (2 \cdot 10^{-4})^{***}$
Detour length, kilometers	$-0.001\ (2 \cdot 10^{-5})^{***}$	$-0.001\ (2 \cdot 10^{-5})^{***}$	$-0.001\ (2 \cdot 10^{-5})^{***}$
Steel structure indicator	$0.018\ (0.004)^{***}$	$0.018\ (0.004)^{***}$	$0.018\ (0.004)^{***}$
Bridge over waterway indicator	$-0.067\ (0.004)^{***}$	$-0.066\ (0.004)^{***}$	$-0.065\ (0.004)^{***}$
Average temperature > 18 deg C	$0.111\ (0.004)^{***}$	$0.104\ (0.004)^{***}$	$0.102\ (0.004)^{***}$
Annual freeze-thaw cycles > 60	$-0.118\ (0.004)^{***}$	$-0.117\ (0.004)^{***}$	$-0.115\ (0.004)^{***}$
Annual precipitation > 127 cm	$-0.085\ (0.003)^{***}$	$-0.083\ (0.003)^{***}$	$-0.081\ (0.003)^{***}$
Logarithm of median income	$0.164\ (0.004)^{***}$	$0.158\ (0.004)^{***}$	$0.160\ (0.004)^{***}$
Black or African American > 50%	$-0.054\ (0.006)^{***}$	$-0.059\ (0.006)^{***}$	$-0.046\ (0.006)^{***}$
Hispanic or Latino > 50%	$0.158\ (0.008)^{***}$	$0.163\ (0.008)^{***}$	$0.171\ (0.007)^{***}$
μ_1	$0.862\ (0.001)^{***}$	$0.863\ (0.001)^{***}$	$0.863\ (0.001)^{***}$
μ_2	$3.304\ (0.001)^{***}$	$3.306\ (0.001)^{***}$	$3.305\ (0.001)^{***}$
σ_η	$1.293\ (0.001)^{***}$	$1.292\ (0.001)^{***}$	$1.293\ (0.001)^{***}$
Log Likelihood	−4710871	−4708425	−4710078
AIC	9421777	9416886	9420193

$^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$

Table S14. Comparison of Census Years, Ordered Probit Random Effects Models, Substructure Condition States 1-4

	2000	2010	2020
Intercept	$0.774\ (0.037)^{***}$	$1.027\ (0.045)^{***}$	$0.966\ (0.046)^{***}$
Age, years	$-0.025\ (4 \cdot 10^{-5})^{***}$	$-0.037\ (4 \cdot 10^{-5})^{***}$	$-0.037\ (5 \cdot 10^{-5})^{***}$
Urban indicator	$0.006\ (0.003)^{*}$	$0.015\ (0.003)^{***}$	$0.015\ (0.003)^{***}$
Interstate indicator	$-0.092\ (0.004)^{***}$	$-0.095\ (0.005)^{***}$	$-0.096\ (0.005)^{***}$
Average Daily Traffic (ADT)	$-6 \cdot 10^{-7}\ (5 \cdot 10^{-8})^{***}$	$-3 \cdot 10^{-6}\ (1 \cdot 10^{-7})^{***}$	$-3 \cdot 10^{-6}\ (1 \cdot 10^{-7})^{***}$
% ADT trucks	$0.054\ (1 \cdot 10^{-4})^{***}$	$-0.008\ (2 \cdot 10^{-4})^{***}$	$-0.011\ (2 \cdot 10^{-4})^{***}$
Detour length, kilometers	$7 \cdot 10^{-4}\ (2 \cdot 10^{-5})^{***}$	$7 \cdot 10^{-4}\ (2 \cdot 10^{-5})^{***}$	$5 \cdot 10^{-4}\ (2 \cdot 10^{-5})^{***}$
Steel structure indicator	$0.102\ (0.004)^{***}$	$0.101\ (0.004)^{***}$	$0.101\ (0.004)^{***}$
Bridge over waterway indicator	$-0.135\ (0.003)^{***}$	$-0.124\ (0.004)^{***}$	$-0.123\ (0.004)^{***}$
Average temperature > 18 deg C	$0.056\ (0.004)^{***}$	$0.051\ (0.004)^{***}$	$0.049\ (0.004)^{***}$
Annual freeze-thaw cycles > 60	$-0.091\ (0.003)^{***}$	$-0.086\ (0.004)^{***}$	$-0.084\ (0.004)^{***}$
Annual precipitation > 127 cm	$-0.104\ (0.003)^{***}$	$-0.101\ (0.003)^{***}$	$-0.098\ (0.003)^{***}$
Logarithm of median income	$0.071\ (0.003)^{***}$	$0.169\ (0.004)^{***}$	$0.175\ (0.004)^{***}$
Black or African American > 50%	$-0.100\ (0.006)^{***}$	$-0.116\ (0.007)^{***}$	$-0.100\ (0.007)^{***}$
Hispanic or Latino > 50%	$0.183\ (0.006)^{***}$	$0.191\ (0.008)^{***}$	$0.197\ (0.008)^{***}$
μ_1	$0.922\ (0.001)^{***}$	$0.913\ (0.001)^{***}$	$0.921\ (0.001)^{***}$
μ_2	$3.289\ (0.001)^{***}$	$3.291\ (0.001)^{***}$	$3.303\ (0.001)^{***}$
σ_η	$1.315\ (0.001)^{***}$	$1.311\ (0.001)^{***}$	$1.309\ (0.001)^{***}$
Log Likelihood	−4825682	−4761727	−4756456
AIC	9651400	9523490	9512948

$^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$

Models by Census Region

We repeated our national analysis for each of the census regions (U.S. Census Bureau 2010) and the results are presented in Tables S15, S16, S17, and S18. When compared to the results of the models in Table 4 of the main paper, the Northeast region (Table S15) has a reversal of the direction of the interstate and steel structure dummy variable coefficients across models for all component conditions. The magnitude and direction of the coefficient for logarithm of median household income is consistent and robust between Table 4 and Table S15, but the coefficients for the race and ethnicity variables are not robust across all models. Average temperature was not included in the model for the Northeast because no records met this criteria as shown in Table S4.

For the Southern region (Table S16), we find that the results are robust and consistent in relative magnitude and direction with the national models (Table 4) with the exception of the coefficients for the urban indicator and high precipitation in the deck and superstructure models, ADT in the superstructure model, and percent ADT trucks and detour length in all models. In fact, this is the only census region with similar results to the national analysis in terms of the logarithm of median household income, majority Black or African American tracts, and majority Hispanic or Latino tracts.

Noting that the intercepts for the Midwestern region models (Table S17) are at least one unit above all of the national model intercepts, we find that almost all of the coefficients are negative or very weakly positive with the exception of detour length, deck protection, steel structure, and logarithm of median household income. The coefficient for Hispanic or Latino majority tracts is also positive across all models which is not consistent with the national analysis.

Logarithm of median household income and Black or African American majority tracts could not be included in the Western region models because convergence was not achieved when they were included (Table S18). The only records in the West that met the Black or African American population over 50% criteria were near San Francisco, Los Angeles, or Tucson. For the Hispanic or Latino majority tract indicator, the model for deck condition had a negative coefficient, unlike the national analysis in Table 4 of the main paper, and the superstructure and substructure models were positive, but of a smaller magnitude than the national analysis.

Table S15. Northeast Region, Comparison of Ordered Probit Random Effects Models, Component Condition States 1-4, 2020 Income, Race, and Ethnicity Indicators, Excludes Average temperature > 18 deg C

	Deck	Superstructure	Substructure
Intercept	0.066 (0.119)	0.478 (0.100)***	−0.456 (0.089)***
Age, years	−0.031 ($1 \cdot 10^{-4}$)***	−0.028 ($1 \cdot 10^{-4}$)***	−0.021 ($9 \cdot 10^{-5}$)***
Urban indicator	−0.061 (0.007)***	−0.017 (0.007)**	0.006 (0.005)
Interstate indicator	0.125 (0.012)***	0.050 (0.010)***	0.011 (0.009)
Average Daily Traffic (ADT)	$2 \cdot 10^{-7}$ ($2 \cdot 10^{-7}$)	$3 \cdot 10^{-6}$ ($1 \cdot 10^{-7}$)***	$2 \cdot 10^{-6}$ ($1 \cdot 10^{-7}$)***
% ADT trucks	−0.006 (0.001)***	−0.012 (0.001)***	0.052 ($4 \cdot 10^{-4}$)***
Detour length, kilometers	$1 \cdot 10^{-4}$ ($8 \cdot 10^{-5}$)	$5 \cdot 10^{-4}$ ($7 \cdot 10^{-5}$)***	0.002 ($6 \cdot 10^{-5}$)***
Deck protection indicator	0.350 (0.007)***		
Steel structure indicator		−0.401 (0.013)***	−0.319 (0.009)***
Bridge over waterway indicator		−0.106 (0.007)***	−0.084 (0.006)***
Annual freeze-thaw cycles > 60	−0.071 (0.037)	−0.162 (0.040)***	0.046 (0.035)
Annual precipitation > 127 cm	0.086 (0.008)***	0.048 (0.007)***	0.052 (0.006)***
Logarithm of median income	0.162 (0.011)***	0.121 (0.009)***	0.128 (0.008)***
Black or African American > 50%	−0.071 (0.040)	−0.023 (0.023)	−0.074 (0.023)**
Hispanic or Latino > 50%	−0.018 (0.035)	−0.060 (0.022)**	−0.050 (0.018)**
μ_1	1.006 (0.002)***	0.766 (0.002)***	1.350 (0.003)***
μ_2	3.055 (0.004)***	2.725 (0.004)***	3.397 (0.004)***
σ_η	1.215 (0.003)***	1.321 (0.003)***	1.118 (0.002)***
Log Likelihood	−647282	−647784	−649620
AIC	1294596	1295601	1299274

$^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$

Table S16. Southern Region, Comparison of Ordered Probit Random Effects Models, Component Condition States 1-4, 2020 Income, Race, and Ethnicity Indicators

	Deck	Superstructure	Substructure
Intercept	$0.926\ (0.048)^{***}$	$1.565\ (0.053)^{***}$	$1.346\ (0.059)^{***}$
Age, years	$-0.017\ (1 \cdot 10^{-4})^{***}$	$-0.026\ (9 \cdot 10^{-5})^{***}$	$-0.035\ (9 \cdot 10^{-5})^{***}$
Urban indicator	$0.039\ (0.003)^{***}$	$0.130\ (0.004)^{***}$	$0.188\ (0.005)^{***}$
Interstate indicator	$-0.155\ (0.006)^{***}$	$-0.124\ (0.006)^{***}$	$-0.054\ (0.007)^{***}$
Average Daily Traffic (ADT)	$-7 \cdot 10^{-7}\ (8 \cdot 10^{-8})^{***}$	$6 \cdot 10^{-7}\ (1 \cdot 10^{-7})^{***}$	$-4 \cdot 10^{-6}\ (1 \cdot 10^{-7})^{***}$
% ADT trucks	$4 \cdot 10^{-4}\ (2 \cdot 10^{-4})^{*}$	$0.006\ (2 \cdot 10^{-4})^{***}$	$0.026\ (3 \cdot 10^{-4})^{***}$
Detour length, kilometers	$1 \cdot 10^{-4}\ (3 \cdot 10^{-5})^{**}$	$8 \cdot 10^{-4}\ (3 \cdot 10^{-5})^{***}$	$-4 \cdot 10^{-4}\ (4 \cdot 10^{-5})^{***}$
Deck protection indicator	$0.148\ (0.003)^{***}$		
Steel structure indicator		$0.077\ (0.007)^{***}$	$0.172\ (0.007)^{***}$
Bridge over waterway indicator		$-0.144\ (0.004)^{***}$	$-0.263\ (0.005)^{***}$
Average temperature > 18 deg C	$0.206\ (0.004)^{***}$	$0.163\ (0.004)^{***}$	$0.128\ (0.004)^{***}$
Annual freeze-thaw cycles > 60	$-0.010\ (0.004)^{*}$	$-0.099\ (0.004)^{***}$	$-0.002\ (0.005)$
Annual precipitation > 127 cm	$0.071\ (0.003)^{***}$	$0.114\ (0.003)^{***}$	$0.152\ (0.004)^{***}$
Logarithm of median income	$0.073\ (0.005)^{***}$	$0.027\ (0.005)^{***}$	$0.080\ (0.006)^{***}$
Black or African American > 50%	$-0.040\ (0.005)^{***}$	$-0.037\ (0.005)^{***}$	$-0.085\ (0.006)^{***}$
Hispanic or Latino > 50%	$0.222\ (0.007)^{***}$	$0.202\ (0.008)^{***}$	$0.198\ (0.011)^{***}$
μ_1	$0.895\ (0.001)^{***}$	$0.863\ (0.001)^{***}$	$1.088\ (0.001)^{***}$
μ_2	$3.650\ (0.003)^{***}$	$3.581\ (0.003)^{***}$	$3.650\ (0.003)^{***}$
σ_η	$1.300\ (0.002)^{***}$	$1.320\ (0.002)^{***}$	$1.323\ (0.002)^{***}$
Log Likelihood	-1674911	-1645711	-1663561
AIC	3349857	3291459	3327158

$^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$

Table S17. Midwestern Region, Comparison of Ordered Probit Random Effects Models, Component Condition States 1-4, 2020 Income, Race, and Ethnicity Indicators, Excludes Average temperature > 18 deg C

	Deck	Superstructure	Substructure
Intercept	2.365 (0.088)***	2.427 (0.078)***	1.970 (0.076)***
Age, years	−0.039 ($7 \cdot 10^{-5}$)***	−0.030 ($7 \cdot 10^{-5}$)***	−0.032 ($7 \cdot 10^{-5}$)***
Urban indicator	−0.228 (0.005)***	−0.140 (0.005)***	−0.040 (0.005)***
Interstate indicator	−0.144 (0.008)***	−0.175 (0.008)***	−0.152 (0.008)***
Average Daily Traffic (ADT)	$-3 \cdot 10^{-6}$ ($1 \cdot 10^{-7}$)***	$2 \cdot 10^{-6}$ ($2 \cdot 10^{-7}$)***	$-1 \cdot 10^{-6}$ ($2 \cdot 10^{-7}$)***
% ADT trucks	−0.001 ($2 \cdot 10^{-4}$)***	−0.010 ($2 \cdot 10^{-4}$)***	0.002 ($2 \cdot 10^{-4}$)***
Detour length, kilometers	0.001 ($4 \cdot 10^{-5}$)***	0.001 ($4 \cdot 10^{-5}$)***	0.002 ($5 \cdot 10^{-5}$)***
Deck protection indicator	0.189 (0.004)***		
Steel structure indicator		0.029 (0.006)***	0.098 (0.006)***
Bridge over waterway indicator		−0.048 (0.005)***	−0.073 (0.005)***
Annual freeze-thaw cycles > 60	−0.223 (0.041)***	−0.388 (0.045)***	−0.056 (0.039)
Annual precipitation > 127 cm	0.022 (0.015)	−0.102 (0.011)***	−0.047 (0.012)***
Logarithm of median income	0.059 (0.008)***	0.001 (0.006)	0.014 (0.006)*
Black or African American > 50%	−0.146 (0.013)***	−0.118 (0.013)***	−0.159 (0.014)***
Hispanic or Latino > 50%	−0.076 (0.028)**	−0.187 (0.028)***	−0.177 (0.031)***
μ_1	1.113 (0.001)***	0.843 (0.001)***	0.823 (0.001)***
μ_2	3.694 (0.003)***	3.064 (0.002)***	2.970 (0.002)***
σ_η	1.071 (0.001)***	1.316 (0.002)***	1.351 (0.002)***
Log Likelihood	−1839796	−1830998	−1840847.286
AIC	3679624	3662031	3681729

$^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$

Table S18. Western Region, Comparison of Ordered Probit Random Effects Models, Component Condition States 1-4, 2020 Income, Race, and Ethnicity Indicators, Excludes Income (little variability) and Black or African American Community Indicator (only 0.02%).

	Deck	Superstructure	Substructure
Intercept	$1.760\ (0.008)^{***}$	$2.306\ (0.011)^{***}$	$2.386\ (0.011)^{***}$
Age, years	$-0.018\ (1 \cdot 10^{-4})^{***}$	$-0.023\ (1 \cdot 10^{-4})^{***}$	$-0.024\ (2 \cdot 10^{-4})^{***}$
Urban indicator	$-0.173\ (0.007)^{***}$	$-0.026\ (0.007)^{***}$	$0.108\ (0.007)^{***}$
Interstate indicator	$-0.113\ (0.008)^{***}$	$-0.038\ (0.009)^{***}$	$0.012\ (0.009)$
Average Daily Traffic (ADT)	$2 \cdot 10^{-6}\ (9 \cdot 10^{-8})^{***}$	$-4 \cdot 10^{-8}\ (8 \cdot 10^{-9})$	$-7 \cdot 10^{-7}\ (9 \cdot 10^{-8})^{***}$
% ADT trucks	$0.014\ (3 \cdot 10^{-4})^{***}$	$0.009\ (3 \cdot 10^{-4})^{***}$	$0.013\ (3 \cdot 10^{-4})^{***}$
Detour length, kilometers	$0.001\ (2 \cdot 10^{-5})^{***}$	$0.001\ (3 \cdot 10^{-5})^{***}$	$0.001\ (3 \cdot 10^{-5})^{***}$
Deck protection indicator	$0.197\ (0.008)^{***}$		
Steel structure indicator		$0.042\ (0.008)^{***}$	$0.087\ (0.008)^{***}$
Bridge over waterway indicator		$-0.120\ (0.007)^{***}$	$-0.270\ (0.007)^{***}$
Average temperature > 18 deg C	$0.038\ (0.009)^{***}$	$0.214\ (0.009)^{***}$	$0.204\ (0.009)^{***}$
Annual freeze-thaw cycles > 60	$-0.113\ (0.007)^{***}$	$-0.244\ (0.007)^{***}$	$-0.365\ (0.007)^{***}$
Annual precipitation > 127 cm	$0.135\ (0.011)^{***}$	$-0.044\ (0.011)^{***}$	$-0.124\ (0.011)^{***}$
Hispanic or Latino > 50%	$-0.065\ (0.009)^{***}$	$0.072\ (0.009)^{***}$	$0.060\ (0.009)^{***}$
μ_1	$0.819\ (0.002)^{***}$	$0.821\ (0.002)^{***}$	$0.829\ (0.002)^{***}$
μ_2	$3.854\ (0.005)^{***}$	$4.118\ (0.005)^{***}$	$4.288\ (0.005)^{***}$
σ_η	$1.200\ (0.003)^{***}$	$1.216\ (0.003)^{***}$	$1.252\ (0.004)^{***}$
Log Likelihood	−670160.332	−539231.098	−527375.453
AIC	1340350.664	1078494.196	1054782.907

$^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$

Binomial Probit Models for Satisfactory or Better Component Condition

We find that the coefficient values for the demographic variables are consistent in direction and statistically significant when we reduce the complexity of the the model from an ordinal model to a binomial model. The dependent variable in our main analysis changes the 0-9 condition ratings in the NBI to four condition states: state 1 - poor (1-5), state 2 - fair (6), state 3 - good (7-8), and state 4 - excellent (9), identical to prior work (Saeed et al. 2017). Table S19 shows the results from a binomial probit model where the binomial condition state is false for poor condition (1-5) and true for bridges in better condition (6-9).

Table S19. Comparison of Binomial Probit Random Effects Models, Component Condition Rating > 6 (State > 2), 2020 Income, Race, and Ethnicity Indicators

	Deck	Superstructure	Substructure
Intercept	$0.914\ (0.072)^{***}$	$0.951\ (0.080)^{***}$	$0.508\ (0.078)^{***}$
Age, years	$-0.034\ (\cdot 10^{-4})^{***}$	$-0.035\ (\cdot 10^{-4})^{***}$	$-0.043\ (\cdot 10^{-4})^{***}$
Urban indicator	$-0.076\ (0.005)^{***}$	$-0.043\ (0.006)^{***}$	$0.094\ (0.006)^{***}$
Interstate indicator	$0.021\ (0.008)^{*}$	$0.008\ (0.009)$	$0.022\ (0.010)^{*}$
Average Daily Traffic (ADT)	$-6 \cdot 10^{-7}\ (5 \cdot 10^{-8})^{***}$	$-3 \cdot 10^{-6}\ (1 \cdot 10^{-7})^{***}$	$-3 \cdot 10^{-6}\ (1 \cdot 10^{-7})^{***}$
% ADT trucks	$0.015\ (3 \cdot 10^{-4})^{***}$	$0.015\ (3 \cdot 10^{-4})^{***}$	$0.028\ (3 \cdot 10^{-4})^{***}$
Detour length, kilometers	$-0.002\ (3 \cdot 10^{-5})^{***}$	$-0.002\ (3 \cdot 10^{-5})^{***}$	$0.001\ (3 \cdot 10^{-5})^{***}$
Deck protection indicator	$0.242\ (0.004)^{***}$		
Steel structure indicator		$-0.012\ (0.007)$	$0.136\ (0.007)^{***}$
Bridge over waterway indicator		$-0.173\ (0.006)^{***}$	$-0.225\ (0.007)^{***}$
Average temperature > 18 deg C	$0.207\ (0.008)^{***}$	$0.227\ (0.008)^{***}$	$0.113\ (0.008)^{***}$
Annual freeze-thaw cycles > 60	$-0.116\ (0.007)^{***}$	$-0.206\ (0.007)^{***}$	$-0.129\ (0.006)^{***}$
Annual precipitation > 127 cm	$0.060\ (0.006)^{***}$	$-0.072\ (0.006)^{***}$	$-0.112\ (0.006)^{***}$
Logarithm of median income	$0.184\ (0.007)^{***}$	$0.213\ (0.008)^{***}$	$0.229\ (0.007)^{***}$
Black or African American > 50%	$-0.126\ (0.011)^{***}$	$-0.146\ (0.012)^{***}$	$-0.193\ (0.012)^{***}$
Hispanic or Latino > 50%	$0.061\ (0.011)^{***}$	$0.227\ (0.012)^{***}$	$0.300\ (0.012)^{***}$
σ_η	$1.231\ (0.001)^{***}$	$1.252\ (0.001)^{***}$	$1.293\ (0.001)^{***}$
Log Likelihood	−1658392	−1500650	−1637675
AIC	3316814	3001331	3275383

$^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$

Ordered Probit Models without Random Effects

We implemented an ordered probit model without random effects using the *MASS* package for R (Ripley et al. 2022) and found that the coefficient values were of the same sign and of a similar magnitude to our main analysis. The results in Table S20 have smaller standard errors because the model assumes that each observation in the data is independent rather than a time-series panel with multiple observations for the same bridge. Thus, we presented the more conservative coefficient estimates with the random effects specification as our main analysis.

Table S20. Comparison of Ordered Probit Models (No Random Effects), Component Condition States 1-4, 2020 Income, Race, and Ethnicity Indicators

	Deck	Superstructure	Substructure
Age, years	$-0.028\ (2 \cdot 10^{-5})^{***}$	$-0.031\ (2 \cdot 10^{-5})^{***}$	$-0.029\ (2 \cdot 10^{-5})^{***}$
Urban indicator	$-0.134\ (0.001)^{***}$	$-0.056\ (0.001)^{***}$	$0.011\ (0.001)^{***}$
Interstate indicator	$-0.120\ (0.002)^{***}$	$-0.111\ (0.002)^{***}$	$-0.096\ (0.002)^{***}$
100,000 ADT	$-0.179\ (0.003)^{***}$	$-0.030\ (0.003)^{***}$	$-0.005\ (0.003)^{*}$
% ADT trucks	$0.267\ (0.006)^{***}$	$0.540\ (0.006)^{***}$	$0.819\ (0.006)^{***}$
Detour length, 100 kilometers	$0.010\ (0.001)^{***}$	$0.018\ (0.001)^{***}$	$0.028\ (0.001)^{***}$
Deck protection indicator	$0.209\ (0.001)^{***}$		
Steel structure indicator		$0.018\ (0.002)^{***}$	$0.102\ (0.002)^{***}$
Bridge over waterway indicator		$-0.072\ (0.001)^{***}$	$-0.129\ (0.001)^{***}$
Average temperature > 18 deg C	$0.136\ (0.002)^{***}$	$0.101\ (0.002)^{***}$	$0.048\ (0.002)^{***}$
Annual freeze-thaw cycles > 60	$-0.066\ (0.001)^{***}$	$-0.121\ (0.001)^{***}$	$-0.089\ (0.001)^{***}$
Annual precipitation > 50 inches	$0.005\ (0.001)^{***}$	$-0.083\ (0.001)^{***}$	$-0.100\ (0.001)^{***}$
Logarithm of median income	$0.064\ (0.002)^{***}$	$0.088\ (0.002)^{***}$	$0.106\ (0.002)^{***}$
Black or African American > 50%	$-0.056\ (0.002)^{***}$	$-0.046\ (0.002)^{***}$	$-0.100\ (0.002)^{***}$
Hispanic or Latino > 50%	$0.076\ (0.003)^{***}$	$0.171\ (0.003)^{***}$	$0.197\ (0.003)^{***}$
1|2	$-1.330\ (0.017)^{***}$	$-1.323\ (0.017)^{***}$	$-0.959\ (0.017)^{***}$
2|3	$-0.500\ (0.017)^{***}$	$-0.534\ (0.017)^{***}$	$-0.177\ (0.017)^{***}$
3|4	$1.868\ (0.017)^{***}$	$1.855\ (0.017)^{***}$	$2.135\ (0.017)^{***}$
AIC	12360904.135	12103161.760	12523806.603
BIC	12361122.875	12103394.170	12524039.014
Log Likelihood	−6180436.068	−6051563.880	−6261886.302
Deviance	12360872.135	12103127.760	12523772.603
Num. obs.	6396168	6396168	6396168

$^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$

Ordinary Least Squares with Original Component Condition Ratings (0-9)

We further simplified the model to an Ordinary Least Squares (OLS) regression with random effects (Croissant et al. 2022) and compared the results to the Ordered Probit with random effects approach. OLS treats the dependent variable as numeric and continuous rather than discrete categories. We used the original range of component condition ratings (0-9) as the dependent variable because ten categories are more appropriately approximated as continuous than four categories. Using the original component condition ratings also confirmed that our results are not sensitive to the transformation of the dependent variable to four categories for computational feasibility and interpretability of Ordered Probit models. With the exception of the intercept values, all of the OLS coefficient estimates in Tables S21 and S22 have a sign and magnitude consistent with the Ordered Probit results in Tables 4 and 5, respectively. All coefficients maintained the same significance level with the exception of ADT and climate variables for some models.

Table S21. Comparison of Ordinary Least Squares Models, Component Condition Ratings 0-9, 2020 Median Household Income, Race, and Ethnicity Indicators

	Deck	Superstructure	Substructure
Intercept	$7.031\ (0.042)^{***}$	$6.817\ (0.045)^{***}$	$6.343\ (0.047)^{***}$
Age, years	$-0.032\ (3 \cdot 10^{-5})^{***}$	$-0.033\ (3 \cdot 10^{-5})^{***}$	$-0.029\ (3 \cdot 10^{-5})^{***}$
Urban indicator	$-0.140\ (0.003)^{***}$	$-0.029\ (0.003)^{***}$	$0.069\ (0.004)^{***}$
Interstate indicator	$-0.128\ (0.005)^{***}$	$-0.110\ (0.005)^{***}$	$-0.094\ (0.005)^{***}$
Average Daily Traffic (ADT)	$-2 \cdot 10^{-6}\ (7 \cdot 10^{-8})^{***}$	$-2 \cdot 10^{-7}\ (7 \cdot 10^{-8})^{***}$	$-2 \cdot 10^{-7}\ (8 \cdot 10^{-8})^{*}$
% ADT trucks	$0.003\ (2 \cdot 10^{-4})^{***}$	$0.007\ (2 \cdot 10^{-4})^{***}$	$0.012\ (2 \cdot 10^{-4})^{***}$
Detour length, kilometers	$2 \cdot 10^{-4}\ (2 \cdot 10^{-5})^{***}$	$3 \cdot 10^{-4}\ (2 \cdot 10^{-5})^{***}$	$4 \cdot 10^{-4}\ (2 \cdot 10^{-5})^{***}$
Deck protection indicator	$0.168\ (0.003)^{***}$		
Steel structure indicator		$-0.006\ (0.004)$	$0.091\ (0.004)^{***}$
Bridge over waterway indicator		$-0.085\ (0.004)^{***}$	$-0.119\ (0.004)^{***}$
Average temperature > 64 deg F	$0.102\ (0.004)^{***}$	$0.067\ (0.004)^{***}$	$0.017\ (0.005)^{***}$
Annual freeze-thaw cycles > 60	$-0.019\ (0.004)^{***}$	$-0.102\ (0.004)^{***}$	$-0.008\ (0.004)^{*}$
Annual precipitation > 50 inches	$0.006\ (0.003)^{*}$	$-0.062\ (0.003)^{***}$	$-0.072\ (0.003)^{***}$
Logarithm of median income	$0.055\ (0.004)^{***}$	$0.096\ (0.004)^{***}$	$0.106\ (0.005)^{***}$
Black or African American > 50%	$-0.038\ (0.006)^{***}$	$-0.032\ (0.006)^{***}$	$-0.081\ (0.007)^{***}$
Hispanic or Latino > 50%	$0.042\ (0.007)^{***}$	$0.150\ (0.007)^{***}$	$0.140\ (0.007)^{***}$
s_{idios}	0.685	0.636	0.637
s_{id}	0.837	0.906	0.956
Adj. R^2	0.321	0.320	0.276

$^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$

Table S22. Comparison of Ordinary Least Squares Models, Component Condition Ratings 0-9, CEJST Disadvantaged Community, Race, and Ethnicity Indicators

	Deck	Superstructure	Substructure
Intercept	$7.610\ (0.004)^{***}$	$7.830\ (0.005)^{***}$	$7.457\ (0.006)^{***}$
Age, years	$-0.032\ (3 \cdot 10^{-5})^{***}$	$-0.033\ (3 \cdot 10^{-5})^{***}$	$-0.029\ (3 \cdot 10^{-5})^{***}$
Urban indicator	$-0.135\ (0.003)^{***}$	$-0.020\ (0.003)^{***}$	$0.080\ (0.003)^{***}$
Interstate indicator	$-0.128\ (0.005)^{***}$	$-0.110\ (0.005)^{***}$	$-0.094\ (0.005)^{***}$
Average Daily Traffic (ADT)	$-2 \cdot 10^{-6}\ (7 \cdot 10^{-8})^{***}$	$-2 \cdot 10^{-7}\ (7 \cdot 10^{-8})^{*}$	$-9 \cdot 10^{-8}\ (8 \cdot 10^{-8})$
% ADT trucks	$0.003\ (2 \cdot 10^{-4})^{***}$	$0.007\ (2 \cdot 10^{-4})^{***}$	$0.011\ (2 \cdot 10^{-4})^{***}$
Detour length, kilometers	$2 \cdot 10^{-4}\ (2 \cdot 10^{-5})^{***}$	$3 \cdot 10^{-4}\ (2 \cdot 10^{-5})^{***}$	$4 \cdot 10^{-4}\ (2 \cdot 10^{-5})^{***}$
Deck protection indicator	$0.168\ (0.003)^{***}$		
Steel structure indicator		$-0.006\ (0.004)$	$0.091\ (0.004)^{***}$
Bridge over waterway indicator		$-0.087\ (0.004)^{***}$	$-0.121\ (0.004)^{***}$
Average temperature > 64 deg F	$0.101\ (0.004)^{***}$	$0.066\ (0.004)^{***}$	$0.016\ (0.005)^{***}$
Annual freeze-thaw cycles > 60	$-0.024\ (0.004)^{***}$	$-0.107\ (0.004)^{***}$	$-0.013\ (0.004)^{***}$
Annual precipitation > 50 inches	$0.010\ (0.003)^{**}$	$-0.061\ (0.003)^{***}$	$-0.071\ (0.003)^{***}$
Disadvantaged community	$-0.059\ (0.003)^{***}$	$-0.073\ (0.003)^{***}$	$-0.073\ (0.003)^{***}$
Black or African American > 50%	$-0.030\ (0.006)^{***}$	$-0.033\ (0.006)^{***}$	$-0.086\ (0.007)^{***}$
Hispanic or Latino > 50%	$0.055\ (0.007)^{***}$	$0.156\ (0.007)^{***}$	$0.142\ (0.007)^{***}$
s_{idios}	0.685	0.636	0.637
s_{id}	0.837	0.906	0.956
Adj. R^2	0.321	0.320	0.276

$^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$

EXTENSION: CONDITION DETERIORATION RATE

We expect bridge condition to deteriorate over time. Is bridge condition inequitably distributed primarily because of the age of the bridges in disadvantaged or historically underserved communities or because the bridges are deteriorating more rapidly? As an extension to our main analysis, we study the interaction between bridge age and community characteristics.

Comparing Bridge Deterioration Models by Socioeconomic Variables

As an initial exploratory analysis of bridge condition over time, we employed generalized additive models (Wickham 2016) to summarize the bridge condition (the minimum of each of the component conditions for each bridge) (Federal Highway Administration 1995) by age for all of the records in the final panel. As shown in Figures S2, S3, and S4 we compared life-cycle condition deterioration for bridges with different community characteristics. From Figure S2, bridges between 25 and 80 years old tend to be in slightly worse condition in tracts with a majority of Black or African American individuals, but the deterioration trend remains parallel. In Figure S3, bridges in tracts with a majority of Hispanic or Latino individuals (in 2020) initially have new bridges in worse condition, but the trend reverses after about 12 years and older bridges tend to be in better condition. Bridges in tracts designated disadvantaged communities by the CEJST have about the same life-cycle performance as other bridges as shown in Figure S4. Our subsequent methodology disentangles these effects from other variables relevant to bridge deterioration and accounts for the individual effects relevant to each bridge.

Ordinary Least Squares with Interaction Terms, Controls, and Random Effects

For an understanding of the differences in the average deterioration rate for disadvantaged communities, majority Black or African American tracts, majority Hispanic or Latino tracts, and all other bridges, we included terms that interact the community dummy variables with age. We include these terms in an OLS with random effects model so that the dependent variable can be the full range of condition ratings (0-9) without computational difficulties. We have shown that this specification produces coefficient estimates similar to our main analysis with Ordered Probit models in Table S22. The interpretation of interaction term coefficients is that positive estimates indicate slower deterioration and negative estimates indicate faster deterioration in comparison to the coefficient for *Age (all other tracts)*.

Introducing the interaction terms change the estimates and increase the standard errors of the tract dummy variable coefficients. As shown in Table S23, the dummy variable coefficient estimates for disadvantaged, Black or African American majority, and Hispanic or Latino majority tracts are negative for all models with one exception which was not statistically significant. The interaction term for disadvantaged communities had mixed estimates across the three models. Consistent with the plots of the generalized additive models for condition ratings over time, the interaction term for Black or African American majority tracts was negative (refer to Figure S2) and the interaction term for Hispanic or Latino majority tracts was positive (refer to Figure S3).

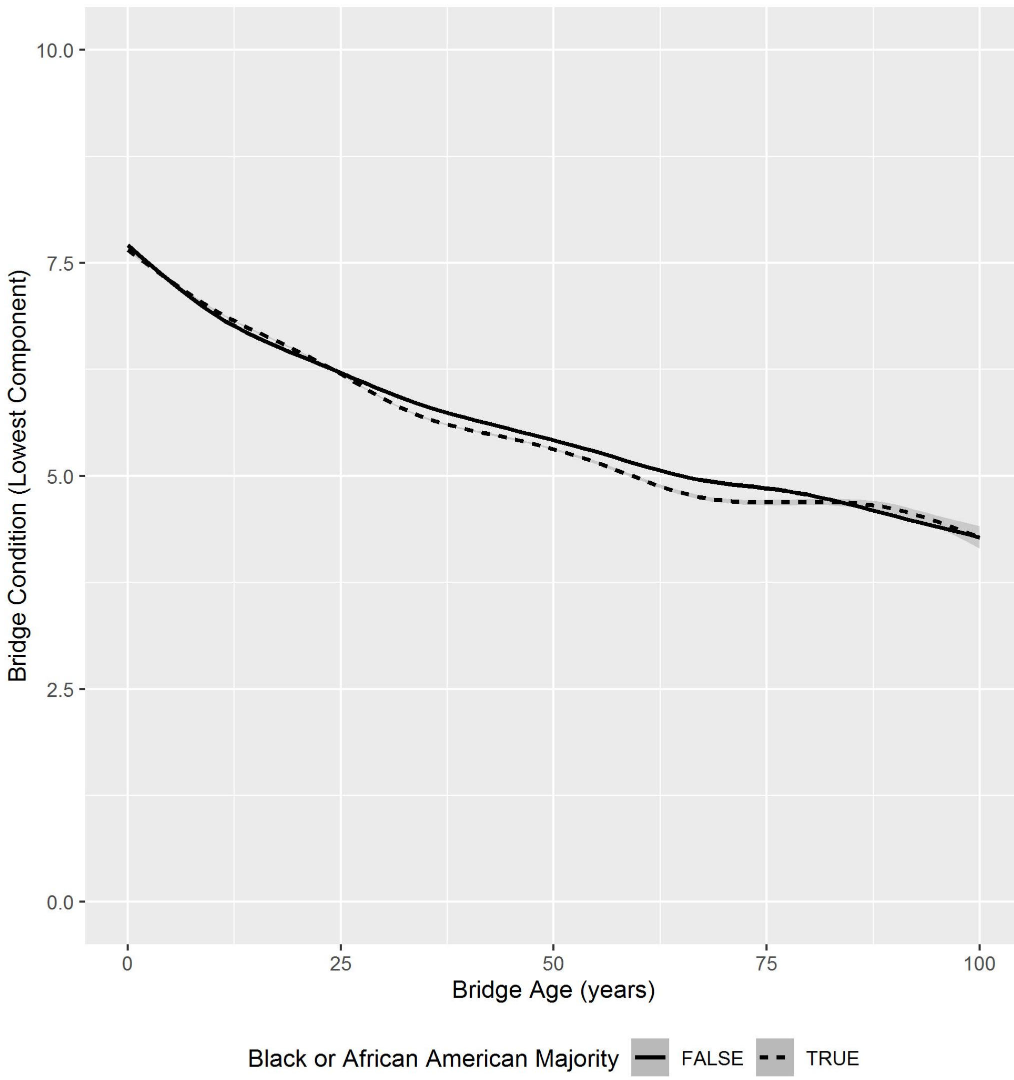

Fig. S2. Life-cycle Bridge Condition, Comparison of Census Tracts with and without a Majority of Black or African American Individuals (2020 Decennial Census)

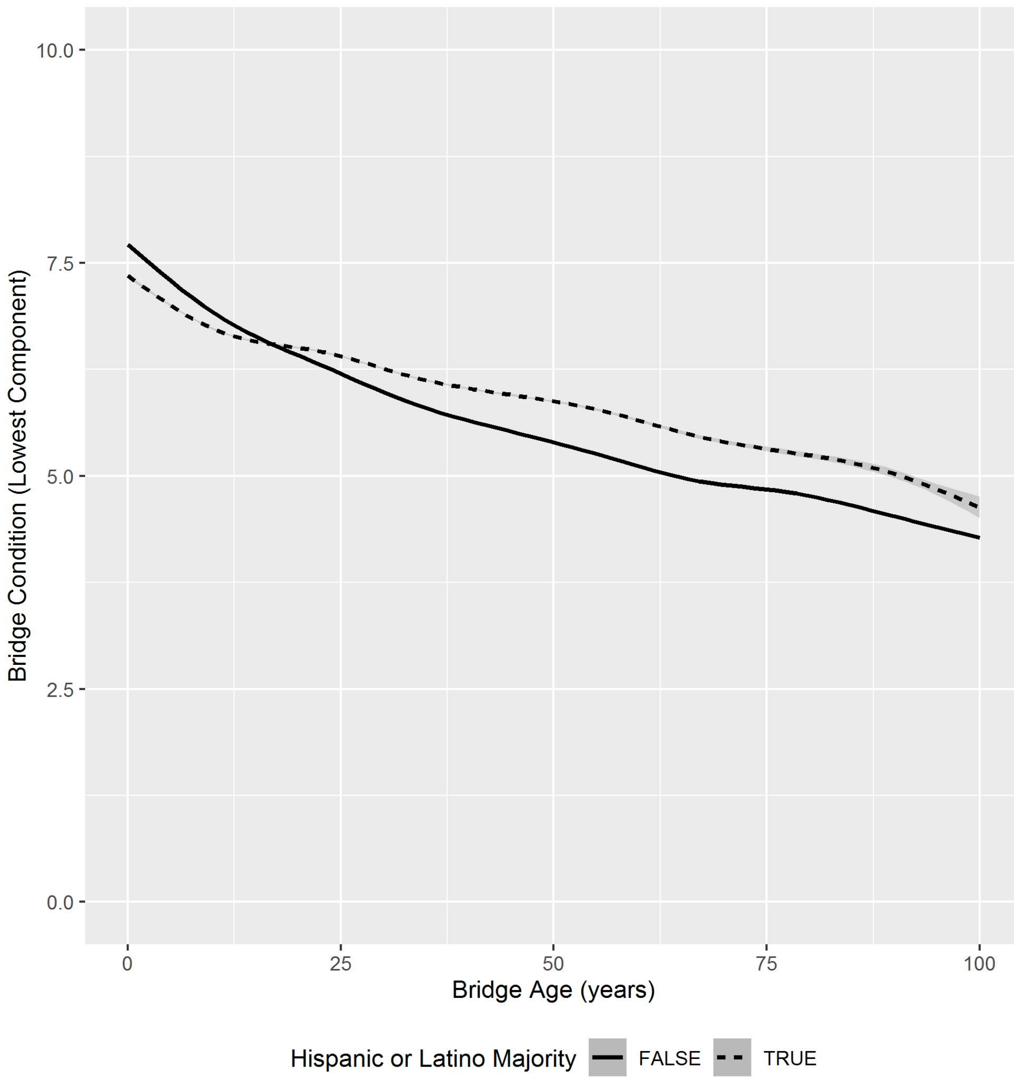

Fig. S3. Life-cycle Bridge Condition by Age, Comparison of Census Tracts with and without a Majority of Hispanic or Latino Individuals (2020 Decennial Census)

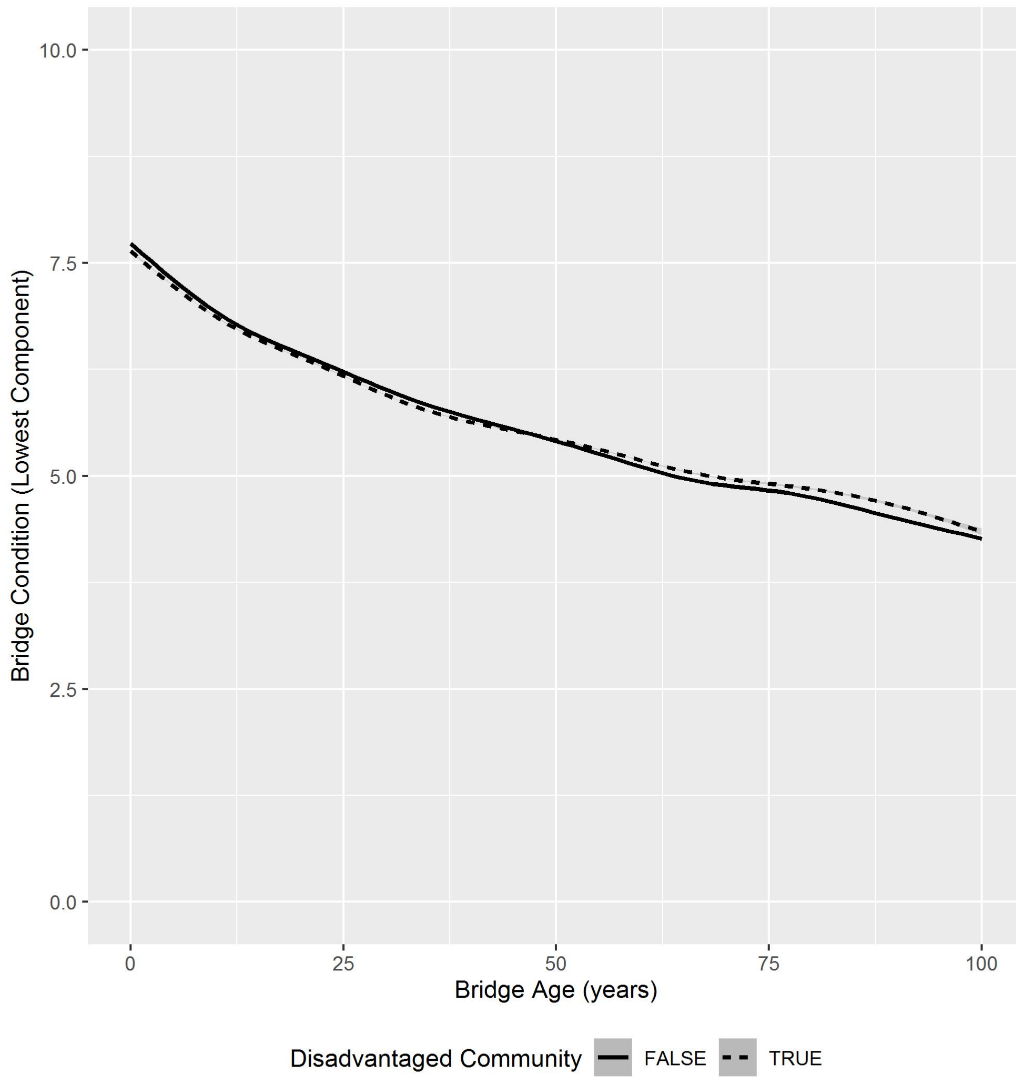

Fig. S4. Life-cycle Bridge Condition by Age, Comparison of Census Tracts Designated Disadvantaged Communities (CEJST) and all other Tracts

Table S23. Comparison of Ordinary Least Squares Models with Interaction Terms and Random Effects, Component Condition Ratings 0-9, CEJST Disadvantaged Community, Race, and Ethnicity Indicators

	Deck	Superstructure	Substructure
Intercept (all other tracts)	7.627 (0.004)***	7.850 (0.005)***	7.456 (0.006)***
Age (all other tracts)	-0.033 $(3 \cdot 10^{-5})^{***}$	-0.034 $(3 \cdot 10^{-5})^{***}$	-0.029 $(3 \cdot 10^{-5})^{***}$
Age in Disadvantaged Tracts	0.001 $(7 \cdot 10^{-5})^{***}$	0.001 $(7 \cdot 10^{-5})^{***}$	-0.001 $(7 \cdot 10^{-5})^{***}$
Age in Black or African American Tracts	-0.003 $(2 \cdot 10^{-4})^{***}$	$-5 \cdot 10^{-5}$ $(1 \cdot 10^{-4})$	-0.003 $(1 \cdot 10^{-4})^{***}$
Age in Hispanic or Latino Tracts	0.009 $(2 \cdot 10^{-4})^{***}$	0.009 $(2 \cdot 10^{-4})^{***}$	0.011 $(2 \cdot 10^{-4})^{***}$
Urban indicator	-0.135 (0.003)***	-0.021 (0.003)***	0.080 (0.003)***
Interstate indicator	-0.130 (0.005)***	-0.112 (0.005)***	-0.098 (0.005)***
Average Daily Traffic (ADT)	$-2 \cdot 10^{-6}$ $(7 \cdot 10^{-8})^{***}$	$-8 \cdot 10^{-8}$ $(7 \cdot 10^{-8})$	$-2 \cdot 10^{-8}$ $(7 \cdot 10^{-8})$
% ADT trucks	0.003 $(2 \cdot 10^{-4})^{***}$	0.007 $(2 \cdot 10^{-4})^{***}$	0.011 $(2 \cdot 10^{-4})^{***}$
Detour length, kilometers	$2 \cdot 10^{-4}$ $(2 \cdot 10^{-5})^{***}$	$3 \cdot 10^{-4}$ $(2 \cdot 10^{-5})^{***}$	$4 \cdot 10^{-4}$ $(2 \cdot 10^{-5})^{***}$
Deck protection indicator	0.166 (0.003)***		
Steel structure indicator		-0.007 (0.004)	0.092 (0.004)***
Bridge over waterway indicator		-0.089 (0.004)***	-0.123 (0.004)***
Average temperature > 64 deg F	0.105 (0.004)***	0.070 (0.004)***	0.020 (0.005)***
Annual freeze-thaw cycles > 60	-0.021 (0.004)***	-0.103 (0.004)***	-0.010 (0.004)**
Annual precipitation > 50 inches	0.011 (0.003)***	-0.059 (0.003)***	-0.069 (0.003)***
Disadvantaged community	-0.106 (0.004)***	-0.116 (0.004)***	-0.038 (0.004)***
Black or African American > 50%	0.047 (0.008)***	-0.031 (0.008)***	0.010 (0.008)
Hispanic or Latino > 50%	-0.216 (0.008)***	-0.127 (0.008)***	-0.184 (0.009)***
s_{idios}	0.684	0.636	0.637
s_{id}	0.836	0.906	0.954
Adj. R^2	0.321	0.321	0.277

$^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$

NOTATION

The following symbols are used in this paper:

$\boldsymbol{\beta}_{nt}$ = Regression coefficient for bridge n in year t;
ϵ_{nt} = Idiosyncratic error term for bridge n in year t;
η_n = Bridge-specific individual effect;
$F()$ = Cumulative normal distribution;
j = Index for condition state;
J = Highest condition state (4);
μ = Interior threshold parameters;
n = Index for an individual bridge;
N = Total unique bridge structures;
ω = Change of variable for Gauss-Hermite quadrature approximation of the models;
$P(y_n|\eta_n)$ = Conditional probability that bridge n is in state y;
$P(y_n)$ = Unconditional probability that bridge n is in state y;
q_n = Number of records for an individual bridge;
$\bar{q}$ = Average number of inspections per bridge;
Q = Total inspection records;
r = Index for Gauss-Hermite quadrature approximations;
R = Number of evaluations of Gauss-Hermite quadrature approximations;
σ_η = Standard deviation of normally distributed individual random effect η;
t = Index for inspection year;
T = Last inspection year for an individual bridge;
V_{nt} = Unobserved latent variable for bridge n in year t ;
$\mathbf{x}_{nt}$ = Regressor for bridge n in year t;
y = Observed condition state

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