CPBS
Center for Pedestrian and Bicyclist Safety

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A Context-sensitive Street Classification Framework for Speed Limit Setting

July 2024

A Report From the Center for Pedestrian and Bicyclist Safety

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About the Center for Pedestrian and Bicyclist Safety (CPBS)

The Center for Pedestrian and Bicyclist Safety (CPBS) is a consortium of universities committed to eliminating pedestrian and bicyclist fatalities and injuries through cutting-edge research, workforce development, technology transfer, and education. Consortium members include: The University of New Mexico; San Diego State University; The University of California Berkeley; The University of Tennessee Knoxville; and The University of Wisconsin Milwaukee. More information can be found at: https://pedbikesafety.org

Disclaimer

Acknowledgments

This study was funded, partially or entirely, by a grant from the Center for Pedestrian and Bicyclist Safety (CPBS), supported by the U.S. Department of Transportation (USDOT) through the University Transportation Centers program. The authors would like to thank CPBS and the USDOT for their support of university-based research in transportation, and especially for the funding provided in support of this project.

TECHNICAL DOCUMENTATION

1. Project No.	2. Government Accession No.	3. Recipient's Catalog No.
23UCB01		

4. Title and Subtitle	5. Report Date
A Context-sensitive Street Classification Framework for Speed Limit Setting	July 2024
	6. Performing Organization Code
	N/A
7. Author(s)	**8. Performing Organization Report No.**
Julia B. Griswold https://orcid.org/0000-0002-1125-3316 Cheng-Kai Hsu https://orcid.org/0000-0001-7254-0602 Melody Tsao https://orcid.org/0009-0009-8361-8474 Robert J. Schneider https://orcid.org/0000-0002-6225-3615 John M. Bigham https://orcid.org/0000-0002-0434-7509 Marcel E. Moran https://orcid.org/0000-0002-5637-4971	N/A
9. Performing Organization Name and Address	**10. Work Unit No. (TRAIS)**
Safe Transportation Research and Education Center University of California, Berkeley 2150 Allston Way Suite 400 Berkeley, CA 94720	**11. Contract or Grant No.** 69A3552348336
12. Sponsoring Agency Name and Address	**13. Type of Report and Period Covered**
United States of America Department of Transportation Office of Research, Development, and Technology (RD&T)	Final Report – June 2023 to May 2024 **14. Sponsoring Agency Code** USDOT OST-R

15. Supplementary Notes

Report accessible via the CPBS website https://pedbikesafety.org and DOI https://doi.org/10.21949/0ezc-1p93

16. Abstract

In the US, speed limit setting (SLS) has historically relied on driver-behavior-based approaches, such as using the 85th percentile speed. While these approaches are considered objective and allow for consistent application, they have significant limitations, including drivers' tendencies to underestimate their speeds, the phenomenon of speed creep, and inadequate consideration of vulnerable road users. These issues may conflict with the Safe System Approach and Vision Zero initiatives endorsed by the USDOT (US Department of Transportation). In contrast, context-sensitive approaches, which classify roads based on roadway typologies, have been effectively implemented in countries like New Zealand, Sweden, the Netherlands, and Australia. Despite their success, such approaches have not been widely adopted in the US, resulting in many roads with speed limits that may not reflect their actual conditions or adequately ensure pedestrian and cyclist safety. Inspired by New Zealand's One Network Framework, we developed a US-based context-sensitive roadway classification framework. This framework integrates "Place," which considers surrounding land uses and locational contexts, and "Movement," which pertains to the road's transport function. Using data from the Smart Location Database (SLD) and the Highway Performance Monitoring System (HPMS), we validated our framework through internal reviews and external interviews with state-level practitioners. This process revealed both opportunities and challenges in implementing a context-sensitive SLS approach in the US. Our findings demonstrate the feasibility of establishing an objective, context-sensitive roadway classification system in the US and provide valuable insights for developing new speed-limit guidance aligned with the Safe System framework.

17. Key Words	18. Distribution Statement
Speed limits; Land use; Types of roads; Pedestrians; Cyclist	No restrictions. This document is available through the National Technical Information Service, Springfield, VA 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	34 pages	

Form DOT F 1700.7 (8-72) **Reproduction of completed page authorized.**

SI* (MODERN METRIC) CONVERSION FACTORS				
APPROXIMATE CONVERSIONS TO SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa
APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

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Acronyms, Abbreviations, and Symbols

DOT	Department of Transportation
EPA	Environmental Protection Agency
FHWA	Federal Highway Administration
HPMS	Highway Performance Monitoring System
SLD	Smart Location Database
SLS	Speed limit setting

Abstract

In the US, speed limit setting (SLS) has historically relied on driver-behavior-based approaches, such as using the 85th percentile speed. While these approaches are considered objective and allow for consistent application, they have significant limitations, including drivers' tendencies to underestimate their speeds, the phenomenon of speed creep, and inadequate consideration of vulnerable road users. These issues may conflict with the Safe System Approach and Vision Zero initiatives endorsed by the USDOT (US Department of Transportation). In contrast, context-sensitive approaches, which classify roads based on roadway typologies, have been effectively implemented in countries like New Zealand, Sweden, the Netherlands, and Australia. Despite their success, such approaches have not been widely adopted in the US, resulting in many roads with speed limits that may not reflect their actual conditions or adequately ensure pedestrian and cyclist safety. Inspired by New Zealand's One Network Framework, we developed a US-based context-sensitive roadway classification framework. This framework integrates "*Place*," which considers surrounding land uses and locational contexts, and "*Movement*," which pertains to the road's transport function. Using data from the Smart Location Database (SLD) and the Highway Performance Monitoring System (HPMS), we validated our framework through internal reviews and external interviews with state-level practitioners. This process revealed both opportunities and challenges in implementing a context-sensitive SLS approach in the US. Our findings demonstrate the feasibility of establishing an objective, context-sensitive roadway classification system in the US and provide valuable insights for developing new speed-limit guidance aligned with the Safe System framework.

Executive Summary

Historically, speed limit setting (SLS) in the US has relied on driver-behavior-based approaches like the 85th percentile speed, which are objective and provide consistency across applications. However, these approaches often overlook drivers' tendency to underestimate speeds, issues with speed creep, and the needs of vulnerable road users, which undermines their alignment with the Safe System Approach and Vision Zero initiatives endorsed by the USDOT (US Department of Transportation). In the US, the prevalence of road designs that encourage higher speeds further complicates the enforcement of safe speed limits based solely on driver behavior. Conversely, countries such as New Zealand, Sweden, the Netherlands, and Australia use context-sensitive approaches that integrate both roadway function and surrounding land use to determine speed limits. New Zealand's One Network Framework, for example, incorporates both "*Place,*" which considers surrounding land uses and locational contexts, and "*Movement,*" which pertains to the road's transport function, to align with Safe System principles, offering a more nuanced classification system that addresses the limitations of traditional methods by considering actual road use and the safety of all road users.

While several transportation agencies and researchers across the globe have developed context-based approaches to classify roadways and set speed limits, most have been applied outside of the US. Therefore, in the US, there is a need for objectively-measured roadway context categories to allow consistent, widespread application of context-based SLS methods. Our study aims to develop a similar context-sensitive framework for the US using nationally available data, validated through both internal reviews and state-level practitioner interviews, to provide a more objective and practical approach to setting speed limits.

We employed three key data sources that are nationally-available, including 1) the 2019 TIGER/Line Shapefiles, 2) the 2019 Highway Performance Monitoring System (HPMS) data, and 3) the EPA's Smart Location Database (SLD) 3.0. The data were processed in ArcGIS Pro, including cleaning, overlaying, and merging of road segments across six states: New Mexico, Wisconsin, Washington, Tennessee, Massachusetts, and Oregon. Subsequently, three *Movement* and five *Place* categories were established based on HPMS functional classifications and SLD land use characteristics. A K-means cluster analysis identified five distinct *Place* categories, which were then integrated with three road classes to create 11 distinct context-sensitive roadway categories.

The roadway classification framework's validity was then tested through both internal and external validation. Through collaborative discussions and leveraging the collective expertise of our research team, we conducted an internal validation process to explore how well our objectively-calculated *Place* categories matched our intuitive perception of the contexts in Wisconsin, evaluating the suitability of our classification framework based on Google Earth and Street View. As for external validation, we conducted interviews with road safety experts from state DOTs from New Mexico, Wisconsin, and Tennessee. The interviews revealed a consensus on the need to adopt more context-sensitive approaches and highlighted several challenges in current SLS practices.

The results underscore the potential for the United States to transition towards a context-sensitive approach to objectively setting speed limit while considering locational context, or *Place.* We demonstrate the viability of this approach through the development of a US street category framework, inspired by New Zealand's leading example of a street category framework based on not only *Movement*—the priority of movement of people or goods on a given road, but also *Place*—the activities, land uses, and types of road users present. This approach enhances the effectiveness of speed limit regulations and removes subjectivity from the SLS process. Establishing an objective, context-sensitive street classification framework for US jurisdictions represents a significant step in removing technical barriers to adopting a Safe System Approach to SLS. This framework not only facilitates the achievement of *Safe Speeds* but also holds the potential to reduce pedestrian and bicyclist fatalities and serious injuries.

Introduction

Historically, speed limit setting (SLS) procedures in the US have relied on driver-behavior-based approaches such as the 85th percentile speed. These approaches have the benefit of being objective, making it easy for speed limits to be consistently applied, regardless of the practitioner conducting the analysis. However, these approaches have several shortcomings, including drivers' tendency to underestimate their speeds, issues with speed creep, and insufficient consideration for vulnerable road users (Grembek et al., 2020; Hauer, 2009; Mannering, 2009; NTSB, 2018). More importantly, the traditional 85th percentile speed approach relies on collective driver behavior to set safe speeds without considering other road users, which is not compatible with the Safe System Approach and Vision Zero initiatives currently adopted and endorsed by the USDOT (U.S. Department of Transportation) (Fleisher et al., 2016; Michael et al., 2022), which aim to eliminate roadway fatalities and severe injuries. The Safe System principles include: humans are vulnerable, humans make mistakes, and redundancy is crucial (USDOT, 2022). The *Safe Speeds* element of this approach calls for speeds that "can accommodate human injury tolerances", ensuring that road users can err without severe consequences. Achieving this requires incorporating redundancy into roadway design, such as separating users traveling at different speeds (USDOT, 2022). Driver-behavior-based SLS methods are not aligned with the Safe System as they rely on the collective behavior of drivers to determine what speeds are safe, regardless of the other types of road users present. Many roads in the US are designed in a way that encourages higher speeds, complicating the setting and enforcement of safe speed limits based on driver behavior alone (Harsha et al., 2007; Wilmot & Khanal, 1999). Some jurisdictions, including Oregon, California, and Washington, are shifting towards a Safe System Approach by integrating contextual factors into SLS processes (Otto et al., 2022). Nevertheless, these methods often involve subjective decisions by practitioners (e.g., setting lower speed limits in certain areas but not others) or still rely on driver behavior to some extent.

Other countries, such as Sweden, The Netherlands, Australia, and New Zealand, which are pioneering the Safe System Approach, have utilized typologies based both on roadway function and surrounding land use context to determine speed limits (Hughes et al., 2015). In the US, the most common and uniform typology is the Federal Highway Administration (FHWA)'s functional classification, which rates roadways based on the level of priority for movement of people or goods. While this movement-based classification is widely used and integrated into many current SLS procedures in the US, it does not account for roadway user mix or adjacent land use context, which may be indicative of activity intensity of vulnerable road users, such as pedestrians and bicyclists. For example, some roadways classified as arterials or highways have speed limits of 60 to 80 kph, despite cutting through villages, neighborhoods, or commercial areas full of pedestrians and cyclists who are shopping, going to work or school, or playing by the roadside. Systemic safety analyses have identified these types of arterial roadways as having the highest pedestrian fatality risk in the US (Schneider et al., 2021).

As a leader in the Safe System Approach, New Zealand has additionally integrated both *Movement* and *Place* into its SLS approach (Waka Kotahi NZ Transport Agency, 2022). *Movement* refers to the priority of movement of people or goods on a given road, which is similar to functional classification. *Place* refers to the context, which includes activities that occur on a street, the adjacent land uses, and the types of road users. Street categories—and their associated speed limits—are established by the priority of both *Movement* and *Place*. An example of high *Movement* and low *Place* road would be a freeway, whereas high *Movement* and high *Place* would be an urban arterial traveling through a retail district, and low *Movement* and low *Place* would be a residential street. New Zealand has applied one of the street categories to every street segment in the country. This uniform, national dataset removes subjectivity from the SLS process. For each street category, there is a baseline *safe and appropriate speed* (SAAS) limit and a range of SAAS limits that may be appropriate if certain criteria are met.

This SLS approach is supported by the *Roads-for-Life* framework proposed by the World Bank, which complements traditional hierarchic road classification systems by addressing their major shortcomings (World Bank Group, 2024). The *Roads-for-Life* framework determines speed limits and road classifications according to actual needs and vulnerabilities of all road users, including pedestrians and cyclists. The framework views roads as places for human presence and activity. It also reflects the growing expert consensus that roads should prioritize not just motorized transport, but the safety and mobility of pedestrians and cyclists and especially vulnerable people including children, the elderly, and persons with disabilities. This framework is based on the principle that speed management needs to reflect how roads are actually being utilized, not in theory, but in practice. It acknowledges that roads can be destinations in their own right, places where people gather and shop in markets and where children play, and that a road can morph from deserted highway to busy suburban thoroughfare, and back again, several times along its length.

While several transportation agencies and researchers worldwide have developed context-based approaches for classifying roadways and setting speed limits, most of these methods have been implemented outside the US (Belin et al., 2022; Schell & Ward, 2022). Moreover, no universal method exists for assigning contextual categories to roadways. Different approaches have established varying numbers of categories and used diverse variables, such as land use, activity, and functional use, to classify roadways. Therefore, there is a need for objectively measured roadway context categories to enable consistent and widespread application of context-based SLS approaches in the US.

To address these gaps, our study introduces a context-based roadway classification framework utilizing nationally available data in the US. We validate the results internally through the expertise of our research team and externally by interviewing state-level practitioners to identify opportunities and challenges in implementing this context-based SLS approach across the US.

Literature Review

This literature review aims to evaluate various alternative SLS approaches and develop a set of urban-typology categories for new speed-limit guidance for the US. It examines urban typologies created by academics, public agencies, and think tanks, including the variables used to define these typologies and their respective strengths and weaknesses. A key focus is how these typologies incorporate land uses, ranging from qualitative descriptions to quantitative metrics (e.g., residential density per square mile). The number of typologies varies from three to over ten, generally spanning an urban-rural spectrum. While most speed-limit setting approaches consider both "*Place*" and "*Movement*", this report does not revisit the FHWA's established "functional classification" system (Stamatiadis et al., 2018). Instead, it focuses on the variety and applicability of "*Place*" formulations, with a primary emphasis on urban streets rather than rural types.

New Zealand

As part of their "One Network Framework" (ONF) (Waka Kotahi NZ Transport Agency, 2022), the Waka Kotahi NZ Transport Agency has developed two distinct street "families" (Figure 1). These families are plotted on a Euclidean graph with two axes: "*Movement*," which pertains to the road's characteristics and transport function, and "*Place*," which reflects the surrounding land uses. The framework includes an Urban Street Family, encompassing Urban Connectors, City Hubs, Main Streets, Activity Streets, Local Streets, and Civic Spaces, and a Rural Street Family, consisting of Interregional Connectors, Rural Connectors, Rural Roads, Peri-Urban Roads, and Stopping Places. The "*Place*" score is determined by three inputs. The first, "Level of On-Street Activity," measures the observable foot traffic and pedestrian crossing opportunities at any given time. The second, "Typical Adjacent Land Use," indicates the type of land use that generates on-street activity, such as destinations like shopping centers. The third input, "Pedestrian Volume," provides a quantitative count of pedestrians throughout the day. Each input is categorized into five levels: the first two use qualitative distinctions (such as high-rise versus low-rise buildings), while the third uses specific numerical thresholds (for example, fewer than 1,000 pedestrians versus more than 2,500 pedestrians).

With these three inputs, divided across five levels, the members of the urban street family map onto the graph in the following way: Urban Connectors (Place 4,3), City Hubs (Place 2,1), Activity Streets (Place 3,2), Local Streets (Place 4,3), Main Streets (Place 2,1), Civic Spaces (Place 2,1). The resulting chart can be challenging to interpret, as the categories appear on the graph somewhat like Tetris pieces. Speed limits are determined based on these designations, though a single category can accommodate multiple speed limits (e.g., Civic Spaces could be set at either 10 km/h or 20 km/h). This flexibility allows planners discretion in assigning speed limits to roads within each family and subtype.

Australia

In adopting the evidence-based Safe System Approach to enhance pedestrian and cyclist safety, Austroads has developed new guidance for street classifications. This guidance also uses

Figure 1. One Network Framework Classification Matrix by the Waka Kotahi NZ Transport Agency. Adapted from Waka Kotahi NZ Transport Agency (2022).

Movement and *Place* axes, yet with some differences from the New Zealand model. In the “Victorian” model, named after the Australian state, there are five levels each for *Movement* and *Place*, and six road/street families are identified: Movement Corridors and Connectors, Activity Streets and Boulevards, City Hubs, City Streets, City Places, and Local Streets (Corben, 2020). Instead of relying on quantitative measures to define *Place*, this model provides descriptions of “Key Places” within each family. For example, "Key Places in Local Streets" include residential dwellings, community facilities, parkland, and schools, whereas "Key Places in City Places" encompass places of employment, recreational facilities, special event venues, and major transport interchanges. This approach is explicitly qualitative, and provides planners assigning significant discretion, without any type of transport or built-environment measures to input.

The Netherlands

Beginning in the early 1990s, the Netherlands renewed its focus on road safety with the introduction of the “Sustainable Safety” program (Wegman et al., 2006). This program uses three key principles—functionality, homogeneity, and predictability—to define three road categories: through roads, distributor roads, and access roads. The program's literature provides detailed design guidelines for each road type, including specifications for width, markings, and speed limits (Wegman & Wouters, 2002). However, guidance on the road type assignment is less detailed. For example, “through roads” are simply specified to be located outside urban areas, while “access roads” are described as providing direct access to residential areas, with “distributor roads” being those connecting through roads with access roads. These typologies, while straightforward, may be suitable for rural settings but could be too simplistic for complex urban environments.

Sweden

In the 1990s, Sweden pioneered the Safe System Approach to transportation planning (Hughes et al., 2015), recognizing that human error is inevitable and the survivability of collisions is impacted by factors such as vehicle mass, velocity, and impact angle (Vadeby & Forsman, 2018; Whitelegg & Haq, 2006). Swedish road design must consider surrounding land uses by law (Ekbäck & Christensen, 2020), and similarly to the Netherlands, it must account for transport functions. The classifications are fairly simple: arterials, collectors, residential, and industrial streets (Afridi et al., 2023). Following a rise in road traffic deaths in 2018, the Swedish Transport Administration called for a "huge effort" in re-calibrating road speed limits, signaling that its limited road types may be too minimal to account for varying locational contexts (Lindberg, 2019).

United Kingdom

Transport for London (TfL), which manages transit and road management, including congestion pricing, for the capital, has developed "London's Street Family." This framework integrates both "*Movement*" and "*Place*" axes (Transport for London, 2013). Created by the Roads Task Force, it aims to balance various street demands and tensions (stationary vs. mobile) while being comprehensible to communities and boroughs responsible for implementation. The framework categorizes streets into six functions: Moving (transport), Functioning (deliveries and utilities), Living (welcoming and inclusive spaces), Protecting (enhancing safety and reducing collisions), Unlocking (improving accessibility), and Sustaining (reducing emissions). On the *Place* axis, streets range from those critical to the city and sometimes the nation to local and residential streets. The report emphasizes that both axes are continuums, with *Place* primarily defined by Living, Unlocking, and Functioning. London's arrangement reflects a distance-based gradient in terms of place: areas of highest strategic importance are in Central London, decreasing toward the city's edges. Intermediate areas include commercial main streets, cultural venues, schools, and hospitals. While this gradient approach can be adapted to other cities, the terminology used for the different functions can be confusing (e.g., whether "Protecting" also implies "Sustaining"), which may hinder clarity.

United States

In an attempt to update and expand the U.S. Functional Classification System, a large research team established road types that had more "place" nuance than basic urban and rural categories (Stamatiadis et al., 2018). Indeed, the authors write: "Designation as urban or rural is insufficient to adequately account for the range of contexts for a highway or street" (Ibid). This expanded FCS provides the following five place types, with included definitions. They are: Rural (lowest density, few houses or structures, large setbacks), Rural Town (low density but with diverse land uses, such as main streets, and shorter setbacks), Suburban (medium density, mixed land uses, and varied setbacks), Urban (high density, mixed land uses, and sidewalks), and Urban Core (highest density and predominantly high-rise structures). These five "contexts" then help determine the type and design of the roadway in question (principal arterial, arterial, collector, or local). A strength of the

Expanded FCS is that there are three specific inputs: density, land uses, and building setbacks. The guidance provides lengthy descriptions of the spectrum for each input, as well as example sketches and photographs, though there are few quantitative distinctions made (e.g. population per square mile, etc.). Therefore, the expanded FCS provides a useful conceptual framework but is difficult to apply objectively in practice due to the absence of concrete, quantitative guidelines.

A different research group took an interesting approach to measuring how the overall character of neighborhoods influences travel behavior (Voulgaris et al., 2017). Rather than considering characteristics discretely, they combined twenty different variables in order to generate seven neighborhood typologies: Mixed Use, Old Urban, Urban Residential, Established Suburb, Patchwork, New Development, and Rural. This is one of the few typologies that distinguishes between the age of development (new vs. old), with the latter generally of higher density and more walkable. The twenty variables that serve as the inputs to these types are:

1. Number of jobs within a 45-minute drive ("Job access")
2. Share of total CBSA employment ("Job share")
3. Share of total activity that is employment ("Percent jobs")
4. Share of total activity that is office employment ("Percent office")
5. Share of total activity that is retail employment ("Percent retail")
6. Jobs-housing balance ("Job-housing balance")
7. Housing density ("Housing density")
8. Employment density ("Job density")
9. Activity density ("Activity density")
10. Total road network density ("Road density")
11. Pedestrian-oriented road network density ("Pedestrian density")
12. Car-oriented road network density ("Car network density")
13. Intersection density ("Intersection density")
14. Transit service density index ("Transit supply index")
15. Share of homes that are single-family homes ("Percent SFR")
16. Share of occupied homes that are rentals ("Percent rented")
17. Share of occupied homes occupied for < 5 years ("Short-term homes")
18. Share of occupied homes occupied for > 20 years ("Long-term homes")
19. Share of homes less than ten years old ("New homes")
20. Share of homes more than forty years old ("Old homes")

This may, by far, be the set or urban typologies with the most quantitative inputs. However, this categorization is not intended for SLS purposes. Due to its reliance on twenty variables, this approach may not be practical for most agencies to update roadway classifications as development patterns change. While the California Department of Transportation (Caltrans) has adopted a similar typology for their Smart Mobility Framework to design speed limits in the Design Information Bulletin-94, they had to simplify the number of categories (Caltrans, 2024). This adjustment, which may involve subjective decisions, underscores the challenges of applying such a typology for SLS purposes objectively.

Data and Methodology

This section describes the data preparation and methodology through which we categorize road segments objectively, following New Zealand's ONF using a street category framework based on *Movement and Place.*

Data preparation

We employed three nationally available, free data sources for our analysis. These included 1) 2019 TIGER/Line Shapefiles street data provided by the US Census Bureau; 2) 2019 Highway Performance Monitoring System (HPMS) street data provided by FHWA; 3) US Environmental Protection Agency's Smart Location Database (SLD) 3.0 based on 2019 Census Block Group (CBG) Boundaries.

Prior to modeling analysis, we processed and prepared data in ArcGIS Pro software. The TIGER street data served as the primary data source as it topologically aligned with the CBG boundaries used by the SLD which provided a cleaner output. Since the default street segments can be long and span multiple intersections and CBG boundaries, the segments were first split at all intersections and CBG boundaries. Overlapping streets with alternate names and non-street features such as railroads were identified and deleted. Additionally, any divided roads were also identified and merged using the ArcGIS Pro Merge Divided Roads (Cartography) Tool.

The cleaned TIGER streets were then spatially overlayed with the SLD and each road segment was assigned the respective SLD values if it was fully contained within a single CBG. For road segments on CBG boundaries, the mean of the two SLD values for the surrounding boundaries was calculated.

Subsequently, the functional class of each of the processed TIGER road segments was determined using the HPMS roadway data. The HPMS data was similar but not consistent between each state, so the process for determining the functional class differed slightly depending on the quality of data. The following steps were undertaken: 1) Determine the nearest HPMS segment to the midpoint of the processed TIGER segment; 2) Match the street names (when applicable); 3) Compare the angles of the matched segments (when applicable). For the most part, the nearest HPMS segment to the processed TIGER segment midpoint would be the correct match, but if the individual state's HPMS data allowed for further confirmation using the name or angles, that information was also utilized. The functional classification from the matched HPMS segment was then assigned to the processed TIGER segment. The final dataset used for the modeling analysis contained the processed TIGER based street segments between each intersection with the HPMS functional class and SLD values assigned.

Finally, we merged road segment data from six diverse states, New Mexico, Wisconsin, Washington, Tennessee, Massachusetts, and Oregon. These states were intentionally chosen for their varied demographics, geography, and socio-economic landscapes. Pooling data across the six states allows us to uncover broader trends that might be overlooked by focusing solely on individual states. Additionally, by selecting states with distinct characteristics, we aim to generate results applicable beyond the scope of this study and provide universal applicability to other states not included in this study. In practice, we tested both a consolidated approach and a state-specific one, and we found the emergence of a similar pattern across the six states.

Data analysis

Movement categories

We defined general *Movement* categories based on the HPMS roadway functional classifications. We excluded road segments with functional classification of Interstate (1), Freeways and Expressways (2), and Local (7). This categorization is informed by the expectation that Interstate and Freeway segments would generally have higher speeds and lower "placeness" compared to Local segments. Additionally, we combined road classes 5 (Major Collector) and 6 (Minor Collector) due to the relatively small sample size of Class 6 segments. Therefore, our three Movement categories are HPMS functional classifications of Principal Arterial (3), Minor Arterial (4), and Major and Minor Collectors (5/6).

Place categories

We established general *Place* categories for each roadway segment based on land use characteristics of the adjacent census block groups. Conceptually, contexts in the US that are denser, have greater land use mix, and have more transit availability have a higher degree of "placeness". To operationalize this concept, we followed the following steps to define *Place*:

First, we selected variables from SLD reflecting characteristics of areas where lower driving speeds are preferred, drawing from literature on pedestrian activity. These variables fall into three main categories: Density, Diversity, and Design (Cervero, 2001; Forsyth et al., 2008)(Cervero, 1996). The Density category included D1D, the Diversity category included D2A_EPHHM and % Industry, and the Design category included D3B and D4A, which are defined as follows:

1. D1D (Density): Gross activity density, encompassing both employment and housing units, on unprotected land. The rationale for selecting this variable is that it represents the potential amounts of trips generated. It should be noted that to focus on urban areas, we followed the definition used in the SLD, where CBGs with D1D values exceeding 0.5 would be considered as urban areas, and only included road segments with average D1D values >= 0.5.
2. D2A_EPHHM (Diversity): Measure of employment and household entropy, reflecting the diversity of activities within an area. The rationale of including this variable is that it is part of the calculation of *NatWalkInd* in the SLD database.
3. D3B (Design): Street intersection density, with auto-oriented intersections eliminated. The rationale of selecting this variable is that it reflects the density of street potentially desired by pedestrians, serving as a proxy of pedestrian density.
4. D4A (Transit Accessibility): Distance from the population-weighted centroid to the nearest transit stop, in meters. Road segments with missing data were assigned a value of 2000.

The rationale for this variable is that it is part of the calculation of "*NatWalkInd*" and it may reflect the propensity of walking trips.

5. % Industry: Ratio of industry activity to total activity within a given area. The reason to include this variable is that the industrial land use may not as relevant to pedestrian activities as other employment-based land use types included in the SLD database (such as service, entertainment, commercial, etc.). By including this variable, we offer a counter-control for D2A_EPHHM, diluting the effects from having too much industrial area.

Second, we standardized the five variables to address differences in their units and distributions. We reversed the values for variables D4A and % Industry, since lower values indicate a higher preference for pedestrians. Specifically, shorter distances to transit facilities and a lower percentage of industrial land use are theoretically more favorable for pedestrians and reflect a higher degree of "placeness."

Third, we explored various weighting schemes and ultimately assigned equal weights to three main categories of variables: Density, Diversity, and Design. The Density category includes only D1D; the Diversity category encompasses D2A_EPHHM and % Industry; and the Design category consists of D3B and D4A. We then calculated a *Place* composite score representing the level of "placeness" by summing the standardized variables with these weights. Further details on the weighting considerations are provided in the Discussion section.

Fourth, we conducted K-means cluster analysis using the *Place* composite score, determining that five clusters were optimal. This resulted in five distinct *Place* categories: "extremely high," "very high," "high," "medium," and "low." Figure 2 displays a histogram and the composite score ranges for each category. Each category represents a specific range of "placeness," reflecting varying levels of trip generation density, pedestrian-friendliness, and vibrancy. The score ranges for each category are as follows: low (-1.6 to -0.24), medium (-0.24 to 0.23), high (0.23 to 1.12), very high (1.12 to 3.80), and extremely high (3.81 to 14.71) (Table 1).

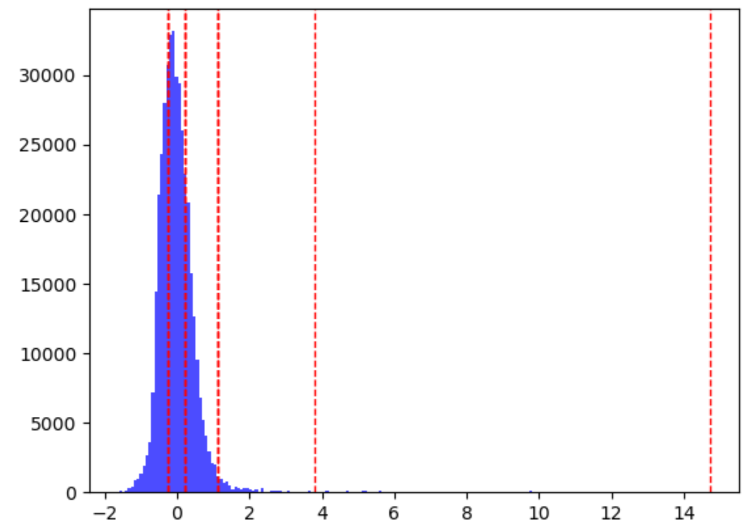


Figure 2. Histogram of place scores from cluster analysis

Table 1. Range of scores for each *Place* Category

***Place* Category**	**Min**	**Max**
Extremely High	3.808987	14.705580
High	0.233087	1.118389
Very High	1.118878	3.804368
Medium	-0.248045	0.233044
Low	-1.606383	-0.248085
Extremely High	3.808987	14.705580

Finally, we integrated these *Place* categories with the road classes to create 11 distinct categories (Figure 3). Specifically, the categories include "extremely high" and "very high" placeness levels, accompanied by the remaining three *Place* categories (i.e., "high", "medium", and "low), each paired with every road class (i.e., "3", "4", and "5").

Roadway Classification				
		Movement Category		
		Road 3 Principal Arterial	Road 4 Minor Arterial	Road 5/6 Collectors
Place Category	Extremely high			
	Very high			
	High			
	Medium			
	Low			

Figure 3. Roadway Classification Framework.

Validation process

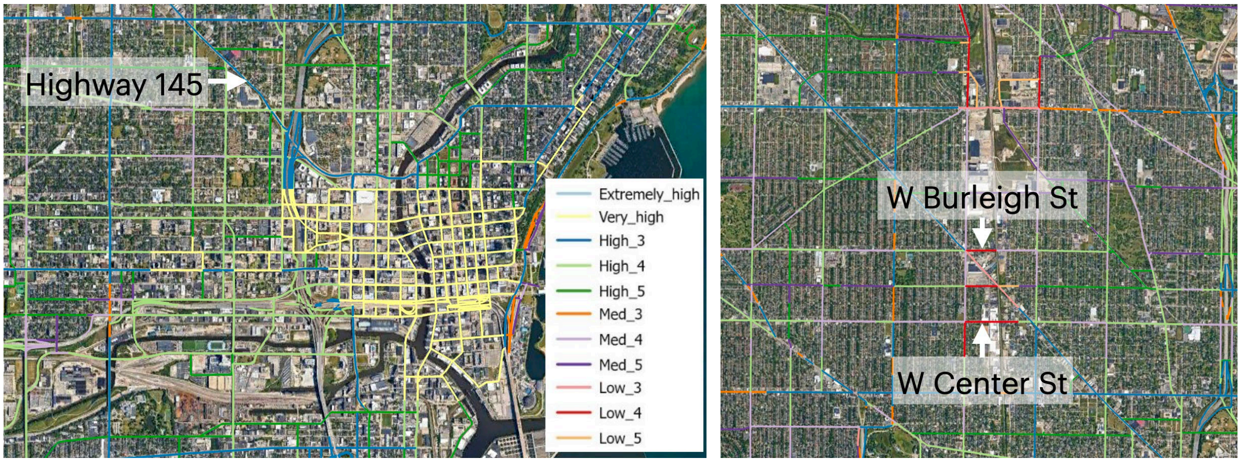
To test and assess the practicality of our roadway classification framework, we employed both internal and external validation processes. For internal validation, we examined how well our objectively-calculated *Place* categories matched our intuitive understanding of various roadway contexts in Wisconsin. We selected a representative sample of road segments from diverse settings, including bustling downtown areas, urban districts, commercial plazas, quiet suburban neighborhoods, and expansive exurban zones, capturing a range of road types. We then randomly selected segments from each category for detailed review using Google Earth and Google Street View. We evaluated qualities such as pedestrian friendliness, street layout, crosswalk accessibility, architectural styles, land use patterns, traffic flow, infrastructure quality, and public amenities (e.g., parks, religious institutions, educational facilities). Collaborative discussions within our team, leveraging our extensive expertise and local knowledge, were used to assess the effectiveness of our roadway classification framework. For external validation, we conducted interviews with representatives from the Departments of Transportation (DOTs) in New Mexico, Tennessee, and Wisconsin to obtain feedback on our approach. The interviews addressed three main areas: the backgrounds of the interviewees, their current practices in SLS, and their evaluation of our methodology and results. The interview scripts were approved by the University of California, Berkeley Institutional Review Board (IRB) under protocol ID: 2024-04-17384.

Internal validation

Extremely high and very high *Place* road segments were predominantly concentrated in the downtown areas of major cities across the six states (Figure 4). Extremely high *Place* segments were primarily located in downtown Boston, MA, Seattle, WA, and Portland, OR. In contrast, very high *Place* segments were found in Boston, MA, Seattle, WA, Portland, OR, Milwaukee, WI, Nashville, TN, and Albuquerque, NM. We also analyzed high, medium, and low *Place* segments across road classifications 3, 4, and 5/6 in Milwaukee and Oshkosh, WI, using Google Street View and team insights for verification. Due to constraints with reporting and publication when using Google Street View, our observations were reported only using Google Maps (aerial view).

Figure 4. Application of Roadway Context Classification in Six Regions

Figure 5 provides two aerial views of Downtown Milwaukee with the road segments clustered into their respective categories. Very high road segments cluster primarily in downtown Milwaukee, specifically Westown and Juneau Town neighborhoods. Along Highway 145, although it may be seen as a main trunk connecting the northwest suburbs of Milwaukee to the city's downtown, the majority of the route is categorized as high *Place*. This is primarily due to higher non-auto orientated street density, closer access to transit, and having little to no industrial employment in the area. There is one section along the roadway between W Center St and W Burleigh St where the roadway becomes a low *Place* because in this stretch of road, the area becomes more industrial with a recycling center and a transit hub. In Street View images from randomly selected high *Place* areas along Highway 145, there are sidewalks, businesses, residences, bus stops, and, in some cases, bike lanes.



a b

Figure 5. Aerial views of Downtown Milwaukee, WI with road segments clustered into their respective categories.

Similarly, as shown in Figure 6, in Oshkosh, W 9th Street to the east of I-41 is categorized as high *Place* due to the commercial plaza. Although density and street-density intersection are low in this area, the area is highly mixed, does not include industrial areas, and has high access to public transit, making this area a high *Place*.

Figure 6. Aerial view of a commercial plaza in Oshkosh, WI.

Additionally, we examined areas with high industrial activity to test the effectiveness of our categorization methodology. We found that without accounting for the industrial percentage, industrial areas were often misclassified as higher *Place* due to their high diversity scores. To address this, we incorporated an industrial percentage variable (i.e., % industry) to adjust for such areas. For example, Figure 7a shows W Silver Spring Drive in Milwaukee, Wisconsin. Before including the industrial percentage, the segment between I-41 and Route 145 was classified as a high *Place* despite its industrial nature, wide roadway with a median, and proximity to an airport. After adding the industrial percentage variable, this segment was reclassified as a medium *Place*. The area features sidewalks on the eastbound side, warehouses, distribution centers, manufacturing facilities, heavy machinery, and transport depots.

Similarly, in Oshkosh along Route 91, we observed a highly industrial area. Figure 7b presents an aerial view of this road segment. Initially categorized as a medium *Place*, the segment is surrounded predominantly by manufacturing facilities and industrial businesses. After incorporating the industrial percentage variable, it was reclassified as a low *Place*. Street View images reveal that the area is primarily farmland, lacking sidewalks, featuring low density, minimal non-auto-oriented street design, and limited transit access.

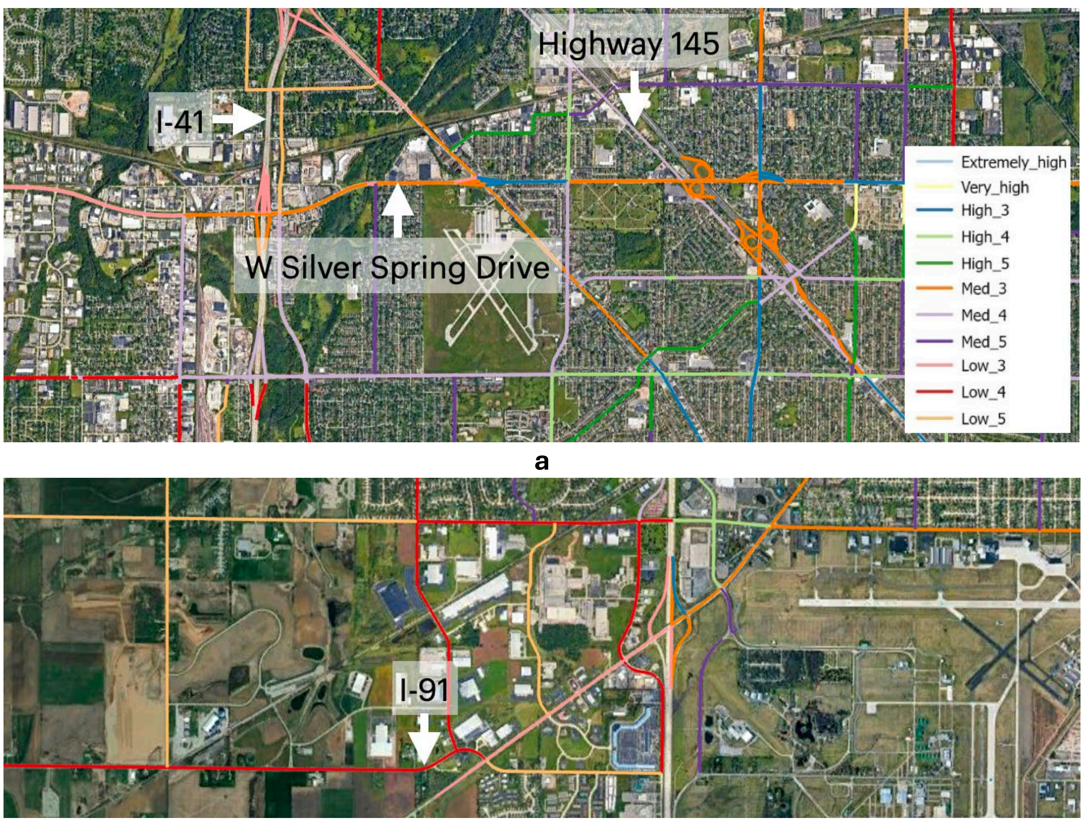


Figure 7. Aerial Views of Industrial Areas with Road Segments Clustered into Their Respective Categories. (a) W Silver Spring Drive (Milwaukee, WI). (b) Route 91 (Oshkosh, WI).

External validation

We summarize insights from three anonymous experts in transportation and road safety, each from a state DOT, who were interviewed to evaluate our roadway classification results. The first expert, a senior official in metropolitan and regional transportation planning, has seven years of experience managing active transportation projects from design through planning. The second expert, a Safety Engineer with five years of experience at a central office, oversees speed limit policies, reviews deviations from statutory limits, conducts speed studies, and coordinates with regional offices. The third expert, from the Active Transportation Office, specializes in GIS and data analysis for speed setting, and regularly reviews projects to adjust or reevaluate speed limits, particularly for vulnerable road users.

Shared insights

The interviews highlighted the crucial role of appropriate speed limits in enhancing road safety. All interviewees stressed the importance of setting speed limits that consider local contexts and address the needs of vulnerable road users. They concurred that a well-informed SLS process and well-calibrated speed limits are vital for reducing road traffic incidents and improving overall road safety.

Several challenges in current speed limit practices were identified. A major concern is the reliance on outdated methodologies, such as the 85th percentile rule, which may not adequately address modern road safety needs, particularly for vulnerable users. Additionally, inconsistent policies across regions contribute to variability in speed limit enforcement and effectiveness. The decentralized decision-making process has led to fragmented and inconsistent regulations. Furthermore, the lack of up-to-date, comprehensive data impedes the ability to make informed, evidence-based decisions about speed limits.

Feedback on the proposed project approach was largely positive. Interviewees valued the contextual approach to speed limit setting and recognized its importance in addressing place-specific conditions. They generally agreed with the classification results from representative examples shared for their states, supporting the classification framework. Despite challenges in obtaining and utilizing comprehensive data, all interviewees considered the SLD data as a valuable resource. It provides a national, standardized dataset that represents the activities of vulnerable road users, offering a solid foundation for improving SLS processes. While they acknowledged the potential benefits and their desires of incorporating state-specific data to complement the methodology, they understood the necessity of using the nationally standardized SLD. State-specific data, though detailed, is not uniformly collected or available across all states.

Interviewee-specific insights

The first interviewee expressed concerns about excluding local roads (road class 7) from the analysis, emphasizing their crucial role in a comprehensive evaluation while also acknowledging the computational challenges that their inclusion might introduce. The interviewee also raised issues related to statutory speed limits (set at the state level), such as the 30-mph restriction in residential areas, and highlighted the procedural difficulties in adjusting these limits. The interviewee expressed interest in integrating their own data on sidewalks and bike lanes for local implementation and stressed the importance of including road characteristics data—such as lane width, curvature, and surface conditions—when available, to enhance context-sensitive SLS. Additionally, they pointed out the ongoing challenge of obtaining current and comprehensive data across various road types and regions and suggested incorporating studies on high-injury segments, yet noting that such data is currently available only for certain major cities in the state.

The second interviewee explained that their state DOT relies on observed speed data, including average and 85th percentile speeds, particularly for highways serving small communities. The agency also collects speed data and engages with local communities. However, challenges arise when communities request lower speed limits without making significant changes to the roadway context, such as road width. Such requests often fail to achieve reduced vehicle speeds. Additionally, implementing infrastructure changes, like adding curbs or medians, to promote lower speeds in rural areas is often prohibitively expensive for small communities, making it difficult to justify or support lower speed limits in these contexts. The interviewee also mentioned difficulties in collecting and utilizing the necessary supporting data and the challenge of addressing stakeholders' adherence to established standards rather than considering the specific roadway context. They suggested incorporating traffic volume data or Annual Average Daily Traffic (AADT), which is generally available across states, and recommended considering additional factors such as driveway density, access points, and building setbacks. While these factors could provide valuable insights for setting speed limits, the interviewee noted that obtaining such detailed data is technically challenging.

The third interviewee indicated that the current process for setting speed limits usually involves maintaining the design speed unless a city explicitly requests a change. They noted that smaller cities often defer to state authorities due to a lack of familiarity with the process, resulting in speed changes occurring primarily in larger cities with more experience. Cultural resistance to lowering speeds, driven by concerns about increased travel time and congestion, also presents a significant challenge. Some state residents believe that reduced speeds could potentially increase crash rates. The interviewee observed that current road safety projects primarily focus on crash rates, advocating for a broader approach that includes various factors to enhance speed limit setting. They emphasized that relying solely on crash data can lead to a reactive approach. Instead, predicting high-risk areas and implementing preventive measures, such as context-sensitive speed limit setting, could be more effective. For further improvement, the interviewee recommended incorporating statewide sidewalk data if conducting a state-level study, noting that their agency has a comprehensive sidewalk layer for the entire state. They also referenced an ongoing project to develop statewide land use data at the parcel level, which would be valuable once completed. Additionally, they suggested considering a weighting scheme for composite score calculations and customizing the approach based on local data and needs. Tailoring the framework to specific cities and fine-tuning it with available local data could optimize implementation.

Discussion

Our exploration underscores the potential for the United States to transition towards a context-sensitive approach to objectively setting speed limit while considering locational context, or *Place*. We demonstrate the viability of this approach through the development of a US street category framework. By adopting a data-driven methodology, we leverage publicly available datasets capturing functional classification (*Movement*) through FHWA HPMS and variables associated with vulnerable road user activity (*Place*) through EPA SLD, including land use mix, household density, job density, pedestrian-oriented street density, and transit accessibility. This approach enables the objective identification of road segments with varying levels of *Place* and *Movement*, enhancing the effectiveness of speed limit regulations and removing subjectivity from the SLS process. As shown by the validation, our classification framework also ensures the visual intuitiveness of the street categories, which should correspond to the road users' natural instinct to adjust driving speed in the corresponding locational context. Establishing an objective, context-sensitive street classification framework for US jurisdictions represents a significant step in removing technical barriers to adopting a Safe System Approach to SLS. This framework not only facilitates the achievement of *Safe Speeds* but also holds the potential to reduce pedestrian and bicyclist fatalities and serious injuries.

Below, we discuss the measures undertaken and discretion made during data processing and analysis, along with their implications on the results. First, we explored the integration of road class into the clustering analysis. However, we decided against it due to potential inconsistencies in thresholds across different road classes (e.g., classes 3, 4, and 5), which could lead to non-uniformity in composite *Place* scores. For instance, a road segment classified as class 3 with "low *Place*" might have a higher *Place* composite score than one classified as class 4 with "medium *Place*".

Second, we opted for five-tier *Place* levels, encompassing "extremely high", "very high", "high", "medium", and "low", as this number of clusters appeared to offer optimal interpretability. This is mainly because additional clusters would have only resulted in further subdivisions within the "extremely high" *Place* category, leading to the continual separation of cities within that cluster and the emergence of new clusters primarily centered around downtown areas in Boston and Milwaukee, for example. This would essentially add less meaningful information in the context of speed limit setting. Therefore, opting for a five-tier system ensured that the granularity remained meaningful and relevant within the context of our analysis.

Third, we explored the potential of employing advanced statistical analyses and data processing techniques. Principal Component Analysis (PCA) was utilized to distill principal components explaining covariances among the five selected variables indicative of "placeness". Additionally, we experimented with calculating a single entropy measure to represent land use diversity, excluding industrial use, as an alternative to including both D2A_EPHHM and % industry. However, we chose not to adopt these methods as they yielded results largely consistent with simpler approaches. This decision ensures a more accessible methodology, facilitating adaptation by transportation practitioners in local agencies.

Fourth, various weighting schemes were explored during the construction of the *Place* composite score. These included: 1) assigning equal weights to all five variables; 2) emphasizing 50% weight for density (D1A) and equal weights for other four variables; 3) allocating equal weights across Density (D1A), Diversity (D2A_EPHHM and % industry), Non-Auto-Oriented Street Density (D3B), and Transit Accessibility (D4A); 4) equalizing weights within three categories: Density (D1A), Diversity (D2A_EPHHM and % industry), and Design (D3B and D4A). The first weighting scheme could potentially lead to an overemphasis on non-industrial land use diversity. For instance, a neighborhood featuring parks, hospitals, and local shops might be categorized as "high *Place*" despite having relatively low density. Conversely, the second weighting scheme appears to systematically under-categorize by one-tier compared to the third and fourth weighting schemes. This results in purely residential areas being labeled as "very high *Place*". Upon comparisons, the fourth weighting scheme emerged as the most balanced approach, effectively capturing the multidimensional nature of "placeness" while maintaining simplicity and interpretability as it adheres to the traditional 3D convention. Therefore, we have chosen the fourth weighting scheme, as presented earlier, for its suitability in our analysis.

Finally, while our study focused solely on urban road segments, future research could explore the differences in driving behaviors between urban and rural areas. Recognizing these disparities can further enrich our understanding of speed limit setting and road safety strategies. Urban environments, with their frequent intersections and pedestrian activity, contrast with rural areas, characterized by expansive, obstacle-free road stretches conducive to higher speeds. Incorporating these distinctions into future research can contribute valuable insights to transportation planning and policy development.

Conclusions and Recommendations

Historically, the process of setting speed limits in the United States has predominantly relied on an engineering approach, often determined by the 85th percentile of free-flowing traffic speeds. While this method has provided a standardized approach, it primarily caters to the preferences and behaviors of car drivers and may not fully consider the diverse environments and needs of all road users. Consequently, there has been a growing recognition of the importance of incorporating locational contexts into the speed limit setting process. However, despite this recognition, there has been a lack of objective approaches to integrate locational context into the speed limit determination process. This gap has left many roads with speed limits that may not align with the surrounding environment or adequately address the safety concerns of vulnerable road users such as pedestrians and cyclists.

In our work, we address this challenge by demonstrating the viability of an objective approach that leverages publicly available data. By developing a framework that considers both *Movement* and *Place* factors, inspired by the leading model of New Zealand's street category framework, we provide a systematic methodology for incorporating locational context into speed limit regulations.

While our study did not explore the entire US, with results based on data from six states, the framework we propose lays the groundwork based on a context-sensitive approach and would enable individual agencies to complete that step according to local needs. Moving forward, we encourage further research and collaboration to expand our framework to encompass the entirety of the United States or tailor to local needs. By fostering dialogue and cooperation among transportation agencies at all levels, we can refine and adapt our methodology to local contexts while ensuring consistency and effectiveness in speed limit regulations nationwide. Ultimately, the roadway classification and SLS process considering contextual factors would help create safer and more inclusive roadways that prioritize the well-being of all users and better reflect the diverse needs.

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