To: City of Bend Citywide Transportation Advisory Committee
Attn: Nick Arnis, Susanna Julber, and Eric King
From: Steve Porter and Michelle Porter, Residents of Bend
Date: July 13, 2018

Public Comment:

Evidence Demonstrating the Efficiency, Safety & Economic Benefits of 20mph Speed Limits

Dear Bend Citywide Transportation Advisory Committee:

As you develop plans for Bend's transportation system, we encourage you to consider a 20 miles per hour (20mph) maximum speed limit for Bend's residential and non-arterial urban roads in a manner consistent with Oregon Revised Statute 810.180.

Below, we outline empirical evidence showing that conversion to a 20mph default speed limit promotes significant improvements not only in transportation system safety, but efficiency as well – including the counterintuitive result of reduced traffic congestion. We also show that such change would require minimal initial investment and generate substantial economic returns.

Since the Bend City Council is pursuing a goal to "Move people and products around Bend efficiently, safely and reliably," we believe adopting a system-wide maximum speed limit of 20mph on residential and urban streets is appropriate. Such change directly addresses each element of this City Council goal in a fiscally responsible manner, and the change is within the City's legal capabilities, as provided for by Oregon State Law.

SUMMARY

It is tempting to dismiss the difference between 25mph and 20mph speed limits as marginal and unimportant. However, volumes of data indicate the contrary, showing that dramatic social and economic gains follow from that 5mph reduction.

For one, significant improvements in transportation system safety occur. When 20mph speed limits are installed in urban and residential streets, citywide risks of serious injury and fatality among pedestrians and cyclists drop by 40% and 30%, respectively. These and similar effects elevate both actual and perceived safety levels for all transportation system users.

With those changes in safety levels, modal substitution rates increase. Data show that as speed limits approximate 20mph, a “tipping point” is reached where widespread adoption of non-vehicle transport occurs. This has a profound effect on vehicle miles traveled (“VMTs”) in 20mph systems. A decrease in Bend’s speed limits to 20mph would be expected to reduce VMTs by about 5%, or 30.5 million miles annually.

Slower traffic speeds, lower VMTs, and increased rates of walking and cycling improve public health and generate economic gains. It is estimated that $7.2 million in annual savings would result from reduced traffic collisions in Bend under a 20mph speed limit system. Other economic consequences include reduced fuel usage and pollution levels. Reduced annual fuel consumption of about 1.4 million gallons would be anticipated, saving Bend’s drivers $4.5 million per year. Decreased air and noise pollution levels would result in one-time in-kind economic gains of $169.4 million and additional yearly social and environmental damages savings of $1.6 million.

Road maintenance savings would also be realized. Estimated to save Bend roughly $1.1 million per year, a 20mph speed limit system would quickly pay for itself since implementation costs are estimated at about $60,000.

All told, if Bend were to make a commitment to 20mph speed limits in a manner consistent with Oregon Revised Statute 810.180 and enforce those speed limits adequately, it would stand to generate one-time economic benefits of $169.4 million and ongoing annual economic savings of $14.4 million - for implementation costs of $60,000.

The following report details empirical research and calculations supporting each point in the above summary. Naturally, all findings are subject to certain data limitations and may be revised in the event additional information becomes available. This report accordingly may be best viewed as preliminary; nevertheless, reasonable professional care has been taken to ensure accuracy and, where applicable, conservatism in estimation.

INTRODUCTION

Over the last few decades, hundreds of municipalities, encompassing tens of millions of residents in North America and Europe, have adopted 20mph speed limits. Cities including Washington, D.C., New York City, Seattle, and, as of April 2018, Portland, Oregon,[1] are among them, as are smaller towns, with populations similar to Bend's.[2]

These cities form natural laboratories for assessing the policy. Substantial quantitative research has taken place across them to evaluate traffic mortality rates, pollution levels, and transportation system throughput, among many other variables. There is accordingly a wealth of "real-world" empirical evidence drawn from locales that have made 20mph their system-wide default speed limits.[3]

The evidence shows that all participants in a transportation system are benefited by reduced speed limits, and, of equal importance, no participants are made materially worse off. Such findings demonstrate a high level of efficiency associated with implementation of 20mph default speed limits: the transportation system is made unambiguously better in a 20mph regime since no one must incur losses in order to confer benefits on others.

Findings associated with 20mph speed limits will be thematically presented as follows: 1) Safety; 2) Traffic Congestion; 3) Fuel Consumption; 4) Pollution; 5) Road Capacity and Infrastructure Spending; and 6) Public Health. Where sufficient data are available, the economic implications of transition to 20mph speed limits will be evaluated within each of these areas. Finally, conclusions following from these analyses will be presented.[4]

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[1] New York City was the first U.S. city to adopt a 20mph program, which it did according to a zoning approach in which certain zones adhere to the 20mph standard while others do not. Under this approach, traffic deaths fell for three consecutive years, declining by approximately 23% in total. Portland's implementation of the 20mph program reduces speed limits on "non-arterial residential streets, which comprise about 70 percent of the city's street grid." New signs were posted citywide in April 2018.

Lazo, L., "As Traffic Deaths Soar, Cities Pursue Lower Speeds to Eliminate Fatalities," *The Washington Post* (February 25, 2017).

Nius, E., "Portland City Council Approves 20 mph Speed Limit on Residential Streets," *The Oregonian* (January 18, 2018).

Seattle Department of Transportation Website, "20 MPH Zones" (accessed May 2018).

[2] 20mph is the default speed limit in most European towns, as well as many towns in the UK, encompassing all population sizes.

[3] In the context of Bend, the terms "system-wide" and "default" are meant to refer to the majority of roads in Bend currently designated with 25mph speed limits, in a manner consistent with Oregon Revised Statute 810.180: "A road authority may establish by ordinance a designated speed for a highway under the jurisdiction of the road authority that is five miles per hour lower than the statutory speed," subject to certain considerations and limitations. Roughly 593 lane-miles in Bend are estimated to be immediately eligible for 20mph limits.

[4] In general, the analysis of social and economic effects relating to 20mph speed limits evaluated in this report can be thought of as reflecting an "average" level of implementation, including placement of 20mph signage along with some measures of public education, enforcement, and traffic calming. "Average" implementation reflects the typical level of signage and ancillary supportive policies adopted by localities moving to 20mph speed limits.

DISCUSSION

1. Improved Safety for All Transportation System Participants

Improved safety outcomes extend from automobile drivers and their passengers to pedestrians, cyclists, and residents in 20mph systems, affecting essentially all those using the transportation system and living or working near it. These benefits derive from reduced traffic collisions, diminished severity of crashes, and decreases in non-traffic crime levels. Each element is addressed in turn, and a detailed evaluation of collision reduction is provided.

The most salient gauge of transportation system safety is found in the quantity of traffic collisions that occur. An ideal system would generate zero collisions and feature safeguards such that, if one were to transpire, it would be of the least serious type. A statistical relationship has been observed between traffic speed changes and corollary changes in the number of crashes. It shows that a decrease in average traffic speed from 25mph to 20mph (which represents a 20% reduction in speed) is associated with:

- a 45% decline in fatal collisions;
- a nearly 30% decrease in collisions resulting in serious injury; and
- a 20% reduction in collisions resulting in minor injury.[5]

Standalone empirical observations (detailed below) that relate to cities adopting 20mph speed limits corroborate these findings. A 20mph default speed limit brings transportation systems closer to a collision-free ideal.

In addition to reduced collision counts, the severity of any collisions that do occur also declines, with a disproportionately large decrease in the worst types of automobile accidents that result in death or serious injury.[6]

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[5] It can be noted, as a logical matter, that actual traffic speeds need not necessarily change just because posted speed limits change. While this is true, it has been empirically observed that 1) a proportion of traffic does adhere to posted limits; 2) a portion of traffic that does not adhere to posted limits tends to "anchor" its speeding against the posted limit (e.g., these speeders will exceed whatever the limit is by X mph); and 3) when posted traffic speed limits change, the average traffic speed changes along with it, in the range of nearly 100% of the change (i.e., if the speed limit declines 5mph, then so will the average traffic speed decline 5mph) to 25% of the change. Due to non-linearity and feedback effects, even 25% of a 5mph decline in average speeds (i.e., a 1.25mph reduction) that brings traffic closer to 20mph can have profound safety and efficiency consequences. When enforcement or traffic calming is added alongside speed limit reductions, compliance is further enhanced.

Elvik, R., "The Power Model of the Relationship Between Speed and Road Safety: Update and New Analyses," Institute of Transport Economics, Norwegian Centre for Transport Research (2009).

"Vision Zero: How Safer Streets in New York City Can Save More Than 100 Lives a Year," Drum Major Institute for Public Policy and Transportation Alternatives (June 2011).

[6] Sammer, G. and F. Wernsperger, "Results of the Scientific Investigation Accompanying the Pilot Trial of 30 kph Limit in Side Streets and 50 kph Limit in Priority Streets," The 23rd European Transport Forum: Proceeding of Seminar G: Traffic Management and Road Safety (September 1995).

This favorable redistribution occurs because of the non-linear relationship between speed and crash severity.[7] As speeds approximate 20mph, mortality and injury risks dramatically decrease in collisions, an effect that will be detailed below. In summary, at lower speeds, drivers have more time to react to events precipitating possible collisions, improving odds of avoiding accidents, and the harm of any crash that does happen is reduced.[8]

This section will focus on statistics showing the level of safety improvement in 20mph systems as reflected by crash counts and severity. These numbers are among the most reliably tallied and studied quantitative elements of transportation systems and therefore provide a useful starting point for understanding the safety implications of 20mph speed limits.[9] They are not, however, comprehensive.

Empirical findings reveal that improved traffic safety enhances non-traffic street safety in 20mph corridors. Reductions in personal and property crime follow from reduced traffic speeds. As more people feel safer walking, cycling, and otherwise contributing to "street life"[10] (an effect encouraged by slower traffic), circumstances conducive to crime dissolve.[11] In this way, a positive feedback mechanism emerges: just as traffic safety is increased with a 20mph system, so too is general safety enhanced. And as general safety gives rise to invigorated street life, yet more people walk, cycle, and participate in street life, which further buoys safety levels;[12] thus,

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[7] Grundy, C., et al., "Effect of 20mph Traffic Speed Zones on Road Injuries in London, 1986-2006: Controlled Interrupted Time Series Analysis," *British Medical Journal*, Vol. 339 (2009).

[8] Two empirical studies observe a "spillover effect" where reduced speed limits on targeted roads lead to reductions in speeding on roads with unaltered speed limits. This implies broader life-saving implications for 20mph speed limit systems than those reflected in analyses solely addressing collisions on 20mph streets and, indeed, evidence shows that, once 20mph speed limits are established on a critical mass of streets, fatalities on non-20mph streets fall by an average of 8%, up to 11.5%. (Archer, J., et al., "The Impact of Lowered Speed Limits in Urban and Metropolitan Areas," Monash University Accident Research Centre (2008). Grundy, C., et al., "Effect of 20mph Traffic Speed Zones on Road Injuries in London, 1986-2006: Controlled Interrupted Time Series Analysis," *British Medical Journal*, Vol. 339 (2009).)

[9] Statistics in this section derive from numerous studies that reflect findings from New York City and the UK, where the most empirical work has been done to evaluate 20mph speed limit safety. Importantly, these regions all reduced speed limits to 20mph from 30mph, rather than from 25mph as would be done in Bend. This has the logical effect of causing reported statistics to likely overstate the level of collision and mortality reductions that would be observed in Bend following 20mph implementation. These figures nevertheless provide important reference points relating to 20mph speed limit safety and, in all events, provide useful directional evidence showing the relationship between 20mph speed limits and road collisions, deaths and serious injuries.

[10] Tovar, M. and Kilbane-Dawe, "Effects of 20mph Zones on Cycling and Walking Behaviours in London," Par Hill Research Ltd. (2013).

Bristol City Council, "Monitoring Report: 20mph Speed Limit Pilot Areas" (2012).

[11] Cairns, J., et al., "Go Slow: An Umbrella Review of the Effects of 20mph Zones and Limits on Health and Health Inequalities," *Journal of Public Health*, Vol. 37, No. 3 (2015).

[12] Jacobsen, P., "Safety in Numbers: More Walkers and Bicyclists, Safer Walking and Bicycling," *Injury Prevention*, Vol. 9 (2003).

increased *traffic* safety serves to enhance *general* safety, and vice versa.[13] "Both ideas of safety - traffic and crime - are served by the same quality: people, and their eyes on the street. Sidewalks busy with pedestrians are a crime deterrent. More people on the street - including on bikes - creates safety in numbers."[14] Overall safety levels thereby increase well beyond what is implied solely by collision statistics.[15] As one researcher summarizes:

> Nor can the safety benefits be measured only by the reduction in the number and severity of accidents. It was seen…that the introduction of 20 mph zones in Britain and their equivalent on the Continent has not only reduced accidents but has transformed the way streets are used. Conditions for walking and cycling have greatly improved and street life generally has flourished, to the very great benefit of the people concerned.[16]

Notwithstanding the limitations of traffic collision and mortality statistics in reflecting safety gains associated with 20mph systems, representative statistics are outlined below showing traffic safety improvements that have occurred upon adoption of 20mph speed limits. As applicable, discussions of specific factors underpinning these reductions and implications for Bend are provided.[17]

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[13] One approach to quantifying perceived safety levels is found in reports of aggressive driving. Since aggressive driving is a highly visible behavior, its prominence can serve as a proxy measure for perceived safety levels. Statistics show that people observe 40% less aggressive driving behaviors in 20mph zones.

Department for Transport, "Interim Evaluation of the Implementation of 20mph Speed Limits in Portsmouth" (2010).

[14] Sadik-Khan, J. *Streetfight*, Viking (2016).

[15] Aiyer, S., et al., "From Broken Windows to Busy Streets: A Community Empowerment Perspective," *Health Education & Behavior* (2014).

Zimmerman, M., "Forget Broken Windows: Think 'Busy Streets'," CityLab (Mary 18, 2018).

"How to Cut the Murder Rate," *The Economist* (April 5, 2018).

[16] Plowden, S. and M. Hillman, *Speed Control and Transport Policy*, Policy Studies Institute (1996), Ch. 10.

[17] The following studies are cited in this section:

Webster, D. and A. Mackie, "Review of 20mph Zones in London Boroughs," Transport Research Laboratory (2003).

Sammer, G. and F. Wernsperger, "Results of the Scientific Investigation Accompanying the Pilot Trial of 30 kph Limit in Side Streets and 50 kph Limit in Priority Streets," The 23rd European Transport Forum: Proceeding of Seminar G: Traffic Management and Road Safety (September 1995).

Department for Transport, "Interim Evaluation of the Implementation of 20mph Speed Limits in Portsmouth" (2010).

"Road Safety Factsheet: 20mph Zones and Speed Limits Factsheet," Royal Society for the Prevention of Accidents (November 2017).

Department for Transport Traffic Advisory Leaflet 9/99 (June 1999), "20 mph Speed Limits and Zones."

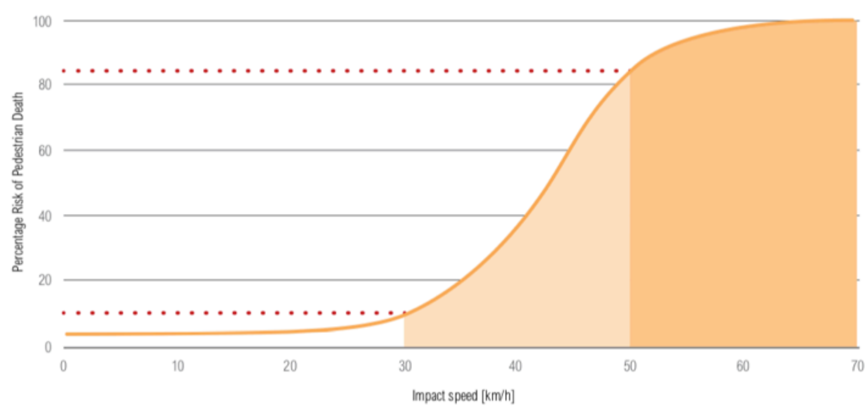
New York City Department of Transportation Website: "Motorists & Parking, Neighborhood Slow Zones" (accessed June 2018).

Pedestrians

Pedestrian involvement in killed-or-seriously-injured collisions ("KSI collisions") has been shown to decrease by 39% to 50% in 20mph systems.

The fatality risks to pedestrians decline as speed limits fall toward the 20mph mark because of the non-linear relationship between pedestrian risk and vehicle speed in collisions. This speed-safety link is illustrated in Figure 1, originally published in the "Cities Safer by Design" manual of the World Resources Institute, based on OECD research. A clear inflection point can be found when vehicle speeds exceed 20mph, shown on the graphic at 30kph. (Since the graphic derives from research conducted in OECD countries, it uses the international standard kilometers per hour ("kph") instead of mph; a speed of 30kph is approximately equal to 20mph, a speed of 40kph is approximately equal to 25mph, and a speed of 50kph is approximately equal to 30mph.)

Figure 1

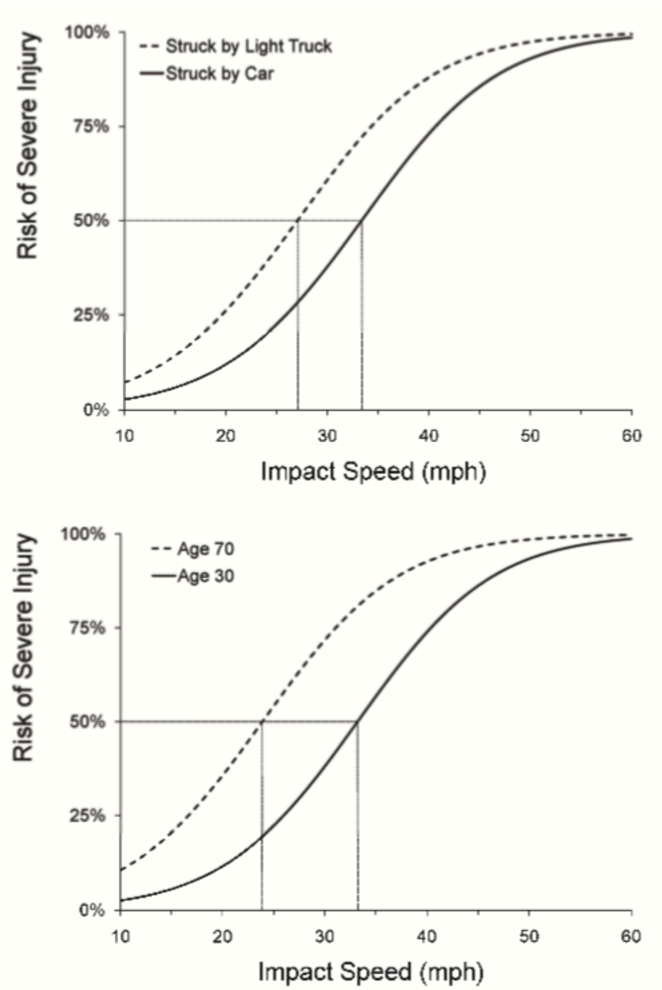


Note: The above figure shows the relationship between pedestrian fatalities and vehicle impact speed published by the OECD (2006). Some recent studies show a similar relationship, but account for sample bias to find slightly lower risks in the 40 to 50 km/hr range. (Rosen & Sander 2009, Tefft 2011, Richards 2010, Hannawald and Kauer 2004) There are not, however, studies from low- and middle-income countries where things like vehicle type, emergency response time and other characteristics may influence this relationship. In any case, there is clear evidence to support policies and practices that lower vehicle speeds to 30 km/hr where pedestrians are commonly present, and no more than 50 km/hr on non-grade separated streets.

The implications of non-linearity in pedestrian mortality risk vis-a-vis automotive speed are striking. It has been found that a pedestrian in contact with a vehicle traveling 30mph is *eight times more likely to die* than in a collision with a vehicle traveling 20mph.[18] Across speeds ranging from 25mph to 20mph, it is shown that each 1mph difference in vehicle speed reduces fatality risk by about 6%, such that a pedestrian's fatality risk *doubles* with an

[18] "Vehicle Speed and Pedestrian Age Determine Crash Outcomes," *Status Report* (Insurance Institute for Highway Safety/Highway Loss Data Institute), Vol. 35, No. 5 (May 2000).

Figure 2



impact speed increase from 20mph to 25mph. Seemingly marginal reductions in traffic speeds within the crucial speed range of 20mph to 25mph have robust impacts on pedestrian mortality.[19]

Beyond fatalities, severe injuries among pedestrians also are substantially mitigated with 20mph speed limits. And, as with fatality risk, a non-linear relationship between injury risk and automotive speed is observed, with a critical inflection point in the slope occurring around 20mph. Figure 2 shows two representations of empirical data, both of which illustrate pedestrians' risk of severe injury plotted against vehicle speed. The top graphic highlights the significance of vehicle type, showing that light trucks (including pickups and SUVs) are more inimical to pedestrians than passenger cars since trucks tend to knock down and then run over victims, while cars tend to roll victims over the windshield, the former being much more damaging to a human body. The second graphic highlights the significance of pedestrian age, showing that the elderly are particularly endangered in collisions.[20]

These findings are emphasized here because both have critical importance for Bend. In the first instance, Bend traffic is heavily populated by light trucks and SUVs, consistent with broader trends in the U.S.[21] In the second instance, Bend's elderly population is large and growing, owing to Bend's prominence as a retirement destination. Bend's senior citizen population increased 43% from 2011 to 2016,[22] now comprising 15.5% of the

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[19] Barrios, L., "Killing Speed," Injury Prevention, Vol. 6 (2000).

Tefft, B., "Impact of Speed and a Pedestrian's Risk of Severe Injury or Death," *AAA Foundation for Traffic Safety* (September 2011).

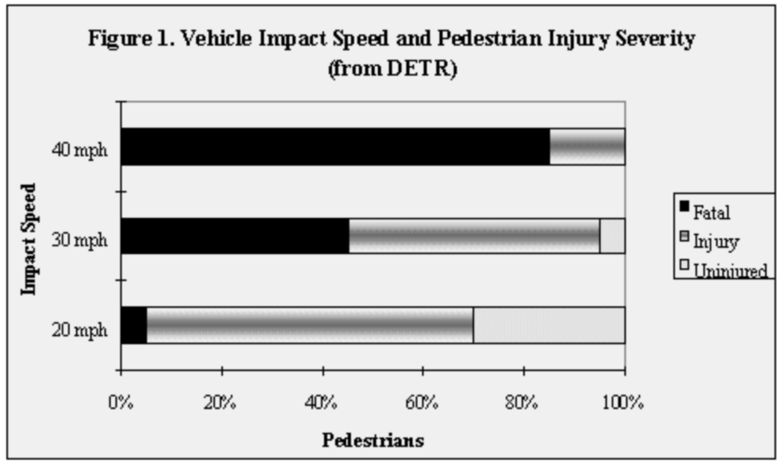
[20] Tefft, B., "Impact of Speed and a Pedestrian's Risk of Severe Injury or Death," *AAA Foundation for Traffic Safety* (September 2011).

[21] Carey, N., "Trucks, SUVs Shine in Mixed January Sales, Cars Less So," *Reuters* (February 1, 2018).

[22] Mesh, A., "Bend Is Where Old People Go to Retire," *Willamette Week* (November 20, 2016).

populace, with the over-65 population in Bend expected to reach 26,000 people in 10 years.[23] This places special duty on Bend's transportation system to meet the safety needs of this cohort of users. For these reasons, emphasis should be placed on these vehicle-type and age-related findings, and additional consideration should be given to the severity of light truck collisions involving the elderly, mortality and injury statistics for which are not available.

Figure 3



The foregoing logic and empirical results are distilled into summarized findings of a review conducted by the U.S. Department of Transportation into the nexus between traffic speed and pedestrian risk, regardless of vehicle type or pedestrian age. As illustrated in Figure 3, a critical threshold of traffic speed is found at 20mph, a speed above which is found a surge in pedestrian fatality and injury.[24]

An acute relationship between pedestrian well-being and traffic speed is well established. At speeds above 20mph, collision incidence rates are higher and those collisions result in worse and more likely fatal injuries. Research conducted in connection with pedestrian risk of mortality and severe injury therefore emphasizes the importance of keeping pedestrian activity removed from high-speed traffic (i.e., traffic traveling much above 20mph), and the most straightforward way of separating pedestrians from high-speed traffic is by reducing traffic speeds to acceptably safe levels (i.e., approximately 20mph) on residential and urban roads.[25]

Children

Children are especially susceptible to roadway injury and death, in part because of their smaller stature and in part because of their undeveloped physiology. It has been demonstrated that children do not perceive approaching vehicles or process that information in the same manner as adults, so they tend to misjudge traffic and be struck

[23] Across the U.S., those 65 and older account for under 15% of the population, placing Bend well above national averages.

Draft Bend Park & Recreation District Comprehensive Plan (May 2018).

United States Census Bureau, "Facts for Features: Older Americans Month: May 2017," Release Number CB17-FF.08 (April 10, 2017).

[24] "Literature Review on Vehicle Travel Speeds and Pedestrian Injuries," U.S. Department of Transportation, National Highway Traffic Safety Administration (October 1999).

[25] Tefft, B., "Impact of Speed and a Pedestrian's Risk of Severe Injury or Death," *AAA Foundation for Traffic Safety* (September 2011).

by automobiles. Crucially, it has been found that children cannot reliably detect an automobile approaching at speeds over 25mph, with better perceptivity at lower speeds.[26] This fact, on its own, argues strongly in favor of system-wide 20mph speed limits, particularly in Bend, where more than 6% of the population is under 5 years old, and 23.1% is under 18 years old.[27]

Consistent with these observations, empirical studies have found that 20mph speed limits are associated with dramatic reductions in child KSI collisions, with observed declines in the range of 45% to 67%.

Cyclists

The rate of cyclist involvement in KSI collisions decreases 29% to 50% with 20mph speed limits.

Drivers

Depending on the particulars of 20mph speed limit implementation, reductions in vehicular crashes of any type range from 15% to 50%. Additionally, collisions in which drivers are killed or seriously injured decrease in the range of 31% to 57%. Elderly driver injuries decline by approximately 50%.

Passengers

Passengers in automobiles are similarly benefited. A reduction in passenger deaths of 31% has been found in 20mph systems, and elderly passenger injuries have been shown to decline by 40%.

Motorcyclists

Motorcyclists experience 68% to 79% declines in casualties.

Economic Implications of Reduced Collisions

It is manifest that a human life defies economic valuation. Human health and well-being are similarly incalculable in worth. From a moral perspective, it may be stated that the loss of a single human life or the erosion of one person's well-being due to traffic accident outweighs any financial consideration; if a life can be saved through improved traffic management and planning, it should be done without resorting to amoral and base cost-benefit analysis of the type that assumes a human's death can somehow be compensated by fast enough traffic flows.

Notwithstanding these views, in the interest of completeness, it is appropriate to mention research that has estimated the economic costs associated with traffic collisions. Fatal crashes result in approximately $1.4 million in economic costs each, and crashes involving serious injury cost roughly $1.0 million per injured survivor. Medical costs and lost productivity comprise the majority of these financial losses, with additional contributions to cost

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[26] Wann, J., et al., "Reduced Sensitivity to Visual Looming Inflates the Risk Posed by Speeding Vehicles When Children Try to Cross the Road," *Physiological Science*, Vol. 22, No. 4 (2011).

[27] United States Census Bureau, "Bend, Oregon QuickFacts" (accessed June 2018).

coming from property damage and traffic congestion. Collisions in which only property damage occurs (i.e., those with no fatalities or injuries) carry an average cost of roughly $3,900 each.[28]

Applied to Bend's traffic collision statistics, these economic values can be used to estimate costs that stand to be saved through implementation of 20mph speed limits. Over the five year span 2011 through 2015 (the latest dates for which complete crash data are available via City of Bend online records), 13 fatal collisions occurred, and 82 traffic accidents involving major ("Level A") injuries occurred.[29] There were 1,707 reported crashes involving either moderate ("Level B") or minor ("Level C") injuries, and 2,581 damaging only property.[30]

Over this five-year span, the fatal collisions carried an imposed cost of $18.2 million; major injury collisions cost approximately $82.0 million; and, conservatively assuming zero medical or lost productivity costs for Level B and Level C injury collisions and property-damage collisions, costs of remaining traffic collisions equaled about $16.7 million.[31] Total calculated costs are therefore approximately $117.0 million, or about $23.4 million per year.

Were Bend to achieve average collision reductions via implementation of 20mph speed limits, it would be expected to experience total economic savings of approximately $7.2 million annually.[32] The particulars of those savings are as follows.

First, Bend would experience a reduction in fatal injuries of roughly 45% (from 13 to about 7 over a five-year window). This would save approximately 6 lives every 5 years and reduce economic losses by about $8.2 million ($1.6 million annually). Second, collisions generating Level A injuries would be expected to decrease by about 30%

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[28] Blincoe, L., et al., "The Economic and Societal Impact of Motor Vehicle Crashes," U.S. Department of Transportation, National Highway Traffic Safety Administration, DOT HS 812013 (May 2015 (Revised)).

[29] Level A injuries "include broken or distorted limbs, skull or chest injuries, abdominal injuries, unconscious at or when taken from the crash scene, unable to leave the crash scene without assistance, etc."

U.S. Department of Transportation, Federal Highway Administration, "KABCO Injury Classification Scale and Definitions" https://safety.fhwa.dot.gov/hsip/spm/conversion_tbl/pdfs/kabco_ctable_by_state.pdf (accessed June 2018).

[30] City of Bend Website, Bend Area Crash Data, "Bend Urban Area Crashes 2007-2016,": https://public.tableau.com/profile/bendmpo#!/vizhome/BendUrbanAreaCrashData07-16Preliminary/BendFatalAndMajorInjuryCrashes (accessed June 2018).

[31] Level B and Level C injuries may well implicate medical attention and productivity losses. Level B injuries are "visible injuries" that include those "evident to observers at the scene of the crash" such as "a visible lump, abrasions, cuts, bruises, minor lacerations, etc." Level C injuries "include momentary unconsciousness, complaint of pain, limping, nausea, etc."

U.S. Department of Transportation, Federal Highway Administration, "KABCO Injury Classification Scale and Definitions" https://safety.fhwa.dot.gov/hsip/spm/conversion_tbl/pdfs/kabco_ctable_by_state.pdf (accessed June 2018).

[32] Importantly, this analysis assumes that "but-for" collisions (i.e., collisions that will occur in the future if not for speed limit interventions) will not increase over time; any increase in but-for collision incidence would cause life and financial savings associated with 20mph speed limits to increase proportionately.

(from 82 to 57 over five years), resulting in saved costs of $24.6 million ($4.9 million annually). Third, remaining collisions would be anticipated to decline in incidence by about 20% (i.e, from (1,707 + 2,581) = 4,288 to 3,430), reducing economic losses by not less than $3.3 million ($0.7 million annually).[33] These calculations are summarized in Table 1.[34]

Table 1

Bend Estimated Collision Savings with 20mph Speed Limits

	Baseline (1)	20MPH Estimate (2)	Reduction	$ Loss Per Collision	Estimated Annual Savings
	[A]	[B]	[C]	[D]	[E]
			([A] - [B])		([C] x [D]) / 5
Fatal Injury Collisions	13.00	7.15	5.85	$1,400,000	$1,638,000
Level A Injury Collisions	82.00	57.40	24.60	$1,000,000	$4,920,000
Other Reported Collisions	4,288.00	3,430.40	857.60	$3,900	$668,928
Total					**$7,226,928**

Note:
(1) Baseline values reflect 5-year totals over 2011 through 2015.
(2) Column [B] calculated as (Column [A] x (1 - 0.45)) for Fatal Injury Collision; (Column [A] x (1 - 0.3)) for Level A Injury Collisions; and (Column [A] x (1 - 0.2)) for Other Reported Collisions.

33 Many of these collisions are subject to self-reporting and do not generate police involvement. It is likely the actual counts of such collisions exceed reported numbers, and it may be further speculated that a share of these unreported crashes are attributable to speed-related factors.

34 Due to safety spillover effects from 20mph to non-20mph roads, safety-related network effects associated with modal substitution, and reduced VMTs, reductions in fatalities, injuries, and non-injury collisions would not occur solely on 20mph speed limit streets. On the basis of statistical evidence, it would be expected that essentially all KSI collisions on urban local roads would be eliminated, with smaller percentage reductions along collector and minor arterial streets. This allows a reasonableness check on the anticipated reduction in fatal injury collisions computed in Table 1. Data from the period 2007 through 2014 show Bend registered 3 fatalities on urban local streets and 7 deaths on collector streets, while minor arterials generated 13 deaths. An elimination of urban local deaths (i.e., on 20mph streets), a 50% reduction in collector street deaths (i.e., on streets that could qualify for 20mph speed limits or, if not, would be surrounded by 20mph streets and thus exhibit strong spillover and safety-related network effects as well as large VMT reductions), and a reduction of 10% on minor arterials (i.e., on roads reflecting spillover and network effects and VMT reductions; empirical evidence establishes an average 8% reduction value, up to 11.5% for spillover effects alone) would result in a net average reduction of one death per year, consistent with the value calculated in Table 1.

City of Bend Website, Bend Area Crash Data, "Crash Data" https://www.bendoregon.gov/government/departments/growth-management/bend-mpo/maps-and-data/links-to-maps-and-crash-data (accessed June 2018).

Jacobsen, P., "Safety in Numbers: More Walkers and Bicyclists, Safer Walking and Bicycling," *Injury Prevention*, Vol. 9 (2003).

Grundy, C., et al., "Effect of 20mph Traffic Speed Zones on Road Injuries in London, 1986-2006: Controlled Interrupted Time Series Analysis," *British Medical Journal*, Vol. 339 (2009).

2. Reduced Traffic Congestion

When system-wide speed limits are reduced to 20mph, the speed reductions are associated with decreases in traffic congestion, rather than increases. This effect stems from two parallel mechanisms. The first relates to increased uptake of walking or cycling, which results in the removal of cars from roads. The second relates to the improved utilization of roadway resources when drivers operate at lower speeds. These two processes play a role in explaining how vehicle travel times in Bend would be negligibly - if at all - changed with 20mph speed limits.

Increased Walking and Cycling Decrease Traffic Congestion

When additional people walk or cycle for transport, those people undertake a simple substitution – walk or cycle rather than drive – and thereby reduce vehicle miles traveled in the transportation system. Owing to this substitution effect, the removal of cars and VMT from the transportation system is directly reflected by increases in walking and biking, growth in which has been observed at rates up to 36% following implementation of 20mph speed limits.[35]

Such large increases in non-automotive modalities, and attendant decreases in vehicular roadway demand, accumulate over time through a positive feedback loop. First, reduced automotive traffic speed limits induce more people to walk or cycle because lower speed limits improve the real and perceived levels of safety for non-automotive transportation. Since the propensity of residents to walk or cycle, rather than drive, is based upon factors of "safety, perceptions of safety, the condition of the surfaces and the overall appearance of the… environment,"[36] as actual and perceived safety increase – in lockstep with reductions in speed limits – more people forgo car travel, thus freeing up roadway resources and reducing congestion.[37]

Second, as additional commuters take to sidewalks and bike lanes, safety levels for pedestrians and cyclists rise further. This is because, as pedestrian and cycling activity increase, drivers become more attuned to their presence, and danger levels fall. Empirical studies show the "likelihood that a given person walking or bicycling will be struck by a motorist varies inversely with the amount of walking or bicycling," as shown in Figure 4.[38]

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[35] Bristol City Council, "Monitoring Report: 20mph Speed Limit Pilot Areas" (2012).

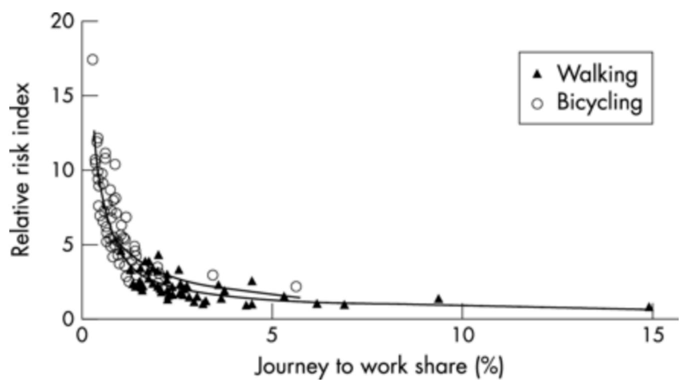
This increase in walking and cycling occurred in connection with implementation of 20mph speed limits and development of additional walking and cycling infrastructure like construction of additional sidewalks. Hence, it has not been determined to what extent the modal substitution can be attributed to speed limit changes. It will be discussed shortly, however, that such increase is consistent with the economics of network effects and empirical observations regarding pedestrian and cyclist safety.

[36] Tovar, M. and Kilbane-Dawe, "Effects of 20mph Zones on Cycling and Walking Behaviours in London," Par Hill Research Ltd. (2013).

[37] From an economic perspective, in addition to a shift in relative safety levels, a 20mph regime also induces walking and cycling uptake because it alters the opportunity costs associated with driving relative to walking or cycling. This is because a lower speed limit network reduces the average speed differential between driving and non-driving modes.

[38] Jacobsen, P., "Safety in Numbers: More Walkers and Bicyclists, Safer Walking and Bicycling," *Injury Prevention*, Vol. 9 (2003).

Figure 4



That is, as more people walk and cycle, the safer it becomes for everyone to walk and cycle, exhibiting a phenomenon known as "network effects" (i.e., the value of walking or cycling increases for all pedestrians and cyclists as each incremental person substitutes from driving to a non-driving mode).[39] This follow-on improvement in real and perceived safety for pedestrians and cyclists induces yet more uptake, which engenders additional network effect benefits, causing traffic levels and congestion to fall further.[40] Crucially, walking and cycling complement each other, with higher rates of either walking or cycling leading to reduced risk for both pedestrians and cyclists.[41]

As summarized by researchers in the U.K.:

> A 20 mph speed limit, properly enforced, would go a long way to removing the present deterrents to cycling. There would be gains both to the cyclists who now brave the present unsatisfactory conditions and to would-be cyclists, now frustrated, who would feel enabled to join them…[and] other road users would gain from reduced congestion.[42]

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[39] Liebowtiz, S.J. and S. Margolis, "Network Externalities (Effects),"

[40] "Vision Zero: How Safer Streets in New York City Can Save More Than 100 Lives a Year," Drum Major Institute for Public Policy and Transportation Alternatives (June 2011).

[41] "The statistics show that bike riders actually protect pedestrians by altering the behavior of drivers." Sadik-Khan, J. *Streetfight*, Viking (2016).

[42] Plowden, S. and M. Hillman, *Speed Control and Transport Policy*, Policy Studies Institute (1996), Ch. 10.

Consistent with these modal substitution mechanisms, empirical evidence shows reductions in vehicle transport are substantial upon 20mph adoption. Following reduction of road speed limits to 20mph, system traffic volumes were observed in one empirical study to decrease, on net, by an average of 15% across 250 measured locales.[43]

A separate analysis of traffic volume responses to the implementation of 20mph speed limits found that net system traffic volumes decreased in the range of 5.3% to 13.4%, depending upon particulars of the implementation such as the extent of 20mph speed limit deployment (i.e., system-wide, resulting in greater traffic decreases, versus zoned), enforcement levels, and other contemporaneous traffic calming measures.[44] Importantly, for reasons including network effects associated with non-driving modes and other time-dependent feedback mechanisms, these traffic reduction levels may be best viewed as short-run consequences, with larger reductions likely over longer intervals when follow-on effects have fully matured.[45]

Quantification of Expected VMT Reductions in Bend with 20mph Speed Limits

These findings provide useful reference for understanding the directional relationship between speed limits and VMTs as well as the general magnitude of VMT responsiveness to implementation of 20mph speed limits. They can accordingly be used to estimate the effects a 20mph speed limits would have on traffic volume in Bend. Care must be taken, however, in applying the empirical findings' results to Bend because, in the 20mph speed limit areas subjected to empirical study of traffic volume change, all underwent speed limit reductions from 30mph to 20mph (i.e., a 10mph reduction) and therefore twice the reduction applicable to the instant analysis. Translating the findings to Bend's circumstances requires consideration of several observations, each of which is discussed below.

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[43] This net reduction figure accounts for route displacement effects. The majority of traffic was found not to circumvent the lower speed limit zones; rather, the traffic simply disappeared, a concept that is sometimes referred to as "reduced demand." The levels of traffic volume reduction are highly variable region to region and appear to depend principally upon the level of commitment made to a 20mph regime: generally, the greater the adoption rate (i.e., closer to system-wide rather than on a zone-by-zone basis, more enforcement and greater implementation of other traffic calming measures, the greater the reduction in traffic volumes). This finding is entirely consistent with the economics of induced demand and the law of demand. (See: Department for Transport Traffic Advisory Leaflet 9/99 (June 1999), "20 mph Speed Limits and Zones.")

[44] Steer Davies Gleave, "Research into the Impacts of 20mph Speed Limits and Zones, (November 2014).

[45] Research relating to VMT responses to road infrastructure changes show that full demand responses tend to mature after approximately three years, while most traffic reduction research evaluates shorter-term responses, often of just one year.

Noland, Robert B. and Lewison L. Lem, "A Review of the Evidence for Induced Travel and Changes in Transportation and Environmental Policy in the US and the UK," *Transportation Research Part D*, 7 (2002).

Litman, Todd, "Generated Traffic and Induced Travel: Implications for Transport Planning," Victoria Transportation Policy Institute (April 17, 2017).

First, it is significant that the speed limit reduction from 30mph to 20mph encompasses the speed limit reduction applicable to Bend (i.e., 25mph to 20mph). The experience of these converted 30mph zones is relevant and enables an initial estimate to be made of VMT responsiveness in Bend as follows. The approximate midpoint of observed traffic volume reductions is 10% (i.e. 5.3% to 15%), implying an average 1% traffic volume reduction per 1mph of speed limit reduction within the 30mph to 20mph range. This suggests that a 5mph speed limit reduction would be met with approximately 5% of VMT decline; such level of response might well be expected in Bend.

Second, it is pertinent to ask whether the relationship between speed reduction and VMT response within the 30mph to 20mph range is linear (i.e., 1% VMT reduction per 1mph speed reduction across the whole range) or whether there are reasons why VMT responsiveness might increase or decrease across the range in non-linear fashion. The mechanism underpinning VMT reduction is modal substitution, and modal substitution rates are modulated by actual safety and perceived safety. Therefore, it is appropriate to evaluate how safety levels vary across the speed ranges of 1) 30mph to 20mph; 2) 30mph to 25mph; and 3) 25mph to 20mph to ascertain whether there is evidence of any safety tipping point within these speed ranges that would serve to generate large modal substitution increases at a certain speed but not above it. If so, that would provide evidence that, above a certain speed limit range, modal substitution rates would be low and, below a certain speed limit range, substitution would higher - i.e., it would indicate a non-linear relationship between speed reduction and VMT response. On this basis, the evidence would show whether a 1% VMT reduction per 1mph of speed limit decrease across the 25mph to 20mph range is likely accurate or too high or too low.

In this connection, several statistical observations are helpful in illustrating relative risk levels across the three speed limit intervals:

> 1) half of pedestrian deaths and 80% of pedestrian serious injuries occur at traffic speeds of 30mph or lower, indicating that speeds up to 30mph retain significant risk levels;
>
> 2) only rare instances of fatality or serious injury are observed at speeds 20mph or lower, with just five percent of pedestrian collisions at 20mph resulting in death, indicating that speeds at or below 20mph provide low risk levels and that it is within the range of 30mph to 20mph where a crucial speed/safety step-change occurs; and
>
> 3) as speeds decline from 25mph to 20mph, risk of pedestrian death in a collision falls by 50% and, as speeds approximate 20mph, pedestrian and cyclist mortality risks stabilize at a low level (i.e., large safety gains occur as speeds fall from 25mph to 20mph and additional large gains are not realized below

20mph), demonstrating significant risks remain in play at speeds 25mph and higher and those risks dramatically fall as 20mph speeds are approximated.[46]

Accordingly, while it is true that every 1mph speed reduction in the 30mph to 20mph speed range is important for health and safety reasons, there is evidence of a tipping point in safety implications at speeds approximating 20mph. It is not until traffic speeds decline to 20mph that safety levels for pedestrians and cyclists stabilize at low levels. It is at this speed limit where perceived and actual safety become sufficient to provoke widespread modal substitution for transportation. In sum, the statistics imply a clustering of perceived and actual safety below 25mph and around the 20mph mark, which, given the importance of actual and perceived safety in motivating modal substitution, indicates responsiveness of VMT reduction to speed limit reduction would be greatest within the 25mph to 20mph speed range.[47] Speed declines from 30mph to 25mph would elicit smaller modal substitution effects since high risk levels remain in this range. This implies that a non-linear VMT reduction relationship with speed decrease exists and that above-average VMT responsiveness occurs within the 25mph to 20mph speed range. A 5% VMT reduction expectation in Bend is conservative.

Third, it is shown that network effects apply to pedestrian and cyclist safety in transportation systems. Network effects generate pedestrian and cyclist safety value in increasing total quantities as more people switch from vehicles to non-vehicle modalities.[48] The lowest risk levels for pedestrians and cyclists occur when large numbers of people walk or cycle rather than drive. This relationship implies a non-linear link between vehicle speed limits and the quantum of network effect benefits since speed limit reductions generate modal substitution. Modal substitution in turn triggers network effect benefits that further reduce pedestrian and cyclist risk to engender more modal substitution.[49] Network effect benefits thus lag and compound other factors provoking modal substitution, so a concentration of VMT reduction as speed limits approach 20mph is consistent with the economics of network

[46] Dorling, D., “20mph Speed Limits for Cars in Residential Areas, by Shops and Schools,” Nine Local Actions to Reduce Health Inequalities, University of Oxford.

“Vehicle Speed and Pedestrian Age Determine Crash Outcomes,” *Status Report* (Insurance Institute for Highway Safety/Highway Loss Data Institute), Vol. 35, No. 5 (May 2000).

Barrios, L., “Killing Speed,” Injury Prevention, Vol. 6 (2000).

Tefft, B., “Impact of Speed and a Pedestrian’s Risk of Severe Injury or Death,” *AAA Foundation for Traffic Safety* (September 2011).

Speck, J., *Walkable City*, North Point Press (2012).

[47] Tovar, M. and Kilbane-Dawe, “Effects of 20mph Zones on Cycling and Walking Behaviours in London,” Par Hill Research Ltd. (2013).

[48] Jacobsen, P., “Safety in Numbers: More Walkers and Bicyclists, Safer Walking and Bicycling,” *Injury Prevention*, Vol. 9 (2003).

[49] “Vision Zero: How Safer Streets in New York City Can Save More Than 100 Lives a Year,” Drum Major Institute for Public Policy and Transportation Alternatives (June 2011).

effects.[50] Modal substitution owing to network effects would exhibit non-linear growth as speed limits decrease, and VMT declines would accordingly accelerate as speed limits approach 20mph. Again, on this basis, a 5% VMT reduction expectation in Bend is conservative.

Consistent with these considerations, it can be stated that, while a 5% VMT reduction in Bend following adoption of 20mph speeds is a meaningful reference expectation, it may well be understated due to existence of modal substitution tipping point and accelerated network effects occurring around, but not much above, 20mph speed limits. Bend could experience VMT decreases in excess of 5% upon adoption and enforcement of 20mph speeds, and thus encounter corresponding reductions in congestion.[51]

Improved Utilization of Roadway Resources Improves Traffic Flow

The second factor that causes reduced traffic congestion in a 20mph speed limit network relates to roadway utilization efficiency. Automobiles can make better use of road supply at lower speed limits in urban and residential areas due to reduced spacing, improved filtering, and decreased collisions.

Reduced Spacing

As speed limits decline, cars traveling in the same lane require less "shy-distance" between them. Also known as "reduced spacing," densification of cars safely occurs when braking distances needed by automobiles contract. Because cars require less distance to come to a stop at lower speeds, they can leave less empty space between them (i.e., they can follow one another more closely) without increased risk of collision.

Automotive braking distance requirements (and thus safe shy-distance intervals) follow an exponential expansion with respect to speed, so even a small reduction in traffic speeds can generate large roadway space savings.[52] As illustration, the distance required for a vehicle to stop when traveling 20mph is roughly 14 meters. At 25mph, the

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[50] Sadik-Khan, J. *Streetfight*, Viking (2016).

[51] A 5% VMT reduction value may further be considered conservative when applied to prospective 20mph implementation in Bend because the availability and affordability of e-bikes continue to grow as the technology diffuses along a typical path of adoption. For trip durations of up to several miles, particularly in urban and suburban settings, e-bikes are particularly good substitutes for automobiles, but their safety profile generally equates to that of traditional bicycles and so increased adoption would be influenced by safety factors modulating modal substitution from vehicles to cycles. Most empirical evidence relating to substitution effects and VMT responses to 20mph limits pre-dates the current level of e-bike availability. This new technology factor implies greater modal substitution and VMT reductions in present and future 20mph applications.

[52] Litman, T., "Whose Roads? Evaluating Bicyclists' and Pedestrians' Right to Use Public Roadways," Victoria Transport Policy Institute (December 2013).

requirement is 26 meters, nearly double the lower speed's stopping distance, despite the seemingly marginal 5mph speed difference.[53]

Reduced spacing leads to transportation system efficiency gains since it enables a safe increase of traffic density on the road (i.e., there is less "dead space" between each car in the system) during peak traffic times. This allows the system to accommodate more cars simultaneously. Significantly, this does not increase congestion; rather, cars are able to move at least as smoothly as at higher speeds, but simply with less empty space separating them. By eliminating unused lane miles, existing roadway resources are used more efficiently. On the basis of observing that braking distance and shy-distance intervals fall by nearly 50% in the 25mph to 20mph range, it can be generally stated that a speed limit reduction to 20mph significantly increases effective road capacity.[54]

Improved Filtering

Filtering is the process by which cars exiting one road merge into the traffic flow on another. When long traffic queues form, that is symptomatic of poor filtering efficiency. Such inefficiency often can be linked to a large speed differential between the stopped/merging traffic and the higher-speed oncoming traffic. As the speed of oncoming traffic increases, the difficulty of merging grows because the required "buffer" distance for safe maneuvering becomes greater; merging traffic requires more room to achieve the target speed.[55]

When speed limits are lower, the required buffer distance for safely merging into moving traffic falls. Long traffic queues are less likely to form and, if they do, are more quickly dissipated. This improves system-wide traffic flow and throughput, and reduces congestion, as road resources are more efficiently utilized. By way of demonstration, a reduction in traffic congestion of 10% was observed at systemically important (and typically congested) traffic interchanges in Sao Paulo, Brazil, in the first month following implementation of reduced speed limits.[56]

Decreased Collisions

Significant reductions in traffic collisions are associated with 20mph speed limits. As collisions and attendant roadway obstructions are reduced, traffic congestion falls and travel time reliability improves since fewer crashes cause less traffic backup.[57]

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[53] "Cities Safer by Design," World Resources Institute, graphic entitled "Higher Vehicle Speeds Require Longer Stopping Times" (2015). Stopping distance totals reflect reaction distance and braking distance.

[54] Duany, A., et al., *Suburban Nation*, North Point Press (2000).

[55] Archer, J., et al., "The Impact of Lowered Speed Limits in Urban and Metropolitan Areas," Monash University Accident Research Centre (2008).

[56] "Numeros de Acidentes Cai 30% Apo Novos Limites na Marginais," *O Estadoa de Sao Paulo* (August 29, 2015).

[57] Blincoe, L., et al., "The Economic and Societal Impact of Motor Vehicle Crashes," U.S. Department of Transportation, National Highway Traffic Safety Administration, DOT HS 812013 (May 2015 (Revised)).

Collisions that stop traffic have sweeping consequences for transportation system efficiency, with effects reverberating through the system.[58] Consider, for instance, the unused roadway just ahead of an accident that stops traffic and the blockages that occur on nearby roads as a traffic stall ripples outward. These are inefficiencies in transportation systems wrought by avoidable collisions. By reducing crashes, 20mph speed limits inoculate against an important cause of congestion.

Collectively, reduced spacing, improved filtering, and decreased collisions enhance road resource utilization and traffic flow, increase vehicle throughput, reduce traffic congestion, and benefit drive-time reliability.

Decreased Speed Limits Do Not Materially Affect Travel Times

Intuition may suggest that lower speed limits significantly increase travel times; however, both empirical evidence and computer simulation models disprove this, particularly as relates to a change from 25mph to 20mph speed limits in residential and urban areas, as will be discussed in detail.

As a prefatory matter, it is necessary to focus discussion only on those vehicle trips that would have any possibility of experiencing meaningful travel time increases - i.e., relatively short trips. Long vehicle trips would be logically unaffected by urban/residential speed limit changes. A 100-mile trip comprised of, say, 2 miles on residential roads and 98 miles on freeways would register no consequential travel time change under urban/residential 20mph speed limits; any time penalty incurred on residential roadway would represent a minuscule fraction of total travel time and thus be indiscernible against the whole.

Conversely, short trips predominantly traversing urban/residential 20mph candidate streets would potentially be subject to appreciable travel time increases. Generalized across a transportation system, it can be stated that, the shorter the trip, the greater the proportion of total travel on urban/residential areas. And, the greater the proportion of travel on urban/residential roads, the better the prospects for meaningfully longer travel times. For this reason, analysis will be circumscribed to travel time changes on trips of 3 miles or fewer. Such circumscription is not overly restrictive, as trips 3 miles or less account for over 40% of all vehicular trips.[59]

Focusing analysis on this short-trip genus of vehicle travel, it has been shown that, for trips within urban and residential areas, travel time delays do not derive from posted speed limits. Instead, the primary generators of "delay" are intersections, traffic queues, and unilateral braking for cornering and turns. While turning speeds are

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[58] Archer, J., et al., "The Impact of Lowered Speed Limits in Urban and Metropolitan Areas," Monash University Accident Research Centre (2008).

[59] Federal Highway Association 2009 National Household Travel Survey, "Vehicle Trips, Number of Vehicle Trips by Trip Distance Including Trips 2 Miles or Less."

unaltered by traffic speed limits, both intersection efficiency and traffic queuing are beneficially affected by 20mph speed limits (owing to reduced spacing, improved filtering, and decreased collisions). Indeed, citing these factors, some researchers have argued that lower speed limits can *reduce* travel times in urban areas.[60]

Additional studies quantifying changes in travel duration due to speed limit changes find that reducing speed limits by approximately 5mph has essentially no effect on travel times. An analysis conducted in Australia determined that a 10kph (i.e., 6.2mph) speed limit reduction was associated with travel time increases of 3 percent in the short-term, and, following behavioral adaptation, 0.6 percent in the long-term.[61] Confirming this conclusion, it has been separately found that speed limit reductions in the range of 5mph increase travel times by about 1 percent.[62]

It is possible to estimate travel time impacts in Bend using these findings. If an average speed of travel of 15mph (accounting for intersections, traffic, etc.) on vehicle trips occurring exclusively within urban/residential areas is achieved, then 1-mile, 2-mile, and 3-mile journeys would exhibit travel times of 4 minutes, 8 minutes, and 12 minutes, respectively.[63] Conservatively using the short-term travel time increase estimate of 3 percent, those travel times would increase by 7 seconds, 14 seconds, and 22 seconds, respectively, in a 20mph system. Since over 40% of vehicle trips cover 3 miles or fewer - and since it is shorter trips most likely to occur on urban/residential roads - a substantial share of all trips in targeted 20mph areas would experience travel time increases of well less than a minute.[64]

Two other empirical studies' findings corroborate these calculations. One shows that a 10kph (i.e., 6.2mph) speed limit reduction is associated with an increased average travel time of less than 26 seconds per trip (or about 21 seconds, adjusted for a 5mph speed limit decrease) - roughly the calculated change for a 3-mile trip.[65] The second study finds that a 5kph (i.e., 3.1mph) speed limit reduction is associated with about 10 seconds longer

[60] Archer, J., et al., "The Impact of Lowered Speed Limits in Urban and Metropolitan Areas," Monash University Accident Research Centre (2008).

[61] SMEC Australia and R.J. Nairn and Partners, "Effects of Urban Speed Management on Travel Time: Simulation of the Effects of Maximum Cruise Speed Changes in Melbourne," Federal Office of Road Safety (1999).

[62] Horeau, E. and S. Newstead, "An Evaluation of the Default 50km/h Speed Limit in Victoria," MUARC Report No. 261, Monash University Accident Research Centre (2006).

[63] This 15mph average speed is obtained using the Google Maps "Directions" feature for automobile travel around residential and urban portions of Bend. Across a variety of routes, Google Maps indicates average travel times of 4 minutes per mile (i.e., 15mph).

[64] Federal Highway Association 2009 National Household Travel Survey, "Vehicle Trips, Number of Vehicle Trips by Trip Distance Including Trips 2 Miles or Less."

[65] Haworth, N., et al., "Evaluation of a 50km/h Default Urban Speed Limit for Australia," National Road Transport Commission, Melbourne (2001).

travel time per mile (i.e., about 16 seconds per mile, adjusted for a 5mph speed limit decrease).[66] Both studies confirm that travel times in Bend would change by well less than one minute per trip, or in the range of 3%, on vehicle travel occurring exclusively within urban/residential areas. And travel times would change by an even lower percentage on trip routes combining urban/residential and non-urban/residential streets. These calculations in all cases show maximum travel time increases since they do not account for VMT reductions generated by 20mph speed limits.[67]

Accordingly, there is reason to believe average vehicle travel times in Bend would not change at all (or could decrease) following implementation of 20mph speed limits. To the extent there would be any travel time increases, they would be vanishingly small and measured in seconds.[68]

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[66] Robertson, S. and H. Ward, "Valuation of Non-Accident Impacts of Speed," MASTER Working Paper R 1.2.2, VTT Communities and Infrastructure (1998).

[67] The difference between the short-term 3% and long-term 0.6% travel time increases reported by one study is explained by behavioral adaptation, which would include things such as modal substitution generating VMT reductions. Using the estimated 0.6% travel time increase generates expected travel time changes that do account for some measure of VMT response. For 1-mile, 2-mile, and 3-mile trips, a 0.6% travel time change translates to a 1.4 second, 2.9 second, and 4.3 second travel time increases, respectively.

[68] It may be perceived that increased drive times displace working hours and diminish earnings, leading to economic loss. Statistics showing concurrent increases in commute times and working hours in the U.S. belie this view. Work is not a substitute of driving. Also, the average American conducts 3.61 hours of work or working-related activities each day, leaving 20.39 hours of non-working time into which commuting time increases measured in seconds could be easily absorbed with *de minimis* economic impact. (See: U.S. Department of Labor, Bureau of Labor Statistics "American Time Use Survey - 2016 Results." Saad, L., "The '40-Hour Workweek Is Actually Longer - by Seven Hours," *Gallup* (August 29, 2014). Ingraham, C., "The Astonishing Human Potential Wasted on Commutes," *Washington Post* (February 25, 2016).)

3. Decreased System-Wide Fuel Consumption

Two distinct lines of inquiry must be addressed to understand the implications of 20mph speed limits on system-wide fuel consumption. The first is the extent to which the speed limit reduces or increases driving overall; and the second is the extent to which fuel consumption among cars in the road system is increased or reduced with lower speed limits.

On net, it is found that, while the fuel consumption among cars in the road system is not materially impacted by lower speed limits, reduced traffic in the transportation system reduces system-wide fuel usage. Overall fuel usage declines in 20mph speed limit networks.

Reduced Traffic Levels Generate Lower Fuel Consumption

When system-wide 20mph speed limits are adopted, modal substitution draws people out of automotive transport and into walking, cycling, and mass transit alternatives. This reduces individual automobile usage and decreases system-wide fuel requirements.

The directional effect of reduced automobile usage and attendant reduced VMTs is unambiguous: under a 20mph speed limit regime, the substitution effect places downward pressure on system-wide fuel usage. In the broadest sense, reduced VMTs would be expected to shrink fuel consumption by an amount roughly proportionate to the VMT reduction.[69] This framework will be used later to quantify the economic implications of reduced fuel usage.

Remaining Traffic's Fuel Consumption Is Not Materially Altered

With respect to vehicles that do traverse a 20mph roadway system versus a 25mph system, two offsetting factors affect how much fuel those automobiles use. The first relates to the energy costs of acceleration, and the second pertains to the relative fuel efficiencies of different cruising speeds. In general, these factors offset, resulting in no material difference in fuel usage rates between automobiles in a 20mph transportation system versus a 25mph network.[70] Nonetheless, some empirical studies have found substantial gains in fuel efficiency among vehicles in 20mph speed limit networks as a by-product of reduced speed limits - i.e., improved driver behavior. Each point is addressed below.

At lower speed limits, automobiles use less energy to reach a road's cruising speed. This is because the energy required to achieve a given speed is proportional to the square of that speed. That is, a non-linear relationship

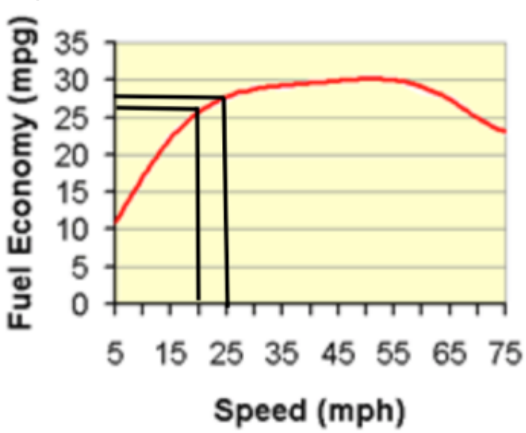
[69] Naturally, factors other than VMTs bear on fuel consumption reductions; fuel consumption could decrease by more or less than the decrease in VMTs because not all vehicle types consume fuel at similar rates, and there may be a systematic bias that favors modal substitution for certain types of vehicles. Driving style of modal switchers also bears on the analysis, as do the particulars of transportation system design.

[70] "An Evaluation of the Estimated Impacts on Vehicle Emissions of a 20mph Speed Restriction in Central London," Transport and Environmental Analysis Group, Centre for Transport Studies, Imperial College London (April 2013).

between target speed and fuel consumption is realized during acceleration; as the target speed increases, fuel usage grows exponentially. As such, the energy required to attain 30mph or 25mph dwarfs that to achieve 20mph, and repeated acceleration to these higher speeds reduces fuel efficiency relative to a 20mph system.[71]

On the other hand, most automobiles maximize their cruising fuel efficiency at speeds greater than 20mph. It is observed that fuel efficiency for most automobiles peaks at cruising speeds of approximately 55mph, with efficiency penalties associated with higher and lower cruising speeds. There is a cruising-speed fuel efficiency loss associated with a 20mph speed limits relative to 25mph limits. The efficiency difference between 20mph and 25mph cruising speeds is nevertheless small, having been calculated as a roughly 8% difference in fuel economy levels once cruising speed has been attained (that is, ignoring the effects of reaching the higher speeds).[72] Figure 5, from fueleconomy.gov, illustrates the relative insensitivity of fuel efficiency to cruising speed levels above 20mph, and the difference between fuel efficiency levels at 20mph versus 25mph (vertical and horizontal black lines have been added for clarity). The effect is relatively small and, importantly, only a small share of any urban/residential trip occurs at cruising speed.[73]

Figure 5



Since acceleration and cruising speed factors are directionally offsetting, and since myriad other particulars must be known to determine which factor dominates in a given setting,[74] the result of any generalized analysis is that, within a speed limit range of approximately 20mph to 25mph, there is no material difference in fuel economy among vehicles in a transportation system.

It is nonetheless worth noting that driving style has substantial bearing on fuel usage, and driving style has been shown to change in response to speed limits. Whether a driver operates a vehicle conservatively or aggressively has dramatic implications for fuel usage

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71 "An Evaluation of the Estimated Impacts on Vehicle Emissions of a 20mph Speed Restriction in Central London," Transport and Environmental Analysis Group, Centre for Transport Studies, Imperial College London (April 2013).

72 The Automobile Association calculates that the percentage difference in fuel economy between a cruising speed of 20mph and 30mph is about 8.5%. "20mph Roads and CO2 Emissions," The Automobile Association website (accessed May 2018).

73 Archer, J., et al., "The Impact of Lowered Speed Limits in Urban and Metropolitan Areas," Monash University Accident Research Centre (2008).

74 These include the types of automobiles used in the affected transportation system, prevailing driving styles, particulars of road and intersection design, the typical trip lengths of users of the road system, etc.

since aggressive driving tends to be marked by rapid speed changes that demand higher fuel usage.[75] Fuel consumption among aggressive drivers has been shown to be as much as *four times* that of non-aggressive drivers.[76] In addition, a single aggressive driver can cause other drivers to operate their vehicles less efficiently by setting off ripple effects that reduce overall traffic smoothness. It has been shown that, with 20mph speed limits, reports of aggressive driving behaviors decline 40%,[77] so it would be expected that reduced aggressiveness in 20mph systems would benefit overall fuel efficiency as a by-product of reduced speed limits.

Indeed, in at least two instances of empirical study, the foregoing logic manifested quantitatively in measured driver behaviors and fuel usage. Upon the introduction of 30kph (i.e., 20mph) speed limit zones in Germany, it was observed that gear change events (a proxy measure for acceleration and cruising speed values) and braking events declined by 12% and 14%, respectively. Since reductions in gear changes and braking collectively reflect smoother driving patterns, the behavioral changes resulted in a measured 12% reduction in fuel usage among drivers.[78] In a second study of urban traffic, it was found that “reduced speeds and more even driving have resulted in 26% reduction in fuel consumption.”[79]

These findings are echoed in a Department for Transport circular which states the following:

> There may also be environmental benefits [associated with 20mph speed limits] as, generally, driving more slowly at a steady pace will save fuel and reduce pollution, unless an unnecessarily low gear is used.[80]

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[75] “An Evaluation of the Estimated Impacts on Vehicle Emissions of a 20mph Speed Restriction in Central London,” Transport and Environmental Analysis Group, Centre for Transport Studies, Imperial College London (April 2013).

[76] Archer, J., et al., “The Impact of Lowered Speed Limits in Urban and Metropolitan Areas,” Monash University Accident Research Centre (2008).

[77] Department for Transport, “Interim Evaluation of the Implementation of 20mph Speed Limits in Portsmouth” (2010).

[78] Hass-Klau, Carmen, *An Illustrated Guide to Traffic Calming* (1990).

[79] Mitchell, P., “Speed and Road Traffic Noise: The Role that Lower Speeds Could Play in Cutting Noise from Traffic,” A Report Commissioned by the UK Noise Association (December 2009).

Van Beek, W., et al., “The Effects of Speed Measures on Air Pollution and Traffic Safety,” Proceedings of the European Transport Conference (2007).

[80] Department for Transport, “Setting Local Speed Limits,” Department for Transport Circular (January 2013).

The U.S. Department of Transportation Federal Highway Administration concurs: “Slower moving vehicles make less noise and, generally, emit fewer pollutants…fuel consumption reductions of 10 to 12 percent have been reported.” See: Federal Highway Administration Course on Bicycle and Pedestrian Transportation, Lesson 11, “Traffic Calming.”

In sum, since there are reasons why a 20mph speed limit regime would not necessarily result in improved fuel economy per mile driven, the most conservative argument is that there would not be meaningful change in drivers' fuel usage in a 20mph regime. Nonetheless, at least two empirical studies showing enhanced fuel economy per mile driven in reduced-speed networks highlight the possibility of diminished fuel usage per vehicle mile in 20mph systems, particularly when driver behavior improves.[81]

Economic Implications of Reduced Fuel Consumption

The absence of any substantive change in fuel economy per vehicle mile driven, accompanied by a reduction in system-wide VMTs due to modal substitution, implies a system-wide reduction in fuel utilization with 20mph speed limits. Considering the extent of traffic volume reductions observed in regions adopting 20mph speed limits, potential fuel savings can be sizable.[82]

It is possible to define the approximate fuel savings and attendant financial savings this effect would generate in Bend. In 2014, total VMTs in Bend equaled 521,950,000.[83] Allowing for average growth, expected Bend VMTs in 2018 are estimated to reach approximately 610 million miles. U.S. automobile fleet fuel economy average is approximately 22 miles per gallon.[84] With a 5% net reduction in vehicle volume, Bend's annual fuel usage would decline by over 1.4 million gallons per year. At an average price of $3.15 per gallon, that fuel savings corresponds to approximately $4.5 million in annual financial savings.

These calculations are summarized in Table 2.

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[81] It has also been shown that, in 20mph systems, traffic idling at intersections can be reduced as a result of improved filtering. Since idling for 10 seconds or longer is associated with fuel wasting, improved junction filtering would be expected to limit idling times and thus reduce fuel consumption.

Gaines, L., et al., "Which Is Greener: Idle, or Stop and Restart? Comparing Fuel Use and Emissions for Short Passenger Car Stops," U.S. Department of Energy, Argonne National Laboratory (2012).

[82] Department for Transport Traffic Advisory Leaflet 9/99 (June 1999), "20 mph Speed Limits and Zones."

Steer Davies Gleave, "Research into the Impacts of 20mph Speed Limits and Zones, (November 2014).

[83] City of Bend Website, Bend Area Crash Data, "VMT Crash Rates": https://public.tableau.com/profile/bendmpo#!/vizhome/CrashRatesByVMT_0/FatalitiesperVehicleMilesTraveledVMT (accessed May 2018).

[84] Using overall miles per gallon is conservative since stop-and-go driving typical of urban and suburban settings such as that where Bend's VMT declines would be observed registers markedly lower fuel economy than highway driving, and both driving types are reflected in overall miles per gallon.

Sivak, M., "Effects of Vehicle Fuel Economy, Distance Travelled, and Vehicle Load on the Amount of Fuel Used for Personal Transportation in the U.S.: 1970-2010," University of Michigan Transportation Research Institute, Report No. UMTRI-2013-10 (February 2013).

"Gas Mileage of Vehicles on the Road: Little Progress Since Early '90s," University of Michigan, Michigan News (August 2015).

Table 2

Bend Estimated Annual Fuel Savings with 20mph Speed Limits

	Baseline Estimate	20MPH Estimate (2)
	[G]	**[H]**
[A] Bend Vehicle Miles Traveled (1)	610,607,675	580,077,292
[B] Fleet Vehicle Fuel Economy (MPG) (3)	21.5793	21.5793
[C] Bend Annual Fuel Usage (Gallons) ([A] ÷ [B])	28,295,991	26,881,191
[D] Bend Annual Fuel Savings (Gallons) ([G] - [H])		**1,414,800**
[E] Average Fuel Price/Gallon (May 2018)		$3.15
[F] Bend Annual Financial Savings on Fuel ([D] x [E])		**$4,456,619**

Note:
(1) Bend Vehicle Miles Traveled is calculated using 2014 as the base year, grown by 4% annually, to estimate 2018 VMTs.
(2) 20MPH Estimate Bend Vehicle Miles Traveled reflects Baseline Estimate value reduced by 5%.
(3) Fleet Vehicle Fuel Economy reflects U.S. national statistics.

4. Lowered Pollution and Noise Levels

Significant decreases in pollution and noise levels are registered in areas with 20mph speed limits. Since fewer vehicle miles are traveled in 20mph systems, corresponding reductions in pollution and noise levels are realized. Additionally, among residual VMTs, lower speeds tend to be associated with reduced noise pollution and particulate matter dispersion from vehicle tires, clutches, and brakes.

Lower Pollution Results from Fewer Vehicle Miles Traveled

Modal substitution causes more users of the transportation system to walk or cycle when 20mph speed limits are enacted, thereby reducing VMTs. Fuel consumption commensurately declines and, in turn, pollution levels diminish, both with respect to carbon-dioxide ("CO2") and particulate matter.[85]

Carbon-Dioxide

One important measure of a transportation system's air pollution is the quantity of CO2 greenhouse gas it emits. Generally, CO2 emissions decline linearly with VMT reductions.[86] Thus, were Bend's VMTs to decline in a manner consistent with empirically studied 20mph networks, Bend's automobile fleet would be expected to emit about 5% fewer tons of CO2.

A general estimate of potential tons of CO2 reduction can be given through the following analysis. In 2018, Bend's VMTs is expected to reach approximately 610 million miles, consuming about 28.3 million gallons of fuel. When burned, roughly 565.9 million pounds of CO2 (about 257,000 metric tons) will be released.[87] If Bend's VMTs are reduced by 5%, then CO2 emissions would also be expected to decline by approximately that percentage, resulting in about 28.3 million pounds fewer CO2 emissions (about 12,830 metric tons) emitted annually.

Economic Implications of Reduced Carbon-Dioxide Emissions

According to research published in 2015, each metric ton of CO2 generated by emissions carries an economic damages value (often referred to as "social cost") of approximately \$220.[88] The Environmental Protection Agency,

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[85] In addition to this effect, reductions in aggressive driving reduce CO2 emissions since aggressive drivers generate approximately four times the CO2 output of non-aggressive drivers.

Archer, J., et al., "The Impact of Lowered Speed Limits in Urban and Metropolitan Areas," Monash University Accident Research Centre (2008).

[86] Every gallon of gasoline burned emits CO2. At a given average fleet fuel economy, VMT reductions generate linear reductions in CO2.

[87] Each gallon of gasoline burned emits 20 pounds of CO2.

"How Can a Gallon of Gasoline Produce 20 Pounds of Carbon Dioxide?" fueleconomy.gov (accessed May 2018).

[88] Moore, F. and D. Diaz, "Temperature Impacts on Economic Growth Warrant Stringent Mitigation Policy," *Nature Climate Change*, Vol. 5 (2015).

Than, K., "Estimated Social Cost of Climate Change Not Accurate, Stanford Scientists Say," *Stanford News* (January 12, 2015).

on the other hand, estimated the social cost of a metric ton of CO2 in 2015 to be about $36.[89] Other estimates peg costs in the middle of this range.[90] Without taking a position on the merits and limitations of any particular approach or set of assumptions used in valuing CO2 social costs, for purposes of this analysis, an approximate midpoint of $125 in estimated social costs per metric ton of CO2 emissions will be used. A reduction in emissions of 12,830 metric tons would equate to about $1.6 million of annual savings in implied damages. These calculations are shown in Table 3.

Table 3

Bend Estimated Annual CO2 Savings with 20mph Speed Limits

	Baseline Estimate [I]	20MPH Estimate [J]
[A] Bend Total Fuel Usage (Gallons) (1)	28,295,991	26,881,191
[B] Pounds of CO2 per Gallon Used	20	20
[C] Pounds of CO2 Generated ([A] x [B])	565,919,817	537,623,826
[D] Pounds of CO2 Saved ([I] - [J])		**28,295,991**
[E] Pounds per Ton		2,205
[F] Tons of CO2 Saved ([D] ÷ [E])		**12,833**
[G] Economic Damages Value/Ton of CO2		$125
[H] Bend Annual Economic Savings ([F] x [G])		**$1,604,081**

Note:
(1) Bend Total Fuel Usage reflects estimated Bend VMTs and U.S. vehicle fleet average fuel economy (MPG).
(2) 20MPH Estimate Bend Vehicle Miles Traveled reflects Baseline Estimate value reduced by 5%.
(3) Fleet Vehicle Fuel Economy reflects U.S. national statistics.

[89] The EPA currently estimates the social cost of carbon to be around $1. There appears to be zero economic merit to this figure and it is accordingly ignored here.

Archived Environmental Protection Agency Website, "The Social Cost of Carbon: Estimating the Benefits of Reducing Greenhouse Gas Emissions" https://19january2017snapshot.epa.gov/climatechange/social-cost-carbon_.html (accessed June 2018).

[90] Harvey, C., "Should the Social Cost of Carbon Be Higher?" *Scientific American* (November 2017).

Micro-plastics & Other Non-exhaust Traffic-related Particulate Matter

Another measure of environmental pollution can be found in plastics dispersed into the environment as a consequence of the mechanical abrasion (i.e., wearing down) associated with car tires. Plastics pollution increases as a function of VMTs, and research indicates that "wear and tear from tires significantly contributes to the flow of (micro-)plastics into the environment."

> The relative contribution of tire wear and tear to the total global amount of plastics ending up in our oceans is estimated to be 5-10%. In air, 3-7% of the particulate matter (PM2.5) is estimated to consist of tire wear and tear.[91]

Aside from micro-plastics, other non-exhaust traffic-related particulate matter generation comprises an important component of traffic environmental impact. "Non-exhaust particles can be generated either from non-exhaust sources such as brake, tire, clutch and road surface wear or already exist in the form of deposited material at the roadside and become resuspended due to traffic-induced turbulence." Within urban and suburban settings, higher VMTs correspond with higher non-exhaust particulate matter levels.[92]

Thus, both micro-plastics generation and particulate matter pollution would be expected to decline as a result of lower VMTs brought on by 20mph speeds.

Lower Speeds and Smoother Traffic Generate Less Particulate Matter

As traffic speeds increase and as traffic patterns become more interrupted (i.e., marked by "stop-and-go" driving), the levels of particulate matter generated by non-exhaust traffic-induced factors, such as tires and brakes, increases. Accordingly, lower average traffic speeds and smoother traffic flows associated with a 20mph system would contribute to reductions in plastics pollution and particulate matter dispersion.

Since 20mph speed limit networks are associated with lower traffic speeds, reduced gear shifts, less braking events, and lower levels of aggressive driving behavior, reduced total particulate matter and lower tire wear levels would tend to be associated with 20mph systems.[93] Indeed, tire-related pollution depends upon speed and driving

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[91] Kole, P., et al., "Wear and Tear of Tyres: A Stealthy Source of Microplastics in the Environment," *International Journal of Environmental Research and Public Health*, Vol. 14, No. 10 (2017).

[92] Grigoratos, T. and G. Martini, "Brake Wear Particle Emissions: A Review," *Environmental Science and Pollution Research International*, Vol. 22 (2015).

[93] Hass-Klau, Carmen, *An Illustrated Guide to Traffic Calming* (1990).

Department for Transport, "Interim Evaluation of the Implementation of 20mph Speed Limits in Portsmouth" (2010).

style (i.e., faster and more aggressive driving generate greater pollution),[94] while the direct generators of particulate matter pollution are braking events and gear shifts.[95]

<u>Economic Implications of Reduced Particulate Matter Pollution</u>

Combining both the effects of reduced VMTs and lower speed limits among remaining VMTs on particulate matter air pollution levels, it is possible to generate a tentative and preliminary estimate of some economic impacts that lower pollution would have in Bend using what is known as "hedonic price method" analysis. It has been found in empirical studies across North America that various traffic-related air pollutant (including particulates and others such as sulphation and oxidants) levels have measurable impacts on residential property values. That is, as pollutant levels decrease, home values rise. Studies show a relationship under which a 1% decrease in pollution levels is associated with approximately 0.1% increase in property value.[96]

If, through implementation of 20mph speed limits, Bend's VMTs decline by 5%, and if it is conservatively assumed that no additional particulate improvement is generated through improved driving behaviors, then Bend's particulate levels generated from traffic would be expected to decrease by 5%. Bend's median home price value is approximately $411,700,[97] and there are about 40,800 homes in Bend,[98] implying a total housing stock value of

[94] Kole, P., et al., "Wear and Tear of Tyres: A Stealthy Source of Microplastics in the Environment," *International Journal of Environmental Research and Public Health*, Vol. 14, No. 10 (2017).

[95] Grigoratos, T. and G. Martini, "Brake Wear Particle Emissions: A Review," *Environmental Science and Pollution Research International*, Vol. 22 (2015).

[96] Bateman, I., et al., "The Effect of Road Traffic on Residential Property Values: A Literature Review and Hedonic Pricing Study," Scottish Executive Development Department (January 2001).

Several empirical studies relate reductions in total suspended particulates to dollar value changes in housing rather than percentage value changes. These estimates vary, but their findings generally align with the per-home change in value implied by a 0.1% value increase per 1% decrease in particulate pollution used for the computations in this report.

[97] Zillow: Bend, OR Home Prices and Values.

[98] Number of homes is taken from city-data.com "Bend, OR Houses and Residents" (accessed May 2018) and verified using estimated data from the Bend-Redmond HMA Comprehensive Market Analysis. Home count captures all dwelling types, including single-family homes and multi-family structures. Rental units are included. Since the analysis is hedonic in nature and all in-kind benefits would accrue to residents whether owning or renting, it is appropriate to include all housing types.

"Comprehensive Housing Market Analysis, Bend-Redmond, Oregon," U.S. Department of Housing and Urban Development, Office of Policy Development and Research (July 1, 2015).

roughly $16.8 billion.[99] Assuming equal distribution of particulate-reduction effects throughout all of Bend's homes, the housing stock value would be expected to increase by 0.5% (i.e., 5 * 0.1%) or $84.0 million.[100]

The foregoing calculation is highly generalized and subject to various sources of uncertainty, making it best suited to providing guidance as to effect magnitude and direction rather than a precise accounting. One step toward refinement is to adjust the initial housing stock value subjected to 20mph speed limit benefits downward by reference to Bend's lane-mile distribution in its transportation network. Roughly 593 of Bend's 848 lane-miles (i.e., 70%) are considered local residential streets that would be immediate candidates for 20mph limits. Although it is clear that Bend's housing stock is proportionately more concentrated along residential streets than arterials and collectors, it is possible to conservatively apply the 70% figure to the above-calculated housing stock value change as means of reducing the likelihood of over-estimating the economic effects of particulate reduction. Taking 70% of the above-calculated $84.0 million value results in a figure of $58.8 million (a $620 per-capita value).[101] These calculations are shown in Table 4.

It is worth emphasizing that these calculations are *not* designed to be predictive of housing price increases; instead, the implied gain in housing stock value is hedonic in nature, generating an "in-kind" remunerative effect that would be realized in life-quality improvements by Bend's residents. In this way, the quality of life of each resident of Bend can be thought of as being enhanced, on average, by the calculated per-capita value.[102]

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[99] Rappaport, J., "A Guide to Aggregate House Price Measures," *Federal Reserve Bank of Kansas City Economic Review* (Q2 2017).

[100] This is a preliminary calculation intended to be representative of the scale of particulate-reduction effects in Bend rather than provide a highly precise accounting of value impacts. Among other shortcomings, this calculation 1) assumes that all housing stock in Bend would be equally impacted by a 20mph speed limit system, even though a certain proportion of Bend's housing might not be subject to substantially altered pollution; 2) assumes Bend's housing stock value is evenly distributed and impacts would also be distributed evenly, though it is unlikely that any 20mph speed limit introduction would generate equally-distributed particulate reduction; and 3) is subject to significant information constraints. For example, recent median home sale price is used to estimate per-home market value despite there being reasons why non-transacted properties' values may differ systematically from transacted properties' values, and the use of median price entails assumptions about home value statistical distributions. This calculation is not intended to be comprehensive in nature, as it does not attempt to capture other effects of reduced particulate matter, such as the financial implications of improved public health brought about by improved air quality, or any other types of effects. It is not estimated to what extent any non-home-value effects would be captured in a home-value effects estimate.

[101] Notwithstanding the merits of this refinement, the analysis remains tentative and most useful as an indicator of effect magnitude. Even if the analysis estimates effects that are 50% too high (due to various sources of uncertainty), the framework still implies economic value ranging well into the tens of millions of dollars. Thus, within context of this report, it can be stated with confidence that the effect is large and positive.

[102] Bend's 2017 population estimate is 94,520.

United States Census Bureau, American FactFinder, "Bend, Oregon 2017 Population Estimates" (accessed May 2018).

Table 4

Bend Estimated Hedonic Gains Associated with Lower Particulate Matter Pollution

	20MPH Estimate
[A] Number of Homes in Bend	40,800
[B] Median Home Price Value in Bend	$411,700
[C] Estimated Bend Housing Stock Value ([A] x [B])	**$16,797,360,000**
[D] Particulate Matter Reduction	5.0%
[E] Home Value Gain Per 1% PM Reduction	0.1%
[F] Home Value Gain (%) ([D] x [E])	**0.5%**
[G] Bend Housing Stock Value Gain ($) ([C] x [F])	**$83,986,800**
[H] Bend Local/Residential Streets (%) (1)	70%
[I] Estimated Net Bend Housing Stock Value Gain ($) ([G] x [H])	**$58,731,335**

Note:
(1) Bend Local/Residential Streets (%) Calculated as the proportion of lane-miles of local/residential streets in Bend's streets network relative to total street lane-miles (i.e., 593 / 848).

20mph Speed Limits Are Associated With Lower Noise Pollution Levels

Three key factors determine traffic noise pollution levels: traffic volume, traffic speed, and prevailing driving style/ aggressiveness.[103]

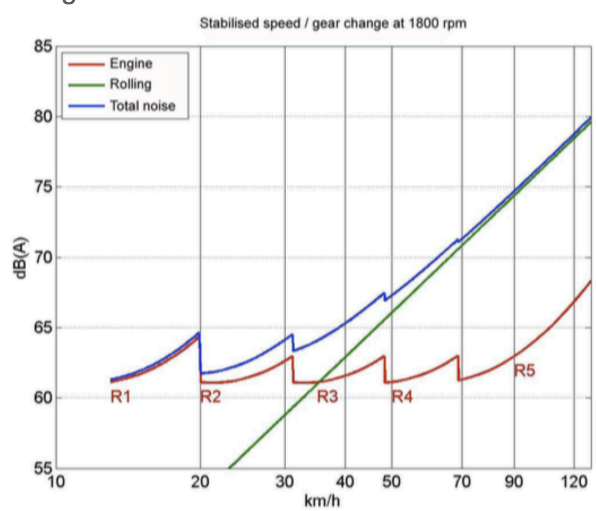
<u>Reduced VMTs</u>

Noise levels fall as traffic volumes decrease. It has been found that a 5% reduction in VMTs is associated with a 0.25 decibel ("dB") decline in noise.

<u>Lower Vehicle Speeds</u>

A much more important variable in predicting traffic noise levels is vehicle speeds. Along roadways "with speeds of between 20 and 35 mph, reducing speeds by 6 mph would cut noise level by up to 40%." Over the range of 25mph to 20mph, noise levels decrease by an average of about 3.0 decibels. This relationship between vehicle speed and noise generation is reflected in Figure 6, which shows an inflection point in the blue "total noise" line at approximately 20mph (i.e., 30kph). At rates above 20mph, increases in vehicle speed generate significant increases in noise due to the effects of "rolling noise," or sound generated by tire rolling resistance on pavement and wind resistance.

Figure 6



Transitioning Bend's roadways from 25mph to 20mph would be expected to reduce noise pollution significantly on the basis of this factor alone. Indeed, speed reduction has been singled out as a crucial strategy for reducing noise pollution: "Cutting speeds is the most immediate, the most cost-effective and most equitable way of reducing traffic noise."

<u>Diminished Aggressiveness</u>

The third factor influencing traffic noise generation is driving style, with more aggressive driving behaviors such as rapid acceleration and braking associated with peaks in traffic noise. "Noise events caused by aggressive or heavy-footed driving stand out from the anonymous background, and can have a disproportionate effect on the perception of noisiness." Reductions in aggressive driving behaviors are associated with 20mph systems; noise from rapid speed changes would be expected to decline as a result.

[103] Statistics and quotations from this section taken from: Mitchell, P., "Speed and Road Traffic Noise: The Role that Lower Speeds Could Play in Cutting Noise from Traffic," A Report Commissioned by the UK Noise Association (December 2009).

Economic Implications of Reduced Noise Pollution

Transportation system noise generation has substantial economic cost implications, quantifiable via hedonic price method analysis relating to housing. One approach to estimating economic effects of traffic noise involves evaluating the extent to which quieter versus louder street adjacencies affect housing value.[104] Empirical research has found that each decibel reduction in traffic noise is associated with an increase of approximately 0.29% in housing value.[105]

With respect to Bend, it is possible to generate a rough approximation of this economic effect. If, through adoption of a 20mph speed limit network, Bend realizes average reductions in noise generation, its streets would become quieter by about 3.25 decibels (i.e., a 3.0 dB reduction associated with a 5mph speed reduction, plus 0.25 dB reduction associated with diminished VMTs).[106] Given Bend's median home price value,[107] and the number of homes in Bend,[108] an implied total housing stock value of roughly $16.8 billion can be calculated.[109] Assuming equal distribution of noise-reduction effects throughout all of Bend's homes, the housing stock value would be

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104 Traffic noise effects on property values are well-known and often included in value analysis by parties negotiating real estate transactions. Research conducted by realtor.com, for example, found 11.3% average price discounts for proximity to highways, due to noise pollution.

Neumann, K., "What Is Noise Pollution and How Does It Affect Property Values?" realtor.com (April 25, 2018).

105 Real estate value/traffic noise studies (of which there are at least 17) presented in literature reviews of recent research have estimated a per-decibel decrease in road noise to result in an average 0.40% increase in home value; however, due to variability in the quality of studies, reviewers of the published research concluded that a 0.29% multiple is the best estimate from the aggregated literature.

Bateman, I., et al., "The Effect of Road Traffic on Residential Property Values: A Literature Review and Hedonic Pricing Study," Scottish Executive Development Department (January 2001).

Pignier, N., "The Impact of Traffic Noise on Economy and Environment: A Short Literature Study," KTH Royal Institute of Technology (2015).

Ozdenerol, E., et al., "The Impact of Traffic Noise on Housing Values," *Journal of Real Estate Practice and Education*, Vol. 18, No. 1 (July 2015).

106 Mitchell, P., "Speed and Road Traffic Noise: The Role that Lower Speeds Could Play in Cutting Noise from Traffic," A Report Commissioned by the UK Noise Association (December 2009).

107 Zillow: Bend, OR Home Prices and Values.

108 Number of homes is taken from city-data.com "Bend, OR Houses and Residents" (accessed May 2018) and verified using estimated using data from the Bend-Redmond HMA Comprehensive Market Analysis. Home count captures all dwelling types, including single-family homes and multi-family structures. Rental units are included. Since the analysis is hedonic in nature and all in-kind benefits would accrue to residents whether owning or renting, it is appropriate to include all housing types.

"Comprehensive Housing Market Analysis, Bend-Redmond, Oregon," U.S. Department of Housing and Urban Development, Office of Policy Development and Research (July 1, 2015).

109 Rappaport, J., "A Guide to Aggregate House Price Measures," *Federal Reserve Bank of Kansas City Economic Review* (Q2 2017).

expected to increase by 0.94% (i.e., 3.25 * 0.29%)[110] or $158.3 million.[111] The analysis can be refined by reference to Bend's lane-mile distribution in its transportation network. Applying the 70% figure residential lane-mile proportion to the above-calculated housing stock value change of $158.3 million results in a figure of $110.7 million (i.e., a $1,170 per-capita value).[112] These calculations are shown in Table 5.

As with the earlier hedonic price method analysis, this calculation is highly generalized and subject to various sources of uncertainty. It is best suited to providing guidance as to effect magnitude and direction rather than a precise accounting. In any case, this computation is *not* predictive of housing price increases, but rather serves to estimate hedonic "in-kind" gains in life quality that would be realized by Bend's residents as a result of reduced traffic noise.[113]

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[110] This finding is corroborated by separate empirical analysis conducted in Shelby County, Tennessee, using a somewhat different methodological approach. It was found that increases in traffic noise in increments of 5 decibels reduced housing values of, on average, 1.3 percentage points. Hence, a 3.85 decibel reduction would be associated with housing value increases of just above 1 percent (i.e., (1.3/5)*3.85), an estimate consistent with that provided in this report.

Ozdenerol, E., et al., "The Impact of Traffic Noise on Housing Values," *Journal of Real Estate Practice and Education*, Vol. 18, No. 1 (July 2015).

[111] This is a preliminary calculation intended to be representative of the scale of noise-reduction effects in Bend rather than provide a highly precise accounting of value impacts. Among other shortcomings, this calculation 1) assumes that all housing stock in Bend would be equally impacted by a 20mph speed limit system, even though a certain proportion of Bend's housing might not be subject to substantially altered traffic noise; 2) assumes Bend's housing stock value is evenly distributed and impacts would also be distributed evenly, though it is unlikely that any 20mph speed limit introduction would generate equally-distributed noise abatement; and 3) is subject to significant information constraints. For example, recent median home sale price is used to estimate per-home market value despite there being reasons why non-transacted properties' values may differ systematically from transacted properties' values, and the use of median price entails assumptions about home value statistical distributions. This calculation is not intended to be comprehensive in nature, as it does not attempt to capture workplace-associated effects of lower traffic noise, nor does it attempt to compute the financial implications of improved public health brought about by reduced traffic noise, or any other types of effects. It is not estimated to what extent any non-home-value effects would be captured in a home-value effects estimate.

[112] Notwithstanding the merits of this refinement, the analysis remains tentative and most useful as an indicator of effect magnitude. Even if the analysis estimates effects that are 50% too high (due to various sources of uncertainty), the framework still implies economic value ranging well into the tens of millions of dollars. Thus, within context of this report, it can be stated with confidence that the effect is large and positive.

[113] In addition to the empirical studies on which these hedonic gain calculations are based, there is anecdotal evidence that generally enhanced street safety supports real estate value. Kensington Street in London is reported to have experienced a 13% value increase following streetscape safety improvements.

Sharpin, A.B., et al., "The Need for (Safe) Speed: 4 Surprising Ways Slower Driving Creates Better Cities," World Resourced Institute (May 9, 2017).

Table 5

Bend Estimated Hedonic Gains Associated with Lower Noise Pollution

	20MPH Estimate
[A] Number of Homes in Bend	40,800
[B] Median Home Price Value in Bend	$411,700
[C] Estimated Bend Housing Stock Value ([A] x [B])	**$16,797,360,000**
[D] Traffic Noise Decibel Reduction (dB)	3.25
[E] Home Value Gain Per 1% PM Reduction	0.29%
[F] Home Value Gain (%) ([D] x [E])	**0.94%**
[G] Bend Housing Stock Value Gain ($) ([C] x [F])	**$158,315,118**
[H] Bend Local/Residential Streets (%) (1)	70%
[I] Estimated Net Bend Housing Stock Value Gain ($) ([G] x [H])	**$110,708,567**

Note:
(1) Bend Local/Residential Streets (%) Calculated as the proportion of lane-miles of local/residential streets in Bend's streets network relative to total street lane-miles (i.e., 593 / 848).

Summarized Economic Implications of Reduced Air and Noise Pollution

Bringing together the foregoing computations, reduced air and noise pollution associated with 20mph speed limits would be expected to generate the following economic results:

- Annual gains of approximately $1.6 million associated with reduced CO2 emissions;
- One-time increase of in-kind housing stock value of about $58.7 million due to reduced particulate matter pollution; and
- One-time increase of in-kind housing stock value of roughly $110.7 million as a consequence of decreased noise pollution.[114]

[114] There also have been studies evaluating the effects of enhanced pedestrian/cyclist accommodations (e.g., safety improvements such as reduced traffic speeds) in retail areas. These studies show increased retail sales and increased retail rents in zones making these accommodations. To the extent retailers are located on streets reducing limits to 20mph, those retailers would be expected to experience economic gains, as would retail property owners. This effect is not quantified here due to data limitations regarding retailer presence on candidate streets and those retailers' financial results, as well as limited data as to the precise mechanisms that generate the economic gains, particularly regarding the isolated effect of installing 20mph speed limits. In any event, such effect likely would be positive and add to calculated economic gains associated with 20mph speed limit adoption.

"The Economic Benefits of Sustainable Streets," New York City Department of Transportation (2013).

"Good for Business: The Benefits of Making Streets More Walking and Cycling Friendly," Heart Foundation (2011).

5. Decreased Road Capacity Requirements & Saved Infrastructure Expenses

There are two means by which a 20mph speed limit system decreases vehicular roadway capacity demands. The first is reduced overall VMTs, and the second is enhanced efficiency of roadway space utilization, particularly during peak travel times. Both factors imply savings on infrastructure costs. Those savings far outweigh costs of implementing 20mph speed limits in Bend.[115]

20mph Speed Limits Reduce Road Capacity Needs

With lower VMTs, consumption of roadway capacity by vehicles declines, freeing roadway resources. This reduction in VMTs is not realized uniformly across a transportation system; rather, network "bottlenecks" tend to experience the greatest traffic reductions. This is due to the mechanics of how modal substitution occurs in a 20mph system.[116]

To illustrate how bottlenecks recognize disproportionately large volume relief, it is instructive to consider typical vehicular trip distances. Nationally, 20% of all vehicular trips are not more than 1 mile in distance, while 32% of trips cover 2 miles or less, and 42% are capped at 3 miles.[117] Thus, a substantial portion of traffic derives from "short-trip" travel. And, in centralized transportation system networks, short vehicle trips comprise a large share of bottleneck traffic (since centralized nodes are where vehicles become funneled and where bottlenecks subsequently occur). Substitution from driving to walking or cycling is most likely to occur when the total distance traveled is lowest, so it follows that shorter trips contributing 40% or more to bottleneck congestion experience the highest rates of modal substitution.[118] Modal substitution thus generates a disproportionately large relief of traffic demand at the points most typically identified as bottlenecks and candidates for roadway expansion.

Superior junction filtering and vehicle spacing in 20mph systems also reduce road supply needs during peak travel hours since vehicular traffic on the roads makes better use of the available space. This effect frees more roadway

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[115] To the extent VMT reductions enable reduced or even slowed construction of new road lane-miles, future structural maintenance costs would be reduced, with significant implications for City budgeting.

[116] Cass, N. and J. Faulconbridge, "Commuting Practices: New Insights into Modal Shift from Theories of Social Practice," *Transport Policy*, Vol. 45 (2016).

[117] Federal Highway Association 2009 National Household Travel Survey, "Vehicle Trips, Number of Vehicle Trips by Trip Distance Including Trips 2 Miles or Less."

[118] Around 74% of all bike trips in the U.S. and over 93% of walking trips cover 3 miles or less. At distances above 3 miles, trip shares for both cycling and walking fall precipitously, suggesting it is at around the 3-mile threshold that modal substitution effects would largely diminish. Longer trips would more likely use roadways outside a city's urban/suburban transportation system, including freeways, and would thus contribute less to bottleneck congestion per VMT.

U.S. Department of Transportation, Federal Highway Administration, 2009 National Household Travel Survey (data extraction tool accessed June 2018).

capacity, particularly at intersections beleaguered by long queues and wait times (i.e., bottlenecks). Traffic throughput efficiency with respect to road supply thereby increases, further reducing perceived needs for additional lane-miles.

Through these two complementary mechanisms, existing vehicular roadway infrastructure can accommodate population growth, a consideration of significance in Bend given the city's rapid recent and anticipated future population gains.[119] A corollary of this increased effective capacity is that construction of fewer additional lane-miles would be implicated, saving Bend funds on roadway expansion and future maintenance costs.[120]

Reduced VMTs Decrease Road Wear and Maintenance Costs

Road wear and attendant maintenance needs are a partial function of roadway usage. All else equal, as VMTs increase (or decrease), maintenance costs rise (or fall).[121] Because of this relationship, estimating the impact of reduced VMTs on road maintenance expenses in Bend should be a straightforward exercise. Complexity arises, however, from the fact that Bend, like many other cities, accumulates deferred maintenance costs each year as its level of maintenance needs exceeds its budgeted capacity for spending. Deferred maintenance costs are not widely available or subject to the same accounting standards as adopted budgets and so some care must be taken in using available figures. All told, these considerations mean that an analysis relying only on Bend's budgeted maintenance spending will understate per-VMT maintenance values, while an analysis that incorporates deferred maintenance costs will be subject to a higher likelihood of approximate accuracy but greater input uncertainty. In order to reflect this issue, two approaches are used complimentarily to bracket the estimated impact of reduced VMTs on Bend's road maintenance costs.

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[119] "Oregon Population Forecast Program, Preliminary Coordinated Forecasts for Deschutes County, Its Urban Growth Boundaries (UGBs), and the Area Outside UGBs," Portland State University, Regional Forecast Meeting (March 6, 2018).

[120] In addition to lower lane-mile requirements, reduced parking capacity would be implicated by VMT reductions, thus reducing space, cost and upkeep requirements for new vehicle parking spots. The cost of a new parking space in a structured parking garage is approximately $15,000.

Flusche, D., et al., "The Bottom Line: How Bicycle and Pedestrian Projects Offer Economic Benefits to Communities," Pedestrian and Bicycle Information Center Webinar Presentation (May 7, 2013).

[121] Currey, M., et al., "Vehicle-Miles Traveled (VMT) Impacts on the Environment, Human Health, and Fiscal Health," (2015).

"Transportation Cost and Benefit Analysis II - Roadway Costs," Victoria Transport Policy Institute (April 2018).

First, simply taking Bend's per-year operations budget for streets of approximately $13.9 million and multiplying it by the estimated VMT reduction of 5% results in one point estimate of about $670,000 in net savings per year, assuming the VMT reduction reflects a 1:1 modal substitution from driving to cycling.[122]

A second approach relies upon additional data to capture deferred maintenance values in the analysis. The City of Bend "Bend Streets Funding" web page states: "During the recession, the City cut back its pavement preservation work. Continually increasing traffic volume has added to streets' wear and tear. The City of Bend has accumulated at least $80 million worth of deferred street maintenance needs and road conditions are declining. Existing funds are not keeping up with the growing backlog of deferred street maintenance." If Bend's stock of deferred maintenance accumulated from the time of the recession (i.e., 2008-2009) forward, then roughly 10 years of accumulated depreciation are accounted for in the $80 million figure. This provides a general estimate of about $8 million per year in deferred maintenance, though that figure would be expected to increase over time in step with VMT growth. Conservatively adding $8 million to Bend's street maintenance budget of $13.9 million yields a value of $21.9 million. Assuming a 1:1 vehicle-to-cycling modal substitution, net maintenance costs would be expected to decline by nearly $1.1 million.[123]

A range of annual savings on streets maintenance of $670,000 to about $1.1 million is thereby generated, with recognition that the $670,000 figure likely understates savings, and the $1.1 million figure is likely more accurate.[124] These calculations are summarized in Table 6.

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[122] Bend's 2017-2019 budget for street maintenance is $27.8 million. A per-year value of approximately $13.9 million is calculated.

Empirical evidence shows that per-VMT maintenance costs are 26.6 times per-cycled mile maintenance costs. A 5% reduction in VMTs reduces vehicle-related maintenance spending by $695,000 and increases cyclist-related spending by about $25,000. This is conservative since the ratio of VMT costs to pedestrian costs is about 133. Any increase in walking would further enhance net maintenance savings.

City of Bend, Oregon, 2017-2019 Biennial Budget, "Streets & Operations Fund: Street Maintenance Program."

Litman, T., "Whose Roads? Evaluating Bicyclists' and Pedestrians' Right to Use Public Roadways," Victoria Transport Policy Institute (December 2013).

Shorack, T., "Bend Road Repair: $84,000 Per Lane Mile," *Bend Bulletin* (August 10, 2015).

Bend City Statistics, "Chapter 5: Mode Split" (accessed June 2018).

City of Bend Website "City of Bend Streets and Operations Division Winter Operations" (accessed June 2018).

[123] A 5% reduction in VMTs reduces vehicle-related maintenance spending by $1.094 million and increases cyclist-related spending by about $40,000.

[124] The upper bound of this bracketed estimate may also understate savings since the $80 million in deferred maintenance was simply divided evenly by year without reference to increasing VMTs over the period. A more refined analysis could provide a higher upper bound.

Table 6

Bend Estimated Annual Street Maintenance Savings with 20mph Speed Limits

	Low Estimate (1)	High Estimate (2)
[A] Bend Annual Street Maintenance Needs	$13,887,770	$21,887,770
[B] VMT Reduction (%)	5%	5%
[C] VMT Street Maintenance Savings ([A] x [B])	$694,389	$1,094,389
[D] Additional Maintenance - Substitution ([C] ÷ 26.6)	$26,105	$41,142
[E] Net Annual Street Maintenance Savings ([C] - [D])	**$668,284**	**$1,053,246**

Note:
(1) Low estimate reflects Bend's budgeted allowance for street maintenance over the 2017-2019 fiscal years, averaged to obtain an annual value.
(2) High estimate reflects Bend's Low Estimate value plus a portion of the $80 million in estimated unfunded maintenance needs. The $80 million is evenly divided by 10 to obtain an estimated annual value.

Cost of Implementing 20mph Speed Limits Is Low

It is possible to estimate costs that would be incurred by the City of Bend if 20mph speed limits are adopted by considering the experience of Portland, Oregon, in its rollout of 20mph speed limits, which took effect April 1, 2018.[125] Since both Bend and Portland are cities in Oregon (and thereby have identical state-level traffic laws), and since both cities would utilize the same legislative path for adopting 20mph speed limits, it follows that Portland's project costs can inform expectations of cost in Bend.

Portland's transportation system encompasses approximately 4,842 lane-miles,[126] of which roughly 3,000 lane-miles received 20mph speed limit designations.[127] Encompassed in the rollout was the installation of about 2,000 new speed limit signs around the city,[128] an undertaking with costs pegged at $300,000.[129]

[125] The City of Portland, Portland Bureau of Transportation Website "Residential Speed Limit Reduction" (accessed June 2018).

[126] The City of Portland, Portland Bureau of Transportation Website "How Portland's Streets Are Maintained and Repaired" (accessed June 2018).

[127] Friedman, G., "3,000 Miles of Portland Streets May Get Slower Speed Limits Under New Bill," *The Oregonian* (April 24, 2017).

The City of Portland, Portland Bureau of Transportation Website "Residential Speed Limit Reduction" (accessed June 2018).

[128] The City of Portland, Portland Bureau of Transportation Website "Residential Speed Limit Reduction" (accessed June 2018).

[129] Njus, E., "Portland City Council Approves 20 mph Speed Limit on Residential Streets," *The Oregonian* (January 18, 2018).

Scaling down the project cost to Bend's size entails consideration of Bend's lane-miles most likely to be subject to 20mph speed limits and then applying a pro-rata cost figure to those lane-miles. Bend has approximately 848 lane-miles of roadway, with 593 classified as local residential streets that would be immediate candidates for 20mph speed limits.[130] Accordingly, Bend's 20mph rollout would encompass about 19.8% of Portland's affected lane-mileage (i.e., 593 / 3,000). Assuming Bend would install new speed limit signs at the same rate and cost as Portland (and it is unclear why there would be any material difference), then Bend's estimated cost of new signage would run to approximately $59,300.

[130] Shorack, T., "Bend Road Repair: $84,000 Per Lane Mile," *Bend Bulletin* (August 10, 2015).

City of Bend Website "City of Bend Streets and Operations Division Winter Operations" (accessed June 2018).

6. Improved Public Health

The public health consequences of 20mph speed limits are far-reaching and implicate many facets of life. Since it is unlikely any review can comprehensively capture the benefits society realizes with slower traffic speeds and lower driving levels, this section is not intended to be categorical in coverage. Rather, it briefly surveys certain empirical findings relevant to Bend's potential adoption of 20mph speed limits, focusing on traffic collisions, pollution, and the obesity and diabetes health epidemics.[131]

Notwithstanding the limited coverage of public health effects discussed in this report, the substantial breadth of public health impacts brought about with 20mph speed limits is notable. In summary of the widespread value of 20mph speed limits on public health, one University of Oxford researcher states:

> …when asked what single policy I would suggest [to improve public health], I always reply '20mph' or, if I'm being a little more verbose: 'twenty's plenty.' This normally elicits some surprise. The person I am speaking to usually expects me to suggest reducing poverty by reducing unnecessary privileges for the rich, narrowing economic inequalities, raising social mobility, or improving health services or education; not simply slowing cars down. All those other things are very laudable, but if you want to do just one thing, then the thing you can actually do, the one thing that has now been done in over one hundred local authorities…, the thing that makes a difference that you can feel, see and measure straight away, is to stick a sign that says 20mph [on posts] where you live. And, fortunately, it is now (almost) as easy as that.[132]

Fewer Collisions Improve Health and Make Health Outcomes More Equitable

Overwhelming empirical evidence, some of which is outlined earlier in this report, chronicles the power of 20mph speed limits to reduce both the quantity and severity of traffic collisions. Drivers, passengers, motorcyclists, pedestrians, cyclists, and children realize significant safety and health gains. A review of 20mph speed limit regimes published in the *Journal of Public Health* concludes that: "Twenty mile per hour zones and limits are effective means of improving public health via reduced accidents and injuries."[133] More evidence will not be

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[131] Other areas of public health that are not addressed, but which have been found to benefit from reduced traffic speeds/levels or from increased non-automotive transport levels include social health, mental health, and depression. See, for instance: Leyden, K., "Social Capital and the Built Environment: The Importance of Walkable Neighborhoods," *American Journal of Public Health*, Vol. 93, No. 9 (2003).

[132] Dorling, D., "20mph Speed Limits for Cars in Residential Areas, by Shops and Schools," Nine Local Actions to Reduce Health Inequalities, University of Oxford.

[133] Cairns, J., et al., "Go Slow: An Umbrella Review of the Effects of 20mph Zones and Limits on Health and Health Inequalities," *Journal of Public Health*, Vol. 37, No. 3 (2015).

presented here to elaborate on this point, but volumes remain available to testify to the significance of 20mph speed limits in securing public well-being.

A related point, and one that has not yet been addressed in this report, relates to questions of socioeconomic equity in the public health implications of 20mph speed limits. It has been found that traffic collisions are disproportionately damaging for those with lower incomes and less education. One's chances of being killed or seriously injured in traffic crashes rise as one's salary or education level falls, with low-income pedestrians *twice as likely to be killed* as higher-income pedestrians.[134] Traffic accidents accordingly represent a significant source of social inequality and, by extension, show that traffic speed limits above 20mph are a forceful promoter of inequity in a transportation system.[135]

While the economics are complex and will only be mentioned in brief here, it is generally the case that the lower a person's income and education, the more likely that person is to lack health insurance. In the event emergency care is required, the individual will either accumulate paralyzing medical debt, or, owing to an inability to pay medical costs, effectively receive "charity care" funded by outside money.[136] Hence, the long-run personal economic implications of traffic collisions inequitably bear on those with lower incomes, and public funds are disproportionately funneled into the treatment of injuries generated by traffic collisions.[137] In Bend, this issue is acute, since it is estimated that almost 16% of the population under 65 years old lacks health insurance.[138] Speed limits of 20mph help pare this root of social inequality by cutting traffic collisions and injuries - especially among

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[134] Harper, S., "Trends in Socioeconomic Inequalities in Motor Vehicle Accident Deaths in the United States, 1995-2010," *American Journal of Epidemiology*, Vol. 182, No. 7 (2015).

Morency, P., "Neighborhood Social Inequalities in Road Traffic Injuries: The Influence of Traffic Volume and Road Design," *American Journal of Public Health*, Vol 106, No. 2 (2012).

Maciag, M., "America's Poor Neighborhoods Plagued by Pedestrian Deaths," Governing Research Report (August 2014).

[135] Dorling, D., "20mph Speed Limits for Cars in Residential Areas, by Shops and Schools," Nine Local Actions to Reduce Health Inequalities, University of Oxford.

[136] "Key Facts about the Uninsured," Henry J. Kaiser Family Foundation (September 19, 2017).

[137] Lam, B., "Who Pays Hospital Bills When Patients Can't?" *The Atlantic* (October 13, 2015).

"A Floor-and-Trade Proposal to Improve the Delivery of Charity-Care Services by U.S. Nonprofit Hospitals," The Hamilton Project, The Brookings Institution, Policy Brief 2015-07 (2015).

[138] United States Census Bureau, "Bend, Oregon QuickFacts" (accessed June 2018).

groups that simultaneously carry both the greatest injury risk and the lowest health insurance coverage - while also helping improve the financial efficiency of local health care provision.[139]

Lower Pollution Levels Enhance Public Health and Reduce Medical Costs

Earlier in this report the influence of traffic speed and traffic volume on various pollutants was described. Levels of CO2, micro-plastics, particulates, and road noise decline in response to slower traffic and lower VMTs. The consequences of reduced pollution on future environmental remediation costs and on resident life quality (measured in the context of real estate) were also mentioned. Unstated were the profound human health consequences of air and noise pollution and the salutary public health effects of reducing those pollutants.

Traffic-related air pollution has been shown as a statistically significant predictor of an array of health maladies, including childhood asthma,[140] cardiovascular risk,[141] as well as inflammation and cancer,[142] and links to pregnancy disorders have also been suggested.[143] Traffic noise, for its part, has been found to contribute to hypertension, heart attack risk, childhood cognitive impairment, and sleeping disorders.[144]

While quantifying the financial consequences of improving public health levels by reducing air and noise pollution will not be attempted, it is clear that the directional relationship between pollution and costs associated with disease and mortality is positive, and it is further apparent that the magnitude of pollution-related healthcare costs is quite high. Even modest pollution reductions would substantially improve public health outcomes and reduce overall medical costs borne by Bend's residents and health care providers.

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[139] St. Charles Health System, Inc. is a not-for-profit Oregon corporation and provides a financial assistance program for those unable to pay for the cost of their care, a practice sometimes referred to as "charity care" in the U.S. healthcare system.

Oregon Health Authority, Division of Health Policy & Analytics, Office of Health Analytics "Oregon Acute Care Hospitals Financial and Utilization Trends, 4th Quarter 2016," (June 2017).

[140] Khreis, H. and MJ Nieuwenhuijsen, "Traffic-Related Air Pollution and Childhood Asthma: Recent Advances and Remaining Gaps in the Exposure Assessment Methods," *International Journal of Environmental Research and Public Health*, Vol. 14, No. 3 (2017).

[141] Nawrot, T., "The Detrimental Health Effects of Traffic-Related Air Pollution," *American Journal of Respiratory and Critical Care Medicine*, Vol. 179, No. 7 (2009).

[142] Krzyzanowski, M., B. Kuna-Dibbert and J. Schneider (Eds.), "Health Effects of Transport-Related Air Pollution," World Health Organization (2005).

[143] Raz, R., et al., "Traffic-Related Air Pollution and Autism Spectrum Disorder: A Population-Based Nested Case-Control Study in Israel," *American Journal of Epidemiology*, Vol. 187, No. 4 (2018).

Krzyzanowski, M., B. Kuna-Dibbert and J. Schneider (Eds.), "Health Effects of Transport-Related Air Pollution," World Health Organization (2005).

[144] Pignier, N., "The Impact of Traffic Noise on Economy and Environment: A Short Literature Study," KTH Royal Institute of Technology (2015).

Increased Walking and Cycling Reduce Incidence of Obesity and Diabetes

Obesity and diabetes constitute two of the most significant health epidemics facing American society. They afflict tens of millions of people and generate hundreds of billions of dollars in medical expenses nationally.[145] Within Deschutes County, Oregon, approximately 30,000 adults qualify as obese, and about 7,000 adults are diabetics.[146]

Obesity and diabetes are linked to sedentary lifestyle factors and can be prevented and managed with physical activity. An increase in activity reduces risk of onset and intensification.[147] Owing to the simple relationship between physical movement and affliction with obesity or diabetes, it follows that modal substitution from driving to walking or cycling would reduce the severity and affliction rates of obesity and diabetes in the community by replacing a sedentary activity, driving, with non-sedentary ones, walking and cycling, in people's routines.

As with the inequitable socioeconomic profile of traffic collisions, obesity and diabetes express a similarly steep relationship across the socioeconomic gradient. Both diseases show strong inverse relationships with income and education level. As income and education levels decline, obesity and diabetes rates increase.[148] Transportation systems that discourage modal substitution into walking and cycling due to unsafe speed limits accordingly impart disproportionately large harms on those people at the lowest socioeconomic status levels. This is because those with less income and education tend to be simultaneously those most at risk for injury or fatality while walking (and thus most discouraged from it) and those whose statistical health profiles could most benefit from walking.[149] Addressing equitability effects in a transportation system requires consideration of this factor.

Beyond 20mph speed limits' modal substitution effects, lower speed limits also can encourage incremental walking trips made solely for exercise or pleasure among those in the lowest income brackets. This effect would generate advantageous health results. Institution of 20mph speed limits would reduce pedestrian risks and remove an impediment to increased physical activity for those most at risk for obesity and diabetes.

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[145] "Adult Obesity Causes & Consequences," Centers for Disease Control and Prevention Website (accessed June 2018).

Petersen, M., "Economic Cost of Diabetes in the U.S. in 2012," *Diabetes Care*, Vo. 36 (2013).

[146] "Deschutes County Health Services Epidemiology Newsletter," Deschutes County, Oregon (Fall 2016).

[147] "Obesity Prevention Source," Harvard T.H. Chan School of Public Health (accessed June 2018).

[148] Ogden, C., et al., "Prevalence of Obesity Among Adults, by Household Income and Education - United States, 2011-2014," *MMWR Morbidity and Mortality Weekly Report (CDC)*, Vol. 66, No. 50 (2017).

Rabi, D., et al., "Association of Socio-Economic Status with Diabetes Prevalence and Utilization of Diabetes Care Services," *BMC Health Services Research*, Vol. 6 (2006).

[149] Morency, P., "Neighborhood Social Inequalities in Road Traffic Injuries: The Influence of Traffic Volume and Road Design," *American Journal of Public Health*, Vol 106, No. 2 (2012).

CONCLUSION

Before enumerating specific findings of this report, one foundational conclusion must be emphasized. Adoption of 20mph speed limits in a transportation system is an important, and perhaps necessary, step toward enhancing that system's safety, efficiency, reliability, and equitability. It is not, however, a standalone cure for all transportation system problems, and information outlined in this report should not be mistaken for suggesting 20mph speed limits are a panacea. Two points illustrate why.

First, the breadth of success in improving safety and generating economic gains associated with 20mph speed limits is modulated by the particulars of its implementation. The greater a commitment to public education, police enforcement of speeds, and installation of complementary traffic calming measures, the greater the traffic speed and traffic volume responses will be, and hence the greater the safety and economic gains will be. It is true that simply replacing speed limit signs has been shown to produce improvements, and those "sign-only" benefits are a good first step. Yet, the full array of social and economic returns will not be realized without supplemental initiatives like education, enforcement, and calming. Thus, any contemplation of adopting 20mph speed limits also implies adoption of some level of complementary policies to support that speed limit change. Indeed, this report reflects an "average" implementation of 20mph speed limits, involving more than changing signs but less than large-scale reconfiguration of roadways to calm traffic as some cities have done. Greater results than those calculated here could be obtained with an above-average commitment to implementation and complementary policies.

Second, even with a "full" implementation of 20mph limits and supportive ancillary measures, a transportation system will still be susceptible to traffic deaths and injuries, system bottlenecks, fuel and resource wasting, travel time variability, and inequitable distributions of the system's benefits and costs. Accordingly, while 20mph speed limits and complementary measures are crucial to improving a transportation system, additional policies to promote safety and social efficiency are required to fully address transportation system needs. The findings of this report should not be mistaken to suggest that 20mph speed limits are a cure-all; they are not. They are important, and they are socially and economically compelling, but they are not, on their own, sufficient.

Having addressed this critical point, we now outline effects that can be reasonably expected to result from Bend's adoption of 20mph system-wide speed limits:

1. Dramatic reductions in traffic collisions of all types are associated with 20mph speed limit systems. Fatal and KSI collisions exhibit especially large decreases. In addition to saving lives from premature death and debilitating injury, 20mph speed limits in Bend would be associated with economic savings in the range of $7.2 million per year.

2. Traffic congestion levels would be expected to decrease in Bend following adoption of 20mph speed limits as a consequence of modal substitution and improved utilization of roadway resources. Total annual VMT reductions in the range of 5%, or 30.5 million miles, would be expected.

3. Vehicular travel times would be either slightly reduced or unaffected by implementation of 20mph speed limits.

4. Declines in VMT and increases in modal substitution result in system-wide fuel consumption decreases. Declines of approximately 1.4 million gallons of fuel usage annually would be realized in Bend, generating financial savings for drivers of about $4.5 million per year.

5. Traffic-related pollution is a function of VMTs. Declines in CO2, particulate matter, and noise pollution result from modal substitution and VMT reductions, and those decreases result in important environmental and economic consequences. One-time in-kind economic gains of approximately $169.4 million would stem from reduced particulate matter and noise pollution levels in Bend, while annual economic returns of about $1.6 million would derive from reduced CO2 pollution.

6. Reductions in traffic speed and volume diminish road wear. Annual road maintenance savings of approximately $1.1 million would result from lower VMTs associated with 20mph speed limits.

7. The cost of implementing 20mph speed limits in Bend is low, estimated to be in the range of $60,000.

8. Public health levels increase as VMTs decline and modal substitution occurs, which would benefit all residents of Bend and enhance efficiency of local health care.

9. A 20mph speed limit system is more socially equitable than a 25mph system, and 20mph speed limits would improve social equitability in Bend.

Thank you for your consideration of this important topic as you proceed with making recommendations about the future of Bend's transportation system.

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