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Climbing Mount Next: The Effects of Autonomous Vehicles on Society

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Climbing Mount Next: The Effects of Autonomous Vehicles on Society*

David Levinson**

I.	Mount Transit and Mount Auto.....	787
II.	Mount Next.....	794
	A. Safety.....	795
	B. Capacity.....	796
	C. Auto-Mobility for All.....	798
	D. Diversity.....	798
	E. Vehicles-as-a-Service (VaaS).....	801
	F. Migration.....	803
	G. Urban Form.....	805
	H. Costs.....	805
	I. Class.....	806
III.	Conclusions.....	806

I. MOUNT TRANSIT AND MOUNT AUTO

In the United States, we have seen a great struggle play out in the twentieth century between what David Jones calls mass motorization and mass transit.¹ The conflict between cars and public transport continues to this day, and has become a morality play in the culture wars.² While the two modes mostly serve different markets, at the margins they compete for users,

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1. DAVID W. JONES, MASS MOTORIZATION AND MASS TRANSIT: AN AMERICAN HISTORY AND POLICY ANALYSIS (Indiana Univ. Press 2010).

2. *Id.* at 97.

roadspace, funding, and the hearts and minds of travelers.³ They are competing on old turf though. As the graph shows, both modes appear to be in decline: while transit has been in decline for decades, the decline of the conventional auto-highway-system is just beginning.⁴

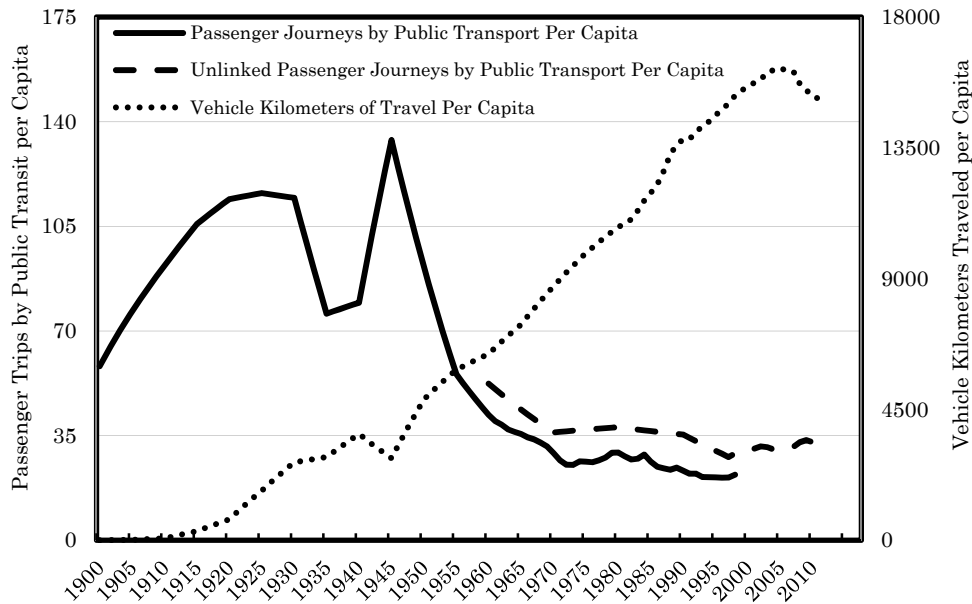


Figure 1. Climbing Mount Transit and Mount Auto: The Rise and Fall of U.S. Highways⁵

3. *Id.*

4. JONES, *supra* note 1, at 181–86.

5. The graph shows both linked and unlinked transit trips, as the way transit trips are counted has changed, and there is no continuous series of both over the entire period. BUREAU OF THE CENSUS, U.S. DEP'T OF COMMERCE, HISTORICAL STATISTICS OF THE UNITED STATES: COLONIAL TIMES TO 1970 (1975), available at https://www.census.gov/prod/www/statistical_abstract.html; JONES, *supra* note 1, at 139; DAVID M. LEVINSON & KEVIN J. KRIZEK, PLANNING FOR PLACE AND PLEXUS: METROPOLITAN LAND USE AND TRANSPORT 274 (Routledge 2008); *Public Road Mileage, Lane-Miles, and VMT*, FED. HIGHWAY ADMIN., U.S. DEPARTMENT TRANSP., <http://www.fhwa.dot.gov/policyinformation/statistics/2012/vmt422c.cfm> (last visited Feb. 20, 2015).

To develop a metaphor Kevin Krizek and I used in *Planning for Place and Plexus*,⁶ the United States spent from the late 1880s through the early 1920s climbing Mount Transit.⁷ Transit was the most important mode of travel (after walking) in large and medium-sized U.S. cities.⁸ The rise of transit was enabled by the electric streetcar, itself a product of electricity, harnessed by Edison and others,⁹ and the modern railroad, developed beginning in 1825 with Stephenson's steam-powered Stockton and Darlington Railway.¹⁰ Transit peaked in the United States in the 1920s, but for a spike during World War II when oil and rubber were rationed, crimping use of the automobile.¹¹ From the end of the War forward, transit began a steady decline from which it has not really recovered.¹² Despite the so-called resurgence of transit, and receiving about a quarter of surface transportation expenditures,¹³ transit trips per capita remain below 1990 levels.¹⁴

The United States spent almost the entire twentieth century climbing Mount Auto.¹⁵ From the 1920s onward, the automobile was the dominant mode of travel for Americans, accumulating more miles per capita than other modes.¹⁶ While the Great Depression slowed the auto's growth, it did not result

6. LEVINSON & KRIZEK, *supra* note 5.

7. JONES, *supra* note 1, at 7, 31–46; LEVINSON & KRIZEK, *supra* note 5.

8. JONES, *supra* note 1, at 53, 55–56.

9. *Id.* at 31.

10. See WILLIAM L. GARRISON & DAVID M. LEVINSON, *THE TRANSPORTATION EXPERIENCE: POLICY, PLANNING, AND DEPLOYMENT* 28–31 (Oxford Univ. Press 2nd ed. 2014).

11. JONES, *supra* note 1, at 35, 98 (“The peak for total bus, streetcar, and rapid transit ridership per capita in a peacetime year occurred in 1926”); LEVINSON & KRIZEK, *supra* note 5, at 113.

12. JONES, *supra* note 1, at 96–97.

13. LEVINSON & KRIZEK, *supra* note 5, at 4 (“Even in the auto-friendly United States more than one in four of all dollars (both federal and state) spent on surface transportation has gone to transit in the last 25 years.”).

14. JONES, *supra* note 1, at 139.

15. LEVINSON & KRIZEK, *supra* note 5, at 274; see *Public Road Mileage Lane-Miles, and VMT*, *supra* note 5 (showing the increase of vehicle kilometers of travel per capita during the twentieth century).

16. JONES, *supra* note 1, at 46–48; LEVINSON & KRIZEK, *supra* note 5, at 274; see also JEAN-PAUL RODRIGUE ET AL., *GEOGRAPHY TRANSPORTATION SYSTEMS 207* (2013) (“From the 1920s, [automobile] ownership rates increased dramatically Within a short time, the automobile was the dominant mode of travel in all cities of North America.”).

in decline.¹⁷ There was a brief downturn during World War II, and a few hiccups in the steady rise of mileage.¹⁸ But the later 2000s and 2010s have seen a sharp downturn in motor vehicle use per capita.¹⁹ This drop is greater than the drop during World War II in absolute terms (though the War saw a drop of twenty-three percent off the pre-war peak, and the 2012 drop is seven percent below 2005).²⁰ It is complemented by an apparent plateauing in total miles of paved roads since 2008.²¹

In *The Transportation Experience*, William Garrison and I trace the policy, planning, and deployment of transportation technologies across time.²² Both car and transit follow the classic lifecycle model or S-curve of birth, growth, maturity, and decline.²³ The S-curve allows us to mathematically approximate the process of growth and decline of technologies.²⁴ S-curve growth is in many ways natural. If we

17. JONES, *supra* note 1, at 91–93, 102.

18. These brief slow downs in the inexorable rise in vehicle travel are usually attributed to the oil supply and price shocks in 1973–74 (Yom Kippur War), 1979–81 (Iranian Revolution), the early 1990s (Gulf War), and the early 2000s (9/11). JONES, *supra* note 1, at 173–76.

19. See *The Future of Driving: Seeing the Back of the Car*, ECONOMIST, Sep. 22, 2012, at 29, available at <http://www.economist.com/node/21563280> (discussing the “current fall in car use,” beginning in the early 2000s).

20. See JONES, *supra* note 1, at 102.

21. *Public Road and Street Mileage in the United States by Type of Surface*, BUREAU TRANSP. STAT., U.S. DEPARTMENT TRANSP., http://www.rita.dot.gov/bts/sites/rita.dot.gov/bts/files/publications/national_transportation_statistics/html/table_01_04.html (last visited Feb. 20, 2015).

22. See generally GARRISON & LEVINSON, *supra* note 10.

23. *Id.* at 371–74. One hesitates to say “death,” since so few technologies actually disappear. For instance, fixed route streetcars are still with us. See KEVIN KELLY, *WHAT TECHNOLOGY WANTS* 56 (Viking Press 2010) (finding that no technologies actually vanish, though obviously they diminish in importance).

24. GARRISON & LEVINSON, *supra* note 10, at 374–75. The growth curves reasonably fit the data for total system size or total system use for a number of technologies in retrospect. A collection of such curves, and descriptions of the development of the associated technologies can be found at the *Transportation Deployment Casebook*, WIKIBOOKS, https://en.wikibooks.org/wiki/Transportation_Deployment_Casebook (last updated Oct. 6, 2014), which is the result of student projects for a few years in my Transportation Policy course. The difficulty is to use such curves in prediction. There are some observations though; the left and right sides of the curve (from the inflection point, where the rate of growth changes from increasing to decreasing) are approximately the same amount of time. *Transportation Deployment Casebook*, *supra*. So it takes about as long to go from 10% to 50% of the final market size as it does to go from 50% to 90% of final market size. See generally

start with zero vehicle kilometers traveled (VKT) by car per capita in 1900, surely the number has to go through 5000 VKT before it reaches 10,000 VKT, and 10,000 before 15,000. One million people must own a car before two million can. Similarly, technologies do not disappear overnight (although transit came pretty close).²⁵ Technological deployments are long, gradual processes, which occur with many technologies that see growth and decline.²⁶ Transportation is among the slowest of these technologies, as fixed infrastructure is expensive to build and long-lasting.²⁷

Is the decline in car use permanent, like what happened to fixed route transit services in the United States (which is well below one-fifth of its previous importance),²⁸ or just a brief digression from the steady march of increasing per capita vehicle travel that has been following the same drumbeat almost continuously from 1910 to 2000?²⁹

History will tell us for sure, but the evidence for “Peak Travel” has been mounting.³⁰ This does not mean there will never be a year in which per capita car travel again rises. The economy and gas prices still fluctuate, and a boom year with

Transportation Deployment Casebook, supra. A key issue is the determination of how large the system will get at its maximum. It depends on the system. For instance if we are modeling the number of U.S. states that will adopt some policy, the maximum is fifty (unless the United States adds states). If we are modeling the percentage of cars that will have some advanced technology, and we believe it will become universal, then we can say 100%. But if we are modeling a continuous number, rather than a share, it is harder. What is the maximum number of kilometers people will travel in a year? What is the maximum number of trips? We can make guesses; we can even make informed guesses, but we can never know for sure until after the fact. However, if the rate of growth has slowed (we are on the right half of the S-curve), we can make a much better guess than if growth is increasing at an increasing rate (the left half of the S-curve). See GARRISON & LEVINSON, *supra* note 10, at 372–74 (discussing the S-curve and life-cycles of various modes of transport).

25. JONES, *supra* note 1, at 96–97.

26. GARRISON & LEVINSON, *supra* note 10, at 372.

27. *Id.*; see Angie Schmitt, *Why Are American Infrastructure Projects So Expensive?*, STREETBLOG NETWORK (Aug. 29, 2012), <http://streetsblog.net/2012/08/29/why-are-american-infrastructure-projects-so-expensive/> (discussing the high costs associated with transportation infrastructure and how governments deal with those costs).

28. See JONES, *supra* note 1, at 139.

29. See sources cited *supra* note 5.

30. Adam Millard-Ball & Lee Schipper, *Are We Reaching Peak Travel? Trends in Passenger Transport in Eight Industrialized Countries*, 31 TRANSPORT REVIEWS 347, 347–78 (2011).

low gas prices following a recession with high gas prices might very well temporarily bump traffic upward, but that is really short-term noise. In the absence of external events (technological shifts, demographic shifts, social shifts), the curve appears to have peaked.³¹

But over the longer term, a significant technological shift could profoundly change how people use the automobile. If there were only one possible significant technological or social shift, this might be predictable, but there are numerous technological and social shifts in play.³²

While there are many reasons people are not driving more, “saturation” satisfies Occam’s Razor. There is only so much time in the day. For a worker who spends at least eight hours at his or her job and eight hours asleep, how much time is reasonable to actually spend traveling as opposed to the other things that comprise life? Each additional minute traveling is one less minute doing something else. The literature on the travel time budget is rich,³³ and while people do want some separation between their home and work lives, most people do not want to spend too much time (say more than ninety minutes per day) traveling on a regular basis.³⁴ The travel speeds of current technologies limit distance.³⁵

Similarly, there are a variety of complementary hypotheses as to why people are driving less per capita in 2015 than 2000. Some of the important ones include:

31. See *id.* at 372.

32. See JAMES M. ANDERSON ET AL., RAND CORP., AUTONOMOUS VEHICLE TECHNOLOGY: A GUIDE FOR POLICYMAKERS 18–28 (2014), available at http://www.rand.org/content/dam/rand/pubs/research_reports/RR400/RR443-1/RAND_RR443-1.pdf; Sarwant Singh, *The 10 Social and Tech Trends That Could Shape the Next Decade*, FORBES (May 12, 2014, 12:54 PM), <http://www.forbes.com/sites/sarwantsingh/2014/05/12/the-top-10-mega-trends-of-the-decade/>.

33. See generally Patricia L. Mokhtarian & Cynthia Chen, *TTB or Not TTB, That Is the Question: A Review and Analysis of the Empirical Literature on Travel Time (and Money) Budgets*, 38 TRANSP. RES. PART A 643 (2004).

34. Todd Litman, *Valuing Transit Service Quality Improvements*, 11 J. PUB. TRANSP., no. 2, 2008, at 43, 45, available at <http://www.nctr.usf.edu/wp-content/uploads/2010/03/JPT11-2Litman.pdf>.

35. See RODRIGUE ET AL., *supra* note 16, at 14–15.

1. Price of fuel: higher energy costs diminish travel
2. Size of the workforce: fewer people working leads to fewer work trips (due to both unemployment and labor force participation)
3. Telework: people working at home for the day leads to fewer work trips (but more nonwork trips)
4. Online shopping: buying over the Internet at home decreases shop trips
5. Virtual connectivity: connecting with friends at home can substitute for visiting

The last three reasons for traveling less by car (and overall) are due to information and communications technologies substituting for travel. But these are all nontransportation reasons.

Obviously different demographic sectors work at home, shop online, or connect virtually in different amounts.³⁶ Just as your grandparents may still receive a physical issue of the newspaper while you read online, your children are more likely to be early adopters of future technologies than an older you and your parents and grandparents. And the habits formed while young may very well persist over time.

Within the transportation sector there have been small shifts over the past fifteen years, which cannot explain much of the decline of travel. There are active transportation modes, like walking and biking, which work well for short trips, and certainly have niches they can grow into if land development intensifies and people reorganize their lives to enable them.³⁷ For instance, I am one of the seven percent of Minneapolitans

36. PETER J. MATEYKA ET AL., U.S. DEP'T OF COMMERCE, HOME-BASED WORKERS IN THE UNITED STATES: 2010 (2012), *available at* <http://www.census.gov/prod/2012pubs/p70-132.pdf> (showing that people from certain demographic groups are more likely to work at home).

37. FED. HIGHWAY ADMIN., U.S. DEP'T TRANSP., THE NATIONAL BICYCLING AND WALKING STUDY: 15-YEAR STATUS UPDATE (2010), *available at* http://katana.hsrrc.unc.edu/cms/downloads/15-year_report.pdf (showing trends in pedestrian traffic over a recent fifteen-year period).

who walk to work.³⁸ The numbers are much lower outside core cities, and nationally, at three percent.³⁹ Transit ridership per capita is up ever so slightly.⁴⁰

There are a slew of “new mobility options” which use information technologies to allow travel without owning an automobile, but are not yet visible in the transportation statistics.⁴¹ These include peer-to-peer taxi and ridesharing services and dynamic real-time rental cars. While these are useful in their niches, they likely are not cost-effective enough to be the main transportation mode for the vast majority of the population with the given technology. Today these new mobility options are supplements when the main mode does not solve the job to be done. In the future, that might change.

Technologies allow people to do more of the same, and they allow people to do new things. It is easier to predict more of the same than new things.

II. MOUNT NEXT

Autonomous vehicles⁴² appear to be the next profound transportation technology. They bring a series of consequences affecting both the transportation sector and the rest of society.

38. CITY OF MINNEAPOLIS, MINNEAPOLIS BICYCLE WALKING AND COMMUTE DATA 8 (2011), *available at* <http://www.ci.minneapolis.mn.us/www/groups/public/@publicworks/documents/images/wcms1p-104839.pdf>.

39. AM. CMTY. SERV. REPORTS, COMMUTING IN THE UNITED STATES: 2009-3 (2011), *available at* www.census.gov/prod/2011pubs/acs-15.pdf.

40. Press Release, American Public Transportation Association, Record 10.7 Billion Trips Taken on U.S. Public Transportation in 2013 (Mar. 10, 2014), *available at* http://www.apta.com/mediacenter/pressreleases/2014/Pages/140310_Ridership.aspx (noting the 1.1% gain over the previous year).

41. *E.g.*, Katherine Krug, *Ditching My Car for Uber Saves Me Over 6 Days of Time and \$11,000 a Year*, BUS. INSIDER (Feb. 9, 2015, 1:04 PM), <http://www.businessinsider.com/how-using-uber-and-lyft-saves-me-money-2015-2>.

42. To describe the new technology, this Article will use the term “autonomous vehicle” throughout, which is taken to be synonymous with an automated vehicle, robotic vehicle, self-driving vehicle, and driverless vehicle, as well as their variants. Just as in the early days of the horseless carriage, it is not exactly clear which term will be the linguistic winner. The term “vehicle” includes cars, buses and trucks. The term “auto” is used to mean automobile rather than autonomous vehicle. In the future, autonomous vehicles will probably just be called “cars,” except to differentiate from early instances of the technology.

A. SAFETY

Cars, which today kill about 33,000 Americans,⁴³ and 1.2 million people globally,⁴⁴ per year, would be much safer if only humans were not behind the wheel. We might plausibly imagine a reduction to hundreds of deaths per year in the United States as we achieve full deployment.

Autonomous vehicles, powered by sensors, software, cartography, and computers, can build a real-time model of the dynamic world around them and react appropriately.⁴⁵ Unlike human drivers, they do not get distracted or tired, have almost instantaneous perception-reaction times, and know exactly how hard to brake or when to swerve.⁴⁶

Autonomous vehicle technology is distinct from “connected vehicle” technology, which allows individual vehicles to communicate with other nearby vehicles (vehicle to vehicle, or V2V) and connected infrastructure (V2I) with Mobile Ad Hoc Networks.⁴⁷ If widely deployed, this not only improves safety for those in the vehicle, it improves the safety and environment for pedestrians, bicyclists, and other drivers.⁴⁸ Connected vehicles should enable vehicles to anticipate better and negotiate with each other for use of a particular bit of road space at a discrete point in time.⁴⁹

43. ANDERSON ET AL., *supra* note 32, at xiv; see NAT'L HIGHWAY TRAFFIC SAFETY ADMIN., U.S. DEP'T OF TRANSP., 2013 MOTOR VEHICLE CRASHES: OVERVIEW 1 (2014), available at <http://www-nrd.nhtsa.dot.gov/Pubs/812101.pdf>.

44. WORLD HEALTH ORG., GLOBAL STATUS REPORT ON ROAD SAFETY 2013: SUPPORTING A DECADE OF ACTION 3 (2013), available at http://apps.who.int/iris/bitstream/10665/83789/1/WHO_NMH_VIP_13.01_eng.pdf.

45. Xi Zou & David Levinson, *Vehicle-Based Intersection Management with Intelligent Agents* 1, 4–5 (ITS Am. Ann. Meeting Proc., 2003), available at <http://ssrn.com/abstract=1748611>.

46. ANDERSON ET AL., *supra* note 32, at 59 (“With perfect perception (a combination of sensor data gathering and interpretation of those data), AVs could plan and act perfectly, achieving ultrareliability. Vehicles never tire; their planning algorithms can choose provably optimal behaviors; and their execution can be fast and flawless.”).

47. ANDERSON ET AL., *supra* note 32, at 66–67; Zou & Levinson, *supra* note 45.

48. ANDERSON ET AL., *supra* note 32, at 16 (explaining that much of the benefit of autonomous vehicle technology is “in the form of a positive externality to other vehicles, pedestrians, and bicyclists”); Zou & Levinson, *supra* note 45, at 13–14.

49. ANDERSON ET AL., *supra* note 32, at 67.

Both autonomous and connected vehicles are coming. It is important to recognize that cars may be autonomous but not connected, connected but not autonomous, both, or as today, neither.⁵⁰

The National Highway Traffic Safety Administration (NHTSA) has a series of levels describing degree of autonomy, from Level 0, “no autonomy,” to Level 4, “full self-driving automation.”⁵¹ Early versions of autonomous cars are anticipated for the 2016 Model Year—for example, the Cadillac SuperCruise—which may be described as somewhere between Level 2 “combined function automation” and Level 3 “limited self-driving automation.”⁵²

The effects of autonomous vehicles are, however, much more profound than connected vehicles, as connected vehicles are only especially useful in the presence of other connected vehicles, while autonomous vehicles are valuable through the transition period when most vehicles are not up-to-date.

As a rough timeline, it is posited in this Article that Level 3 (“limited self-driving automation”) autonomous vehicles will be on the market by 2020, Level 4 will be required in new cars by 2030, and required for all cars by 2040 (i.e., human drivers will be generally prohibited on public roads).⁵³

B. CAPACITY

Because they are safer, autonomous vehicles can have shorter headways.⁵⁴ They can follow other each other at a significantly reduced distance.⁵⁵ Because they are safer and more precise and more predictable, autonomous vehicles can

50. See *supra* text accompanying note 45.

51. NAT'L HIGHWAY TRAFFIC SAFETY ADMIN., U.S. DEP'T OF TRANSP., PRELIMINARY STATEMENT OF POLICY CONCERNING AUTOMATED VEHICLES 4–5 (2013), available at http://www.nhtsa.gov/staticfiles/rulemaking/pdf/Automated_Vehicles_Policy.pdf.

52. See Ed Oswald, *Cadillac Self-Driving Cars: Out by 2015?*, PCWORLD (Apr. 20, 2012, 3:15 PM), http://www.pcworld.com/article/254192/cadillac_self_driving_cars_out_by_2015_.html.

53. *Id.* Once driverless cars become widespread, human drivers will be more widely recognized for the hazard they are, and perhaps like smokers, will slowly be exiled in time and space. For instance, we may see Sunday afternoon Motor-vias, when the old cars, mostly driven by old drivers, make their appearance on selected roads.

54. ANDERSON ET AL., *supra* note 32, at 21.

55. *Id.*

stay within much narrower lanes with greater accuracy.⁵⁶ Lateral distances can be closer; lanes can be narrower.⁵⁷ If skinny cars emerge (designed for one-passenger, or several passengers in tandem) lanes can be narrower still, or be shared with two such cars.

Thus, capacity at bottlenecks should improve, both in throughput per lane and the number of lanes per unit road width.⁵⁸ These cars still need to go somewhere, so auto-mobility still requires some capacity on city streets as well as freeways, but ubiquitous adoption of autonomous vehicles would save space on parking, and lane width everywhere.

It follows that if transportation systems require reduced lane width, and have adequate capacity, transportation agencies can reduce paved area and still see higher throughput. Today, most roadspace is not used most of the time,⁵⁹ but the road agencies cannot just roll it up when it is not being used.

With autonomous vehicles and better management, unused roads still cannot be rolled up. However, on freeways the space could be deployed more dynamically to increase either safety (by increasing spacing) or capacity (by reducing spacing), simultaneously adjusting speed and spacing accordingly. On local streets, roadspace no longer needed for movement because of added capacity could be reallocated to other uses (pedestrians, bicyclists, transit, parks, and so on).

As a result human travel will be much more point-to-point, with far fewer pick-up and drop-off passenger trips required. Deadheading autonomous vehicles, driving around without a passenger to pick up their next passenger will as a result become common, though logistics and shared vehicles can minimize the amount of this.⁶⁰

56. ALEX FORREST & MUSTAFA KONCA, AUTONOMOUS CARS AND SOCIETY 13–16, 36–37 (2007), available at <https://www.wpi.edu/Pubs/E-project/Available/E-project-043007-205701/unrestricted/IQPOVP06B1.pdf>.

57. *Id.*

58. ANDERSON ET AL., *supra* note 32, at 21; FORREST & KONCA, *supra* note 56.

59. See also Tom Vanderbilt, *Heading for the Cloud*, ITS MAG., Mar. 2011, at 10, 11, available at <https://www.mobility.siemens.com/mobility/global/SiteCollectionDocuments/en/news/customer-magazines-and-newsletters/its-magazine/its-03-11-en.pdf> (citing a RAND studying finding that “more than 90 percent of American roads are not congested 90 percent of the time”).

60. ANDERSON ET AL., *supra* note 32, at 27.

C. AUTO-MOBILITY FOR ALL

With autonomous vehicles, the transportation disadvantaged—children, the physically challenged, and others who cannot or should not drive—will be enabled.⁶¹ The “parent taxi” days will end.

Parents, friends, and siblings need not shuttle children around, the vehicle can do that by itself with Level 4 autonomy. The child would be securely identified with camera and in-vehicle biometrics, and parents could even monitor their child with an in-vehicle video camera. This would be far more secure than the school buses and carpools children are now using. There likely will remain debate about how old a child must be before she is placed alone in an autonomous car, but the consensus is likely to be, if they are in kindergarten, they can ride alone, as with school buses.⁶²

D. DIVERSITY

Autonomous vehicles along with sharing may bring about a Cambrian explosion⁶³ of new vehicle forms, such as cars designed for specific jobs, since they do not need to be everything to their owner. For instance, narrow and specialized cars are more feasible in a world of autonomous vehicles; the fleet will have greater variety, with the right size vehicle assigned to a particular job.⁶⁴ Today there is a car-size arms race: people buy larger cars, which are perceived to be safer for the occupant, and taller cars, which allow the driver to see in front of the car immediately in front of them.⁶⁵ Both of these advantages are largely obviated with autonomous vehicles. The car-size arms race ends.

61. *E.g.*, ANDERSON ET AL., *supra* note 32, at 16–17.

62. *E.g.*, MINN. STAT. § 123B.90 (2014) (mandating bus safety training for kindergarten to tenth grade riders).

63. The Cambrian explosion was a period beginning about 542 million years ago when many new animal phyla appeared. Charles R. Marshall, *Explaining the Cambrian “Explosion” of Animals*, 34 ANN. REV. EARTH & PLANETARY SCI. 355 (2006). Many different body types evolved and were tested for the next twenty million years before the environment settled on the forms that became widespread. *Id.*

64. GARRISON & LEVINSON, *supra* note 10, at 459.

65. Michelle J. White, *The “Arms Race” on American Roads: The Effect of Sport Utility Vehicles and Pickup Trucks on Traffic Safety*, 47 J.L. & ECON. 333, 333–35 (2004).

Evidence for this is already emerging. Google has proposed and built prototypes of a new, light, low-speed neighborhood vehicle designed for slow speed (twenty-five miles per hour or forty kilometers-per-hour) in controlled environments like corporate or college campuses.⁶⁶ The United Kingdom is launching four pilot programs.⁶⁷ Singapore is testing similar vehicles.⁶⁸ The low mass of these vehicles is important as it saves energy, but also causes less damage when it accidentally hits something or someone.⁶⁹ Combining the low mass with the lower likelihood of a crash at low speed will magnify its safety advantage for nonoccupants in this environment compared with faster, heavier vehicles (which privilege the safety of the vehicle occupants).⁷⁰

The Cadillac SuperCruise entrant implies the first market for autonomous vehicles would be the relatively controlled environment of the freeway.⁷¹ However, the relatively controlled environment of low-speed places is plausible. These are two different types of vehicles (high-speed freeway versus low-speed neighborhood), and though they may converge, there is no guarantee they will, and perhaps today's converged multipurpose vehicle will instead diverge.

There has long been discussion of Neighborhood Electric Vehicles, ranging from golf carts to something larger, which are in use in some communities, particularly southwestern U.S. retirement complexes.⁷² In Sun City, Arizona, for instance,

66. Chris Urmson, *Just Press Go: Designing a Self-Driving Vehicle*, GOOGLE (May 27, 2014), <http://googleblog.blogspot.com/2014/05/just-press-go-designing-self-driving.html>.

67. *Driverless Cars Set to Be Tested in Four English Cities*, BBC (Dec. 3, 2014), <http://www.bbc.com/news/technology-30316458>; Stephen Potter, *Driverless Public Transport Will Change Our Approach to City Planning—and Living*, CONVERSATION (Dec. 22, 2014), <http://theconversation.com/driverless-public-transport-will-change-our-approach-to-city-planning-and-living-35520>.

68. Michael Fitzgerald, *Singapore Wants a Driverless Version of Uber: Singapore Plans to Let Anyone Test Driverless Cars in One of Its Busy Neighborhoods in 2015*, MIT TECH. REV. (Dec. 23, 2014), <http://www.technologyreview.com/news/533601/singapore-wants-a-driverless-version-of-uber/>.

69. See K. M. Hunter-Zaworski, *Impacts of Low-Speed Vehicles on Transportation Infrastructure and Safety*, 5 J. TRANSP. & LAND USE 68, 72–73 (2012).

70. *Id.*

71. Oswald, *supra* note 52.

72. See generally Hunter-Zaworski, *supra* note 69.

people use the golf cart not just for golfing, but for going to the clubhouse or local stores (usually as the household's second or third car, but occasionally as the primary vehicle).⁷³ They can do this because local streets are controlled by low speed limits, and there are special paths where golf carts are permitted and others are not.⁷⁴ Campuses, retirement communities, neighborhoods in some master planned communities, and true parkways are almost ideal for these types of vehicles, as they discourage fast traffic and do not have high flows.

To accommodate these low-speed vehicles, most nonideal places will likely require retrofits. Retrofitting cities for transportation has a long history as cities and transportation technologies co-evolve.⁷⁵ Cities, which had originally emerged with human and animal powered transportation, were retrofitted first for streetcars, then for the automobile, and in some larger cities for subways.⁷⁶ We have also redesigned our taller buildings for escalators and elevators.⁷⁷

Some places where retrofits might be required and feasible include cities laid out and built before the automobile, where much of the street grid can be retrofitted to disallow high-speed traffic, in much the same way bicycle boulevards are established.⁷⁸ Similarly, retrofits are technically feasible anywhere there is space to retrofit a slow network in parallel with the existing fast network, for instance, with barrier separated lanes on wider suburban roads.⁷⁹

Other designs can be found for other situations. Mixing vehicles of different sizes and desired speeds will always remain a challenge. Though in many ways mixed traffic is transitional until humans are fully taken out of the driving

73. Philip Haldiman, *Sun City Residents Celebrate New Golf-Cart Law*, AZCENTRAL (Aug. 14, 2014, 11:41 PM), <http://www.azcentral.com/story/news/local/surprise/2014/08/14/golf-carts-rule-roads-sun-city/14095291/>.

74. *Id.*

75. FENG XIE & DAVID M. LEVINSON, *EVOLVING TRANSPORTATION NETWORKS* 34 (Springer 2011).

76. *Id.* at 34, 66.

77. We did not, however, redesign cities for Segways. See Susan A. Shaheen & Rachel Finson, *Bridging the Last Mile: A Study of the Behavioral, Institutional, and Economic Potential of the Segway Human Transporter* (Transp. Res. Bd., Working Paper No. 03-4470 2003), available at <http://tsrc.berkeley.edu/node/622>.

78. See XIE & LEVINSON, *supra* note 75, at ch. 4.

79. See *id.*

loop, when additional controls can ensure different types of vehicles mix safely.

Vehicle diversity applies not only to a larger variety of motorized vehicles of various sizes, but also to a greater variety of transportation using the existing streets, which today are highly segregated with cars (both moving and parked) dominating the street and pedestrians the sidewalk. Slow-speed, lightweight vehicles make shared spaces, which do not differentiate between the road and the sidewalk, much more palatable.

E. VEHICLES-AS-A-SERVICE (VAAS)

Today, people keep their personal transportation “near their person, parking cars and bikes at their homes, workplaces, or other destinations.”⁸⁰ This is the only way to “guarantee point to point transportation in a timely way where densities were low, incomes high, and taxis scarce.”⁸¹

Information technologies that are today dubbed part of the “sharing economy” or “collaborative consumption” permit “carsharing”⁸² and “ridesharing.”⁸³ Coupling these technologies with autonomous vehicles allows the creation of “cloud commuting.”⁸⁴

In this scenario, cars from a giant pool operated by organizations based “in the cloud”⁸⁵ would dispatch a vehicle that drives to a customer on demand and in short order, and then deliver the customer to her destination (be it work or otherwise).⁸⁶

80. Vanderbilt, *supra* note 59.

81. *Id.*

82. Carsharing companies active in the United States in 2015 include Zipcar and car2go, among others. ANDERSON ET AL., *supra* note 32, at 31; GARRISON & LEVINSON, *supra* note 10, at 460.

83. “Ridesharing” includes traditional taxis, carpooling, and firms that include Uber, Lyft, Gett, Curb, Hailo, Blacklane, Sidecar, Zimride, iHail, and Flywheel. Adrienne Jeffries, *The Battle Over the Future of the Taxi*, VERGE (Feb. 8, 2013, 11:15 AM), <http://www.theverge.com/2013/2/8/3967604/the-battle-of-the-taxi-apps>.

84. GARRISON & LEVINSON, *supra* note 10, at 460.

85. The “cloud” is an early 2000s marketing term referring to computer servers located somewhere physically, or maybe multiple places, but nowhere you would actually know by logging into their system. *See id.*

86. *Id.*; Eric Jaffe, *Imagine: A World Where Nobody Owns Their Own Car*, ATLANTIC (Feb. 13, 2014), <http://www.citylab.com/commute/2014/02/imagine-world-where-nobody-owns-their-own-car/8387/>.

The vehicle would have the customer's preferences preloaded, such as seat position, computing interface, and audio environment.⁸⁷ The customer benefits by not tying up her capital in vehicles, nor having to worry about maintaining or fueling vehicles. The fleet is used more efficiently, each vehicle would operate at least two or three times more distance per year than current vehicles, so the fleet would turnover faster and be more modern.⁸⁸

Fewer vehicles overall would be needed at a given time. It is likely customers would need to pay for this service either as a subscription or a per-use basis. Though advertising might offset some costs, surely it would not entirely cover them. However, retail stores (if they survive) or employers might subsidize transportation, as benefits for the customers or staff.

VaaS will work better in urban areas than rural areas, as the response time will be shorter and size and variety of the nearby vehicle pool will be greater.⁸⁹ It will also work better for random trips than work trips, as the regularity of work trips by car increases the value of ownership versus renting by the trip. Instead perhaps work trips will be made by transit in the absence of an owned vehicle.

An interesting aspect of this from the perspective of travel demand is that people will probably pay by the trip (either directly, or through choosing the right plan of service roughly proportional to use) when using "Shared Autonomous Vehicles" (SAVs).⁹⁰ While the average cost of car ownership, now a quite significant share of household expenses,⁹¹ goes to zero for those who join this system, the out-of-pocket marginal cost per trip rises quite significantly.⁹² The implication is that there will be fewer trips once people give up on vehicle ownership.⁹³ People

87. GARRISON & LEVINSON, *supra* note 10, at 460.

88. *See* Jaffe, *supra* note 86.

89. Michael Duncan, *The Cost Saving Potential of Carsharing in a US Context*, 38 *TRANSP.* 363, 365–66 (2011).

90. *See* Jaffe, *supra* note 86.

91. *See* Duncan, *supra* note 89, at 364.

92. *See id.* at 365 ("In effect, carsharing can act as travel demand management tool. Making the cost of driving more immediate will decrease the likelihood of discretionary auto trips . . .").

93. *Id.*

paying by the minute or the mile will want to reduce trip distances.⁹⁴

In contrast, if the time cost of traveling per trip declines, the theory of induced demand predicts, all else equal: more trips, longer trips, and more trips in the peak period.⁹⁵ Induced demand is more likely to apply when people own their autonomous vehicle (and thus have paid for the fixed costs before the trips, and have a low marginal cost), while reduced demand applies when short term out-of-pocket costs rise, as expected for those who subscribe to VaaS.⁹⁶ The share of ownership versus VaaS is thus an important predictor of travel demand.

F. MIGRATION

While VaaS suggests less future driving, there is an alternative outcome. Historically, every increase in mobility (such as the ability to go faster, either due to new technologies or more connected networks) has increased the size of metropolitan areas, since people can reach more things in less time.⁹⁷ Subways drove the expansion of London,⁹⁸ while streetcars did the same for many American metropolitan areas such as Minneapolis-St. Paul.⁹⁹ The history of the U.S. Interstate Highway System and suburbanization is well known.¹⁰⁰ The time saved from mobility gains is used mostly in

94. *Id.*

95. See Robert B. Noland, *Relationships Between Highway Capacity and Induced Vehicle Travel*, 35 *TRANSP. RES. PART A* 47, 47–48 (2001).

96. *Id.*

97. See, e.g., David Levinson, *Density and Dispersion: The Co-Development of Land Use and Rail in London*, 8 *J. ECON. GEOGRAPHY* 55, 57 (2008). Accessibility is usually measured as the number of opportunities that can be reached in a given amount of time, for instance, jobs within thirty minutes at 7:00 a.m. by transit. See ANDREW OWEN & DAVID LEVINSON, *ACCESS ACROSS AMERICA: TRANSIT 2014* 1, 6 (2014), available at <http://www.its.umn.edu/Publications/ResearchReports/pdfdownloadl.pl?id=2506>, for results from the Accessibility Observatory.

98. Levinson, *supra* note 97, at 73–74.

99. Feng Xie & David Levinson, *How Streetcars Shaped Suburbanization: A Granger Causality Analysis of Land Use and Transit in the Twin Cities*, 10 *J. ECON. GEOGRAPHY* 453, 467–68 (2010) (describing how streetcars led to “land development in the Twin Cities”).

100. See Nathaniel Baum-Snow, *Did Highways Cause Suburbanization?*, 122 *Q.J. ECON.* 775, 775–76 (2007) (stating that the construction of new limited access highways has contributed markedly to central city population decline).

additional distance between home and workplace, maintaining a stable travel time.¹⁰¹ In short: speed decentralizes.

Autonomous vehicles should be faster than today's vehicles, particularly on freeways, especially after widespread deployment when all other vehicles are also autonomous. This will occur either once human-operated cars are prohibited from freeways or separate lanes are designated for autonomous cars.

Fully autonomous vehicles also lower the cognitive burden on the former driver (now passenger).¹⁰² Modes with lower cognitive burden tend to have longer trip durations.¹⁰³ Time is important, of course. What you can do with that time (the quality of the experience) also matters. If you can work while traveling, the value of saving time is less than if you must focus on the driving task.¹⁰⁴ This may also explain the premium people are willing to pay for high quality transit and intercity rail service.¹⁰⁵

As acceptable trip distances increase, we would expect a greater spread of origins and destinations (pejoratively, sprawl), just as commuter trains today enable exurban living or living in a different city.¹⁰⁶ More people will live in the suburbs or exurbs, as the pain of travel reduces.¹⁰⁷ This does not mean fewer people live in cities, just that as places grow, this will tend to encourage people to move out rather than up.

Similarly, as the cost of travel decreases, people will be more willing to live in cities far from where they work. The Northeast Corridor of the United States already sees people living in one city and commuting to another (for instance from Washington to Baltimore, or Baltimore to Wilmington, or Wilmington to Philadelphia, or Philadelphia to New York, and vice versa).¹⁰⁸ At speeds of nearly 100 miles per hour (160 kilometers-per-hour), the commuting range expands widely.¹⁰⁹

101. *See id.* (“[F]aster commuting times push up the demand for space in suburbs relative to central cities.”).

102. *See* ANDERSON ET AL., *supra* note 32, at 26.

103. *Cf. id.* 26–27.

104. *Id.*

105. *See, e.g.*, Glenn Lyons et al., *The Use of Travel Time By Rail Passengers in Great Britain*, 41 *TRANSP. RES. PART A* 107, 107–108, 117 (2007).

106. ANDERSON ET AL., *supra* note 32, at 26.

107. *See id.*

108. NE. CORRIDOR INFRASTRUCTURE & OPERATIONS ADVISORY COMM'N, *THE NORTHEAST CORRIDOR AND THE AMERICAN ECONOMY* 14–17 (2014),

For a select few, driverless vehicles may bring back the recreational vehicle, as some choose the fully nomadic lifestyle, spending much if not most of their lives in motion, especially if energy costs are low.

G. URBAN FORM

At the more local level, the VaaS model suggests spaces now devoted to cars can be repurposed.¹¹⁰ Garages can become accessory dwelling units. Gas stations and parking lots and structures can see a new higher and better use. Autonomous vehicles can drop off their passenger at the front door, and then park themselves in far less space than drivers currently require (or move on to their next passenger), and that space need not be so close to the most valuable urban areas.¹¹¹ On-street parking is not needed at all, one more aspect of roadspace reconfiguration that was discussed above.¹¹²

H. COSTS

At first, the capital costs for autonomous vehicles are likely to be higher than traditional cars, as the sensors and computers add some cost compared to existing systems.¹¹³ Eventually driver-facing technologies (like the steering wheel, brake and accelerator pedals, and so on) can be removed for cost savings.¹¹⁴

Fuel costs on the other hand should be lower, as autonomous vehicles are likely to be more efficient, both due to less congestion and to more optimized driving styles (ranging

available at http://www.nec-commission.com/wp-content/uploads/2014/02/NEC_american_economy_report.pdf (describing how the Northeast Corridor provides commuters efficient travel between the major cities in the Northeastern United States).

109. AMTRAK, THE AMTRAK VISION FOR THE NORTHEAST CORRIDOR 11 (2012), *available at* <http://www.amtrak.com/ccurl/453/325/Amtrak-Vision-for-the-Northeast-Corridor.pdf>.

110. ANDERSON ET AL., *supra* note 32, at 5, 25–27.

111. *Id.*

112. *See id.*

113. Brad Plumer, *Here's What It Would Take for Self-Driving Cars to Catch On*, WASH. POST (Oct. 23, 2013), <http://www.washingtonpost.com/blogs/wonkblog/wp/2013/10/23/heres-what-it-would-take-for-self-driving-cars-to-catch-on/>.

114. *Id.*

from smoother acceleration to various hypermiling techniques like drafting to reduce drag).¹¹⁵

Most importantly, for vehicles such as taxis, buses, and trucks, which today require a driver, that labor cost can go away.¹¹⁶ Labor is a significant share of costs in transportation, and that will diminish.¹¹⁷ This lower cost benefits taxis, buses, and trucks, which had higher labor costs compared to their competitors: cars and trains.¹¹⁸

Delivery services with online purchasing will become even more cost-competitive compared to traditional retail.¹¹⁹ Transit will either be more cost effective than it is now, or be able to offer lower fares, or some combination of the two.

I. CLASS¹²⁰

Just as owning a car was once a class signifier in the United States,¹²¹ and remains so elsewhere in the world, and as owning a particular model of car persists as a signifier, we can expect that during the transition period, owning an autonomous car will be a class signifier. It indicates at once that you are wealthy enough to own a new car, and technologically sophisticated enough to trust your life to it. While eventually we expect this to be uniform, early adopters will have very different economic and social characteristics from the population at large.¹²² Those who cannot afford such cars may come to be vilified as the cause of crashes.¹²³

III. CONCLUSIONS

I believe the most important technological changes in transportation over the next few decades are those associated with autonomous vehicles. Cars that drive themselves change how people use them.

115. ANDERSON ET AL., *supra* note 32, at 28–29, 40.

116. FORREST & KONCA, *supra* note 56, at 41–45.

117. *Id.*

118. *See id.*

119. *Id.* at 41–42.

120. The author thanks Anna Potter here for her ideas.

121. JONES, *supra* note 1, at 127.

122. *See* Jaffe, *supra* note 86.

123. *See* ANDERSON ET AL., *supra* note 32, at 39.

In the “more of the same” category, we might see more travel. Generally, as the cost of travel declines, travel increases.¹²⁴ Since fully driverless cars make it easier to drive (by reducing the cognitive burden on the driver), the initial effect, assuming people continue to own their cars, would be that people would travel farther, to places they are less familiar with, and move to places farther from their place of work, to get more real estate for the dollar. Today’s commuter rail passengers travel farther (and longer) than auto users, and autonomous vehicles, where the passenger can do something else while traveling, are more like commuter rails than are today’s cars.¹²⁵ Such cars also can deposit drivers in front of buildings and park themselves, reducing the amount of time that drivers spend parking and accessing and egressing their cars,¹²⁶ which would naturally lead to longer distances.

Autonomous vehicles are likely to be safe at higher speeds, since humans will not be driving, which will also lead to longer distances in the same travel time.¹²⁷ Autonomous vehicles expand mobility for those who are now restricted (the young, the disabled, and so on).¹²⁸

However, such cars also make the so-called new mobility options much more useful in cities. Instead of owning a car, VaaS (renting on demand) becomes much more viable.¹²⁹ The right-sized car can in principle be summoned at any time. And if a driver is paying by the minute when the car is used instead of paying for a car loan or lease by the month (whether or not she uses it), the incentive structure the driver faces changes.¹³⁰ Travel will be less frequent and more thoughtful. The daily pattern of transit for routine trips and VaaS for special trips becomes feasible. The lack of effective VaaS options now pushes people to owning vehicles, and once they own a vehicle, they are going to use it. This lifestyle model works in cities, where transit can be a mainstay transportation mode, and VaaS are conveniently located.

124. *See supra* notes 95–96 and accompanying text.

125. *See supra* text accompanying notes 102–109.

126. *See supra* notes 60, 111–112 and accompanying text.

127. *See supra* Part II.A.

128. *See supra* Part II.C.

129. *See supra* Part II.C.

130. *See supra* text accompanying notes 90–96.

It works less well in the suburbs, exurbs, and rural areas, where the baseline transportation mode cannot be as expensive on a per-trip basis as the VaaS rental model requires, but the density is not high enough to support fixed route transit on most corridors.

Obtaining better capital utilization out of our surface transportation fleet (like the airlines have achieved with planes that are in motion as much as possible) through VaaS will reduce the lifespan of cars by using fewer vehicles more intensively, and wearing them out sooner.¹³¹ Thus, VaaS will on average be newer than today's fleet. As technology continues to advance with greater rapidity, this becomes increasingly important. The difference between a 2030 and 2020 model likely will be far greater than the difference between a 1970 and 1960 model car.

These are gradual processes. The rapid change in information technology can inform us of the direction of changes in transportation, but the pace cannot be replicated. The lifespan of a car (upward of twenty years, with a median age of 11.4 years) far exceeds that of a smart phone (about two or three years), so the technology people possess lags far behind the technology that is possible.¹³² The technologies are different. Building roads or rails have socio-spatial implications that laying fiber optic cables or constructing cell phone towers do not.

With the emergence of peak travel already, and autonomous vehicles just over the horizon, society needs to think not about adding road capacity, but maintaining what we have and what we need. We also need thinking about strategic reductions or rationalizations, or right-sizing. Unfortunately, that conversation is not really taking place.

The mountain analogy implies society cannot climb to the peak of the next technology in the same market niche (for

131. See *supra* text accompanying note 88.

132. Farhad Manjoo, *A Wild Idea: Making Our Smartphones Last Longer*, N.Y. TIMES, Mar. 13, 2014, at B1, available at <http://www.nytimes.com/2014/03/13/technology/personaltech/the-radical-concept-of-longevity-in-a-smartphone.html> ("On average, Americans keep their smartphones for about two years . . ."); Reno Charlton *American Drivers Keeping Cars on the Road for Longer: Average Age Now 11.4 Years*, HUFFINGTON POST (Aug. 9, 2013, 11:52 AM), http://www.huffingtonpost.com/reno-charlton/american-drivers-keeping-_b_3718301.html.

instance, serving daily transportation needs) until it climbs down the first. One can imagine a technological helicopter or zip line, or leaping off the peak (abandoning existing function technology, rather than just depreciating it over time) to accelerate transformation. Such sudden changes, however, are rarely wise and even less politically acceptable, with entrenched interests having accumulated power desirous of maintaining (or expanding) the status quo.

If the future of transportation does not involve more information technology and more automation, I will be both disappointed and surprised. But the exact shape of what comes next is hard to say. In the 1980s, we had a vision of a future of telecommunications and information that was something like what the Internet came to be, all the world's information at your fingertips. But few foresaw that it would be supported by online advertising. The idea that a collaboratively-built online encyclopedia would displace Britannica and be one of the world's biggest websites, or that an online bookstore (a bookstore!) would become the world's largest online retailer, were all unpredicted and unpredictable.¹³³ So it is with transportation in the early twenty-first century.

133. See Caitlin Dewey, *Gamergate, Wikipedia and the Limits of 'Human Knowledge'*, WASH. POST (Jan. 29, 2015), <http://www.washingtonpost.com/news/the-intersect/wp/2015/01/29/gamergate-wikipedia-and-the-limits-of-human-knowledge/> ("Wikipedia . . . [is] the world's largest work of reference and its sixth-largest Web site . . ."); Clare O'Connor, *Wal-Mart vs. Amazon: World's Biggest E-Commerce Battle Could Boil Down to Vegetables*, FORBES (Apr. 23, 2013, 4:53 PM), <http://www.forbes.com/sites/clareoconnor/2013/04/23/wal-mart-vs-amazon-worlds-biggest-e-commerce-battle-could-boil-down-to-vegetable/> ("Once just a bookseller, Amazon is now the biggest online store on the planet.").
