Smart Funding for Smart Infrastructure:
Examining and Evaluating Funding Methods for Infrastructure to Support Autonomous Vehicles

Abstract

“Self-driving cars won’t work until we change our roads,” wrote Andrew Ng, chief of research at Chinese tech giant Baidu.[1] Though Ng may exaggerate, autonomous vehicles (AVs) do benefit greatly from “smart infrastructure.” Witnessing AVs’ rise, American governments have eagerly begun smart infrastructure projects, but few have developed stable methods of funding them.

In this paper, I explore the funding mechanisms that exist today—the national gas tax, pooled and local financing, and AV mileage taxes—and evaluate their track record, future feasibility, and ability to make the largest beneficiaries pay a proportionate share. While the federal government has dedicated decreasing amounts of gas tax revenue to smart infrastructure, it also distributed gas tax dollars in the Smart City Challenge, an innovative contest that successfully if unsustainably drew in private contributions. Meanwhile, the Connected Vehicle Pooled Fund Study and Atlanta’s North Avenue Smart Corridor show how states and localities have self-funded intelligent transportation systems through general revenues. However, none of these methods impose costs on smart infrastructure’s largest users to the same degree as AV mileage fees, seriously considered in Tennessee and other states.

No funding stream has simultaneously levied costs proportionately and dedicated its revenue back to smart infrastructure. The Smart City Challenge and especially AV taxes have come closer, but both involve political tradeoffs. In coming decades, autonomous vehicles and their supporting infrastructure offer a chance to rethink the fairness of transportation finance and the role of the public and private sectors in the city of tomorrow.

Introduction

Paying for Autonomy: Questions, Findings, Literature, and Methods

Algorithms may be able to drive cars, but they cannot fund infrastructure. Such is the dilemma facing local, state, and national governments as they plan for the advent of autonomous vehicles (AVs). No longer speculation or fantasy, semi- and fully autonomous cars traverse America's roads today—often significantly aided by so-called "smart infrastructure" that municipalities are hurrying to build.[2] These systems and devices improve performance and safety for all traffic, but especially for AVs. Funding, however, has not caught up to technology. In this paper, I examine three intertwined questions: how *can* governments pay for such infrastructure, how *are* governments paying for such infrastructure, and how *should* governments pay for such infrastructure. The answers thereto will help define the roles of users and taxpayers, of the public sector and the private sector as mobility undergoes perhaps its greatest revolution since the car itself.

Overall, I find that governments generally rely on traditional funding sources for smart infrastructure, like gas taxes and bonds, which do not fairly levy money from those who most benefit. However, governments at all levels have experimented with a number of novel funding strategies, like the Smart City Challenge and AV mileage fees, that either make users pay or entice private companies to contribute. Indeed, automakers, tech firms, and certain drivers benefit disproportionately from AV-supporting infrastructure. Those new methods of financing do impose costs on these private interests, but they often come with policy tradeoffs or rely on voluntary contributions.

A number of opinion pieces have discussed smart infrastructure funding. Many worry that America's roads require significant upgrades, that cities will have to foot the bill for them, and that municipalities will be unprepared to do so. Academic literature, though, hardly touches on funding. Papers and books about smart infrastructure often concern its technical aspects, but even among planning studies, funding does not usually inform the analysis. Mashrur Chowdhury and Adel Sadek's *Fundamentals of Intelligent Transportation System Planning*, an early, comprehensive book on the subject, only mentions funding once, briefly. Likewise, Erick Guerra found that only one of the largest twenty-five metropolitan planning organizations mentioned AVs in their most recent regional transportation plan. Thus, practicing planners too have not incorporated autonomous vehicles and smart infrastructure into long-range planning. Planners may have good reason for this: AVs' effects are still far from certain, and premature infrastructure investments may become obsolete quickly. Nevertheless, both planners and academics have discussed funding little, especially given the potential magnitude of the changes AVs might cause.[3]

Into this lacuna, I evaluate how well various smart infrastructure funding methods meet the "user pays/user benefits" principle. This proposition holds that people or interests should pay for public improvements in proportion to how much they gain from them, and vice versa. In general, this rule should not be the only way to judge a funding scheme. After all, welfare recipients should not pay for the bulk of government aid to the poor, even though they themselves most benefit. But in the case of smart infrastructure, the "user pays/user benefits" principle also satisfies socio-economic equity concerns. Richer people tend to own today's autonomous vehicles—a steeper version of the positive relationship between income and car ownership generally. Moreover, users of smartphones and other technologies that can receive data from intelligent transportation systems tend to have higher incomes than those without.[4] A "user-pays" financing mechanism for smart infrastructure is thus also equitable. Still, the principle alone cannot provide a full assessment; I also consider the political feasibility and practical implementability of various funding measures.

Of course, dilemmas around the "user pays/user benefits" principle are not new. Governments have massively subsidized autos from their infancy. In the early 1900's, cities and states literally paved the way for cars, out of general revenues. Today, governments continue to offer free roads and free parking to most motorists. Drivers do pay for many improvements through the gas tax, but as discussed below, this revenue does not meet need. Auto and fuel companies largely do not pay, passing on any taxes and fees to consumers.[5] The financing of AV-supportive infrastructure is not unique in its failure to meet the "user pays/user benefits" principle. Still, connected infrastructure right now provides much value to a very select group of drivers, who face no special surcharge for it. The rise of autonomy therefore offers an occasion to overhaul an inequitable, preexisting system of transportation finance—or to double-down on it.

One might argue, though, that the "user pays/user benefits" principle should not apply here, as AVs cause positive externalities. By this logic, smart infrastructure deserves a subsidy, since it will encourage AV adoption, which will in turn likely prove safer than human driving for all road users. In other words, perhaps government should subsidize AVs, through supportive infrastructure, because they may save lives. This line of thinking, though, uses the wrong baseline. The costs and benefits of autonomous driving need to be assessed on their own terms, not relative to current driving. Injuries and deaths from autonomous car crashes do not change from societal costs to benefits simply because there may be fewer of them than from human driving. Setting aside vehicle electrification, which has no necessary relationship to vehicle autonomy, AVs also impose the same emissions, pollution, and health costs as current driving. These costs may even increase. While debate rages, researchers like Daniel Fagnant and Kara Kockelman, Adam Cohen, and a team from Fehr and Peers all project that autonomy will lead to more vehicle miles traveled, even if many AV trips are shared, in part by making driving easier and inducing demand.[6] Supportive infrastructure will only contribute to that trend. Like the cars of the past century, AVs may provide some public benefits, but from a public policy perspective, the significant external costs they impose call for a user-pays response.

If You Build It, Robots Will Drive: Autonomous Vehicles and Their Supporting Infrastructure

Sometimes called driverless cars or self-driving cars, autonomous vehicles operate some or all of their functions without driver input. Autonomy is less a binary and more a spectrum. Experts classify AVs into five levels, from mere driver assistance to full autonomy (*See Figure 1*). Partially autonomous vehicles, like Teslas with Autopilot, have already driven over a billion miles to date, and newer models creep closer to full autonomy every year. For the purpose of this analysis, I define "autonomous" as Level Four or better—but vehicles at all levels of autonomy will benefit from smart infrastructure, to a corresponding degree.[7]

Figure 1: Levels of Autonomy[8]

SAE Level	SAE Name	Description*	
0	No Automation	Full-time performance by the *human driver* of all aspects of *dynamic driving task*	Human Driver Monitors Driving Environment
1	Driver Assistance	Driver assistance system controls either steering or speed while the *human driver* performs all remaining aspects of *dynamic driving task*	
2	Partial Automation	Driver assistance system(s) controls both steering and speed while the *human driver* performs all remaining aspects of *dynamic driving task*	
3	Conditional Automation	*Automated driving system performs* all aspects of *dynamic driving task with the expectation that human driver* will respond to a *request to intervene*	Automated Driving System Monitors Driving Environment
4	High Automation	*Automated driving system* performs all aspects of *dynamic driving task*, even if a *human driver* does not respond to a *request to intervene*	
5	Full Automation	*Automated driving system performs* all aspects of *dynamic driving task* under all roadway and environmental conditions that can be managed by a *human driver*	

To be sure, tech boosters may overstate how much and how soon AVs will change mobility. But autonomous cars do appear poised to gain a significant share of sales and miles, even if manufacturers have pushed back their release timelines. ABI Research, for one, forecasts 8 million vehicles sold in 2025 worldwide will be Level-Three autonomous or above, representing 8.5 percent of 2017 sales.[9] If this estimate proves even near-correct, AVs will become an established feature of the transportation landscape, well beyond their current experimental state. Regardless of the exact timing and penetration, the possibility of eliminating the need for active driving merits serious study, and their AVs’ current presence and projected growth warrant a user-pays/user-benefits analysis.

A variety of physical and informational improvements can support autonomous vehicles. Such projects go by many names (which I use relatively interchangeably throughout): intelligent transportation systems (ITS), connected vehicle programs, smart cities projects, vehicle-to-infrastructure (V2I) communication, etc. They include hardware and software to optimize road usage, speeds, and safety, especially for advanced cars. ITS signals can broadcast their timings and can coordinate with each other to improve traffic flow. Cameras and sensors can detect crashes, slowdowns, emergency vehicles, vulnerable road users, and parking occupancy; make adjustments; and send out information accordingly. Kiosks, phone apps, and in-car navigation systems can receive and display data from ITS devices. Lane markings and signs can even become “smart” by adding detectable magnetic particles to their paint or by making them able to better reflect LIDAR waves from cars’ remote sensors. These projects will help autonomous vehicles overcome problems big and small. A traffic light that broadcasts data to AVs, for instance, will help them find optimal, time-efficient routes but will also tell them what color the light is when the sun blinds their cameras.[10]

Smart infrastructure helps more than just autonomous vehicles. Connected vehicles—cars with the ability to receive data broadcast by ITS devices—will benefit too. Instead of automatically adjusting routes, connected vehicles will inform their drivers to reroute manually. Pedestrians and bicyclists can view the same information on phone apps. Every road user will gain from enhancements like adaptive signal timing. However, autonomous vehicles—particularly Level Four and Five autonomous vehicles—will benefit most from these improvements. Some systems, like traffic-speed data, will help AVs slightly more than other cars, while others, like detectable lane markings, are almost exclusively useful to AVs. Self-driving cars become faster, safer, and more marketable because of the full range of ITS devices, while phoneless pedestrians or drivers of older cars benefit very little.[11] Thus, for the purposes of analyzing how well a funding method meets the "user pays/user benefits" principle, autonomous vehicles far disproportionately gain from smart infrastructure.

Conversely, AVs can operate without intelligent transportation systems. Cars with various degrees of autonomy drive today with very little infrastructural support. Fagnant and Kockelman conclude that "even without [V2I] communication, significant congestion reduction could occur if the safety benefits alone are realized."[12] On the other hand, smart infrastructure does dramatically increase the effectiveness of AVs. A study by Qing Li, Fengxiang Qiao, and Lei Yu found that communicative infrastructure decreased cars' emissions of four major pollutants. Fagnant and Kockelman also note that smart street improvements will ensure, in part, that AVs do not overburden existing roads. The head of research at Chinese tech company Baidu put these impacts in stronger terms: "Self-driving cars won't work until we change our roads."[13] While not strictly necessary, smart infrastructure represents a major component in the roll-out and mass adoption of AVs. Especially after an Uber self-driving car struck and killed a pedestrian in Tempe in 2018, autonomous vehicles' public acceptance may depend on street improvements to make AVs safer.[14]

Federal Funding for Smart Infrastructure

It's a Gas, Gas, Gas: The Gas Tax and the ITS Program

Since the 1980's, the United States Department of Transportation (USDOT) has provided the most significant funding for the research and development of new types of smart infrastructure. To do so, the federal government has primarily drawn from the Highway Trust Fund, the pot of revenue from the national gas tax, other fuel and vehicle taxes, and more recent transfers from other sources. Traditionally, Congress has allocated the Trust Fund in major transportation bills enacted every five to eight years, though numerous short-term extensions have cast doubt on the stability of this legislative process. Regardless, since 1991, Congress has dedicated a portion of the Trust Fund to smart infrastructure grants, under the Intelligent Transportation Systems Program and its predecessors. Today, the ITS Program receives $100 million annually.[15]

Though the gas tax now faces structural problems and declining revenue, it long provided a reasonable user fee for financing national transportation improvements. In simplest terms, drivers nationwide paid for projects that helped them specifically. This model suited the type of research funded by the federal ITS Program in the past. Through its support, USDOT helped create and spread electronic tolls, 511, and in-car driver-warning systems. These innovations came to benefit most American drivers.[16] But looking forward, the gas tax makes less sense as a funding source for smart infrastructure. First, less fuel-efficient cars—likely older and less technologically equipped—pay the most per mile in fuel taxes, yet gas-tax-funded ITS projects of the next decade will disproportionately benefit more advanced cars. Private auto manufacturers, insurance companies, etc. will also gain from these technologies without contributing to their funding. The issue of untaxed private gain befell the ITS Program in prior eras, but given the potentially transformational rise of autonomy, it is especially salient now. In these respects, the gas tax fails to abide by the "user pays/user benefits" principle when it funds today's connected-vehicle infrastructure. Furthermore, the ITS Program works well for cutting-edge research and pilots, but it likely cannot scale to fund widespread implementation.

On top of this, funding for the ITS Program has flatlined or declined. Aside from a spike at the turn of the millennium, Congress has appropriated around $100 million in nominal dollars each year to the program, as shown in Table 1. Accounting for inflation, ITS has received less every year since 2005, even as smart infrastructure has become more important and better able to interact with increasingly connected vehicles. In fairness, Congress has supplemented the official ITS Program with other grants. The Advanced Transportation and Congestion Management Technologies Deployment (ATCMTD) Program, which funds somewhat similar work, now receives $60 million in Trust Fund money annually. More traditional transportation grants also pay for smart infrastructure as part of larger projects. Nonetheless, the ITS Program itself—the longest-running and best-established federal fund for smart infrastructure—has stalled out.[17]

Table 1: Annual Funding for the Federal ITS Program or Its Predecessors (in Nominal Dollars)[18]

Bill	*Fiscal Years*	*Average Annual Funding for the ITS Program or Predecessors*
ISTEA	1992-1997	$110 million per year
TEA-21	1998-2003	$214 million per year
SAFETEA-LU	2005-2009	$110 million per year
MAP-21	2013-2014	$100 million per year
FAST	2016-2020	$100 million per year

A Contest-ed Funding Source: The Smart Cities Challenge

In December 2015, the Department of Transportation made headlines with its highest profile grant to date for ITS infrastructure: the Smart City Challenge. Before Amazon’s HQ2 search, USDOT spurred a comparable competition among mid-sized cities across the nation. The winning city stood to receive $50 million to test and implement the latest in connected infrastructure: $40 million from USDOT from the Highway Trust Fund and $10 million from Vulcan, Microsoft founder Paul Allen’s philanthropy. While the Challenge aimed to foster a host of data- and technology-based solutions, autonomous vehicles and their supporting infrastructure had significant emphasis. In their applications, every finalist intended to fund some form of AV infrastructure or autonomous shuttles.[19]

The huge prize motivated 78 cities to apply—and to pull out all the stops in their bids. For example, the City of New Haven, where I once worked, applied despite not meeting the minimum population requirement; both of Connecticut’s senators argued for an exception. Playing into the publicly marketed nature of the Challenge, USDOT Secretary Anthony Foxx announced the seven finalists at the South by Southwest Festival, joined in a panel by six of the cities' mayors. Each finalist received $100,000 for outreach and development of its final proposal (*See Figure 2*). In the end, Columbus, Ohio won the Challenge. According to various accounts, Columbus prevailed because it focused on improving access among disadvantaged communities, because it best engaged local stakeholders, or because it lies in a key presidential swing state. More than any other reason, though, Columbus won because it successfully leveraged millions of dollars in private investment.[20]

Figure 2: Finalist Cities in the Smart City Challenge[21]

Beyond its size, the Smart City Challenge's most substantial innovation was its ability to bring in corporate and philanthropic contributions. The seven finalists collectively received pledges for around $500 million in matching funds from companies, universities, and other levels of government. Columbus alone secured $140 million in monetary and in-kind support, including millions from automaker Honda and hundreds of thousands from traffic-data firm INRIX, signal manufacturer Econolite, fleet-management company FleetCarma, and more. Some local foundations may have given out of civic pride or the goodness of donors' hearts, but for many firms, the expenditure will ultimately prove lucrative. Scholar Barbara Kanninen asserts that when "the private benefits…of [ITS] technologies exceed the full cost of implementation, private firms will find it profitable to invest in infrastructure"; the Smart City Challenge demonstrates as much.[22] Honda, for its part, plans to expand electric-vehicle manufacturing in Ohio, so contributing to charging stations in Columbus may well lead to more sales. Other companies may use the opportunity to test and improve their products, to gain exposure and experience for future contract bids in other cities, and to generate goodwill towards their company. In fact, the CEOs of a few of the contributing firms earned spots on the Board of Trustees that will oversee Columbus' project and how its funds are spent. Columbus proved so successful at securing private donations that by May 2017, the city announced its funding had ballooned to $500 million—equal to nearly $569 for every resident.[23]

As gimmicky as it may have been, the Smart City Challenge has so far proven an effective means of jumpstarting the deployment of AV-supporting infrastructure. Beyond Columbus, USDOT later gave $65 million from the ATCMTD Program to pilots from some of the losing finalist cities. San Francisco, for instance, received $11 million to implement projects like a driverless shuttle on Treasure Island. Again, private companies, including suppliers, contributed.[24] The work of finalist cities to develop projects and secure donations thus did not go to waste. Still, a grant so concentrated in just one winning city and a few runners-up may not have been a fair use of national gas tax money. Nonetheless, USDOT's investment will pay off if the technologies tested in Columbus prove beneficial and scalable for implementation across America.

Along these lines, USDOT is now overseeing a smaller-scale competitive grant, the Connected Vehicle Pilot Deployment Program, that focuses specifically on infrastructure that can communicate with autonomous cars and other smart vehicles. Lacking the same amount of publicity, the program awarded a total of $45 million to three pilot projects in the diverse locations of New York City, Tampa, and Wyoming. Like in the Smart City Challenge, USDOT is encouraging private firm contributions, but the program appears to have induced few to no documented donations so far.[25]

In some ways, the Smart City Challenge and the Connected Vehicle Pilot Deployment Program proved more successful than any other method so far in getting the companies that benefit from smart infrastructure to contribute to its construction. Without taxation or other compulsion, USDOT aligned governments' and manufacturers' interests and secured unprecedented voluntary private support. Yet the federal government cannot replicate this model for long. The Connected Vehicle Pilot Deployment Program has partly sustained the Smart City Challenge's model, but it is much smaller and attracted no donations that I could find.[26] Broadly, while technological improvements will continue incrementally, the coming of autonomous vehicles and their supporting infrastructure will only happen once. Companies will have less incentive to donate funds or services as smart cities become widespread and as innovations earn diminishing marginal returns.

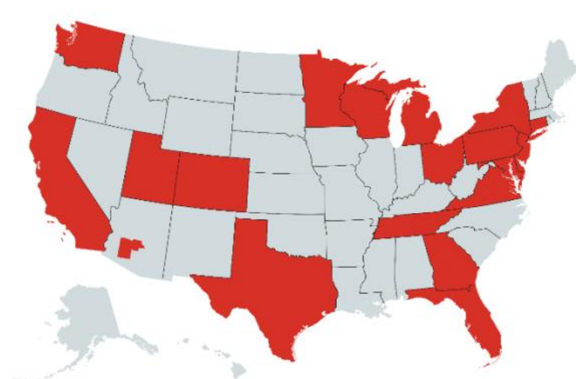
Moreover, governments should remain wary of a system dependent on donations. Firms may expect a governing role in project development and spending or favors from municipalities to which they have donated. Companies often make contributions in-kind, instead of in cash, allowing them to use their own, potentially proprietary technology. Manufacturers who have donated to Columbus now have the chance to set standards that may become accepted nationwide. With these limitations in mind, the Smart City Challenge model is ill-suited to fund the building of connected infrastructure across every part of the U.S. for years to come. But as a one-time, start-up effort, the Challenge managed to get major private beneficiaries to pay, in a manner unlike any other funding mechanism.

Pooled and Local Funding for Smart Infrastructure

Pooled Party: The Connected Vehicle Pooled Fund Study

Given the fluid and evolving nature of smart infrastructure itself, some states are attempting an equally novel funding method. Coordinated by the Center for Transportation Studies at the University of Virginia, a group of "core participants"—nineteen state departments of transportation, one county department of transportation, the U.S. Federal Highway Administration (FHWA), and Transport Canada—have formed a consortium called the Connected Vehicle Pooled Fund Study (*See Figure 3*). These agencies, all voluntary members, contribute $50,000 per year (or less with a demonstration of financial hardship). A non-voting set of additional "associate members" do not pay. The fund members decide on studies and projects to finance; they have backed eleven completed pilots and three current pilots since the fund's beginnings in 2008.[27]

Figure 3: Core Members of the Connected Vehicle Pooled Fund Study (plus the FHWA Transport Canada)[28]



The Pooled Fund demonstrates how states and localities have taken initiative in the connected infrastructure field, putting up their own money as federal spending on ITS has declined. On the other hand, the fund's projects tend to be small-scale and closer to academic research than widespread implementation. In its decade of existence, the Pooled Fund has only raised $8 million, an amount dwarfed by the Smart City Challenge and the Connected Vehicle Pilot Deployment Program. For better or worse, the Pooled Fund also includes automakers and industry experts on its committees and panels, though without formal decision-making power.[29] Their presence may help the Pooled Fund's projects to better integrate public infrastructure and private vehicles. However, as in Columbus, private companies can gain immensely from early involvement in the creation of smart infrastructure, especially if they need not contribute money themselves. All in all, the Pooled Fund represents an innovative mechanism for backing new research, but it shows little promise so far as a sustainable means of larger-scale financing.

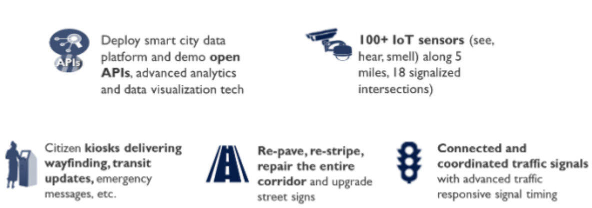
Atlanta Goes It Alone: The North Avenue Smart Corridor

Besides pilots, most connected vehicle initiatives funded by federal and Pooled Fund research dollars have not yet reached completion. Atlanta, Georgia, however, has a heavily used ITS project in operation today. Relying only on bonds backed by local revenue, the city has constructed the North Avenue Smart Corridor, an arterial monitored, managed, and optimized by the latest ITS technology. The corridor offers an illustrative case study in how governments will build and pay for the vast majority of smart infrastructure projects too small and too numerous to receive federal funds.

A busy six-lane road, North Avenue separates Midtown and Downtown Atlanta. It connects major job centers like Coca-Cola's headquarters, redevelopment projects like the Ponce City Market, and parks like the BeltLine. It also runs by the campus of Georgia Tech, whose engineers have provided extensive support and data analysis for the project, and, perhaps parochially, by the office of the Georgia Department of Transportation. The City of Atlanta had initially planned merely to resurface three miles of North Avenue and replace its traffic signals, but as planners secured more funding, the project developed into a test corridor for the latest intelligent transportation systems.[30]

The first phase, completed in September 2017, includes a suite of improvements that draw on a network of over a hundred "Internet-of-things" sensors along the corridor: detectors embedded in the pavement, cameras perched atop signals, etc. (*See Figure 4*). Sensor data on vehicle, pedestrian, and bicycle traffic enable the Surtrac system to adjust signal timing in real time to relieve congestion, speed emergency vehicles, and promote safe driving. Roadside transmitters also use the data to alert people of slowdowns, dangers, and signal timing via the TravelSafely smartphone app and cars' on-board units. The corridor additionally includes high-speed, public wi-fi; adaptive streetlighting; information kiosks; and solar trash compactors. Finally, the city is currently seeking proposals from auto and tech firms to operate a public, autonomous shuttle along the corridor. Overall, 25 percent fewer crashes have occurred on North Avenue since the improvements' implementation.[31]

Figure 4: Improvements Included in the North Avenue Smart Corridor[32]



Renew Atlanta, a municipal bond, funded the first phase of the corridor. A voter referendum in March 2015—passed with over 85 percent of the vote—authorized the City of Atlanta to issue $252 million in general-obligation infrastructure bonds. While Atlanta has pledged property tax revenue as the ultimate security behind the bonds, it actually intends to repay them through cost savings elsewhere. Unlike similar bond measures in other places, the city did not raise tax rates to pay the debt. Instead, a "Blue Ribbon Commission on Waste and Efficiency" identified $20 million in annual savings and revenue, like asset sales, increased fines and fees, a partial hiring freeze, and other internal reforms. "The City will repay the bonds…with no impact on taxpayers," bragged a 2016 press release.[33] While these patchwork sources may prove less secure than actual tax revenue, they offered a powerful selling point to the electorate.[34]

Just under three-quarters of Renew Atlanta's $252 million in bonds are funding transportation investments; the rest will construct public facilities. To date, Renew Atlanta's projects have leveraged over $100 million in other public money, especially from a state gas tax increase and local development fees. Between the bonds themselves and leveraged funds, intelligent transportation systems and other traffic signal programs will receive $52 million. On top of this, the city also passed a local sales tax in 2016, which planners will use to build future ITS corridors across the city.[35]

However, the city built the North Avenue Smart Corridor itself with Renew Atlanta bond money alone—without state, federal, or private matches. Faye DiMassimo, Renew Atlanta’s general manager, cited the fast-evolving nature of the project and the relative stinginess of current federal funding as reasons. USDOT in fact rejected a grant application for the corridor; its small size, at only $3 million, may have proved a disadvantage against bigger ventures vying for national transportation dollars. Moreover, no private investment nor monetary partnerships went into the project. In fairness, the corridor did receive technical support and publicity—though no actual money—from winning the Safer Roads Challenge, a worldwide contest put on by a coalition of businesses including IBM, General Motors, and AT&T. Still, DiMassimo said her team did not consider the idea of direct private funding, even though firms have expressed great interest so far in working with the corridor’s data and applying for the autonomous shuttle contract.[36]

To some degree, funding the corridor solely publicly makes sense. The project provides a host of safety and mobility improvements to normal cars alone. People can use the corridor’s app to detour around crashes, and cars of any age have smoother trips thanks to the adaptive signal timing. Nevertheless, DiMassimo and the City of Atlanta built the corridor with autonomous vehicles in mind. In press interviews, DiMassimo has sold the corridor as a laboratory for self-driving cars. The wealth of publicly available data from the projects’ sensors can greatly enhance the efficiency of autonomous driving and model what streets may look like in the future. With over a dozen bids to operate the corridor’s autonomous shuttle, private investors have already demonstrated their interest in North Avenue. Instead of building a test track themselves, vehicle manufacturers will be able to use North Avenue to improve their own marketable technology free of charge—or, for the winning shuttle bidder, be paid to do so. Perhaps Atlanta leaders see benefit in subsidizing private autonomous vehicle technologies. But whether worthy or not, the implicit subsidy has not merited mention in the planning and discussion of the corridor.[37]

Rather, the corridor’s funding perhaps

represents the tail wagging the dog. Planners developed the smart corridor concept only after the Renew Atlanta bond passed; they did not include it in the initial funding plan nor use it as a selling point during the election. After the city began receiving its influx of bond money, local planners created a small yet innovative project on which to spend their newfound bounty. The same causality may play out nationwide.[38] Besides a few new revenue streams (like AV mileage taxes, described below), planners will instead gradually repurpose existing sources, first on small demonstration projects and then on larger-scale ITS implementation.

User Fees to Fund Smart Infrastructure

As Simple as "Do, Re, Mi," "AV Fee," "1-2-3"?: Autonomous Vehicle Taxes

As the North Avenue Smart Corridor and the federal ITS Program exemplify, most ITS funding comes from traditional, public sources without private contributions. None of the models described above have secured a permanent, obligatory funding stream for smart infrastructure funded by the very vehicles that most benefit therefrom. However, within the past two years, a few states have proposed or enacted new taxes on driving autonomous vehicles.[39] As direct user charges, these fees offer many advantages over other financing mechanisms. While passing them has involved a number of political trade-offs, they represent a major future funding source for smart infrastructure.

Much of the scholarly work and popular press on autonomous vehicle taxes conflates them and their motivation with electric car fees.[40] Representative of this trend, a 2015 op-ed in *Forbes* states that "self-driving cars are likely to get much better fuel economy, which will result in dwindling gas tax revenues."[41] Nothing about autonomy, though, necessitates cleaner cars, and vice versa. While electric vehicle fees may fall more on driverless cars than traditional ones by happenstance, they fail to address the unrelated issue of funding smart infrastructure.

The Eno Center for Transportation and former Secretary of Transportation Mary Peters have offered a direct solution: a federal 1¢ per mile fee on fully autonomous driving. Unlike most of the funding strategies described above, their plan embodies the "user pays/user benefits" principle. Under their model, autonomous vehicles would track their driving using any of the proposed vehicle-miles traveled (VMT) fee systems that states and think tanks are developing. More so than standard cars, AVs already contain the geographic sensing and reporting technologies needed for effective VMT charging. Only autonomously driven miles would count; the meter would stop if a human took the wheel. The tax could track with inflation and vary by vehicle type, but the Center and Peters propose 1¢ per mile as an initial rate low enough not to dissuade technological development. They suggest that the federal government levy the fee on manufacturers, not car-owners themselves. While firms will likely pass along the price to consumers anyways, charging manufacturers makes sense for two reasons. First, just as the gas tax costs only about one percent of its revenue to collect because governments levy it on just a few fuel distributors, an AV fee would become cheaper to administer if imposed on as few parties as possible. Second, at least symbolically, charging car companies publicly highlights their responsibility for infrastructure funding. Finally, the Center recommends designating fee revenue for a federal smart infrastructure grant. The Center estimates $318.6 million in annual revenue if one percent of driving is autonomous.[42]

Congress has not taken up the proposal, but states like Tennessee have considered their own autonomous vehicle taxes. In 2016, the Tennessee General Assembly passed S.B. 1561, which legalized autonomous vehicles on state roads and codified definitions of autonomy. The original bill would have also established a certification system and imposed a per-mile tax on autonomous driving: two-axle self-driving cars would face a 1¢ per mile fee; vehicles with more axles would owe 2.6¢ per mile (presumably due to their greater wear on roads). Unlike in the Eno Center's proposal, Tennessee tax revenue would not have been earmarked specifically for AV infrastructure, with instead ten percent sent to the state's general fund, ten percent returned to municipalities, and the rest dedicated to various transportation funds. The bill's main sponsor, Senator Mark Green, told the Transportation and Safety Committee that smart corridors were not a state priority, though his press statements implied that the tax revenue would have at least fund the AV certification program.[43]

A conservative state like Tennessee may seem an unlikely pioneer for a new tax. And indeed, amendments just before the final vote removed the tax and certification elements of the bill (without significant discussion in the record as to why). Nonetheless, the original bill with the tax passed out of a Republican-dominated committee in a Republican-dominated legislature, garnering near-unanimous support from legislators of both parties. While the tax did not ultimately get enacted, the fact that one of the few AV tax bills in the nation was proposed and gained major support in a state like Tennessee merits examination.[44]

Senator Green, a Republican, sold the bill as a pro-business, pro-innovation measure that legalized the testing of self-driving cars with few regulations. Never during committee discussions did Green or anyone else mention the tax, even when it was still a core part of the bill. Instead, discussion centered on the bill's clear definitions of autonomous technology, its unrestrictive permitting process, and its backing by the state's growing auto industry. Green unabashedly announced that a key definition "was…written by the manufacturers, and they support the amendment."[45] Given the confusion some senators showed in understanding AV technology, the industry had an upper hand in the passage of the bill. Although the tax was removed in the end, Senator Green claimed automaker support from the beginning. Thus, S.B. 1561 shows that car manufacturers and tech companies can support or even champion an AV tax if packaged with pro-AV legal changes.[46]

Other states are also considering AV taxes or have enacted them. Last year, Nevada passed a three-percent tax on rideshare fares on autonomous vehicles. Again, legislators bundled the tax with a permissive, new legal framework for AV operations and gained industry support. In Massachusetts—a state as liberal as Tennessee is conservative—legislators proposed a 2.5¢ per mile, inflation-indexed AV tax, with possible discounts and increases based on vehicle occupancy, time of day, driver income, etc. The bill likewise legalizes AV testing but imposes stricter regulations. It stalled, but its sponsors recently revived it for discussion after the deadly 2018 Uber AV crash.[47]

Just as localities and states have self-funded their transportation systems more and more instead of relying on the federal government, the future of autonomous vehicle taxes lies at the state level.[48] For states, these fees come with many advantages. They directly charge beneficiaries—users and manufacturers—instead of relying on broader taxes. They are also remarkable proactive—rarely does government establish a tax for something that does not yet fully exist! Indeed, with essentially no current owners of completely self-driving cars, legislators have little worry about constituent backlash. However, none of the three states above plan to dedicate AV tax revenue towards smart infrastructure, leaving open the question of how it will be funded. Moreover, in exchange for a small, new revenue stream, Nevada traded away significant power to regulate the safety and operations of self-driving cars, and Tennessee lost out on the tax itself. Nonetheless, these proposed or enacted taxes represent a likely future for AV public finance, especially if they are a foot in the door to later raise rates, implement congestion pricing, etc.

Conclusion

Smart cities, connected infrastructure, and autonomous vehicles convey an air of modernity and novelty, of a future within reach but not quite here yet. However, not only are they already significant parts of cities in America and across the globe, but they are also part of a long intellectual history. As social geographers Alan Wiig and Elvin Wyly argue, the smart city is simply the latest step—albeit an accelerative one—in the politics of the “city as a growth machine.”[49] Growth-machine governance concerns itself with the commodification of real estate and the increase of local land and property values, above all else. In transportation and in other sectors, smart cities fuel the growth machine with both data and techno-optimistic messaging, breeding faith in analytics over deliberation. Indeed, municipalities can hardly say no to new surveillance and autonomous technologies: as Wiig and Wyly write, “the logic [is] inescapable: what city would not want to be ‘smart’?”[50] The advent of smart infrastructure and communication has even changed the discourse of what it means to be a citizen. In Britain, Simon Joss et al. found that a key government smart city policy document conflates “citizen” with “customer,” muddies the rights and responsibilities of citizenship in favor of entrepreneurship, and assumes effortless consensus through big data, though it does encourage popular participation in governance via technology. Worrisomely, cities may become more technocratic under the guise of becoming more participatory, thanks to smart cities.[51]

These broad socio-political concerns may seem removed from the details of funding ITS infrastructure. However, how America pays for the next generation of roads involves significant philosophical and political questions. Are autonomous vehicles and the infrastructure that support them going to be mere extensions of the growth machine—governance that takes public money and puts it toward private interest? Or can governments make users and manufacturers of autonomous cars pay for their share of the disproportionate benefits they receive? Will the powerful draw of smart infrastructure push leaders to repurpose existing general revenue streams? Or will governments create new levies and dedicate them specifically to ITS? Finally, what role do auto and tech companies have in a smart city citizenship regime: what rights do they have to shape standards and what responsibilities do they have to contribute?

These questions involve a degree of speculation, to be sure. But as USDOT's Smart City Challenge, Atlanta's North Avenue Smart Corridor, state AV taxes, and more demonstrate, decisionmakers at all levels of government are grappling with them right now and coming to different answers. All told, traditional forms of funding still pay for much of the nation's smart infrastructure, failing to abide by the "user pays/user benefits" principle. Yet novel modes of financing have demonstrated that voluntary and compulsory contributions from AV users and firms are possible, though not without political compromises. Governments are far off from resolving the philosophical questions and policy issues that autonomous vehicles raise. Nevertheless, the most significant revolution in automobility since the invention of the car calls for a similar rethinking of infrastructure funding.

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