Sustainable Transportation: A Sociotechnical Analysis

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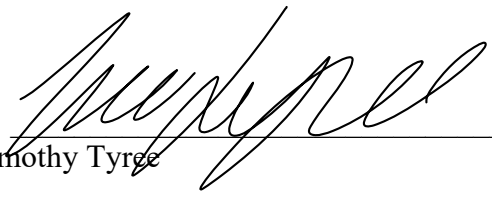
On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

Signature  Date 05/04/2020
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1 Fable of Tomorrow

This is going to be a nightmare, Jason thought on a chilly Monday morning, *but it'll only last a week*. He had wrecked his Lexus over the weekend and the car was in the shop. Until then his wife would be dropping him off at the park-and-ride on her way to work. Jason has seen the people who get off the bus near his private parking deck downtown. Construction workers, janitors, lower-level business admin types, and people who look like they're up to no good. *People my tax dollars support*, he thought.

The bus drove down the interstate for twenty minutes and then pulled off to a park-and-ride closer to downtown. Jason was sitting in an aisle seat and avoided eye-contact with people getting on the bus – he didn't want to sit next to anyone. *Excuse me sir, can I sit there*? Jason looks up and notices the bus is now full. *Fine*, he thinks, and lets the woman slide by. She spends the rest of the ride making small talk – she was nice enough, so Jason didn't mind, but he wasn't enjoying himself either. The bus pulls up downtown and before exiting she says, *oh I'm Marta by the way*, and he responds, *Nice to meet you Marta, I'm Jason*.

It was just any other Monday after that – Jason is high up the management chain at his company – so most days are spent in meetings. Sometimes at the office – sometimes at five-star restaurants. Six O'clock came around and he needed to catch the 6:15 bus home, so he made his way down to the lobby. The elevator stopped at the third floor and when the doors opened, he saw Marta waiting. *Hi Mr. Jason!* She exclaimed. She got on the elevator and as they walked to the bus stop, she explained that she works in the cafeteria on the third floor. Jason tells her who he is within the organization, and laughs, because it didn't seem to faze Marta at all. *We hire Stanford grads who stutter when they meet me*, he thinks jokingly.

During the next few days Jason started to get used to the bus – on Monday he had been so focused on staying to himself that he didn't notice how the bus would fly past the traffic he normally sits in. His conversation with Marta continued as well. By Friday Jason learned that she had come to the United States a few years ago and was working multiple jobs so that she could send money to her family back home, and Jason had told her all about his kids that are off at college. The more they talked, the more Jason began to develop a profound respect for Marta.

Jason picked up his Lexus on Saturday morning and went about his normal weekend routines. Him and his wife were watching the news on Sunday night – as they normally do - and Jason noticed the words they were using to describe people from Marta's country. *Marta is none of those things*, he thought, and then wondered if he would have questioned what he was hearing a week ago.

That question rolled around his head most of the night – and Jason was extremely tired when he left for work in his car Monday morning. *This is going to take forever*, he thought as he saw traffic forming on the interstate. Part of him wished he could pull off to the park-n-ride up ahead and take the bus, and then he thought *why can't I?* Jason got on the bus, checked his emails, and when Marta got on, they continued their conversation from where it left off.

2 Introduction

Traffic has always been of interest to me. Given our twentieth century technology, the act of sitting in traffic seems archaic. Yet it is a deeply engrained part of our societies transportation methods. Growing up in Houston, TX, has given me a very familiar relationship with traffic. Countless hours have been spent idling on highway 290 just to get a few miles. The gridlocked highways not only cause mental distress, they can cause physical harm. The mandated hurricane evacuation of Houston in 2005 left the highways so gridlocked, that people died in their cars. The hurricane never hit the city. I went to high school downtown, and during this time I fell in love with public transportation. I would ride the park-and-ride bus downtown, transfer stops onto the light rail, and hop off a block from my school. I felt connected to the city in a way that personal vehicles can't provide. I walked by the same homeless camp everyday and formed relationships with people that society typically ignores. I learned the routes and found cool parts of the city that I had never seen before. On the way home, while the bus flew down the HOV lanes, I looked out the window at cars stuck in traffic for miles. It seemed so mundane; did they realize how much time and money they would save if they just took the bus?

Every year the average number of vehicle miles traveled (VMT) and vehicle hours of delay (VHD) is rising. The average number of cars per household is also increasing from 1.86 vehicles in 2009 to 1.88 vehicles in 2017 [16]. These steadily increasing metrics contribute to the rise in congestion, accidents, and degradation of the environment. Multi-modal transportation is also rising, albeit at a somewhat stagnant pace.

The term congestion refers to travel conditions where the current speed is less than 90% of the free-flow speed (speed limit). A recent study by the Texas AM Transportation Institute found that the average American spends 54 hours a year in congestion. This finding seems somewhat expected, but one should keep in mind that this is an average over a mostly rural country. When broken down by city, they found that New York, Washington DC, and San Francisco commuters all spend between 92-103 hours per year in traffic. These are tangible impacts on the environment, economy, and people.

The costs of congestion are increasing as well, in 2016 the cost of extra time and fuel amounted to $157 billion, in 2017 that number rose to $166 billion. In 2017 8.8 billion hours of extra travel time occurred due to congestion, and this resulted in 3.3 billion gallons of wasted fuel. For the average commuter, these numbers result in $1300 in lost time, and 21 gallons of fuel wasted per year [5].

Route reliability, which is the probability that a route will offer the same travel time, during the same time period of any given day is also decreasing. Historically a commuter would expect rush hour times as the only congestion periods, but about 33% of the total delay is now midday and overnight. Congestion rates increasing are not bound to urban areas; during Texas AM's study, they found communities of all sizes are experiencing significant growth trends [16].

These trends have now passed the previous congestion records in the years leading up to the Great Recession from 2007 to 2009. Assuming the country does not go through another recession, the steadily rising rates suggest that our current transportation infrastructure is not sustainable. By 2025 all the metrics listed above are projected to increase by 10-20% [5].

Why hasn't anything worked? What does a sustainable transportation system look like? Are technologically driven solutions going to help ensure our transportation systems remain viable? This thesis takes a historical approach to investigate how congestion became an increasingly significant problem. Based on the historical understanding, I will examine various proposed methods and their validity as solutions to sustainable transportation, while keeping in mind cultural roadblocks.

3 How Did We Get Here?

In 1956, President Dwight D. Eisenhower signed the Federal-Aid Highway Act, allocating twenty-six billion dollars to fund 41,000 miles of highway expansion [10]. Originally Eisenhower envisioned this as necessary means to connect rural America with urban without having to gut through city centers. However, once signed, the highway engineers were in control.

The resulting expansion decimated entire neighborhoods, predominantly lower-income and black communities — Brown v. The Board of Education had passed two years earlier, and engineers saw this as an opportunity to physically force segregation [14]. Dividing neighborhoods in this way often neglected the entire point of a highway; to get a person from point A to B in as little time as possible. The roads curved around affluent areas, creating bottlenecks. Major American cities can still see the class divide between highways [12].

No longer restricted to urban living, wealthy residents began moving to the suburbs in a mass exodus commonly

Figure 1: Image on left is historic Jackson Ward in Richmond, VA. On the right is an overlay showing same area after the highway was built.

referred to as 'White Flight' throughout the '60s and '70s. As metropolitan areas grew, traffic became worse. In the years after white flight, city planners and engineers started working on different ways to fight traffic.

A glaring solution would have been to expand public transportation out to the suburbs, but suburban residents

blocked these efforts. To this day, public transportation expansion continues to get voted down [12]. For decades, the solution to fighting congestion has been to add highway lanes.

4 If You Build It, They Will Come

There are two fundamental laws of congestion. The first is the fundamental law of highway congestion, which claims the elasticity of a given highway's vehicle miles traveled (VMT) to added highway lane miles is approximately one. In layman's terms, it will not relieve congestion [8]. This phenomenon is known as induced demand. In economics, induced demand shows that if the supply of a good increases, more of that good is consumed. Studies show that adding highway miles increases the number of commuters on that highway, and congestion stays relatively constant.

Multiple factors explain how induced demand happens. Adding lanes to highways creates more efficient trucking corridors. A growing number of factory jobs sent overseas leaves workers looking for employment opportunities in urban areas. The United States population grows at a rate of around 0.6% per year. Critics of the fundamental law of highway congestion claim that due to these contributing factors, induced demand should not be a concern to policymakers. Special interest groups make exuberant claims - the American Road and Transportation Builders Association quote, "adding highway capacity is key to helping to reduce traffic congestion." The American Public Transit Association states that without investment, highways will become too congested and no longer work. Data does not support these definitive claims.

Congestion is a complex problem that is not universal. Investment in non-intrusive traffic operations, advanced technologies, better land development, congestion pricing, autonomous vehicles, park and rides, and construction - where necessary - all play a vital role in keeping traffic flowing, but the best way to do this is getting cars off the road. How can we reduce the number of drivers? I explore this question in the following sections by analyzing public transportation, pricing methods that treat roads as a commodity, and hardware optimization. The question then becomes whether people are willing to accept transportation improvements.

5 Public Transportation

Public transportation is not the only solution, but it is one of the most important. The number of commuter rail riders has remained relatively stagnant over the past 20 years. Countless factors explain this, absurdly high-ticket prices, slow trains due to bottlenecks through urban corridors, and convenience seems to be the most prominent. Taking the train from Richmond, VA to NYC will cost anywhere from $100-$300; the trip takes 7 hours, which averages to 47 miles per hour, and only two trains leave Richmond a day. A comparable route in Europe would be Paris to Amsterdam, which will cost around $40; the trip takes 3-4 hours, which averages to 90 miles per hour, and trains depart every 2 hours.

Every wealthy nation in the world has invested in high-speed rail, including the United States, albeit at a much slower pace. Amtrak recently received $1.8 billion in subsidies, in comparison to $19 billion Germany received in 2014.

An argument was going to present that Amtrak deserves exponentially higher funding; upon research, I realized that Amtrak requested the federal government take 141 million back [4].

Amtrak's business plan states their goal is to be the preferred mode of intercity transport, and double ridership by 2040 [4]. The goal is respectable, but one could argue that success is attainable much sooner than that. Throughout the urban corridors (east coast and west coast) rail expansion projects comparable to the Highway Act would benefit congestion, commuters, and freight. This does not mean it needs to be a nationwide high-speed rail network. What this is referring to are separate high-speed rail networks throughout the Northeast corridor, hitting all of the main cities (Boston, New York, Philadelphia, Baltimore, Washington DC) and then connecting to the growing southeast economic powerhouses (Richmond, the Research Triangle, Charlotte, down to Atlanta.)

Implementing rail/subways through inner cities can be a daunting project if there is no existing rail infrastructure.

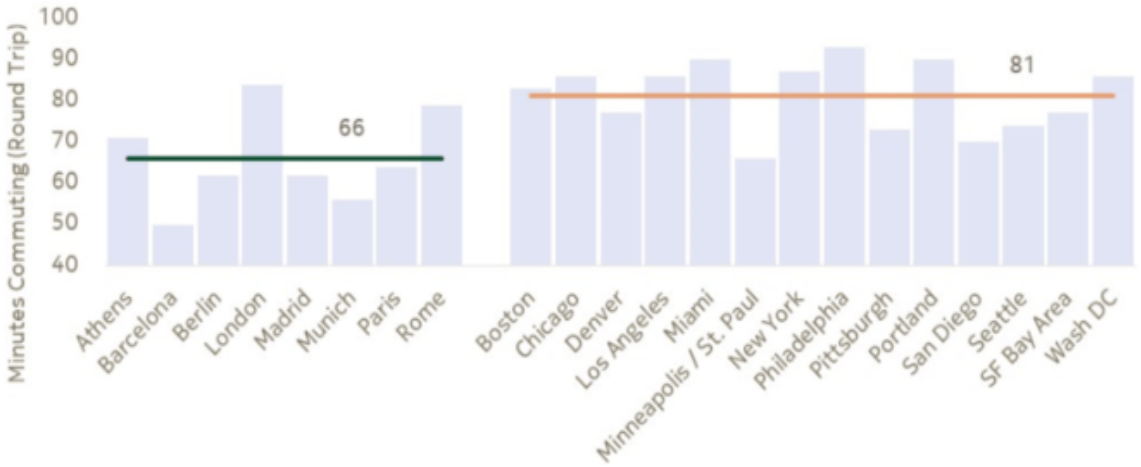

Figure 2: Avg. round trip commute times in european and US cities [2].

For this reason, there have been successful projects involving bus-only lanes that are showing promise. In 2018, Richmond, VA opened the PULSE system [11]. The PULSE is a bus that operates in the same fashion as a typical subway would. It goes up and down the main thoroughfare through Richmond, and each stop is serviced every 10 minutes. Downtown business centers like MCV, the Government Center, and Shockoe Bottom are all serviced. Since the PULSE's rapid transit implementation, Richmond's transit ridership has increased by 17%, while national transit ridership has decreased by 2% [3].

There is currently a southeastern high-speed rail project that has been approved, but we are years away from seeing it come to fruition, and it took years to be approved. Many jurisdictions fought over proposed routes, and there were problems with funding. Funding becomes a major issue when a project to this scale is being implemented. Where will the money come from? Political opponents would surely raise concerns about taxpayers footing the bill, so a project this large requires multiple sources of income being generated in order to be successful. The most promising options to generate income while also reducing congestion on the highways are presented below.

6 Congestion Pricing

Congestion pricing is a zone-based tolling meant to lower congestion and pollution by dynamically charging by demand. It can be viewed within the same scope of other demand-based pricing such as airline travel during the holidays, skipping lines at a theme park, and uber prices surging after an event. The benefit of congestion pricing is that the extra tax dollars can be used to fund public transportation. The theory is that when there is regular stop and go traffic and congestion prices are implemented, then fewer people are driving. This results in more walk, carpool, biking, and less delay on the road (Administration). When you add in the transportation alternatives that it can help fund, and consider the benefit of cleaner air in the city, then one can see how this is a crucial implementation for sustainable transportation systems [6].

The four main types of congestion pricing are variably priced lanes, also known as HOT lanes, variable tolls for an entire roadway (regular toll road), the cordon pricing strategy, and area-wide charges. HOT lanes dynamically toll drivers with prices spiking during peak hours. HOT lanes have been successful in Northern Virginia. I-95, I-395, and I-495 all have HOT lanes that go down the middle of the highway. The HOT lanes have succeeded in reducing congestion, but this implementation comes with some drawbacks. The downside to variably priced lanes is that people will naturally be inclined to find ways around it, this includes simply taking the general-purpose lanes, waiting for prices to drop and then driving (this causes abnormal and unpredictable traffic patterns), or taking arterial routes that are not connected to the highway. In my research, An Econometric Analysis of the Northern Virginia I-495 Express Lanes, I found that these patterns can have an adverse effect on the value of reliability, and value of travel time [18]. This is not to say that I believe these programs to be unsuccessful, it's simply stating there are areas of improvement to be considered.

The first improvement for future HOT lanes is that they should be publicly funded, the reason for this is so that the profits can go towards the public benefit. Most of the HOT lanes in Northern Virginia are owned by Transurban, an Australian company. Some of the toll money goes towards a community grant program [1], but the majority goes to Transurban. Congestion pricing will have optimal benefits when the revenue generated is used to fund mass transit initiatives and community projects. Paying $25 a toll can certainly reduce congestion but when that money is being sent to a company overseas, little benefit remains.

The second improvement is that the cordon strategy should be implemented in all major metropolitan areas. The cordon strategy does not restrict the tolling to a certain roadway or lane, it cordons off an entire geographical area, and anyone driving in or out of this area during peak times will pay. The first US city to pass cordon pricing legislation was New York City this past April. The legislation states that the area of Manhattan south of Central Park will be a congestion pricing zone during the day. The plan begins in 2021 and with 880,000 people driving into Manhattan on a given day, an expected $15 billion will be generated for the Metropolitan Transportation Authority. This money will be used to improve subways, modernize aging rail infrastructure, and expand rail access. [9].

A common, and valid, argument against congestion pricing are concerns regarding equitability. New York has dealt with this by offering a tax write-off for anyone making less than $60,000 [9]. Implementing an equitable cordon

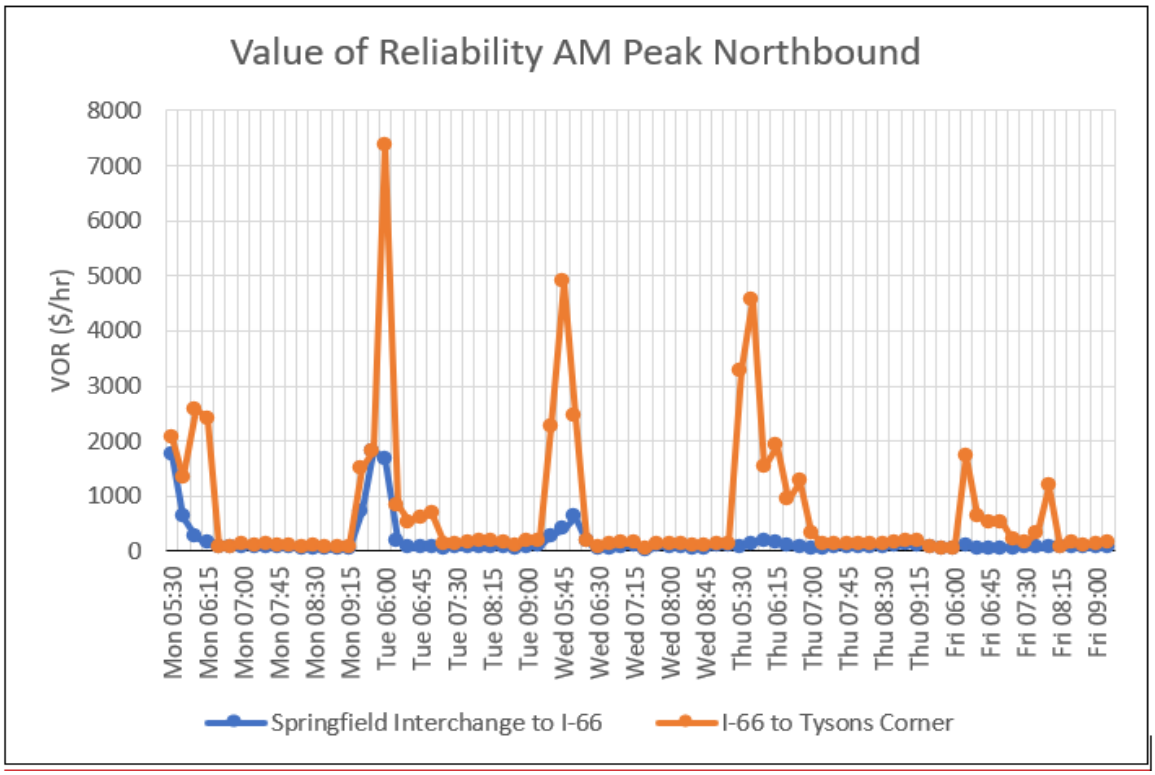

Figure 3: Results showing unstable value of reliability [18].

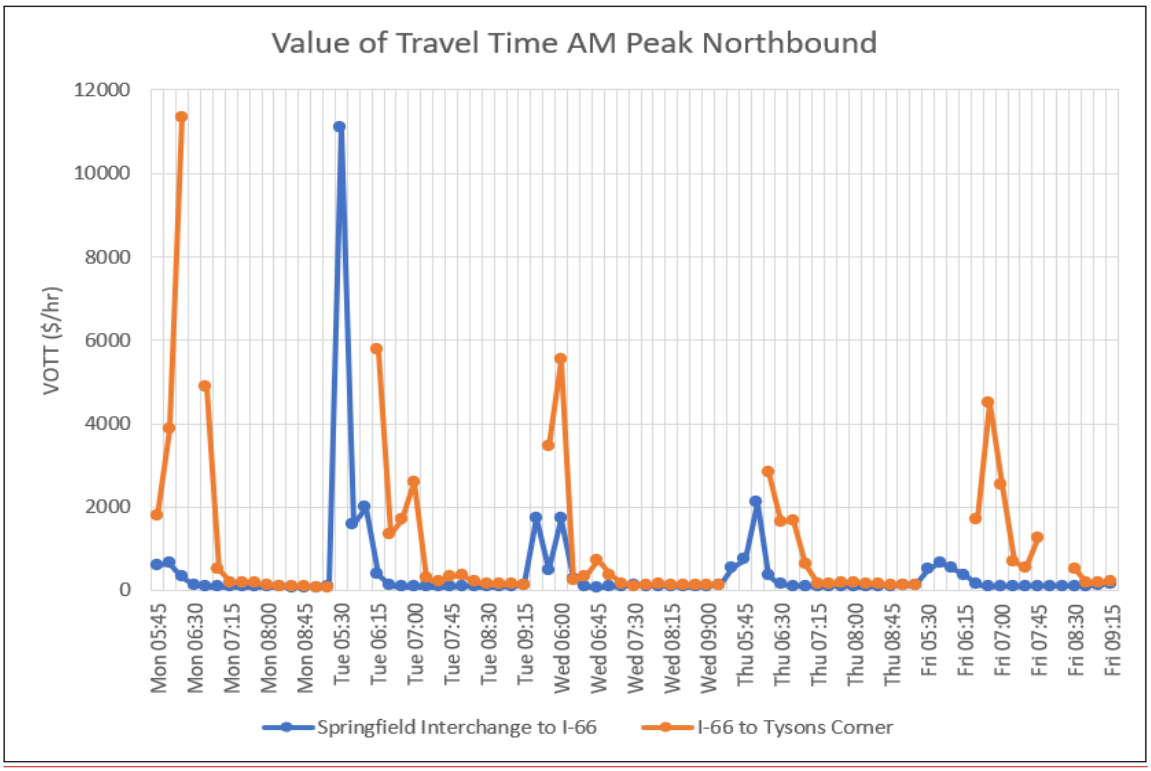

Figure 4: Results showing unstable value of time travelled [18].

strategy in Northern Virginia in business districts such as Tysons' Corner, Crystal City, Ballston, etc. would net billions in revenue that could be used to expand transit and increase the public well-being. Another way to ensure equitability that has recently been proposed is making all public transportation free. While there isn't enough data to make a definitive claim on whether free public transportation would be viable – there is enough conjecture that multiple cities across Massachusetts are trying it out [7].

7 Technological Solutions

Some refuse to take public transportation – and there are communities where expanding public transit is not the most excellent option. Predictive technologies surround us (YouTube, Netflix, targeted ads, etc.). At the same time, traffic is an extremely sophisticated model to predict – technology has enabled us to model broad trends in traffic that aren't affected by everyday outliers. We could have an excellent public transportation infrastructure – but for the cars still on the road, we need to provide a modern-day roadway network. Powerful non-human objects making use of real-time data could transform the efficiency of our roadways. Intelligent Transportation Systems (ITS) is an emerging field that is modernizing our current roads. For example, Rapid Flow is a company based out of Pittsburgh, PA, and they have been able to reduce travel time delay, the number of stops, and emissions at every location they have installed their adaptive stoplight, Surtrac. Surtrac learns from historical data and then uses the findings to evaluate the best course of action from its real-time data. [17].

Upgrading hardware, such as Surtrac, is an equitable solution that benefits everybody. Interactive cameras embedded with classification algorithms could enhance incident clearance. Since traffic accidents are a seemingly random event, incident clearance time is notoriously difficult to predict [13]. It can be challenging to evaluate a roadway's safety and predict the impact of incidents when most of the data is input by humans. When an incident occurs, the real-time occurrence isn't known. The event first needs to be witnessed (a pedestrian, commuter, or a human sees it at the traffic operations center), and then confirmed. Training cameras to recognize an incident, and what type of event could speed up incident clearance times. Eventually, the cameras would have enough training data to make high accuracy predictions on the best emergency response plan (what size tow truck, how many vehicles, etc.) quicker than humans.

The same methods applied to Ramp metering would improve laminar flow on the highway. Ramp meters are traffic signals on freeway on-ramps meant to manage the frequency and density of vehicles entering a section of the highway.

Autonomous vehicles (while years away from being commonplace) offer a safety advantage over our current vehicles. Human error accounts for the majority of vehicle incidents. Taking the randomness out of highway transport will aid in achieving a predictable, sustainable transportation system. Of course, the randomness won't subside until autonomous vehicles are commonplace, resulting in connected vehicles delivering laminar flow through cities.

All of these projects are currently happening, so why don't we see nationwide improvement? We have the technology; we know the best engineering solutions, so what is left standing in the way? It seems we lack collaboration, and this missing link is significant because it will take a web of different entities to be able to deploy a new, sustainable network properly.

8 Non-Technical Factors For Sustainable Transportation

Deciding which actants should contribute to this proposed web leads to a critical question: Is sustainable transportation a technical problem that solely lies on technical solutions? Or does society play an important role, making this a sociotechnical problem? Three significant nontechnical factors to explore are individualism, independent policy/regulation, and party politics.

8.1 Individualism

The western world is often described as a "me" culture, as opposed to “we” eastern cultures. Western cultures tend to focus on individualism, independence, and one’s own needs. In contrast, eastern cultures focus on interdependence, how one fits within a group, and doing one’s part to contribute to society at large. There are significant differences in perception as well. In ‘Culture and systems of thought: Holistic versus analytic cognition’ the authors find that eastern cultures are holistic, meaning they take in the whole picture of a problem; the context. The authors described western cultures as analytic, using rules and formal logic to focus on a specific issue without factoring in outside noise, or background [15].

These findings suggest that in western societies, especially the US, where the personal vehicle is the preferred mode of transportation, people may not care about the overall benefit expanded public transit brings.

8.2 Independent Policy/Regulation

A broader example of the “me” culture can be put into context by the United States’ emphasis on states’ rights. Emerging technologies are not cohesive nationwide. Technologies face different standards, legislation, definitions, and licensing regulations throughout localities. For example, in 2015, when Chris Urmson, CEO of Aurora Innovation, testified before the Senate Committee on Commerce, Science Technology, he explained 23 states had introduced 53 pieces of legislation that affect self-driving cars [19]. Regulatory standards are essential for any technology. A set of guidelines that share the same terminologies and implementation practices allow for intelligent transportation systems to grow beyond localities and states.

8.3 Party Politics

Partisanship has dominated American politics for the past ten years, and the divide is growing. United States citizens value the concept of respecting other political opinions, but what about when those opinions can be proven wrong? Do anti-science views that affect the public deserve mainstream attention? The spread of fake news has significantly affected discourse in the US. The goal of a nationwide sustainable transportation system will need bipartisan support to be successful, democrats and republicans have to work together. The current state of affairs suggests bipartisanship could be a difficult hurdle to jump. Even if two opposing interstate administrations begin working together, the rotations of electoral politics could bring in new administrations that throw out any past dealings.

The secretary of transportation is a cabinet position appointed by the president, and while transportation is a bipartisan issue, many of the matters described have been partisan. For example, the cordon pricing strategy under implementation in New York took ten years to pass. The legislation, first drafted when Michael Bloomberg was mayor, was continually voted down by republicans. The turning point was not until 2018 when democrats took control of the New York state senate.

9 Conclusion

Congestion is a multi-variate, complex issue that deserves data-driven solutions to create sustainable transportation infrastructure throughout the nation. Interstates are nearing capacity and are unable to support the projected VMT rates over the next decade. To be prepared for the future, sustainable transportation initiatives are needed now.

These initiatives include a federal high-speed rail expansion on the major coastal corridors, data science projects done within cities to determine the optimal form of public transportation improvement, pricing strategies that fund public well-being projects and force roadway consumers to financially consider their carbon footprint, hardware optimization that increases the efficiency of our roadways, and social collaboration between a network of actors.

A starting point will be studies that determine the efficiency, and value of public health, that similar strategies have produced in Europe. If simulation results show that areas of the US will have alike benefits, then transportation and academia personnel need to ensure their legislative bodies see the results and act on them. Creating a network of traffic engineers, legislators, urban planners, and academics all working together to reduce congestion will set the US up for future success and sustainable infrastructure.

There have been some lofty ideas proposed within this paper, but going from the current network to the improved system would be the most challenging. Given the current state of affairs, it can be challenging to imagine bipartisan legislation passing on a federal level. Thankfully this is less of an issue on the state level. Achieving sustainable transportation on the national level requires persuasion. Fiscally minded legislators will need education on the fact that sustainable transport is not only good for the environment but good for the economy as well.

References

[1] Express lanes community grant programss.

[2] Moovit unveils its 2019 global public transport report.

[3] Ridership reports | grtc.

[4] Service line plans base (fy 2019) + five year strategic plan (fy 2020-2024).

[5] Transportation statistics annual report 2018 | bureau of transportation statistics, 2018.

[6] What is congestion pricing? - congestion pricing: A primer - fhwa office of operations, 2019.

[7] Nicole Daniels. Should public transit be free? *The New York Times*, 01 2020.

[8] Gilles Duranton and Matthew A Turner. The fundamental law of road congestion: Evidence from us cities. *American Economic Review*, 101:2616–2652, 10 2011.

[9] Erin Durkin and Lauren Aratani. New york becomes first city in us to approve congestion pricing, 04 2019.

[10] History.com Editors. The interstate highway system, 08 2018.

[11] Jeremy Hobson. A year ago, richmond debuted a new bus system. transit ridership is up 17

[12] Kevin Kruse. How segregation caused your traffic jam. *The New York Times*, 08 2019.

[13] Ruimin Li, Francisco C. Pereira, and Moshe E. Ben-Akiva. Overview of traffic incident duration analysis and prediction. *European Transport Research Review*, 10, 2018.

[14] Johnny Miller. Roads to nowhere: how infrastructure built on american inequality, 02 2018.

[15] Richard E. Nisbett, Kaiping Peng, Incheol Choi, and Ara Norenzayan. Culture and systems of thought: Holistic versus analytic cognition. *Psychological Review*, 108:291–310, 2001.

[16] David Schrank, Bill Eisele, and Tim Lomax. 2019 urban mobility report, 08 2019.

[17] Rapid Flow Technologies. Surtrac: Intelligent traffic signal control system, 2018.

[18] Timothy Tyree. An econometric analysis of the northern virginia regional express lanes on i-495, 04 2019.

[19] Chris Urmson. Testimony before the senate committee on commerce, science technology, 03 2016.