# TOYOTA
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# MIT Sloan School of Management

15.913 Strategies for Sustainable Business (S-Lab)

# **Opportunities and Challenges of Adopting Alternative Fuel Vehicles in Shared Mobility**

## FINAL REPORT


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# Abstract

The purpose of this report is to identify opportunities and challenges of adopting Alternative Fuel Vehicles (AFV) in shared mobility services. The reports, further, identifies conditions under which shared mobility with AFVs, which includes battery electric vehicles, plug-in hybrids, and fuel cell vehicles, can be a sustainable business concept. In addition, this report analyzes how shared mobility addresses the needs of select customer segments with underserved mobility options and how this may change if AFVs were introduced into shared mobility.

In a first step, conventional shared mobility is established as a baseline. Shared mobility like ride hailing or car sharing, which are commonly based on Internal Combustion Engine (ICE) or Hybrid Vehicles (HEVs), has transformed urban mobility in recent years. In more and more urban areas, customer needs for on-demand, fast, and affordable mobility creates increasing demand for shared mobility, for example as substitute for car ownership or as last-mile solution in combination with public transportation. Besides high- and mid-income communities some people with underserved mobility options have benefited from shared mobility as well, such as senior citizens, while others have not, such as many low-income communities. Different shared mobility services like car sharing or ride hailing are able to build profitable business models and compete with other shared mobility providers, OEMs, and start-ups. This report illustrates how through sufficient customer demand and viable business models shared mobility can scale to a new mode of transportation system that improves urban inter-modal mobility, increase vehicle utilization through ride sharing, reduce car ownership, encourage more efficient mobility behavior through price control, accelerate the vehicle purchase cycle, increase the demand for and use of fuel efficient vehicles, and, thus, contribute to reducing carbon emissions. Therefore, conventional shared mobility is an innovative and sustainable business model today.

In a second step, the effects of introducing AFVs in shared mobility are contrasted with conventional shared mobility to identify opportunities and challenges in the adoption of AFVs. For customers, the service level would hardly change unless premium charges increase the cost for AFV-based shared mobility services and poor charging or fueling infrastructure constrains the service range. On the business side, AFVs yield no significant benefits compared to cost efficient ICE/HEVs. In fact, a comparison of ownership costs reveals that, today, costs for AFVs are typically about equal to or higher than those of fuel efficient ICE/HEVs, even if tax credits are applied and regional energy price differences

are considered. Given today's limited ranges of electric vehicles, they may require daytime DC fast-charging at public charging infrastructure in addition to overnight charging which adds infrastructure fees and opportunity costs to ride hailing drivers or car sharing fleet providers. The resulting higher ownership costs of AFVs in comparison with fuel efficient ICE/HEVs make services less profitable and, thus, suppress the adoption of AFVs in shared mobility. Further, poor charging infrastructure limits range and scalability of AFV-based shared mobility and, therefore, prohibits adoption of AFV on a large scale even more. Broad environmental benefits through AFV-based shared mobility cannot be realized under current conditions. Policy levers like purchase, infrastructure, and investments incentives, emission free zones, or carbon tax in combination with significant battery or cell technology improvements and close coordination among public and private partners are required to bring AFV adoption in shared mobility beyond a tipping point to sustainable success. Otherwise, shared mobility is unlikely a sustainable path to increase adoption of AFVs in the U.S..

In conclusion, this report highlights opportunities for the Toyota Mobility Foundation going forward as well as associated challenges and risks. The findings of this report suggest to drive the expansion of HEV-based shared mobility, pursue and scale electric two-seater car sharing, pilot an AFV-based shared mobility concept partnering with a city and mobility providers that can help create the necessary conditions, drive the development of autonomous AFVs, and conduct a focused study on Fuel Cell Vehicles (FCV) based shared mobility.

# 1. Background

Toyota is one of the largest global automotive Original Equipment Manufacturer (OEM) with 2.5M car sales in the U.S. and 10.2M car sales worldwide[1]. Challenging its own business in order to "establish a future society in harmony with nature," Toyota has set up a 2050 Environment Master Plan to reduce vehicle $CO_2$ emissions by 90% from 2010 levels and achieve 0 $CO_2$ emissions for new car sales by 2050[2]. Introducing alternative fuel vehicles (AFV) in replacement for, in particular, conventional Internal Combustion Engine (ICE) but also Hybrid Electric Vehicle (HEV) is crucial in addressing this agenda. Within the AFV segment, we distinguish the following:

- BEV: Battery Electric Vehicle
- REX: BEV with Range Extender (combustion engine)
- PHV: Plug-in Hybrid Electric Vehicles
- FCV: Fuel-Cell Vehicle

In parallel, Toyota Mobility Foundation, a Japanese Foundation established by Toyota, is working to advance mobility around the globe. The Foundation actively explores ways to address the mobility needs of underserved communities, including low-income populations. In order to improve the environmental impact and equitable accessibility of future mobility, Toyota Mobility Foundation is considering shared mobility services in combination with other transportation systems, AFVs, and the prospect of autonomous driving as key stepping stone to achieve this mission.

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[1] FY2016, Toyota US Newsroom, 5/2017, http://corporatenews.pressroom.toyota.com/releases/toyota-lexus-december-2016-sales.htm

[2] Toyota Global, "Challenge of Establishing a Future Society in Harmony with Nature, 5/2017 http://www.toyota-global.com/sustainability/report/er/pdf/er15_01_en.pdf

# 2. Objective, approach, and scope

### Objective

The Toyota Mobility Foundation is exploring the potential for shared mobility to accelerate the adoption of alternative fuel vehicles as a path to improve mobility access and environmental justice in underserved communities (social impact). We note that this simultaneously helps achieve Toyota's goals. The objective of this report is primarily to identify opportunities and challenges of introducing AFVs in shared mobility services in lower income communities. This report further evaluates under what conditions AFV-based shared mobility can be a sustainable business opportunity and accelerate AFV adoption.

Given Toyota Mobility Foundation's interested in improving the mobility for underserved populations, this project analyzes how shared mobility addresses the needs of select customer segments with underserved mobility options and how this may change if AFVs were introduced into shared mobility.

### Approach and Scope

To achieve our objectives, we employ the Sustainability Oriented Innovation (SOI) framework developed at MIT Sloan School of Management[3]. The SOI framework defines that in order to be sustainable, a new business opportunity has to be good for customers, the business, and the system, (see Figure 2.1).

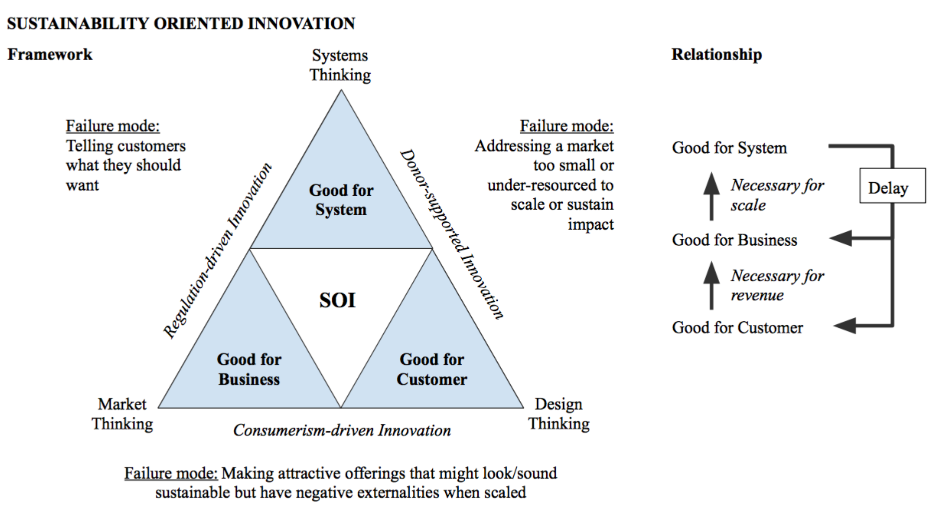


*Figure 2.1: Sustainability-Oriented Innovation framework[3]*

[3] Sustainability Initiative, J. Jay, J. Sterman, MIT Sloan School of Management, 2017

This report applies design, market, and systems thinking to analyze two different scenarios. First, we consider conventional shared mobility services without AFVs and analyze the implications for different customer segments and business services as well as the environmental and social aspects of the system. Second, we evaluate how each of the three areas are affected by introducing AFVs into shared mobility and contrast the benefits or downsides for customers, businesses, and the system against conventional shared mobility. This comparison will allow us to derive opportunities, challenges, and conditions to achieve sustainable pathways for AFVs in shared mobility in the future.

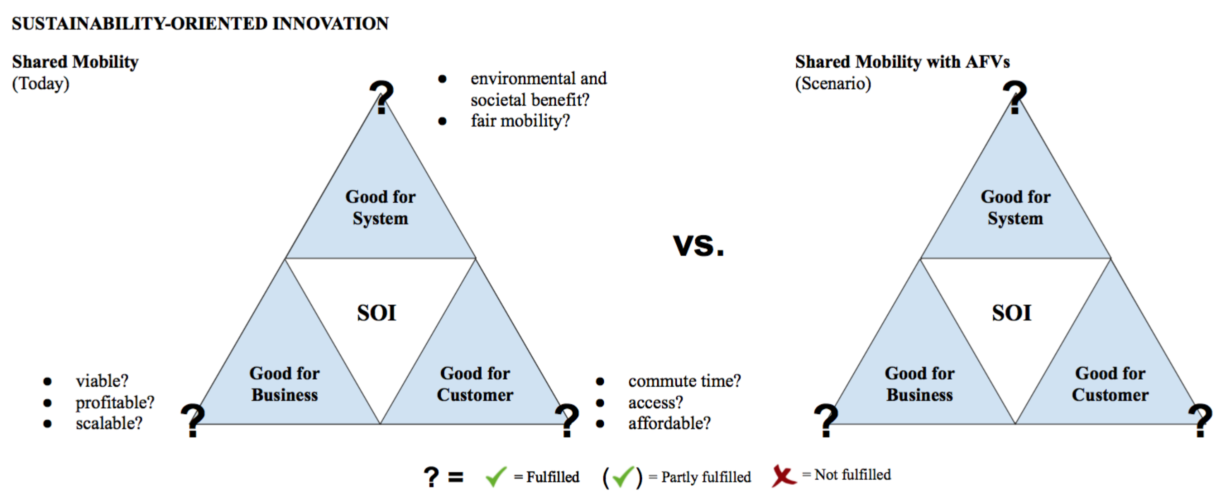


*Figure 2.2: Two scenarios to evaluated along the SOI framework*

The SOI framework helps to identify where innovation and sustainability are weakest, where they can fail, and under what conditions AFV-based shared mobility can become sustainable.

Within each of the three lenses of the SOI framework, we employ different analysis methods: 1) Customer lens: Customer needs analysis for low-income and other underserved customer segments based on secondary research; 3) Business lens: Ownership cost analysis for a HEV and AFVs. As cost is paramount to many business decisions, this cost analysis helps us identify key cost drivers and efforts are needed to address cost challenges; 3) Systems lens: Causal Loop Diagrams (CLDs), taken from System Dynamics frameworks. These allow us to better understand the full effects of shared mobility on the broader mobility system. Major concerns around the emergence of shared mobility are related to car sales implications for OEMs, effects on other modes of transportation and the environment, and the mobility needs of, in particular, underserved communities. This paper does not include systems dynamics modelling but provides qualitative assessments of feedback loops and leverage points.

# 3. Analysis of shared mobility today

This chapter analyzes ICE- and HEV-based shared mobility as it exists today along the three lenses of the Sustainability Oriented Innovation framework, the customer, business, and systems lens. Taking the outcome of this analysis as a baseline will allow us to contrast the scenario of introducing AFVs to shared mobility.

## 3.1. Customer lens: Customer segments and needs

The first step in our SOI analysis examines the mobility needs of the customers, and how well shared mobility can meet their needs. The innovation of shared mobility can impact large segments of the population in the U.S., from individuals to businesses, government to community organizations. Shared mobility is a small fraction of total mobility but a sizable and further growing market, with various private business models thriving and new models springing up yearly. Some of these models have been very successful - i.e. Zipcar, Uber, and Lyft, which count billions of dollars in revenues yearly - but only serve select portions of the total potential customer base. It is important to note that shared mobility models tend to follow a typical technological innovation adoption curve, targeting affluent, urban customers first, and 'trickling down' service and products to mass markets over time.

Transportation systems are a basic building block of modern society. Though transportation options and systems exist everywhere, they are not equitable. In the U.S., in urban and rural areas alike, public transportation remains a vital factor in households' ability to access quality jobs, schools and commodities. This is especially true for those who are underserved. The aim of our analysis is to investigate if shared mobility can provide new or expanded access to quality transportation options, particularly for underserved customer segments, and what role the Toyota Mobility Foundation can possibly serve in this market. Having started with a 'wide-lens' approach we narrow down our evaluation to select customer segments.

### Selecting customer segments

To select an appropriate focus customer segment, we first analyzed the broader shared mobility market to understand relevant customer breakdown (see Figure 3.1).

| Customer segment | | Mobility Needs | Mobility Hassles | Example Services | |
|---|---|---|---|---|---|
| **"White collar" / Mid/high income** | urban/ suburban | on-demand, fast, end-to-end transport, convenience | Traffic congestions, public transport cumbersome and time-consuming, inter-modal inefficiencies | Uber, Lyft, Car2Go | Main user today (out of scope) |
| **Low income** | urban/ suburban | job-accessible, affordable, predictable | Own inefficient cars, rely on public and multi modal systems, long-distances | King Cty. Vanpool, City CarShare (SF) | **Focus**: Customers with limited mobility options |
| **Children/ Families** | urban/ suburban | school shuttling, reservable, safety, ride tracking, (driver preference) | Parents with limited time to drive children to school/activities, limited pre-bookable and safe mobility options, children with additional needs (car seat) | GoKid, Pogo Rides, HopSkipDrive, Zum, ZemCar, Kango, etc. | |
| **Senior** | urban/ suburban | end-to-end transport, safety, convenience | Don't own a car or prefer not to drive due to safety concerns, last-mile issue to/from public transport, less tech affine | GoGoGrandparent | |
| **Disabled** | urban/ suburban | assistance, safety, end-to-end transport, convenience | Can't drive, requires assistance, mobility often very constrained | ParaTransit providers | Special service (out of scope) |

*Figure 3.1: High-level customer segment analysis of shared mobility services*

The chart above identifies the main customer segment that is served by shared mobility today - "white collar" and mid-high income segments. This customer segment includes several sub-segments, but for Toyota Mobility Foundation's purposes these can be lumped together as the customer group that shared mobility services mainly targets today.

In this paper, we analyze three of the remaining underserved segments in more detail: low-income households, parents with children under the age of 16, and seniors. We deemed the disabled customer segment to be out of our scope given the special service and vehicles required to adequately serve these customers. The three segments in our study are currently under- or un-served by shared mobility business models, but represent a significant share of the potential market for any innovation by the Toyota Mobility Foundation.

Toyota Mobility Foundation's stated goal is "to create a truly mobile society that will help people live better lives no matter where they are."[4] In thinking about our client's needs, we balance the company's social mission with Toyota's more widespread mission to remain a leading OEM in the vehicle industry in the long-term. Our analysis identifies the tensions between the need to improve mobility access, while creating a sustainable business model within the AFV and shared mobility sectors. We first analyze the segments' needs, and then match existing business models to these needs.

## Customer segment: Low-income Communities

The customer segment needs of low-income communities are broad, diverse, and location-specific. For this project, we focus on the customer needs that are most relevant to shared mobility, and that current

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[4] Toyota Mobility Foundation, "About Us", 5/2017, http://toyotamobilityfoundation.org/en/about.html

shared mobility businesses attempt to address. In addition, we restricted our analysis to low-income communities in urban, suburban and semi-urban areas. This decision is largely driven by the focus of most existing shared mobility business models, the benefits of population density for networked innovations, and availability of research and data.

Decades of research has shown the clear need for improved transportation options for low-income communities.[5] These neighborhoods are often isolated, far from economic centers, and suffer from poor infrastructure and maintenance. While public transit systems in the US are inadequate in many places, low-income communities are not able to access alternative methods of transportation, such as personal vehicles, corporate shuttles, or carpools, as easily as wealthier citizens. Estimates find that the cost of owning a personal vehicle can range from $2,000 - $10,000 per year, depending on location, commute distance, and other demographic factors.[6] These basic facts make any innovation targeted for low-income customer's needs focus on spending levels and unit economics. Often the solution is, "make it cheaper." However, the customer needs for this segment are more nuanced, with three main factors:

1) commute time
2) improved access to quality jobs
3) affordability

Commute time and overall time spent in transportation is one of the most important needs for low-income customers. Recent research has focused on the ability of improved transportation to transform low-income families' quality of life, helping them move up the income ladder and improve social mobility. In a multiyear longitudinal study examining the variables associated with upward social mobility capacity of low-income households across the US, Chetty and Hendren find that transportation has the greatest impact on upward social mobility, allowing low-income households to access areas with increased economic activity.[7] Their research compares households in various regions of the U.S. as some move to new areas, against those that stay put. This allows the researchers to examine (by holding other variables constant) what variables affect intergenerational wealth creation and incomes.

A significant variable in their study is *commute time*, showing that low-income families in areas with longer commute times have a lower probability of escaping poverty.[8] This data and analysis suggests that improved transportation options, which lower commute time at reasonable cost, can be a driving need

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[5] T. Sanchez, "Poverty, policy, and public transportation", Transportation Research Part A: Policy & Practice Vol 42, Issue 5, 6/2008, Pg 833–84

[6] Kevin DeGood and Andrew Schwartz, "Can New Transportation Technologies Improve Equity and Access to Opportunity?" Center for American Progress, 4/26/2016, www.americanprogress.org/issues/economy/reports/2016/04/27/135425/can-new-transportation-technologies-improve-equity-and-access-to-opportunity/

[7] Chetty & Hendren, "The Impacts of Neighborhoods on Intergenerational Mobility," *National Bureau of Economic Research* Working Paper No. 23001, Revised Version, May 2017, pg. 1

[8] Mikayla Bouchard, "Transportation Emerges as Crucial to Escaping Poverty," The New York Times, May 7, 2015.

for many low-income households with under-served mobility.

Access to quality jobs - related to commuting time - can significantly improve quality of life for low-income households. A New York University Rudin Center for Transportation study, examining the potential benefits of a shared mobility innovation in New York City, estimate how many more jobs became available within a certain commute time window. They find that, "In Red Hook, Brooklyn, for example, a smart shuttle bringing residents to Downtown Brooklyn would reduce travel times to Midtown Manhattan from 50 to 28 minutes, making 89,498 more jobs accessible within one hour on transit."[9] This is a prescient example as it illustrates two key findings of our research: 1) access to economic opportunity and jobs is a primary need for low-income customers, more so than 'affordability;' and 2) shared mobility innovations work well in conjunction with public transit, not as a substitute.

Affordability is another significant customer need for low-income households. Low-income households currently spend a significant portion of their household budgets on transportation already, mixing in a variety of methods. In addition, like all rational consumers, they make choices based on a combination of cost, convenience and function to assess various options. In many cities in the US, owning a car is still a cheaper option than public transportation when factoring in opportunity cost of commute time and limited accessibility.

The Figure 3.2 (from an analysis of Uber's affordability in major cities[10]) illustrates some of the cost comparisons that consumers make when assessing transport options. The analysis shows that the economic rationale for using a shared mobility service heavily depends on the availability of public transit options. In areas where there is no or poor public transit access, low-income customers will likely never adopt shared mobility. This is because the cost of owning a car is still lower than using shared mobility for everyday use. However, when quality public transit is introduced, the downward sloping line from the second chart becomes the dominant choice. Mixing shared mobility with public transit can create the conditions necessary to serve the needs of low-income customers.

[9] Kauffman et. al., "Mobility, Economic Opportunity and New York City Neighborhoods," NYU Wagner Rudin Center, pg. 8.

[10] Silver and Fischer-Baum, "Public Transit Should be Uber's New Best Friend", FiveThirtyEight.com, 8/28/2015, https://fivethirtyeight.com/features/public-transit-should-be-ubers-new-best-friend/

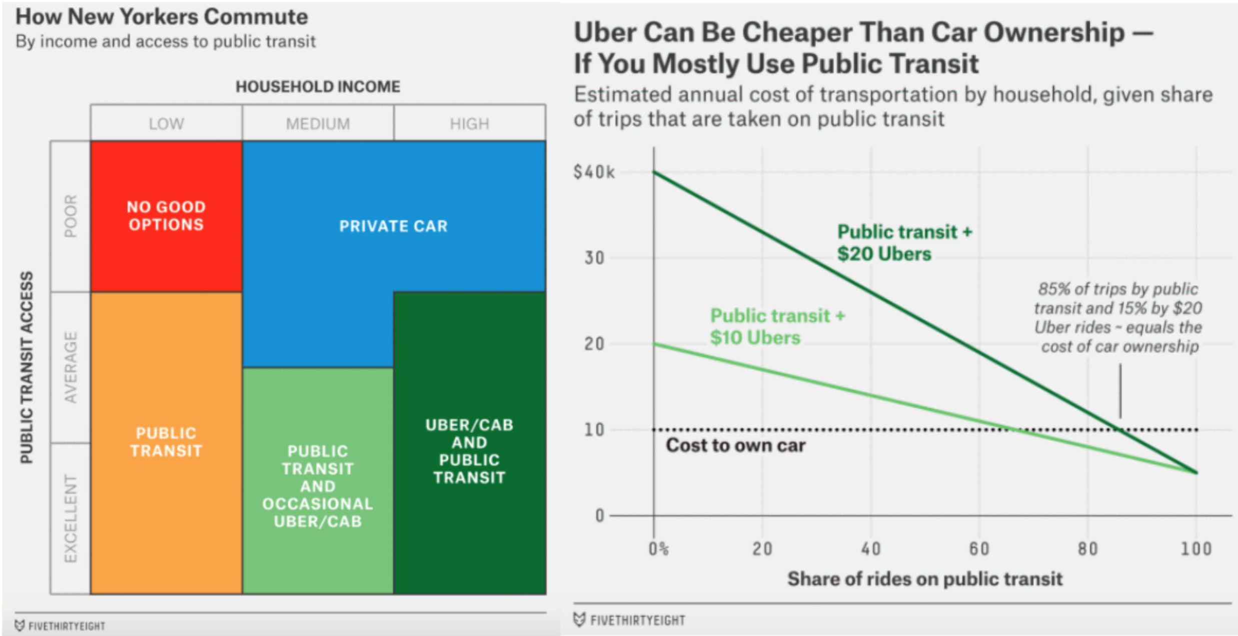


*Figure 3.2: Transport option comparison by access, income level, and cost*[11]

Some barriers currently obstruct shared mobility, specifically ride-hailing, services from meeting the needs of some low-income communities. According to Pew Research Center, 26% of Americans with an annual household income of at least $75,000 have used ride-hailing services, while only 10% of people living in households with an annual income of less than $30,000 have used these services; 49% of this lower-income population are not familiar with ride-hailing apps.[12] The dependence of ride-hailing services on smartphones means that the digital divide can limit access of these shared mobility services to low-income populations.[13] These services' reliance on credit cards also presents an obstacle to unbanked users.[14]

## Customer segment: Seniors

Seniors can face limited mobility options. Many seniors without disabilities do not drive (at all or at night), and find public transportation inaccessible or inadequate.[15] While ADA paratransit services for disabled people with unmet mobility needs serve senior people who require assistance, many seniors with

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[11] N. Silver, R. Fischer-Baum, Public Transit Should Be Uber's New Best Friend, FiveThirtyEight, August 2015, https://fivethirtyeight.com/features/public-transit-should-be-ubers-new-best-friend/

[12] Smith, A. On-demand: Ride Hailing Apps.Shared, Collaboratve and On-Demand: The New Digital Economy. Pew Research Center. http://www.pewinternet.org/2016/05/19/on-demand-ride-hailing-apps/

[13] Zikhur, K. and Smith, A. Digital Differences. Pew Reserach Center, April 13, 2012. http://www.pewinternet.org/2012/04/13/digital-differences/.

[14] FDIC, 2015 FDIC National Survey of Banked and Underbanked Households. October 20, 2016. https://www.fdic.gov/householdsurvey/2015/2015execsumm.pdf

[15] Ride-sharing: Bridging the Digital Divide to Improve Mobility for Seniors and Persons with Disabilities. Clackamas County Social Services. Project Proposal, http://www.clackamas.us/socialservices/documents/ridesharingproject.pdf

unmet mobility needs are not eligible to use these services.

Shared mobility has the potential to help address this customer segment's mobility needs, but barriers do exist. Like some people in the low-income segment, the digital divide, both in terms of access to and comfort with smartphone technology (i.e. need for training), can inhibit the accessibility of ride-hailing services to seniors. In addition, safety concerns present another obstacle to seniors' adoption of many shared mobility services.[16]

Several companies are working to address this specific set of customer needs for seniors. A startup called GogoGrandparent, for example, founded with the mission of making the ride-hailing service user-friendly for seniors, provides on-demand car service that can be booked by phone and include automatic tracking for family members. Ride-hailing services offered by Uber and Lyft have also gained traction among senior communities. Uber is working with municipalities, like the City of Gainesville and Town of Miami Lakes, and public transportation authorities to offer city-subsidized on-demand point-to-point transportation for senior residents[17,18]. These programs include technology tutorials to help overcome digital hurdles.

### Customer segment: Parents & Children

Mobility needs of parents and children stem from children's inability to transport themselves. In dual-income or single-parent families, transportation of children for academic or extra-curricular activities can be challenging. In many cases, the need for children's transportation is combined with the need for childcare. Several local and regional companies have begun to address this issue through shared mobility. Companies like HopSkipRide and RideGuru are providing carpooling and ride-hailing services specifically for children that address specific needs for this customer segment: car seats for different aged children, tracking of vehicle and child during the trip, pre-booking and requests for repeated service providers, specially qualified drivers and caregivers (often nurses and teachers) with specified credentials for childcare, options to combine driver services with additional babysitting/supervision services.

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16 Ride-sharing: Bridging the Digital Divide to Improve Mobility for Seniors and Persons with Disabilities. Clackamas County Social Services. Project Proposal, http://www.clackamas.us/socialservices/documents/ridesharingproject.pdf

17 M. Watkins, The Gainesville Sun, "City hopes to use Uber to give rides to seniors", 6/4/2015

18 Uber Newsroom, Kate, "More Options for Senior Mobility", 7/13/2015 https://newsroom.uber.com/creating-more-options-for-senior-mobility/

# 3.2. Business lens: Shared mobility market and business models

## Shared Mobility Business Models

Shared mobility is the shared use of various transportation, including shuttles, vehicles, bicycles or other travel modes.[19] Especially, the rapid development of mobile phones and data analytics enabled the aggregation of various transportation providers and the optimization of dispatching and route planning. As a result, more and more people are relying on shared mobility for their daily transportation needs. According to Forbes, Uber now has 40 Million monthly active users worldwide.[20]

To examine available shared mobility business models, Frost & Sullivan[21] distinguishes between two broad categories: Drive yourself, and Be driven (Figure 3.3). Each category had different variations, depending on type of mobility (cars, shuttles, etc.), terms/restrictions on the vehicle use (one way or two way) as well as the target customer segments (personal or corporate). Figure 3.3 provides an overview of common business model categories. However, it is to be noted that differences in business models fade or change. In particular, with the emergence of autonomous driving and autonomous shared mobility, the line between drive yourself and be driven business models will blur as the two business models of ride hailing and car sharing will eventually converge once cars become autonomous.

| | DRIVE YOURSELF Business Models | | Examples |
|---|---|---|---|
| 1 | **One-Way Car Sharing** | 1-way free floating fleet or fixed point-to-point trips in a defined zone | Car2Go, DriveNow |
| 2 | **Two-Way Car Sharing** | 2-way/round-trip/station based service, return to same location | ZipCar, Rentals |
| 3 | **Peer-To-Peer Car Sharing** | Vehicle rental from private car owners when the car is unused, e.g., during the weekend | Getaround, Koolicar |
| 4 | **Corporate Car Sharing** | Dedicated vehicle fleet shared by a employees of a company | AlphaCity |
| | **BE DRIVEN Business Models** | | |
| 5 | **Ride Sharing** | Dynamic or fixed route ride matching between driver and passenger traveling from/to the same area (incl. fixed, dynamic, corporate ride sharing) | Scoop |
| 6 | **Ride/Taxi Hailing** | Private or taxis drivers can be booked, tracked, and rated through a smartphone app | Uber, Lyft, MyTaxi (Waymo) |
| 7 | **Shuttle/Bus Transit** | Shuttle buses, e.g., to the airport, can be booked and tracked online | Bridj (closed in 4/2017) |

*Figure 3.3: Shared mobility business model categories[21] and examples*

19 S. Shaheen, UC Berkeley, Shared Mobility, "Definition, Industry Developments, and Early Understanding", 11/2015, http://innovativemobility.org/wp-content/uploads/2015/11/SharedMobility_WhitePaper_FINAL.pdf

20 K. Kokalitcheva, Fortune Tech, "Uber Now Has 40 M Monthly Riders Worldwide", 10/19/2016, fortune.com/2016/10/20/uber-app-riders/

21 Frost & Sullivan, Competitive Benchmarking of OEM Mobility Strategies, 10/2/2017

To look at the business model from a modular perspective, we further decompose each model into a set of configurations. Each column represents one dimension of the business model and each dimension can cover one or more configurations. One example of a common configuration, ride hailing, is shown below.

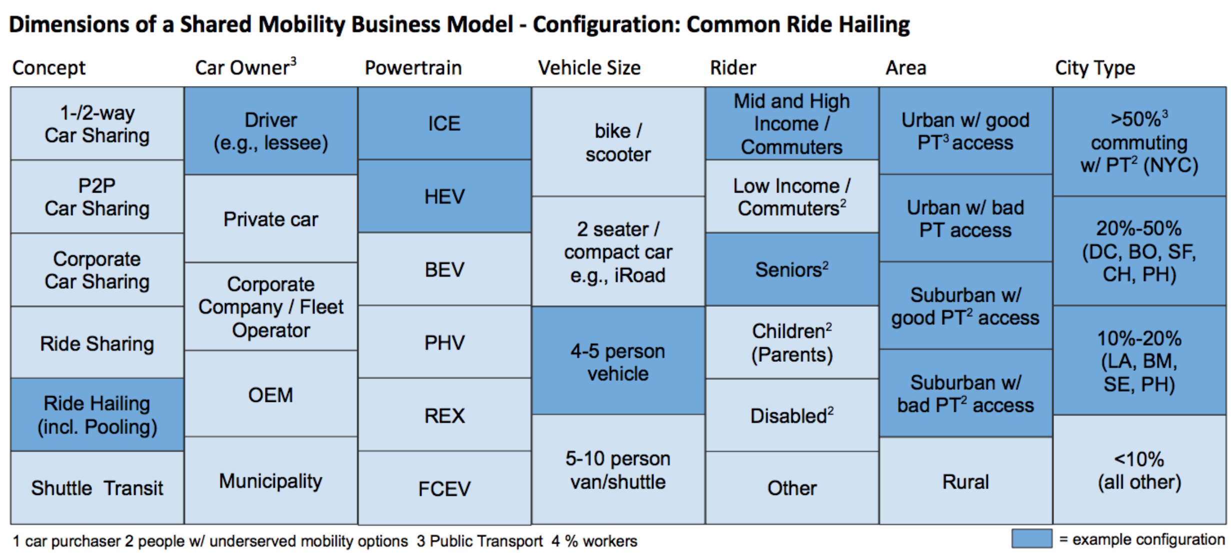


*Figure 3.4: Shared Mobility Business Model - Example: Common Ride Hailing*

As illustrated in Figure 3.4, there is no one-size-fit-all business model - customer needs and characteristics (demographics, economic situation, individual preference, etc.) and other factors need to be taken into consideration to determine the best model that creates and captures most value for a certain customer segment.

**OEM Mobility Initiatives**

The automotive and transportation sector is undergoing a transformation. Value creation is gradually shifting from individual consumption to collaborative consumption. And more people move away from owning a car towards accessing a car on demand.

To join the trend, OEMs start to actively participate in this new paradigm shift in order to maintain or grow revenue. OEMs have formed new partnerships with existing mobility startups or create own shared mobility subsidies/brands. Above is an overview of most active OEMs in the shared mobility space and their current mobility initiatives and partnerships across different business models. From the table, we see that car sharing is currently a main focus of investments and partnerships for most OEMs. Few shared mobility businesses that are purely based on AFVs are known, such as BlueSolution, Autolib, and BlueIndy, DriveNow, Toyota's Cité Lib, and Carma[22,23,24]. But it is unknown whether these businesses are profitable and sustainable. Barriers for wide adoption AFVs in shared mobility include lack of infrastructure, upfront costs, range anxiety and others which are all analyzed in more depth in Chapter 4.

| | DRIVE | | | | BE DRIVEN | | |
|---|---|---|---|---|---|---|---|
| | 1-way Car Sharing | 2-way Car Sharing | P2P Car Sharing | Corporate Car Sh. | Ride Sharing | Ride Hailing | Shuttle transit |
| Daimler | Car2Go | | Getaround, Flightcar, Croove | Daimler Corp Carsharing, Athlon Car Lease | Via | MyTaxi, Hailo, Blacklane (auton.) | Flixbus |
| BMW | DriveNow, ReachNow | | ReachNow Share | Alphabet | Scoop, Flinc | Ride Cell/Summon | |
| Audi, VW | | Audi at Home, Select VW: Greenwheels, GoFun | | Audi Unite, on Demand, Silvercar; VW: VRent | | Gett | |
| Hyundai | BeeZero | WaiveCar | | | | | |
| Ford | GoDrive (closed) | Ford CS, Zoomcar | Getaround, Carswap | Ford Credit Link | Chariot | w/ Uber, Lyft | Bridj |
| PSA | Multicity, Bollore, emov | | Koolicar | ShareUrFleet, TravelerCar | | | |
| Ren-Nis | | R.Mobility, Scoot, Get n Go | | Nissan Corp CS | | | |
| Toyota | Ha:Mo | Yuko | Getaround | Toyota Rent a Car | | Partnership w/ Uber | |
| Honda | Zipcar partnership | Zipcar partnership | | | | | |
| GM | Maven | Maven, CS Shanghai, NYC | CarUnity, Flinc | Yi Wei Xing | | w/ Lyft, Uber, Sidecar | |
| FCA | Enjoy Fiat | | | Fiat 500e Pass | | | |
| Volvo | | Sunfleet | | Volvo Rent | | | |

*Figure 3.5: Shared mobility initiatives by major OEM. BMW and Daimler are strongest players in car sharing*[25]

In summary, shared mobility is commonly seen as a disruptive force for the traditional automobile and transportation industry as it creates a new and expanding market. Leveraging mobile technology and available big data, it is possible to serve a wide range of people and achieve strong systems efficiencies. However, while technology is the backbone and catalyst for the transformation, the collaboration between public and private sectors are important enablers. Government incentives and policies are necessary to promote shared mobility, automakers supply the vehicle fleet and provide additional service, and shared mobility startups commonly face and service the end customer. Local city and transportation authorities will see a change in urban landscapes as shared mobility increases and car ownership and public transportation ridership changes. The dynamics in this mobility sector are analyzed in more detail in the following chapter.

**Shared mobility services meeting the needs of different customer segments**

The different business models of shared mobility meet different needs of the customer segments

22 BlueSolution, http://faculty.washington.edu/dwhm/2017/04/03/bluesolution-to-california/

23 B. Lufkin, 6 Electric Car Sharing Programs, Gizmodo, March 31, 2016, http://gizmodo.com/6-electric-car-sharing-programs-better-than-a-billion-t-1766904615

24 car3go announces first all-electric car sharing fleet in Norther America, Daimler, July 11 2011, http://media.daimler.com/marsMediaSite/en/instance/ko/car2go-Announces-First-All-Electric-Carsharing-Fleet-in-North-America.xhtml?oid=9919298

25 Frost & Sullivan, Competitive Benchmarking of OEM Mobility Strategies, 10/2/2017

as defined in the previous chapter. Figure 3.6 provides a qualitative and indicative mapping how well each business model meets the needs of each customer segment.

**Business models meeting customer needs**

| Urban/suburban Customer segments | Drive: 1-/2-way Car Sharing | Drive: P2P Car Sharing | Drive: Corporate Car Sharing | Be Driven: Ride Sharing | Be Driven: Ride Hailing | Be Driven: Shuttle Transit |
|---|---|---|---|---|---|---|
| Mid/high income | + | + | + | + | + | + |
| Low income | (+) | (+) | | (+) | (+) | (+) |
| Children/Families | | | | (+) | (+) | (+) |
| Senior | + | | | + | + | + |
| Disabled | | | | | (+) | (+) |

\+ = customer needs are met well
(+) = customer needs can be met only under conditions, e.g., Public-Private Partnerships (subsidies), special service/product offering (assistance, child seat)

*Figure 3.6: Mapping of how well business models meet the needs of select customer segments*

Given that the Toyota Mobility Foundation is particularly interested in supporting low-income communities we will analyze today's gaps between the services that are provided and the needs of these communities in the following. In short, shared mobility services still have a long way to go to be able to provide affordable and accessible shared mobility. According to our analysis, shared mobility services as they exist today do not serve a high percentage of low-income markets. The main barriers these services face are affordability and reliability. Models like 1-or-2-way car sharing remain too expensive to be used reliably for commuting or regular use. Ride hailing still remains too expensive for many households to be used as a substitute for public transit or personal car ownership, as shown by various analyses of total cost.[26] Ride hailing apps have provided needed service to underserved urban areas, like the outer boroughs of New York City, where traditional taxis rarely go. However, these tend to be 'stop-gap' measures taken by riders occasionally, when public transit fails to meet their needs. New ride-sharing functions do go a long way in addressing cost, which is promising for the business model. However, when distance and time are factored in, we see that many low-income households still prefer public transit or car ownership (see Figure 3.2 "How New Yorkers Commute").

Shuttle services, or shared vans, have proven to be fairly successful models in some cities. Seattle's King County Van service, originally started as an ad hoc system, now provides affordable commuting options to outer suburbs. New York City's informal 'dollar vans' service is a similar concept, where individuals drive their own vans along established routes in the outer boroughs. According to the Rudin

[26] Silver and Fischer-Baum, "Public Transit Should be Uber's New Best Friend", FiveThirtyEight.com, August 28, 2015, https://fivethirtyeight.com/features/public-transit-should-be-ubers-new-best-friend

Center for Transportation, "dollar vans carry up to 120,000 passengers every day, fill in transit gaps throughout Brooklyn and Queens, often with 45-60 vans an hour running through corridors where buses only pass through four times an hour."[27] While these services remain profitable for the drivers, they are not equally accessible. New technologies have tried to bridge this gap, with companies like BRIDJ, based in Boston, MA, using a ride-hailing feature to route shared vans across suburbs of busy urban areas. However, BRIDJ recently shut down due to lack of Demand, indicating that the cost structure remains difficult to make work.[28]

From our analysis, we have seen that shared mobility services have not successfully served low-income communities, largely due to affordability issues. However, we believe that smart, targeted public policy can help bridge this gap, making shared mobility affordable for low-income households, while still creating a profitable business opportunity. An analysis of the MARTA system in Atlanta found that if an Uber-like service were subsidized by the city for 'last-mile connections' to their public transit network, it would cost the city $19 million per year in subsidies, if it were to serve individuals and families on public assistance who do not have access to a personal vehicle.[29] If this budget were to be substituted for the existing 'outer bus service', it could even be a cost-neutral project. However, an experiment like this would need to be tested in order to observe its true impacts. We believe that a sustainable innovation for publicly subsidized shared mobility can exist, and it should be explored further in partnership with local governments and shared mobility providers.

## 3.3. Systems lens: Shared mobility as part of urban mobility

Shared mobility has the potential to play a key role in enhancing urban mobility and its environmental impact. Reinforcing and balancing feedback loops indicate the systems dynamic of the urban transportation network that includes shared mobility (e.g., car sharing, ride hailing, ride sharing), public transportation, and car ownership.

**Growth of Shared Mobility**

Figure 3.7 shows the feedbacks contributing to the perpetuation and expansion of shared mobility. As more people adopt shared mobility (here: ride-hailing), the combination of greater demand and ride-

27 Kauffman et. al., "Mobility, Economic Opportunity and New York City Neighborhoods," NYU Wagner Rudin Center, pg. 10.

28 Bliss, Laura, "Bridj is Dead, but Microtransit Isn't", CityLab, May 3rd, 2017, https://www.citylab.com/transportation/2017/05/bridj-is-dead-but-microtransit-isnt/525156/

29 K.DeGood, A. Schwartz, "Can New Transportation Technologies Improve Equity and Access to Opportunity?" Center for American Progress, 4/26/2016, www.americanprogress.org/issues/economy/reports/2016/04/27/135425/can-new-transportation-technologies-improve-equity-and-access-to-opportunity/

hailing platforms' price controls - both in the form of surge pricing to address short-term demand increases[30] and general minimum base price increases once an SM network has been established in a city or region[31] - increase driver earnings and thus supply. This supply enhances the accessibility of ride-hailing service and, thus, its attractiveness and further adoption of shared mobility (R1 *Availability-Driven Demand* Loop). As supply increases to meet demand, price then again decreases (B1 *Affordability-Driven SM Demand* Loop), balancing this effect. Several other features of ride hailing models, including user ratings, word of mouth and network effects (excluded from the diagram below), further perpetuate reinforcing feedback loops that drive the growth of these platforms.

The balancing effect of price controls (B2 *Surge Pricing* Loop) on attractiveness of ride-hailing services tempers these positive feedbacks loops driving their growth. As prices increase, attractiveness of ride hailing decreases, resulting in a decline in shared mobility's potential enhancement of mobility access, in particular to price-sensitive low-income populations.

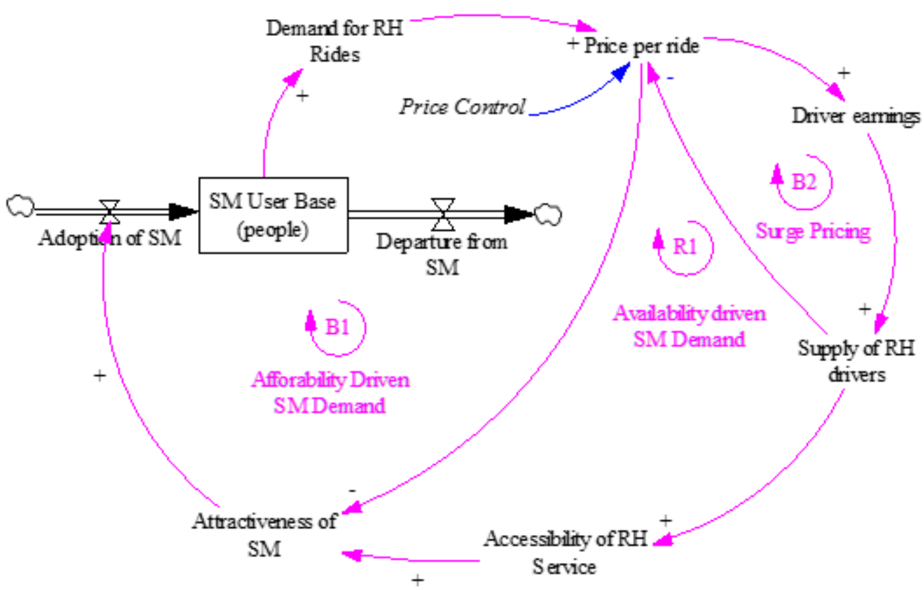


*Figure 3.7: Reinforcing and balancing feedback driving growth of shared mobility (ride-hailing)*

**Effect of Shared Mobility on Public Transportation**

Independently, a reinforcing feedback loop can accelerate the growth or demise of public transportation (Figure 3.7). As public transportation use increases, so does its revenue and network

30 How Surge Works. Uber website. https://www.uber.com/info/how-surge-works/. Accessed May 16, 2017.

31 Uber increases Minimum Fares in 20 Cities. Rideshare Dashboard. April 13, 2016. http://ridesharedashboard.com/2016/08/31/uber-increases-minimum-fares-20-cities/

investment (along with external funding), enhancing the adequacy and attractiveness of PT to more people, further driving adoption. Investment in public transportation networks can drive improvements and usership that reinforce revenues for additional enhancements and growth. The same reinforcing feedback (without investment) can diminish PT user base and drive demise of PT system (R2 *PT Growth/Demise* Loop)[32] .

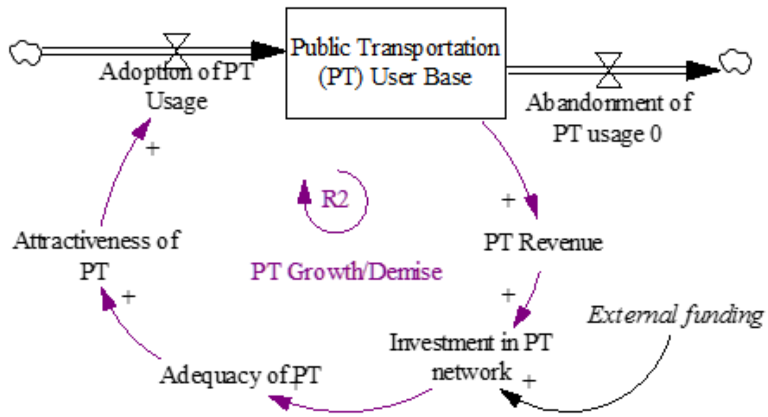


*Figure 3.7: Reinforcing feedback driving growth or demise of public transportation*

The relationship between these two loops indicates the potential effect of shared mobility on public transportation (Figure 3.8). As shared mobility becomes more attractive due to enhanced affordability and accessibility, users may be less inclined to use public transportation; likewise, when SM becomes affordable and less accessible (e.g. due to demand-related price hikes), PT adoption and usage can increase.

32 John D. Sterman, "The Mass transit Death Spiral", Business Dynamics, Systems Thinking and Modeling for a Complex World, page 186, 2000

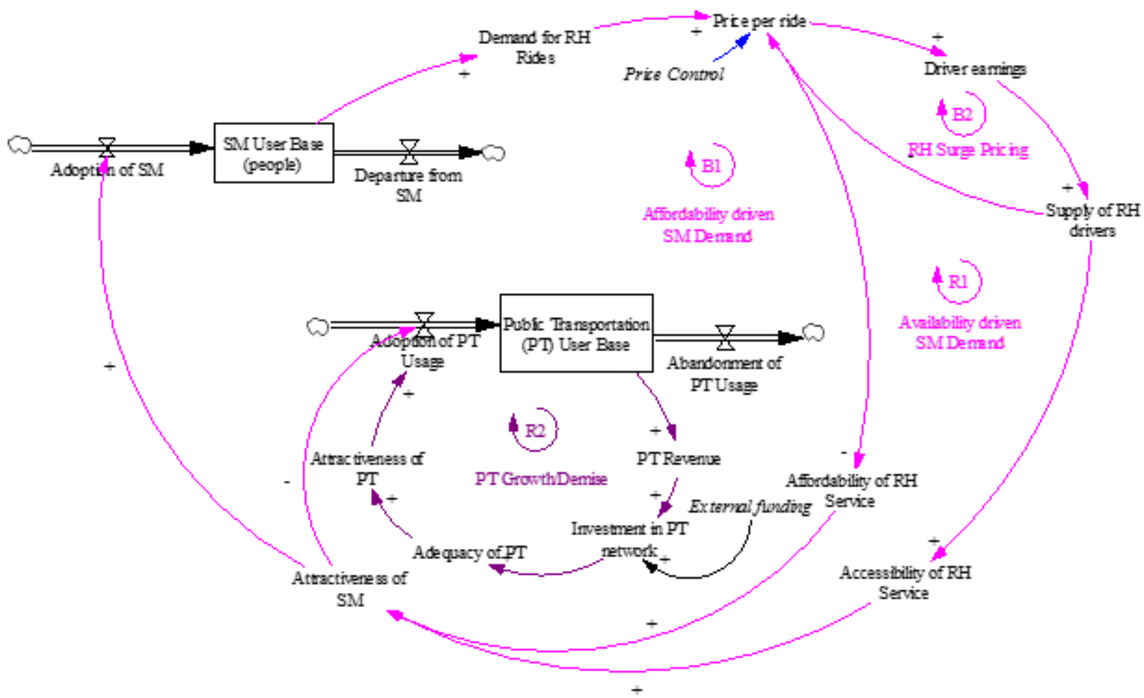


*Figure 3.8: Shared mobility's potential threat as a substitute of public transportation*

Shared mobility, and ride-hailing specifically, can also serve as a supplement to public transit. The reinforcing feedback loop (R3 *SM/PT Intermodal Mobility Loop)* in Figure 3.9 illustrates the "first-and-last-mile" benefit that SM can provide to make current public transportation networks more accessible[33]. Under certain conditions, growth of the public transportation system (B3 *PT Growth* Loop) could render first-and-last-mile ride-hailing services obsolete. However, through public-private partnerships, the extension of the public transportation system could include flexible route options, similar to SM mobility models. Pew Research Center study shows that people who use ride-hailing services are more likely to take public transportation (and use other forms of shared mobility, including bike sharing and car sharing) than non-users (Figure 3.10).

Overall, the synergies between shared mobility and public transportation may outweigh their substitutive effects and, together, achieve positive externalities of enhanced overall urban mobility access.

[33] Cohen, A. and Shaheen, S. PAS Report 583, Planning for Shared Mobility, American Planning Association, July 2016

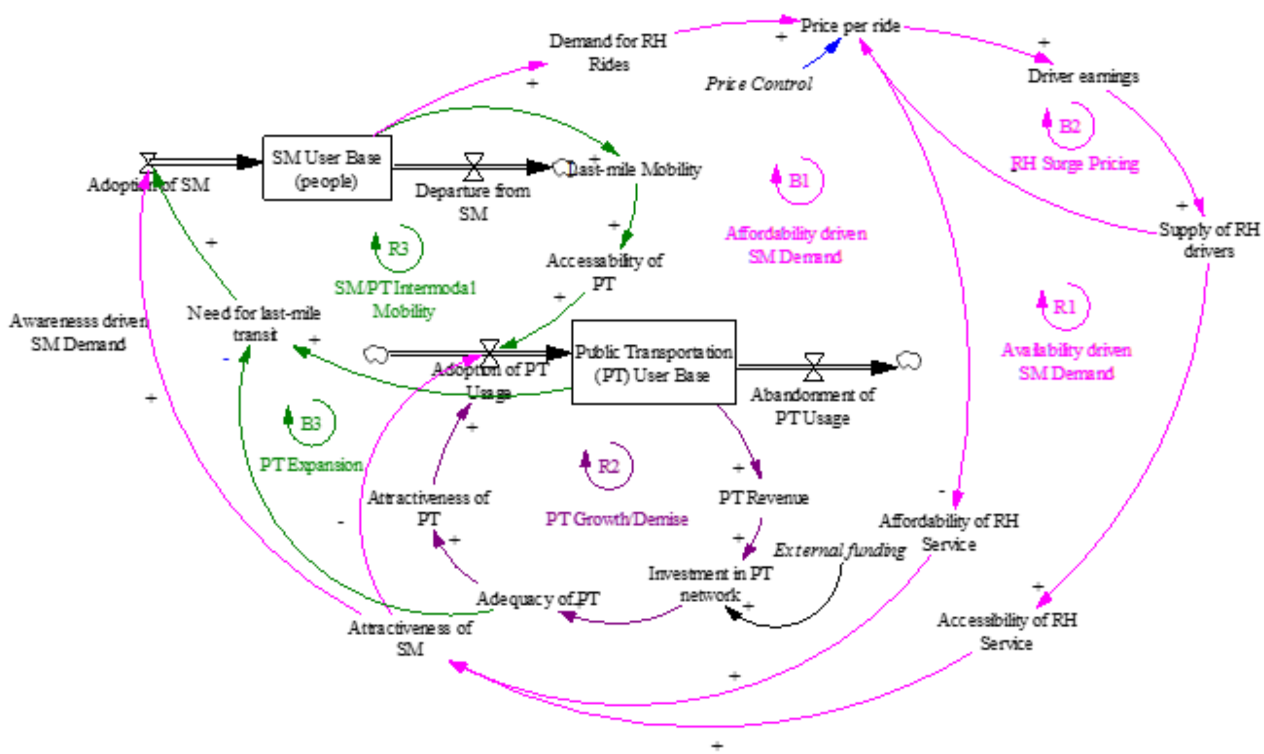


*Figure 3.9: Feedbacks conditioning the interdependency of shared mobility and public transportation*

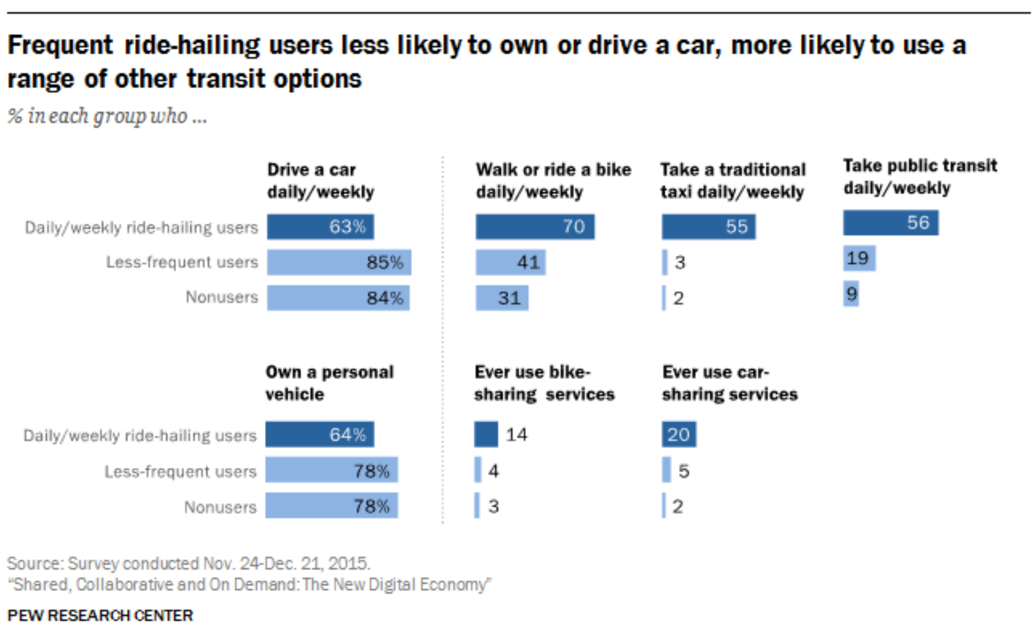


*Figure 3.10: Relationship between use of ride-hailing and other transit options*[34]

[34] Smith, A. On-demand: Ride Hailing Apps.Shared, Collaboratve and On-Demand: The New Digital Economy. Pew Research Center. http://www.pewinternet.org/2016/05/19/on-demand-ride-hailing-apps/

**Effects of Shared Mobility on Car Ownership and traffic congestion**

Figure 3.11 shifts the focus of this analysis to the interdependency between shared mobility and car ownership. Following this section, the feedbacks conditioning all three mobility options, shared mobility, car ownership, and public transportation will be merged.

While car culture (i.e. car enthusiasts' affinity for cars and driving) reinforces car ownership and can discourage shared mobility (R6 *Car Culture* Loop), several studies acknowledge that both ride-hailing and ride-sharing can reduce vehicle miles traveled (VMT, also VMT stock flow) and household car ownership.[35] As identified by Pew Research Center identifies, ride-hailers (as would ride-sharers) tend to drive less and own fewer cars than non-users. Particularly, in urban areas where parking is at a premium, the adoption of shared mobility can discourage car purchase.

As increased shared mobility user base should reduce VMT by owned cars, cars on the road should decrease which would lead to reduced traffic congestion. However, this reduces travel time and, thus, increase attractiveness of driving an owned car in return and reduces the incentive of ride-sharing (several passengers per ride) and ride-sharing user base. Consequently, this leads to a rebound of VMT traffic and traffic congestion and slows the adoption of shared mobility (B6 *Traffic vs SM*, B7 *Demand vs. Car Ownership*, and B8 *Traffic vs Car Ownership* Loop).

Although traffic congestion incentivizes car-pooling/ride sharing and use of high-occupancy vehicle (HOV) lanes. The increase in vehicle utilization results in reduced traffic and increased attractiveness of driving resulting in a balancing effect the attractiveness of ride-sharing (B4 *Traffic vs Ride Sharing* and B5 *HOV* Loop). Levers like price incentives can help increase ride sharing, vehicle utilization, and, therefore, overall mobility efficiency.

Finally, an increasing shared mobility user base increases the mileage of shared mobility vehicles. The reduced lifespan of these vehicles increases fleet turnover (R5 Purchase & R&D Cycle Loop). This reinforcing loop accelerates the purchase of vehicles cycle which gives OEMs the opportunity to bring in learnings from R&D at a faster pace.

[35] Cohen, A. and Shaheen, S. PAS Report 583, Planning for Shared Mobility. American Planning Association. July 2016; Li, Hong, and Zhang (2017); Murphy, 2016

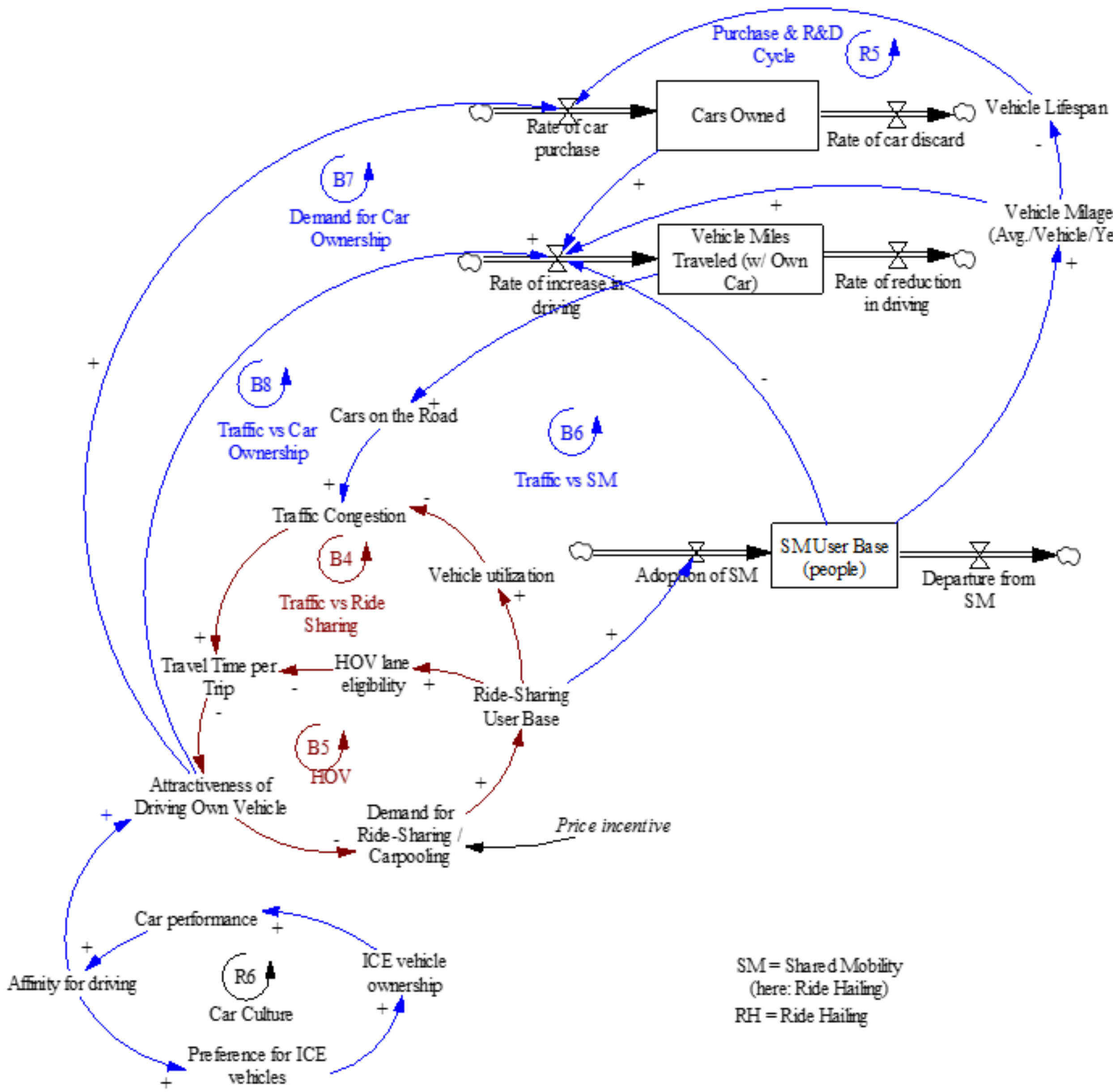


*Figure 3.11: Balancing effects of shared mobility on car ownership, independent driving, and traffic congestion*

**The big picture: Impact of shared mobility on mobility system and environment**

Figure 3.12. shows the effects of all transportation systems combined, shared mobility, car ownership, and public transportation. The effect of shared mobility on other modes of transportation and VMT points to its potential net impact on urban mobility and environment.

Shared mobility can pull people away from driving their own cars and, in combination with ride-sharing, improve vehicle utilization. Further, it can improve access to public transportation and, therefore, be a driver of intermodal mobility. In addition, regular ride-hailing users are also more likely to use other shared mobility services, including car-sharing, shuttle-sharing, and bike-sharing[36]. However, shared mobility is often too expensive in particular for low income communities or requires additional safety guarantees, for example for children and disabled and senior citizens. Policy levers like price discounts or subsidized subscriptions could make shared mobility more affordable for low income communities. Special vetting requirements, vehicle adaptations, and simplifications of mobile and online ordering platforms can make shared mobility fleets more accessible for senior and disabled citizens.

While shared mobility can enhance urban mobility, it also has an impact on the type of drivers and vehicles on the road. More and more shared mobility cars on the road creates additional awareness and social acceptance and, thus, reinforces demand for shared mobility (R7 Awareness Driven SM Demand Loop). At the same time, shared mobility providers (e.g., car sharing) and drivers (i.e., ride hailing) are conscious of fuel efficiency (R8 *Fuel Efficiency Drivers* Loop). They demand vehicles with high fuel efficiency to minimize the operating costs of their vehicles (R9 *Fuel Efficient Fleet* Loop). This demand for fuel efficient vehicles in combination with shorter fleet turnover cycles is accelerates the adoption of fuel efficient ICE and HEVs which will contribute to reduced carbon emissions in the environment as a positive externality.

Finally, the increase in demand for fuel efficient vehicles by providers of shared mobility services increases their willingness to consider AFVs. This creates the opportunity for shared mobility to become an enabler to accelerated adoption of AFVs. Chapter 4 will explore from the customer, business, and systems perspective under what conditions shared mobility can be a sustainable business opportunity for AFV adoption.

36 Smith, A. On-demand: Ride Hailing Apps.Shared, Collaborative and On-Demand: The New Digital Economy. Pew Research Center. 2016. http://www.pewinternet.org/2016/05/19/on-demand-ride-hailing-apps/

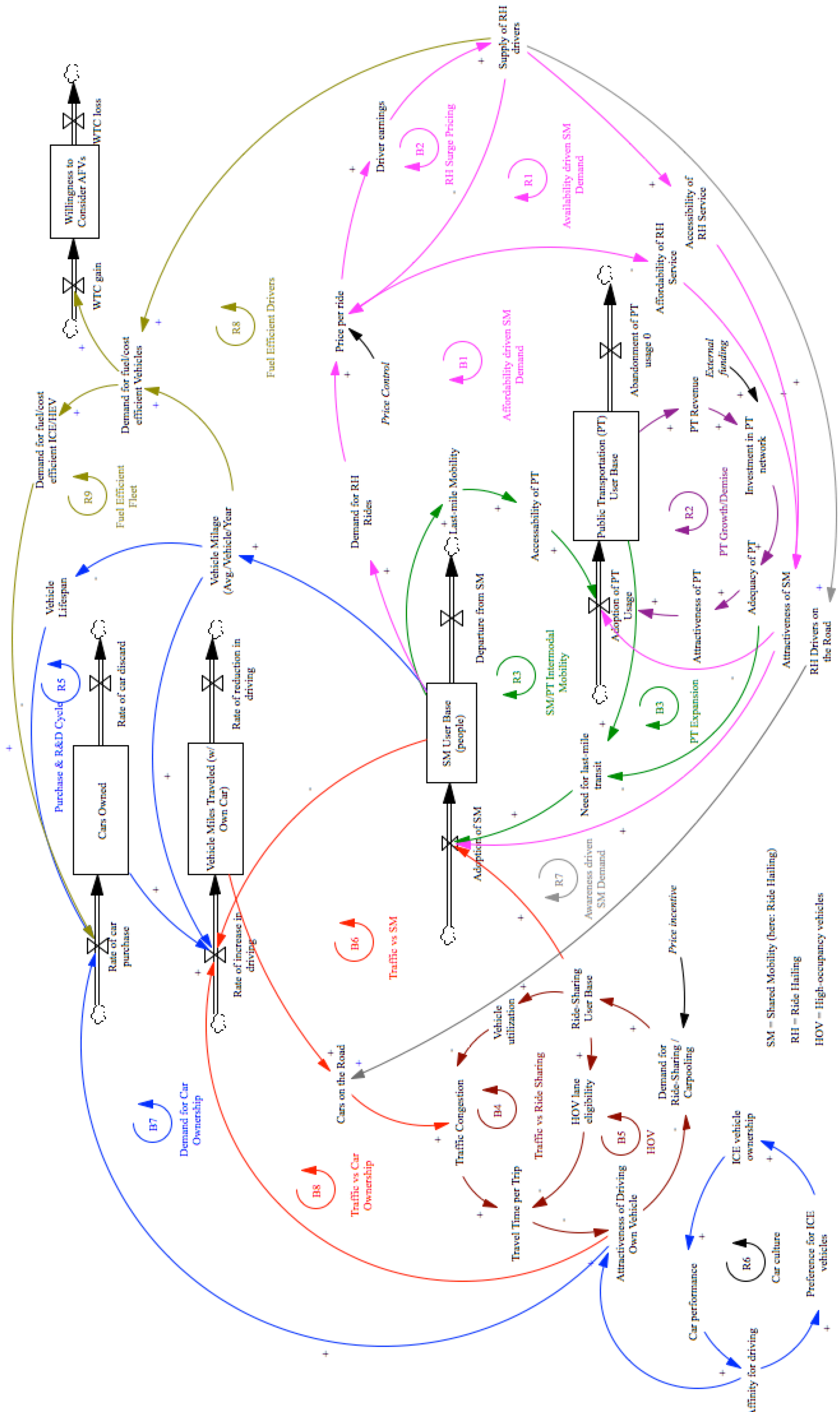


*Figure 3.12: Feedbacks of Shared Mobility, Public Transportation, and Car Ownership conditioning urban mobility*

# 3.4. Evaluation under the SOI framework

This chapter analyzed common shared mobility services along the SOI framework prior to the addition of AFVs to the equation.

**Customers**: As the above analysis reveals, various variations of business models of shared mobility exist today that successfully serve the needs of different customer segments. On-demand, convenient, and affordable shared mobility meets the needs of mostly mid-age high- and mid-income customers and increasingly as well seniors who gain additional mobility options, in particular seniors who do not need additional assistance. While many customers have benefited from shared mobility, many people with underserved mobility options today cannot or do not yet equally benefit from shared mobility, in particular low-income communities in urban and suburban areas as well as children and families.

**Business**: As a result of large customer acceptance and widespread demand for shared mobility, businesses have been successfully piloted and expanded in urban and suburban areas by transportation network providers and OEMs worldwide. Car sharing concepts like Zipcar, Car2Go, and DriveNow and ride hailing services like Lyft and Uber provide mobility options in addition to car ownership, public transportation, and taxi services. In some cases, these private provideers are working with local transportation or public transportation authorities to provide services that complement existing options. For low-income communities, expanding pooling- and ride-sharing opportunities as well as public subsidies may be paths to bridge the cost gap that prevents low-income populations from using shared mobility services. Ride hailing service providers for children, seniors, and disabled who require assistance require special equipment or training (e.g., child seats, large trunk for walkers, assistance) and convey an increased level of safety and trust. Specialized rather than common shared mobility services will continue to play a key role to fill the mobility gaps for these underserved communities.

**System**: Transportation contributes to 23% of the world's emissions[37], two third of which is from passenger vehicles, and over 50% of the world's population live in cities (including urban and suburban level densities)[38]. As shared mobility is expanding and transforming urban mobility around the world shared mobility is also becoming a major driving factor in energy use and emissions. The rise of collaboratively consumed systems allows us to more efficiently share assets and space and encourages urban citizens to behave in a more efficient way as eco-friendly vehicles and congestion and road pricing encourage them to choose mobility options that suit the appropriate need.[39] Sharing rides with others increases car utilization

37 Transport and its infrastructure, S. K. Ribeiro, S. Kobayashi, Intergovernmental Panel on Climate Change, 2012; World

38 World Urbanization Prospects, United Nations, Department of Social and Economic Affairs, 2014

39 Innovating for Smart, Sustainable Cities, Robin Chase, 5/2015, http://www.wri.org/blog/2015/01/innovating-smart-sustainable-cities-qa-

and may initially reduce total vehicle miles driven on the road (e.g., car-pooling, reduced time to find parking) and, thus, reduce emissions. However, given balancing feedback loops imply that reduced traffic may lead to a rebound in additional cars on the road, either in form of owned or shared vehicles, or encourage mode shift to a vehicle. It remains inconclusive whether shared mobility will reduce traffic[40]. However, it is likely that shared mobility is a path to increased use and purchase frequency of more eco-friendly vehicles, and, therefore, to reduced criteria pollutant emissions in urban areas overall as the fleet turnover accelerates and the stock of vehicles increases in efficiency and low or zero GHG.

Besides its environmental impact, under the right conditions, shared mobility can provide convenient last-mile mobility and easier access to jobs and education. However, this option remains mostly unaffordable for low-income communities who will likely continue to rely on public transportation. It remains uncertain whether shared mobility may lead to a reduction in use of and revenue for public transportation. However, this may result in a reinforcing loop leading to divestments and further decline in public transportation quality which will harm low-income populations the most. Continuous investments to maintain attractiveness of the public transportation system are needed to support multi-modal mobility that, in return, can both benefit from and support shared mobility.

All in all, shared many successful mobility business models can be considered Sustainable Oriented Innovation when they effectively and broadly address customer needs, generate sufficient revenue to scale businesses, and benefit the system by improving mobility and accelerate the demand for fuel efficient vehicles.

zipcar-founder-robin-chas

40 Mackenzie, Leiby, and Wadud. Help or hindrance? The travel, energy and carbon impacts of highly automated vehicles, 2016

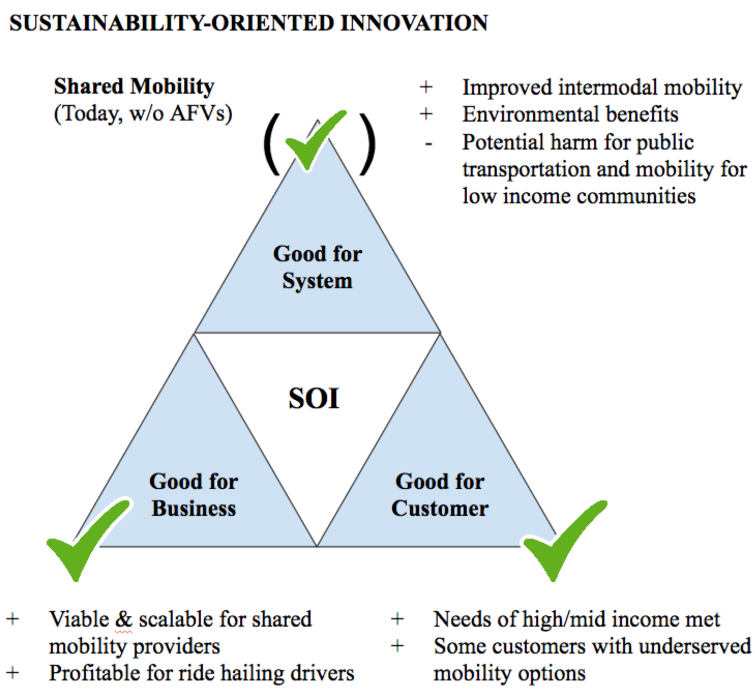


*Figure 3.13: Evaluation of Shared Mobility under the SOI framework*

# 4. Scenario analysis: Introducing AFVs into shared mobility

Given the above analysis of today's common ICE- and HEV-based shared mobility this chapter contrasts shared mobility assuming the introduction of AFVs into shared mobility fleets. Along the SOI framework this chapter identifies changes, downsides, and benefits that would result from this scenario for customers, businesses, and the system. This chapter finally evaluates whether AFV-based shared mobility can be sustainable and identifies leverage points to accelerate the adoption of AFV in the shared mobility economy.

## 4.1. Customer lens: Implications for customers

To understand how introducing AFVs to shared mobility services will impact customers we return to our three main customer needs identified above: 1) commute time; 2) access to quality jobs; and 3) affordability. In principle, changing the drivetrain of the vehicle should have little to no impact on the customer needs in shared mobility. Customers care about getting from point A to B in an efficient, safe and affordable manner - it shouldn't matter if it is an ICE vehicle, HEV, or an AFV. However, in our analysis of the business case for AFVs below, we find that most AFV systems will lead to higher ownership costs for the driver or the business. In addition, the downtime that results from charging their BEVat daytime between routes adds opportunity costs (see the next chapter for a more detailed analysis). Given that higher costs are characteristics of AFVs, it will be less viable to integrate them into a shared mobility service without charging higher fees. However, this will make the service less attractive for most customers, in particular low-income customers.

In addition, the customer needs of commute time and access to quality jobs may not be met with an AFV powered system, especially BEV. The charging infrastructure limits the reach and coverage of a BEV based shared mobility network and creates logistical inefficiencies as charging periods create downtimes and interrupt routings. Further, given that BEVs require more "refueling" time than ICE/HEVs, we can expect less shared mobility AFVs on the road at average (compared to a fleet of the same size with HEV/ICE vehicles). This will decrease network density, increase travel time to route origins, and make customers' wait times longer. Given the decreased convenience of AFV based shared mobility customers will consider alternatives, e.g., ICE/HEV based shared mobility, driving their own car, or Public Transportation. Finally, customers of, in particular, car sharing services will need to become familiar with driving an AFV and the associated limited range (range anxiety) depending on the vehicle.

## 4.2. Business lens: Changes in economic value and viability

Whether car sharing companies like Zipcar or car owning drivers providing ride hailing service through Uber and Lyft - all of which are simplified as 'business' in the following - , the economic value is primarily dependent on the total ownership costs of a vehicle. The economic value and other service related factors, like the availability and accessibility of charging or refueling infrastructure, determine whether businesses are willing to consider and adopt AFVs. In the following, we will compare the ownership costs for AFVs with those of an HEV, consider other service related factors, and evaluate whether it is viable for businesses to adopt AFVs for the purpose of providing shared mobility services today.

### Economic value

Assuming that within one vehicle service category (e.g., compact and mid-sized cars, premium cars) businesses cannot charge the customer more or gain any other benefit from offering a ride with an AFV than with an ICE or HEV a business will be incentivized to purchase a car with minimal total cost of ownership. Vehicles with good fuel economy like HEV are particularly attractive as fuel costs are a major cost component for vehicles with high mileage per year. Switching to an AFV would only be reasonable if ownership costs are equal to or lower than those of a fuel efficient HEV or ICE.

In the following, we are comparing total costs of ownership for the Toyota Prius 4 2017, one of the most common vehicles used in shared mobility, with three electric vehicles of similar size (compact and mid-sized car segment): two Battery Electric Vehicles (BEV), the Ford Focus Electric 2017 and the Nissan Leaf S 2017, and a Plug-in Hybrid, the Chevrolet Volt 2017.

| | Toyota Prius 4 2017 (Two Eco) | Ford Focus Electric 2017 | Nissan Leaf S 2017 (6.6kW) | Chevrolet Volt 2017 |
|---|---|---|---|---|
| Cash price 5/2017 ($) | 27,170 | 28,191 | 33,412 | 35,721 |
| Battery size (kWh) | N/A | 23 | 24 | 18.4 |
| Li-ion battery value | | | | |
| - at $400/kWh (avg. 2016) | N/A | 9,200 | 9,600 | 7,360 |
| - at $200/kWh (est. avg. 2020) | N/A | 4,600 | 4,800 | 3,680 |
| Range, electric (mi) | N/A | 76 | 107 | 53 /420 |
| Charging time, Level 1, AC (hr) | N/A | 16 | 17 | 13 |
| Charging time, Level 2, AC (hr) | N/A | 3.5 | 3.5 | 4.5 |
| Charging time to 80% capacity, DC (hr) | N/A | 0.5 | 0.5 | |
| MPG (combined) | 52 | N/A | N/A | 42 |
| MPGe (MPG-equivalent) | N/A | 107 | 112 | 106 |
| kWh/100mi | N/A | 31 | 30 | 32 |

*Figure 4.1: Key metrics for the Prius 4 and select AFVs (sources: battery values from Frost & Sullivan[41], other metrics from Edmunds[42])*

The ownership costs presented in Figure 4.2 covers 5 years of ownership, 15k miles per year, in Cambridge, MA, and considers U.S. average fuel costs for gas and electricity (gas: $2.2 per gallon[43], residential electricity: $0.13/kWh[44]). Today, all three electric vehicles are eligible for tax credits of $7,500 (Plug-In Electric Drive Vehicle Credit, IRC 30D, IRS).

41 Frost & Sullivan, Global Electric Vehicle Market Outlook 2017, average Li-ion battery prices for LG Chem, BYD, and NEC, 3/13/2017

42 Edmunds, True Cost to Own ® based on 15K miles per year for Cambridge, MA, 5/4/2017, www.edmunds.com/tco.html

43 U.S. annual moving avg., 5/2017, U.S. Energy Information Administration, www.eia.gov/dnav/pet/pet_pri_gnd_a_epmr_pte_dpgal_a.htm

44 U.S. average, 2/2017, U.S. Energy Information Administration, www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_5_6_a

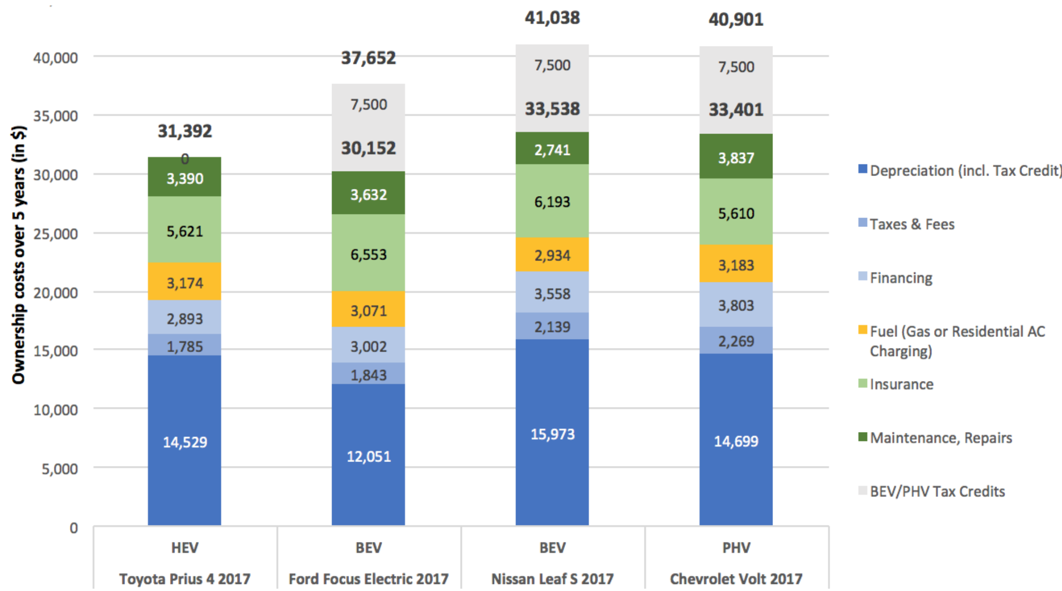


*Figure 4.2: Comparison of ownership costs for Prius 4 vs. select BEV/PHVs (5 years, 15k miles per year, U.S. average fuel prices)*

The comparison shows, that today the ownership costs for the three electric vehicles are significantly higher than those of the Prius 4 if tax credits were not applied. This price difference is primarily due to current prices for Li-ion batteries. However, even if tax credits were applied, none of the three electric vehicles yields significant cost benefits. Only the Ford Focus Electric would have slightly lower ownership costs than the Prius. The largest cost drivers across all vehicles are depreciation and insurance costs which are linked to the value of the vehicle, fuel costs and fuel prices are the third largest cost factor.

Depreciation: Federal tax credits will end in the next years pressuring OEMs to further reduce AFVs costs significantly. Given current price trends and capacity improvement for Li-ion batteries, it is expected that after 2020 prices drop under $200/kWh reducing the average cash price by $4,000 to $5,000[45]. It can be said with certainty that it will take far beyond 2020 until electric vehicles can be widely offered with adequate battery capacity enabling ranges of over 200 mi at prices that are competitive with same-sized HEVs.

Fuel costs: Electric vehicles achieve low fuel costs, one of the commonly seen key cost benefits of electric vehicles in comparison to ICE vehicles. However, the Prius 4 shows that HEVs can achieve strong fuel economy rates and similar fuel costs to those of electric vehicles assuming U.S. average fuel prices for gas and electricity remain unchanged. If the assumption of 15k miles per year (60 mi per weekday) was changed to 30k miles per year (120 mi per weekday) to reflect higher average mileage of shared mobility vehicles fuel costs would increase as share of total ownership costs. However, given the

[45] Frost & Sullivan, Global Electric Vehicle Market Outlook 2017, average Li-ion battery prices for LG Chem, BYD, and NEC, 3/13/2017

comparable fuel cost levels this would not lead to any cost advantage for either the Prius nor the electric vehicles.

Electricity Price: Given the sensitivity analysis in Figure 4.3, fuel costs for an electric vehicle like the Ford Focus Electric can vary significantly depending on regional or time related differences in electricity price. A Ford Focus Electric could yield lower fuel and total ownership costs in states with low electricity prices like Washington, it would result in higher fuel and ownership costs than the Prius 4 in states like California or Massachusetts.

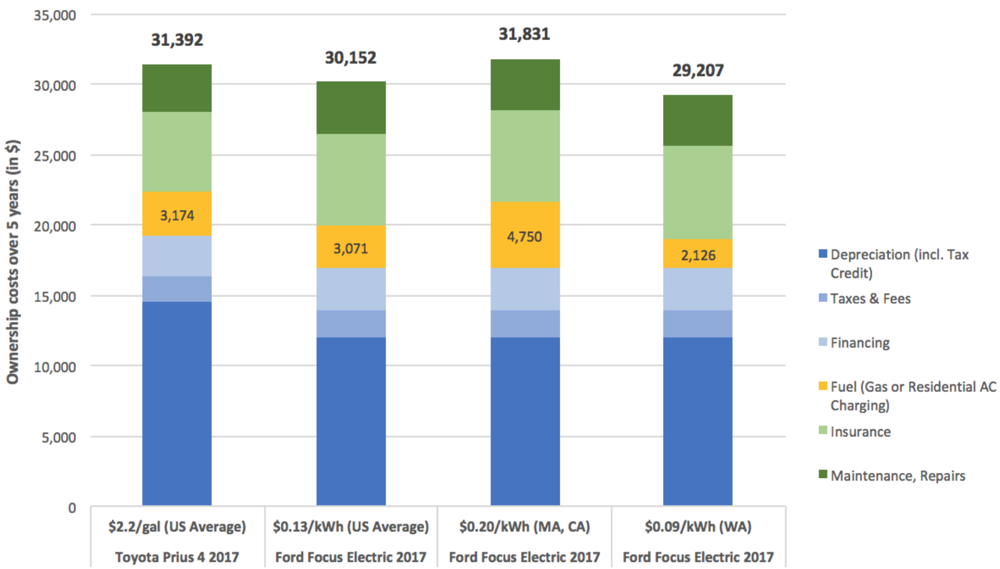


*Figure 4.3: Sensitivity analysis of ownership costs for Prius 4 vs. Ford Focus Electric by electricity price (5 years, 15k miles per year)*

Finally, given that learnings in fuel economy and battery technology will likely benefit HEV development as well it remains uncertain whether ownership costs of electric vehicles will become competitive with those of HEVs any time soon (assuming fuel prices and taxes remain unchanged and tax credits run out). Similarly, research and market simulations suggest that HEV - in contrast to AFVs - will significantly gain market share over the next decades given their strong fuel economy, low ownership costs, and independence from charging infrastructure. This is predicted to happen largely independently from AFV subsidies, purchase incentives, marketing efforts, or charging infrastructure investments.[46] All in all, assuming that tax credits for most BEVs and PHVs will run out over the next years, electric passenger vehicles will not provide improved economic value compared to HEVs neither today nor in the near future.

[46] MIT Sloan School of Management and Forio, "Driving the Future: Alternative Fuel Vehicle Market Simulator, https://forio.com/app/mit/afv/

### Viability

Given the cost and sensitivity analysis above businesses will not be incentivized to switch to electric vehicles for economic reasons. In addition, the limited capacity of batteries and range of electric vehicle, the need for charging infrastructure, and long charging times add further hassle points to the owner and driver of AFVs. For residential charging overnight, owners of electric vehicles require access to AC charging and equipment at home. Charging times range from 3.5 to 17 hours. Given the current limited ranges of most compact and mid-sized electric vehicles[47], additional charging at daytime may be required. Fast Charging at DC stations can charge batteries to 80% capacity in 30 minutes. However, using public charging infrastructure adds additional fees and opportunity costs (downtime is lost revenue). Using the Ford Focus Electric as an example, the sensitivity analysis in Figure 4.4 adds fees and opportunity costs depending on the amount in % of daytime charging used. Not only does the need for frequent charging add additional costs to the owner of the AFV (e.g., Blink charges $6.99 per charge which can be converted to $038/kWh [48]) but also charging related hassle points and range anxiety to the driver. It is important to note that if a driver has access to home charging and drives less than ~100mi, daytime charging may not be required and downtime is not an issue.

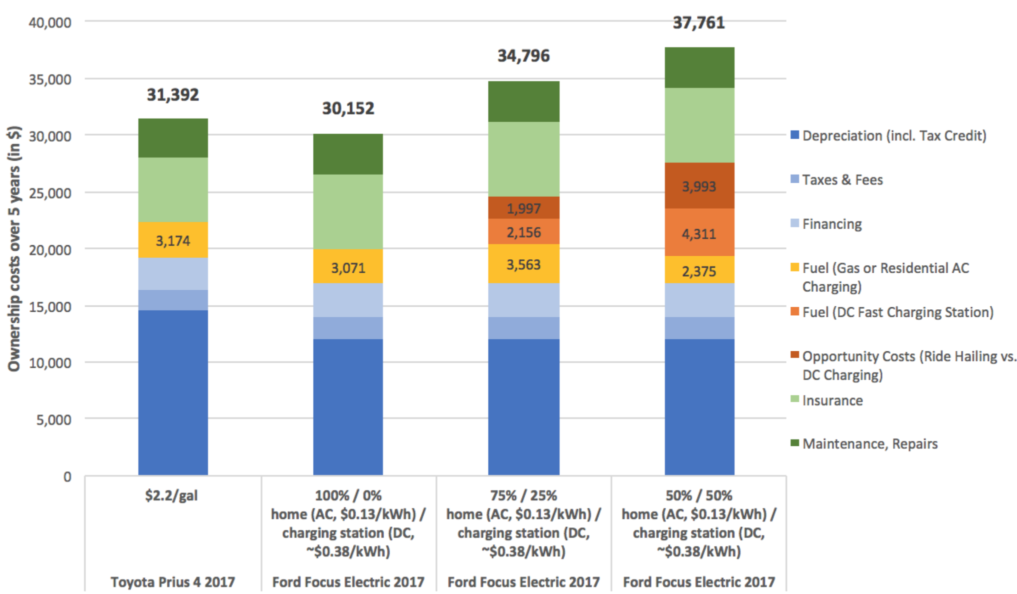


*Figure 4.4: Sensitivity analysis of ownership costs for Prius 4 vs. Ford Focus Electric by charging pattern (5 years, 15k miles per year)*

In conclusion, drivers for ride hailing services will have little or no interest in adopting AFV given

47 E. Schaal, 10 Electric Vehicles with the Best Range in 2017, Autos CheatSheet, May 2, 2017, http://www.cheatsheet.com/automobiles/electric-vehicles-with-the-longest-driving-range.html

48 DC charging costs of $0.38/kWh are based on $6.99 per charge assuming 30min charging time to reach 80% of 23kWh battery capacity; Blink, 4/2017, http://www.blinknetwork.com/drivingelectric

higher ownership costs than HEVs as well as additional hassle points and range constraints as they rely on charging/fueling infrastructure. For the same reasons, car sharing services would have little incentive to adopt AFVs. However, they have the opportunity and financial capabilities to collaborate with infrastructure providers to build out charging/fueling infrastructure to expand the range of their shared mobility services.

## 4.3. Systems lens: Dynamics of adopting AFVs in shared mobility

This chapter analyzes reinforcing feedbacks that condition the adoption of AFV in shared mobility on a systems level.

**Dynamics of AFV adoption**

Figure 4.5 shows the feedbacks conditioning the adoption of AFVs and general transition challenges of AFV adoption based on research by J. Sterman and J. Struben[49,50]. According to Sterman and Struben, high costs and low functionality of AFVs in comparison to ICEs and HEVs limit their market potential today. The dominance of ICE vehicles and infrastructure prohibits the emergence of alternatives making the adoption of AFVs difficult even if their performance equaled that of ICE vehicles.

Today, several reinforcing feedback loops are working against the increased adoption of AFVs in general. Lack of charging infrastructure (R1 *Charging Infrastructure* Loop) and range anxiety (R2 *Range Anxiety* Loop) will prohibit drivers from considering AFVs. However, with low demand, OEMs, energy and infrastructure providers, shared mobility providers, and governments will remain hesitant towards new investments into AFV technology and infrastructure. Social exposure to the AFV and word of mouth are critical to create awareness and increase customer's willingness to consider AFVs. However, low attractiveness suppresses AFV purchases and vehicles on the road, suppressing public exposure and further purchases, and, thus, limit growth of the market (R3 *Awareness* Loop). This further suppresses improvements in cost, variety, and performance of AFV as they rely on economies of scale, industry standards, R&D, and learnings from experience (R4 *Scale, Learning, Standards* Loop). Policy levers that are available to the industry and governments to stimulate the AFV market include purchase incentives, subsidies, carbon prices, and marketing efforts.

Given the high technological complexity of AFVs, high costs, limited variety and performance,

49 J. Sterman, Stumbling towards Sustainability, MIT Sloan School of Management, 11/11/2013

50 J. Struben, J. Sterman, Transition challenges for alternative fuel vehicles and transportation systems, MIT Sloan of Management, 5/23/2008

infrastructure limitations, as well as organizational and political complexity, successful adoption of AFV requires close collaboration among OEMs, infrastructure and energy providers, and local, state, and federal governments. However, today, such collaboration is weak (Sterman, Struben).

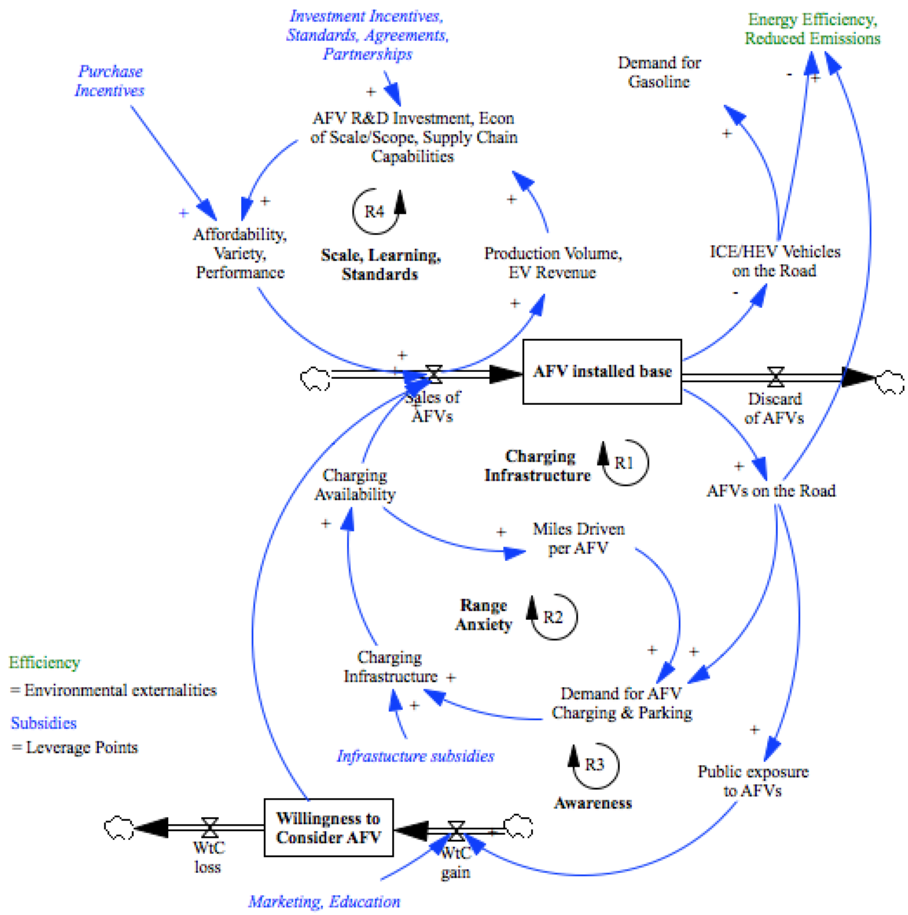


*Figure 4.5: Feedbacks conditioning drivers' willingness to consider and adopt AFVs*[51]

**Dynamics of AFV adoption in Shared Mobility**

Figure 4.6 expands the previous causal loop diagram adding major feedbacks conditioning the adoption of AFV in shared mobility. The same feedback loops (R1, R2, R3, R4) affecting the overall AFV installed base also affect the adoption of AFVs in shared mobility. For example, the adoption of AFVs in shared mobility is driven by the willingness of ride hailing drivers or car sharing companies to consider AFVs. Adopting AFVs for shared mobility brings the opportunity to expose both drivers and customers to AFVs in a highly visible mobility environment (R5 *Rider/driver Experience* Loop).

51 Based on J. Sterman, Stumbling towards Sustainability, MIT Sloan School of Management, 11/11/2013

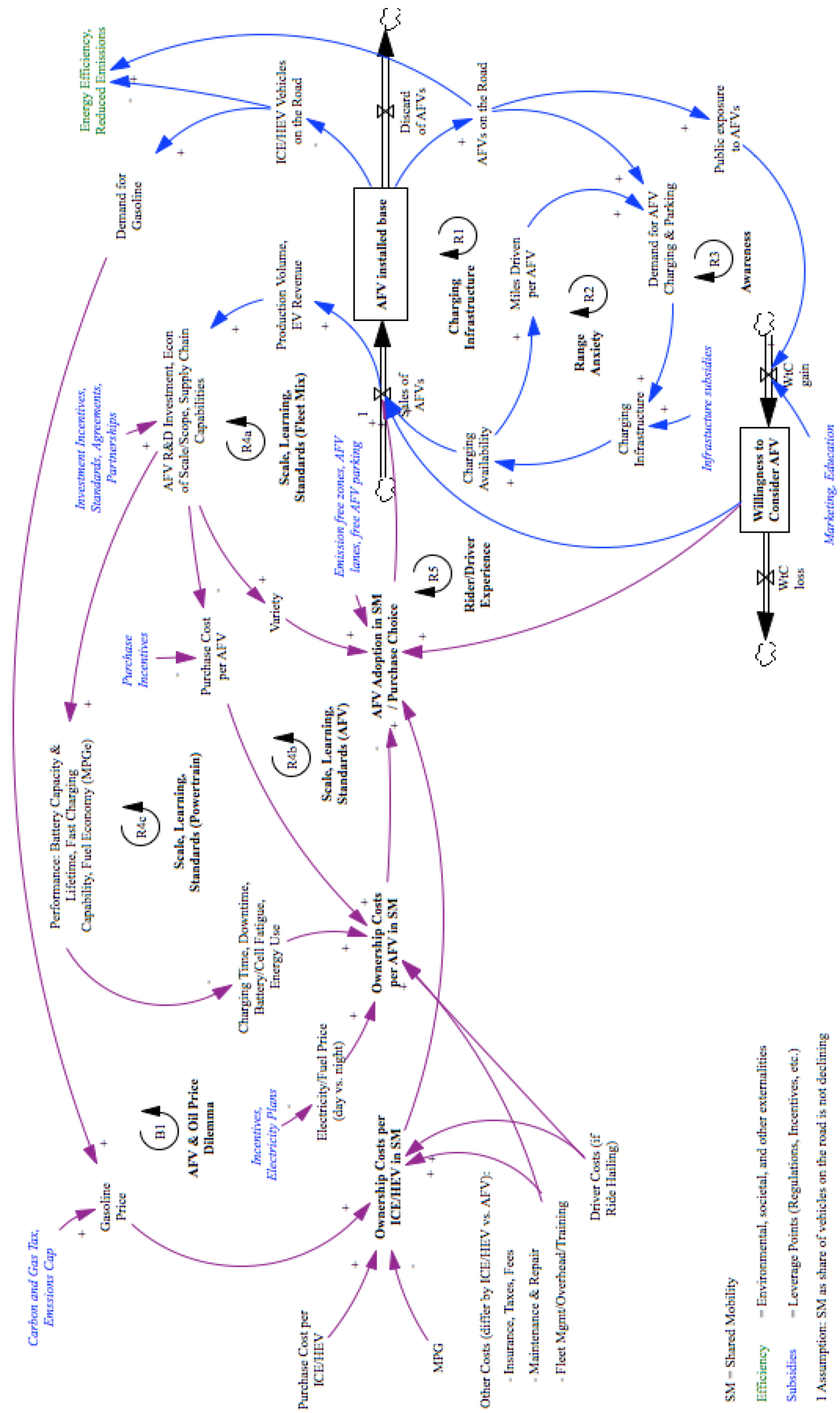


*Figure 4.6: Feedbacks conditioning the adoption of AFVs for shared mobility based on ownership costs of AFVs and ICE/HEVs, drivers/companies' willingness to consider AFVs (e.g., for ride hailing, car sharing), and OEM's Investments*

The adoption of AFV in shared mobility, that is the choice to purchase an AFV, is significantly driven by the benefit in economic value which is determined by lower total ownership costs for an AFV than for an alternative ICE vehicle or HEV. As analyzed in chapter 4.2, ownership costs for AFVs are dominated by the purchase costs (higher depreciation driven by battery costs and limited lifetime), fuel costs (driven by fuel economy and fuel/electricity price), charging fees and opportunity costs (driven by battery capacity and fast charging capability), and other costs (e.g., insurance, taxes, fees, maintenance, repair, fleet management costs).

As chapter 4.2 shows, AFVs like electric vehicles and plug-in hybrids are still significantly more expensive than ICE/HEVs today. Even with the current tax credits total ownership costs of AFVs are higher or only at par with those of ICE/HEVs. The low demand limits learning effects and costs advantages through economies of scale, lack of standards (e.g., different charging standards) hinder effective R&D development investments, confuses customers, and suppress demand (R4a *Scale, Learning, Standards (AFV)* Loop). Similarly, little variety of available AFVs constrains the ability to develop attractive fleet mixes and further suppresses adoption of AFVs in shared mobility (R4b *Scale, Learning, Standards (Fleet Mix)* Loop). Furthermore, battery and cell technology show limited performance. For example, current battery capacities at reasonable costs per vehicle commonly limit the range of most compact battery electric vehicles to less than 100 miles requiring higher charging frequencies and, thus, inconvenience for the driver. To address this issue, newer models of electric vehicles are developed with ranges up to 100 miles today. And more and more electric vehicles are developed with DC fast charging capabilities but battery lifetime suffers as a result. Common charging times range from 30min to 13 hours, depending on charging capability, resulting in downtime. Although battery and cell technology is improving, the limited powertrain performance suppresses adoption of AFVs in shared mobility further (R4c *Scale, Learning, Standards (Powertrain)* Loop).

In contrast, the ownership costs of ICE/HEV are commonly below those of AFVs at comparable vehicle type. They are driven by purchase costs, fuel economy and oil price, and other costs that affect AFVs equally. It can be assumed that technological advancements of AFVs lead to technology spillover effects for hybrid vehicles partly improving their fuel economy and ownership costs at the same time. In addition, if the number of AFVs on the roads in a metropolitan area increases and the number of ICE/HEV on the roads decreases, demand for gasoline decreases which may lead to lower local and overall gasoline prices, improving the cost advantages of ICE/HEVs and, thus, further suppressing AFV adoption in shared mobility (B1 *AFV & Oil Price Dilemma* Loop).

Overall, the above reinforcing loops related to scale, learning, and standards are weak and, consequently, ownership costs for AFV are typically higher than those of ICE/HEV.

**Charging Infrastructure**

Finally, the charging infrastructure is an important criterion in the decision to purchase AVFs for shared mobility. Figure 4.7 expands the previous causal loop diagram with related feedback loops. Good range and coverage of a shared mobility infrastructure charging network are critical to be able to optimize reach and flexibility of routes (R6 *Network Effects & Scale* Loop) and get the economies of scale required to minimize fied costs of charging infrastructure per additional AV that is added to the fleet (R7 *Economies of Scale*). Shared mobility providers like ride hailing drivers require public infrastructure for daytime charging. They cannot rely on home charging only, not considering that many drivers cannot access their homes for nighttime charging or would require additional equipment. Only with sufficient public charging infrastructure will shared mobility drivers and providers consider purchasing an AFV, but without demand infrastructure providers have little incentive to expand their network, also known as the *Chicken and the Egg* problem[52].

However, today, the coverage and range of charging infrastructure in urban and suburban areas is still poor which limits scalability and route flexibility for shared mobility providers[53]. Given the limited economies of scale, incremental costs per AFV are still relatively high. Therefore, scaling and expanding an AFV-based shared mobility network becomes very difficult and costly, in particular in suburban and rural areas with underserved infrastructure. The hope to leverage shared mobility as a platform to provide positive AFV experience for riders and drivers vanishes without sufficient traction (R7 *Rider/Driver Experience* Loop).

52 M. Kane, National Science Foundation on Electric Chicken & Egg Problem, Inside EVs, 2015, http://insideevs.com/national-science-foundation-electric-car-chicken-egg-problem/

53 J. Higham, Overview of Plug-in Electric Car Charging Infrastructure, Inside EVs, 2016, http://insideevs.com/overview-of-plug-in-electric-car-charging-infrastructure-in-the-u-s-part-1/

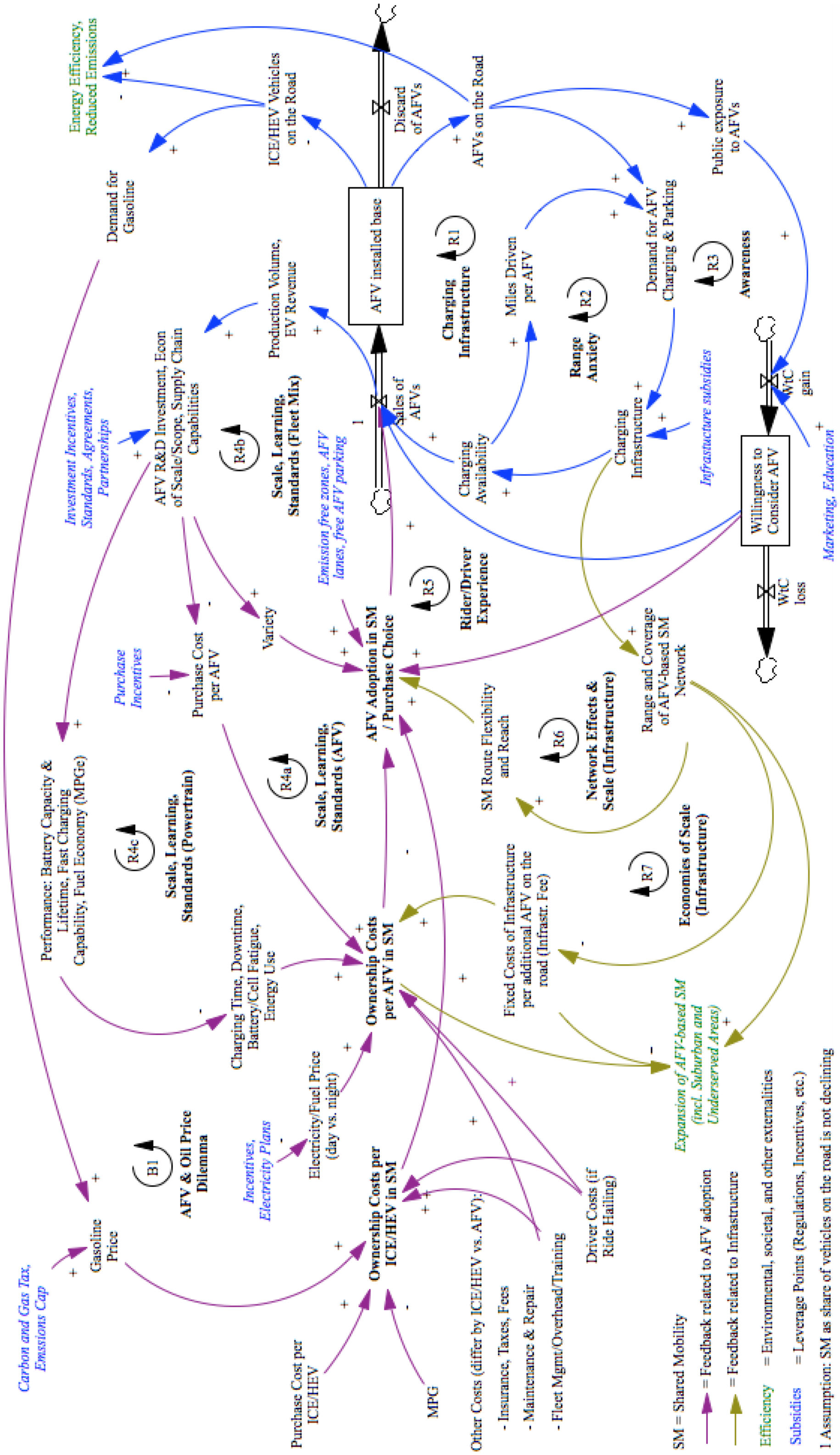


*Figure 4.7: Feedbacks conditioning the adoption of AFVs in shared mobility, including reinforcing infrastructure-driven feedbacks*

**Leverage points**

The reinforcing feedback loops, in particular the dominant cost loop R4a (Scale, Learning, Standards) and the infrastructure related loops R6 and R7 paired with the dominant position of ICE vehicles will suppress AFV adoption in shared mobility.

Policy levers available to industry actors and governments include purchase and investment incentives, electricity plans, and carbon tax. They can help partly offset the cost disadvantage of AFVs today. But as tax credits will be running out and other incentives are either not yet in place or have limited effect, AFVs need to become more cost competitive or open up other advantages over ICE/HEVs in order to convince shared mobility providers to adopt AFVs on a large scale[54]. R&D investments in battery/cell technology is required to improve battery/cell capacity and charging capability in order to extend range, avoid the necessity for daytime charging, and minimize charging times and downtimes.

In order to overcome the *Chicken and Egg problem* of AFV demand and charging infrastructure, further infrastructure investments and subsidies, efforts for standardization, and marketing campaigns are required. More drastic measures like emission free zones, AFV only lanes, or free AFV parking can create incentives for AFV for shared mobility providers in addition to cost incentives. In order to achieve the required economies of scale and network effects of the infrastructure, adopting AFVs in shared mobility can only be successful if adoption of AFVs for personal use accelerates as well, and vice versa.

All of the leverage points above are necessary for a longer time period beyond 2020 to bring the installed base of AFVs to a tipping point to sustained success. Without sustained coordinated support expanded adoption of AFVs will stagnate or fail (Figure 4.8).

**Implications for shared mobility businesses and urban mobility**

The above feedbacks conditioning the adoption of AFVs apply to ride hailing and car sharing and related shared mobility business models equally. In the case of ride hailing, drivers have to make the evaluation of costs, benefits, and disadvantages of purchasing and driving an AFV. In the case of car sharing, fleet providers will make this decision. Car sharing providers have the advantage that they can purchase more vehicles at lower costs. However, economies of scale equally apply to ICE/HEV and AFV. Further, they have to develop a solution for the charging/fueling infrastructure and charging/fueling process for their fleets. Dedicated parking with charging/fueling capabilities and incentives for customers to charge/fuel the cars in between or after use are possible solutions. Low vehicle utilization is often tolerated for ride hailing or car sharing. Thus, downtimes for charging may not necessarily make these businesses with AFVs unprofitable. For example, charging of electric vehicles can be done at off peak times when

54 Conversations with Jaycie Chitwood (Toyota Motors, North America) and Uber and Lyft drivers

demand is low. However, if high utilization rates are required, downtimes from charging of electric vhiecles can become a major issue. Poor charging infrastructure remains typically the major pain point for car sharing providers[55].

As described in chapter 3.3., the system's benefits from shared mobility without AFVs already given higher adoption of fuel efficient cars, reduced emissions, and improved urban mobility including for underserved communities. However, unless strong cost incentives, expansive charging infrastructure, and AFV-driving regulations (e.g., emission free zones) are in place, adopting AFVs in shared mobility (compare CLDs in Chapter 3.3.) becomes unattractive and will under current conditions suppress the supply of AFV vehicles and drivers and prohibit successful expansion of shared mobility capacity. Benefits in fuel efficiency and reduced emissions from AFVs could not be leveraged on a large scale.

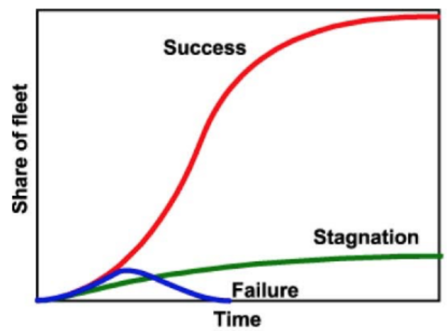


*Figure 4.8: Possible scenarios of AFV adoption in shared mobility fleets*[56]

## 4.4. Evaluation under the SOI framework

In contrast to shared mobility with ICE/HEV (see Chapter 3), introducing AFVs into shared mobility will have various disadvantages and only minor benefits for customers, businesses.

**Customer**: Although shared mobility services with AFVs would be similar to those with ICE/HEVs, additional "clean energy premium" charge may apply to make AFVs a viable solution for businesses. In addition, AFVs may allow access to emission-free zones and special parking but the weak charging/refueling infrastructure limits the availability of AFVs to certain areas, ranges, and routes. Waiting times could potentially be shorter if AFVs were allowed to use fast or car pool lanes.

**Business**: Shared mobility drivers and providers have to evaluate the economic benefit if they

55 Adam Cohen, Transportation Sustainability Research Center, University of California, Berkeley, Interview, 5/2017

56 J. Sterman, Stumbling towards Sustainability, MIT Sloan School of Management, 11/11/2013

consider switching from ICE/HEV to AFVs. However, the analysis in chapter 4.2 shows that ownership costs for AFVs, even with tax credits, are commonly higher than or on par with those of a eco-friendly HEV, like the Prius 4. In addition, drivers or businesses have to find solutions for daytime and nighttime charging/fueling which adds charging/fueling hassles, additional fees, opportunity costs due to downtimes. While an AFV-based shared mobility business model could potentially be profitable assuming cost incentives and available charging/fueling infrastructure, it is most likely less profitable and viable than a shared mobility model with ICE/HEV. Given the cost pressure and small margins[57], however, AFV-based shared mobility business models with passenger cars can most likely not be profitable under common conditions of U.S. cities today[58].

**System**: As shown in chapter 4.3., various feedback loops suppress the adoption of AFVs. High costs, limited demand and scale, limited battery/cell capacity and charging/fueling capabilities, and poor charging infrastructure are some of the effects working against the adoption and scalability of AFV based shared mobility. Multiple policy levers and close coordination among partners are required to bring AFV adoption in shared mobility beyond a tipping point to sustained success. However, if that can be achieved, AFVs in shared mobility could significantly boost the social acceptance of AFVs and further accelerate the adoption of AFVs outside shared mobility. As a result, intermodal mobility would continue to improve through shared mobility. Finally, emissions could be reduced significantly if shared mobility providers would switch to SFVs on a larger scale.

Overall, providing shared mobility services with AFVs instead of ICE/HEVs comes with various disadvantages for businesses and, thus, for customers as well. AFV based shared mobility services cannot be scaled without significant and long-term investments. However, benefits for the system are linked to the scale of AFV based shared mobility. In terms of the SOI framework, this situation would be similar to a donor-based innovation approach that relies on strong public and private investments and incentives. Under today’s conditions such a model cannot be sufficiently scaled and become sustainable on its own. A market willing to pay more for AFV based shared mobility services would be too small.

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[57] E. Newcomer, E Huet, Facing a Price War, Uber Bets on Volume, Bloomberg, 1/2016, https://www.bloomberg.com/news/articles/2016-01-21/facing-a-price-war-uber-bets-on-volume

[58] Conversations with Jaycie Chitwood (Toyota Motors, North America) and Uber and Lyft drivers

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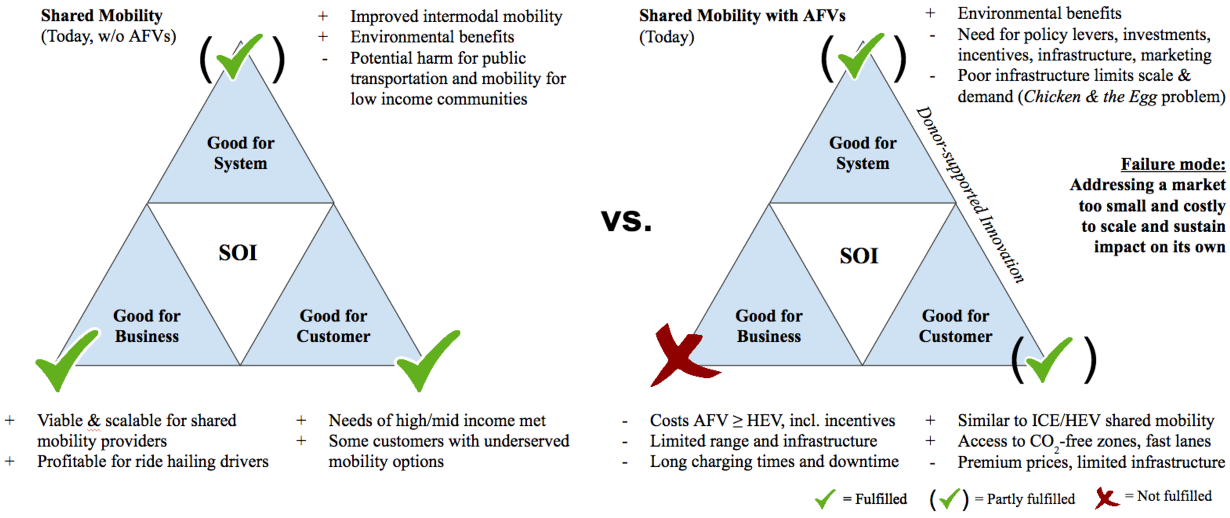


*Figure 4.9: Evaluation of shared mobility without and with AFVs under the SOI framework*

# 5. Recommendations for the Toyota Mobility Foundation

The above scenario analysis in chapter 4 reveals that introducing AFV into conventional passenger vehicle based shared mobility services under current conditions will be very costly for businesses or drivers but bring no key benefits to customers. Dynamics under current conditions will suppress AFV adoption in shared mobility and limit scalability.

However, chapter 3 showed that shared mobility is a transforming mobility force and indeed a sustainable path to increased adoption of fuel efficient vehicles. It is likely that highly fuel efficient hybrid vehicles may become the dominant vehicle type of shared mobility and car ownership in the near future[59]. OEMs could benefit from accelerated vehicle purchases and R&D cycles (see Figure 3.11) and adjust product development of HEVs as well as AFVs to the needs of shared mobility. Furthermore, OEMs could pilot AFV based shared mobility services in focused markets. It is to be determined what supporting policy conditions, adequate product offering, and partnerships would need to be established to build a sustainable path to accelerated adoption of AFVs in shared mobility (Figure 4.10).

This chapter provides select opportunities for Toyota going forward based on this reports' findings.

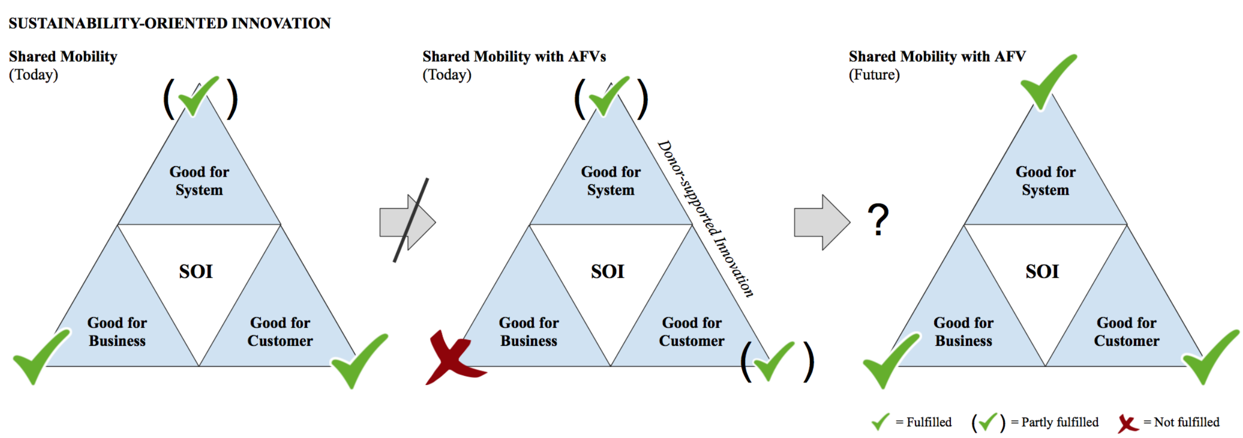


*Figure 4.10: If not today, under what conditions can shared mobility with AFVs be sustainable in the future?*

## Opportunities

### 1. Drive the expansion of HEV-based shared mobility

Shared mobility services require fuel efficient vehicles. Hybrid vehicles like the Toyota Prius already meet many of the needs of shared mobility today, such as good fuel economy and durability. Toyota would focus its R&D to tailor its products to the needs of shared mobility

[59] Driving the Future: Alternative Fuel Vehicle Market, D. Keith, Sloan School of Management, 2017, https://forio.com/app/mit/afv/

providers or car sharing fleets. Besides fuel economy and reliability, some drivers and customers have demanded more comfort and compelling exterior and interior design to increase attractiveness to drivers and riders equally[60]. Further, Toyota can focus its R&D to tailor vehicle design to the needs of underserved communities, e.g., senior or disabled citizens. It is to be noted that investing into HEVs in combination with shared mobility alone is insufficient to reduce emissions by 90% until 2050, but help put Toyota on the right trajectory. Toyota can pursue two major options:

<u>Option a) In collaboration with ride hailing or car sharing providers</u>

*Pros:*

- Fits into today's strategy to collaborate with shared mobility providers like Uber
- Provider brings existing customer and driver base and brand awareness
- Provider brings existing partnerships with municipalities, communities, states, and the federal government as well as experience operating in different cities
- Toyota focuses solely on product development, sales, and vehicle financing
- Some opportunity for Toyota to improve mobility for underserved communities (i.e., through Uber's collaboration with MBTA in Boston[61])

*Cons:*

- No own data collection and related learnings in shared mobility, unless it is shared by the shared mobility provider
- Toyota does not expand its service offering as a mobility provider and may miss out on capturing additional market value
- Relying on collaboration, integrity, and success of shared mobility service providers

<u>Option b) Building own car sharing program</u>

*Pros:*

- Become full-service mobility provider and capture shared mobility market value (some financial subsidy to driver and/or rider may be needed to help capture the market share)
- Direct data collection from own car sharing fleet
- Owning brand and car sharing fleet
- Price-product differentiation with focus on low/mid-cost volume segment and service offering (under Daimler's Car2Go and BMW's ReachNow)
- Opportunity for the Toyota Mobility Foundation in a public-private partnership to improve

60 Select interviews with Uber and Lyft drivers driving Toyota Prius and Camry, 4/2017

61 N. Dungca, Boston Globe, MBTA to subsidize Uber, https://www.bostonglobe.com/metro/2016/09/16/first-its-kind-partnership-mbta-subsidize-uber-and-lyft-rides-for-customers-with-disabilities/QDdHJgzg87JpwbOazyW14H/story.html

and expand shared mobility, in particular towards areas with people facing underserved mobility options, e.g., low income, families, senior and disabled citizens

- Opportunity to draw from experience of other car sharing projects (e.g., iRoad) and build out platform to autonomous shared mobility in the future

*Cons/Risks:*

- High initial investment (fleet, customization, online car sharing platform)
- Market and business risk (brand, awareness, customer needs, profitability, scalability, etc.)
- High competition in the car sharing space
- Parking terms to be negotiated with municipalities; parking availability

For Option b), the degree to which financial subsidy may or may not be needed is to be further analyzed.

**2. Electric two-seater car sharing pilot**

Building on the latest test of the i-Road car sharing programs in Tokyo, Japan, and Grenoble, France, Toyota could continue develop the vehicle and further tailor it to the constraints and demands of urban and suburban U.S. cities. In this car sharing model charging stations across the city are provided and can be located in targeted areas with underserved mobility options (also see business model in the Appendix, Figure 6.1).

*Pros:*

- Existing experience with i-Road pilots in France and Japan (business model, product design, customer experience)
- Control of charging infrastructure stations
- Control of data collection
- Small vehicles may meet more use cases, be more agile in an urban environment than passenger vehicles, and build public awareness faster (stands out, high volume)
- Support intermodal transportation, in particular, low income populations may gain affordable mobility through this opportunity
- Department of Energy (DOE) could serve as public partner and provide funding[62]

*Cons:*

- Close coordination and partnerships required with cities and infrastructure and energy providers
- High initial investment needs for infrastructure and R&D (yet, lower than 1b)

[62] Jeff Lindley, CTO, Institute of Transportation Engineers, Interview, 5/2017

- Incentives/subsidies preferable for initial ramp-up
- Range and coverage limited by charging infrastructure
- U.S. market may not accept new product design
- Failures of similar products (e.g., BMW C1 due to design, helmet requirements, customer needs, etc.)

**3. AFV-based shared mobility pilot**

To test the findings from this project, Toyota could prepare a pilot project in partnership with a suitable city, energy provider, and infrastructure provider, and collaborate with a shared mobility service provider or build its own car sharing program (also see business model in Appendix, Figure 6.2).

Option a) In collaboration with ride hailing or car sharing providers

*Pros and Cons/Risks* → Same as Opportunity 1a)

Note: Less public infrastructure is needed. In case of EVs, some drivers can home charge.

Option b) Building own car sharing program

*Pros and Cons/Risks* → Same as Opportunity 1b)

Note: No drivers are needed, eliminating home charging as a purchase constraint (EVs). But charging/fueling infrastructure needs to be developed

*Example:* BlueIndy by the Bollore Group, Indianapolis[63]

*Major Conditions:*

- City, government: Identify a mid-sized city with high sharing capacity[64], low electricity prices, low or moderate shared mobility options, and high willingness to collaborate with participating partners, and that is willing to invest in infrastructure expansion and potentially implement regulations that benefit AFVs (e.g., low-emission zones, AFVs in pool lanes, free AFV parking). Work with the Department of Energy or Transportation to raise additional funds (in return for reduced emissions and improved mobility)
- Infrastructure and energy providers: Collaborate to build out a charging/fueling infrastructure that matches the route demand (not population density). Funding may require investments by the city, DOT/DOE, Toyota, and other investors. Develop favorable electricity plans
- R&D: Develop a low-cost compact car (AFV) with high fuel economy that qualifies for

63 BlueIndy by the Bollore Group, Indianapolis, https://phys.org/news/2015-09-french-electric-car-sharing.html

64 M. Vazifeh, Senseable City, Interview on sharing capacity, optimization of shared mobility fleet utilization and charging locations, 5/2017

tax credits and promises lower ownership costs than for example the Prius 4. Significant investments in battery or cell technology is required to improve capacity, lifetime, costs, and charging/fueling capability. Additional discounts on the sales price may be required

- Marketing & Pricing: Create regional public awareness through strong marketing campaigns. Apply pricing that is competitive with other shared mobility options. Offer price discounts to drivers for charging the car (car sharing only)
- Charging/fueling equipment: Provide AC or DC charging/fueling equipment to drivers at no or low costs (ride hailing only)

*Challenges and risks:*

- High investment needs
- Close public private partnerships and collaboration
- Significant incentives required
- Infrastructure coverage, range anxiety
- Ending tax credits
- Cost, capacity, and charging/fueling capability of battery/cells
- Lack of attractiveness to customers and drivers
- Competing/emerging shared mobility providers

**4. Drive development of Autonomous AFVs to drive AFV adoption in shared mobility**

Shared mobility platforms and improved safety are the main focus for current autonomous vehicle R&D efforts by OEMs, tech companies, and shared mobility providers worldwide. Their goal to achieve Level 4 to 5 driving in the next five years[65]. Shared mobility providers are incentivized to deploy autonomous vehicles as they promise to eliminate driver costs and improve logistical inefficiencies (i.e., floating fleet, 24/7 operations, no parking, improved supply/demand balance, minimal congestion). Cities and governments are incentivized to support autonomous vehicles to reduce the need for parking space in urban areas, reduce urban mobility costs, improve urban mobility, and accelerate the adoption of electric vehicles. Autonomous capabilities have significant impact on shared mobility while the differences between ride-hailing and car sharing merge.

Using the CLD from Figure 6.3 in the Appendix we can deduct that Electric Vehicles (EV) may benefit from autonomous capabilities more than ICE/HEVs. Impact of Autonomous Driving on AFV adoption in shared mobility:

65 Frost & Sullivan, Global Autonomous Driving Market Outlook 2017, 3/10/2017

- Autonomous capabilities eliminate the driver and associated costs for both ICE/HEVs and EVs
- Autonomous technology will increase purchase costs for both AFVs and ICE/HEVs. However, autonomous vehicle may favor electric drivetrains (electric platform, less moving mechanical parts, easier to control and optimize) over ICE/HEV-based drivetrains. Therefore, costs for EVs should increase less than for ICE/HEVs
- In case of electric vehicles, collaborative effort and investment into shared DC fast charging parks in cities or along high demand routes may allow autonomous, wireless, low-cost charging. This would reduce fixed infrastructure costs per additional EV, reduce downtime, make home charging unnecessary, and optimize charging schedules by demand and electricity prices. This should significantly reduce the hassles points and additional costs of charging AFVs
- Autonomous vehicles would minimize range anxieties for drivers and riders and improve public exposure and awareness
- Autonomous capabilities would allow to improve energy management and efficiency for EVs and ICE/HEVs equally

Overall, EVs should benefit from autonomous capabilities more than ICE/HEVs as costs and hassle points are minimized. Autonomous vehicles may become a major driving force to accelerate the adoption of AFVs in urban environments[66]. Two options:

<u>Option a) In collaboration with ride hailing or car sharing providers</u>

*Pros:*

- Provider brings existing customer and driver base and brand awareness
- Provider brings existing partnerships with municipalities, communities, states, and the federal government as well as experience operating in different cities
- Use fleet data to optimize machine learning algorithm, routing, and charging/fueling locations[67]
- Toyota can focus on development of autonomous capabilities (Level 4/5) and EV platform, while the shared mobility provider operates the fleet and manages customer base
- Builds on today's strategy to collaborate with shared mobility providers like Uber

*Cons:*

- Costs for shared mobility provider

66 Robin Chase, 5th event in Volpe's Future of Transportation speaker series, 10/18/2016

67 M. Vazifeh, Senseable City, Interview on sharing capacity, optimization of shared mobility fleet utilization and charging locations, 5/2017

- Reputational risks; dependence on partners integrity, collaboration, and success
- Toyota does not expand its business model to a full-service mobility provider and may miss out on capturing additional market value
- Possibly limited access to shared mobility data

Option b) Building own car sharing program in partnership with a city or region

*Pros:*

- Full-service mobility provider captured shared mobility market value
- Own brand and car sharing fleet
- Unrestrained data collection from own car sharing fleet to optimize machine learning algorithm, routing, charging/fueling locations, etc.
- Potentially lower costs to operate the fleet
- Opportunity to draw from experience of other car sharing projects (e.g., iRoad) to build out platform to autonomous shared mobility
- Independence from shared mobility provider

*Cons/Risks:*

- High initial investment (fleet, customization, sharing platform capabilities)
- Market and business risk (brand, awareness, customer needs, profitability, scalability, etc.); no existing customer base
- High potential competition in the autonomous shared mobility space (OEMs, tech companies, start-ups, etc.)
- Partnerships with cities to be established; regulations may require adjustments/negotiation to ease restrictions

**5. Focused study on Fuel Cell Vehicle based shared mobility**

Although many findings from this report apply to FCV as well, several technology related characteristics are significantly different from EVs, e.g., longer range capabilities, short refueling times, and high fuel efficiency. However, certain issues like high purchase costs, fuel costs, lacking technology performance, and limited refueling infrastructure apply in similar ways. These have an impact on feedbacks conditioning the adoption of FCV in shared mobility. The analyses of chapter 4 should be reviewed with a specific focus on FCVs. Conditions under which shared mobility with FCVs can be a sustainable need to be understood before further investment decisions are made.

Toyota and the Toyota Mobility Foundation can pursue one or several of the above opportunities in parallel or in sequence. In the short-term, Toyota could invest in improving fuel economy and tailoring the product design of HEVs to the needs of shared mobility (Opportunity 1). In the mid-term, Toyota could expand its iRoad project to other cities and use scale and learning experience as leverage to bring down costs, improve product design, and optimize the mobility service experience for customers (Opportunity 2). Toyota could further apply its learnings from the iRoad program to car sharing programs with larger AFVs that will become more affordable as battery costs fall (Opportunity 3). On the long-run, Toyota can bring autonomous EVs to the shared mobility market, experiment with different partnership models, and continue to shape the future of urban mobility.

In addition, we propose to the Toyota Mobility Foundation to continue its collaboration with MIT Sloan School of Management, for example with Sustainability Lab or Next Lab. These projects could be dedicated to explore some of the opportunities above. In addition, projects could focus on modeling and quantifying the effects of shared mobility on traffic and urban transportation systems based on the qualitative systems analyses and causal loop diagrams in this report. Another project should be dedicated to explore under what conditions shared mobility and other transportation systems can improve mobility for people with underserved mobility options like low income communities given the motivations of the Toyota Mobility Foundation in this field.

# 6. Appendix

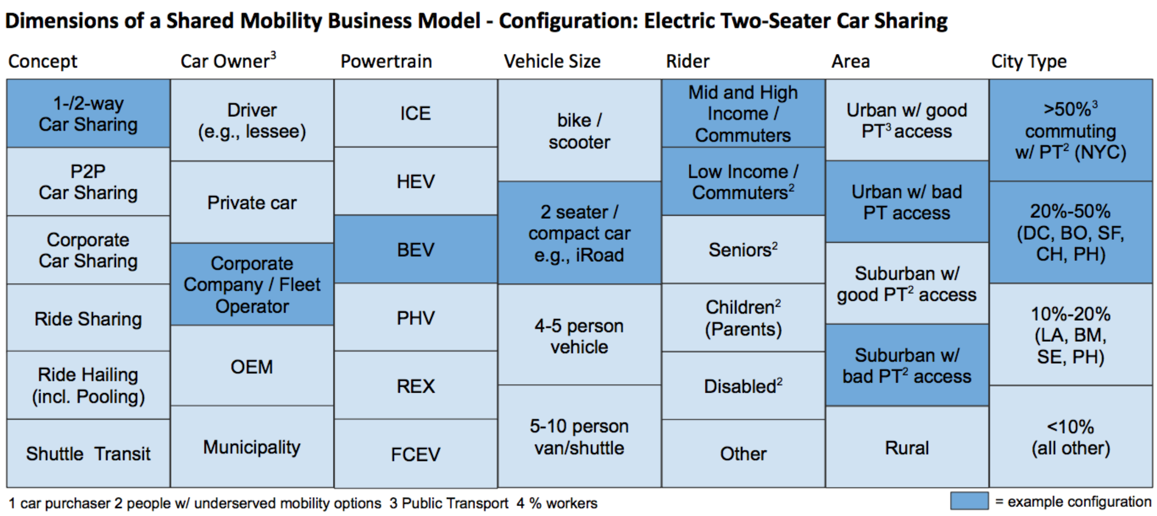


*Figure 6.1: Shared Mobility Business Model - Example: Electric Two-Seater Car Sharing*

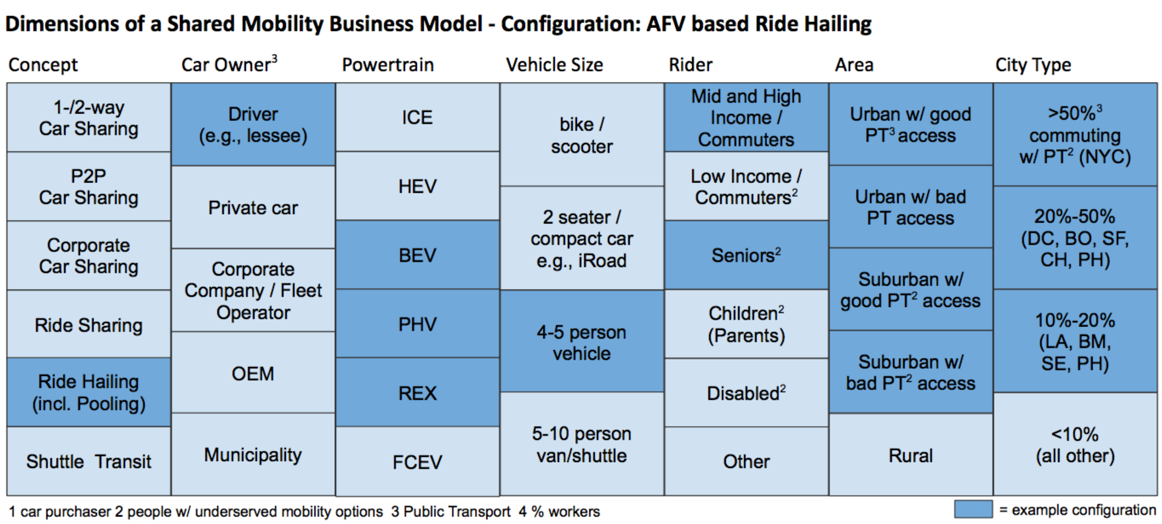


*Figure 6.2: Shared Mobility Business Model - Example: AFV based Ride Hailing*

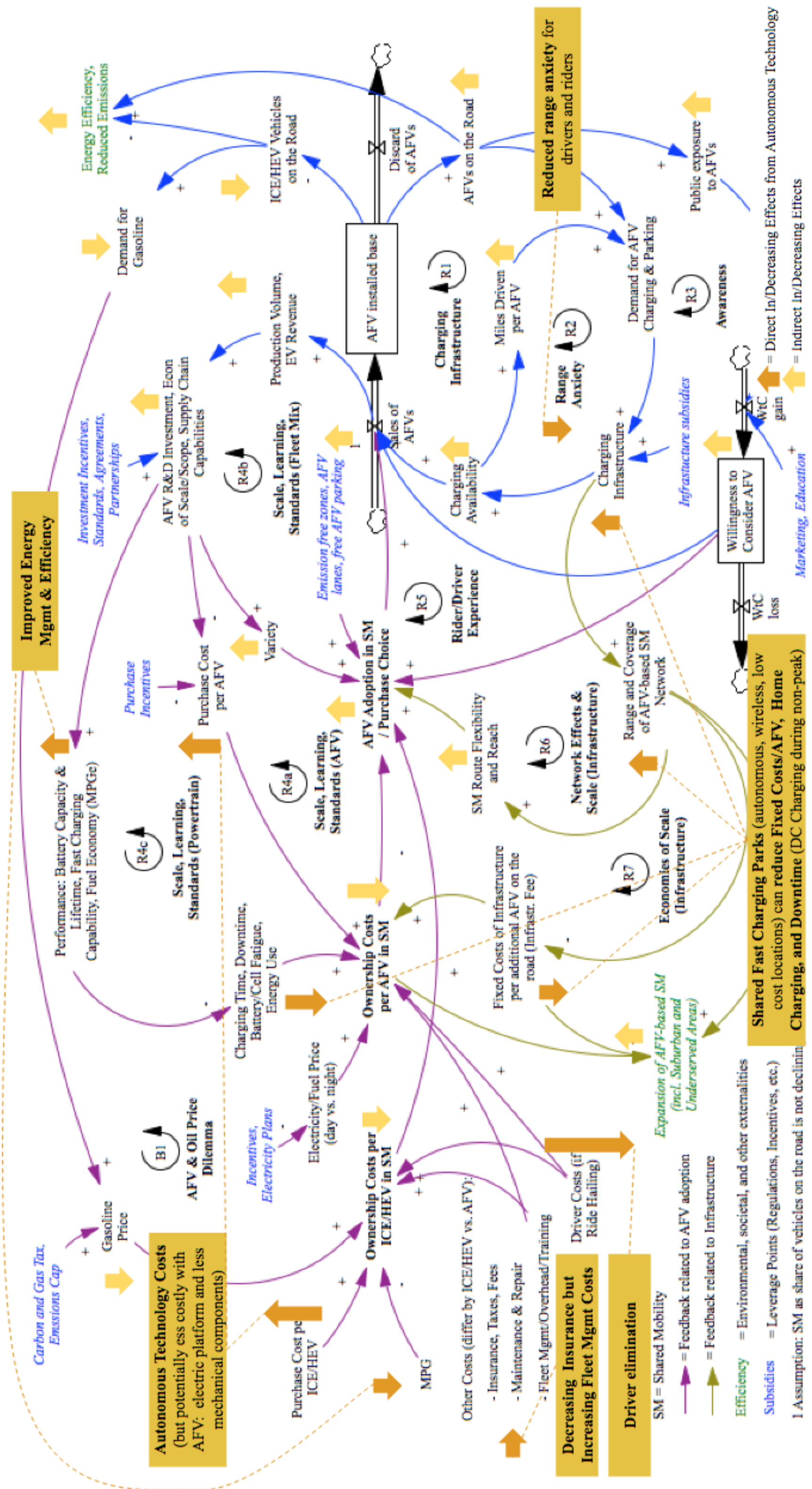


*Figure 6.3: Effect of autonomous capabilities to feedbacks conditioning the adoption of AFVs in shared mobility*