Beyond Single Occupancy Vehicles: Automated Transit and Shared Mobility

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Abstract It is commonly accepted that Automated Transit will still be as relevant as it is now, if not more so, even when fully-automated vehicles become a reality. We need to develop a consensus on how vehicle automation will transform and perhaps disrupt the traditional transit systems, what new and different types of market-driven and publicly-run frameworks will emerge, and how we should invest our limited public resources. The two day session on Automated Transit and Shared Mobility Track (ATSM) during the 2015 Automated Vehicle Symposium (AVS) explored implications for the changing roles of transit and shared mobility as vehicle automation progresses. This chapter not only documents the main ideas presented during the symposium, but also supplements certain ideas with further discussions and clarifications after the conference.

Keywords Automated transit · Automated guideway transit · Personal rapid transit · Group rapid transit · Automated personal transit · Shared mobility

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1 Introduction

Rapid development in vehicle automation technologies not only brought us hope for providing mobility for all, but also made us worry about the onset of urban sprawl when more and longer trips can be made without stressed drivers. It is commonly accepted that Automated Transit will still be as relevant as it is now, if not more so, even when fully-automated vehicles become a reality. We need to develop a consensus on how will vehicle automation disrupt traditional transit systems, what new and different types of market-driven and publicly-run frameworks will emerge, and how should we invest our limited public resources?

The two day session on Automated Transit and Shared Mobility Track during the 2015 Automated Vehicles Symposium explored implications for the changing roles of transit and shared mobility as vehicle automation progresses. This chapter not only documents the main ideas presented during the symposium but also supplements certain ideas with further discussions and clarifications after the conference.

The next section of this chapter defines Automated Transit and various members or “sub-modes” of the Automated Transit family. The third section provides a brief review of Automated Transit development and lessons learnt from the process. The forth section presents the current status of various fronts in terms of public policies, transit market shares, technologies, demonstration projects, and implementation potentials. The last but not least section explores the relationship between automated transit and shared mobility.

As such, this document will serve as a formal record identifying current and planned deployments as well as their anticipated impacts. It may be used by transit agencies, shared mobility providers, planners and policy makers in order to inform future decision-making.

2 Definitions

During the transit and shared mobility breakout session at the 2015 Vehicle Automated Symposium, attendees and participants sought to understand the changing role of transit, leading to the very question of what exactly constitutes a transit service, specifically Automated Transit. Taking a step back, it is useful to first define various transit services and identify clear examples of automated transit systems.

In this particular context, Automated Transit is passenger transportation service that is available to any person who pays a prescribed fare but is not required to be operated by driver, conductor, or station attendant [1]. As shown in Fig. 1, Automated Transit is made of a family of individual automated transit modes. So far, all of the existing commercial applications or driverless transit services can be grouped under the umbrella of Automated Transit, especially Automated Guideway

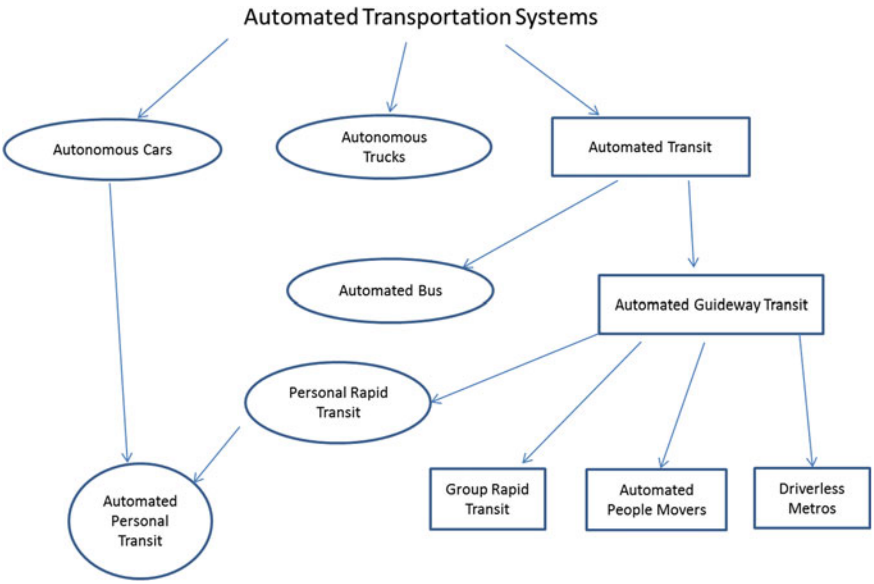

Fig. 1 Automated transit and its relationship to other modes [1]

Transit (AGT) since there is no commercial application of fully Automated Bus Transit as of 2015. However, partially automated bus transit systems with either lane guidance or speed control functions have been deployed in revenue services. These systems do require drivers to attend the system.

2.1 Automated Guideway Transit

Nesting under the Automated Transit umbrellas, Automated Guideway Transit (AGT) is defined as a class of transportation modes in which fully automated vehicles operate along dedicated guideways [2]. The capacities of the AGT vehicles range from 3 or 4 up to 100 passengers. Vehicles are made of single-unit cars or multiple-unit trains. The operating speeds of current systems range from 10 to 55 miles per hour (mph), and headways may vary from a few seconds to a few minutes. Automated guideway transit may be made of a single trunk route, multiple branches, or interconnected networks.

Depending on the vehicle size, capacity, and other operating characteristics, AGT may be categorized into various subgroups, such as Driverless Metros (DLM), Automated People Movers (APMs), Group Rapid Transit (GRT), and Personal Rapid Transit (PRT). Different operating environments often give AGT applications generic names, such as airport circulators or downtown people movers. Diversified track configurations, propulsion powers, and other technological features impart to AGT other names, such as monorail, duo-rail, and maglev; among others.

As illustrated in Fig. 1, all of the existing applications of automated transportation services belong to Automated Transit, especially Automated Guideway Transit (AGT), denoted by rectangles. For example, the first Group Rapid Transit Application, Morgan Town People Mover, has been operating for more than four decades without casualty or any major incidents [3]. Similar to other AV technologies, denoted in oval in Fig. 1, Automated Bus technologies are emerging and there are currently a number of demonstration projects around the word but no commercial Automated Bus applications. The Automated Personal Transit (APT) mode, to be defined in the next section, can only be realized once both AV technology and shared mobility platforms mature and intersect, and is therefore denoted by a circle in Fig. 1.

2.2 Automated Bus

Parallel to the definition of bus [4], an Automated Bus, or Driverless Bus (DLB), is defined as an automated vehicle designed to carry more than 15 passengers and operates on either exclusive or non-exclusive roadways [1]. Automated buses combine the advantages of automation technology with the high efficiency of public transit. When reaching a high level of automation, an Automated Bus may operate on non-exclusive roadways, where pedestrian and/or automotive traffic also exists.

2.3 Automated Personal Transit

With rapid development in vehicle automation (VA), it is not difficult to image what a great leap or interruption it will be when fully-automated vehicles become a reality, i.e., NHTSA Automation Level 4. According to Morgan Stanley Research [5], vehicle automation may very well develop along two diverging paths. As demonstrated in Fig. 2, the current travel scenario depicted in the first quadrant has been invaded by various shared economy pioneers such as Uber and Lyft, which are depicted in the second quadrant. The third quadrant points to the direction of automated vehicles that continue on the current private ownership axis. Far in the future, there will be the convergence of vehicle automation and shared economy—termed shared autonomy.

As one of the examples of shared autonomy, the Automated Personal Transit (APT) will have great potential to form and prosper. As an integral part of modern life in most of developed countries, a private automobile may also be one of the least utilized assets while its expense is only second to housing or shelter. If a vehicle is only utilized 1 or 2 h each day, and if the cost of hired taxi can be dramatically reduced via automated vehicles, it is quite possible that individual

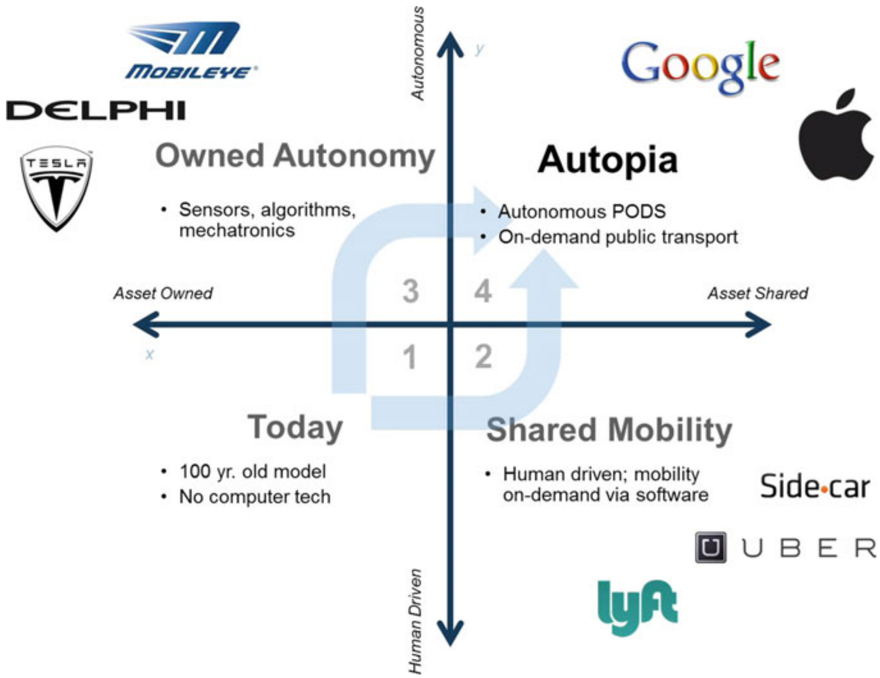

Fig. 2 Vehicle automation and share mobility path [6]

households will forego owning a vehicle altogether, while others reduce their levels of vehicle ownership. It will be much more efficient to summon an automated vehicle when one needs to travel but not have to worry about maintaining, storing, insuring, and owning the vehicle at all. This scenario will usher in a new mode, Automated Personal Transit (APT), which combines the advantages of both automated vehicles and Personal Rapid Transit (PRT), as depicted in Fig. 1.

The fleet of APT vehicles will be owned, maintained, and insured by a public or third party entity, thus transit mode. It will provide personalized, direct door-to-door service with comfort, convenience, and privacy of an automobile, thus personal, though depending on implementation, rides may be shared. An APT vehicle will be liberated from the confined tracks of PRT, the expenses of owning a private vehicle, and associated costs like parking. Instead, an APT service will possess some of the characteristics of public transit, accessible to anyone who is willing to pay a fare, and operated by a public agency over a regional network. It will also take full advantages of vehicle automation capabilities, direct door-to-door services, and reduced costs comparative to taxi, since no human driver is needed [7]. The automated or driverless features will keep the cost down and make it affordable for most travelers to hire an automated taxi—another name for APT, along with other terms like shared autonomous vehicles (SAV), autonomous taxis (aTaxis), and automated mobility on demand systems (AMODS), though these three terms are not necessarily reliant on the 'public' component of APT. The transit classification or public ownership will ensure potential funding sources, regulatory jurisdiction, and safety oversight for the sustainable development of APT.

3 Historical Development

The concept of vehicle automation may be colored by many fictions or dreamy depictions of flying machines or robotic cars. The origin of vehicle automation may be traced back to 1939 New York World's Fair where an automated highway concept was first presented at the General Motors Pavilion of the Futurama exhibit. Meantime, Automated Transit, particularly Personal Rapid Transit has been systematically documented by Fichter [8].

3.1 Automated Guideway Transit

The first AGT application was born in the US since quite a few "catalysts" worked perfectly during 1960 through 1980s [1]. First, the concept of automatic control, essential to Automated Transit, had been firmly established by the early 1950s. Second, the completion of the Apollo Moon Landing Program had freed up government funds and research capabilities, PRT had the potential and promise to fill up the plate. Third, with the fast invasion of automobiles and disappearing streetcar services, some Americans just started to question the validity of automobiles and their far reaching impact on lifestyle, environment, and society beyond.

Inspired by the Apollo Moon Landing spirit, the newly established Urban Mass Transportation Administration (UMTA), the predecessor of the Federal Transit Administration (FTA) today, made great leaps into automated transit development. UMTA not only organized technology exposition, such as TRANSPO 72 but also funded pilot projects, such as Morgan Town People Mover in West Virginia and three Downtown People Movers (DPM) in Miami, FL, Detroit, MI; and Jacksonville, FL.

Looking back, few would regard the UMTA's DPM program as a "success." Among all the three cities that implemented DPMs, Miami was often criticized for its higher initial unit costs. However, a recent examination [9] indicated that its ridership and costs closely match the original forecast, especially after the network was expanded to connect with other transit networks as originally planned, but implemented at a later stage. The DPM Program in the US was only a brief chapter as there was no more DPM application except those three pilot projects.

As the demonstration projects in the US since the 1970s faced their continuous criticism due to high cost, low ridership, and most importantly unmet expectations, AGT applications in various airports, major activity centers (MAC), and private institutions, such as amusement parks, hospitals, and museums, have been gaining steam quietly and successfully. As of 2014, there are nearly 60 Airport APM (AAPM) applications around the world [10].

While DPM and PRT applications have been riding the roller coaster of novelty thrills, government support, and disappointing implementations in the United States, AGT applications have quietly gained momentum overseas. The initial concept of a fully automated, integrated transit system in Lille, France was conceived in 1971, almost at the same time that the UMTA initiated its DPM Program.

If the very early implementation of Automated Transit technology in VAL is considered a lonely experiment with vague technology, the continued implementation of Driverless Metros in various French cities such as Lyon (1991), Toulouse (1993) and Paris (1998) has certainly solidified the pioneer position of France in embracing transit innovation and technology, and as they continually demonstrate a propensity to adapt the most advanced technologies into practical solutions. If there is any doubt about the potential of automated transit and its application in a truly dense urban area or high frequency operation systems with legacy systems, the conversion of Paris Metro No. 1 Line, the oldest and second busiest metro line in Paris, from manual operation to driverless in 2011, should have vaporizes all those doubts.

Personal Rapid Transit (PRT) was the prototype conceived by the early pioneers of Automated Transit development since the 1950s. Fitchter conceptualized the small vehicle, “Veyar”, and its extensive network in an urban environment in the 1960s. UMTA attempted the PRT concept in the 1970s in Morgantown, WV, but ended up with a Group Rapid Transit (GRT) application since it utilizes much larger vehicles, a simpler network, and rarely executed direct origin to destination operations [11]. Despite many criticism and negative publicity, the hybrid Morgantown GRT has been chugging along during the past four decades and more.

3.2 Automated Bus Transit

The development of road vehicle automation began in the 1950s, when General Motors and RCA conducted experiments on automated vehicle technologies. As far as the Automated Bus Transit application, the first electronically guided transit bus was put in operation near Stuttgart, Germany, following an intensive research on vehicle lateral control by the Regional Research Lab in Germany in the 1960s and 1970s.

Under a large research program, Prédit, the French Department Transportation (DOT) committed to investigate innovative ideas for improvements of land transportation systems in the 1990s. Under this program, an optical computer vision technology was developed by MATRA, since acquired by Siemens, for bus guidance. A bus precision docking system based on optical guidance technology has been put in operation in the French city Rouen since 2001. Later the technology was deployed in Clermont-Ferrand in France. Significant saving in dwelling time was observed. Surveys of passengers have shown comparable levels of satisfaction among passengers on the electrically guided bus lines and on the LRT system.

The city of Eindhoven in the Netherlands has developed an Advanced Bus Rapid Transit System, Phileas, in collaboration with Advanced Public Transport Systems and then Frog Navigation Systems. The Phileas bus was designed ground up with integrated fully automated vehicle control capabilities. The electronic guidance system uses magnetic markers embedded in the roadway. The system was first demonstrated in 1999. However, the combination of the vehicle control system with other innovative features makes the Phileas a very complicated system to design, develop and maintain. The developers have been struggling with both the functionalities and the reliability of the automated features.

California PATH has conducted systematic research on a full array of automated road vehicle system since 1987 and demonstrated a fully automated platoon system during the National Automated Highway Systems Consortium Demonstration in San Diego in 1997. In 2003, PATH and California Department of Transportation demonstrated a fully automated bus system for a bus convoy on highway and precision docking at bus stations based on magnetic guidance technology invented by PATH.

In Japan, research and development of autonomous vehicles started in 1960s. Toyota developed an Intelligent Multimodal Transit System (IMTS) and demonstrated it in the World Expo in Nagoya in 2005. IMTS uses magnetic guidance as primary technology. Three fully automated buses were operated on a convoy on an exclusive bus way, taking passengers between the Expo centers.

While electronic guidance systems are being developed and began to see its deployment, mechanical guidance system has been deployed in several cities across the world. Essener Verkehrs, AG, the public transit agency for Essen, Germany, is the first to deploy a mechanical guidance system for transit buses on dedicated busways and the system has been in operation since 1980. Subsequently, Mannheim in Germany, West Sussex in England, and Adelaide in Australia have also followed suit. Comparing with electronic guidance, mechanical guided buses require extensive infrastructure support.

3.3 Automated Personalized Transit

Parallel efforts have been devoted to low speed, fully automated shuttle systems. A Cybercar concept was introduced by French INRIA in the 1990s. Cybercars are fully automated road vehicles that can be operated individually or in group to serve public transportation purposes. The cybercars can provide either a direct connection or operate over an elaborate network, providing on-demand door-to-door transportation. The fleet of cybercars is under control of a central management system in order to distribute transportation requests efficiently and coordinate traffic in specific settings and environment [12]. Cybercars have been demonstrated in multiple cities in Europe.

4 Current Status

In line with the theme of the Automated Vehicle Symposium, the ATSM Track has touched upon all issues related to Automated Transit, from public policy to transit share, from on-going demonstration to expansive shared economy, from to Automated Transit operation to its impact on land use and urban development.

4.1 Public Policies and Regulations

Government agencies are often expected to develop policies, create dialogue, issue guidance on standards and equity, encourage collaboration between stakeholders and conduct research that promotes integration, customer safety, reliability, and equity [13]. Policies and practices for AGT have been well developed. However, in the case of road vehicle automation or particularly in the area of Automated Transit, most government agencies are in the modes of catching up or reacting to the technology or private sector development. For example, the Mobility on Demand (MOD) Program, led by the ITS Joint Program Office (JPO) in collaboration with Federal Transit Administration (FTA), put great emphasis on connectivity and replaced "Transit" with vague "New Multimodal Mobility Concept". The US Department of Transportation (USDOT) prioritized the connected world in the order of light vehicles, then trucks, then transit. The newly developed strategic plan by USDOT [14] did not include Automated Transit in either their discussion of transit or vehicle automation.

On the regulation side, government agencies have begun to develop new regulations for autonomous vehicles. Several states in the U.S. have already published regulations for autonomous vehicles to be operated on the road in traffic for testing purposes. These regulations are applicable for Automated Transit in mixed traffic condition. However, it is yet not clear whether and what regulation will be required for exclusive operation of Automated Transit on exclusive right of way for transit corridors.

According to many transportation professionals [13, 15, 16] transit should not be the last. With exclusive right of way (ROW), 100 % market penetration, and long existing automated operations, transit has been and should have the potential to lead the pack in the path of vehicle automation. It seems that private sector is driving the technology development in this round of vehicle automation but it is strongly voiced that technology can only advance to a certain stage before it is hindered or slowed down by policy, insurance, legal, social and other related issues. Government agencies are not expected to hand out large sum of money for demonstration projects as in the past but its role of developing policy and facilitate dialogs are critically needed, especially for transit agencies and Automated Transit development.

4.2 Market Share for Transit

In the era of Connected Vehicles and Automated Vehicles (CV/AV), autonomous vehicles and Transportation Network Companies (TNC) are likely to provide travel options both complementing and competing with transit [16]. Equipped with mobile devices and widely exposed to social media, new generations of travelers are less attached to their Single Occupancy Vehicles (SOVs) and pulled more toward public transit. However; if conventional transit cannot provide safe, affordable and convenient door to door travel, many of the millennials will lose their faith in transit and turn to other alternatives.

Transit will change passively or proactively. Automation and connectivity will make transit more efficient and the newly developed multimodal transportation system will incorporate more flexible forms of transportation. For example, when automation becomes a reality, paratransit should cost much less to operate and overall mode share for transit has the potential to realize significant increases.

Discussion revealed that the transit lexicon may be further expanded when APT or privately operated transit services emerge from the combined PRT and AV technology as described in Sect. 2.3. The key is not to mince words but to understand the service concept, engineer design, and market acceptance of various shapes and forms of transportation alternatives in the new era.

4.3 Vehicle Assist and Automation

The Vehicle Assist and Automation (VAA) Program, funded by the USDOT, is one of the early exploration and demonstration projects for Automated Bus Rapid Transit technologies. The essential technology for the VAA program is based on the magnetic guidance developed in late 1980s and was demonstrated in the National Automated Highway Systems Consortium Demonstration in San Diego in 1997 [17].

The VAA initiative demonstrates Level 2 automation of steering on transit buses. The driver controls the throttle and speed and braking, while the automated system provides lane keeping and precision docking. The VAA system was tested in Eugene, Oregon. The VAA system was installed in the maintenance yard and a three mile long route.

The VAA technology uses permanent magnetic markers placed in the pavement at 1 m spacing. The costs for installing magnets are approximately $20 to $30 K per mile. The roadway magnetic reference system, sealed in the pavement by epoxy, is low maintenance, as the magnets are passive, reliable and more mature than other automated approaches. One bus was equipped and operated 6–8 h per day over six months in 2014. Full evaluation of the demonstration was conducted, and a report is anticipated.

Preliminary feedback from operators is positive. The VAA field operational test is the real-world deployment of automated bus in revenue service in the United States. Benefits of the VAA application include reduced stress on the driver and ability to use the bus in narrower rights-of-way.

Under the European Union's Seventh Framework Programme for research and technological development, CityMobil2 is a demonstration program of a pilot platform for automated road transport systems [15]. Citymobil2 follows the initial Cybercars concept, enabling the automated vehicles operating without a driver in collective mode. Six months demonstrations were conducted in several European cities in 2015 and 2016.

4.4 Gateway Project in UK

"Innovate UK" was launched in February 2014 to spearhead the Gateway Project in Greenwich, UK, along with two other projects: "UK Autodrive" led by ARUP and "Venturer" led by Atkin. About £19.2 Million government funding was matched by 12 consortium members to create "Innovate UK" and support three year projects. "Venturer" in Bristol is a mixture of physical and virtual environments to test sensor equipment and communication for automated vehicles, with bus comprising the primary vehicle type for data collection. "UK Autodrive" demonstrates interoperability and scalability. It uses LIDAR on carpods and LUZ Pathfinder. It also explores insurance/liability issues and identifies new business models. Finally, Gateway, led by TRL, is the consortium of members from energy, university, insurance, and car makers.

The Gateway project uses a Meridian Shuttle, which is a car-pod with an 8–10 passenger capacity. Trial 1 is the shuttle transport service in 2.2 mile route in the Meridian passing residential/commercial areas. There are shuttles serving a route from the National Maritime Museum to the Royal Observatory. Trial 2 is on the autonomous valet parking in Greenwich. In this system, participants drive to a drop-off point, get out of the vehicle, then send the vehicle off to park using a smartphone interface. Trial 3 is concentrated on urban deliveries using automated van. This trial uses Digicar to test behavior with automation and teleoperation to remotely control vehicles.

4.5 Shared Mobility by Zipcar

While the demonstration projects in prior sections represent the progress along the automation axis, the following two, Zipcar and the SMART project, showcase the development along the shared and sustainable mobility in our modern lives.

As stated by Holmes [6], Zipcar's mission is to "enable simple and responsible urban living", which has been guiding and driving the enterprise for the past

15 years. The Zipcar model is to give people the ability to live in urban areas and access to cars while freeing them from car ownership. Building on the emerging concept of shared economy, Zipcar leverages and utilizes the automobile asset across a large membership body. Since most private automobiles sit idle on average 23 h each day, there are great potentials for those under- utilized capacities to be included in the mobility spectrum.

Started with one green buggy in Cambridge Square in Boston MA, Zipcar grew into 10,000 plus cars, 900,000 members across 470 cities and towns. There are also more than 400 university campus and 50 airport Zipcar locations in the US. Collaborating with many vehicle manufacturers, Zipcar offers a wide range of fleet, about 50 makers and models. Labeled as a millennium brand, Zipcar not only saves money but also has the potential to affect auto ownership and travel behavior in the long run. Zipcar is currently a round-trip service with designated vehicle parking space homes, but is piloting one-way trips in Boston.

So far, Zipcar has been most successful in densely populated areas. The ability to support about 50 members within walking distance is the sweet spot for Zipcar selection; other transportation modes are needed for Zipcar to be effective, and propensity of population to be open to new transportation solutions are essential for Zipcar to survive.

Zipcar does not offer mobility services in isolation. It often works with transit agencies as strategic growth partners to supplement or coordinate intermodal travel for various users. Figure 3 illustrates Zipcar locations along the Redline in Boston subway systems.

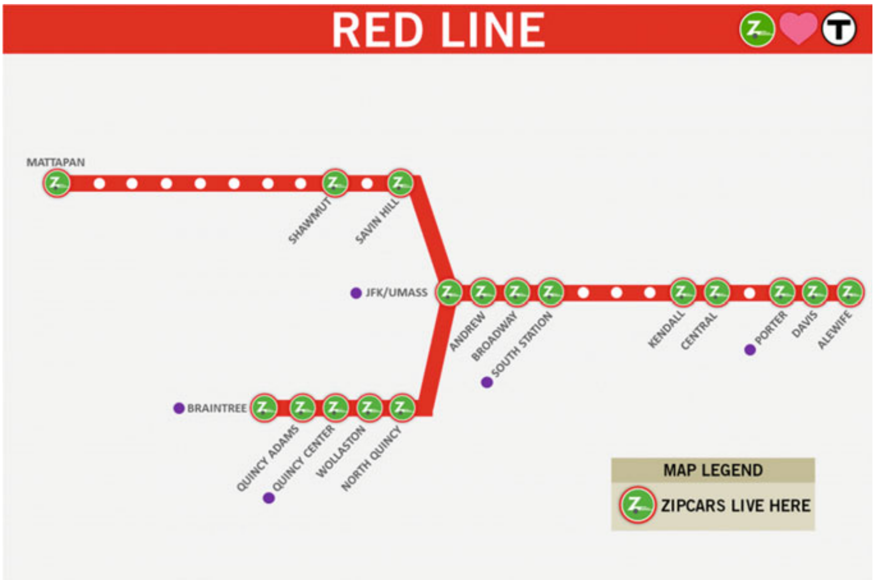

Fig. 3 Zipcar and public transit [6]

According to Shaheen [18], Zipcar users have the ability to reduce their transportation cost from 19 % of the household budget to just 6 %. As low car diet members often make more conscious decisions on travel, Zipcar users often decrease their total Vehicle Miles Travelled (VMT) in an extended time period, such as a year or a quarter, which subsequently reduces energy consumption, decreases emission and increases sustainability.

In the current business model, Zipcars are located near where members live. With Vehicle Automation, Zipcars will come to members, though their efficiency will still rely on population density, to avoid excess unoccupied travel and associated costs. Having accumulated experiences with fleet management, OEM technologies, and user interface, Zipcar will likely be partnering with more stakeholders in the new shared mobility society where community transportation solutions are woven together.

4.6 Sustainable Mobility

Expanding the shared economy and shared mobility themes, the SMART, Sustainability Mobility and Accessibility Research and Transformation, Program [19] focuses on the importance of the users and the seamless utilization of the system by people. In the fast moving, fast changing, and urbanizing transportation spaces today, there are already large quantities of infrastructure and services in place. However, those individual modes and/or elements may not be connected with each other or in the ways that serve users and/or traveler better. SMART provides a platform for initiating ideas, exchanging information, and piloting various projects related to shared mobility, connectivity and automation.

Collaborating with a large number of industries and enterprises, SMART works hard to advance connected multi-modal, IT-enabled transport systems in various locations around the globe. For example, the Veolia TRANSPORT program allows users request the super shuttle via their cell phone apps to arrange door to door transportation services. Another platform, Mobi, is a global B2B databank and network for new mobility enterprises and startups.

With great exposure to multi-culture, diverse economy and multi-modal transportation systems, the SMART experience not only opens our eyes to many, many solutions to various challenges but also made us thinking and trying to answer more specific questions:

- In what contexts do shared use, connected and automated systems make sense?
- How will shared use, connected, and automated systems be integrated within whole systems deployments both in the US and globally?
- What physical and infrastructure foundations and innovations are needed to support shared, connected, and automated systems within whole systems deployments door to door?

- What policy enablers and barriers will come into play in shared, connected, and automated systems? And related, what financing and revenue factors will come into play
- What social, psychological, and marketing factors, challenges, and opportunities will arise?

5 Relationship Between Automated Transit and Shared Mobility

The two day transit and shared mobility session of the 2015 AVS reached its climax when Alain Kornhauser, Princeton, faced off Peter Muller, PRT Consulting, in a debate moderated by Stan Young, University of Maryland. The topic centered around public investment in emerging transportation technologies, specifically a hypothetical matchup between a privately operated, fully-automated vehicle fleet, aTaxis, advocated by Alain Kornhauser, and a publically run PRT, promoted by Peter Muller.

The scenario introduced by Young hypothesized a City Council that is setting aside $1 million for the expressed purpose of a grant to facilitate testing and operation of the aTaxi fleet, or alternatively for planning and preliminary design for a PRT system. The audience of around 60 attendees affiliated with a variety of government, academia, private-sector and research institutions were invited to represent the city council to make recommendations.

Muller advanced his case, articulating arguments in support of PRT largely by contrasting with aTaxis. His arguments centered on the technology and its implementation: readiness, safety, and sustainability. Muller began by asserting the proven reliability of PRT systems, the first of which, Morgantown GRT, has been in operation since the 1970s. Muller also attacked aTaxis as an unproven product still in the testing phase, and not yet ready for implementation on any sort of scale that would provide meaningful benefits to the public at large. He next noted a zero fatality, near-perfect safety track record of PRT systems, again in contrast with the virtually unknown level of safety that may be achieved using aTaxis. He claimed that aTaxis must necessarily be less safe than PRT, since PRT removes conflicts with other vehicles and pedestrians through grade separation, while such conflicts remain when using an aTaxi fleet. Finally, Muller argued that the environmental sustainability of a PRT system was superior to that of an aTaxi fleet, asserting that PRT systems' operation on fixed guideways should provide a more efficient mobility per unit of energy, aTaxis would just add to existing traffic congestion problems, and rides in PRT vehicles would be more commonly shared.

Kornhauser's response began by questioning the viability PRT systems altogether in face of aTaxi competition. Kornhauser used the long-time existence of PRT as an indictment of the technology, citing the construction of around just one system per decade worldwide since its initial inception. On a cost-per-trip basis, he argued, PRT systems would be much more expensive than aTaxis, with significant infrastructure investment requirements; whereas an aTaxi fleet could potentially simply use the existing roads. Moreover, the superior aTaxi flexibility, i.e. an ability to travel on just about any roadway, rather than being confined to a fixed guideway, would provide a greater utility to travelers, thus boosting market share beyond what might be realized by PRT. Kornhauser asserted that aTaxis would be safer than conventional vehicles since they would effectively eliminate human error, and that while they may be involved in a crash at some time in the future, he argued that it's better to provide many people with a substantial safety improvement, rather than a dramatic safety improvement for just a few. Finally, he rebutted environmental claims by arguing that superior market share, along with shared rides, would lead to significant environmental benefits for aTaxis, while noting that PRT also carried added environmental costs in terms of new infrastructure construction.

After a brief discussion by the audience at large, Young called for a vote on the two propositions. As a result, both positions garnered above 40 %, with the privately run shared fully automated vehicle fleet winning out by a handful of votes. Yet with a number of abstentions, neither vision received a clear majority from the room, as both remained below 50 %.

6 Summary

So what exactly is public transit, in light of recent vehicle automation and other technological developments? At the 2015 AVS, many heated and passionate discussions ensued throughout the duration of the transit and shared mobility breakout session, with no firm conclusions drawn. This chapter too arrives at no definitive conclusion to this question, but rather investigates the various characteristics that help define such a system. There may be no singular criterion for what defines public transit, even though this point too was hotly debated, but rather a broad idea that public transit is a transport system that draws from among pool of key elements.

Most people's immediate conception of public transit is likely bus, metro, or light rail, systems commonly seen in daily life. Each of these examples are complete transport systems that are typically operated by a public agency, serve the general public at large, stop at pre-determined stations, and can carry large numbers of persons.

Yet recent innovations and technological developments are changing the face of transit, bringing to light this very question of what constitutes public transit. Must transit services be managed by public agencies? Must they serve the general public, or could use be restricted via membership? Does transit necessarily have to be associated with stations or physical space, or could a transit system exist as a door-to-door service? Do individual vehicles need to carry multiple unrelated travel parties? And if a given transport service connects to a larger transit system, can violations of the former criteria such as public management, unrestricted membership, station-based service, and multi-party vehicle occupancy, be acceptable? If the answer to each of these questions is no, the resulting transport mode is a private car service, an assuredly non-transit mode. Yet if the answer is no to just some of these questions, could a system still be considered transit, and if so when?

To highlight this conundrum, consider four transport systems that are generally accepted as various forms of transit: automated transit networks (ATNs) or PRT, paratransit, privately-run bus, and demand-responsive feeders for line haul mass transit. An ATN may be implemented using a single-party occupancy framework, thus violating the above noted occupancy condition. Paratransit usage is typically restricted to qualified riders, and operates using a door-to-door framework. A privately-run bus system is by definition not run by a public agency. The demand-responsive feeder may be set up to connect single parties to the line haul system, and may use door-to-door service on the non-station end. But if the feeder becomes run by a private entity does it cease to become a form of public transit? What if it restricts use to pre-qualified members, similar to how car-sharing companies like Zipcar and Car2Go operate?

Moreover, as automated on-demand shared use vehicle fleets look set to become a reality, the distinctions between shared mobility and transit systems look to become further blurred. Transportation network companies, such as Uber and Lyft, and carsharing companies, such as Zipcar and Car2Go, may be considered examples of shared mobility systems. Yet suppose their fleets eventually become fully automated and suppose a transit agency similarly determines that it can more effectively serve the public through single-party fully automated vehicles, rather than through a conventional or even automated bus service. While organizational objectives may differ, the only functional distinction may be the public versus private ownership. If that is the case, is this enough of a distinction to declare one form transit and the other not?

In closing, it should be noted that these distinctions between what does and does not constitute transit have real world impacts. The regulatory and public funding environment for transit is dramatically different from the shared mobility space, yet clarity is becoming increasingly difficult due to rapid developments in mobility platforms and may become even more difficult to discern as the pace of vehicle automation accelerates. However, regardless of what new types emerging transportation modes are classified transit, the one near-certainty is that they will bring a host of new alternatives and opportunities to the traveling public.

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