System Initiative on Shaping the Future of Mobility

Reshaping Urban Mobility with Autonomous Vehicles
Lessons from the City of Boston

In collaboration with The Boston Consulting Group

June 2018

Contents

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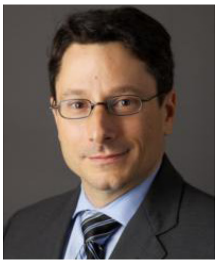
Foreword



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At the World Economic Forum Annual Meeting 2014, a group of chief executive officers from the global automotive industry discussed an intriguing emergent technology: self-driving vehicles. What started as an industry-level discussion quickly evolved into a deep collaboration with The Boston Consulting Group (BCG) on how autonomous vehicles (AVs) will shape the future mobility system in the world's cities.

While AVs have many exciting use cases – truck platooning, for example – we chose to focus on urban mobility because AV technology, combined with new business models, can radically transform not only how people get around cities, but also cities themselves.

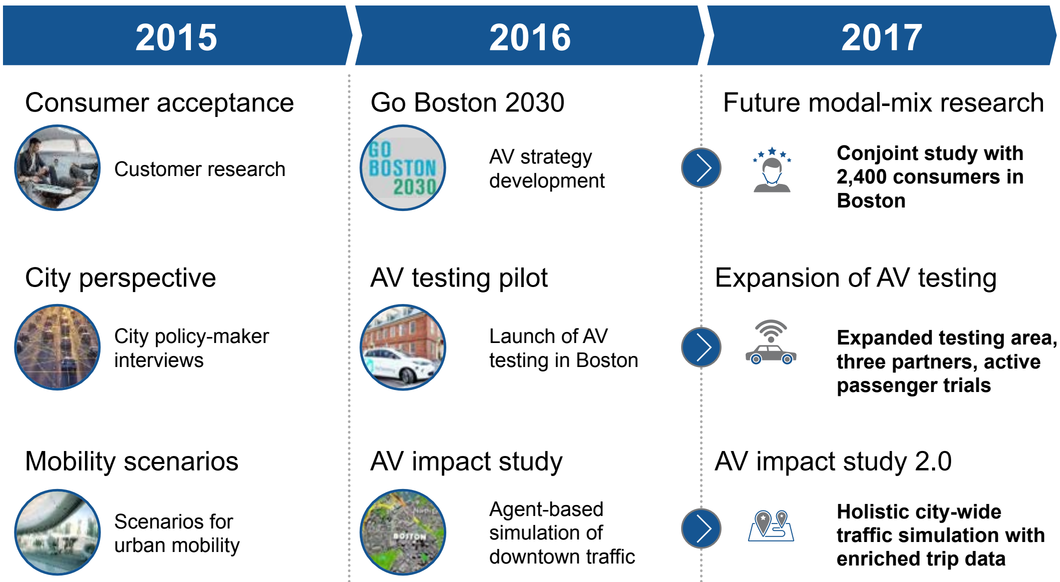
Rather than focusing on AV technology, we first sought to understand the drivers of the move towards AVs, focusing on consumer sentiment and the needs and expectations of cities (Figure 1). For example, we surveyed 5,500 urban dwellers in 27 cities around the world in 2015 to understand their attitudes to this emergent technology, and complemented these findings with interviews of city planners.

In 2016, we shifted our focus from insight to impact by inviting cities to apply to collaborate with our Autonomous and Urban Mobility Working Group (Working Group). Part of the Forum System Initiative on Shaping the Future of Mobility, it is made up of about 35 executives from multiple industries and cities, such as Singapore and Gothenburg, that are leading the thinking on AV policies. We received ten detailed applications from cities around the world, each with a cover letter signed by the city's mayor, to explore all aspects of AV operation and management in an urban environment and ultimately to test AVs on the city's streets. The Working Group decided to partner with the City of Boston, USA.

Our findings, detailed in this report, offer insight and guidance to help both policy-makers and mobility providers reshape urban mobility systems into new versions that are safer, cleaner and more inclusive. As the line between public and private transportation systems in cities becomes increasingly blurred, policy-makers have an opportunity to develop incentives that enhance urban mobility for all city residents, not just the wealthy. Despite the recent tragic loss of life that occurred when an AV test vehicle struck a pedestrian in the United States, AV technology will continue to develop, and cities will continue to embrace this transformational opportunity.

The partnership between the Forum, BCG, our Working Group and the City of Boston has fostered relationships among business and government leaders and yielded deep insight through a series of workshops, reports, videos and CEO- and ministerial-level sessions at the World Economic Forum Annual Meetings in Davos-Klosters, Switzerland. In addition, we have had an impact on Boston's mobility strategy. More importantly, many of our findings are scalable and transferable to other cities. We are grateful to the Working Group as well as our Forum and BCG colleagues for a fruitful collaboration.

Figure 1: Project timeline



Source: World Economic Forum, BCG analysis

Executive summary

This report summarizes findings from a three-year collaboration between the World Economic Forum and The Boston Consulting Group (BCG) to explore how autonomous vehicles could reshape the future of urban mobility. The project built on the collective insights generated from the Autonomous and Urban Mobility Working Group (Working Group) of the System Initiative on Shaping the Future of Mobility, composed of roughly 35 business executives from diverse industries (including automotive, technology, logistics, insurance, utilities and infrastructure) that convened for 10 full-day workshops and numerous conference calls.

From January 2015 through June 2016, the partnership focused on generating insight into how consumers, businesses and cities could benefit from autonomous vehicles (AVs). In July 2016, we partnered with the City of Boston to assess the impact of AVs in the city, to catalyse testing of AVs there and to strategize how the city could foster this technology to achieve its mobility goals. Our findings have important implications for cities around the world.

Mobility-on-demand will account for one-third of trips in Boston

Three waves of consumer research supplemented our collaboration with the City of Boston. A 2015 consumer survey showed strong interest in AVs around the world, with 60% of respondents indicating that they would ride in an AV. Among the many perceived benefits of the new technology, city dwellers valued AVs most because they eliminated the need to find parking.

In 2016, we conducted a series of detailed focus groups with residents of the Greater Boston area. Our findings revealed that families with young children struggle with alternatives to the private car; that consumers are rapidly embracing Uber, Lyft and other ride-sharing services to fill a gap between public transport and private-vehicle ownership; and that consumers are concerned about the public transportation system. Boston residents were generally interested in and intrigued by the prospect of AVs but were somewhat wary about the idea of *shared* AVs.

In 2017, we conducted a large-scale conjoint analysis to forecast the penetration of several types of AVs in Boston's future modal mix. Research participants were presented with variables, such as the length of the trip and the time of day, and were required to make discrete choices about what mode of transport they would use. This approach generated a realistic and granular view of how mobility will evolve in Boston.

Our analysis predicts a clear shift to mobility-on-demand (for both autonomous and traditional vehicles), which will account for nearly 30% of all trips in the Greater Boston area and 40% of trips within city limits in the future. Driving this shift are the cost-competitive nature of robo-taxis and robo-shuttles – especially on shorter trips – and the added convenience and comfort compared with mass transit.

In suburban and other areas outside the city proper, our analysis found that mobility-on-demand will mainly replace personal-car usage. In urban areas, it will replace the use of both personal cars and mass transit, to equal degrees, with the shift creating a risk of increased congestion. Policy-makers must assess and address the potential challenge and identify the right policy levers to influence this transition.

AVs' impact on traffic will vary by neighbourhood and be shaped by policy

To understand the effects of AVs in Boston, we built a sophisticated traffic simulation model that showed the contrasts between current traffic patterns and future scenarios. In 2016, we modelled the effects of introducing shared AVs in the area immediately around Boston City Hall. This study provided interesting initial findings on how the number of vehicles and miles travelled will change. We wanted, however, to gain a deeper understanding of the effects citywide.

In 2017, we used the results of the conjoint analysis – including the projected modal mix of personal vehicles, taxis, private AVs and shared AVs – as input to a more sophisticated traffic model of the entire city. Three important findings emerged:

- Shared AVs will reduce the number of vehicles on the streets and reduce overall travel times across the city. Our findings showed that the number of vehicles on the road will decrease by 15% while the total number of miles travelled will increase by 16%. However, travel time will improve by just 4% on average – not as dramatic as other studies have forecast, but still an improvement.

- Introducing shared AVs will worsen congestion in the downtown area, mostly because these vehicles will be chosen as substitutes for short public transportation trips. Travel time will increase by 5.5% in downtown Boston. In Allston, a neighbourhood outside the city's core, mobility-on-demand will mainly replace the use of personal cars rather than mass transit, and travel time will decrease by 12.1%.

– With the new modal mix, Boston will require roughly half as many parking spots, including those on streets and in parking structures. AVs present an opportunity to rethink the overall design of the city's streets.

Local governments hold the key to influencing these results because they have the power to implement the right policies and incentives. The greatest effects are likely to come from occupancy-based pricing schemes, in which financial incentives discourage single-occupancy rides. This measure could improve citywide travel time by 15%.

Collaboration enables rapid scaling of AV pilots

One of our goals in partnering with the City of Boston was to catalyse AV testing to deepen our understanding of this Fourth Industrial Revolution technology. When Boston formally announced its collaboration with the Forum in September 2016, no companies were testing AVs in the city. In January 2017, AV operator nuTonomy completed the first autonomous mile in Boston, and in November 2017, AVs from the partnership of nuTonomy and Lyft, which provided the booking platform, began travelling with passengers on board. By the end of the year, Optimus Ride and Aptiv were also participating in the pilot, and more than 1,500 autonomous miles had been completed in an expanded testing area. Further expansion of testing continues in 2018, with Optimus Ride's approval for passenger trials counting as one recent achievement.

The key to success in Boston was collaborative leadership. The mayor, along with his transportation team and their counterparts at the State of Massachusetts, committed to embracing a transformational technology, taking advantage of Boston's highly innovative workforce in software and robotics. State and local government worked hand in hand with the participating AV operators to test options, learn, iterate and scale. Other cities can follow this model to introduce AVs onto their roads and successfully collaborate with the private sector.

Integrating AVs into the mobility ecosystem is vital

Cities need to develop a strategy for moving towards an integrated mobility platform. Starting small to prove certain ideas and concepts can help build momentum. The Connected World: Transforming Travel, Transportation and Supply Chains, a joint Forum and BCG project, defined two mobility platform concepts in 2014 that remained very relevant in the Working Group discussions with Boston.

They were:

– Integrated proactive intermodal travel assistant (IPITA), a customer-facing travel planner that enables door-to-door trip planning, booking and ticketing
– Condition-based megacity traffic management (COMET), a holistic system that enables a city to actively influence the modal mix and traffic patterns to manage towards relevant key performance indicators (KPIs) on mobility

Continuing the journey towards an autonomous future

The Forum pursued this collaboration with a city to understand how to unlock AVs' tremendous potential to generate social value (saved lives, saved time and enhanced access for people who are elderly, disabled and disadvantaged). We conclude that cities, nations and the world will need to embrace a regulatory and governance framework for AVs that nudges us towards an "AV heaven" scenario and away from "AV hell".

With more than 100 AV pilots under way around the world, the lessons learned in Boston are timely and relevant. Given the rapid expansion of pilots and advances in technology, commercial robo-taxi service will become available in a few large cities in 2018 despite fatalities that have occurred. Every automotive-related death is of course a tragedy. Indeed, one goal with AVs is to confront and diminish the toll of such deaths, with 1.25 million people killed on the world's roads each year.

AVs enable the greatest transformation in urban mobility since the creation of the automobile. However, their social benefits can be unlocked only if governments understand and implement the appropriate policies and governance structures. Looking ahead, the World Economic Forum Center for the Fourth Industrial Revolution in San Francisco will further the Forum's work on this topic. We will seek partnerships with other cities to continue the journey towards maximizing the societal and user benefits of AVs.

Chapter 1: Understanding consumer adoption of autonomous vehicles

In 2015, our Autonomous and Urban Mobility Working Group (Working Group) focused on consumers' hopes, fears and expectations regarding AVs.[1] We sought to understand how consumers would perceive AVs and what they would consider to be the technology's greatest potential benefits. Futuristic images of AVs from the 1950s show a family facing one another in a car as they chat or play a game. Would that scenario excite modern consumers?

Surveys and interviews

Our survey of 5,500 consumers in 27 cities around the world found that potential AV users are interested in avoiding traffic jams and being productive in the car, among other things. Surprisingly, the survey indicated that the single most important benefit of AVs is not having to look for parking (Figure 2). This finding is significant: it indicates that the mobility system in which the automobile operates is more important than the automobile itself.

Figure 2: Top three consumer benefits of autonomous vehicles

"Drops me off, finds a **parking spot** and parks on its own"

"Allows me to **multitask**/be productive during my ride"

"Switches to self-driving mode **during traffic**"

Source: World Economic Forum, BCG analysis, 2015

AVs have broad acceptance around the world. About 60% of consumers surveyed said they would be likely or very likely to ride in an AV (Figure 3). The proportion varied across countries, from 36% in Japan to 75% in China and 85% in India. A few trends are evident in these findings:

- Countries at the lower end of the acceptance spectrum have had a strong established car culture for more than 100 years, whereas motorization in markets at the higher end is still on an upward trajectory. Our conclusion: a long history with automobiles is hard to relinquish.

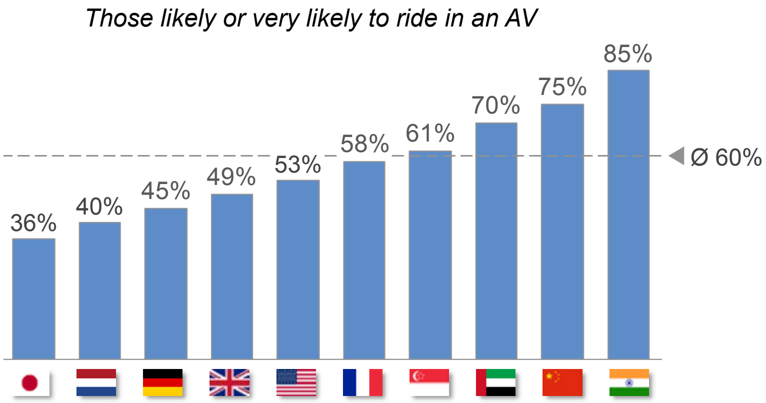
- Some megacities in high-acceptance, rapidly developing economies, such as Mumbai and Beijing, have higher levels of congestion than those in developed markets, such as Osaka and Amsterdam, where the survey revealed lower acceptance of AVs. Our conclusion: heavy traffic and its consequences influence consumers' commuting choices.

At the beginning of our collaboration with the City of Boston, we conducted a series of focus groups to understand Bostonians' starting point concerning mobility and AVs in their city (Figure 4).

That qualitative view was valuable. Our next step was to *quantify* a future mobility scenario for the city. How would the availability of AVs at attractive price points change the use of different transport modes (personal car, mass transit, taxi/ride-hailing)? What would the future modal mix look like? In collaborating with the city, we developed an extensive conjoint analysis to forecast its future modal mix. The main concept of such an analysis is that respondents are forced to make trade-offs between options. For our analysis, the defined options included the vehicle type, the number of other passengers, the overall travel time (including wait and transit times) and the trip's total cost.

Our focus shifted from the simple "Would you ride in an AV?" to the more complex "For a specific trip scenario, which vehicle option would you choose?" The conjoint analysis provided respondents with realistic scenarios and a set of meaningful travel options, including both autonomous and conventional modes. Respondents chose their mode of transportation for each scenario, comparing the specific experience, travel time and trip cost. (See the sidebar "Conjoint analysis methodology.")

Figure 3: 60% of surveyed consumers would ride in an autonomous vehicle



Source: World Economic Forum, BCG analysis, 2015

Figure 4: Focus group findings on mobility and autonomous vehicles

1. **E-hailing fills a gap** between public transport and personal mobility
2. **Sharing a ride is not the preferred travel mode** for most Bostonians
3. Families **do not have good mobility alternatives** to using their private car
4. Residents of all ages are willing and **eager to give AVs a try**
5. People worry about **mixed traffic, cyberattacks and software failures**
6. The **benefits of having an AV system** at an individual level needs to be explained
7. **Dedicated lanes** and **human monitors** give users peace of mind
8. Users expect to **pay as much as they currently pay for e-hailing**
9. Bostonians trust **established local brands** to provide AV-enabled services
10. Car owners are willing to **replace some but not all car trips** with AV-enabled services

Source: World Economic Forum, BCG analysis, 2016

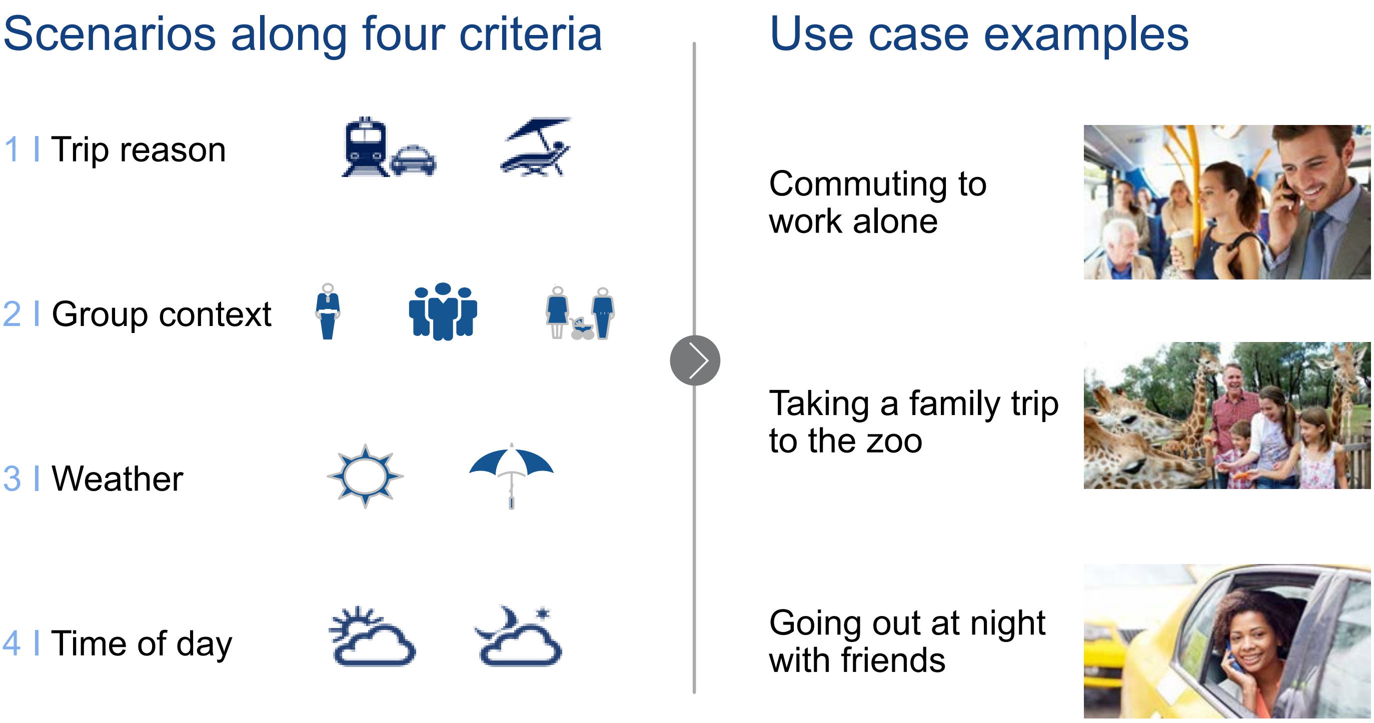
Methodology for the conjoint analysis

Specific scenarios were defined and categorized according to the reason for the trip (work or leisure), the group traveling (alone, with friends or colleagues, or as a family), the weather (clear or inclement) and the time of day (daytime or night-time). In addition, three trip lengths were considered: short trips of up to 20 minutes, mid-length trips of 20 to 40 minutes and long trips exceeding 40 minutes. Each respondent was presented with two scenarios and was asked to select a transport mode for each of them (Figure 5).

For each scenario, respondents were presented with eight transportation modes along with a description, the travel time and the cost per trip.[2] When analysing the survey data, we grouped these into mass transit, personal car and mobility-on-demand (Figure 6). Responses to the conjoint analysis survey were provided by 2,400 Bostonians in a representative sample across gender, age, location and income. Participants could select from the transportation modes presented as follows:

- **Bus/subway:** This choice represents the Massachusetts Bay Transportation Authority (MBTA) bus or subway as you use it today. It runs on a defined path with scheduled stops and no reserved seats. You must make your way to the nearest stop before you can initiate a ride.
- **Commuter rail:** This choice represents the MBTA suburban passenger train system as you use it today. It runs on a defined path with scheduled stops and no reserved seats. You must make your way to the nearest stop before you can initiate a ride.
- **Taxi/ride-hailing:** This choice represents a regular taxi or ride-hailing service (such as Uber and Lyft) as you use it today. You can hail one on the street or via an app whenever you need it. The car has a driver and will take you directly to your destination.
- **Personal vehicle:** This choice represents a regular, personally owned car as you use it today. You must find parking at your destination but can leave personal belongings in it during the day. The personal car could be equipped with personal items, such as child seats.
- **Autonomous personal vehicle:** This choice represents a self-driving personally owned car. You do not need parking at your destination because the car can drive itself back home or to other places. This car could be equipped with your personal items. The autonomous personal car is equipped with modern safety features, including buttons to stop the ride and call for assistance.
- **Autonomous taxi:** This choice represents a self-driving taxi available on demand, similar to taxis today except that there is no driver. You can hail one via an app whenever you need it. It will take you directly to your destination. The autonomous taxi is equipped with modern safety features, including buttons to stop the ride and call for assistance.

Figure 5: Conjoint scenarios and use cases

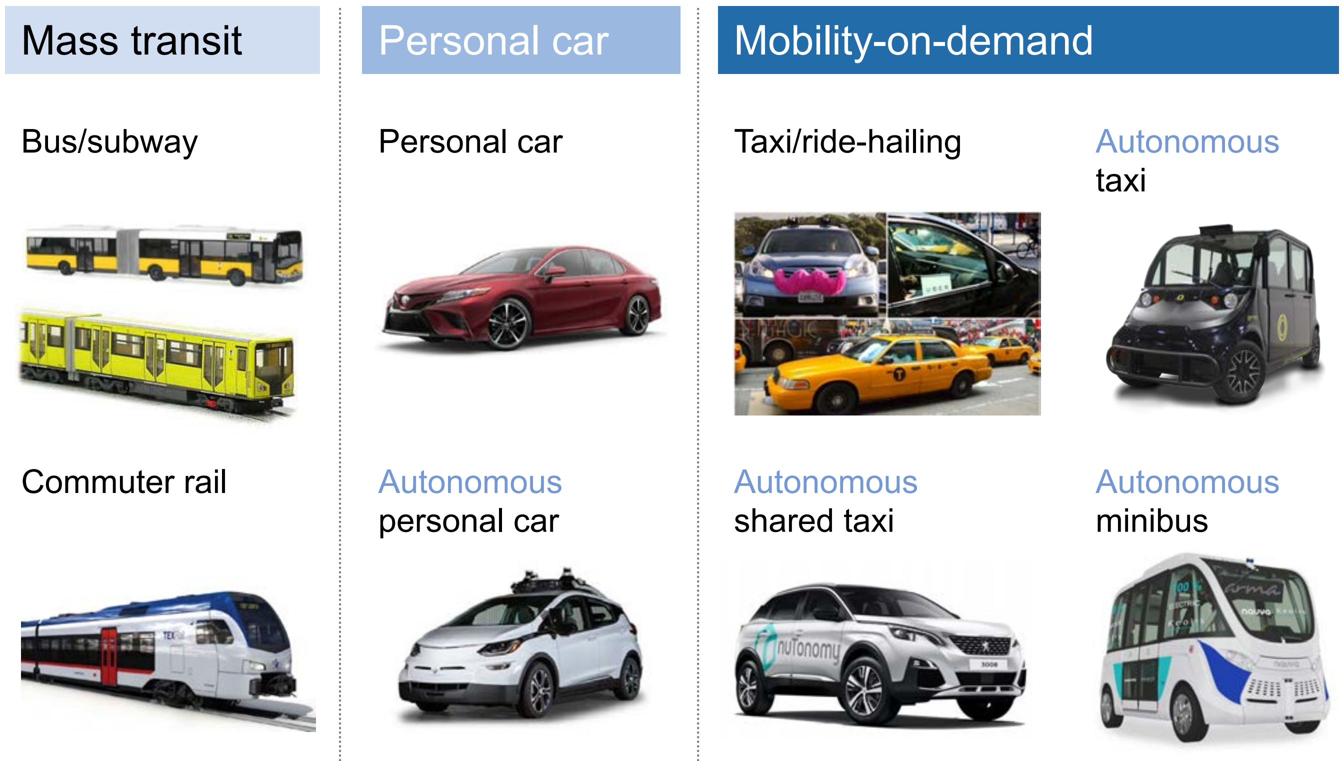


Source: World Economic Forum, BCG analysis

- **Autonomous shared taxi:** This choice represents a self-driving taxi that you share with other passengers whom you do not know (this model is similar to uberPOOL). There is no driver. You can hail one via an app. It will take you directly to your destination. The autonomous shared taxi is equipped with modern safety features, including buttons to stop the ride and call for assistance.
- **Autonomous minibus:** This choice represents a self-driving minibus with 12 to 16 seats that you share with other passengers whom you do not know. There is no driver. You can hail one via an app. It will take you directly to your destination or to a stop in close proximity. The autonomous minibus is equipped with modern safety features, including buttons to stop the ride and call for assistance.

While the media extensively covers research on making traditional taxi and ride-sharing vehicles autonomous, the autonomous minibus, sometimes called a robo-shuttle, is likely to play a vital role in urban mobility in the future. It fills a gap between small-capacity sedans or sport utility vehicles and large-capacity buses or trains. Eventually, the autonomous minibus could replace unprofitable bus routes with a more cost- and energy-efficient solution. Many autonomous minibus trials around the world are using vehicles made by NAVYA, EasyMile, 2getthere, Local Motors and other companies.

Figure 6: Conjoint analysis – eight transport modes



Source: World Economic Forum, BCG analysis

Top findings from the conjoint analysis

The conjoint analysis revealed five major findings:

- Mobility-on-demand will grow to account for one-third of trips in Boston
- Mass-transit ridership will drop in urban areas
- AV adoption – the indication by those surveyed that they would ride in autonomous vehicles – will vary considerably across city neighbourhoods
- Age and income are significant drivers of AV adoption
- The shorter the trip, the higher the AV adoption

The analysis yielded a rich data set for gathering multiple perspectives on potential AV uptake by trip type or neighbourhood.

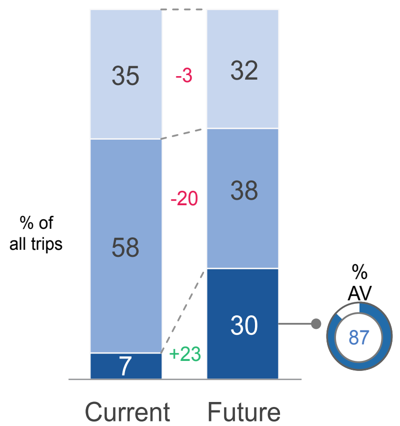
Mobility-on-demand will grow to account for one-third of trips in Boston

The advent of AVs will be a key driver of growth in overall mobility-on-demand, provided by both autonomous and traditional taxis and ride-hailing vehicles. For Greater Boston, use of mobility-on-demand from all sources will rise from 7% of trips currently to about one-third of all trips in the future. (We used 2030 as a reference point for our cost-per-mile calculations.) The vast majority of those trips (87%) will be autonomous, with the remainder coming from traditional taxis and conventional ride-sharing services. The increased use of mobility-on-demand is a big shift in mobility patterns for the city, one that predominantly pulls people out of their personal cars (Figure 7).

Mass-transit ridership will drop in urban areas

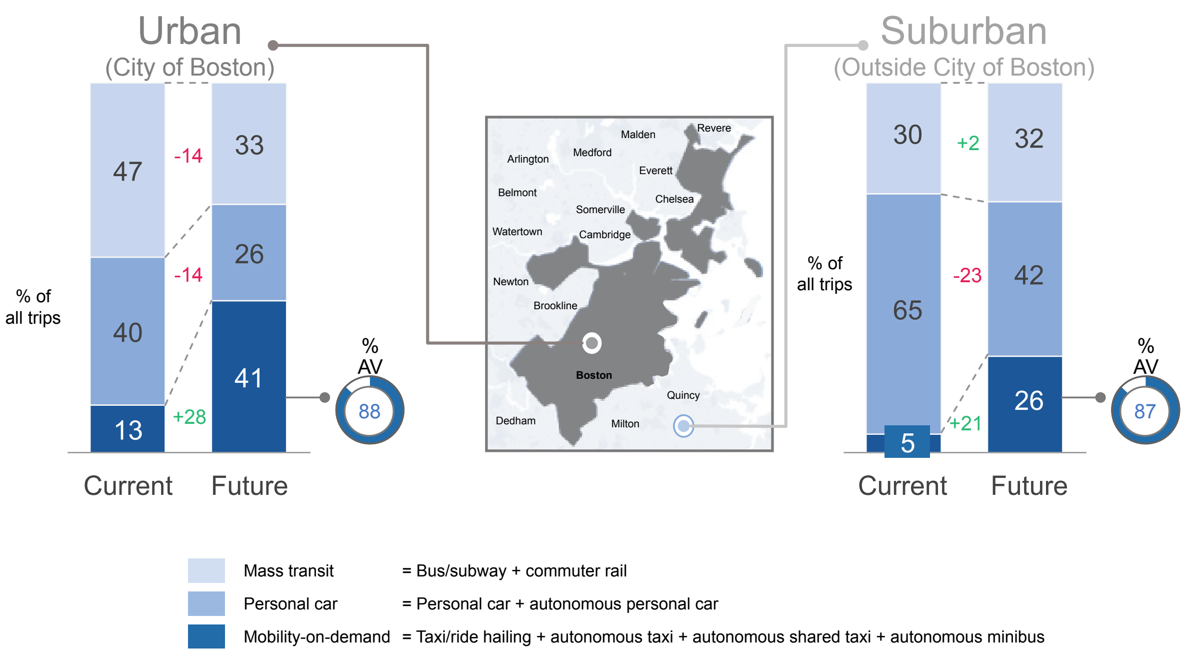
A more granular analysis of the modal-mix numbers shows stark differences between respondents from downtown Boston, those from Boston neighbourhoods like Allston and Dorchester and respondents from the suburbs (such as Newton, Brookline and Medford). Our analysis indicates that mass-transit ridership will decline significantly in urban areas due to the cost-competitive nature of autonomous ride-sharing services that provide door-to-door convenience and a guaranteed seat. Mobility-on-demand will account for more than 40% of trips in urban areas, with an equal defection rate from personal car and mass transit (14 percentage points each) (Figure 8).

Figure 7: The shift in Boston's modal mix



Source: World Economic Forum, BCG analysis

Figure 8: Boston's modal mix – urban vs suburban

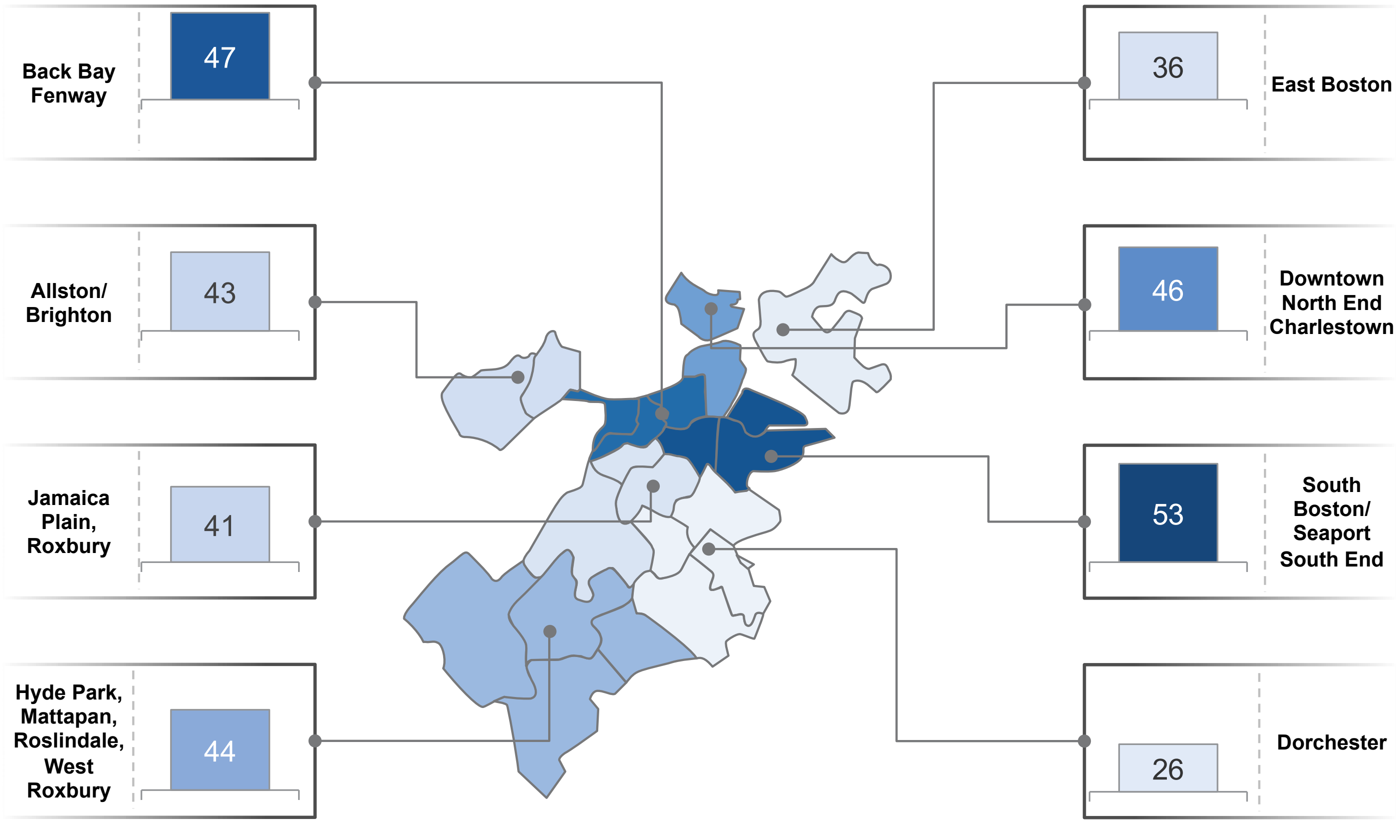


Source: World Economic Forum, BCG analysis

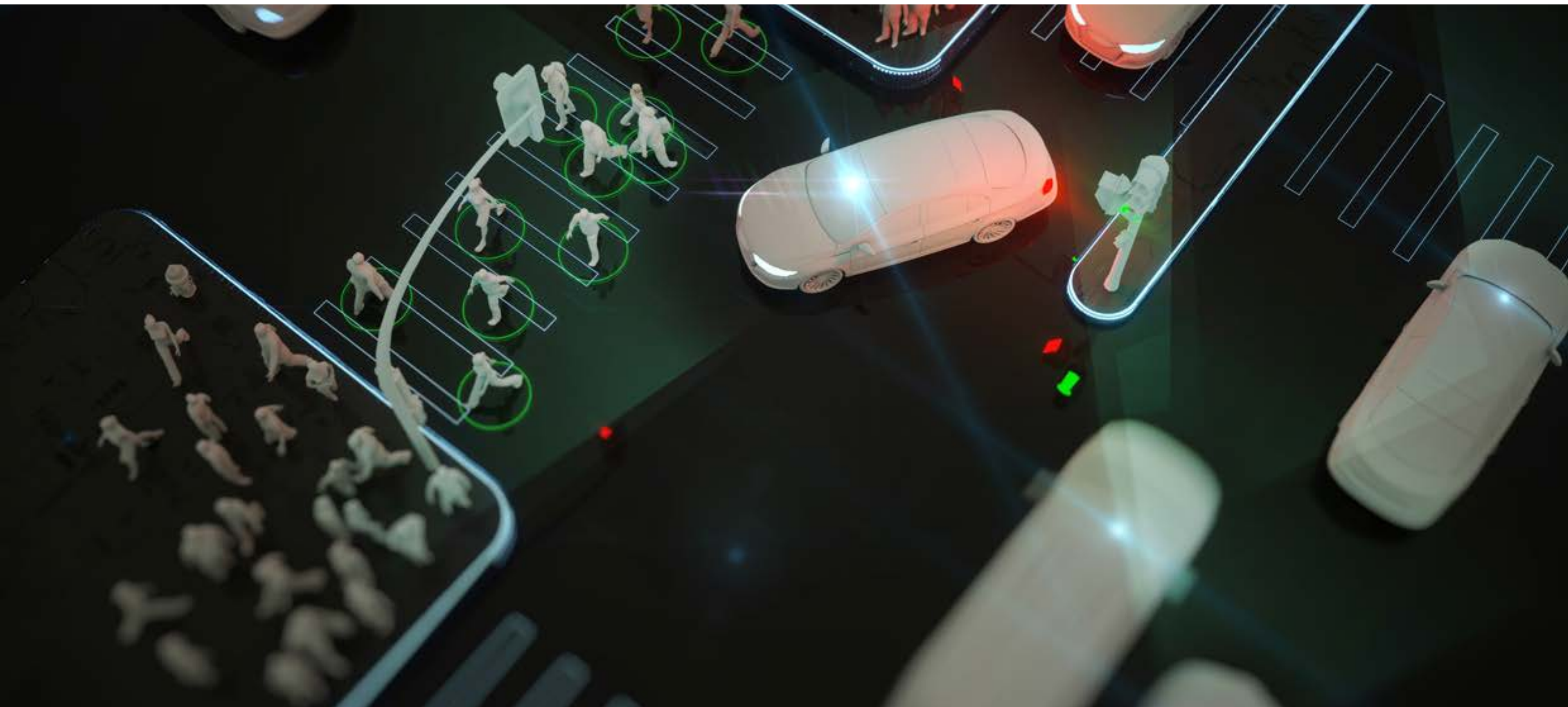
AV adoption will vary considerably across city neighbourhoods

Even within the City of Boston, AV adoption levels will vary significantly by neighbourhood (Figure 9). Perhaps not surprisingly, the highest adoption rate will likely be observed in the South Boston/Seaport area; it was branded as an "innovation district" in 2010 and has attracted businesses and residents connected to innovation industries. Moreover, this part of Boston has limited access to the subway and is the site of the AV testing, so its residents have had the greatest exposure to AVs. This could have inclined them to respond more favourably to AVs, as interaction with them on the street makes AVs less theoretical and more familiar. The Dorchester neighbourhood had the lowest adoption rate (26%), or half that of the South Boston/Seaport area. A variety of factors drove this disparity, including the density of the mass transit, the demographics of each neighbourhood and the duration of a typical trip.

Figure 9: Autonomous vehicle adoption* rates (%), by Boston neighbourhood



* "Adoption" is the percentage of trips for which survey respondents would choose AVs.
Neighborhoods have been grouped based on zip codes, not wards
Source: World Economic Forum, BCG analysis

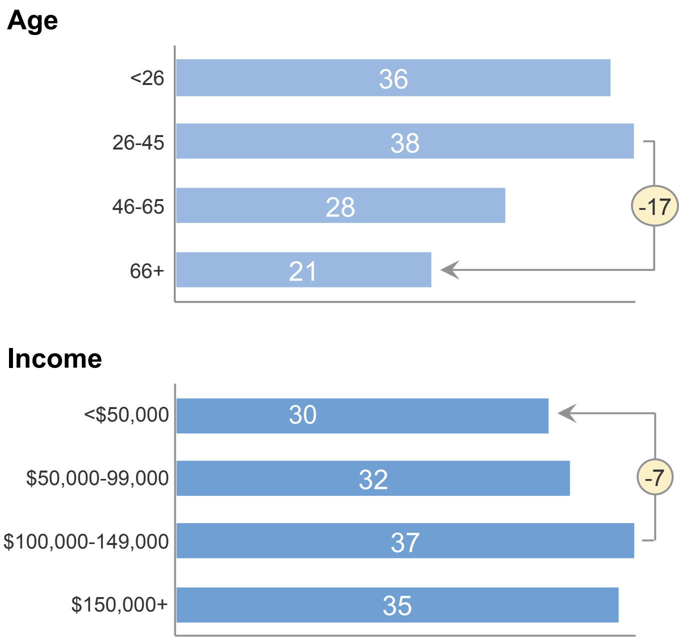


Age is a more significant driver of AV adoption than income

Both the age and income level of respondents showed a correlation to the adoption of AVs; age, though, had a much more pronounced influence (Figure 10). Older people were less likely to adopt AVs, driven perhaps by two related factors. First, higher age brackets are in general less willing to try new technologies; correspondingly, it can be assumed that trust in a driverless vehicle is less pronounced in these age groups. Second, for baby boomers and the previous generation, getting a driver's licence and having the freedom to drive was a major life event, cementing the reluctance to relinquish private-car ownership. Conversely, in younger age groups, the driving mindset is much less engrained; indeed, members of Generations X and Y are already heavier users of ride-sharing services.

The positive correlation between AV adoption and income levels speaks to being able to pay for the more convenient and comfortable ride, even when it is more expensive than mass transit.

Figure 10: Autonomous vehicle adoption rates (%), by Boston demographics



Source: World Economic Forum, BCG analysis

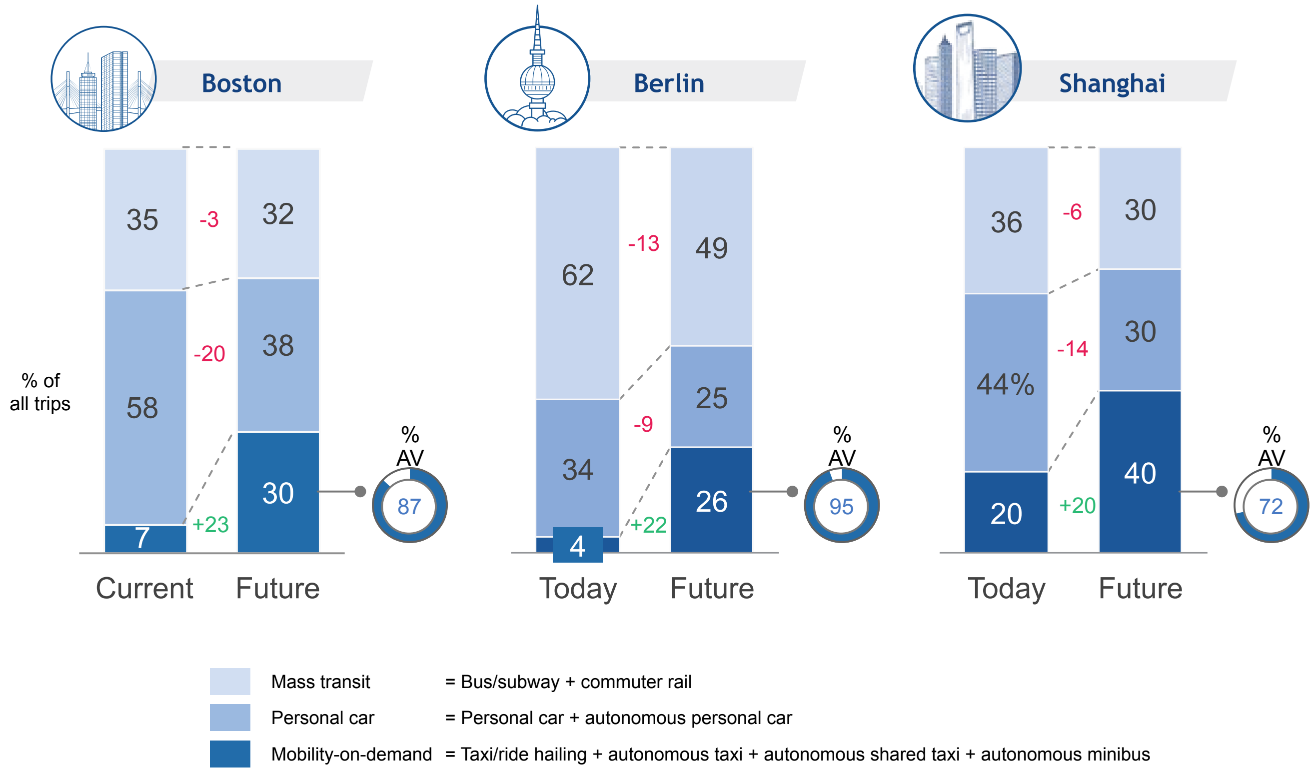
The shorter the trip, the higher the AV adoption

AV adoption drops with increasing (and therefore more expensive) trip length, a reflection of consumer cost economics. The decrease in AV adoption with longer trip length could explain the lower adoption rates among survey respondents from Dorchester, whose residents often have long commutes into the city. In Boston, mass-transit tickets are ride-based, so the fare is a constant $2.25 for bus and subway and $6.25 for commuter rail. The model for mobility-on-demand and personal-car travel, however, assessed cost on a per-mile basis. Thus, these offerings become more price-competitive as the trip time shortens. A shared (with other passengers) autonomous taxi at $0.35 per mile is less expensive than a bus ride for trips under six miles – and, it provides an experience with guaranteed seating and more convenient start and end locations. For longer trips, though, the price gap quickly grows, and adoption drops accordingly (Figure 12). Dorchester is the city's largest neighbourhood, and travel experience varies widely. In addition, the neighbourhood is well served by the MBTA, which has a line connecting the neighbourhood directly with the Financial District, Downtown Crossing and other key destinations.

Boston in a global context

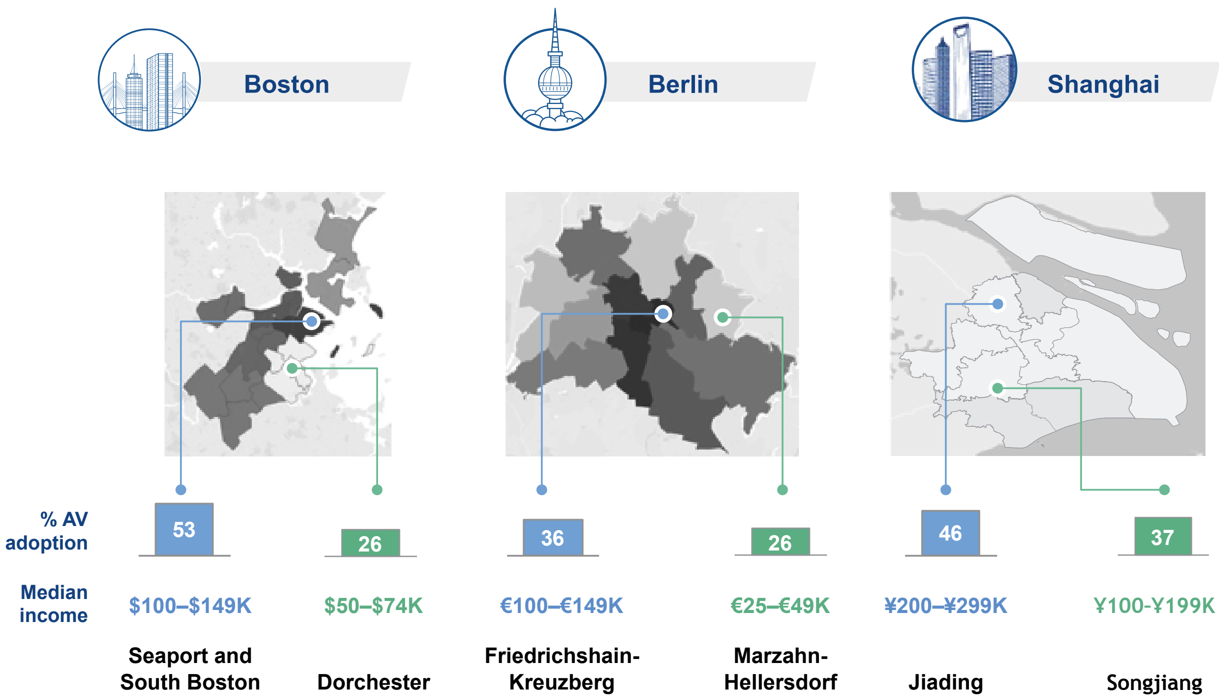
The conjoint analysis was also conducted in Berlin and Shanghai. The results are similar to the key findings in Boston. In all three cities, mobility-on-demand increases significantly: from 7% to 30% in Boston; from 4% to 26% in Berlin; and from 20% to 40% in Shanghai (Figure 11). In all three cities, this gain in share of mobility-on-demand comes at the expense of lost share in both mass transit and personal car. Contrasting higher-income versus lower-income neighborhoods in each of the three cities shows AV adoption rates declining significantly in the lower-income neighborhoods, with Boston showing the most significant decline (Figure 12).

Figure 11: The shift in modal mix, comparison of Boston, Berlin and Shanghai



Source: World Economic Forum, BCG analysis

Figure 12: Autonomous vehicle adoption rates (%) and income, comparison of Boston, Berlin and Shanghai



Source: World Economic Forum, BCG analysis

Chapter 2: Quantifying the impact of autonomous vehicles

How will AVs change the traffic flow in a large city like Boston? Will they fulfil all the much-anticipated promises for cleaner, safer, more accessible and more reliable transportation? Or will they worsen congestion by converting mass-transit-system passengers to car users? These are among the key questions that Boston and cities around the world seek to answer.

To explore these questions, the World Economic Forum and BCG completed two AV impact studies. Starting in 2016, we developed an agent-based simulation[3] of traffic and vehicle-to-vehicle interaction in downtown Boston, with results detailed in the October 2017 report, *Making Autonomous Vehicles a Reality: Lessons from Boston and Beyond*.[4] In 2017, the project expanded the model from downtown to the entire city and simulated a future scenario rooted as closely as possible in real-world data and consumer research.

Fewer cars driving longer distances

The 2017 AV impact study included the entire City of Boston and relied on key inputs (see "AV impact study methodology" for more details):

- A 142 km^2 (54.83 mi^2) area (city limits)
- 2 million daily passenger vehicle trips (data from INRIX, a mobility data provider, and from the City of Boston)
- 10,000 commercial vehicles daily (data from INRIX and UPS)
- A future modal mix derived from the 2017 conjoint analysis
- A 6.3% increase in vehicle throughput (based on a 37.5% AV share)

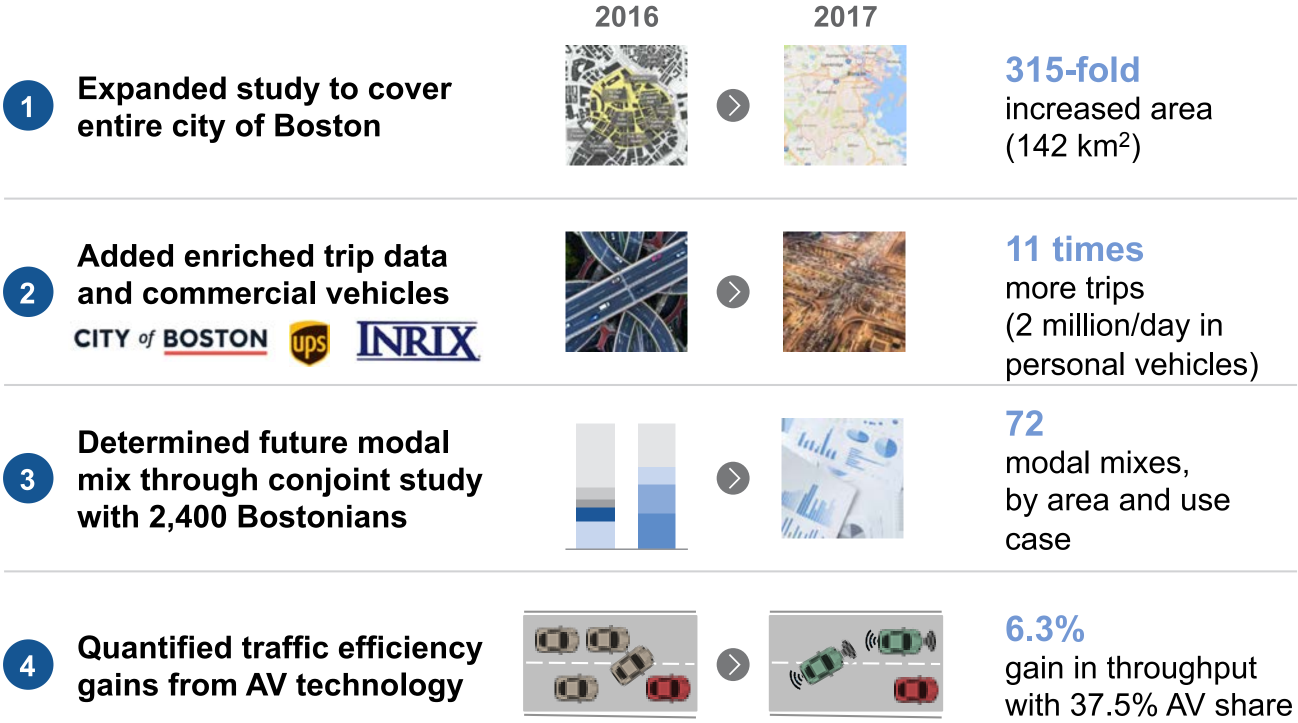
AV impact study methodology

In 2016, the project completed an agent-based traffic simulation for a 0.5 km^2 (.19 mi^2) downtown area around Boston City Hall. A granular approach, it included vehicle-to-vehicle interaction and modelled each vehicle's behaviour – for example, how long a car waits in an intersection before making a left turn. The simulation looked at a revolutionary AV adoption scenario that assumed no personal cars, and an evolutionary AV adoption scenario that assumed reduction of personal cars by one-third. The goal was to determine the impact on the number of vehicles, distance travelled, parking spaces needed and overall travel time.

In 2017, the simulation model was significantly improved to better represent real-life scenarios and provide a holistic understanding of Boston traffic (Figure 13). Among the changes:

- Expanding the geographic area from just 0.5 km^2 (.19 mi^2) around City Hall to the entire City of Boston, representing a 315-fold increase
- Adding trip and vehicle data sets from the city and our Working Group partners UPS (logistics provider) and INRIX (mobility data provider) to better capture the actual movement of vehicles on Boston's streets; this data enabled modelling 2 million daily trips in personal vehicles (versus 180,000 in 2016) and adding 10,000 commercial vehicles not included in 2016
- Leveraging the conjoint analysis data from Boston rather than using theoretical scenarios (see Chapter 1)
  - 72 individual modal mixes were included in the impact study
  - 12 neighbourhoods, 3 trip lengths and 2 trip occasions were included in the impact study to capture the diversity of modal-mix changes identified in the conjoint analysis

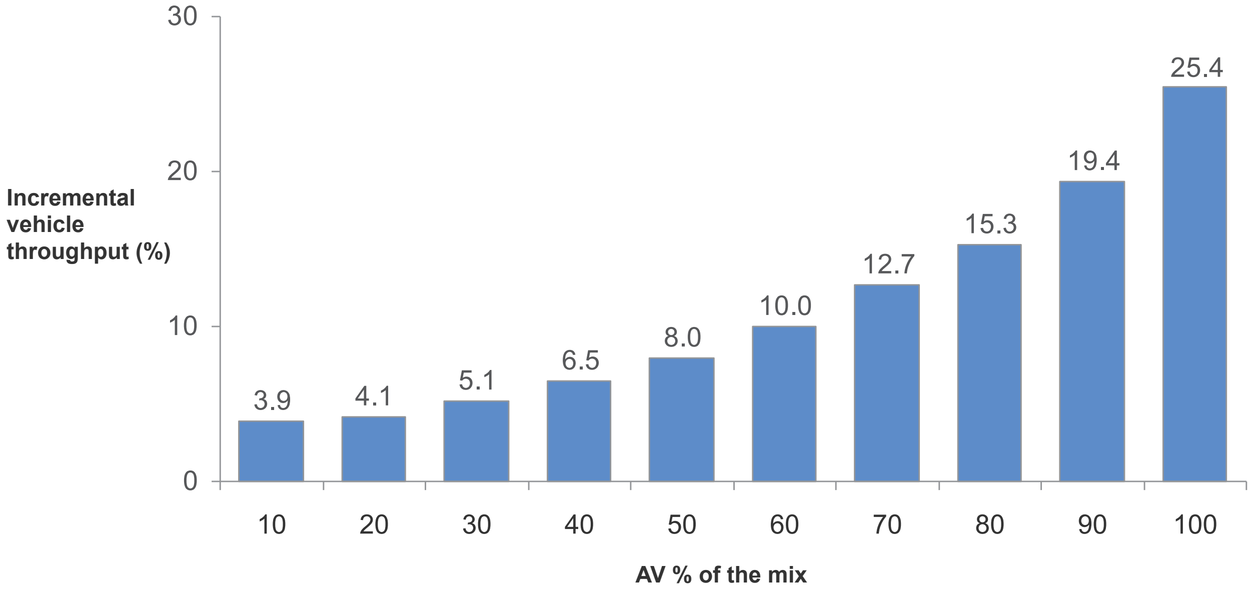
Figure 13: Expansion of autonomous vehicle impact study



Source: World Economic Forum, BCG analysis

Finally, we set out to put a number on the traffic flow efficiency gained from AVs. AVs act rationally and are not slowed by human driver behaviours such as spectatorship ("rubbernecking"), inefficient lane merging or double parking. Therefore, the throughput of AVs for the same segment of street at the same speed would be higher than that of conventional vehicles. To quantify this impact, we completed a separate set of 1,000 simulations of common traffic situations on a three-lane road. These showed an increased throughput potential of 25.4% in a fully autonomous fleet environment (Figure 14). For our forecasted AV percentage of the mix (37.5%, from the conjoint analysis), we would see a 6.3% incremental improvement in throughput.

Figure 14: Autonomous vehicle efficiency gains



Source: World Economic Forum, BCG analysis

The simulation, built by BCG's advanced analytics arm BCG GAMMA, included a large geographical area, 2 million trips and more than 600,000 vehicles, and ran almost in real time. It took about 20 hours to simulate 24 hours of traffic. Running the simulation with the granularity of street-specific traffic data generated equally granular insights.

The main findings of the impact study are structured along four KPIs (Figure 15):

Number of vehicles on the road
The number of vehicles on the road will decrease by 15%, driven mainly by the shift from personal car to mobility-on-demand, as outlined in the conjoint analysis. This value lies somewhere between the evolutionary (11%) and revolutionary (28%) scenarios in the 2016 study.

Vehicle distance travelled
A 16% increase in the distance vehicles travel will result from additional trips to pick up or drop off passengers in mobility-on-demand offerings and from empty miles driven by mobility-on-demand vehicles between passenger rides. The value is higher than those in the 2016 evolutionary (13%) and revolutionary (6%) scenarios of the 0.5 km^2 (.19 mi^2) downtown area around City Hall, driven by a higher mix of shared AVs. Those AVs have additional mileage for picking up and dropping of passengers as well as empty mileage while waiting for requests.

Parking spaces needed
The sizeable decrease (48%) that will occur in the number of parking spaces needed reflects the reduction of trips in personal vehicles requiring a parking spot. Many of those trips, especially regular commutes, will convert quickly to mobility-on-demand scenarios where the vehicle keeps travelling onwards. The value is comparable to the decrease found in the revolutionary scenario (48%) and higher than that in the evolutionary scenario (16%) from the 2016 study. The total parking space inventory in Boston is currently about 10 km^2 (3.86 mi^2) including street and garage parking.

Average travel time
The simulation predicts that average travel time will decline by 4%. Although fewer vehicles will be on the road, and those vehicles will drive more rationally and increase throughput (all positive impacts), the vehicles will travel longer distances (a negative impact). This decrease in travel time is lower than the value in the 2016 evolutionary (11%) and revolutionary (30%) scenarios. One reason is that commercial vehicles, such as delivery vans and garbage trucks, have a very consistent trip load throughout the day (from 07.00 to 19.00) and thus contribute significantly to slowing down traffic, an effect not accounted for in the 2016 study of the downtown area around City Hall. Another reason is that our future modal mix is now rooted in the conjoint consumer study instead of in an assumed future-state scenario. So, we incorporated the transition from mass transit to mobility-on-demand, which adds vehicles to the mix.

Addressing congestion

The more granular and holistic approach to the AV impact study provides valuable insight that will allow policy-makers to more proactively address the risk of increased congestion through AVs. The results of the impact study raised two important questions:

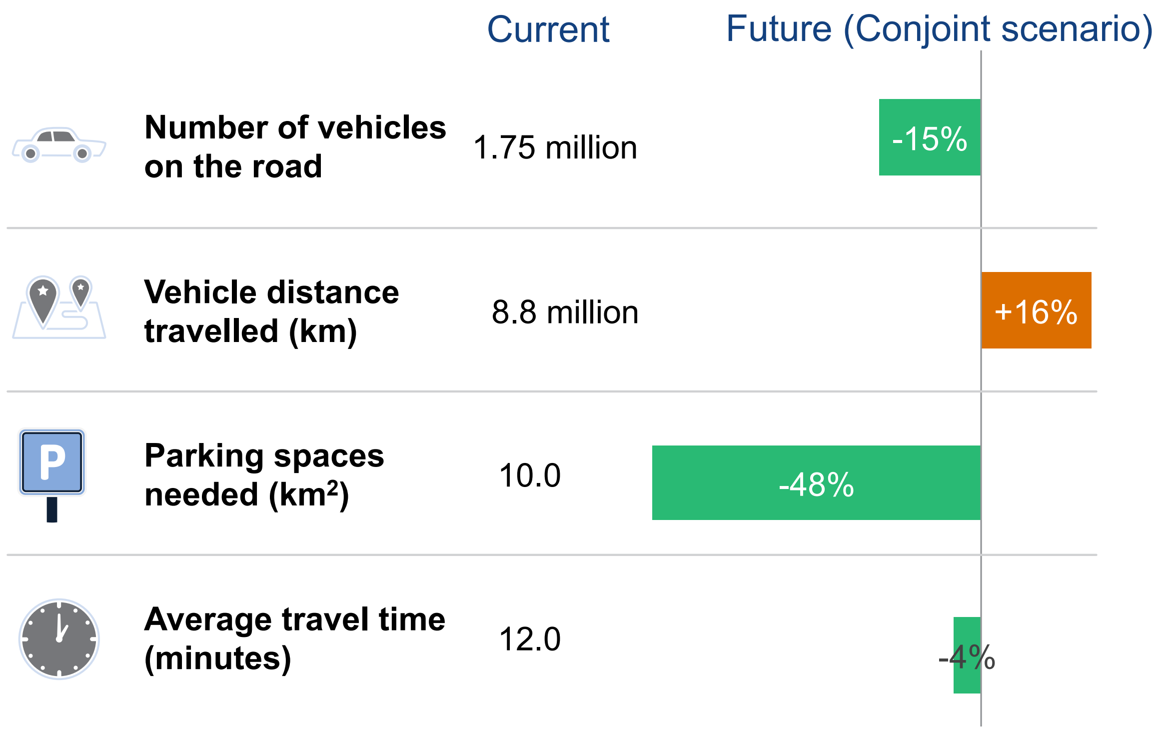
- Where will the risk of congestion occur?
- What policy levers can reduce this risk?

Identifying the risk of congestion by disaggregating changes in travel time

The modal-mix shift observed in the conjoint analysis is directly correlated with the travel time improvement identified in the traffic simulation. The citywide 4.3% decrease in travel time is based on a relatively stable share of mass-transit trips and a 20% drop in personal-car trips, which become mobility-on-demand trips. Still, in the future scenario, nearly 40% of trips will rely on personal vehicles, which limits the opportunity to reduce congestion (Figure 16).

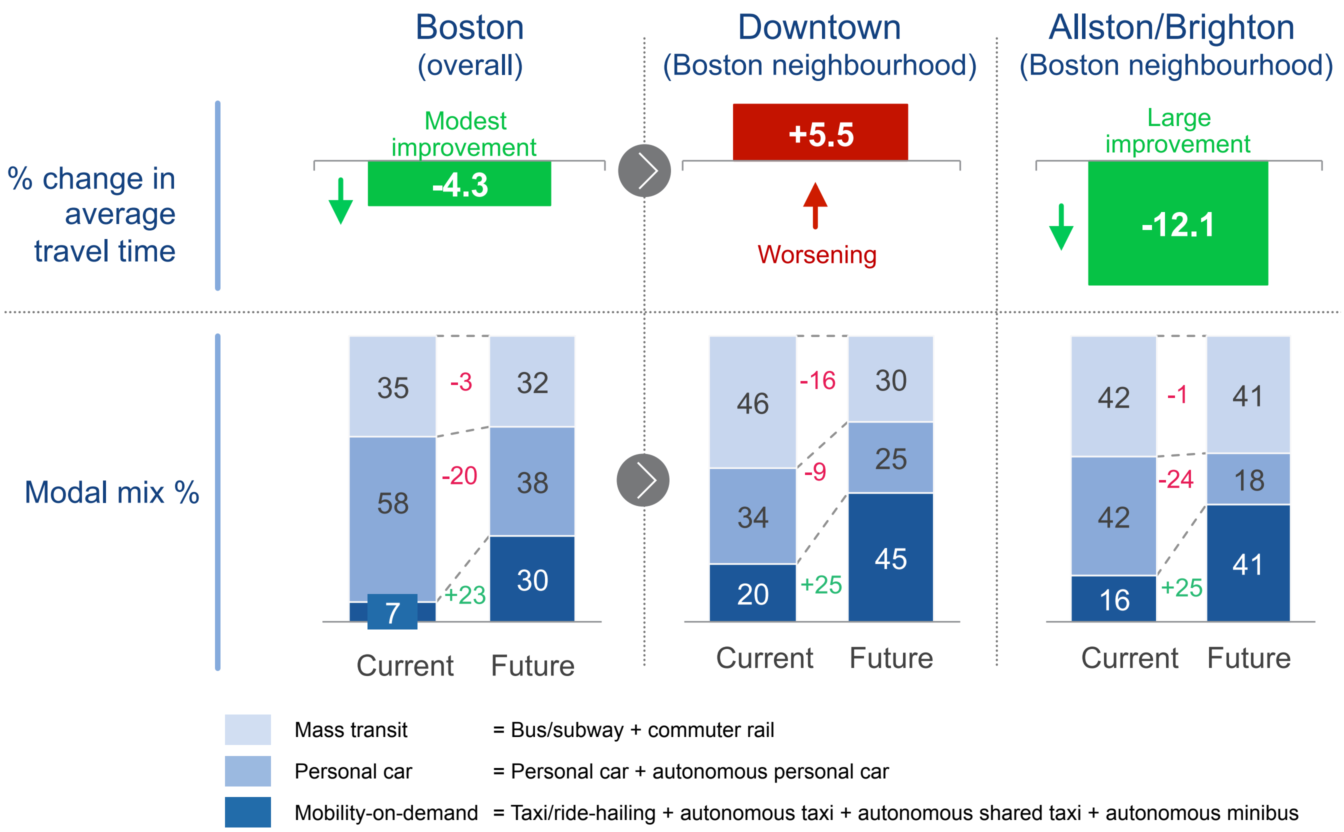
Examining how future travel time varies by neighbourhood offers city planners insight for developing policy levers to address congestion. Allston, a neighbourhood in the far west of Boston, has many commuters who use mass transit or personal cars to travel into the city. In the starting modal mix, about 40% of travel to and from Allston is via mass transit – very high for a United States city neighbourhood – and that proportion remains flat going forward in the model (not many users defect). Several factors most likely account for this behavioural pattern: the average trip is rather long; the price gap between mass-transit and mobility-on-demand alternatives is significant; and the neighbourhood has a significant student population that walks, bikes or uses mass transit to nearby university campuses.

Figure 15: Key outputs of the autonomous vehicle impact study



Source: World Economic Forum, BCG analysis

Figure 16: Disaggregating travel time impact



Source: World Economic Forum, BCG analysis

The use of personal cars in Allston presents a different story; personal-car use is less cost-competitive than mobility-on-demand, especially given the city's significant parking costs. Consequently, the use of personal vehicles will drop by 24% in the future scenario as consumers choose instead to share vehicles. An increase in shared vehicles will reduce the number of cars on the road, resulting in reduced travel time (an average improvement of 12.1%). That improvement is visible in a snapshot of Allston from the traffic simulation, where green highlighting indicates free-flowing traffic and red highlighting shows congestion (Figure 17).

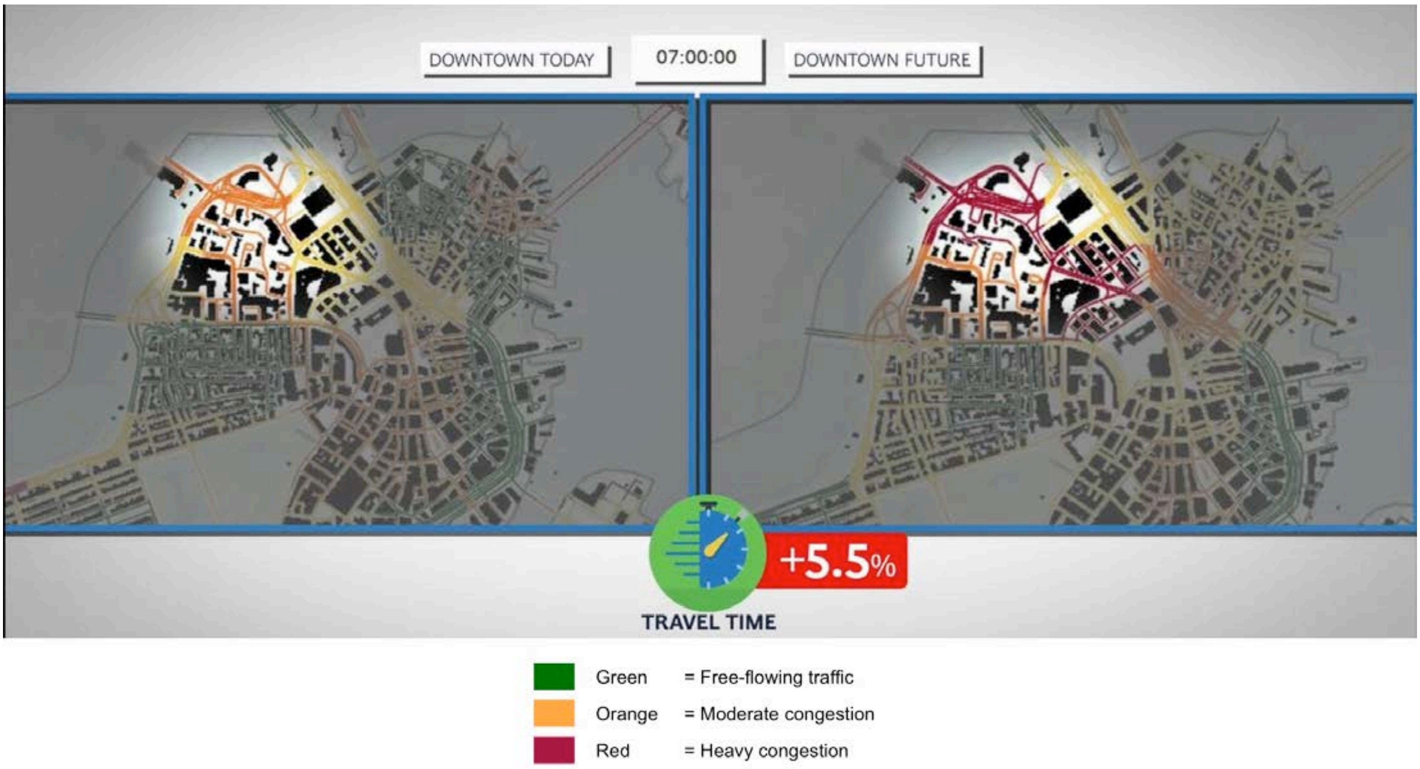
Conversely, in the downtown area, shorter trips account for most travel. For those trips, mobility-on-demand presents strong competition to mass transit because it is more convenient (door-to-door service without connecting or walking) and more comfortable (a guaranteed seat and fewer fellow passengers) at a comparable cost per trip. Consequently, the shift to mobility-on-demand in the downtown area comes more from travellers abandoning mass transit (a 16% decline) than from travellers abandoning personal-car travel (a 9% decline). A decrease in mass-transit use takes passengers off high-capacity trains and buses and moves them into 4- to 16-seat AVs, which increases the number of road-based trips, adds to congestion and increases travel time by 5.5%. That effect is visible in a snapshot of downtown traffic, where more streets are highlighted in red, which represents congestion (Figure 18).

Notably, the simulation shows that introducing AVs and shared AV vehicles into the Boston vehicle mix will improve travel times for the city overall but increase travel times (increase congestion) in the downtown area. This has significant implications for city planners as they consider how to prepare for a future that will surely include shared autonomous mobility options for residents. In particular, the Go Boston 2030 plan aims for an increase of public transit use of 34% by 2030. Without deploying some combination of policy levers, this goal will be difficult to achieve.

Figure 17: Allston impact

Source: World Economic Forum, BCG analysis

Figure 18: Downtown Boston impact



Source: World Economic Forum, BCG analysis

Policy will determine the degree of impact

If implementing AVs is left simply to consumer preferences and market forces, the impact will vary by neighbourhood, with congestion and travel times actually getting worse in the downtown area. Local and state lawmakers must put forth policies and incentives that maximize the benefits of AVs and address these imbalances. However, cities are currently considering policies that are reactionary and merely tactical; these include taxing ride-hailing as this service grows or raising subway fares as ridership drops. These approaches are not forward-looking and fail to address the mobility equation strategically.

Policy-makers can turn to many options to address the impact on travel time, including delivering innovative public transit offerings, such as dynamic route minibuses ("microtransit"). Potential policy levers include:

– **Creating an occupancy-based pricing scheme:** Cities could implement financial incentives that discourage riding alone, whether in a personal car or in a mobility-on-demand vehicle. Making single-occupancy rides more expensive shifts passengers to both mass transit and shared mobility-on-demand rides. Once the per-mile price of single-occupancy modes is increased, the conjoint analysis indicates that this modal-mix shift will occur. For example, a $0.50-per-mile upcharge for single-occupancy modes in downtown Boston would result in a 7% shift of trips from robo-taxis to shared robo-taxis and autonomous minibuses.

– **Converting on-street parking:** The shift to mobility-on-demand correlates to a reduction in personal cars, which reduces the need for parking by 48%. What happens with the freed-up space? Options vary depending on whether the parking spaces are in garages or on the street. Garage and on-street parking each account for about 50% of Boston's parking space. Reducing on-street parking areas opens new opportunities for the curb: dedicated drop-off and pick-up zones for mobility-on-demand, urban logistics loading zones, bike lanes, dedicated lanes for surface mass transit or even conversion to green space. During peak times at rush-hour, curb space could be converted to driving lanes to increase street throughput capacity. Our estimates show that about 20% of on-street parking could be leveraged for conversion to driving lanes during peak hours.

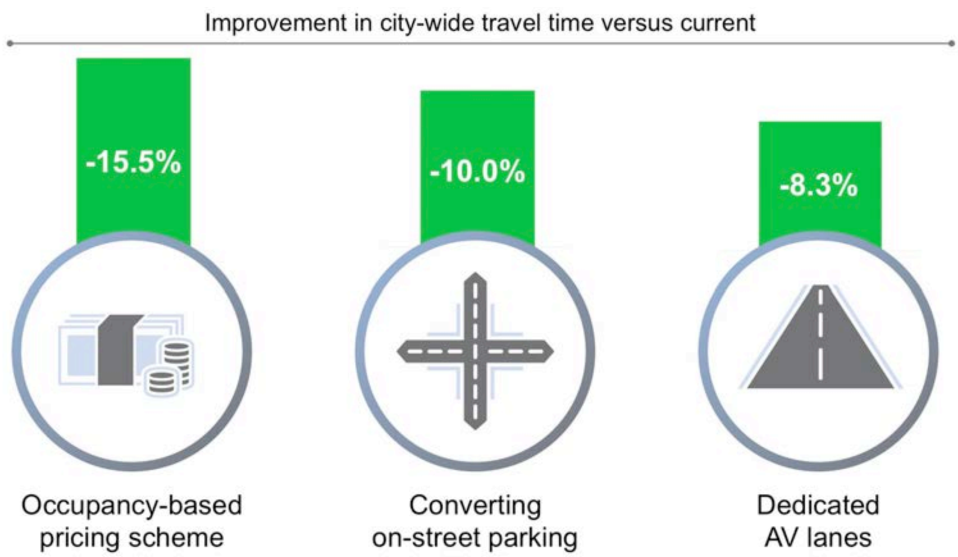
– **Dedicating lanes for AVs:** The concept of high-occupancy-vehicle lanes is fully established in cities and on highways; bus lanes and lanes for vehicles with two or more passengers, respectively, are common. Similarly, lanes could be dedicated for all AVs, or specifically for shared AVs. In those lanes, AVs could leverage the full efficiency potential of 25% higher throughput (Figure 14), thus increasing the throughput of all vehicles.

While an overall policy design will require more in-depth discussion, the simulation used one assumption for each of the three above policy levers – for example, converting 20% of on-street parking to driving lanes. To compare the effects on travel time, we subsequently reran the entire simulation of Boston traffic in three different ways, each with the addition of one of the three above policy levers. Results showed that occupancy-based pricing promises the greatest travel-time improvement, at 15.5%. Converting on-street parking or dedicating lanes to AVs would at least double the 4% travel-time improvement compared to making no additional policy changes (Figure 19).

This analysis is a starting point for the ongoing dialogue between the public and private sectors on how to maximize the benefits of AVs. While the concerns of cities and mobility-on-demand companies seem to be at odds, areas of common interest and mutual benefit exist. For example, with occupancy-based pricing, the city has an interest in increasing the number of passengers in each car and would put in place a tax or toll to make the cost of traveling lowest when occupancy is highest (e.g. four passengers in an average sedan). Mobility providers have an interest in operating their rides profitably and gaining share versus rides of one passenger. Were mobility providers like Uber and Lyft to develop the best-in-class algorithm to get four people in a car, they would benefit from the lowest tax charges while increasing their utilization.

Though simplified, this example demonstrates that a common win-win ground can be explored. Mobility providers must create value for cities and not be perceived simply as a threat to public transit.

Figure 19: Effect of policy levers



Source: World Economic Forum, BCG analysis

Chapter 3: Scaling up an autonomous vehicle pilot in Boston

Just four months after Boston announced its collaboration with the World Economic Forum and BCG,[5] the first AV test vehicle completed its first autonomous mile within the city. Great collaboration between policy-makers at the local and state levels was required to create a regulatory framework that allowed for testing and operating AVs. It also took collaboration with the private sector, such as with AV operators nuTonomy and Optimus Ride (two local companies originating out of the Massachusetts Institute of Technology [MIT]), that had advanced the development required to have AVs ready for operation in Boston. After just over a year of the AV pilot, we can highlight key milestones of its scaling and identify best practices applicable for cities anywhere in the world that seek to pursue AV testing.[6]

From the first mile to more than a thousand miles

The State of Massachusetts and the City of Boston jointly defined a testing plan that included an expansion of geography, mileage, testing conditions and passengers in the vehicle. This plan was adjusted slightly for each individual AV company that signed a memorandum of understanding with the state and the city, but it served as a clear framework for testing expansion. Each phase included a clear definition of scope[7] and the requirements the AV company needed to demonstrate to the city and the state to get approval for the next phase. nuTonomy implemented a multiphase approach to AV testing on Boston's streets. As the first company to launch pilot testing, it provides an example for how AV testing is completed.

Phase A

This first phase focused on ensuring the technology was ready for on-street testing. It included extensive high-definition mapping of the testing area and populating the autonomous-driving software with the collected data.

Phase B1

On 4 January 2017, nuTonomy launched this phase of on-street testing. It completed the first autonomous mile in Raymond L. Flynn Marine Park, an industrial park along the South Boston Waterfront. The park was chosen as the launch area because it includes public roads and a relatively straightforward driving environment with few pedestrians, a low vehicle volume and few traffic lights or complex intersections. Phase B1 included 100 miles of good-weather daytime testing throughout January 2017.

Phase B2

Phase B2 expanded testing to include night-time and mixed-weather driving. Because Phase B2 launched during February, the cars encountered some snowy days, which proved to be one of the technology's greater challenges. Snow not only alters the vehicle's traction but also changes how the vehicle's cameras and sensors perceive the street. In Singapore, where nuTonomy also has ongoing AV testing, snow is not a challenge.

Seagulls also presented another challenge to AV testing in Boston. They stood on streets and did not fly away when nuTonomy's quiet electric car approached. The car's cameras and sensors simply detected an object and came to a full stop, creating a standoff. nuTonomy's engineers programmed the car to make a small move forward to prompt any seagulls to fly away.

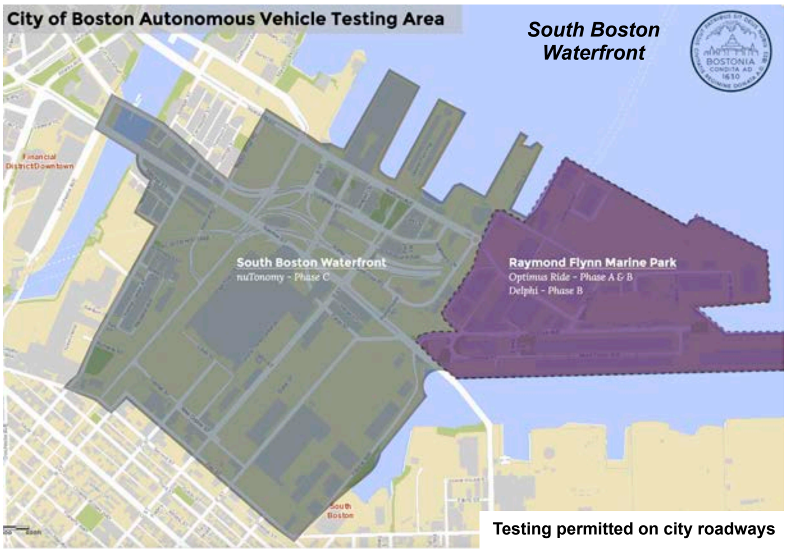
Phase C

In March 2017, nuTonomy was approved for this phase, which covered the larger South Boston Waterfront (Figure 20). This expanded testing region included not only more challenging traffic and street layouts, but also Boston's South Station – a deliberate attempt to test the use of AVs in a multimodal transportation environment. More than 200,000 commuters arrive daily at South Station, one of the city's two major commuter rail stations, and continue their journey to offices across Boston. Given that 90% of commuter rail passengers continue their trip on foot, the cars encountered very dense pedestrian traffic, a big change from the quiet neighbourhood of Marine Park (Figure 21).

Throughout 2017, nuTonomy continued to expand its testing. The company announced its partnership with Lyft at mid-year, a collaboration that sought to define user interactions with AVs. It also sought to make nuTonomy vehicles available on the Lyft platform, which began offering AV rides much earlier than expected. In November 2017, the first Lyft users requesting a ride within the Seaport area were matched with an autonomous nuTonomy vehicle. The initial sentiment has been overwhelmingly positive; for example, the first legally blind AV passenger described his rider experience with "all the positive words I can think of".[8]

Figure 20: nuTonomy autonomous vehicle testing plan

Testing area in Boston



Test plan

- **A** Off-site testing
- **B** 200 miles Raymond L. Flynn Marine Park
- **C** 400 miles South Boston Waterfront
- **C+** Passenger pilot and collaboration with Lyft
- **D** City of Boston

Sources: City of Boston, New Urban Mechanics, "Autonomous Vehicles: Boston's Approach", https://www.boston.gov/departments/new-urban-mechanics/autonomous-vehicles-bostons-approach; World Economic Forum, BCG analysis

Figure 21: Key challenges faced during testing

Phase B

Raymond L. Flynn Marine Park

- Variety of vehicles: construction, long buses, etc.
- Cyclists
- Seagulls
- Speeding of other vehicles
- Inclement weather, including snow

Phase C

South Boston Waterfront

- Two bridges in the area
- Multi-lane roads with two or three lanes of traffic
- Double parking
- Dense pedestrian traffic
- Rotary/traffic circle

Sources: City of Boston; nuTonomy; World Economic Forum, BCG analysis

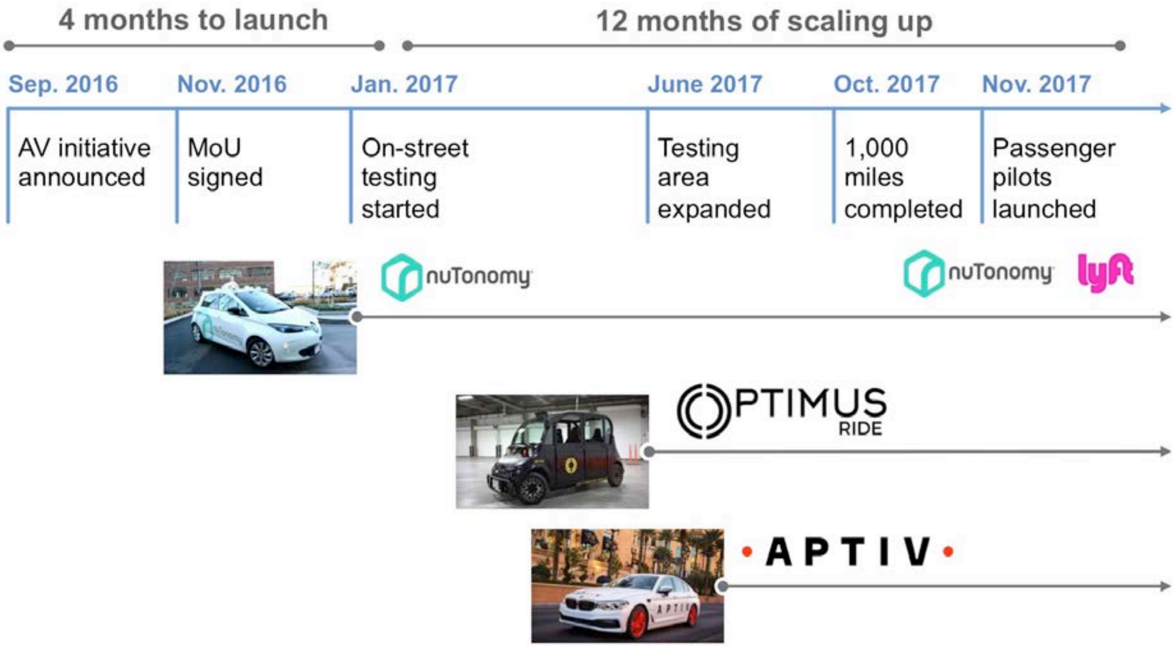
From one testing company to three testing companies

By June 2017, the AV fleets on Boston's streets expanded to include Optimus Ride and Aptiv, which the city announced as the second and third testing partners (Figure 22).

Optimus Ride applied for the second testing licence in February 2017. Like nuTonomy, Optimus Ride is an MIT spin-off, but the two start-ups have a slightly different focus. Optimus Ride vehicles are four- and six-seat Polaris models that visually resemble more a golf cart than a typical passenger vehicle. The company is looking to address first- and last-mile mobility, shuttling passengers to and from public-transit stations. In June 2017, the State of Massachusetts and the City of Boston approved Optimus Ride as the second official AV testing partner.

Confirmed as the third AV partner shortly thereafter, Aptiv is the new company name for the autonomous-driving and electronics business spun off from Delphi, which is now running its traditional powertrain unit separately. Aptiv has invested heavily in autonomous-driving technology and has partnered with the technology company IBM, the camera start-up Mobileye (acquired by Intel for $15.3 billion in August 2017) and automakers such as BMW. While some of Aptiv's earlier AV tests had been executed with an Audi Q5, the company sought to bring a BMW 5 Series with Aptiv autonomous-driving technology to Boston. In October 2017, Aptiv announced it would acquire nuTonomy and create a new AV technology hub in Boston, taking advantage of abundant software and robotics talent in the Boston area.

Figure 22: Timeline of Boston pilot testing



Sources: City of Boston; World Economic Forum, BCG analysis

Five best practices for AV testing

The AV testing on Boston's streets revealed five key success factors. While not all locations have snow or seagulls, Boston yielded principles that will be relevant to other cities looking to pilot AVs as they prepare for the mobility system of the future (Figure 23).

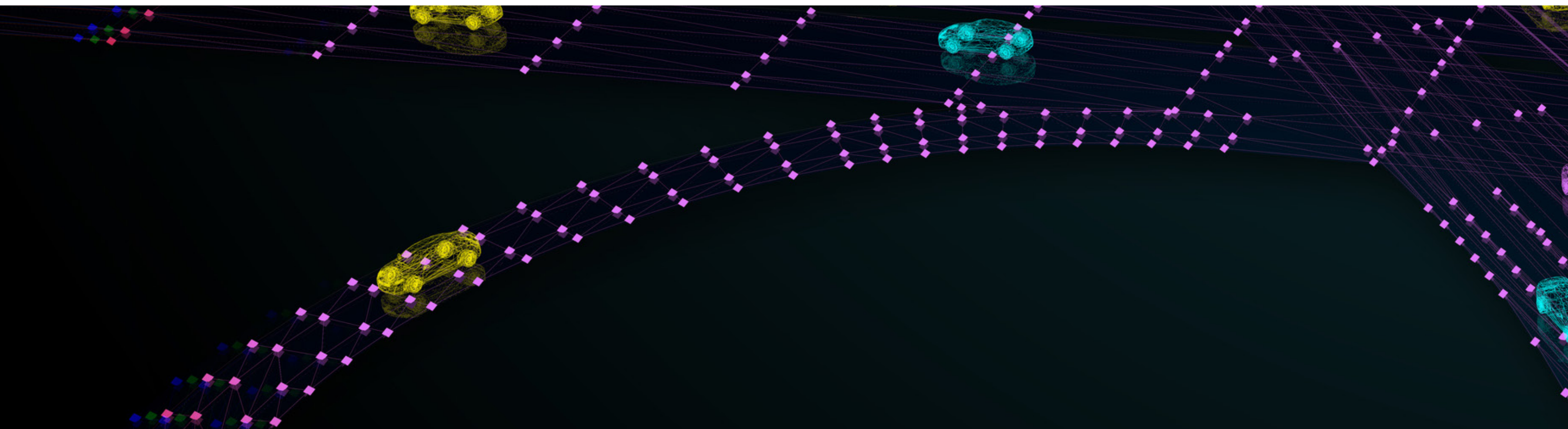
Start with a clear mobility vision and KPIs

The Boston AV pilot benefited from Go Boston 2030, the city's previously established mobility plan.[9] Rooted in policy goals and based on interactions with thousands of Bostonians, the robust framework provided a foundation for defining the scope of the city's AV pilot and linked everything back to articulated targets and KPIs.

Go Boston 2030 identified three overarching objectives for transportation and mobility: to expand access, to improve safety and to ensure reliability. The Go Boston 2030 vision is to reduce the number of fatalities on the city's roads from about 20 annually to nearly zero. The plan calls for a 30% increase in public-transit ridership by 2030, which is an impetus to focus on first- and last-mile offerings where AVs would complement public transit and not replace it. Cities looking to test AVs should consider putting in place similarly robust objectives and KPIs.

Balance stakeholder interests in the approval process

The debate about AV regulation in the United States has highlighted friction between federal, state and local regulators as they determine which government entity is responsible for different aspects of regulation. Events in the State of New York illustrate some of the challenges to AV pilot testing. Governor Andrew Cuomo announced planned testing of General Motors AVs in the City of New York's Manhattan borough. City of New York Mayor Bill de Blasio voiced concerns about public safety and indicated opposition to the plan. Implementation in Boston was



successful because it engaged collaborative teams at both the city and state levels to speak to AV companies with a common voice and to come together and align on joint decision-making criteria.

Create a tiered testing plan with achievement milestones

The policy-makers' strict and granular testing plan served the Boston project well because it prevented any ambiguity regarding next steps and what was needed from AV companies before testing could be expanded. However, the testing plan, as a living document, permitted some flexibility to address changes in technology or in needs, such as testing at night to avoid congested rush hours in shorter winter days. Boston's comprehensive plans attracted additional test partners and allowed expansion of the tested use cases. The standard, tiered testing plan served as a concrete starting point to align stakeholders (Figure 20).

"The collaboration with the World Economic Forum and The Boston Consulting Group has been an amazing opportunity for the City of Boston. We've come a long way in the last year and a half. It wouldn't have been possible without their support.

This collaboration has enabled us to expand autonomous vehicle testing and take enormous strides. We have really benefited from the insight of the Working Group. They've pulled together a diverse group of stakeholders covering all aspects of urban and autonomous mobility that includes carmakers, suppliers, mobility providers, insurance companies, academia and leadership from other world-class cities.

We believe collaboration is what allows us to unlock the potential of technology. Collaboration will help us make mobility safe, more accessible and more reliable in Boston."

Marty J. Walsh
Mayor of Boston, USA

Build public acceptance early
One of the key principles of Boston's AV strategy was to involve citizens and ensure that they bought into the journey. Having public confidence in the technology is a key adoption enabler and, at the same time, one of the most volatile criteria – one incident could drastically shift the conversation to a negative tone, even if the AV technology is not at fault.

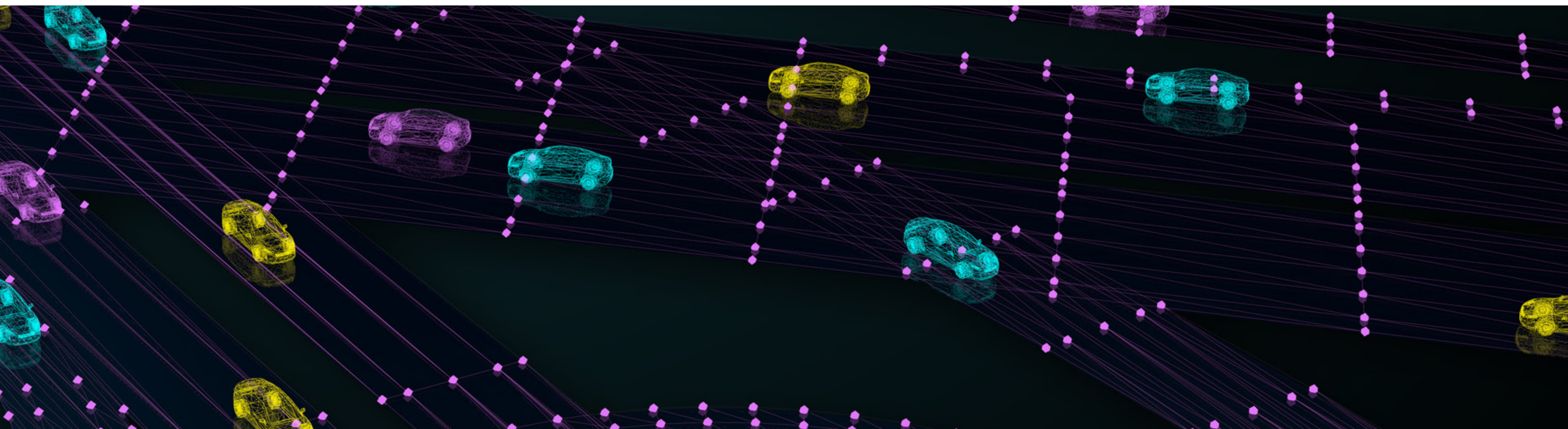
Boston pushed to maximize exposure to AV technology. One tactic was a "robot block party", held in front of Boston City Hall in October 2017 with more than 6,000 Bostonians participating and experiencing the world's first "AV petting zoo". The city's objective was to use the festivities to increase people's comfort with AVs. NuTonomy, Optimus Ride and Aptiv showcased their vehicles during the block party and provided residents with an opportunity to ask questions and share concerns.

Keep residents in the loop

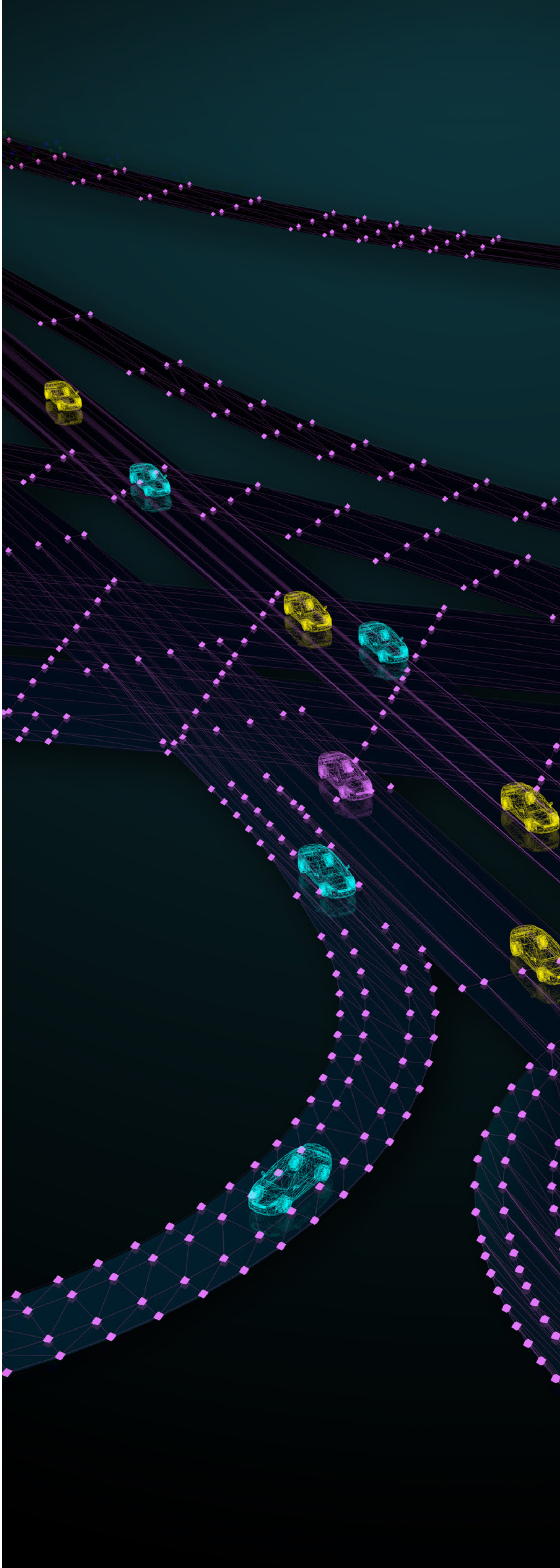
In addition to building awareness about AV technology with constituents, Boston determined that publicly sharing the progress of the pilot would improve awareness, understanding and ultimately acceptance of the new technology. To facilitate this transparency, the city publishes relevant documents – from testing plans to quarterly progress reports to consumer research – on its AV initiative website.[10]

Figure 23: Best practices for launching an autonomous vehicle pilot

Sources: City of Boston; World Economic Forum, BCG analysis



Chapter 4: Integrating autonomous vehicles into the mobility ecosystem



Urban mobility needs to be managed holistically

Both the conjoint analysis and the AV impact study made clear that addressing one part of mobility in the city is too narrow a lens. Cities must look broadly at how people and goods should move through them.

Policy-makers face a set of key questions: How can trips be distributed more evenly to reduce peak congestion? How can the total number of vehicles on roads be reduced? How can it be ensured that AVs do not exacerbate the gap between the haves and the have-nots? What are the right financial incentives and pricing structures to drive resident behaviour in line with the city's objectives? How much control and regulatory influence does the city take in shaping mobility flows and shifting the modal mix? Which data sets are needed to make the right investment decisions?

Consumers have their own perspective, centred on optimizing the balance of convenience, cost and environmental impact when making mobility decisions. How can consumers best compare mobility alternatives and make integrated decisions for their individual travel patterns?

Mobility providers are looking to maximize their user base and generate fare revenue. While part of a competitive market, mobility providers need to work together to create win-win situations in which providers, consumers and policy-makers benefit.

These three primary stakeholder groups have different incentives and interests; hence, a multistakeholder approach is required.

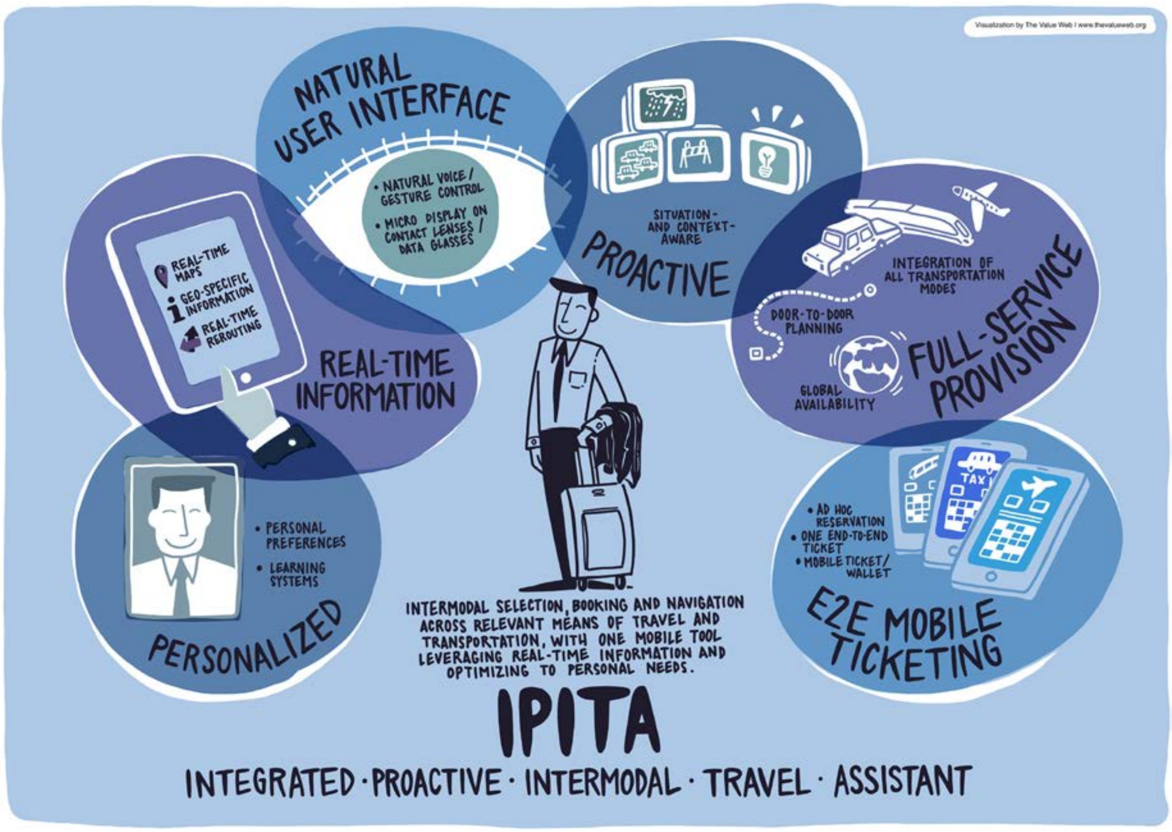
A mobility platform can meet stakeholder needs

A mobility platform could potentially address several needs of consumers as well as the public and private sectors. The Working Group defined a mobility platform as *a technology-enabled architecture that facilitates the exchange of transportation data and services between multiple stakeholders within a defined geographic area.*

Importantly, two layers within that architecture must be differentiated: the customer-facing layer, where multimodal trip planning and booking takes place; and the back-end layer, where cross-modal traffic management occurs.

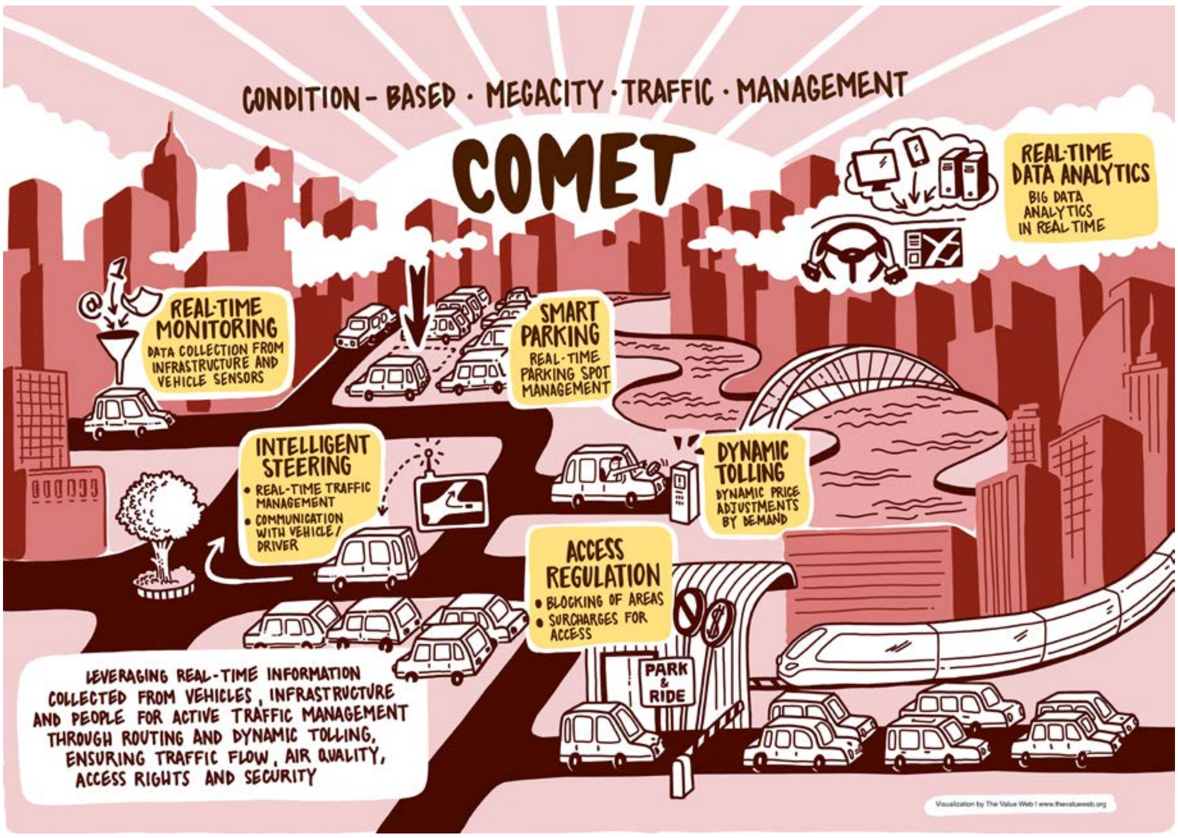
Two concepts described in *Connected World: Hyperconnected Travel and Transportation in Action*, a 2014 World Economic Forum report created in collaboration with BCG, are still directly relevant to a mobility platform: the integrated proactive intermodal travel assistant (IPITA) and condition-based megacity traffic management (COMET).[11] We shared these concepts with the Working Group to focus the discussions and clarify the solutions required for different layers of the mobility platform (Figures 24 and 25).

Figure 24: Integrated proactive intermodal travel assistant (IPITA)



Source: World Economic Forum, BCG analysis

Figure 25: Condition-based megacity traffic management (COMET)



Source: World Economic Forum, BCG analysis

Establishing a mobility platform that comprise both IPITA and COMET elements will create the optimal outcome for society while balancing the interests of competing stakeholders. The objectives of a successful mobility platform include (see also Figure 26):

A seamless customer experience

The IPITA element simplifies the process for customers by consolidating all potential mobility options and allowing not only comparison, but also booking and ticketing in one central place. This goes along with much improved real-time availability of vehicles and current travel times given road and track conditions.

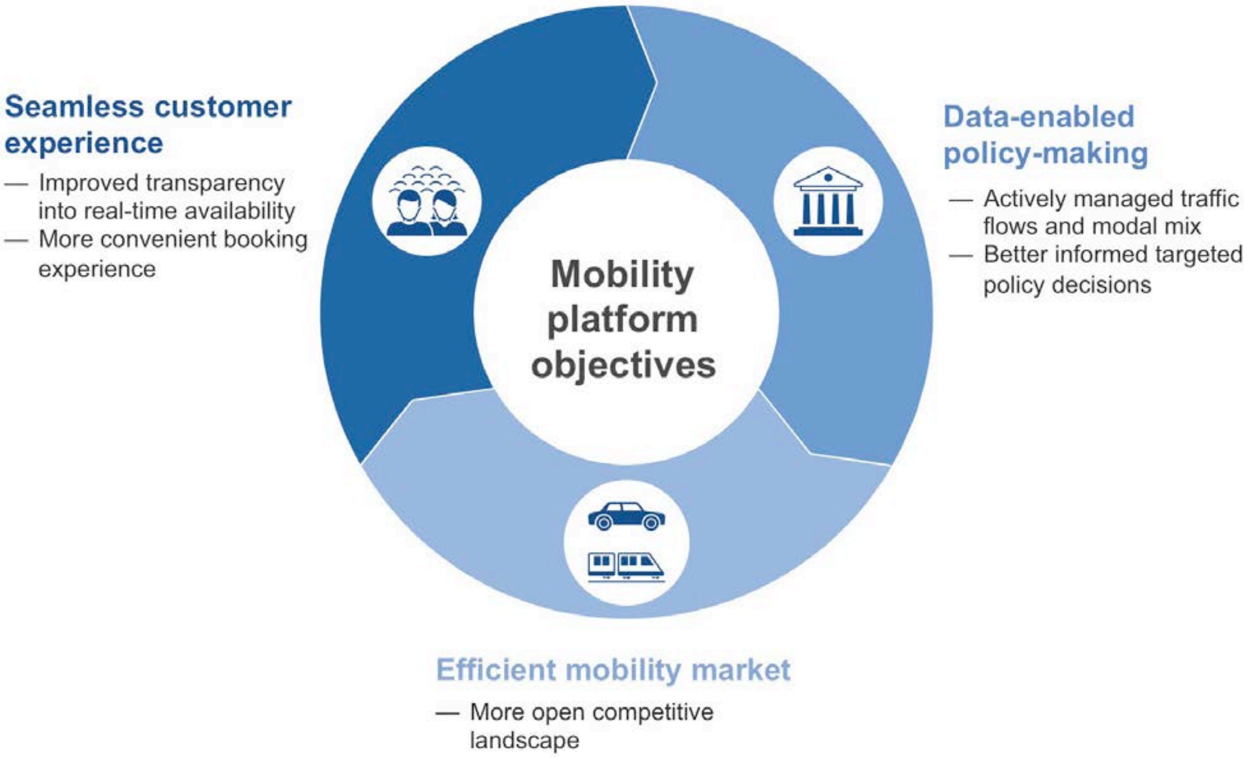
Data-enabled policy-making

For policy-makers at the city and state levels, better tools must be developed to capture data and actively influence the transportation modal mix and traffic flows on streets to inform investment and policy decisions. By focusing on COMET solutions, urban mobility data analytics enters the era of big data and machine learning. Key elements include smart parking, dynamic tolling and real-time traffic monitoring.

An efficient mobility market

Mobility providers are looking for a level playing field within the urban environment, where equal opportunities are presented to legacy and new players. A mobility platform with clearly defined application programme interfaces and integration opportunities for mobility providers creates an environment for companies of all statures to participate and compete for market share.

Figure 26: Mobility platform objectives



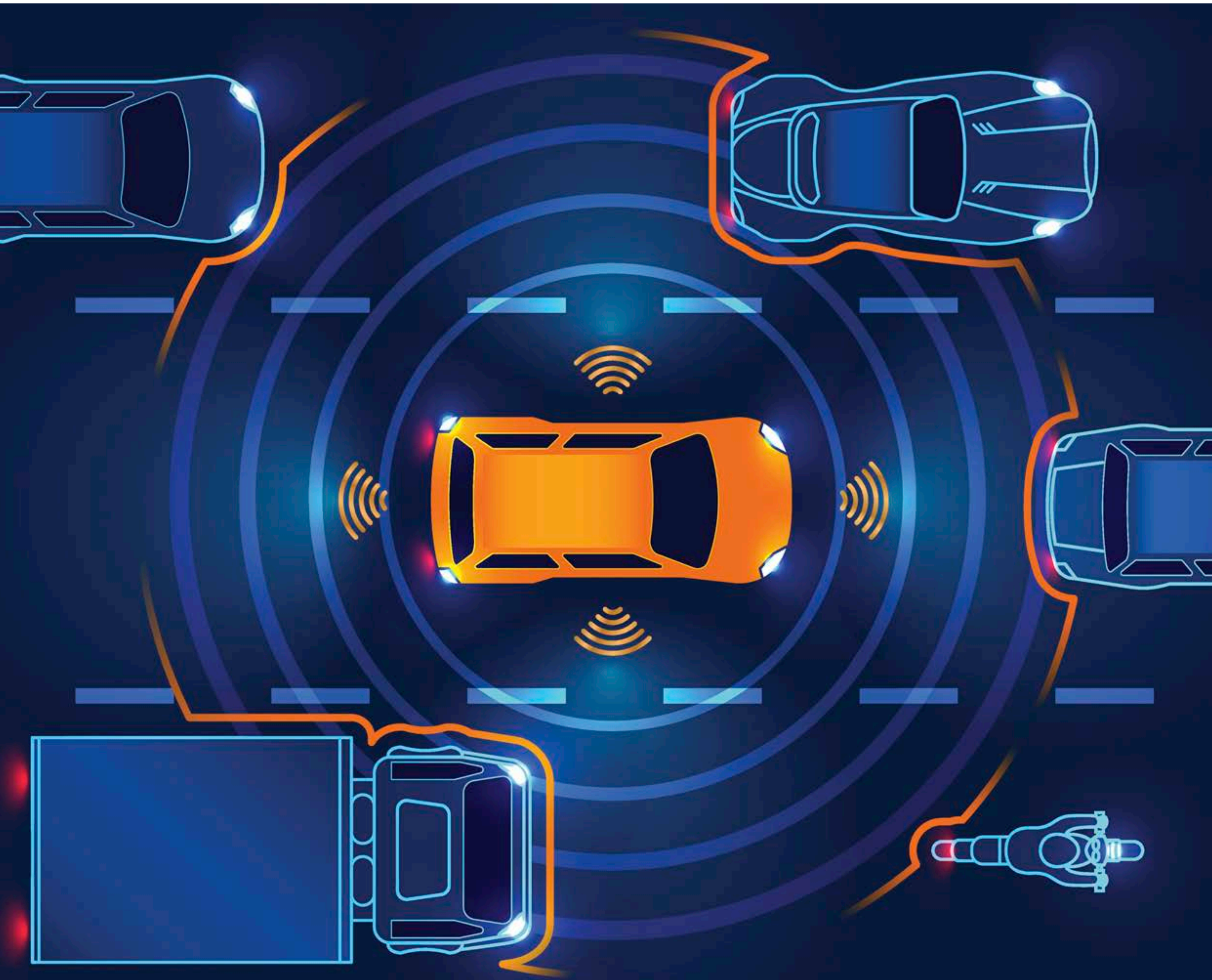
Source: World Economic Forum, BCG analysis

Start small to build momentum for expanded implementation

The idea of a mobility platform is appealing to all stakeholders. Cities around the world are closely monitoring early initiatives, such as Whim (Helsinki, Finland), the first multimodal platform with one consolidated payment plan. However, building such a platform can seem overwhelming, especially when infrastructure projects often take years just for the proper bidding process. Many cities are considering the strategy of starting with pilots on a smaller scale to prove the concept and build momentum with policy-makers, mobility providers and constituents to pursue expansion.

Singapore is a prime example of a city that has launched into dynamic tolling, adjusting pricing on a quarterly basis as a reaction to traffic levels from the preceding three months. London was a first mover in introducing a congestion charge for the inner city in 2003. Several German cities, including Berlin and Duisburg, are pursuing first-mile and last-mile shuttle offerings that feature integrated ticketing and public-transit rides through door2door, a Member of the Forum.

In Boston, the discussion also centred on which elements of IPITA and COMET could be put in place in a first phase. For IPITA, the latest thinking is to institute a pilot with a commuter rail line, where customers could purchase an integrated ticket for point-to-point transit, including a first- and last-mile shuttle in addition to the commuter rail portion. Once the MBTA has completed its fare card digitalization project, further integration of ticketing is envisioned. On the COMET side, Boston is looking to benefit from the advent of AVs as a first venture into expanded data collection on vehicle movement for making better traffic management decisions. Further expansion of AV fleets will allow the city to develop a clear understanding of the most effective levers in managing traffic flows and the data required to inform those decisions.



Conclusion and outlook

The commercialization of robo-taxis and shuttles will happen soon

More than 100 AV pilots are taking place around the world. Given the rapid expansion of pilots and advances in technology, commercial robo-taxi service will become available in a few large cities in 2018 and will scale up from there. In the second quarter of 2018, Aptiv announced the launch of a fleet of 30 autonomous vehicles in Las Vegas using the Lyft platform. Waymo has completed test miles and conducted initial on-street tests with safety drivers in the backseat and not behind the wheel. Many robo-shuttles are being tested on private and public roads around the world. The realization of AVs in an urban fleet paradigm will likely happen faster than most predict.

Other cities can learn from Boston's example

For the Forum and BCG, it was never just about the city of Boston; it was about realizing the potential of AVs for cities around the world. A key success factor in Boston was the open communication and collaboration across stakeholders from all angles: policy-makers, mobility providers, academia, the Autonomous and Urban Mobility Working Group and BCG. Understanding customer needs, likely shifts in behaviour and the impact of those shifts on traffic was incredibly helpful in thinking about the right policy framework for AVs.

Work by the World Economic Forum on autonomous and urban mobility continues

Entering its next phase, the project will be headquartered at the Center for the Fourth Industrial Revolution as part of the Forum System Initiative on Shaping the Future of Mobility. The Autonomous and Urban Mobility Working Group will continue to cultivate its multistakeholder community, share lessons from the partnership with Boston with other cities and identify key governance gaps related to AVs.

Acknowledgements

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Endnotes

1 For full results of a global examination of consumer sentiment, see The Boston Consulting Group, Self-Driving Vehicles, Robo-Taxis, and the Urban Mobility Revolution, July 2016, at https://www.bcg.com/publications/2016/automotive-public-sector-self-driving-vehicles-robo-taxis-urban-mobility-revolution.aspx.
2 The cost was derived either from actual costs (e.g. bus/subway fares) or a BCG calculation (e.g. $1.22 per mile for a personal car, $0.70 per mile for an autonomous taxi and $0.35 for an autonomous shared taxi).
3 Agent-based models are "detailed representations of real-world environments that treat the individual components – such as cars, roads, and passengers – as entities that interact dynamically with each other." (From Making Autonomous Vehicles a Reality: Lessons from Boston and Beyond, The Boston Consulting Group, October 2017).
4 See the report at https://www.bcg.com/publications/2017/automotive-making-autonomous-vehicles-a-reality.aspx.
5 For more information, see City of Boston, Mayor Walsh Announces Autonomous Vehicle Initiative, Mayor's Office, 14 September 2016, at https://www.boston.gov/news/mayor-walsh-announces-autonomous-vehicle-initiative.
6 Ibid.
7 Geographical area, daytime versus night-time, weather conditions, and with or without passengers.
8 Statement made during post-ride interviews by nuTonomy.
9 See City of Boston, Department of Transportation, "Go Boston 2030", at https://www.boston.gov/departments/transportation/go-boston-2030.
10 See City of Boston, New Urban Mechanics, "Autonomous Vehicles: Boston's Approach", at https://www.boston.gov/departments/new-urban-mechanics/autonomous-vehicles-bostons-approach.
11 See World Economic Forum in collaboration with The Boston Consulting Group, Connected World: Hyperconnected Travel and Transportation in Action, May 2014, at http://www3.weforum.org/docs/WEF_Connected_World_HyperconnectedTravelAndTransportationInAction_2014.pdf.

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