Transit & Emerging Technologies
Nelson\Nygaard puts people first to create great places, and great places around transit. We are in a period of rapid technological and, potentially, behavioral change in the mobility landscape. To ensure community values of sustainability, equity, and healthy living are upheld, we demystify emerging mobility through 30 years of transportation planning expertise and help cities proactively plan for the future. The future is what we make it.

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Introduction

- What new technology and emerging mobility options will come into fruition?
- How will autonomous vehicles affect the demand for transit?
- How will automation affect transit service?
- How can transit agencies prepare for the future of transportation?
Towards an autonomous future

Automation of personal vehicles and transit vehicles over the next several years will not only change the buses and trains we use, but also the rights-of-way they navigate. Transportation Network Companies (TNCs) like Uber and Lyft have given us a glimpse of what to expect: increased mobility but also increased vehicle miles travelled on city streets and thus more traffic – even if rides are shared. Today, both personal vehicles and TNCs outcompete buses for door-to-door travel time – and the field of mobility options will only grow. Some of these emerging mobility options are complementary to transit, some directly compete, and many do both.

The changes brought by automation to transit represent an opportunity to fundamentally improve transit systems. In an autonomous future, high-capacity transit service will likely be more important than ever. Infrastructure changes such as dedicated right-of-way are needed to take full advantage of technology improvements like automation. Other improvements to transit operations that are currently implemented for high-capacity transit projects – transit signal priority, seamless off-board fare collection, level boarding, and dedicated lanes, among others – are also key to improving transit’s performance in an increasingly competitive mobility landscape. There are new opportunities to expand beyond core fixed-route operations to engage in strategic partnerships with mobility service providers to capture changing travel demand patterns. However, assessing their merits requires a focus on system goals and priorities as well as an understanding of the full operational and organizational trade-offs of entering these partnerships. This report explores how emerging technology will affect transit, and how transit agencies should leverage their strengths to take full advantage of current and upcoming technology changes to stay competitive. Transit agencies and their partners must identify ways to use and prepare for technology to make high-capacity transit a more attractive mode.
What will an autonomous future look like?

Transit vehicle fleets may lag behind personal vehicle fleets in the transition to autonomy over the next several decades. When autonomous vehicles (AVs) become widely adopted, they will not only alter transit agencies’ fleet composition but also significant elements of transit’s operating environment. Full autonomy in the personal vehicle market may make driving – and driving longer distances, in particular – more attractive by freeing up drivers’ time to be spent on tasks other than driving. Another likely outcome is an increase in roadway congestion, particularly in dense urban centers where pick-up and drop-off activity from TNCs is likely to continue to increase.

Together, these trends are likely to undercut transit’s cost- and time-based competitive advantages compared to driving, especially in mixed-traffic environments in congested urban areas. Transit agencies must tackle these emerging challenges by investing in projects that prioritize the speed and smooth operations of transit, which will set the stage for agencies to eventually operate competitive autonomous transit services.
The use of connected and autonomous vehicles for personal use (owned and for-hire), as well as for freight and public transit, has the potential to reshape the landscape of mobility in the United States. As costs for the technologies underpinning autonomous vehicles, such as high-resolution LiDAR 3-D imaging and electric vehicle batteries, fall dramatically, autonomous vehicles are likely to become increasingly cost-competitive in the personal vehicle market. Projections for full adoption of autonomous technology vary. Some sources suggest the technology will evolve to complete autonomous capability by 2022, and that autonomous penetration will occur by 2045—though others have longer forecasts and suggest autonomous penetration will be partial for several decades.

Most autonomous mobility projections focus primarily on the personal automobile industry. Although the timeline for when AVs will be available for large-scale public use is uncertain, it is clear that this technology is reshaping the industry. In 2016, the U.S. Department of Transportation’s National Highway Traffic Safety Administration (NHSTA) released new policy guidance and a proposal to invest nearly $4 billion on AV research and development, steering state governments to be flexible and innovative yet pursue AV regulation. Vehicle manufacturers are also shifting course, anticipating market share loss as autonomous technology drives down transportation costs and the industry shifts from personal vehicle ownership to shared fleets. Autonomous vehicle technology is likely to be expensive when first introduced, and its introduction in fleet vehicles may allow for higher utilization and streamlined maintenance. By 2030, some manufacturers estimate 37% of miles traveled will be done by shared or autonomous vehicles. Like automation, electrification is also poised to transform both the personal and transit vehicle industries. Future fleet modernization efforts will combine both electric and autonomous features at various development stages.

The U.S. Department of Transportation defines connected vehicles as technologies that allow a vehicle to communicate with fixed traffic infrastructure (i.e., signals and light poles), with other vehicles, and with smartphones using radar, cameras and other sensors. Autonomous vehicles (AVs) use connected vehicle technologies in order to operate on their own without the assistance of a human driver.
Factors guiding autonomous application

Adoption depends on more than timing

1. When is the technology available?

<table>
<thead>
<tr>
<th>Level</th>
<th>Driver Role</th>
<th>System Role</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Driver Only</td>
<td>Driver has longitudinal &amp; lateral control</td>
</tr>
<tr>
<td>1</td>
<td>Assisted</td>
<td>System has lateral or longitudinal control</td>
</tr>
<tr>
<td>2</td>
<td>Partial Automation</td>
<td>System has lateral &amp; longitudinal control</td>
</tr>
<tr>
<td>3</td>
<td>Conditional Automation</td>
<td>System warns driver to resume control</td>
</tr>
<tr>
<td>4</td>
<td>High Automation</td>
<td>System can cope with all situations in defined use case</td>
</tr>
<tr>
<td>5</td>
<td>Full Automation</td>
<td>Driver not required for specific use case</td>
</tr>
</tbody>
</table>

Source: Mike Lemanski

2. What is the environment for the application?

- Controlled environment
- Semi-controlled environment
- Uncontrolled environment

3. What is the regulatory context?

- Transit industry has different policy incentives and factors
  - Desire to allow or encourage autonomous operations
  - Operations requirements
  - Risk profile
  - Fiscal incentives to adopt AVs

Stages of automation

Although AVs are commonly imagined as completely driverless vehicles, the National Highway Traffic Safety Administration (NHTSA) classifies AVs into a 5-point scale of autonomy, with level zero being a completely human-driven, traditional vehicle and a level five being a fully driverless vehicle that requires no human oversight. The full spectrum of levels is described below:

- **Level 1**: One specific function may be done automatically by the vehicle, such as steering or accelerating;
- **Level 2**: A driver assistance system in which the vehicle operates smaller aspects of both steering and acceleration concurrently (such as cruise control or lane centering) using computer vision, with the driver constantly monitoring the situation and ready to take control at any time;
- **Level 3**: Driver is still present and ready to intervene, but safety-critical functions are operated by the vehicle and do not require constant monitoring by the driver;
- **Level 4**: The vehicle is fully autonomous for most safety-critical driving functions and major roadway conditions for the entire trip;
- **Level 5**: Fully autonomous performance for every driving scenario, including extreme conditions.

While research and development of AVs has been going on for some time, recent technological advances have allowed companies, including traditional automakers such as Ford, Tesla, Volvo, Audi, and BMW, to start testing AVs. Currently, Level 2 vehicles are available on the market, and Level 3 and 4 vehicles are in testing on public rights-of-way in several cities and private test sites.
Automation may put more car traffic in the way of transit

The automation of personal vehicles will affect the roadways that transit navigates daily— an impact we can expect to see before transit itself becomes more automated. There are several possible ways automation of personal vehicles will affect how people drive. People may continue to own private vehicles and make low-occupancy trips. Alternatively, private ride-hailing trips may increase in efficiency but replace some transit trips. Most likely, some combination will emerge— at least in the mid-term. Regardless, researchers expect an increase in congestion, as convenience will likely increase the total number and length of vehicle trips. Research shows TNCs are increasing miles traveled as they create demand for new trips. Roadways that are more crowded will make it more challenging for transit to operate in a mixed-traffic environment.

All vehicles will be autonomous, not just personal vehicles

The same trends reshaping the personal vehicle market— electrification and automation— will affect transit but on a different timeline. Transit vehicles are transitioning to electric due to increased sensitivity to fuel savings. Though currently only a small percent of national transit fleets are electric, the figure is expected to grow quickly in upcoming years. The timeline and pace for U.S. transit system adoption of autonomous technology is less certain. Past technology adoption trends suggest that once full automation integrates into vehicle technology, it will spread quickly to other modes. Already, many new buses use some level of autonomous technology, such as automated alignment of chargers on electric buses.

The transition to autonomous transit operations is likely to occur gradually over the next several decades, and it will be highly context-sensitive. This transition may create significant opportunities for agency operations cost savings that can be reinvested in system-wide improvements, such as additional service frequency, coverage, or other operations improvements.

Transit’s advantage over other modes is its singular ability to transport large numbers of people efficiently, and this advantage will remain regardless of whether transit fleets are autonomous or not. As shown in the image below, bus rapid transit operating in dedicated lanes has more than seven times the passenger throughput per hour as private vehicles. If operating in dedicated lanes, autonomous transit is likely to increase transit’s advantage on this front.

**Person throughput by mode**

<table>
<thead>
<tr>
<th>Mode</th>
<th>Throughput</th>
</tr>
</thead>
<tbody>
<tr>
<td>Private Automobile</td>
<td>1,000</td>
</tr>
<tr>
<td>Bicycle</td>
<td>1,000</td>
</tr>
<tr>
<td>Bus</td>
<td>2,000</td>
</tr>
<tr>
<td>Walking</td>
<td>3,000</td>
</tr>
<tr>
<td>BRT or Light Rail</td>
<td>7,500</td>
</tr>
</tbody>
</table>

Number of people travelling in one-lane in an urban environment during a one-hour period
Some transit is already autonomous

Autonomous heavy rail systems, like Vancouver’s SkyTrain, use communications-based train control (CBTC) to operate fully automated trains from remote operations control centers. CBTC increases potential service frequencies, to as high as one train per minute, and allows for faster incident response and safer operations. In addition to Vancouver, Dubai, Paris, and Singapore currently operate autonomous heavy rail lines, while cities such as New York, London, and Hong Kong have used CBTC to improve existing subway systems.

Autonomous shuttles have been operating in Singapore and Switzerland, as well as on a small number of U.S. corporate or university campuses. The shuttles use LiDAR sensors and cameras to detect obstacles, and communicate GPS location for live monitoring. These examples have primarily operated on private property, though the Swiss example is slated for integration with the local public transport system, with the autonomous shuttle serving as a first/last mile connector.

RIDOT is developing its own autonomous shuttle pilot, soliciting providers and researchers to test the technology and shape a public-private partnership framework. Under consideration is an initial testing period at Quonset Business Park in North Kingston, and then potentially a pilot of an Olneyville neighborhood connector shuttle to the train station in downtown Providence, filling an current lack of transit services. The pilot is part of the State of Rhode Island’s Transportation Innovation Partnership (TRIP) initiative, which aims to ensure the state manages emerging mobility technologies in a responsible, sustainable, and equitable manner, using partnerships, research, and test projects.
Autonomous Transit

Automation will reach different types of transit on different timelines. Medium-occupancy shuttle models are already in testing. Mass transit includes some elements of autonomy now, but full autonomy will likely lag behind adoption of autonomous technology in personal vehicles, despite transit operations having the most to gain. While autonomous products are not yet available, transit agencies should consider piloting new technology for its rolling stock, includes phasing in autonomous technology. This effort can overlap with fleet electrification testing as well as broader fleet modernization initiatives.

High-capacity transit vehicles may be among the last vehicle classes to become autonomous, due to the relative lack of research and development underway in this field compared to personal AVs. However, autonomous transit could operate far more efficiently than personal AVs in terms of total person-movement or throughput, especially in dedicated lanes or guideways. Transit agencies and cities can create the ideal operating environments for autonomous vehicles by creating a separate, dedicated operating lane – an advantage that private vehicles do not have. Autonomous transit, if thoughtfully guided, has the potential to increase the type and frequency of transit service available.

Some transit agencies are beginning to plan now for shifts in travel demand, curbside access, procurement, and safety requirements.

To understand how automated vehicles are going to fall in terms of technology, we can look at current new mobility models and existing models for serving varying numbers of riders.
Chapter Two | Technology Impacts on Transit

As autonomy and electrification transform transit vehicles, transit agencies should aim for high-capacity modes to benefit the most from these innovations. Right-of-way and technology needs accompanying each generation of autonomous and electric transit vehicles will also evolve. Preparing for eventual high-capacity Autonomous Rapid Transit can help guide design decisions in the interim.

Autonomous shuttles

Autonomous shuttles are similar in size to existing shuttle vehicles, generally with a capacity of about 6 to 20 passengers. They are intended to be shared though they may be owned by a private corporation. Autonomous shuttles operate at low-speeds (typically 15 MPH) on surface streets, and most are electric.

There are many opportunities to deploy autonomous shuttles to supplement or replace existing, low-ridership transit service. They are ideal for short-distance service, where they can address first/last-mile connectivity issues, for campus transportation, or for other controlled environments where interactions with mixed traffic are limited. Deployments today have generally been showcase opportunities for an agency or organization to show they are supportive of AV technology.

Autonomous buses

Some companies, such as Mercedes-Benz and Proterra, are developing full-sized autonomous buses, but these vehicles are not yet operational. Mercedes-Benz markets improved interiors, including café-style seating. While the Mercedes-Benz product is likely furthest along in development, its application to transit agencies may be limited by Buy America requirements.

Autonomous Rapid Transit

Autonomous Rapid Transit (ART) is an emerging train/bus hybrid mode that operates using driverless software and follows tracks painted on the road. Currently only available in China, several U.S. cities have expressed interest in bringing the technology to American transit systems. At present, the electric vehicles can run up to 43 MPH and hold up to 300 passengers.

While it deserves further study, ART technology is not a candidate for a near-term pilot due to procurement and technology safety barriers still under development. Much about ART is unknown, though it is possible it could be cheaper to manufacture than rail options - and cheaper to operate due to labor changes.

2020

2023

2028

Increasing capacity

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Automation presents an opportunity to reduce costs

While it is likely that the cost to operate transit will decrease with automation, it is not guaranteed that the savings will be reinvested in additional service frequency. What happens with those savings will be guided by policy that may or may not reinvest savings in transit operations. One or more of the following may occur:

- **Transit could become less heavily subsidized by public dollars.** Policy makers could opt to keep service levels the same and reduce transit agency budgets. This would reinforce the pattern of transit offering a relatively unchanged product to its users while other modes become increasingly more convenient and reliable.

- **Savings could be passed on to the customer in the form of lower fares.** Given that transit has historically been a very economical transportation option, this may benefit very price-sensitive populations, but in most contexts would not significantly change the perceived value or convenience of transit.

- **Savings could be reinvested in more coverage.** Investing in coverage, whether temporal or geographical, would give more users access to transit overall, and make transit a travel option for more trip types. The coupling of dynamic dispatching and routing technology with smaller autonomous shuttle vehicles may provide an enhanced user experience in low-density areas. Though demand levels may not warrant frequent service, “on-demand” transit can provide users with improved wait times and reliability.

- **Savings could be reinvested to provide higher service frequency.** This would allow a larger portion of the transit network to operate at ‘turn-up-and-go’ frequencies of 15 minutes or less, one of the most effective means of shifting people from low-occupancy vehicles to transit.

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**What happens if transit operations get cheaper?**

### Potential Scenarios

<table>
<thead>
<tr>
<th>Customer Benefit</th>
<th>Potential Scenarios</th>
</tr>
</thead>
<tbody>
<tr>
<td>★★★</td>
<td>Investments in service improvement &amp; expansion</td>
</tr>
<tr>
<td>★★★</td>
<td>Lower fares</td>
</tr>
<tr>
<td>★★★</td>
<td>Reduced transit subsidies</td>
</tr>
</tbody>
</table>

**Going Forward**

As the cost to operate transit declines, the role of the public and private sectors play in providing transit may change. Private companies may be able develop profitable transit business models while the public sector may change the way it provides transit service. **The future is uncertain.**

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### Unanswered Questions

- How might AV bus manufacturers deliver savings sooner?
- How can agencies ensure operators unique needs and skills are accommodated in the transition to autonomy?
- Should public transit operators compete against private companies?
- How should private companies be regulated to ensure equitable access to transit?
Will transit still be needed?

While there will be an increasing number of mobility options for people to choose from, the need for efficient travel will also grow. In general, cities do not have space to accommodate a large number of new vehicle trips that could be created by easier travel by autonomous personal vehicles. The increase in vehicle trips would cause congestion on the state’s roadway network to increase even if a city’s population is projected to remain about the same in the next 20 years. If congestion does become more challenging over time, the need for efficient, high-capacity travel will become increasingly important in many urban areas.

Autonomous vehicle service models that promote shared usage and high vehicle occupancy present the best opportunity to efficiently move people through the region. The transition to autonomous vehicles creates a unique opportunity to improve transit.

Cities and transit agencies, however, will have to take a proactive and collaborative approach to make this happen. Regardless of capacity of autonomous transit models, separating transit operating lanes can help speed up autonomous integration and improve the competitiveness of transit amid increasingly crowded roadways.

Buses must improve to compete

Buses are currently being outcompeted by personal vehicles and ride-hailing. With few exceptions, the experience of riding transit has remained relatively unchanged in the past century. Transit vehicles have become more comfortable (air conditioning, low-floor boarding, etc.), and real-time arrival information has improved the user’s ability to plan trips more accurately. Relative to the experience of driving a personal vehicle, however, transit has significant drawbacks such as wait times, slower travel speed, unreliability, and the need to share space with strangers.

Bus ridership has fallen recently in most American cities, and TNCs are one possible cause. Recent research on TNC ridership has shown that about half of TNC trips are replacing transit, walking, or bike trips, rather than taxi or vehicular trips, as many public agencies had hoped. Cities and transit agencies are responding in different ways: adjusting routes to make them more attracting, experimenting with first/last mile partnerships, or improving the ease of fare payment.

Resources currently allocated to demand-response services that generate a very small portion of ridership could be much more effectively allocated to provide higher-frequency fixed-route services along key transit corridors, though doing so would isolate some transit-dependent riders and may be unlawful under Title VI and/or ADA regulations.

High-capacity transit services can provide high-quality options for increased mobility. Rather than fixed-route and demand-response bus services, high-capacity transit generally operates faster, higher frequency transit services in busier, denser travel corridors.

While the comfort and convenience of TNCs may be considered the obvious immediate trend affecting bus ridership, new modes are not the only factor affecting travel demand. More people are working remotely, shopping online, and using delivery services than ever before. The marketplace of mobility options has become more crowded and diverse in recent years. As our mobility options are reordered, buses are being outpaced. The competition for ways to get around will only increase. New transportation technologies will appear - some will fade and others will last. By comparison, transit tends to adapt less nimbly due to the complexity and cost of new capital improvements.

Finding a more resource-efficient means of service delivery to peripheral areas currently served by demand-response should be a city and transit agency priority.
With no action, competition for customers and road space will grow

More options

Many questions about the future travel patterns and traffic from autonomous vehicles depend on whether most autonomous vehicles are privately owned or accessed on-demand from shared fleets. Preliminary modeling suggests that even shared, autonomous fleets could create increased congestion if lower-cost travel spurs excessive driving on constrained road networks. Thus, travel management and pricing of autonomous vehicles will affect transit operations. It is likely that congestion will get worse.\(^8\)

TNC adoption offers insights on what to expect from AVs. Research on TNC partnerships with transit agencies suggests TNCs have tended to attract riders away from bus and light rail service, but perhaps increase ridership of commuter rail services. TNC adoption is associated with an overall average net reduction in transit use among Americans in major cities. About half or more of TNC trips would not have been made at all, or by walking, biking, or transit. Ride-hailing is likely to contribute to growth in vehicle miles traveled in the major cities.\(^9\)

While some transit riders may elect to use TNCs as a faster or more convenient option, transit still typically has the benefit of being less expensive. However, with the advent of pooled ride-hailing services like Lyft Line and Uber Pool, that cost difference may shrink. These services may begin to resemble traditional buses as they pick up and drop off strangers along either a fixed or variable route. Higher capacity TNC products could lower costs and become increasingly similar to public buses in some cities.

Some advantages of transit experience will be reduced

Today, transit maintains one key advantage by allowing users to spend travel time doing other activities, such as reading, writing emails, or using social media. However, the experience of autonomous personal vehicle users will shift dramatically from needing to spend all travel time occupied by the task of driving, to being able to use the time for anything that can be currently done when riding transit. Furthermore, the ability to travel while in a private space may expand the range of what can be done while traveling beyond what can be done on transit to include exercising or sleeping. More than ever, transit will be competing with transportation options that provide superior comfort and convenience.

Some transit agencies have looked to amenities such as on-board Wi-Fi to enhance user experience. However, these amenities will not differentiate the transit user experience from future autonomous vehicles, and will likely pale in comparison to on-board amenities found in personal vehicles.

Furthermore, national research has shown that frequency and travel time are the two most important determinants of rider satisfaction, and amenities that do not significantly alter the effectiveness of mobility are less important.\(^10\)

Increasing transit frequency is costly, and becomes more costly when buses encounter congestion. When travel times increase, more vehicles are required to operate the same level of service. As urban areas continue to grow and congestion increases, travel on general-purpose roadways, whether in a personal, shared, or high-capacity vehicle, will become slower, and will erode the user experience quality of all travel. Bus travel speeds in New York City, for instance, have declined 6\% between 2016 and 2017 because of increased congestion.\(^11\)

However, cities and departments of transportation have the authority to prioritize how roadways are used, and can give transit a competitive edge over other modes through transit priority treatments. If successful, transit will become more attractive and grow in use, making more efficient use of roadway capacity.
Autonomy could lead to more comfortable vehicle interiors, both for private automobiles and transit vehicles.
How can technology make transit more competitive?

The most commonly cited barriers to transit use are infrequent service and slow service. Autonomous buses and trains could reduce operating costs. If those savings are leveraged to provide more frequent service, transit can be made more competitive - particularly if combined with transit prioritization measures.
A combination of infrastructure and technology improvements will be essential to making transit more attractive

Dedicated right-of-way

- Transit-only lanes — but ideally physically separated rights-of-way — will become more important to the success of transit as congestion associated with urban growth and ease of vehicle use increases.
- Some autonomous vehicle and TNC lobbyists are trying and will try to gain access to separate transit lanes. Allowing this could set a poor precedent that is ultimately bad for transit. Creating and preserving dedicated travel lanes for high capacity transit is one of the most important ways to leverage city and agency strengths in an autonomous future.
- Travel time savings: 34-43%. Reported travel time reductions from dedicated rights-of-way (i.e. grade-separated and exclusive bus lanes) range from 25% to 50%.
- Examples: Albuquerque Rapid Transit (Albuquerque, NM); Metro Orange Line (Los Angeles, CA)

Both today’s transit and tomorrow’s transit need to get out of the increasing congestion of mixed traffic to improve their competitiveness. Transit prioritization infrastructure investments that can help transit compete now and prepare for more competitive autonomous transit of the future are on the following pages:
126 people move through this roadway during each traffic light cycle - 80 (63%) are riding transit.

235 people move through this roadway with transit-only lanes during each traffic light cycle. 204 (87%) are riding transit.

Dedicated Right-of-Way = Higher Capacity

Source: Capital Metro
**2 Queue jump lanes**
- Queue jump lanes are short, dedicated transit facilities with either a leading bus interval or active transit signal priority (TSP) to allow buses to easily enter traffic flow in a priority position. Applied thoughtfully, queue jump treatments can reduce delay considerably, resulting in run-time savings and increased reliability.
- Travel time savings: 5%-15% at intersections.\(^6\)
- TSP with queue jump can reduce bus delays more than TSP with no queue jumps, especially under high traffic volume conditions.\(^9\)

**3 Transit signal priority**
- TSP is an operation improvement that uses technology to reduce time at traffic signals for transit vehicles by holding green lights longer or shortening red lights.
- Travel time savings: 8%-12% is typical.\(^5\)
- TSP has been shown to improve travel times by 5 to 18%.\(^7\)
- TriMet is doing innovative transit signal prioritization work using embedded transponders and signals inside buses (also known as an Internet of Things approach).

**4 Cashless/barrier-free fare payment**
- Having fare payments occur before boarding the bus and with the aid of a smart card reduces the amount of time spent at each stop (also known as dwell time). Off-board fare payment resulted in a 38% to 50% reduction of passenger dwell times and in one case, a travel time reduction of up to 8%.\(^8\)
- Examples (off-board fare payment): RTA Healthline (Cleveland, OH), Albuquerque Rapid Transit (Albuquerque, NM), Select Bus Service (New York City)
5 Universal fare payment

- Fare collection system that has compatibility with other transit systems in a region.
- Examples: London’s Oyster Card, Chicago’s Ventra Card, LA Metro TAP card
- This can be taken a step further with digitization and mobile ticketing, and some agencies aim to integrate other modes.

6 Level boarding

- Platform level boarding occurs when the station platform is same height as the bus (or train) floor.
- Level boarding eliminates need to ascend steps onto the bus (difficult for elderly/mobility impaired), thus decreasing dwell times for all passengers.
- Level boarding will make it more possible to transition to fully autonomous transit vehicles as it reduces some need for additional assistance from drivers.
- Examples: RTA Healthline (Cleveland, OH), Albuquerque Rapid Transit (Albuquerque, NM).

7 Information

- More extensive and better real-time information in stations, distributed on screens, in search engines, or via transit information aggregator apps may help retain or attract riders.
- Examples of companies providing transit information:
  - Transit App - data aggregator displaying real-time arrival and bikeshare dock locations/availability
  - TransitScreen - real-time information screen, mainly used in multifamily residential, office, universities, retail
  - CHK America - provides real-time info kiosks/displays for transit agencies, government, traffic, aviation, and hospitality industries
Fare technology

Ease of fare payment can be a surprisingly important factor in someone choosing to use transit – and in a bus’s ability to operate efficiently. Improved payment technologies can speed up boarding, reduce dwell time, facilitate faster transfers, allow more types of fare structures, and reduce agency operating costs. Other sectors of the economy have already leveraged easier, faster payment formats and transit needs to stay competitive with customer expectations for seamless, cashless payment.

Technology has the ability to improve ease of payment, and several new technologies are emerging and gaining adoption, allowing transit agencies to move away from cash handling and providing more choices in how to operate fare collection. The potential future fare media landscape is crowded, including smartphones, contactless credit cards, smart cards, and futuristic concepts like biometrics.

Many major transit agencies are implementing universal payment, making their fare media work across all transit agencies in the region. As fare payment technology evolves, there is increasing benefit to transit agencies in moving away from maintaining their own fare payment infrastructure, as these functions are increasingly outsourced.

Mobile ticketing is a first step towards a transit fare collection system upgrade. Following the lead of transit agencies like Boston’s MBTA and Portland’s TriMet, a viable fare collection upgrade project typically involves reloadable, agency-branded smartcards linked to an account-based fare payment system, with an expanded network of retail sales locations statewide. An account-based system will enable transit agencies to increase passenger throughput and reduce bus dwell times by reducing cash transactions, set more complex fare structures with finer gradations of time and distance-based fares, and reduce the capital costs of cash handling. It would also enable riders to register their fare cards online to insure against loss or theft, as well as automatically top-up their account when a low balance is reached. Open payment is considered the next stage in the evolution of fare media, and is a prerequisite for Mobility-as-a-Service, described on page 22. Open payment systems allow riders to use a contactless bank card, agency-issued smartcard, prepaid debit cards (as alternatives to cash for unbanked riders), student or employer ID card, or mobile phone to pay for transit fares as well as rides from private mobility service providers. The underlying financial and technology infrastructure changes require major changes to fare collection infrastructure and cooperation between transit agencies and mobility service providers.

Multimodal fare integration

To stay competitive with alternative transportation providers, the transit industry may need to alter and integrate their fare media – and fare structure. Streamlined, user-friendly fare media can signal that transit is an attractive mode. Better information about fares (and other information) is a hurdle for first time users. Installing payment kiosks at BRT stops and allowing all-door boarding can help make the system faster and more attractive.
Improvements in fare payment technology and processes make crucial operational improvements, such as all door boarding, possible.
Mobility as a Service (MaaS)

Taking the goal of seamless payment a step further, Mobility as a Service (MaaS) is the integration of various forms of transportation services (public and private) into a single mobility service accessible on demand. This could combine trip planning and fare payment functionality. Private-sector MaaS tools may also add trip booking, creative partnerships and incentives, and some are creating subscription payment models.

Increasingly, most people do not make distinctions between public and private transportation options, rather assessing modes by cost, convenience, comfort, and travel time. With a deluge of potential new information about travel options and services, MaaS offers an opportunity to make the overall transportation network more efficient and user-friendly. MaaS involves the ability to plan, book, and pay for trips among variety of modes from single interface – helping to improve access and save money among customers. MaaS offers transit agencies the ability to create increasingly attractive incentives to take transit and other high-capacity modes. One day it is possible transit agencies can use MaaS to redirect riders in response to real-time operational changes or major travel demand changes.

At its core, MaaS relies on a digital platform that integrates end-to-end trip planning, booking, electronic ticketing, and payment services across all modes of transportation, public or private. It is a marked departure from where most cities are today, and from how mobility has been delivered until now. Building a platform that allows someone to move among multiple modes for a single payment is a challenging task for both transit networks and technology firms. Transit agencies can start by improving access to their own high-quality, real-time information, and looking for opportunities to push private providers to do the same when opportunities arise. A transit agency’s approach to MaaS should center on increasing use of high-capacity transit, particularly in the most congested corridors.
**Loyal to Mode**
- Tend to use just one option and rarely switch

**Perception of Limited Options**
- Personally-owned car often the default option

**THEN**

**Mobile Phone**
- Helps make choices but each tool has its own app

**New Options**
- Many people use just one or two new options (ride-hailing, bike share) in addition to their primary mode.

**Ride-Hailing**
- Car ownership separated from car use

**NOW**

**FUTURE**

**Mobility as a Service**
- Use mobile device to select among many options and seamlessly book and pay for them

**More New Options**
- Including innovative new private sector mobility tools

**Choose the Right Tool for the Right Trip**
- Based on better information about cost, time and comfort
Mobility hubs

With more private and public mobility services appearing, connecting between them seamlessly will become more important. Mobility hubs have gained popularity in recent years as an increasing number of mobility options has emerged. Leveraging station areas as mobility hubs can make public transit the focal point in the transportation network and connect first/last mile options to transit. **High-capacity transit stops make ideal mobility hub locations.** Development of mobility hubs around these transit stops can improve the competitiveness of high-capacity transit by connecting more riders directly to the system, using the real estate around stations to cluster mobility options, and improving customer service.

**Ideal mobility hub features**

- Connects to high-capacity transit
- Seamless transfers between modes, including new private mobility options
- Sense of place
- Real-time information about travel options

**How will station areas change?**

- Emerging mobility technologies are likely to affect station areas in the following ways:
  - Decreased need for parking
  - Increased need for pick-up and drop-off zones
  - Space for bike-share, scooters, and other new mobility tools
- Opportunities:
  - Leverage new tools to increase first/last mile access to high-capacity transit stations
  - Turn high-capacity transit stations into mobility hubs

**Mobility hubs provide multiple transportation choices all in one site.** They offer a variety of services and amenities such as ride-hailing loading zones, commuter shuttle stops, real-time transit information, electric vehicle charging stations, transit pass sales kiosks, bike and car share parking, and secure bike lockers. Mobility hubs can encourage riders to try more sustainable commute modes by improving access and connectivity.
Many new options are appearing and blurring the line between private goods and public transportation. All of these mobility options – not to mention those that will surely appear in the future – have different applications in people’s lives, and their role will continue to grow and evolve as consumers try them on for size and compare them to traditional transportation options.

### Vendor Type

<table>
<thead>
<tr>
<th>Vendor Type</th>
<th>Description</th>
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<tbody>
<tr>
<td>Transportation network companies (Ride-hailing/Ride-sourcing)</td>
<td>Transportation network companies (TNCs) match drivers with riders in real-time through mobile apps that also process payment. These platforms typically operate through a network of third-party contractor drivers using non-commercial vehicles. The services typically offer several ride types, such as private ride (similar to traditional taxi), and pooled-ride/fare splitting (multiple users with origins and destinations along a similar route can hail the same driver in real time).</td>
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<td>Microtransit</td>
<td>Microtransit is a shuttle service that can be on-demand in real-time or fixed route service updated frequently to meet market needs. The shuttles often operate in areas during peak-period commute hours where public transit is reaching capacity or may be unavailable. Companies can vary by fleet type (buses or vans), route structure (fixed or dynamic), and, more recently, fleet ownership. Microtransit is distinguished from private shuttles because, in addition to being available to the public, of its ability to automate routing, billing, customer feedback, and reservations.</td>
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<td>Autonomous Vehicle Shuttles (AV Shuttles)</td>
<td>AV shuttles operate on pre-defined, fixed routes in controlled environments, thus minimizing many remaining technical and operational challenges and enabling the vehicles to operate with minimal human intervention.</td>
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<td>Car Share</td>
<td>Car sharing programs allow people to access a shared fleet of vehicles on as-needed, per-hour or per-mile basis for point-to-point or round-trip trips. Car sharing programs reduce the need for businesses or households to own vehicles, and they also reduce personal transportation costs and vehicle miles traveled (VMT).</td>
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<td>Bike Share</td>
<td>Bike sharing is a system of bicycles that is available to users to access as need for point-to-point or round-trip trips, traditionally to station kiosks in dense urban areas. Docked bikeshare systems are generally unattended and offered through public-private partnerships. Advances in bike share locking technology have allowed for dockless, free-floating bikes, lockable anywhere within a geographic region. This model is becoming increasingly popular; vendor companies are often fully privately owned and operated.</td>
</tr>
<tr>
<td>Scooter share/eScooters</td>
<td>Scooter share is a system of electric scooters whereby users use an app to rent and ride to their destination and then park the scooter in a similar fashion to parking a dockless bike.</td>
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Over the past few years, many transit agencies have piloted public-private partnerships with TNCs and other mobility providers. Not all of these partnerships had clear goals, and their benefit to transit agencies was not always evident. TNC and transit partnerships have limited use cases, often best at providing paratransit or similar, demand-response services. With limited public dollars, subsidizing TNC rides without a clear goal has not proved fruitful. Partnership opportunities are evolving and can be guided by lessons learned from TNC and other “first generation” partnerships with private mobility service providers. The first microtransit pilots operated by transit services are under way, and autonomous shuttles are finding more use cases beyond campuses, including on some city streets. These offer higher potential efficiency than TNC partnerships — but must be assessed carefully.
Partnerships are **competition** when they:
- Poach riders from transit, thereby increasing overall vehicle trips — which could worsen if pricing of TNCs and other mobility service providers becomes much cheaper due to automation
- Disaggregate high-capacity trips into smaller vehicles and worsen congestion
- Take resources away from core transit services
- Do not have clear goals or way to measure success

Partnerships are **complementary** when they:
- Reduce total vehicle trips in congested areas
- Lower operating costs for transit
- Improve response times

What are common **implementation hurdles** to a successful partnership?
- Partnerships require heavy investment in marketing and outreach to explain eligibility, costs, benefits, and how to use associated technology.
- Adequate flexibility to experiment new businesses models, including new modes, prices, service design, and contract arrangements.
- Cross-organizational coordination is commonly undervalued in establishing new partnerships.
- Service quality and monitoring become more important if a service is outsourced to a third party and the transit agency has ceded control of day-to-day service
- Technology barriers and financial, particularly for those without smartphones and credit cards, can hinder equitable access to new mobility partnerships
- Long-term risks are difficult to assess. TNCs and other private mobility providers are seeing rapid growth but businesses models are still evolving. Major outsourcing might expose a transit agency to significant risk

Key partnership **opportunities** include:
- Extend the reach and duration of transit service
- Faster response times compared to infrequent fixed-route or flex services
- Improved access to regional transit hubs and trunk lines
- Operating cost savings compared to the least productive fixed-route and flex services
- Requires a high degree of collaboration and integration between the transit agency and the private provider is necessary — including on the need for a seamless user experience
- Provide a better, on-demand service for seniors and people with disabilities
- In rare cases, private providers may provide alternative to traditional transit
Create a partnership strategy based on transit agency’s priorities

Fiscal impacts of partnerships

Lesson 1: Where demand is unknown or low, allocating a high-dollar amount to a program is ill-advised.

Lesson 2: Where demand is known, such as replacement or crowd-source routes, allocating a high-dollar amount could be more compelling.

Lesson 3: A subsidy variable based on the demand will yield (relatively) low operating costs.

Lesson 4: A subsidy variable based on the demand can prove more costly in aggregate. Thus, it is not recommended to commit to a time-period without a cap on amount.

Several agencies have tested the first generation of partnerships, typically with TNCs, and the industry is now better positioned to analyze the many partnership pitches they receive from private mobility operators each year. It is clear that all pilots have a cost – even those that appear free – if only in staff time and operational resources. With limited public dollars, investments in private partnerships that may not produce results could otherwise be invested in improving frequency of core transit services. Transit agencies should:

• Evaluate future pilots in terms of cost and mode prioritization. If partnerships do not meet those criteria, they should only be considered if the private operator bears the true cost of the arrangement
• Appoint an individual or group to oversee partnerships, clearly defining who operates these arrangements and where they fit into the organization. This role should be cross-functional with service planning and finance, so that pilots and preparation for autonomy are not planned in isolation.
The current generation of partnerships and pilots: microtransit and AV shuttles

Microtransit

A number of private companies have started to introduce “microtransit” services. Microtransit is still an amorphous term, sometimes even applied to nearly any shared ride service in vehicles larger than a sedan but smaller than a bus. Usually following a public-private partnership model with agencies, the companies tend to use passenger vans or cutaways (sometimes using existing agency vehicles) and provide ride-hailing and trip planning technology. Case studies either completely replace a traditional fixed-route bus in a lower ridership productivity area or offer service to an area previously underserved or not served by local transit.

Microtransit providers are operating in only a small number of cities as they continue to experiment with how best to provide service. Scalability can be a challenge for microtransit, as companies generally start with the highest-demand routes. Over the past few years, many microtransit companies have abruptly shut down due to legal and regulatory challenges or difficulty developing a sustainable business model.

Typically, microtransit providers charge a fixed fee that is known to passengers when they book a ride. This fee may vary depending on time-of-day, distance, and current demand, and is generally higher than public transit and lower than ride-hailing (around $3-6 per trip). Some companies, such as Via, are approved for use with commuter benefit cards. Others, such as Transdev Link, are branded and operated in partnership with existing transit services. These services may be subsidized, though most microtransit is not.

Microtransit is an unproven model with little evidence to suggest it is more useful than fixed route transit service operating in an otherwise “unproductive” area.25 However, its passenger-carrying capacity potential is more promising than that of TNCs and its technology is more proven than that of AV Shuttles. Transit agencies may have potential to augment the fixed route network in otherwise “unproductive” areas or re-attract riders into the system by providing nearly door-to-door on-demand service.
AV Shuttles

As autonomous vehicle (AV) technologies continue to advance, many companies have begun testing, marketing, and piloting vehicles with low levels of autonomy, such as AV shuttles. AV shuttles operate on pre-defined, fixed routes in controlled environments, thus minimizing many remaining technical and operational challenges and enabling the vehicles to operate with minimal human intervention. However, in deployments to date, a human operator has still been on board to interact with passengers and step in if necessary.

AV shuttles perhaps capture an outsized level of attention compared to their current mobility impact because of the technology involved. While these projects can serve to generate excitement for transit, they also offer the opportunity to study a mode that has significant (though decreasing) capital costs, low to no vehicle emissions, and lower operating costs. Bishop Ranch, a large, mixed-use development that markets its sustainable transportation management practices is replacing its conventional buses with electric AV shuttles. These shuttles will eventually serve as connectors to a transit center within two miles from the site. The city of Arlington, TX is piloting a similar AV shuttle program branded as “Milo.” Although the Milo shuttle is currently being tested in a large, off-street convention center and sports complex grounds, Arlington is aiming for eventual on-street use. As quoted on the website for the pilot, “the City is testing the driverless shuttles to explore potential uses for autonomous transportation technology in a real-world setting. This pilot program is currently expected to run through mid-2018.”

Some AV shuttle providers are exploring the potential for offering on-demand service, which is likely to be implemented in the United States sometime in 2018. In such a model, passengers would either press a button at stop locations to board the shuttle or hail a ride through their smartphone. Once on board, passengers would press a button to request to alight at the next stop.

It is likely that ride-hailing, microtransit, and AV technology will converge. For example, Navya has introduced a smaller, six-passenger vehicle advertised as a taxi to serve some use cases that their 15-passenger vehicle may not be suitable for. At the same time, some AV microtransit providers are beginning to explore using larger, full-sized buses. Larger vehicles will require more sensors to enable detection of all potential obstacles around them, but the basic principles of autonomy are the same so there should be minimal challenges applying the technology to larger vehicle types (as has been demonstrated with AV trucks).

Most of these vendors offer their vehicles for sale or for lease, and most procurements in the United States so far have been via lease agreements. Notable exceptions include the Navya shuttle in Ann Arbor and the EasyMile shuttle in San Ramon,
both of which involved a vehicle purchase to enable a long-term testing procedure rather than simply offering a transportation service. These were likely purchased rather than leased because they were intended to be used for multiple years, so the additional cost of buying over leasing became less significant. These two purchases were also early in the timeline of AV shuttles, and perhaps the business model for leasing had not yet been fully developed. Some vendors, such as May Mobility, are exploring alternate business models to purchase and lease. May Mobility’s business model is to charge a per-hour operating fee to clients, and completely operate their own fleet, providing a seamless customer experience.

Vendors have often included in their RFP response a partnership with a traditional operating entity such as Transdev or Keolis to provide a turnkey solution. Leasing rather than purchasing a vehicle can also help an agency navigate AV regulations, because it may be easier to pursue an exemption. Non-American vendors have become more familiar with US transit regulations since first introducing their vehicles in the US, and have begun installing additional features (such as ramps to comply with ADA regulations and steering wheels to comply with AV regulations) in newer vehicle models. They have also begun opening manufacturing facilities in the US to comply with Buy America requirements.
GOING FORWARD

What does this mean for transit agencies?

Transit agencies, working with other partners and stakeholders, especially City agencies that operate the right-of-way, must use technology to make high-capacity transit a more attractive mode. Priorities for preparing for emerging mobility should include:

1. Dedicate road spaces to high-capacity transit.
2. Leverage automation to improve the transit experience.
3. Recognize the growing competition for travel options and strive to compete on the agency’s strengths.
4. Pursue partnerships only when and where they directly match the agency’s existing policy priorities and service needs and performance toward such goals can be measured and tracked.
5. Leverage high-capacity transit stops to make multimodal travel seamless.
### Action Phases

<table>
<thead>
<tr>
<th>DO</th>
<th>WHEN</th>
<th>BECAUSE</th>
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<tbody>
<tr>
<td><strong>Anticipate transit system priorities to help evaluate new technologies and partnerships</strong></td>
<td>1-5 years + ongoing</td>
<td>There will be an increase in calls for partnerships and pilots. Determining which meet core goals is key. Experience with the first generation of partnerships taught transit agencies to guard such financial investments.</td>
</tr>
<tr>
<td><strong>Ensure new technologies and partnerships prioritize high capacity transit system core</strong></td>
<td>1-10 years</td>
<td>High capacity transit has the best competitive edge amid changing mobility options as autonomous technology becomes adopted. Technology will change some factors – but the efficiency mandate for high occupancy travel will likely increase.</td>
</tr>
<tr>
<td><strong>Establish high-capacity transit stops as gathering points for new mobility options</strong></td>
<td>Ongoing rollout 5+ years</td>
<td>Gathering public and private mobility services near high capacity transit helps improve first/last mile connections, exchange user networks among providers, and leverage the real estate advantage of transit systems</td>
</tr>
<tr>
<td><strong>In areas with infrequent/unproductive service, leverage new technologies to enhance access to high quality transit lines</strong></td>
<td>1-10 years</td>
<td>Transit agencies cannot wait for autonomous transit technology to start improving the attractiveness of transit.</td>
</tr>
<tr>
<td><strong>Anticipate tomorrow’s autonomous technology when designing today’s infrastructure</strong></td>
<td>5-20+ years</td>
<td>The same dedicated right of way, mobility hubs, and station features that will help autonomous high capacity transit be successful are the same features that will help non-autonomous high capacity transit succeed in the meantime.</td>
</tr>
<tr>
<td><strong>Monitor technology changes to see when they enable policy and operations improvements</strong></td>
<td>Ongoing</td>
<td>Transit agencies cannot pilot or implement some improvements until the technology exists.</td>
</tr>
</tbody>
</table>


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RESOURCES

Autonomous Technology & Rollout

Research
• Connected Car Report 2016: Opportunities, Risk, and Turmoil on the Road to Autonomous Vehicles. PWC Strategy and PWC. 2016. [https://www.strategyand.pwc.com/reports/connected-car-2016-study]

Policy Development Examples
• Smart Mobility Roadmap, Austin Texas. [https://austintexas.gov/sites/default/files/files/Smart_Mobility_Roadmap_Executive_Summary_-_Final_with_Cover.pdf]

Early Developments in Autonomous Transit

Research
• Transit Automation Research, Federal Transit Administration. [https://www.transit.dot.gov/automation-research]

Shuttle Examples
• Milo shuttle in Arlington, Texas: [http://www.arlington-tx.gov/visitors/milo/]
• Fribourg, Switzerland: [https://www.swissinfo.ch/eng/first-autonomous-transport-service-in-switzerland-inaugurated/43541214]
• Singapore: [https://navya.tech/en/singapore-opens-an-autonomous-vehicles-centre/]

Autonomous Rapid Transit

Transit Network Company (TNC) & Partnership Research
• Legal Considerations in Relationships Between Transit Agencies And Ridesourcing Service Providers. TCRP Legal Research Digest 53, June 2018. [http://www.trb.org/Publications/Blurbs/177575.aspx]

Mobility as a Service


Dockless Mobility

Additional Resources
• NACTO People Movement: [https://nacto.org/publication/transit-street-design-guide/introduction/why/designing-move-people/]
• NACTO Blueprint for Autonomous Urbanism
• NACTO Global Street Design Guide
• SDOT New Mobility Playbook
• APTA Autonomous Vehicles Resource Page: [https://www.apta.com/resources/mobility/Pages/Autonomous-Vehicles.aspx]
GLOSSARY

Autonomous Rapid Transit (ART)
An emerging train/bus hybrid mode that operates using driverless software and follows tracks painted on the road.

Autonomous Vehicles (AVs)
Vehicles that use connected technologies in order to operate on their own without the assistance of a human driver.

Autonomous Vehicle Shuttles (AV Shuttles)
Driverless shuttles that currently operate on pre-defined, fixed routes in controlled environments, thus minimizing many remaining technical and operational challenges and enabling the vehicles to operate with minimal human intervention.

Bike Share
Bike sharing is a system of bicycles that is available to users to access as need for point-to-point or round-trip trips, traditionally to station kiosks in dense urban areas. Docked bikeshare systems are generally unattended and offered through public-private partnerships. Advances in bike share locking technology have allowed for dockless, free-floating bikes, lockable anywhere within a geographic region.

Car Share
Car sharing programs allow people to access a shared fleet of vehicles on as-needed, per-hour or per-mile basis for point-to-point or round-trip trips.

Connected vehicles
Technologies that allow a vehicle to communicate with fixed traffic infrastructure (i.e. signals and light poles), with other vehicles, and with smartphones using radar, cameras and other sensors.

Geofencing
The use of GPS or RFID technology to create a virtual geographic boundary, enabling software to trigger a response when a mobile device enters or leaves a particular area.

Mobility as a Service (MaaS)
The integration of various forms of transportation services (public and private) into a single mobility service accessible on demand.

Mobility Hubs
A designated location that provides multiple transportation choices and amenities all in one site.

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Microtransit is a shuttle service that can be on-demand in real-time or fixed route service updated frequently to meet market needs. The shuttles often operate in areas during peak-period commute hours where public transit is reaching capacity or may be unavailable. Companies can vary by fleet type (buses or vans), route structure (fixed or dynamic), and, more recently, fleet ownership. Microtransit is distinguished from private shuttles because, in addition to being available to the public, of its ability to automate routing, billing, customer feedback, and reservations.

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