FROST & SULLIVAN

Mobility as a Service

Crafting the Next Generation of Vehicles and Mobility Experiences with Automotive Electronics

A Frost & Sullivan White Paper
In collaboration with Murata

muRata
INNOVATOR IN ELECTRONICS

Contents

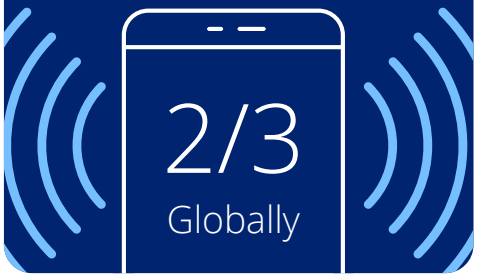
1. Overview

A. Why Mobility as a Service?

Urbanization continues to change mobility. More than half of the world's population lives in cities, according to the United Nations; by 2050, the number will increase to 70%. The concentration of economic activities in cities will result in additional demand for personal transport across urban, suburban, and rural areas if public transport systems cannot keep pace with the continued growth in the number of commuters and trips. For those living in suburban areas, this means greater pressure to own one, if not multiple vehicles because of fewer public transport options compared to cities. Those residing and working in less-populated rural areas would have similar needs for personal transport, but serving them becomes more challenging given fewer users.

Many cities are experiencing more traffic congestion and pollution than ever before. Vehicles are a main source of greenhouse gas emissions. About 4% of global gross domestic product (GDP) is already spent every year on healthcare to counter the adverse effects of these emissions from just the top polluting countries, and the number of preventable deaths due to air pollution remains significant: 4.2 million annually, according to the WHO, and 400,000 in Europe, per the European Environmental Agency. The economic costs of congestion also are noteworthy: in the United States alone, productivity losses because of traffic congestion have been estimated by mobility analytics company INRIX to be about US$87 billion per year.

The smartphone also is contributing to mobility's transformation. From just about 30% in 2014, smartphones now make up around two-thirds of all mobile connections globally



In developing countries where public transport options are even more limited, traffic congestion and vehicle emissions pose even more serious risks to people's well-being and the environment; in Delhi, India, for example, the government closed roads several times in recent years due to dangerous air quality levels.

The smartphone also is contributing to mobility's transformation. From just about 30% in 2014, smartphones now make up around two-thirds of all mobile connections globally, according to the GSM Association. Smartphone use has changed expectations for ease of use, convenience, and speed for users across many services, including those related to mobility. The spread of ride-hailing in the past decade—beginning in the United States—was made possible by the smartphone, and is in direct response to global demand for more transport options and better services from public and private transport operators.

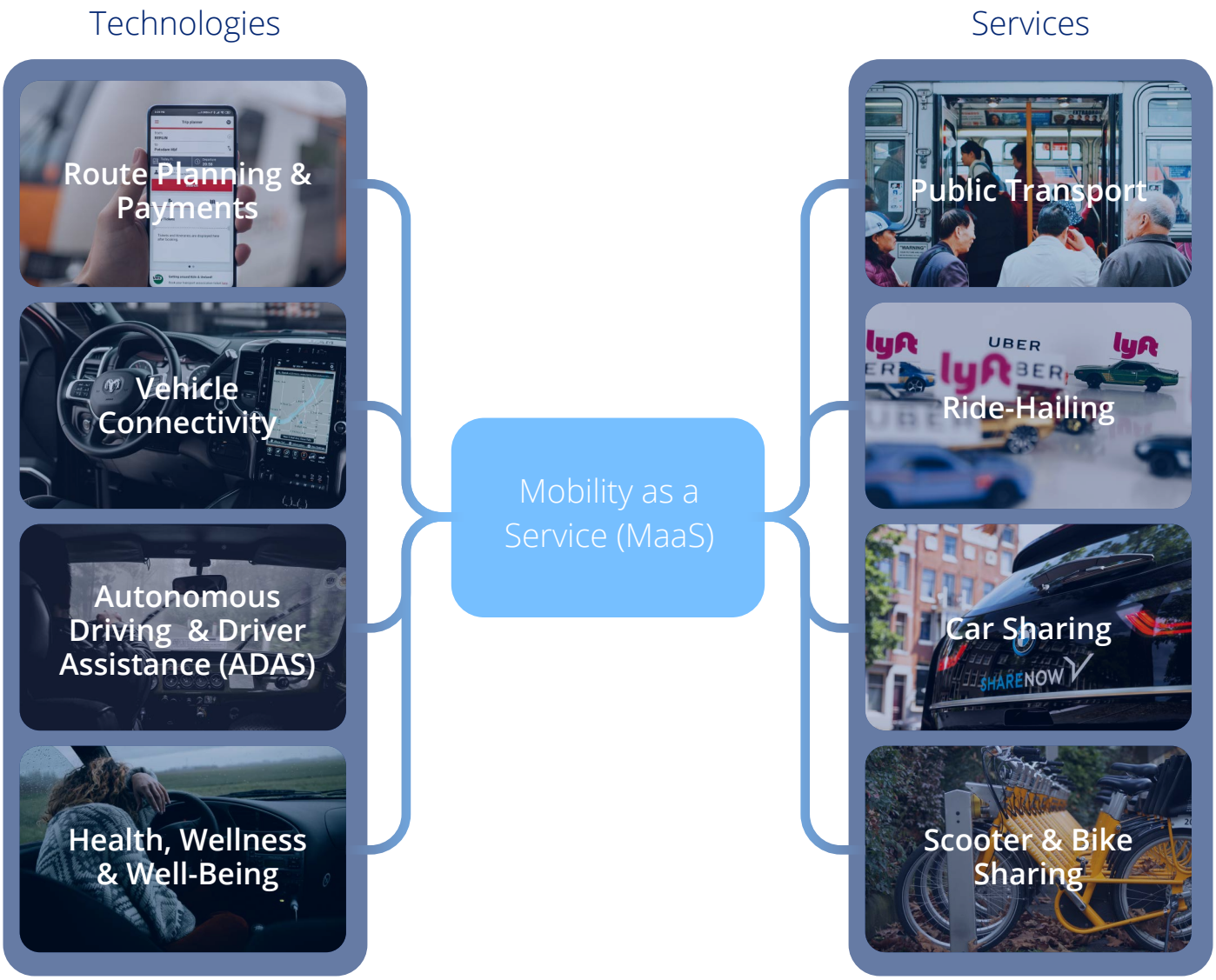
Ride-hailing's emergence has resulted in a heightened awareness of the concept of mobility as a service (MaaS).

B. MaaS Defined

Ride-hailing has popularized integrated booking and payment, but MaaS actually is the integration of transport mode selection, booking, and payments into a single service for ride-hailing, car-sharing, public transport, and scooter and bike-sharing.

While this definition is correct, it does not sufficiently account for or explain the technologies that make the integration of transport services possible. Thus, in this white paper, MaaS is defined in a broader, more holistic way: **MaaS is not just the consolidation of transport mode selection, booking, and payments, but also the increasing sophistication of key underlying technologies for route planning & payments, autonomous driving & advanced driver assistance systems (ADAS), vehicle connectivity, and health, wellness & well-being features (Figure 1).**

Figure 1: MaaS Technologies and Services



Understood this way, it becomes much clearer how MaaS minimizes the inconvenient aspects of different mobility services while also reducing congestion and addressing capacity constraints in transport systems.[1] With MaaS making all forms of transport available at all times to all users, traffic congestion in cities can decline with fewer people in cities and suburban areas having to own vehicles to meet their personal transport needs. MaaS opens possibilities for reducing the number of parking and driving facilities and even repurposing them into welfare-improving amenities such as parks. The benefits are not limited to those in or close to cities: MaaS ensures that transport operators can serve the mobility needs of those in less-populated rural areas in economically sustainable ways.

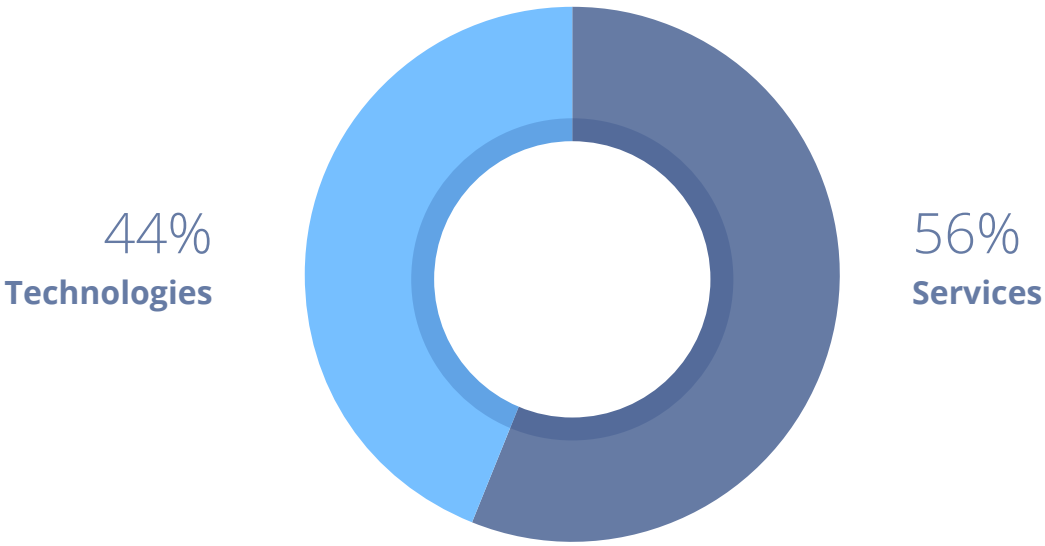
Most importantly, thanks to the capabilities of underlying technologies, MaaS considerably improves the safety, reliability, and accessibility of all transport modes. Ultimately, the goals of MaaS are seamless, intermodal travel and convenience and ease in using and managing vehicles across all drivers, passengers, and transport service operators.

The broad MaaS technology and service segments represent a combined US$92.75 billion in global revenue in 2020, with services accounting for 56% of the total (Figure 2):

Ultimately, the goals of MaaS are seamless, intermodal travel and convenience and ease in using and managing vehicles across all drivers, passengers, and transport service operators

Figure 2: Global MaaS Market Revenue, 2020

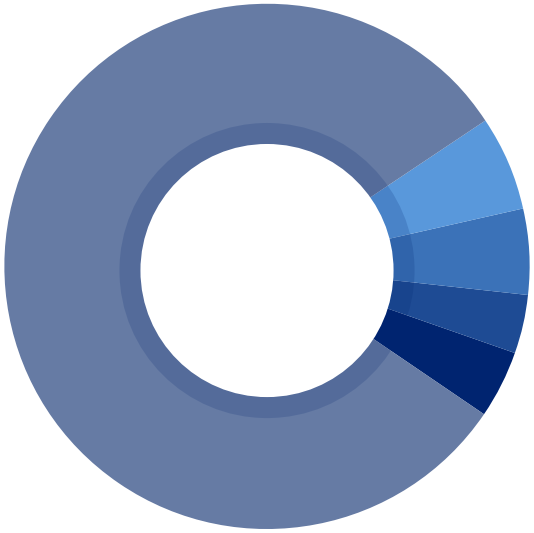
Source: Frost & Sullivan



[1] MaaS Alliance

Figure 3: Global MaaS Services Market Revenue, 2020

Source: Frost & Sullivan

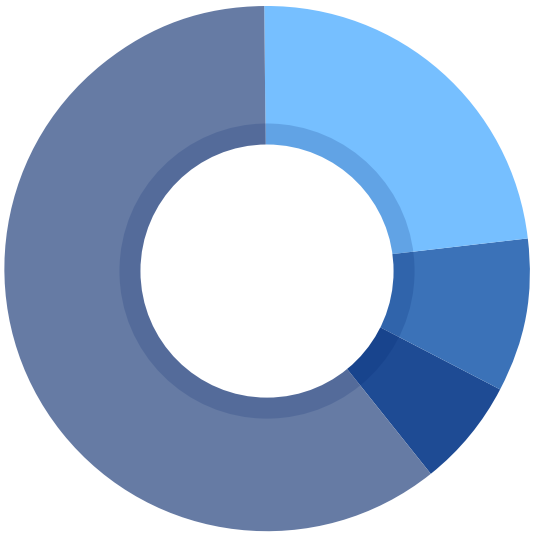


Of the services that make up MaaS, ride-hailing contributes the most revenue (Figure 3).

Ride-hailing companies operate in many countries and often use this business as a springboard to expand into other mobility services.

Figure 4: Global MaaS Technology Market Revenue, 2020

Source: Frost & Sullivan



Of MaaS technologies, vehicle connectivity currently has the largest share, followed by autonomous driving/ADAS (Figure 4). Leveraging vehicle connectivity and ADAS for greater convenience and more features in vehicles will determine how quickly MaaS will move toward seamless intermodal travel and ease of use for all.

C. MaaS Trends, Drivers, and Restraints

Over the next few years, the following trends will define growth and advancements in MaaS-related opportunities and technologies:

High-speed networks

With high-speed cellular and Internet connectivity becoming the default for consumers and businesses everywhere, standards for speed, user-friendliness, and convenience in transport will continue to go up. Examples include same-day or next-day deliveries and on-demand taxis and scooters. Expectations for ease of use across platforms and apps will be even higher when 5G networks become mainstream in many markets over the next decade. For mobility service operators, this means not just having apps as the default means for interacting with users and drivers but also app interfaces and in-app transaction processing times that are as quick and responsive as the fastest speeds available over local networks. And as users become accustomed to ever-faster service speeds, they will be less tolerant of downtime or interruptions for mobility services.

The main challenge to offering mobility services that maximize high-speed connectivity is cost. Data usage is not free and could be easily become very expensive for many users. Large segments of potential MaaS users could be left out if mobility service operators simply optimize for speed and do not consider affordability. Nonetheless, there are ways to address such affordability concerns, such as the bundling of similar on-demand services for scale.

Data sharing

Bundling disparate services while ensuring seamless experiences across platforms and apps for shared transport requires sharing data among companies. This should lead to more partnerships that cut across industries: charging station operators, battery pack providers, and ride-hailing companies for electric, shared mobility fleets; automakers, insurers, dealers, and parts providers for doorstep, remote, and mobile workshop services through onboard diagnostics and in-vehicle communication networks; and navigation solution providers, telecom companies, and payments processors integrating infotainment and navigation to present the best, closest options for dining and entertainment.

In practice, however, many mobility players consider their data stack as proprietary and are hesitant about sharing data even with non-competitors. Public transport operators, for example, would have legitimate concerns about potentially opening themselves to greater liability if they do not meet service standards of third-party companies that incorporate their services. Creating rules and regulatory frameworks for responsible data sharing, particularly when different types of organizations are involved, is essential. Standards for data security and anonymization also would have to be in place.

Smart cities

The spread of ride-hailing has made governments and city planners much more aware of the need to provide better commuting experiences and use technology solutions to address local transport issues. For example, installing smart traffic lights and signs in pilot areas could pave the way for more ambitious and expansive traffic management schemes. Bringing together government funding and private sector technical knowledge via public-private partnerships to breathe life into these kinds of projects is common and widely accepted.

With public-private partnerships being the norm for smart cities, the primary challenge is properly structuring them: alignment on aspects such as measuring project success and ensuring equal treatment of transport operators in the awarding of incentives and contracts is complicated; data ownership rights and responsibilities in overlapping projects could become contentious if not defined properly or agreed upon early.

Shift from ownership-to subscription-based models

This shift is happening for both mobility services and vehicles and will enable greater flexibility, reduced ownership costs and liability, and opportunities to experience different vehicle types. Retaining customers and building loyalty will depend on having more data on vehicle use and customer behavior. Onboard diagnostics and embedded telematics will facilitate this; both are becoming standard in all new vehicles. For ride-hailing operators, this would allow for expansion into adjacent verticals such as vehicle insurance and financing.

Similar to broader high-speed networks, subscriptions for vehicles and mobility services face challenges of wide access and affordability. For example, users subscribing to multimodal services would expect a uniform rate across different transport modes. Bringing various ride-hailing, public transportation, taxi, and scooter services into a common model that is affordable to the vast majority of target users represents a challenge for MaaS operators.

2. MaaS Solutions: Major Players, Case Studies, and Components

A. North America

North America is the largest market for MaaS technologies due to the presence of many large cities with historically car-oriented transport systems. Uber is dominant, generating more than 80% of shared mobility market revenue. Other major shared mobility players in the United States are Lyft, Curb, Via, and Arro. Despite its relatively large size, the North American market will still see robust growth in over the next 2 to 3 years due to the large number of start-ups challenging Uber and Lyft and developing platforms that accommodate all modes of transport and offer personalized, on-demand services.

Major MaaS Service Providers

Company	Services Offered
Communauto Inc.	Car-sharing business application for in- town and out-of-town trips
Uber Technologies	Ride-hailing, food delivery, package delivery, courier, freight transport
Lyft	Vehicles for hire, bike/scooter sharing, food delivery
Cubic Corporation	Public transport app
Curb Mobility	On-demand taxi app
Via	On-demand shuttle app
Arro	On-demand taxi app

Major MaaS Technology Providers

Company	Services Offered
Moovit Inc. (an Intel company)	Real-time trip planning, trip payment, public transit APIs, urban mobility analytics
Waymo (an Alphabet company, formerly Google Self-Driving Project)	Autonomous driving technology development, self-driving taxi
Zoox Inc. (an Amazon company)	On-demand autonomous ride sharing service
Airbiquity	Telematics solutions for connected vehicles, automatic technology integrations, data management
Lytx	Video thematic solutions, fleet safety and management systems, in-vehicle monitoring systems, driver behavior monitoring system

Case study
Zoox autonomous taxis

Global eCommerce giant Amazon acquired Zoox, a US self-driving technology company, for US$12 billion in 2020 to develop fully autonomous robotaxis designed for passenger rides. Over the next few years, according to Zoox, the plan is to have an app-based autonomous taxi service in San Francisco and Las Vegas.

Zoox's robotaxi, unveiled in 2020, can accommodate 4 passengers and has a top speed 120 kilometers per hour. Zoox claims that its robotaxi is the only autonomous vehicle being deployed with 4-wheel steering and capable of bidirectional travel. Zoox also says that its vehicle has been designed with redundancies in powertrains and batteries that, working together with a diagnostic system, ensure that the vehicle has no single critical failure point.

While its current focus is autonomous taxis, Zoox will likely diversify to delivery fleets to ensure same-day deliveries for Amazon, particularly for "hyper-local fulfillment" (i.e., delivering from fulfillment centers in cities), logistics services, and deliveries of food, groceries, and parcels.

US$12 Billion

Global eCommerce giant Amazon acquired Zoox, a US self-driving technology company, for US$12 billion in 2020 to develop fully autonomous robotaxis designed for passenger rides

B. Europe

MaaS in Europe focuses on building services that make travel seamless across public and private transport modes. Close economic and geographic ties between European countries and harmonized regulations via the European Union mean MaaS is privacy- and data security-oriented and interoperable across languages and platforms. Major MaaS players are working on solutions that allow customers to configure and buy service bundles and select ideal transport modes or services from a list of recommendations.

Major MaaS Service Providers

Company	Services Offered
Free Now (a BMW-Daimler joint venture)	Ride-hailing service bringing black cabs and private vehicles for hire together in an app in London
Transdev	Mobility service integrator offering public transport information
Transit App	Car-sharing, bike-sharing, taxi for hire, ride-hailing services
RATP	State-owned public transport operator in Paris offering bus, metro, and other public transit service information

Major MaaS Technology Providers

Company	Services Offered
Whim	Mobility subscription for car, bikes, taxis, and public transport
UbiGo	Real-time trip planning, ticket booking, and payment services
Citymapper	Public transit app and mapping service providing live updates, transport modes available for entered destination, and data integration and management
EasyMile	Driverless vehicle solutions for passengers and goods

Case study
Whim Global

Whim Global is a MaaS operator that offers different transport services under a unified, monthly subscription plan. With a single interface for public transport, shared scooters and bikes, ferry tickets, taxis, and car rentals, Whim users can plan trips, make reservations, and pay for all mobility services through a single app.

Whim has positioned itself as a direct, environmentally sustainable alternative to personal vehicles, targeting the replacement of 1 million private cars with Whim subscriptions by 2030. Currently available in 5 countries (Finland, Austria, Belgium, Switzerland, and the United Kingdom), Whim recently acquired Wondo, a similar start-up based in Spain to help it expand to more markets.

1 Million Private cars

Targeting the replacement of 1 million private cars with Whim subscriptions by 2030

C. Japan

Japan is a smaller market for MaaS services and technologies than Europe or North America, but its extensive public transport network can be a foundation for building MaaS services. More importantly, Japan has the potential to lead the way in demonstrating how MaaS can be incorporated into smart city projects and how governments can actively work with private companies on such initiatives. In May 2020, legislation was passed to allow selected local governments to engage private companies in the planning and development of smart cities that would revitalize less-populated locations that are not near major metropolitan areas.. Smart city demonstration projects include Panasonic's Fujisawa Sustainable Smart Town in Kanagawa Prefecture and the Accenture-led "urban operating system" in Aizuwakamatsu in Fukushima Prefecture.

Major MaaS Service Providers

Company	Services Offered
Monet	Ride-hailing services, shuttle bus and taxi services
JR East	Public transportation services offering train and bus information; manages and operates Japan's largest smart card for payments and public transport (Suica)

Major MaaS Technology Providers

Company	Services Offered
Woven Planet Group	Holding company for autonomous driving technology development (Woven Core), smart city projects (Woven Alpha), and technology investments (Woven Capital)
Tier IV	Open source autonomous driving software development for self-driving and intelligent vehicles for passenger and goods movements
Val Laboratory Corporation	Software developer of Ekispert (application programming interface for route search and payments), integrated with MaaS Global in Japan

Case study
Toyota's Woven City

During CES 2020, Toyota announced that it will be developing Woven City, a smart city at the base of Mount Fuji, Shizuoka Prefecture. Woven City is envisioned as a "living laboratory" for testing new technologies while housing about 2,000 residents in its 175-acre/70-hectare area.

Autonomous, electric vehicles will be the only vehicles allowed in Woven City; driverless vehicles will operate on dedicated streets and underground and perform multiple tasks: delivering packages to each household's "smart post," collecting rubbish, and fetching items for delivery to the logistics center. Sensors and cameras throughout Woven City will gather data and provide them to the driverless vehicles above ground so they can operate safely and adjust quickly to city conditions.

Woven Planet Group, the holding company in charge of the project, wants Woven City to be a leading site for autonomous vehicle development. The group is particularly interested in mapping, announcing agreements with Isuzu, Hino, and Mitsubishi for high-precision maps for autonomous vehicles. Ride-hailing company Lyft's Level 5 division and US artificial intelligence company CARMERA were also both acquired in 2021 to strengthen software development.

Autonomous

Driverless vehicles will operate on dedicated streets and underground and perform multiple tasks: delivering packages to each household's "smart post," collecting rubbish, and fetching items for delivery to the logistics center

D. China

China's size in terms of population and vehicles in operation makes it essential to any MaaS service or technology company: with 14 smart cities expected by 2030 and a higher urbanization rate and population density than North America and Europe, China is already a dynamic market for MaaS-related opportunities. Didi Chuxing is the most prominent shared mobility company to date, but many smaller players such as T3 Chuxing offer very localized and diverse services. Autonomous taxis, in particular, are seeing great interest from China's leading technology and mobility companies as the next frontier for personal mobility and will allow MaaS to become truly affordable to almost all of China's population.

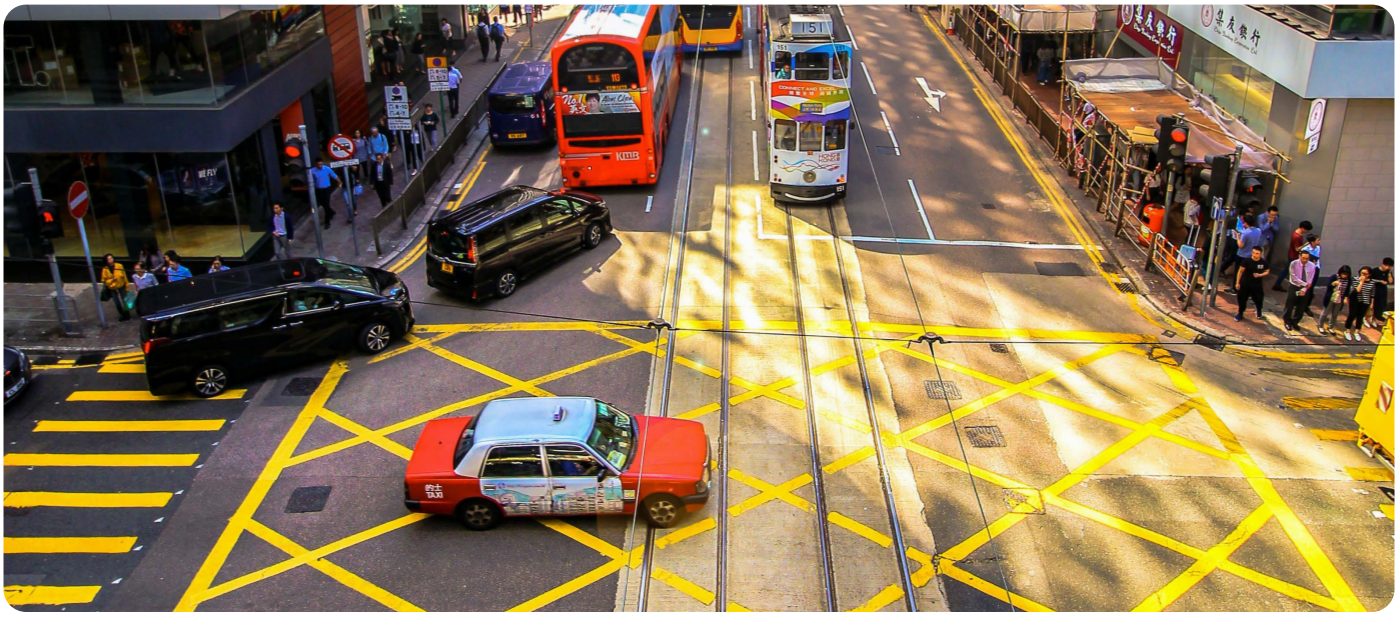
Major MaaS Service Providers

Company	Services Offered
Didi	Vehicle-for-hire service, mobile transportation platform
Auto Navi	Mapping, navigation, and location-based service provider
Baidu	Ride-hailing services
Meituan Bike	Bike/scooter sharing services
T3 Chuxing	Ride-hailing services

Major MaaS Technology Providers

Company	Services Offered
Baidu Apollo	Internet-related and artificial intelligence (AI)-based services
AutoX	Advanced self-driving AI platform
Pony Pilot	Autonomous robotaxi
Momenta Flywheel	Autonomous self-driving vehicle technology

Case study
Baidu Apollo Robotaxi



Search engine and AI company Baidu launched China's first paid robotaxi service (Apollo Go) in 2020. Via the Apollo Go or Baidu Maps app, users in Beijing, Changsha, and Cangzhou can hail autonomous taxis to take them to their destinations. First introduced in Beijing, 10 robotaxis were initially deployed for service within a 1.2-square-mile area. The vehicles were found to be precise in identifying jaywalkers and maintaining safe braking distances to avoid collisions.

Baidu is aiming to have 3,000 Level 4 autonomous taxis operating in 30 cities by 2030, but the overall goal is the commercialization of a MaaS platform that will allow for on-demand robotaxis, autonomous buses, and self-driving shuttles. The company has worked with the Guangzhou Huangpu District Government in piloting its MaaS platform. The scaling up of the robotaxi service to more areas in China will be accompanied by a rebranding of Apollo Go to Luobo Kuaipao to represent a focus on improving user experiences and increasing the number of available vehicles. A recently announced expansion of its partnership with Chinese automaker BAIC to build more than 1,000 driverless cars over the next 3 years will help Baidu scale up its MaaS platform.

Baidu is aiming

to have 3,000 Level 4 autonomous taxis operating in 30 cities by 2030

In 2021, Baidu announced that it is forming a dedicated joint venture with Geely for the development of self-driving vehicles. It also just unveiled a Level 5 concept (Baidu Robocar) that it claims can drive independently with the same capability as a human driver, and the next generation of its autonomous buses (Apolong II) that could be the start of a wave of autonomous commercial vehicles fulfilling functions beyond passenger transport, such as last-mile deliveries.

3. MaaS Enablers

A. Route Planning and Payments

A true route and journey planning solution allows users to easily and conveniently visualize and schedule transfers between transport modes, and select from a variety of payment options, via a single user interface. This is critical to raising MaaS adoption among the general public.

Stream Data Processing via Distributed Software and Cloud Computing

The most important feature, however, is dynamic, data-driven, responsive updates that allow the solution to generate (in real time and from any given starting point) the fastest and most cost-effective options for reaching any destination. This requires the integration of data on road traffic conditions, and travel times across transport modes, and actual availability. The most effective solution would be local in scope or at least have access to location-specific travel demand data.

> “
>
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Real-time updates are done via stream processing, or taking action on data once it is generated. This is different from batch processing, or acting on data only after a certain period of time or steps are completed, which is how data has traditionally been processed. All route and journey planning capabilities (i.e., real-time routing; fare, time, and distance calculations; and user notifications and messages) are enabled by software that is distributed, or designed to be run on many servers rather than a single computer. Being distributed means that data can be stored and analyzed as it comes in. With cloud computing (on-demand computing services), this also means route and journey planning providers do not have to own their IT infrastructure, but only pay for actual usage of computing power and storage.

An example of route and journey planning enabled by distributed software and cloud computing is the regiomove app and platform launched in November 2020 for the Karlsruhe region in Baden-Württemberg, Germany. With funding from the European Commission and the state government of Baden-Württemberg, regiomove—designed by German-based public transport solution firm INIT—provides a single interface for shared bikes, car rentals, buses, and trams in the Karlsruhe area.

The regiomove app suggests possible routes and displays information on CO2 emissions for each option alongside parking information and operating hours. Users pay once and receive the appropriate ticket or access code at the right time in their journeys. Mobility hubs and service terminals are being built to support intermodal transport, and there are plans to integrate on-demand minibuses and shared electric vehicles.

B. Autonomous Driving and ADAS

Fully autonomous driving will make MaaS a truly universal service for people of all ages and backgrounds.

Fully autonomous driving requires collecting and processing vehicle, user, and environment data—changing the hardware requirements for data management in vehicles and making buffers, high speed processors, and Ethernet-based electrical and electronics (E&E) architectures. Today, "Level 2 Plus" features (Level 2 driver assistance features enhanced by local and map data) are just beginning to be commercialized, with Level 3 autonomy not far behind. Tesla, Audi, Honda, and Volvo are all working on sensor fusion to achieve autonomous capabilities beyond Level 3. To facilitate the introduction of autonomous vehicle features, automakers are reducing architectural complexity by adopting domain controllers that lower chassis weight and increase data transmissions speeds.

> "Fully autonomous driving will make MaaS a truly universal service for people of all ages and backgrounds

MaaS represents a natural application and a means to showcase the autonomous driving capabilities that many automakers are beginning to introduce in new vehicles. Autonomous driving and driver assistance require a variety of sensors and data collection and processing technologies that the following discussions explore in more detail.

Piezo Technology

Piezo technology is at the heart of ultrasonic sensors commonly used for detecting obstacles while parking. Piezoelectric sensors measure a vehicle's distance from parking obstacles via the time it takes to reflect the inaudible, high-frequency sound waves generated by the piezo device (similar to how bats use echolocation). This also is the foundation for more advanced forms of parking assistance that, for instance, allow vehicles to steer automatically into parking spaces.

Given ultrasonic sensors' use for parking assist features, it is not difficult to see how the same piezo technology—in concert with other high-precision sensors—can be extended to vehicle-to-everything (V2X) applications. V2X in autonomous vehicles could be used to sense vehicle locations in relation to devices and pedestrians, and communicate road hazard warnings.

Another potential application of piezo technology is in the development of cleaning devices that clear dirt, snow, mud, and other materials from vehicle cameras. Cleaning devices that clear mud and debris from camera lenses are important to autonomous vehicles because cameras are the autonomous vehicle's most visually accurate information source for colors, depths, and textures. With ultrasonic atomization and piezo vibration, cleaning devices will be able to ensure that vehicle cameras will be functional at all times.

Piezo technology also could be used for haptic applications, which will lead to the development of new human-machine interfaces (HMI). Combined with haptic feedback, ultrasonic technology could be helpful in safety warning systems. Haptics could provide driving assistance and give warnings to ensure that drivers are giving their complete attention to the task via feedback through the steering wheel, seatbelt, and pedals. One example is Murata's haptic technology based on ultrasonic vibration and piezo film. This approach has several advantages, including allowing for variety in haptic feedback and vibration strength while having very fast response times. It also opens the door for feedback through in-vehicle infotainment systems, which could be critical if used for safety alerts.

Microelectromechanical System Technology

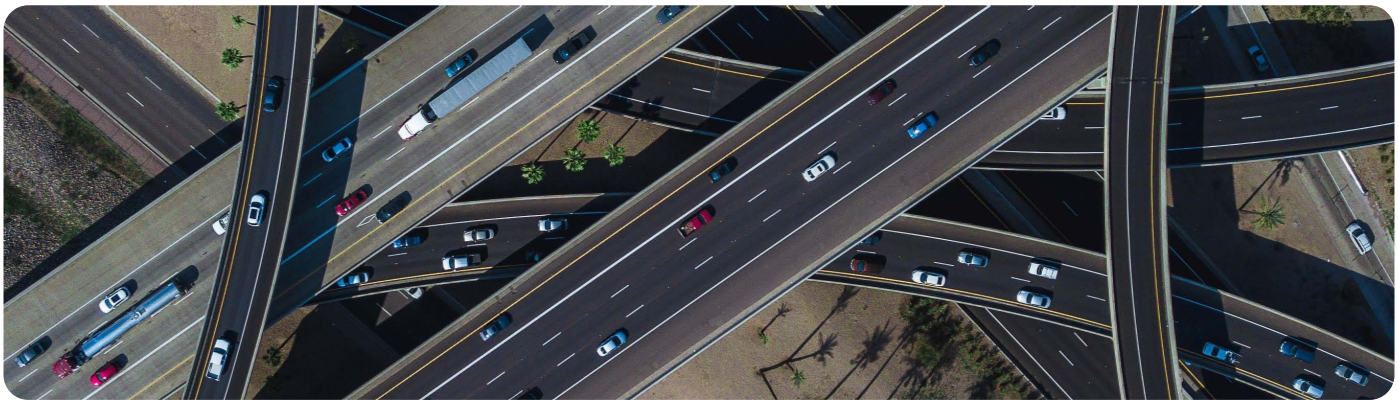
Current car navigation systems determine a vehicle's location and position using information from GPS, accelerometer sensors, and gyro sensors. In ADAS, more accurate and reliable sensors will be needed because dead reckoning is necessary to navigate safely even when GPS signals are limited or unreliable. Microelectromechanical system (MEMS) technology is an extremely fine processing technology that makes it possible to offer high-reliability sensors with stable processes at a reasonable cost. Murata realized 6-axis sensors by integrating accelerometer sensors and gyro sensors that are already used for electronic stability control and headlight levelling using MEMS technology. Murata's sensors have a proven track record in automobiles, making them suitable for use in ADAS.

C. Vehicle Connectivity

Vehicle connectivity today is most commonly associated with connecting to the car's infotainment system via Bluetooth or Wi-Fi. As more countries mandate in-vehicle emergency call functions, cellular connectivity in vehicles is becoming more widespread.

Connectivity in vehicles, overall, means that cars can access and share data, download software and updates, and communicate with other vehicles and their environment. In-vehicle marketplaces and on-demand features are 2 of the main avenues by which connectivity is changing how vehicles are used. In-vehicle marketplaces turn vehicles into valuable business platforms by allowing third-party merchants to interface with customers via the car's infotainment system on-demand features can transform vehicle pricing and financing. In-vehicle marketplaces and on-demand features require 5G connectivity and the ability to communicate with infrastructure and other vehicles (V2X connectivity).

For MaaS, the ability to collect and share data across vehicles, devices, and road traffic infrastructure is necessary to be adaptive and responsive to user needs in real time. This means understanding that vehicle connectivity is about more than developing applications: to fully realize V2X communication, reliable infrastructure will be needed to power the vehicles, manage traffic, and make use of all the data collected to improve transport system efficiency.



V2X Communication Technology

V2X encompasses vehicle-to-vehicle, vehicle-to-infrastructure, vehicle to pedestrian, and other forms of communication.

V2X communication technology makes it possible for vehicles to interact with other vehicles, pedestrians, and surrounding traffic infrastructure. V2X communication enables data sharing of speeds and positions between vehicles and surrounding objects—even those not in its line of sight. V2X can warn drivers of potential dangers, improving collision avoidance and significantly reducing the chances of injuries or fatalities. V2X technology also enhances efficiency by providing congestion warnings and proposing alternate routes to drivers when possible. Vehicle communications have become prominent with the use of radio frequency in intelligent transport systems, providing drivers with reliable information including safety through communications between road surroundings and vehicles facilitated by a traffic management center or operators.

V2X communication technology tends to require coaxial cables to cover the distance between antenna and the V2X control unit. However, the longer the cables used, the larger the losses will be, so a compensator is needed to compensate these data losses. Dedicated short-range communication (DSRC) devices provide short to medium 2-way wireless communications and have the capability of facilitating high-speed and secure data communication between vehicles and infrastructure. Cellular V2X (C-V2X) is a 3GPP technology that could also meet V2X requirements. C-V2X will coexist with DSRC technology, enabling both direct vehicle-to-vehicle and vehicle-to-infrastructure (including vehicle-to-network) communications.

For safety reasons, it is imperative that V2X communication allows for vehicles to determine the presence of approaching vehicles as soon as possible. A single-package module for V2X that is high output and compatible with both DSRC and C-V2X—such as the one being developed by Murata—would make this possible, and would make a V2X system be much easier and simpler to design.

Traffic-sensing Technology

Real-time traffic information would be accessible through traffic sensors—portable electronic devices that collect multiple data points including number of vehicles, pedestrians waiting to cross roads, and vehicle speeds. With in-road sensors and conventional traffic lights, they could be used to analyze traffic bottlenecks and identify road infrastructure wear and tear. Automated traffic sensors require less supervision and the software, with AI, could be used to manage difficult traffic situations in real time. A smart traffic management system would be able to use collected data to make predictions and better manage traffic flows. Murata's Traffic Counter solution, for example, records the number of vehicles on road, the average speed at which vehicles are traveling in a specific route, and vehicle emissions. It keeps sampling traffic data every minute and provides consolidated analysis to mobility service operators and government authorities for optimal route planning and transport services.

Battery Technology

Batteries power connected electric vehicles and the infrastructure required to support them. Backup power from batteries is important to ensure that infrastructure communicating with vehicles is running even during power outages, guaranteeing safety and reliability; fluctuations in power generated from renewable sources such as solar and wind mean a need for reliable batteries to store excess power and deliver it when needed.

Technology companies, including Murata, have developed an all-in-one battery system in response to this need: a hybrid power conditioner that has optimal storage capacity and necessary functions integrated in a compact unit.

D. Health, Wellness, and Well-being

Automakers are realizing the potential to differentiate themselves by developing in-vehicle attention and health monitoring features. Toyota and Ford, for example, have both announced development work on in-vehicle heart rate monitoring. Driver-assist systems that detect attention such as those in Tesla, Mercedes-Benz, and Cadillac vehicles could eventually incorporate other health sensing and monitoring functions. Over the next 2 to 3 years, similar features based on recording oxygen and temperature levels are likely to be rolled out by automakers. For health and well-being features in vehicles, driver and passenger monitoring and child presence detection would be the key underlying technologies.

> “Driver-assist systems that detect attention such as those in Tesla, Mercedes-Benz, and Cadillac vehicles could eventually incorporate other health sensing and monitoring functions

MaaS needs health, wellness, and well-being features in vehicles to significantly reduce risks and accidents under all driving conditions. This is supported by evidence that suggests that current driving remains quite risky due to the presence of many potential distractions. For example, over 15% of vehicle-related injuries that occur in crashes are due to distractions, according to the US National Highway Traffic Safety Administration. Research supported by the EU has also found that up to 30% of driving time is spent on distracting activities.

For mobility service operators, health & well-being solutions in vehicles would ensure that driver and passenger safety and health are never being compromised at any point. For MaaS specifically, with the emergence of autonomous vehicles in public transport and ride-hailing means there will be a greater need for more active and precise monitoring of passengers and, when required, backup drivers.

Driver Monitoring

Cameras are commonly used for driver monitoring, but there are good reasons to also consider using sensors for this purpose. All cameras have blind spots and could be less effective in bright or low light. There are also legitimate concerns about cameras creating privacy issues, even when image and video data are collected as a means to improve driver behavior. To overcome these concerns about privacy and data precision related to using cameras for driver monitoring, alternate technologies are now being developed to measure and track vital signs, such as radars, vibration sensors, and radio sensors.

Child Presence Detection

Child safety incidents often involve small children being locked unintentionally inside stationary vehicles. The European New Car Assessment Program (Euro NCAP), in fact, has mandated a child presence detection feature in car beginning in 2023. Radar technology is becoming more common for child presence detection, but there is clear potential for using Wi-Fi technology as well.

A demonstration of this is Murata's child presence detection system via Wi-Fi modules placed at front and rear end of the car. The modules use radio waves to detect breathing and movement, sensing any slight change in Wi-Fi signal traveling within the car. Child presence detection via Wi-Fi has notable benefits: it can detect children just by installing software in existing infotainment systems, and there are no blind spots or dead angles because Wi-Fi's signal strength is comparable to radar.

Radar-based solutions also could be used for monitoring driver health and cabin conditions. Radars with short range are preferred for cabin applications, where the field of view can be configured for different vehicle models based on dimensions and sensor position.

Fatigue and Stress Monitoring System

Vehicles could soon have widespread built-in systems to monitor fatigue and detect and analyze driver behavior. These systems would gather information from driver inputs and body measurements such as control of the vehicle, eye movement, brain waves (EEG), lateral position, steering wheel grip, and speed.

For safety purposes, cars capable of autonomous operations should still be able to give back control to human drivers under extraordinary situations such as severe weather or the absence of road or lane markings. The idea is that human drivers would be better able to adapt and take appropriate actions than autonomous driving systems mostly relying on sensor data. This makes monitoring driver stress and fatigue important, even with continuous advancements in vehicle autonomy.

There are other technologies that are not originally for automotive functions but can be used for MaaS market as well. For example, Murata's fatigue and stress monitoring meter, originally designed for employee health monitoring, could become valuable for individual drivers and fleet managers. For drivers, proactive health monitoring could prevent driver health condition-related accidents from even taking place. An example would be detecting and preventing a driver who might not have gotten enough sleep from driving, even when technically compliant with hours of service rules by not having worked the previous day. For fleet managers, monitoring stress and fatigue can mitigate driver error and make smarter work scheduling possible.

Conclusion

Urbanization and higher expectations for convenience and ease of use for transport are driving development of MaaS around the world. As cities continue to grow, the negative health, environmental, and economic impacts of vehicle emissions and longer travel times due to traffic congestion will have to be managed more aggressively. By encouraging alternatives to vehicle ownership and making the transport system more adaptive to real-time conditions, MaaS services and technologies will be increasingly important for everyone's mobility needs.

MaaS is more than the integration of services for different transport modes. Sophisticated autonomous driving and ADAS, vehicle connectivity, route planning and payment, and health, wellness & well-being features are gradually becoming standard in vehicles; higher expectations for safety, functionality, and usability will allow MaaS to thrive.

Partnerships even among potential competitors will continue to increase as OEMs, technology companies, and transport operators work together to realize truly seamless, multimodal, and convenient transport for all.

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> MaaS services and technologies will be increasingly important for everyone's mobility needs

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