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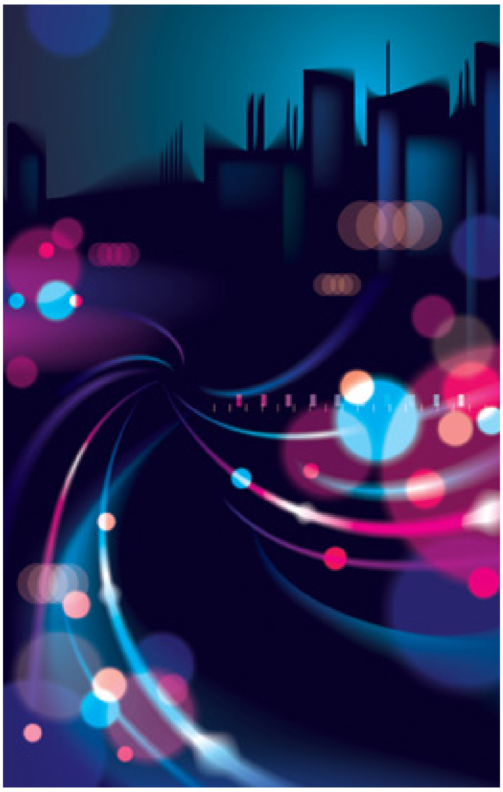
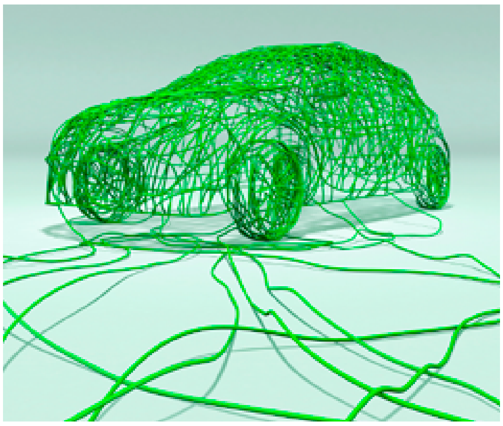
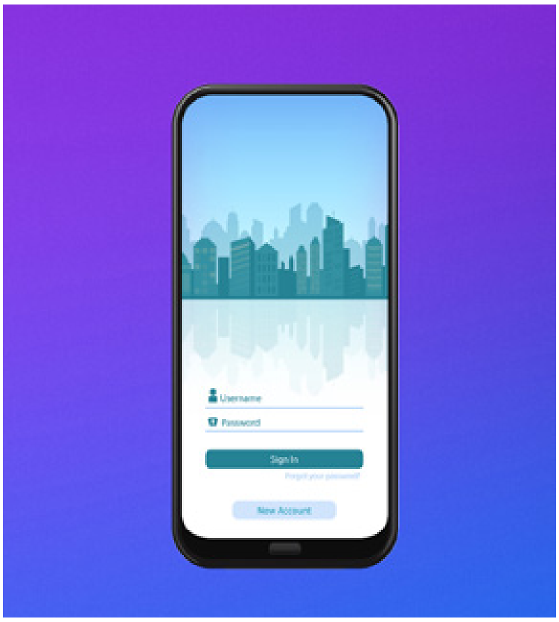
Anticipate, Innovate, Transform

Trends in the Automotive & Mobility Industries

CONTENT



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OPENING STATEMENT

BY KLAUS SCHMITZ

The automotive industry suffered significant sales losses during the COVID-19 pandemic, and its manufacturing supply chain is still recovering. All told, this is perhaps the greatest crisis the industry has ever faced. At the same time, the pace of innovation in both the automotive and mobility sectors has accelerated — and new business models have emerged.

Decarbonization, digitalization, and the reshaping of the global supplier and automotive market has disrupted the industry like never before, giving rise to a climate of renewed innovation. Creating a competitive advantage requires businesses to reimagine and/or differentiate themselves — adopting new digital business models, collaborating with partners in redefined ecosystems, leveraging customer data, and implementing sustainable practices and solutions.

In particular, innovation has been driven by a popular demand for more sustainable and climate-friendly technologies. Cars have run on fossil fuels since their invention and have shaped the face of our cities and transport infrastructure for decades, not to mention our social behaviors.

Today, vehicles are not just transitioning to electric power; the very nature of car ownership is changing. For instance, an ever-increasing number of people are turning away from individual car–based mobility in urban environments. In fact, the "peak car" concept — where private car usage is at its peak and now spiraling downward — is in full effect in the Western world, and the industry needs to respond robustly to this development.

Alternatives to privately-owned vehicles and transportation are becoming more widely available, meeting consumer needs for accessibility, convenience, and affordability. Mobility-as-a-Service (MaaS) platforms, in particular, such as on-demand ride services, ride/car sharing, and autonomous vehicles (AVs) like robo-taxis not only benefit consumers and the environment, but are providing opportunities for industry newcomers with innovative mobility payment systems and apps to facilitate these services.

It is becoming very clear that, with growing populations and urbanization around the world, both the automotive and mobility sectors must find new ways to prevent the collapse of traffic and transport ecosystems. Manufacturers and service providers should enter into new, cross-industry partnerships and be open to changes in business models — for example, managing the shift away from hardware sales to hardware operation and/or services.

For mobility and automotive players, this is a period of major structural change. Huge investments in transformation are required, which will inevitably coincide with a decline in revenue for some players. This will cause some businesses to exit while new ones emerge.

IN THIS ISSUE

Cutter Fellow Robert Charette starts us off with an in-depth look at the electric vehicle (EV) market in the next decade. Currently, automakers are focused on dethroning Tesla, which disrupted the auto ecosystem with its skateboard battery and advanced autonomous driving capabilities. Where charging will take place and how the world can produce enough EV batteries are major considerations in this initial skirmish. But the real battle begins around 2025, when EV makers shift their focus to production efficiencies and lifecycle sustainability as they battle against ICE vehicles for market share. Around 2030, the winners will emerge into a world of new technological competitive threats: billions of dollars will have been spent on battery technology, automated driving capabilities, and alternative fuels. Not to mention that convincing families to buy two EVs (instead of one EV and one ICE) will require designing affordable EVs that meet a range of family, work, and leisure needs.

Next, we shift gears to focus on MaaS. Arthur D. Little authors Olivier Pilot, Francois-Joseph Van Audenhove, and Mickael Tauvel have been studying the reasons traditional approaches to MaaS have failed (i.e., a failure to take all stakeholders into account), and they offer a model for a mature, value-creating MaaS initiative. It starts with digitally enabling organizational authorities to manage multi-modal mobility and connect users' digital experience (e.g., account management and trip planning) with physical access. As the authors suggest, account-based ticketing is key to this transition, decoupling a MaaS user account from the mobility-access device; simplifying account management; and allowing sophisticated, multi-modal back-end fare rules. They also argue for moving beyond the traditional plan-book/ticket-pay approach in favor of know-and-go, in which users *know* what they need to know about their journey *when* they need to know it and can *go* without worrying about mobility access, fare, or journey alternatives.

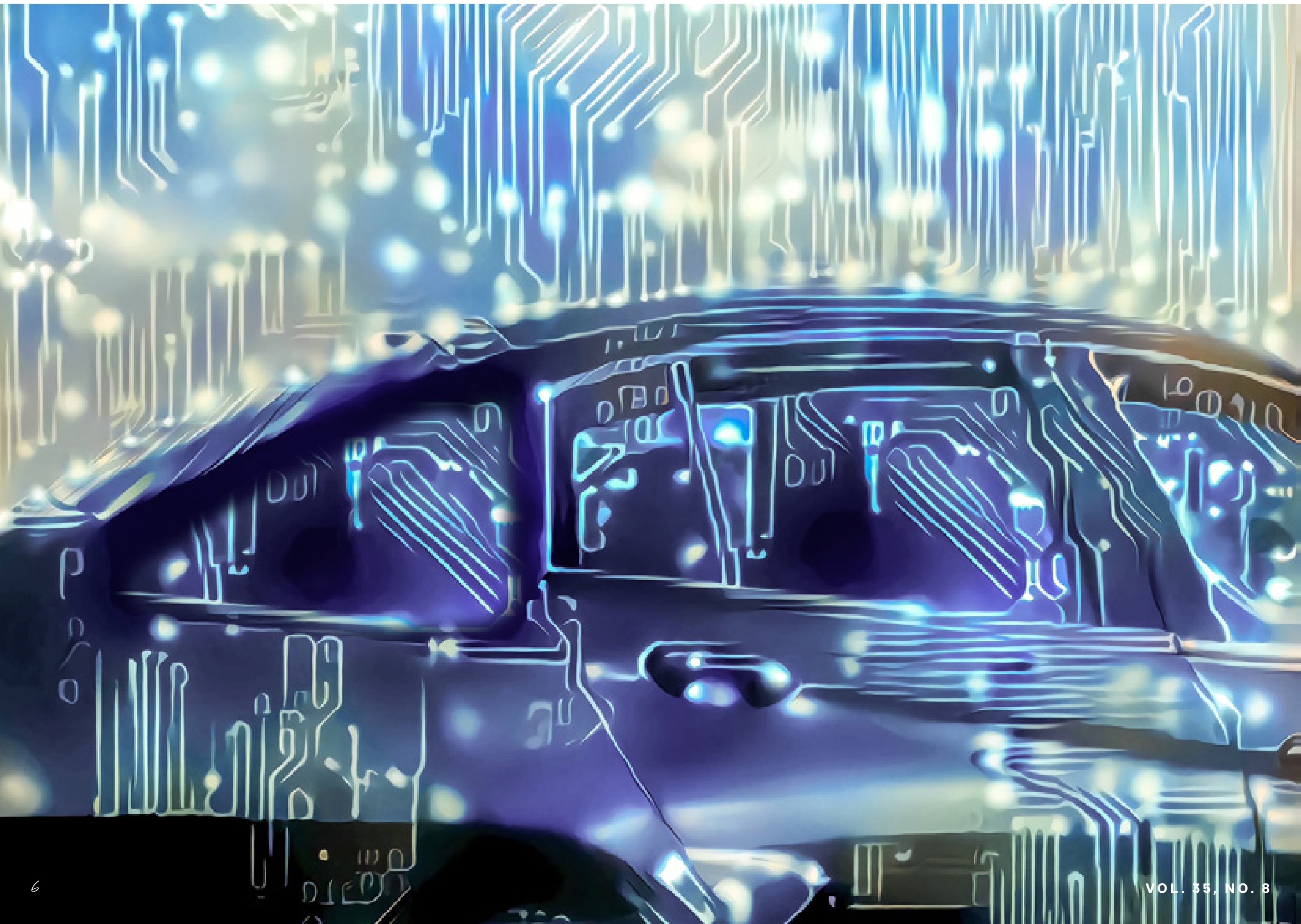
Our third article takes us back to vehicles, this time autonomous ones. Cutter Expert San Murugesan says now is the time to examine the potential effect of autonomous vehicles on climate change so we can take appropriate steps before widespread adoption is upon us. We need to examine the potential positive and negative environmental impacts of AVs, look at whether they can help reduce the transport sector's carbon emissions, and consider how we can minimize their carbon footprint as they become mainstream. After explaining the six levels of automation as defined by SAE International, Murugesan describes several potential AV benefits, including fewer road accidents, making elderly populations more mobile, and solving the last-mile-delivery dilemma with autonomous trucks. After a careful examination of the possible environmental impact of AVs, he offers recommendations for creating an autonomous future that will not only be safer and more convenient, but also better for the environment.

> **INNOVATION HAS BEEN DRIVEN BY A POPULAR DEMAND FOR MORE SUSTAINABLE AND CLIMATE-FRIENDLY TECHNOLOGIES**

Next, returning contributor Ralph Menzano takes us on a fascinating journey into the world of smartphone-based tolling — a way to increase road-based revenue, help cities control peak-time congestion, and (at long last) enforce high-occupancy vehicle (HOV) lane use. Next-gen toll systems not only cost less than RFID-based ones, but have the potential to reduce the number of cars on the road, replace gas-tax revenue lost due to EVs, and provide a mountain of information to transit authorities to help them better manage traffic. Menzano offers a success story from a pilot program in Texas, USA; looks at how the US has fared against Europe and Asia in tolling; and helps us understand why much of the world is looking to the US for leadership in usage-based road pricing for light vehicles.

THE CHANGING FACE OF THE AUTOMOTIVE AND MOBILITY INDUSTRIES IS THRILLING, BUT THE CHALLENGES ARE MANY

Our final article is from Cutter Expert Curt Hall, who explains how machine vision systems using machine learning (ML) and other artificial intelligence techniques are gradually spreading from use in large auto manufacturers to being incorporated in aftermarket businesses. Increased accuracy of ML-based cameras, edge computing systems, machine vision startups targeting the market, and MaaS are all driving the expansion. One main area of use, Hall explains, is in camera-based robotic systems to automate basic maintenance operations like tire changing. Another area is automated vehicle inspection that can be used by repair shops, dealership service departments, online vehicle marketplaces and auction sites, and auto parts recyclers.



Hall says the trend is just getting under way, so we'll see a steady rise in the use of these systems in the near future.

The changing face of the automotive and mobility industries is thrilling, but the challenges are many. To stay in the game, business leaders must be willing to invest heavily in R&D while keeping in mind fluctuating consumer behaviors, emissions compliance, security and privacy concerns, supply chain shortages, and more.

About the guest editor

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Klaus Schmitz is a Partner at Arthur D. Little (ADL) and leads ADL's Automotive practice in Central Europe. He predominantly serves clients in the automotive industry. Dr. Schmitz also serves ADL's Technology and Innovation Management (TIM) practice, where he supports clients in the high-tech industry on innovation and technology topics. His main fields of work comprise marketing, sales and after-sales, as well as strategic innovation, technology, and information management. Relevant project examples include customer experience, strategic planning, sales and after-sales excellence, and product lifecycle management. Dr. Schmitz's special interest lies in mastering the disruptive change of digitization and new mobility for clients. Prior to ADL, he cofounded a research-oriented consultancy and led it as Managing Director for five years. Dr. Schmitz has also been a researcher, lecturer, and project leader in large external projects with big German corporations. Dr. Schmitz's education and background in information systems (IS) and software development enable him to understand technology issues. He earned a PhD in IS from the University of Bamberg, Germany. He can be reached at experts@cutter.com.

WINNING & LOSING IN EMERGING EV WARS

Author

Robert N. Charette

The "Age of Electric Vehicles" is finally upon us. Interest in electric vehicles (EVs) is at an all-time high. Surveys indicate that more than half of interested car buyers globally are seriously considering purchasing a battery electric (BEV), plug-in hybrid electric (PHEV), or hybrid electric (HEV) as their next vehicle. Even in the US, where the appeal of owning EVs has been lukewarm at best, interest in buying an electric-only vehicle has more than tripled, rising from 4% in 2020 to 14% in 2022.[1]

One obvious reason is the belief that recent elevated gasoline prices represent a long-term norm. Perhaps more motivating is the fact that automakers other than Tesla are beginning to deliver zero- or near-zero-emission vehicles that offer compelling performance outside the luxury, high-performance sports car market. Ford Motor Company's BEV version of its F-150 pickup truck that began delivery this May is a case in point. Priced similarly to its F-150 internal combustion engine (ICE) version, the best-selling pickup in the US for 40 years, the F-150 Lightning represents a solidly mainstream customer offering. Ford quickly sold out its initial production run of 200,000 and now plans to produce at least 150,000 Lightnings annually by 2024.

A tidal wave of new EV models will soon be hitting the market, offering consumers a wide range of choices. At least 30 legacy automakers along with EV startups have committed more than US $500 billion over the next decade to building new EV and battery factories for millions of new vehicles.[2] By 2025, around 100 new BEV and PHEV models spanning all automotive market segments will be available for sale in the US, along with scores of HEV models. Hundreds of EV models will be introduced by 2030, along with an increasing number of hydrogen fuel cell vehicle (FCV) models.

With so many EV models becoming available, and ICE vehicles still preferred over EVs, the question is whether the market can support them all. EVs have much slimmer profit margins than their ICE counterparts, making low-volume EV production runs unprofitable. Attaining production efficiencies and large-volume sales are critically important for an EV model's survivability. With EV sales in 2025 projected to be around 3.2 million for BEVs and PHEVs in the US and about six times larger in the rest of the world, clearly not every EV model introduced will be a winner.[3]

> **WITH SO MANY EV MODELS BECOMING AVAILABLE & ICE VEHICLES STILL PREFERRED OVER EVs, THE QUESTION IS WHETHER THE MARKET CAN SUPPORT THEM ALL**

Ford CEO Jim Farley says that given the immense capital investment needed to produce EVs, the ever-increasing costs of the basic materials required, and the need for a return on the massive investments being made, he expects a major consolidation of legacy automakers in the next few years.[4] "The old OEMs [original equipment manufacturers] absolutely will get consolidated," he says. "There'll be some big winners. Some people who transition, some won't." Farley expects many auto suppliers and EV-only startups to begin falling by the wayside as well, as they have no ICE vehicle revenue to fall back on if their offerings stumble.

> **WINNING, OR MORE LIKELY, NOT LOSING, IN THIS COMPLEX RISK ECOLOGY WILL REQUIRE AN AUTOMAKER TO SURVIVE THE FLOOD TIDE OF EVs**

Some of what Farley predicted is already occurring. In the first quarter of 2022, 35 deals involving $6.4 billion in US automotive supplier-related M&As were announced.[5] In June of this year, EV startup Electric Last Mile Solutions declared bankruptcy because it could not secure the investment needed to complete production of its preorder for 45,000 EV delivery vans. Last year, the EV startup was valued at over $1.4 billion.[6] Another startup, Canoo, itself valued at $2.4 billion in 2020, says it is barely holding on.[7] How many of the more than 80 EV startups will survive to 2025 is an open question. However, each one that fails undercuts future investment support for the remainder that manage to carry on.

Even Ford is experiencing EV-related punishment. Introduced in late 2020, its electric Mustang Mach-E is no longer profitable because of the rising costs of raw materials, even after Ford raised its price. Paradoxically, it has become a highly popular model, forcing Ford to use it as an unintended EV loss leader. Other EV makers have had to raise their prices, too, to protect profitability.

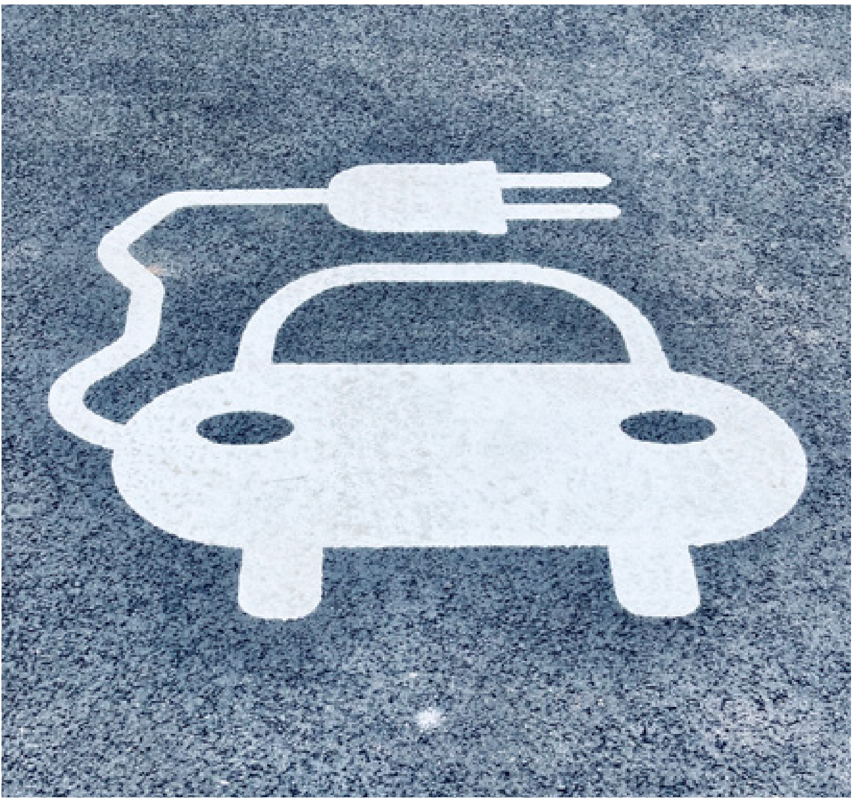
The effect of EV price increases on customer interest is uncertain. Current US EV buyers are generally more affluent than average American wage earners, but for EVs to evolve into a mass-market purchase, they'll need to be priced below the average EV price tag of $65,000 and closer to the ICE vehicle average of $46,500.[8] Even with high petrol prices, ICE vehicles are still more affordable to a larger and more diverse demographic of car buyers than EVs.

Inflation is only one of the many risks and uncertainties legacy and emerging automakers making the transition to EVs face. The effects on the auto supply chain from the ongoing computer chip shortage and the Ukraine conflict are two in a long list that characterizes a dynamic and highly competitive EV risk environment. Making it even more fraught is that many of the risks, like the ability of the electric grid to support EV charging, are outside the direct control of the auto industry.

Winning, or more likely, not losing, in this complex risk ecology will require an automaker to survive the flood tide of EV introductions over the next three years and stay alive until the EV market becomes more predictable — likely around 2030.

BATTLEGROUND 2023–2025: THE FIRST GREAT SHAKEOUT

Nearly every automaker seems to have one objective: topple Tesla in 2025. Ford is making moves to increase capacity in its attempts to dethrone Tesla in EV sales in the US by 2025.[9] Mary Barra, GM's chief executive, is bolder, promising that GM will sell more EVs than Tesla in the US that year.[10] Herbert Diess, the outgoing CEO of the Volkswagen (VW) Group, believes the German automaker could sell more EVs than Tesla worldwide by 2025.[11] Stellantis, BMW, and Hyundai, among others, are also planning to entice potential Tesla buyers away. Chinese auto manufacturers will have a lot to say about who will be the EV market share leader as well. Tesla, meanwhile, hopes to produce upward of 4 million EVs globally by 2025, a number that may be hard for its competitors to match.[12]



Why is everyone gunning for Tesla? Because, as VW's Diess has acknowledged, "Tesla sets the new benchmarks" for automakers to measure themselves against.[13] Tesla proved to a highly skeptical automotive industry that EVs with acceptable range, high performance, increased safety, and strong consumer appeal could be produced and sold. More importantly, Tesla proved such a vehicle could be made profitably.

Tesla permanently disrupted the entire automotive ecosystem with its novel "skateboard" battery design, innovative software-defined system architecture, provision of over-the-air (OTA) updates to its vehicles for both recall fixes and functionality increases, and advanced autonomous driving capability. Tesla also led the way by creating a strategic infrastructure to support its vehicles' production and support, including building its own giga-battery factories and EV charging station network.

Tesla's disruptive power can be seen in its July 2022 market capitalization, which is equal to the eight top global automakers' capitalizations combined.[14] Tesla's success has strongly influenced policy makers around the world and encouraged them to move aggressively to ban the sales of ICE vehicles in the next 15 years or less. Tesla, being an EV-only manufacturer, only benefits from these policies, unlike legacy automakers that must both produce new EVs and continue to support legacy ICE vehicles.

Both legacy and EV entrants are moving as quickly as they can to duplicate Tesla's recipe for success in one form or another. Most have moved to some form of skateboard battery pack design and are trying to create a software-defined EV. Doing so means bringing in new skill sets in both battery and computing technologies; the latter is proving especially difficult. Tesla's competitors are also trying to secure adequate supplies of batteries, either by building their own factories or partnering with battery providers. GM, for instance, is spending $2.6 billion to build a battery plant in Lansing, Michigan, USA, one of four it's constructing in the US.[15]

Securing raw materials and refining capacity are major obstacles to producing enough batteries. Stellantis CEO Carlos Tavares says he expects an EV battery shortage to emerge in 2024 or 2025 and predicts a shortage of raw materials for batteries by 2027 or 2028.[16] There are a limited number of mines and refineries to produce the minerals EVs need, a mere handful of which are in the US. EVs use about six times more minerals than ICE vehicles. Even Tesla is worried about not having enough batteries to support its future production plans.

Another issue out of the direct control of automakers is the assurance that all EVs produced can be charged. Although the majority of EV charging will take place at home, a network of fast chargers will be needed to give consumers confidence that EVs can be quickly charged on long trips. Tesla has created a network of 1,300 charging stations, which it will soon open to other EV models, and automakers like Ford and GM are trying to create their own networks of chargers. Moreover, the US government is investing $5 billion to help create 500,000 charging ports along major highways, but that network will not be complete before 2028. If the public believes there are not enough EV chargers available to support the estimated 7 million EVs on the road by 2025, a Massachusetts Institute of Technology (MIT) study indicates that EV sales could rapid ly drop off soon afterward.[17]

> **A WILDCARD IN THE MIX IS WHETHER OR NOT THE 2025 PREDICTIONS OF EV SALES FOR THE US AND GLOBALLY ARE ACCURATE**

Tesla is certainly the one to beat in 2025, but the company does have some vulnerabilities. CEO Elon Musk has long promised an affordable EV for the mass market, but that does not look like it will happen soon. The company's promised Cybertruck, which was supposed to come out last year, may be offered in late 2023 but with a much higher price than the originally advertised $39,000. Tesla will also face stiff competition in the EV luxury class market it has thus far owned. Luxury class vehicles are highly profitable, which is why nearly every legacy automaker, and many EV startups, will have some type of offering in this category by 2025.

In addition, Tesla's software reliability is beginning to be questioned. Poor software and electronics reliability is a major consumer turnoff, and it's a core reason 25% of BEV owners purchase ICE vehicles for their next car.[18] A "saving grace" for Tesla may be that nearly every EV being introduced by Tesla's competitors is having software problems, too. For example, VW is delaying several new EV models because of vexing software issues. Indeed, EVs are rated as having the lowest reliability of all vehicle types, in large part due to poor-performing software features and electronics. Sales may stall if EVs gain a reputation for unreliability.

A wild card in the mix is whether or not the 2025 predictions of EV sales for the US and globally are accurate. These projections are much higher than those made last year, which were themselves raised from years previous. More interesting is that even a cursory look into the number of EV sales that established brands and startups are publicly announcing for 2025 exceeds this upwardly revised projected demand.

However, both automaker EV plans and analysts' EV sales projections are based on the assumption that there will be major governmental incentives and/or rebates to EV buyers. With these incentives looking constrained, at least in the US, and ICE vehicles still retaining their price advantages, EV sales may not be nearly as robust as the current predictions.

If this happens, automaker investments in battery and manufacturing plants ("cash furnaces," as Musk calls them) will become major financial burdens, especially to EV startups. This happened in China, where numerous EV factories were built to meet a demand that never materialized.[19] In that case, consolidation and bankruptcies may be even more severe than Ford's Farley predicts.

The more imbalances among the various factors affecting production and supply, the greater the knock-on effects, placing both legacy automakers and EV startups in precarious competitive and financial positions. The EV shakedown cruise in the next three years will indicate who will be strong enough financially to go to the next round of competition.

BATTLEGROUND 2025–2030: STAYING ALIVE

"We are in the Darwinian world," says Stellantis's Tavares.[20] Given the expected raw material resource constraints, "The guys who survive are the guys that adapt," he says.

Adaptation will especially be needed between 2025 and 2030. Whereas 2023–2025 will be an EV-versus-ICE fight for market share, this period will see the competitive shift to a bruising EV-versus-EV market share knife fight. A new tsunami of EV model introductions is expected during this period. Stellantis alone promises to introduce at least 75 BEV models worldwide, with 25 BEV models for North America. Toyota promises at least 30 BEV models globally, and Nissan plans another 15 BEV models. These will join the hundreds already on the market by then.

One can expect this period to be competitively brutal, much more so than the initial EV shakeout period, even if one generously assumes that the EV raw material/refining/chip-shortage issues are reduced, EV production and demand generally become balanced, EV charging and battery range become minor issues, EV incentives are available, and EV price parity with ICE vehicles is achieved. If any one of these assumptions, let alone several, does not hold, the competitive environment will be even fiercer.

The 2025–2030 period will shift the focus to production efficiencies and lifecycle sustainability, improved software-driven capability and services, customer service, and pricing and profitability. Lowering EV prices will be a high priority. Ford's Farley thinks they can be reduced to around $25,000, which he predicts will spark a "huge price war," not only among EVs but remaining ICE vehicle models on the market.[21]

This can be done, Farley believes, with increased production efficiencies made possible by the simpler designs and fewer parts EVs need in comparison to ICE vehicles. There will also be significant manufacturing and supply chain learning curve gains, along with major cost savings from reducing unnecessary personnel management overhead related to ICE vehicle production.

The focus on EV software will be strong during this period and will focus on the 3Ps: performance, performance, performance. Automakers are looking at a software-as-a-service model, in which certain EV features and capabilities would be paid for by subscription. For example, VW is proposing that self-driving capabilities could be paid on an hourly rate. Automakers think they can make billions of dollars in EV software subscriptions. Of course, that would require rock-solid, invisible performance — a world away from today's EV software.

Another focus area will be improving customer service to maintain owner loyalty. EV repairs, especially after accidents, will come to the fore during this period. Whether or not there will be enough EV-trained mechanics to support EV volumes and model varieties (including different battery systems and motors) is a legitimate concern. Automakers acknowledge that this area must be addressed to prevent alienating future customers.

Social issues are also a major emphasis for automakers. As government deadlines to eliminate ICE vehicles grow nearer, political pressure on automakers to move away from them will increase. This will push legacy automakers to decide which ICE vehicles will no longer be sold and the date after which they will not be supported. These decisions will have a major impact on ICE owners and their support network, from dealers to mechanics to parts suppliers. If a legacy automaker is not careful about how it makes these decisions, it risks losing future EV customers to other brands.

Finally, automakers will need to ensure that the millions of used EV batteries are either being recycled or repurposed as batteries for the grid. They will also have to ensure EV owners can replace EV batteries at an acceptable price. Recycling/replacement of EV batteries promise to be major environmental and consumer issues that automakers will need to confront by 2027 at the latest.

> **THE NEXT FIVE TO SEVEN YEARS ARE GOING TO BE THE MOST INTERESTING — AND FRAUGHT — TRANSITION OF THE AUTOMOTIVE INDUSTRY IN 125 YEARS**

2030 & BEYOND

Surviving into the early 2030s will not be easy for today's legacy automakers and EV-only startups. Those that do are likely to face new technological competitive threats. Billions of dollars are being poured into battery technology, automated driving capabilities, and alternative fuels such as hydrogen FCVs. Breakthroughs in any of these areas could radically change the competitive landscape.

Another challenge will be convincing families to buy two EVs rather than an EV for short trips and an ICE vehicle for longer ones. Overcoming this challenge will mean designing and making affordable EVs that meet a wide range of family, work, and leisure needs.

Furthermore, a critical issue during this period will be disposing of tens of millions of ICE vehicles in a sustainable and economically feasible manner. Abandoned service stations may also become an environmental concern.

CONCLUSION

The next five to seven years are going to be the most interesting — and fraught — transition of the automotive industry in 125 years. Historians will be writing books about the winners and losers during this period, including the mistakes made and the fortunes created. By 2030, the EV market should be becoming mature, and most of the problems will (we hope) be worked out. It will be a precarious ride, but it is one we all must take.

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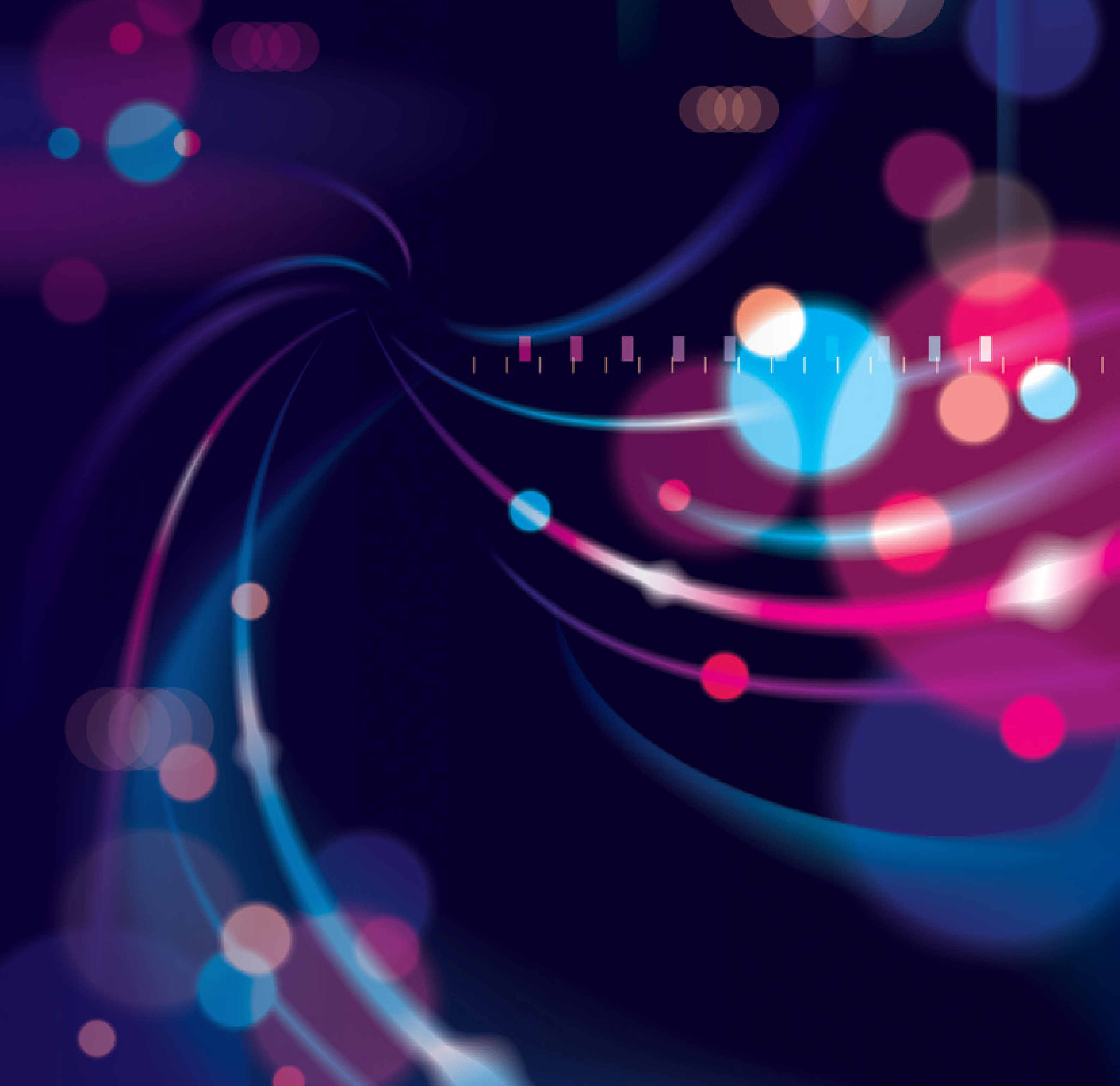
TECHNOLOGY AS ENABLER OF THE MAAS PROMISE



Authors

Olivier Pilot, Francois-Joseph Van Audenhove, and Mickael Tauvel

The recent succession of global crises shows us why it is so important to become more sustainable, adaptable, and resilient. For cities, regions, and even countries, mobility has a fundamental role to play in achieving those objectives.

The concept of Mobility as a Service (MaaS) that emerged nearly 10 years ago has the potential to shift mobility in the right direction. A digital channel letting users plan, book, and pay for multiple types of mobility services could offer access so convenient and beneficial that it would trigger the demise of the private car. But even in places where MaaS was deployed in the most innovative way, this hasn't happened to the expected extent.

In our 2021 Arthur D. Little (ADL) report on the promise of MaaS, we wrote:

> Several more years and multiple further attempts at defining appropriate market models, enabling regulations, and value propositions will however be required to test and learn what are the required ingredients — and the order in which they need to be added to the mix — for the MaaS concept to be able to deliver on its promises. Successful design and deployment of MaaS should be considered as a journey requiring a comprehensive approach, including strategic, technical, regulatory, and change considerations.[1]

In this article, we will go through some of those key considerations and shed some light on crucial technical implications.

TRADITIONAL MAAS APPROACHES HAVE FAILED

MaaS has historically been driven by business-to-consumer (B2C) actors, public transport operators (PTOs), and transport organization authorities (OAs). B2C actors were user experience–focused but lacked the necessary foundation to enact their vision, while PTOs were often driven by the need to ensure the enduring relevance of public transport alongside the emergence of new types of mobility service providers (MSPs).

Both approaches focused on a partial view of the puzzle. Consequently, an outright failure to consider the needs and constraints of all involved stakeholders (mobility users, OAs, MSPs, and actors in the wider mobility ecosystem) led to most MaaS deployments implementing partial use cases. In the absence of robust coordination between stakeholders, they ended up implementing whatever was technologically achievable for their use cases, usually leading to underwhelming user experiences because of limited ecosystem integration and collaboration.

> **A FAILURE TO CONSIDER THE NEEDS AND CONSTRAINTS OF ALL INVOLVED STAKEHOLDERS LED TO MOST MAAS DEPLOYMENTS IMPLEMENTING PARTIAL USE CASES**

Figure 1[2] shows a useful model to understand the levels of integration required for a mature, value-creating MaaS initiative that enables seamless experiences and robust management. Certainly, this doesn't mean technology cannot help address mobility challenges and opportunities, but it must do so in the context of a coherent, end-to-end, user experience–driven approach. This requires some key actions:

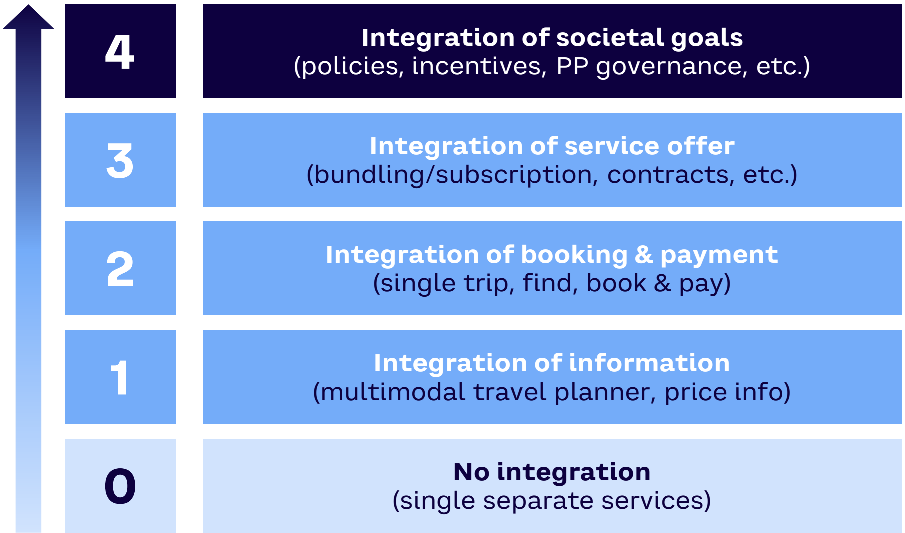


Figure 1. Integration levels for MaaS (source: Sochor et. al)

1. **Supporting end-to-end mobility supply management from planning to real-time operation,** going beyond just presenting travel options to helping organize all mobility supply in line with demand and wider societal goals.
2. **Universally addressing the digital/physical interface to mobility,** typically linked to the way mobility is accessed and charged, to stop breaking user experiences along physical silos, especially since the mobility landscape constantly shifts.
3. **Enabling a proactive, multi-modal mobility experience that goes beyond a broker model** (i.e., one that juxtaposes independent MSP offerings). Most journeys aren't explicitly planned by users, and delivered journey options and fares should be integrated based on a desired outcome, not MSP silos.

Importantly, all items above need much higher levels of standardization and data and services exchange to allow market solutions to scale. This is an area where technology can digitize the necessary collaboration between ecosystem actors to help reach high levels of MaaS integration.

MAAS NEEDS TO EXPAND BEYOND TRYING TO SIMPLIFY END-USER ACCESS TO MOBILITY SUPPLY INTO A SPACE WHERE SUCH SUPPLY CAN ALSO BE MANAGED

DIGITALLY ENABLING ORGANIZATION AUTHORITIES TO MANAGE MULTI-MODAL MOBILITY

From the OA viewpoint, MaaS needs to expand beyond trying to simplify end-user access to mobility supply into a space where such supply can also be managed, in line with demand and overarching mobility ambitions. Several limitations will need to be overcome, including the following:

- Many current MaaS deployments either display mobility options users don't need or are unable to display options users would need because they aren't available. Simplifying access to mobility is most useful when the supply matches user needs.

- If behavioral change aligned with declared societal goals is a key objective for MaaS, then OAs must increase their understanding of end-to-end mobility needs and coordinate the supply in a way that reinforces those goals. This cannot be left to MSPs and free market principles only.
- There is no cross-mode collaboration similar to the one that has been used between public transport authorities (PTAs) and PTOs over the last several decades. An updated model incorporating everything from planning to operation is needed across all modes.
- OAs must frame data-sharing regulations across the mobility ecosystem, ideally based on a set of converging global practices and standards coordinated between cities, regions, and countries worldwide, enabled at the speed of digital.

From a technical perspective, the key enabler is the digitization of new data-sharing regulations between actors in a local mobility ecosystem. This will drive a new set of technical capabilities for OAs in the mobility management space, helping them make supply-and-demand balancing decisions aligned with stated societal goals:

- **Mobility modeling and planning.** Historical movement and usage data from MSPs, including new modes such as micro-mobility, should be collected with existing data, covering the assets, supply, and usage of mass transit, road networks, parking, and private car (and, soon, self-driving vehicles). Leveraging artificial intelligence (AI) will complement classic modeling approaches to paint a more accurate picture of mobility flows and patterns. If combined with carefully collected mobility event data (see next section on integrated mobility access), it can also be used to more accurately segment mobility users according to their behavior and potential attraction to MaaS.
- **Tactical planning.** A new type of collaboration on tactical supply/demand alignment (similar to what typically takes place between an OA and mass transit operators on things like timetables) should happen for new mobility modes, potentially with "softer" alignment mechanisms (e.g., trip-based subsidies to incent shared mobility). Such collaboration should be digitized to help the production and maintenance of a master mobility transport plan.[3]
- **Operational window.** Pushing for near-real-time exchange of supply and usage data from all MSPs should be a top OA objective. This should also extend to the exchange of dynamic mobility regulation, covering everything from capacity requests (e.g., the maximum number of scooters allowed in an area) to speed limits and parking constraints. When combined with supply and usage data from MSPs, this will open up the ability to monitor and control the enforcement of mobility regulations.

ADDRESSING THE FRICTION BETWEEN DIGITAL & PHYSICAL ACCESS TO MOBILITY

There's a lack of continuity between the digital experience of users (to manage their accounts, plan trips, etc.) and physical access to mobility.

LADOT-LEVERAGED STANDARDIZATION IN MICRO-MOBILITY DATA SHARING

In 2016, California's Los Angeles Department of Transportation (LADOT) became a pioneer in OA-led data-sharing regulation when it announced its intention to ask mobility providers to share data that would enable it to optimize safety, efficiency, and passenger experience.[1] The result was the creation of the Mobility Data Specification (MDS).[2] Thanks to this, the city was able to better understand interchanges between micro-mobility and mass transit, reduce excess scooters in specific areas, and enforce parking rules for them.[3] The specification has continued to expand in scope and has been adopted by many OAs since.

1 Carey, Christopher. "How Los Angeles Took Control of Its Mobility Data." Cities Today, 1 July 2020.

2 "About MDS." Open Mobility Foundation, accessed August 2022.

3 "Use Cases: How & Why Cities Use MDS." Open Mobility Foundation, 9 December 2021.

This is the area where most users experience friction in MaaS. In the worst cases, the user's experience breaks along MSP lines, with the use of deep links into multiple apps and accounts. In the best cases, mobility access and even payment are digitally integrated for some MSPs but fares are not, leading to a broker model in which the user accesses a variety of separate offerings. These issues have a few underlying causes:

- New MSPs mean new ways to physically access mobility (e.g., vehicles) using mechanisms like near-field communication (NFC), Bluetooth, or QR codes. These cannot be centrally imposed if we want to remain flexible to new MSPs.

THINGS TO KEEP IN MIND WHEN IMPLEMENTING ABT

Although the concept of ABT provides a practical pathway to MaaS enablement, benefits such as user experience, flexibility, and total cost of ownership (TCO) can be drastically reduced if care is not given to the following:

- Open-loop EMV (contactless bankcard) cannot be the only access mechanism. It is critical to run a hybrid system with OA-issued cards to: (1) support complex fares (and discounts) targeted at specific groups; and (2) cover the needs of the entire user population, regardless of whether they're banked or unbanked, residents or visitors.
- ABT implies transferring more data than the user might be aware of (or willing to share), like a record of all of the user's mobility events. This is particularly an issue in open-loop scenarios that don't require preregistration. Data privacy, anonymization, and minimization must be front of mind.
- Better separation of concerns should be enforceable in the future. In ABT, one organization often ends up assuming many roles, which not only prevents deployment when no obvious coordination entity exists, but also stifles innovation if one does and micromanages. Open standards should be considered to avoid this — including secure device authentication, user account identification programs, and mobility event representation — as well as to help avoid vendor lock-in.

- User accounts are usually split between MSP lines, forcing users to register individually with MSPs and link their accounts.
- Apart from the workaround of implementing "all you can eat" subscriptions, fares are not simplified or integrated across mobility modes. The complexity of MSPs' offerings is made visible to the user, with multi-modal journeys incurring a financial penalty. Features like needs-based mobility subscriptions, multi-modal daily or weekly caps, and trip discounts aren't possible. This means fares cannot be effectively used to drive sought-after behavioral change.
- In some cases, the issues above still exist even between legacy mass transit PTOs.

From a technical standpoint, moving to a careful implementation of account-based ticketing (ABT) coordinated by the OA is a sensible step to support this transition:

- **ABT decouples a MaaS user account,** managed on the back end, from the mobility-access device. Devices simply become a token to identify the account, increasing choice and allowing the integration of MSP-specific access and mobility events.
- **ABT can define universal, sophisticated, multi-modal, back-end fare rules** based on transactions received from various mobility modes. This allows MaaS operators to implement integrated multi-modal fare management (e.g., a micro-mobility leg is less expensive when combined with a mass transit ride in a single journey), as well as mobility offerings that go beyond a list of competing offerings from MSPs. Combined with sophisticated compensation rules and clearing, this can drive a simpler experience and a behavioral nudge.
- **ABT can simplify mobility account management for users,** offering MaaS accounts that cover the integrated mobility offerings users have subscribed to and allowing invoicing and charging for all mobility usage.
- **ABT provides a new data source to trace end-to-end journeys** across all modes. However, care must be taken when collecting and using this data (see sidebar "Things to Keep in Mind When Implementing ABT").

- **With ABT, there is also an option to offer an EMV** (contactless bank card or mobile wallet) as an already-in-your-pocket mobility access method doubling as a payment method.

Beyond ABT, solutions aiming to replace a centrally managed repository of mobility events (e.g., bookings, mobility usage events) with a distributed general ledger are appearing (e.g., FairsFair[4]). This promising approach would give users control over their data and digital identities and natively enforce privacy. This would also foster trust and data transparency for collaboration between parties that can process data they have access to for the purposes agreed with users (e.g., fare calculation).

As for already-in-your-pocket identification tokens, continuous progress in personal digital wallets and sovereign digital identities (e.g., eIDAS[5]) means that the advantage of open loop–based systems might be attainable soon without the need to mix concerns between identification and payment.

GOING BEYOND A GLORIFIED JOURNEY PLANNER & MOBILITY MARKETPLACE

Most people think of an app when they think of MaaS. It is, of course, bigger than this, but a dedicated user interface is still an important piece of the puzzle. Unfortunately, most MaaS apps take a traditional plan-book/ticket-pay approach, limiting their potential:

- Multi-modal journey planning is not always fully dynamic, often failing to consider a real-time supply of unscheduled mobility modes. Many MaaS journey planners still rely on set rules for combining modes and only then look for options to fulfill journey legs.
- More fundamentally, there is also an assumed proactivity of users for planning and booking mobility, even though that's only one way people consume mobility. Many journeys are recurring, and ways to complete them become quickly known by the users, rendering the need for proactive planning far less useful; users tend not to plan journeys they know.

UNFORTUNATELY, MOST MAAS APPS TAKE A TRADITIONAL PLAN-BOOK/ TICKET-PAY APPROACH, LIMITING THEIR POTENTIAL

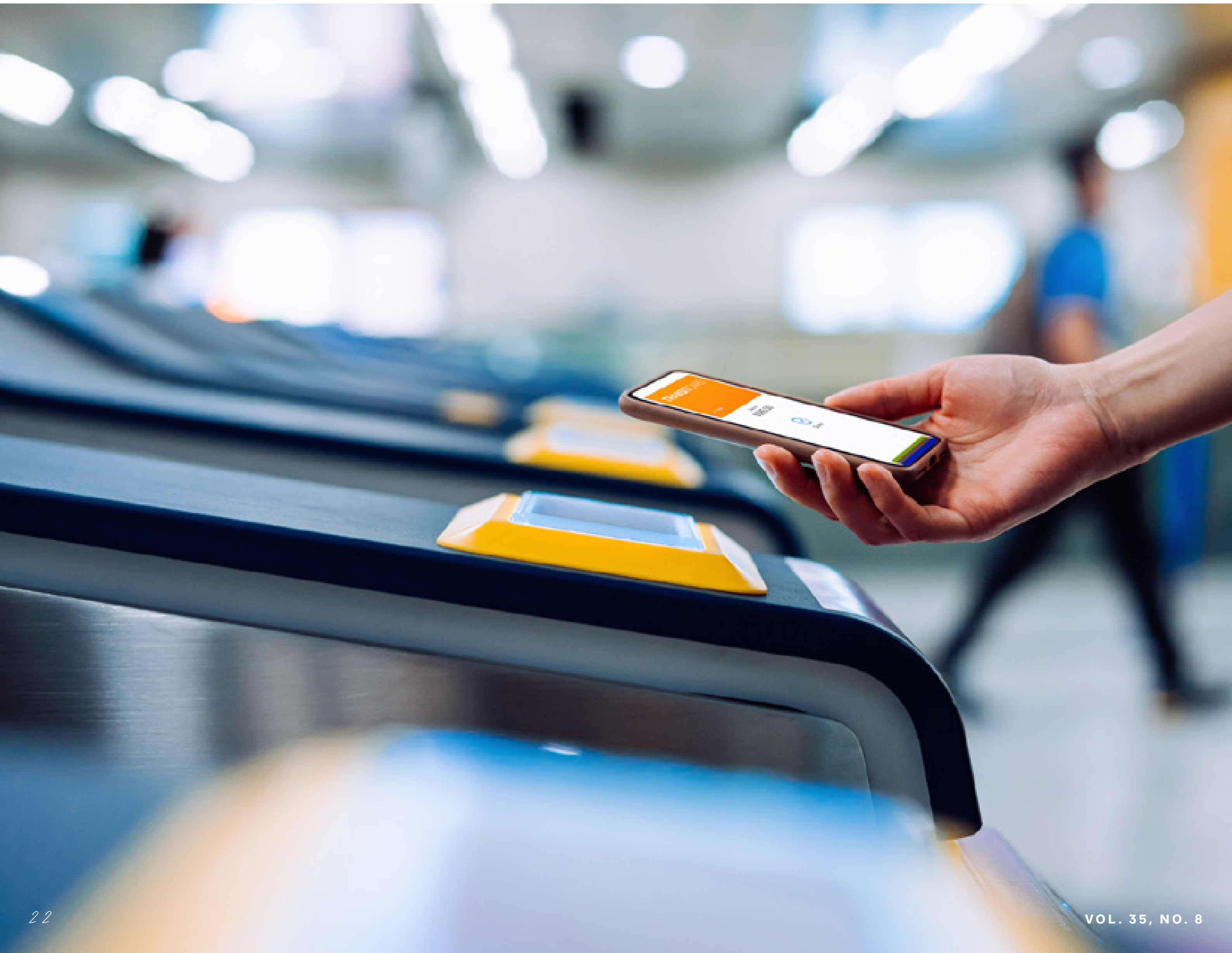
- Use cases are too focused on single trips by individuals and fail to consider the various contexts within which mobility needs emerge. For example, return journeys, access to private vehicles, traveling with a group or family, and traveling for leisure versus business purposes all impact the relevance of journey options. Your Saturday morning family trip to the mall should probably not involve e-scooters!
- In a similar way, there is an excessive focus on MSP-specific advance booking, often caused by a lack of proper integration with MSPs' back ends and mobility access events. This reinforces a marketplace and broker-style user experience with a nonintegrated juxtaposition of mobility options and fares.
- MaaS applications often provide a limited way to interact with users to promote behavior change during disruptions. They are usually limited to providing information on such disruptions outside the context of a future or current journey, leaving the user to plan their own alternative arrangements.

To respond to these challenges from the user interface point of view, we should move away from a plan-book/ticket–pay model in favor of a know-and-go one:

- When users explicitly plan a journey, it's important to ensure that the journey-planning engine is truly multi-modal, considering real-time options alongside expected location and status of all available mobility to put together the best journey.

- For other journeys, the services powering the MaaS user experience need to be better at predicting a user's mobility needs and the context from captured usage and preferences data (and possibly agenda or event data), in compliance with applicable user data privacy regulations. AI is key in this scenario to identify mobility needs, especially recurring ones before they happen, and to proactively propose options that consider real-time supply conditions. Real-time journey tracking should also be implemented to provide appropriate support within a started journey (planned or not), especially during disruptions.
- Options provided by journey planners, prompted by users or not, need to align to rules set by OAs to regulate mobility. There must be a way for them to decide when and what options to present to users, depending on considerations other than supply. Adding a loyalty management element to the equation can strengthen this ability, especially when fully integrated multi-modal fares and offerings cannot yet be achieved via ABT.
- MaaS applications and services should master end-to-end multi-modal journey orders and coordinate just-in-time bookings across various mobility services as required, an essential step toward providing users with journey assurance. MaaS services need to more closely resemble e-commerce apps in which an order includes multiple items with appropriate replacements or cancellations when something goes wrong.

When integrated into a MaaS user interface and combined with seamless access and charging across mobilities, these actions can enable users to *know* what they need to know *when* they need to know it, and *go* without worrying about mobility access, fares, or journey alternatives when required.



PUSHING FOR FURTHER STANDARDIZATION OF MOBILITY DATA & SERVICES

There is, however, a key underlying enabler to the capabilities discussed above: data. Whether it's to understand historical access or supply, predict how and where new types of mobility should be deployed, share mobility access events that are used to calculate fares or integrate with MSPs' own ticketing and booking systems, predict a recurrent mobility need, or provide real-time advice on a current journey, significantly wider data exchanges and service integration are required.

Here are the categories that must be addressed by advanced data-sharing regulations, ideally framed and enabled by enhanced OAs:

- **Mobility infrastructure data exchanges.** These cover the data managed by the OA relating to mass transit networks, stations and mobility hubs, road networks and infrastructure, and traffic and parking data, whether historical or real time. NeTEx and General Transit Feed Specification (GTFS)/GTFS-Flex (guided scheduled and on-demand transport), DATEX II (traffic), and APDS (parking) are all good standards to consider.
- **MaaS and MSP data and services exchanges (public and private).** These cover data provided by MSPs regarding their routes and schedules for mass transit and guided transport in general (note that MSPs include PTOs), as well as real-time and historical status of vehicles, fleet capacity and deployment information, and telemetry. Data regulation information must also be covered here. Services such as ticketing, booking, and direct vehicle commands (e.g., unlock/lock) should be provided by MSPs. NeTEx and SIRI, GTFS, GTFS-Flex, GTFS-Realtime, GTFS-Fares v2, MDS (shared mobility), and Transport Operator Mobility-as-a-Service Provider Working Group (TOMP-WG) are all standards to consider.
- **Urban planning and events data exchanges.** These cover information on public spaces as well as points of interests. Such a data exchange could (and should) expand to many new classes of points of interest, including businesses and venues (think Google Maps) and events planned across a geography to help plan mobility accordingly.

Accelerated global coordination will be needed to further the standardization movement to help MSPs mutualize their investments across geographies and help solution providers provide advanced solutions that benefit from deeper data and services integration. Such standardization will foster innovation in the MaaS space.

> **OAs NEED TO ENABLE DATA AND SERVICE EXCHANGE HUBS THAT DIGITIZE THE RELATED DATA-SHARING REGULATIONS AND FACILITATE SECURE EXCHANGES**

Many encouraging initiatives already exist. Some focus on developing specific standards families, like MobilityData for the GTFS/General Bikeshare Feed Specification (GBFS) family of standards or the Open Mobility Foundation for MDS. Other initiatives aim to create cohesive bundles of data and services standards that can be used to enable MaaS, including the Data4PT initiative[6] for mass transit data and the NAPCORE project,[7] focused on harmonizing data standards for National Access Points in the EU. In the Netherlands, the CDS-M Working Group covers more ground and more specifically centers on defining a coherent group of standards that enable MaaS.[8]

Lastly, OAs need to enable data and service exchange hubs that digitize the related data-sharing regulations and facilitate secure exchanges between all involved parties of the mobility ecosystem. They need to implement clear data governance enforced by technical capabilities, such as data and services catalogs and strict privacy-aware access-control mechanisms.

DIGITALLY ENABLING MOBILITY GOES BEYOND MAAS

The seamless mobility experience and expected behavioral shifts that are at the core of the MaaS promise can only be delivered if MaaS is considered within the context of a new organization and the integration of the mobility ecosystems and systems supporting them. We can see the seeds of that change in a few places where meaningful MaaS initiatives have been implemented, but there is still a long way to go.

OAs are in a natural position to act as facilitators to regulate and orchestrate such ecosystems. This includes initiating new capabilities (in multi-modal mobility planning and management, integrated ticketing and fare management, and — if they decide to — MaaS user interfaces), as well as data- and services-sharing regulations and hubs that enable open, privacy-conscious exchanges between actors. And another type of effort, regarding the definition and expansion of standards to cover all aspects of services and data that should be exchanged in a modern multi-modal MaaS scenario, also needs to accelerate — this time at a global level.

To conclude, let's remember that the starting point to successful MaaS must be an offer that is attractively priced, accessible, and sustainable based on the needs and goals of users, society, and businesses. This requires the creation of a mobility ecosystem in which all actors, private and public alike, benefit. Such an ecosystem should be framed by regulations codifying the way it has agreed to collaborate; only then can it reach success, with the meaningful contribution of technology.

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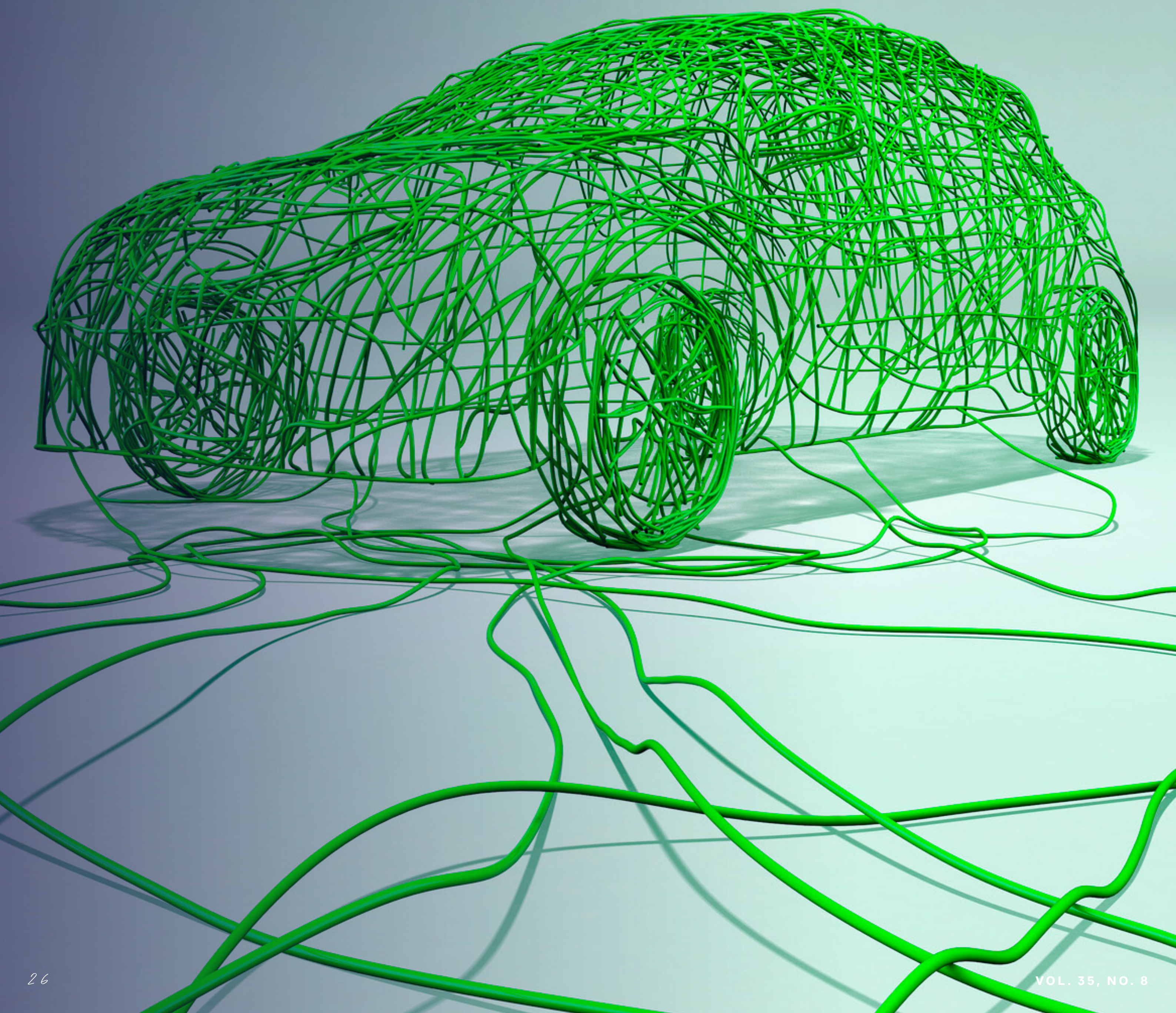
AUTONOMOUS VEHICLES:

HOW GOOD ARE THEY FOR ENVIRONMENTAL SUSTAINABILITY?



Author

by San Murugesan

"We can't simply dismiss the idea that autonomous vehicles are going to be a big part of our transportation system."
— Ted Wheeler, mayor of Portland, Oregon, USA[1]

Transport is integral to business, the economy, and our daily lives. It is currently undergoing significant structural reforms as it moves toward digitalization and decarbonization and is poised for new norms. The automotive sector, a major transport segment, is already seeing major disruptions that impact stakeholders.

Electric vehicles, solar-powered cars, connected vehicles, autonomous driving technology, and ride-sharing services are contributing to this disruption.[2] Moreover, there are related disruptions in areas like auto insurance, vehicle registration, and driving regulations.[3] Research from CB Insights indicates that driverless cars are likely to transform 33 industries, including healthcare, food delivery, and hotels.[4] We are just beginning to see the types of opportunities these changes may bring and the issues they may create, as indicated by detailed, interactive maps available from the World Economic Forum.[5,6]

As they transition from science fiction to the forefront of transportation technology news, autonomous vehicles (AVs) like driverless cars, vans, buses, trucks, and tractors are becoming our reality. There are still some hurdles, but we'll see a significant increase in AV design and production over the next five years.[7] This will drive change far beyond the auto industry and its allied businesses, affecting our lives and movements and causing unexpected changes in employment and social norms. AVs offer enough benefits that they represent an unstoppable trend that will reshape our world.

Currently, the key stakeholders in this market are autonomous vehicle system developers; private-use, commercial service, and industry service vehicle manufacturers; and users such as car owners, rental car companies, transport companies (bus/shuttle), Mobility-as-a-Service providers, delivery-service providers, and trucking and logistics companies.[8]

Although widespread commercial and personal adoption of AVs is still a few years away, now is the time to examine their potential effect on climate change so we can take appropriate technical, policy, regulatory, and behavior modification measures. The key questions are:

- What environmental impacts will AVs have, both positive and negative?
- Will AVs help reduce the transport sector's overall carbon emissions and address today's climate crisis?
- What can we do to minimize the carbon footprint of AVs as they develop and become mainstream?

These questions are difficult to answer holistically and pragmatically because they involve several interdependent factors. Some factors are currently unknown and may remain so until AVs become mainstream. For example, we may see positive impacts from more efficient driving, better use of shared AVs, eco-friendly smart traffic signals, vehicle platooning, and reduced time hunting for parking in city centers.

There may be negative impacts from changes in driving patterns as well. For example, we may see an increase in vehicle miles traveled because AVs make travel easier and more relaxing (or productive), which could raise greenhouse gas (GHG) emissions. Thus, we must consider AVs' environmental impact throughout their entire lifecycle, including manufacturing and Scope 3 emissions.[9] Further muddying the waters are contradictory qualitative anecdotal claims based on narrow perspectives, rather than holistic ones. Nevertheless, we must attempt to examine AVs' environmental impact and make an educated assessment based on realistic assumptions.

This article begins with a brief overview of AVs, particularly driverless cars and trucks, then presents a comprehensive view of the environmental impact of the AV ecosystem with new insights on this complex topic. It also looks at current and near-future trends and offers some recommendations.

> **AN AV IS CAPABLE OF SENSING ITS ENVIRONMENT AND MOVING SAFELY WITH LITTLE OR NO HUMAN INPUT**

A BRIEF OVERVIEW OF AVs

In automation, robotics, and other domains, the term "autonomous" describes self-governing systems. Specifically, an autonomous system is a machine or system capable of "performing a series of operations where the sequence is determined by the outcome of the previous operation or by reference to external circumstances that are monitored and measured within the system itself."[10] Such a system must be able to sense the environment it operates within and interact with that environment. A system is autonomous if it can attain a set of goals under a set of uncertainties without human or external intervention.[11]

Key features of an autonomous system are self-operation/governance without human or external intervention, independence, a wide operating range, adaptation to uncertainty, and the ability to achieve set goals. Various types of sensors, the Internet of Things, high-speed communication networks (including 4G and 5G), artificial intelligence and machine learning, data analytics, augmented/virtual reality, high-performance processors, nanotechnologies, and smart signage are all coming together to extend the scope and range of operations of autonomous systems.

Overall, an AV is capable of sensing its environment and moving safely with little or no human input. To perceive their surroundings, AVs synthesize data from a variety of sensors, including cameras, radar, LiDAR, sonar, GPS, odometry, and inertial measurement units.[12] Complex algorithms interpret sensory information to control and manage driving and to identify appropriate navigation paths and obstacles.[13,14]

6 LEVELS OF AUTOMATION

SAE International, formerly named the Society of Automotive Engineers, defines six levels of driving automation:

- **Level 0 (no driving automation).** Most vehicles on the road today are at this level.
- **Level 1 (driver assistance).** Vehicles at this level offer driver assistance like cruise control and steering. Adaptive cruise control, in which the vehicle keeps a safe distance behind the car in the front, qualifies as Level 1 because the human driver still monitors and controls steering and the other driving functions.
- **Level 2 (partial driving automation).** An AV at this level has an advanced driver assistance system (ADAS) that may include pedestrian detection, lane-departure warning/correction, automatic emergency braking, and blind-spot detection.[15] A human is in the driver's seat and can take control of the car at any time.
- **Level 3 (conditional driving automation).** These vehicles can detect objects in the surrounding environment and make informed decisions, such as accelerating past a slow-moving vehicle. They require human oversight and have an override option. The driver must remain alert and be ready to take control if there is a problem or danger.
- **Level 4 (high driving automation).** These vehicles can intervene autonomously if something goes wrong or there is a system failure. Cars at this level do not require human interaction in most circumstances, as the autonomous system can intervene in the event of a system failure. However, the human driver has the option to manually override. Level 4 vehicles can operate in self-driving mode.

- **Level 5 (full driving automation).** Vehicles at this level are fully autonomous and do not require human attention. These vehicles won't have steering wheels or acceleration/braking pedals and will be capable of any action an experienced human driver would take. Fully autonomous cars are undergoing testing in several countries.

These automation levels are the gold standard for industry benchmarking and have been adopted by the US Department of Transportation (DOT). Several companies, including many startups, are competing to get a slice of the fully autonomous future.

AV BENEFITS

The principal benefits of AVs are convenience, comfort, and safety, but there are a number of less apparent benefits. For example, according to a study from the World Economic Forum, self-driving vehicle technology could create a 40% improvement in fuel economy and lower auto emissions.[16]

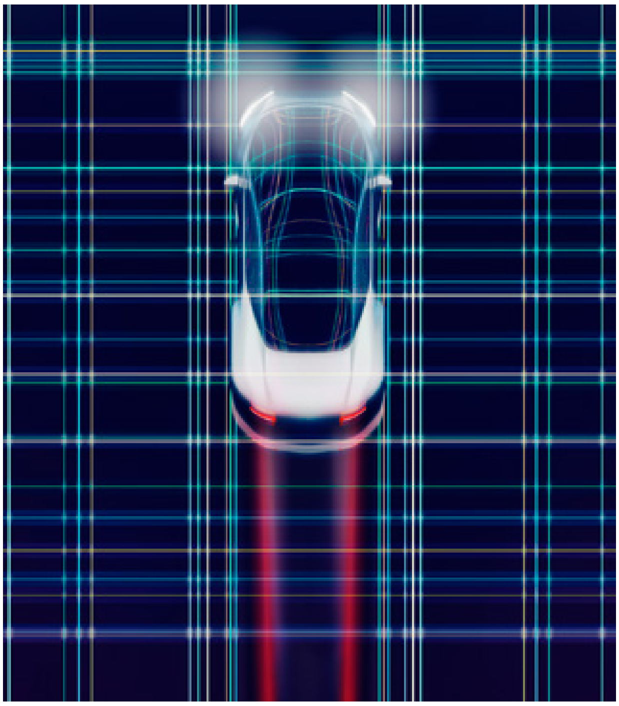
Self-driving cars could result in fewer road accidents: there is no risk of drunk driving or driver fatigue, and these cars are expected to make fewer mistakes than humans. They also let people use travel/commute time for work, entertainment, or creative pursuits.[17]

Self-driving vehicles could make elderly populations more mobile, an important advance as the world's population ages. Similarly, AVs would enable people who can't drive a vehicle because of physical or psychological conditions to have an independent means of transportation.

If, as expected, AVs lower the cost of transportation, AVs would improve mobility for those at the low end of the income scale. Some researchers estimate this form of transportation could cost around 50% less than current vehicles.[18]

AVs could help during health crises like pandemics as well, transporting people while maintaining isolation and sterilization.

Plus, autonomous trucks have the potential to address the global supply chain crisis[19] and optimize last-mile delivery,[20] the most labor-intensive and costly stage of delivery.



ENVIRONMENTAL IMPACT

Carbon dioxide (CO2) and nitrogen dioxide emissions from automobiles have a major impact on the environment and must be reduced. According to the US Environmental Protection Agency (EPA), a typical passenger vehicle emits nearly 4.6 metric tons of CO2 a year,[21] and the World Health Organization estimates that 7 million people are killed annually by outdoor air pollution.[22]

By 2050, urban mobility systems will consume five times more of the planet's bio capacities (the ability of a natural area to generate resources while absorbing waste) than they did in 1990, according to Arthur D. Little.[23]

Clearly, to create a model for safe, clean, affordable mobility that can support the needs of a growing population, we must reduce the overall carbon footprint of transport vehicles. The circular economy is driving the automotive industry to make environmentally friendly vehicles, addressing their environmental impact along their entire lifecycle (production, use, recycling/reuse, and battery/other parts disposal).

The rise of AVs will have a profound effect on the environment, but whether it's for better or worse will depend on technological and policy choices, energy sources, adoption levels, and usage levels. In fact, the effect of AV adoption on consumer travel patterns may have a greater influence on environmental impact than technical attributes.

AVs could reduce energy consumption in transportation by as much as 90% or increase it by more than 250%, according to a study by the US National Renewable Energy Laboratory.[24] That difference matters: more than a quarter of GHG emissions come from the transportation sector, according to the EPA.[25]

AVs COULD REDUCE ENERGY CONSUMPTION IN TRANSPORTATION BY AS MUCH AS 90% OR INCREASE IT BY MORE THAN 250%

By eliminating the erratic acceleration and braking common to human drivers, AV technology might reduce energy consumption. With more AVs on the road, traffic flows should smooth out, resulting in less energy-consuming, stop-and-go traffic (not to mention less time spent in traffic jams).

Self-driving vehicles, especially heavy trucks, can communicate with each other and form highway platoons. The vehicle at the front of the platoon controls the speed and movement of the platoon; the following vehicles snap together in a single-file line behind the first vehicle and drive themselves safely in close proximity on the highway. The combined aerodynamics of the platoon require less energy to travel along highways.[26]

By making shared-use vehicles more convenient, AVs could make private ownership less necessary, with users simply summoning a shared-use vehicle any time they need one.

In estimating the environmental impact of AVs, we should consider:

- More efficient driving (less fuel/energy consumption) facilitated by AVs that minimize frequent stops and eliminate aggressive driving (i.e., speeding, rapid acceleration, and sudden breaking). Efficient driving can reduce gas mileage by 15%-30% at highway speeds and 10%-40% in stop-and-go traffic.[27]
- Autonomous cars can safely travel faster than human-driven vehicles because they respond much more quickly than even the best human drivers. However, due to aerodynamic drag, fuel efficiency declines rapidly at speeds over 50 mph.[28]
- An overall increase of travel due to faster travel, reduced traffic, and/or more relaxing or productive travel time.
- An increase in the popularity of lighter, more fuel-efficient vehicles because accidents are less frequent.
- Less fuel wasted hunting for parking in city centers.
- Higher occupancy from automated carpooling.

AVs bring the following secondary environmental benefits:

- **Embodied-energy benefit.** In a shared-use model, there would be fewer total vehicles, leading to lower energy for manufacturing and raw material use.
- **Land-use benefit.** With fewer, smaller vehicles on the road, cities could repurpose land currently used for parking and transportation.
- **Safety benefit.** AVs could bring less need for repairs from auto accidents and fewer vehicle replacements.
- **Interaction with mass transit.** AVs could solve the first- and last-mile problem and lower labor costs for transit.[29]

The AV environmental impact will, in the end, depend on adoption patterns. Cost, reliability, safety, on-road performance, insurance premiums, policy offerings, requirements, supporting transport infrastructure, and local regulations will all influence AV adoption at scale, and it's not yet clear which of these forces will dominate.

POSITIVE FACTORS	NEGATIVE FACTORS
• Improved efficiency of vehicles and smoother traffic flow • Low-carbon emissions from electric, hybrid, and other eco-friendly vehicles • Greater popularity of lighter, more fuel-efficient vehicles due to reduced collision risk • Lower emissions from AV platooning • More efficient parking in city centers • Increased ride sharing and on-demand mobility, leading to fewer vehicles on the road • Reduced traffic congestion due to optimized traffic flow and enhanced vehicle operation	• Higher-speed and/or longer-distance travel, leading to increased emissions • Increased commuting radius • Increased private-vehicle use in underserved populations due to lower costs • Increased long-distance luxury travel • Increased car ownership due to faster and/or less taxing travel

Table 1. Factors determining the environmental impact of AVs

Thorough, pragmatic examination and estimation of the environmental impact of AVs in the next five to 10 years will be complex, as it involves a number of factors, some of which are interdependent (see Table 1). At present, we don't have suitable comprehensive models containing a quantitative value of determinants. Further studies will be required to gain a better understanding of the disruptive forces of AVs, including how they will be adopted and used, as these patterns may ultimately dictate the environmental impacts of AVs. To model potential AV adoption scenarios and environmental impacts, we need better integration of engineering, social science, and planning disciplines.

TRENDS, CONCLUSIONS & RECOMMENDATIONS

Despite current technical challenges and concerns, AVs are on track to reshape our world. Governments are eager to be seen as winning the technology race in this sector.[30] Manufacturers are planning to introduce a variety of AVs, including cars, trucks, tractors, ships, flying cars, and robotaxis (a driverless car or shuttle bus that can be ordered to your location), and even flying motorcycles. Unfortunately, laws and regulations are lagging AV development rather than leading it.

The rise of AVs is being facilitated by both market push (from large industry players and startups) and market pull (from industrial and individual users). For example, Millennials are more inclined to use AVs than Baby Boomers, especially when they create opportunities for on-demand mobility or ride sharing. On the industry side, autonomous trucks offer the potential for longer operating hours with reduced labor and fuel costs. The resulting cost reductions could trickle down to logistics companies and retailers.

Further research will be needed to fully understand the implications of AV adoption on emissions and environment, roads and intersection capacity, driver and public behavior, and land use, among others. We also need more holistic simulation models to understand the implications of a future where AVs are prevalent. Further studies are needed to determine how to solve current AV deployment challenges.

Nevertheless, we must be cognizant of the challenges inherent in deploying AVs at scale and the transport infrastructure that will be required, including smart roads and compatible signage. Deploying AVs en masse in an environmentally friendly manner will be a huge undertaking.

There are reasons to believe that AVs will help reduce transportation's carbon footprint. At present, experts (including those in the automotive industry) are uncertain about the overall environmental impact of AVs and driverless driving. We're hopeful that, on balance, the environmental benefits will outweigh the detrimental factors; of course, only time will tell.

Let's work toward realizing an autonomous future that will not only be more convenient, safer, and efficient, but also better for the environment.

> I'm really looking forward to a time when generations after us look back and say how ridiculous it was that humans were driving cars.
>
> — Sebastian Thrun, CEO, Kitty Hawk Corporation; founder, Google's self-driving car team[31]

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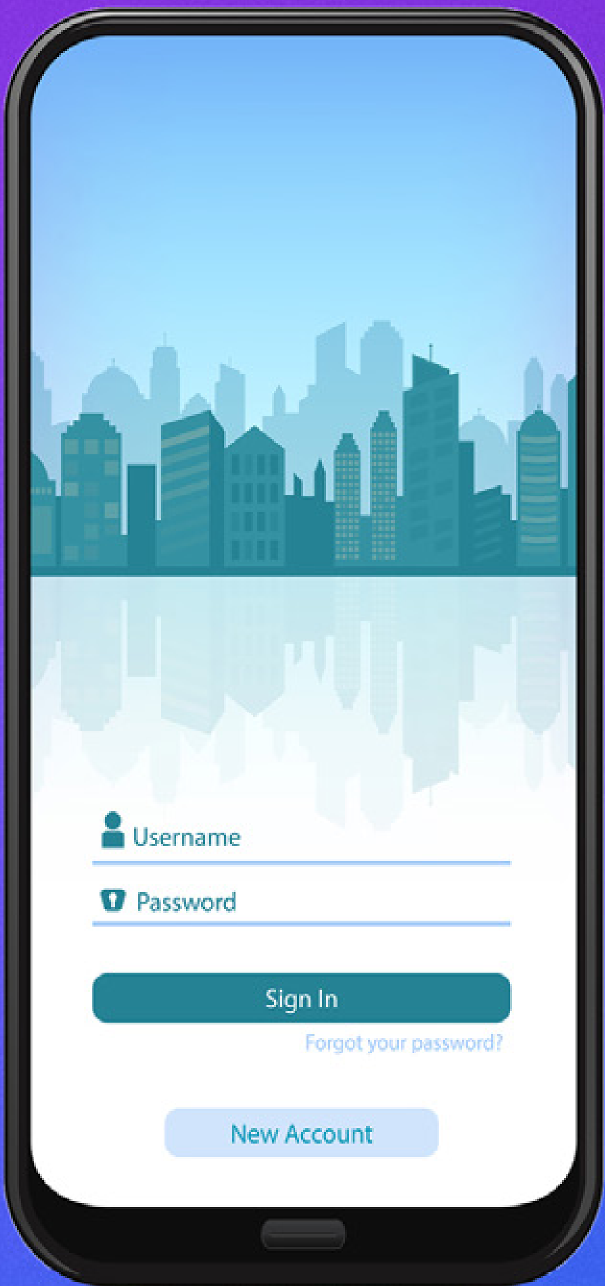
SMARTPHONE TOLL SYSTEMS:

BOOST REVENUE, ENABLE CONGESTION CONTROL & PROMOTE HIGH-OCCUPANCY COMMUTING



Author

Ralph Menzano

Tolling has been a part of US highway maintenance programs since the American Revolution.[1] Things have changed quite a bit since Pennsylvania's Philadelphia and Lancaster Turnpike opened, and new technology promises to advance tolling even further.

In the US, today's electronic tolls involve a vehicle-mounted transponder, introduced in the 1990s, that uses radio frequency identification (RFID) to communicate with antennas in the toll lane. If you are a subscriber, the system reads your account information, charges the toll to your account, and lifts the gate so your vehicle can pass. Archways with invisible gates are slowly replacing gated tolls in many areas in the US. According to the International Bridge, Tunnel, and Turnpike Association (IBTTA), 37 million Americans currently have this type of RFID transponder.[2]

Electronic tolls made it considerably easier to create a toll road, and at first, only positive news was associated with the systems. A few years later in the US, reports began appearing of monumental amounts of uncollected tolls. Some US states connected their electronic toll system with their department of motor vehicles (DMV) system so registrations and/or license renewals could be withheld until in-state toll debts were satisfied. Debts from out-of-state drivers were (and are) much harder to collect. Indeed, several New England states signed reciprocity agreements so that travelers with unpaid tolls in a participating state face DMV issues in their home state. Other states, such as Georgia, use collection agencies to pursue toll violators, with varying degrees of success.[3]

Electronic tolls also facilitate congestion pricing: raising or lowering a toll charge based on time of day (e.g., rush hour), day of the week (weekdays vs. weekends), or unusual circumstances. Both Singapore and London have successfully implemented congestion pricing models; adoption in the US has thus far been lackluster.[4]

Electronic toll systems have a key role to play in high-occupancy vehicle (HOV) lanes. Created to encourage carpooling (vehicles with two or more passengers), HOV lanes have the potential to reduce the number of cars on the road — decreasing emissions and reducing commute times. However, enforcing HOV-lane usage has proven difficult. According to one transportation research study, about 80% of the cars in HOV lanes in the US are single-occupancy vehicles.[5] Some violators are caught on camera and fined, while others are chased by police, but most get away with the violation. This encourages many drivers to chance it, feeling that the faster commute and/or reduced toll are worth the risk.

In the US, new legislation is bringing HOV monitoring and toll discounting front and center for many states. The Infrastructure Investment and Jobs Act (IIJA), passed in November 2021, requires HOV monitoring for all new road construction — with "toll facilities on the Interstate System constructed or converted after the date of enactment to allow high occupancy vehicles, transit, and paratransit vehicles to use the facility at a discounted rate or without charge unless the public authority determines that the number of such discounted vehicles would reduce the travel time reliability of the facility."[6]

In other words, IIJA allows states to impose tolls on interstate highway sections running through their state only if they allow for HOV lanes and provide toll discounts for those using the lanes.

Fortunately, new smartphone technology is available to facilitate electronic toll collection, congestion pricing, and HOV monitoring and discounts. Because this solves a multitude of tolling issues, these systems likely will begin replacing RFID systems in many countries and some US states in the next few years.

Two states in particular, Louisiana and Texas, have implemented smartphone-based HOV monitoring using the GoCarma app from Carma Technology. The cloud app enables road-user charging (no toll booths or arches needed) and verifies occupancy for HOV lanes. Carma is funded by SOS Ventures, a global top-five venture capital firm.

> **SMARTPHONE TOLL SYSTEMS HAVE THE POTENTIAL TO DRAMATICALLY INCREASE TOLL REVENUE BY REDUCING UNCOLLECTED TOLL DEBT AND RAISING TOLL PRICES DURING PEAK TRAFFIC**

In an interview for this article, Carma's cofounder and Chief Business Officer Paul Steinberg said the company believes smartphones "offer the unique potential for making road pricing more impactful, dynamic, and transparent." He said the technology is designed to help state departments of transportation comply with new HOV requirements in the IIJA legislation, adding that the hands-free GoCarma app helps road users automatically qualify for HOV benefits. The company won the 2021 Toll Excellence award for Private Sector Innovation from IBTTA for its North Central Texas implementation.

8 BENEFITS OF SMARTPHONE TOLL SYSTEMS

In the US, there are eight main benefits to smartphone toll systems: (1) IIJA compliance, (2) lower infrastructure costs, (3) improved revenue collection, (4) emissions reduction, (5) congestion-pricing and driver-reward enablement, (6) improvements in road safety from vehicle reduction, (7) the potential to replace gas-tax revenue, and (8) improved traffic-pattern data collection.

Specifically, these systems eliminate the need for transponders, RFID antennas, toll plazas, and toll arches and are estimated to cost about a third of RFID-based toll systems. The only infrastructure required for smartphone systems is a pole arching over the lane and the software.

Once implemented, smartphone toll systems have the potential to dramatically increase toll revenue by reducing uncollected toll debt and raising toll prices during peak traffic periods in metropolitan areas and highly trafficked areas (e.g., vacation destinations on a summer Friday).

Smartphone tolling systems also have the potential to help countries finally realize the air quality improvements inherent in the concept of HOV lanes. They also eliminate the need for local policing. Cities and states could take their systems a step further, offering toll discounts to drivers that use the HOV lane a certain number of days per month or avoid peak-period driving on certain roads.

According to the National Highway Traffic Safety Administration (NHTSA), US roads saw more than 42,000 fatalities in 2021, a 10.5% increase from the 38,824 fatalities in 2020 and "the largest annual percentage increase in the Fatality Analysis Reporting System's history."[7] The rationale behind the IIJA is that combining tolling and congestion pricing with HOV lanes will lead to fewer cars on the road, making roads safer and thus saving lives.

Smartphone tolling also has the potential to replace gas-tax revenue from increased use of electric vehicles (EVs). Hybrids and EVs have already reduced gas-tax revenues in some areas, and auto manufacturers are gearing up to greatly increase EV production.[8] Increasing the number of smartphone-based tolls in a geographic area and/or raising prices during peak periods can ensure EV owners are seen as paying their fair share toward maintaining the roads they travel. Tolls can also be directed to ongoing maintenance on the highway where they are located — another move toward fairness.[9]

Finally, state and local governments and tolling authorities can receive a treasure trove of information about the vehicles traveling their roads, lane utilization, and the time needed to travel certain distances during peak and off-peak periods.

CASE IN POINT: NORTH CENTRAL TEXAS, US

The project for which IBTTA gave Carma Technology an innovation award came after the North Central Texas Council of Governments (NCTCOG) evaluated a plethora of cameras, in-vehicle transponders, and roadside enforcement systems and found them lacking. The organization turned to the GoCarma smartphone app because it required neither driver interaction nor roadside enforcement and implemented it in the Dallas-Fort Worth area, the fourth-largest metropolitan region in the US. Drivers with the app receive a 50% toll discount if they carpool during rush hour.

The program began with three federally funded pilots and was then integrated with the North Texas Tollway Authority's (NTTA's) regional electronic tolling systems. According to Carma representatives, more than 40,000 people use the system today, and more than 1.25 million HOV discounted toll transactions have taken place. HOV lane violators receive a series of escalating warnings, and violation rates in the area have fallen from 60% to less than 2%. GoCarma provides a free Occupant Pass for passengers without smartphones, such as children.

US TOLLING VS. EUROPE & ASIA

There are 32 countries and hundreds of cities around the world that use electronic toll collection to support their roadways.[10] The Singapore and London congestion-pricing implementations are perhaps the most famous. All these collection systems started with either the video capture of license plates and/or traditional RFID transponder recognition methods.

Singapore is considered a global leader in road-pricing innovation, having pioneered cordon pricing in 1975 and electronic congestion pricing in 1998. In 2023, the country will introduce location-based road pricing for all vehicles, not just those for transporting heavy goods. The requirement for all vehicles, including motorcycles, to be equipped with a dedicated, on-board unit will result in vehicles eventually being charged only on the basis of the distance covered by them on a congested road. This next-generation usage-based approach is expected to go live in 2025.[11]

Europe is going even further by requiring truck fleets to have new technology. Emmett Murphy, Carma's chief product officer, told me: "A transition from legacy roadside road pricing technologies has long been evident in other countries, primarily in relation to tolling heavy goods vehicles. In 2001, Switzerland introduced a distance-based fee for trucks traveling on Swiss motorways. Germany, Europe's most important transit country, soon followed. Today, 11 European countries have embraced satellite/global navigation satellite system [GNSS]-based distance charging, replacing roadside electronic toll collection. Vehicles are typically equipped with dedicated [GNSS-enabled] on-board units. This year alone, three European countries [Slovakia, Lithuania, and Switzerland] are tendering nationwide satellite-based tolling systems."

Murphy explained that the pervasive adoption of smartphones among the public (evident in Europe, especially Poland, and, now, the US) has been coupled with a significant increase in smartphone capabilities, including improvements in GPS accuracy, battery strength, and privacy controls. "An efficient use of proximity-detection technologies, both in-vehicle using Bluetooth, and ex-vehicle using cellular vehicle-to-anything communications, will make it possible for a smart-phone-based road pricing platform to replace roadside [electronic toll collection]," he said.

Nevertheless, much of the world seems to be looking at the US for leadership in smart and usage-based road pricing for light vehicles. Although urban congestion zones have not yet taken off in the US, dynamic pricing on congested highway zones is common in many states. Pricing on these corridors adjusts according to time of day, traffic flow, vehicle class, clean air vehicle status, and/or vehicle occupancy status.

By combining its experience in dynamic pricing along congested corridors with its leadership in usage-based pricing technologies, the US is well positioned to become a global leader in smart, impactful, infrastructure-light road pricing.

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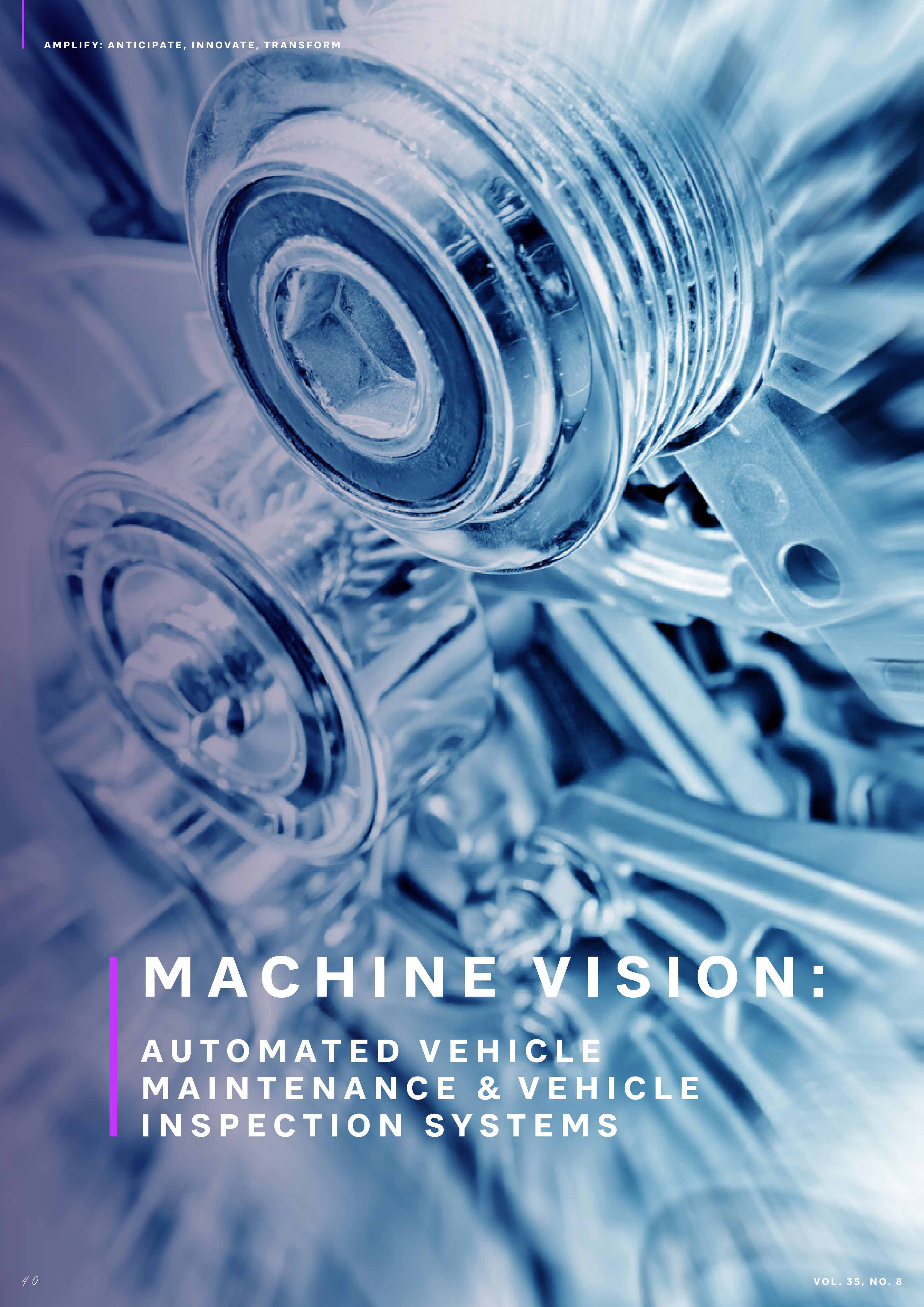

MACHINE VISION:

AUTOMATED VEHICLE MAINTENANCE & VEHICLE INSPECTION SYSTEMS

Author

Curt Hall

The auto industry helped pioneer the use of machine vision systems to automate various vehicle manufacturing processes. Today, the technology has evolved to the point where it's spreading beyond vehicle manufacturing into automotive aftermarkets. This represents a significant development in the evolution and application of machine vision technology, as well as the use of the technology in the automotive market in general.

Today, auto aftermarket product and service providers are turning to advanced machine vision systems employing machine learning (ML) and other artificial intelligence (AI) techniques to automate various operations. Examples include automating basic maintenance and repair activities like tire inspection and replacement (in conjunction with robotics technology) and automating the vehicle inspection and repair order–generation processes.

Companies are also using machine vision to assess and present the status of a used vehicle to customers of online auto resale marketplaces and auctions as well as to identify and classify parts on salvage vehicles to optimize auto recycling operations.

WHAT'S DRIVING THIS TREND?

Various technical and industry developments are driving the use of AI-powered computer vision and imaging in the automotive aftermarket and online resale marketplaces, including:

- Increased accuracy of ML-based camera systems
- Availability of cloud and edge computing systems, including service-based offerings
- Machine vision startups targeting the auto aftermarket
- Partnerships between large automakers and machine vision startups
- Mobility as a service (MaaS)

INCREASED ACCURACY OF MACHINE VISION SYSTEMS

By employing deep learning neural networks that have been trained on millions of vehicle images (including various examples of damages), the accuracy of the algorithms used by computer vision systems has increased considerably over the past five years. Camera-based computer vision systems can now identify, classify, and precisely locate multiple types of defects in a single image. This includes damaged parts like bumpers, fenders, and grilles; fluid leaks; corrosion; and even underinflated or worn-out tires.

> **VARIOUS TECHNICAL AND INDUSTRY DEVELOPMENTS ARE DRIVING THE USE OF AI-POWERED COMPUTER VISION AND IMAGING**

CLOUD-BASED SYSTEMS & EDGE COMPUTING

The availability of computer vision applications in the form of cloud-based solutions and the use of edge computing are helping accelerate technology use. The former makes the technology more accessible to repair shops, dealers, fleet operators, and other aftermarket businesses. The latter helps reduce the latency associated with image processing and analysis. For example, models can run autonomously on or near the edge, including on self-contained, high-resolution, smart camera components installed in the workshop areas of service centers. Additionally, camera-based vehicle inspection systems are now integrated with car dealership management systems, online auto selling/auction platforms, and other applications, making their use even more appealing for aftermarket applications.

MACHINE VISION STARTUPS

Vendors now offer advanced machine vision systems, including solutions targeted at auto aftermarket uses. Such products are available as self-contained components for easier installation and integration into existing operations at repair shops, dealers, fleet operators, and online marketplaces.

BIG AUTO & STARTUPS

Partnerships involving machine vision startups and the large automakers are on the rise, mainly in an effort to expand the use of the technology into aftermarket operations. Examples include computer vision–based vehicle inspection systems from UVeye and Tractable (discussed further in the auto inspection section).

MAAS

In the not-too-distant future, the rise of on-demand, personalized transportation services — MaaS — in the form of ride sharing and car sharing and (perhaps most importantly) in combination with autonomous vehicles will require fleet operators to quickly service vehicles to get them back on the road. This is expected to lead to significant disruptions in the auto servicing industry, in which automation will play a major role.

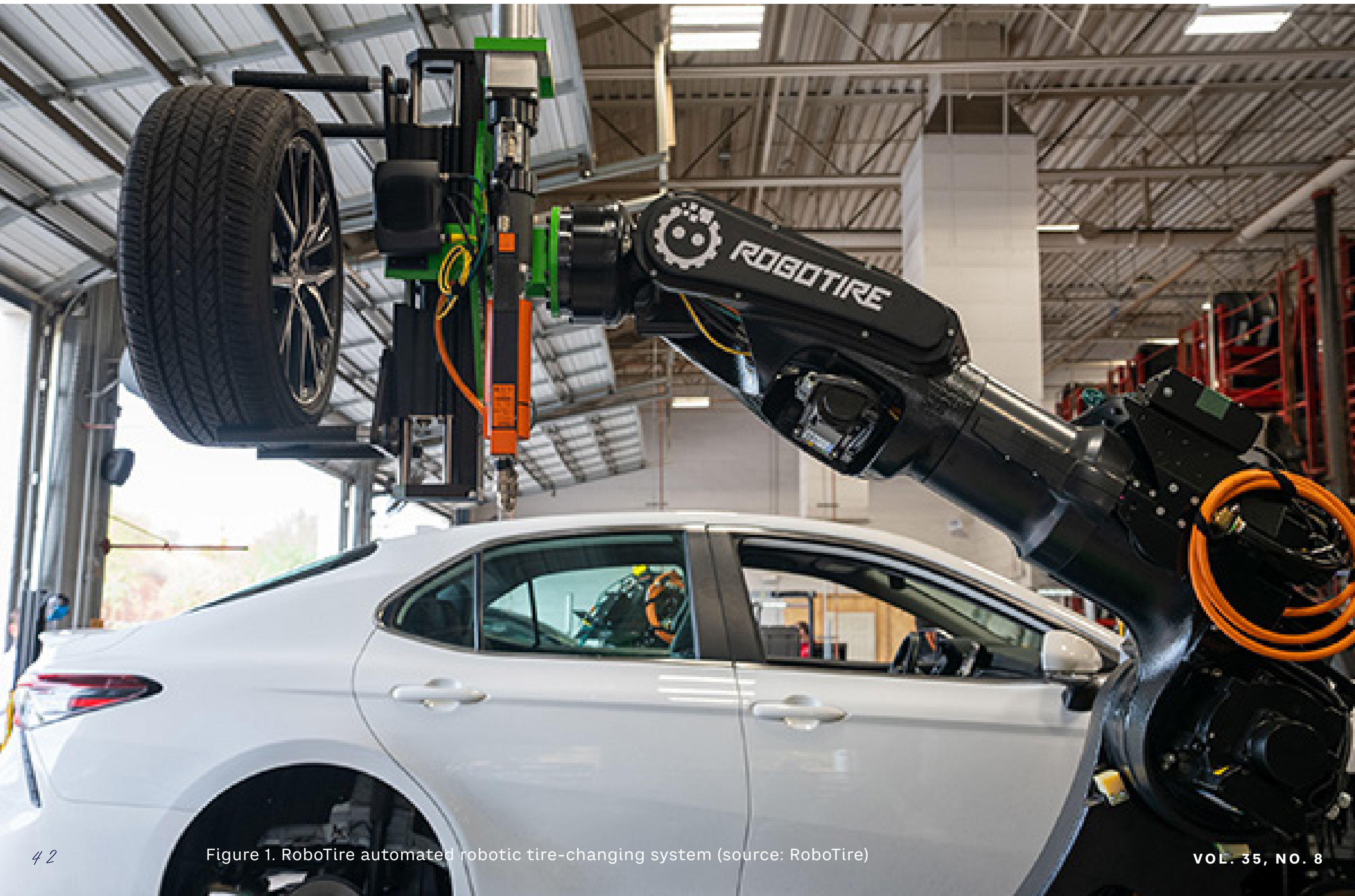

Figure 1. RoboTire automated robotic tire-changing system (source: RoboTire)

AUTOMATED VEHICLE MAINTENANCE SYSTEMS

Automakers have used systems combining machine vision and robotics to automate key manufacturing operations for decades. Adoption of the technology to automate aftermarket operations has been slow, but service shops are starting to use camera-based robotic systems to automate basic repair and maintenance operations.

For example, tire changing is one of the most common and time-consuming vehicle maintenance jobs. RoboTire, a Detroit, Michigan, USA–based robotics and automation company, has developed a robotic tire-changing system (see Figure 1).[1] Using high-definition cameras, ML, and advanced robotics, the system automates much of the tire-changing process. The robot can remove lug nuts, lift off old tires, and install new tires and wheel assemblies with limited human assistance.

Using a combination of high-definition cameras, ML, and pressure-sensitive sensors, the system accurately identifies the placement of lug nuts for removal and reinsertion, tightening them to the desired degree during remounting.[2] Cameras and sensors prevent the robot from coming into contact with the body of the vehicle it is servicing. The company claims the system can change four tires on a passenger vehicle in approximately 25 minutes, a job that takes about an hour when performed manually.[3] Tire pressure monitoring and tire balancing must still be performed by human mechanics.

RoboTire's sophisticated camera system can identify issues such as stripped/damaged lug nuts or corroded hubs and alert a mechanic to the problem. In addition, the robot is programmed to allow time for mechanics to complete their visual safety inspections, including the need to clean the wheel hubs, if necessary.

Automated robotic tire-changing systems bring several benefits to auto repair providers and fleet operators. They can increase the number of customers a shop can service and enable the completion of more work with fewer staff. Freeing up mechanics lets them focus on more complex services and repairs, helping get vehicles serviced and back on the road sooner, which translates into a better customer experience. Robotic systems also lessen the possibility of injuries to workers related to manually lifting and mounting heavy tires and wheels.

ANY TIME ROBOTS NEED TO OPERATE AROUND PEOPLE, THEIR USE BECOMES MORE COMPLICATED DUE TO HUMAN-MACHINE INTERACTION

Of course, any time robots need to operate around people, their use becomes considerably more complicated due to human-machine interaction: auto repair shops are busy environments with many safety hazards. To mitigate this issue, RoboTire uses sensors, cameras, and an ML component to interpret and adapt to the environment within which it's functioning — including in response to humans in its immediate vicinity.

Discount Tire, an independent tire and wheels retailer, has installed and is operating a RoboTire system in its Fountain Hills, Arizona, USA, store. It will be interesting to see if Discount Tire deploys the system in any of its other 1,100 store locations.

RoboTire has indicated it is looking at developing robotic systems to automate other vehicle maintenance operations, such as brakes, oil changes, and battery replacements.[4]

AUTOMATED VEHICLE INSPECTION IN THE AFTERMARKET

Machine vision has been a staple of auto manufacturing in automating quality-control processes, enabling quick and accurate identification of defects in paint finishes, body welds, and improperly aligned parts as vehicles proceed along the production line.

Today, dealer service centers and independent repair shops are using machine vision systems to automate the vehicle inspection process for various aftermarket uses, including:

- Maintenance and servicing
- Online used car marketplaces and auctions
- Vehicle-salvaging and parts-recycling operations

Tel Aviv, Israel–based UVeye offers a drive-through, ML-based vehicle inspection system designed to automate service department operations for dealerships, fleet operators, car rentals, used car marketplaces, and repair shops (see Figure 2).[5]

The system features comprehensive vehicle inspection capabilities, including an underbody scanner for detecting problems like frame damage, oil leaks, and rust. The system's tire inspection function can identify the brand of tire on a vehicle and its specifications and status, including air pressure, tread depth, and sidewall damage, even if a vehicle's tires are mismatched. External inspection capabilities provide a 360-degree exterior scan of a vehicle's parts, including bumpers, door locks, grilles, mirrors, and windows.

In a key development, UVeye's vehicle inspection system is now integrated with CDK Global's

Figure 2. UVeye's machine vision–based automated vehicle inspection system (source: UVeye)

Fortellis Automotive Commerce Exchange application, a popular platform that connects auto dealers, manufacturers, developers, and lenders.[6] The combined system offers an integrated platform for automating the vehicle repair process — from initial vehicle inspection to repair order generation.

UVeye says it takes about 15 minutes for a vehicle to pass through its vehicle inspection system and have a repair order generated, about 45 minutes less than the same process performed manually. As a customer's vehicle drives through a UVeye inspection lane (which takes just a few seconds), a service writer using a tablet can view a series of photos and a list of problems detected by the system. Serious problems (e.g., a worn tire, a damaged muffler, or a fluid leak) are flagged in red on the service advisor's screen. Customers are shown photos of the issues and work with the service advisor to determine which repairs to carry out. On approval, the system auto-generates a repair order (including an estimate) based on information from the inspection report.

A number of US dealerships are using this system. In March 2022, Volvo Car USA initiated a program to use UVeye's camera-based inspection system at select dealers.[7] Volvo says it gives retailers the ability to quickly and cost effectively evaluate trade-ins and to examine the condition of customers' cars as they come in for servicing.

Volvo hopes to expand use of the system to more of its 280+ independent US retail locations. Volvo has been involved with UVeye since 2019, when it became a strategic investor in the company and installed UVeye's body inspection technology on its assembly lines to support its manufacturing quality assurance program.

In June 2022, UVeye received an investment from the capital venture arm of General Motors to help fund the vehicle inspection technology.[8] UVeye is also working with GM to explore expanding UVeye's system to GM dealerships. The two companies are undertaking other vehicle inspection projects, including those involving used car auctions, fleet operations, and auto dealership sales. In the future, UVeye plans to incorporate electric vehicle and autonomous driving platforms into its inspection system.

Visual AI company Tractable offers machine vision inspection solutions for insurance agencies, auto service departments, and others.[9] Tractable's vehicle inspection platform uses ML and image classification to conduct a pixel-by-pixel assessment of a photo of a car. It can determine vehicle damage down to the individual part level, classify the condition or the degree/severity of damage, and generate a detailed estimate, which can include a certainty score.

DEALER SERVICE CENTERS AND INDEPENDENT REPAIR SHOPS ARE USING MACHINE VISION SYSTEMS TO AUTOMATE THE VEHICLE INSPECTION PROCESS

In March 2022, Tractable teamed with Black Widow to integrate its AI visual inspection system with Black Widow's 4K imaging system.[10] Black Widow is an eight-camera, drive-through system designed to capture high-definition vehicle images that are auto-assembled into a 360-degree virtual tour of the inside and outside of a vehicle. These images can be edited and published to online vehicle marketplaces and auction sites.

Tractable's system applies ML-based analytics to images captured by Black Widow to detect external damage and generate a vehicle condition report that includes estimated repair costs. This enables auctions and dealerships to more accurately and consistently assess each vehicle and make better decisions during the vehicle remarketing and merchandising process. Additional benefits include improving the customer experience by offering a more comprehensive and transparent view of the vehicle being considered for purchase.

Tractable's systems are also being used to automate parts recycling — specifically, the processes involved in identifying suitable parts on salvaged vehicles and ensuring those parts can be recycled and reused. The system can also help repair shops source needed parts.

LKQ North America is using the Tractable system to accelerate and optimize its auto parts recycling and distribution operations for procuring salvaged vehicles.[11] Tractable's algorithms visually analyze and classify images of parts on salvaged vehicles that come up for sale, allowing LKQ to assess the damage of a body part on a particular vehicle and determine which parts can be resold. Tractable then matches the salvaged parts to the needs of repair shops and notifies them about availability.

CONCLUSION

Machine vision is one of the most successful commercial applications of AI. This is particularly true when it comes to the auto industry, where it is used extensively to automate manufacturing operations. The technology has now evolved to the point where companies are increasingly applying machine vision to the aftermarket, most noticeably for automated inspection applications and, to a lesser extent, in combination with robotics systems for automating basic servicing tasks. This trend is just getting under way, but we're likely to see the use of machine vision systems in auto aftermarkets increase steadily in the near future.

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