The Economics of Autonomous Vehicles

Will AVs improve social welfare — or create unprecedented congestion? The jury is still out.

by Opher Baron, Oded Berman and Mehdi Nourinejad

AUTONOMOUS VEHICLES (AVs) are widely expected to radically change mobility patterns and improve the efficiency of our transportation systems. The highest level of automation that is currently being tested allows for vehicles to travel without a human on board. This concept opens up abundant opportunities in the transportation industry, but it also has implications for road capacity — both positive and negative.

As a result of the predicted benefits of AVs — which include smoother traffic and improved safety — more than 50 cities worldwide have committed to deploying them in the near future, and another 27 are preparing for automation by undertaking surveys of regulatory, planning and governance issues raised by these vehicles.

Not surprisingly, the private sector is actively pursuing vehicle automation. By now, most car manufacturers have established an AV division and expect to make the technology available to the mass market as early as 2025. By the year 2045, AV market share is predicted to be as high as 87.2 per cent. In this article we will discuss some of the opportunities and challenges that lie ahead for this burgeoning sector of the automobile industry.

The Current State of the Art

At present, **Daimler AG (Mercedes-Benz)** is considered the leader among the world's automakers in the development of automated driving technologies. Its Drive Pilot system allows the driver not only to stay within the boundaries of a lane, maintain a safe trailing distance and stop when necessary while in congestion, it also assists with steering, switching lanes and overtaking other cars when the driver signals a lane change. **Tesla**'s Auto Pilot system, installed on its flagship models, features a similar set of autonomous-driving functions.

Turning to Japan, **Nissan Motor Corporation** has been the

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keenest to develop autonomous technologies, marketing some models installed with an autonomous driving system called Pro-PILOT, which features keep-in-the-lane and keep-the-distance functions for highway driving and follow-and-stop functions for driving in congestion. Meanwhile, **Subaru Corporation** has earned recognition for its EyeSight tool — an emergency braking system to help avoid or reduce front-end crash damage as well as keep-in-the-lane and keep-the-distance functions, which are installed on many of its flagship models.

Many car manufacturers have also recognized the emerging 'shareability' of AVs and are planning to initiate their own ride-sharing programs. For example, **Ford** recently released a plan to roll out Level-4 AVs designed for commercial ride-sharing applications by 2025; **General Motors** is also developing automated Chevy Bolts for shared use; and **Waymo** (which is owned by **Google**) is partnering with **Chrysler** to create a shared AV enterprise.

One of the perceived drawbacks of vehicle sharing in the automated age is the increased traffic that will be injected into transportation networks as a result of 'relocation trips' — whereby a driverless car returns to its 'home base' after completing a ride. In addition to the increased traffic caused by these 'zombie trips', regular trips may also increase, as passengers will get to engage in alternative activities while riding. Skeptics of automation claim that AV trips — both regular and zombie — will worsen traffic conditions and clog major urban streets. Some even argue that average vehicle occupancy by humans might get as low as 50 per cent due to zombie trips, and that overall traffic will increase by up to 15 per cent.

In response to the skeptics, advocates of automation believe that AVs will make traffic smoother overall, due to minimized abrupt acceleration and braking, improved communications through vehicle-to-vehicle and vehicle-to-infrastructure channels, and a reduction in accidents. Several studies address this claim. For instance, journalist **Clifford Atiyeh** has estimated that automation will increase speeds by 23 to 39 per cent under fuel-economy conditions and by eight to 13 per cent in congested traffic. In this view, reductions in accidents will also improve traffic, as 25 per cent of congestion is attributed to traffic incidents.

Moreover, when AVs reach their predicted high market-share, systemic improvements may appear in terms of intersection controls (i.e. traffic light design). One futuristic vision is to have no traffic lights whatsoever at intersections, but instead, a scenario where cars pass through the area in a synchronized manner without having to stop.

With recent advancements in automation technology, many provincial and state governments in North America, Europe and South Asia are now issuing permits for AVs to drive on designated roadways. Google has tested driverless vehicles over more than two million miles in cities, including Mountain View, Austin and Phoenix. The U.S. is a leader in this testing stage, partly due to its **National Highway Traffic Safety Administration**, which has issued a set of national guidelines outlining the principles of driverless vehicle pilots. These guidelines streamline the testing phase and motivate companies to pilot their prototypes in real-life traffic conditions. Canada has also begun several pilots in the provinces of Ontario and Quebec by allowing firms such as **Uber** to run their driverless vehicles on 'live' streets.

Broadly speaking, once the *testing* phase is complete, the next step for AVs will be *regulation*. There are already 17 states in the U.S. pursuing AV-enabling legislature by passing bills to regulate operations and licensing. Regulatory policies include changing traffic rules to accommodate AVs, land use intervention, starting new ride-sharing services, initiating 'pilot zones' (where AVs can be tested), taxi reform (i.e. making taxis automated) and transit automation (e.g. making buses and subways automated). **Figure One** shows some of the cities that are taking a holistic approach to implementing multifaceted policies. As Indicated Austin, Singapore and Helsinki are among those taking the lead in automation.

Autonomous Vehicle Initiatives by City

	Traffic rules	Land use	Ride-sharing	Pilot zone	Taxi reform	Transit autonomation
Austin	X	X	X	X	X	X
Boston	X	X	X			
Gothenburg, Sweden	X	X	X			
Helsinki, Finland	X	X	X	X	X	X
London, UK	X	X	X		X	X
Milton Keynes, UK		X	X		X	
Montreal	X	X	X	X	X	X
Paris, France	X	X	X		X	X
Pittsburgh	X	X	X		X	
San Jose	X	X	X		X	
Singapore	X	X	X	X	X	X
Tampere, Finland	X		X	X		
Trikala, Greece		X	X	X		

Note: These cities were chosen from a larger pool of 55 that we studied.

FIGURE ONE

One approach that is being neglected thus far is subsidization, and we believe this is a mistake. Subsidization — whereby households would be granted rebates for purchasing AVs — is a practical policy approach because most households will not be able to afford AVs due to their high ownership costs and the expensive embedded-autonomy equipment in the vehicle. At the moment, the technology used in AVs includes light detection and ranging systems, sensors, software and other advanced computing power. These components alone can cost more than US$ 30,000 (up to US$ 100,000 for military uses). However, this equipment is expected to become more affordable as AVs become available to the public on a mass scale. **Hensley** estimates that 15 years after the commercialization of AVs, their cost will drop from a US$ 10,000 markup (i.e. the additional payment for autonomy technology) to a US$ 3,000 markup. Before reaching these affordable markups, however, we believe that governing agencies should promote AV purchases by implementing rebates and subsidies.

The coming trade-off between infrastructure efficiency and induced traffic has caused a heated debate about the benefits of vehicle automation, and experts are taking sides based on speculations — without substantial scientific evidence. Of course, this is partially because AVs are not yet commercialized and no data is not yet available to support either side's arguments. Nevertheless, the fact is that semi-autonomous vehicles already exist in the consumer market, and fully autonomous vehicles are likely to arrive in the next decade. As indicated earlier, AVs are expected to promote shared mobility because they can be relocated among multiple passengers in driverless mode. By sharing a 'fleet' of AVs, each user would pay less for mobility and have a higher incentive to travel due to the extra free time provided. This paradox will potentially lead to more traffic in urban areas.

On the upside, the connectivity features of AVs will enable them to use road space much more efficiently. This efficiency would offset the extra traffic from zombie trips and overall decrease travel times. Going forward, cities should not inadvertently support AVs without an in-depth analysis of their impacts.

Our Research

A number of studies have investigated the impact of AVs in terms of fuel economy, induced traffic, willingness-to-pay, traffic flow, safety, intersection control, parking, and their use as a shared fleet between a group of users. Among the key findings to date, researchers have shown that network capacity generally increases with AV market share because of 'platoon formation' and the lower reaction time of AVs. These studies relate capacity to the share of AVs in the network, where the highest capacity is reached when the entirety of traffic is automated.

While research on vehicle automation is growing, the majority of studies to date have taken an engineering approach by looking at either infrastructure management or the travel patterns of AV users in futuristic scenarios. Very few studies have focused on optimal policies for vehicle automation from an operations management perspective. Among those that have, Northwestern Professor **Xin Chen** et al. propose 'automated zones' comprised of a particular set of streets allocated to driverless vehicles. Researchers have also considered policies for managing a fleet of shared AVs and the implications of parking provision in an era of automation.

While these policy-based studies are inarguably important, their findings will be relevant only when a reasonable ratio of a city's population has converted to AVs. There has been a general lack of investigation into policies that encourage travellers to switch over to driverless modes while considering the benefits

Automotive's New Value-Creating Engine by J. Brockhaus, J. Deichmann, J. Pulm and J. Repenning

In recent years, the automotive industry has been intensely discussing four disruptive and mutually reinforcing trends: autonomous driving, connectivity, electrification and shared mobility. These 'ACES' trends are expected to fuel growth within the market for mobility, change the rules of the sector, and lead to a shift from traditional to disruptive technologies and innovative business models.

Artificial intelligence is a key technology for all four ACES trends. Autonomous driving, for example, relies inherently on AI because it is the only technology that enables the reliable, real-time recognition of objects around the vehicle. For the other three trends, AI creates numerous opportunities to reduce costs, improve operations and generate new revenue streams. For shared mobility services, AI can, for example, help to optimize pricing by predicting and matching supply and demand. It can also be used to improve maintenance scheduling and fleet management.

These improvements through AI will play an important role for automotive firms because they enable them to finance and cope with the changes ahead of them. One expected key result from the ACES trends is a marked shift in the industry's 'value pools'. This change will primarily affect large automotive original equipment manufacturers (OEMs) and their business models, but the impact will be felt throughout the industry and beyond.

The products and services made possible by the ACES trends will not only impact the business of all incumbent and traditional industry players, but will also open the market up to new entrants. Many companies that were previously focused on other industries — e.g. technology players— are heavily investing in the ACES trends and the underlying key technologies. As a result, a new ecosystem of players is emerging.

New players will be important partners for traditional automotive companies. While automotive OEMs can use new players' technology expertise to unlock value potential from AI, new players will have opportunities to claim their share of the automotive and mobility markets. To master the ACES trends, OEMs need to invest substantially into each of the four ACES — not just in their development, but also in their integration.

Our analyses has yielded the following key insights:

• **In the short to medium term, there is a substantial industry-wide AI-enabled value opportunity**, which by 2025, will reach a total accumulated value potential of around US$ 215 billion for automotive OEMs worldwide. This corresponds to the value of nine EBIT percentage points for the whole automotive industry, or to an additional average productivity increase of approximately 1.3 per cent per year—a significant value to boost the industry's regular ~2 per cent annual productivity and drawbacks of automation.

In the absence of data, analytical methods that provide insight on vehicle automation in different operating scenarios can be very useful. In a recent paper, we addressed the automation controversy by using economic analysis based on supply-demand curves, capturing the impact of automation on the supply-demand equilibrium. Several insights emerged. One key conclusion is that we cannot blindly support or dispute automation without knowledge of a) the transportation infrastructure in a given area, and b) the vehicle-sharing behaviour of consumers. Based on these two factors, one of three scenarios will occur:

1. A widespread acceptance that any level of automation is beneficial for society;
2. A belief that partial automation is the best approach; or
3. A recognition that no vehicles should be automated.

Previous studies of vehicle subsidization show great promise in fleet electrification, and in our paper, we extend them by developing subsidization regimes for AVs and comparing them with two other policies founded on taxation and vehicle-sharing. We assessed the impact of three policies that can promote automation once it is deemed to be beneficial to society:

POLICY 1: Government subsidization, whereby a governing agency subsidizes AVs by offering rebates to buyers from an exogenous budget.

POLICY 2: Rebates are provided to AV owners using funds generated from a tax collected from regular vehicle owners.

POLICY 3: The industry promotes sharing AVs among groups of users to distribute ownership costs.

aspiration. Most of this value is derived from the optimization of core processes along the value chain.

• **Even in the short term, AI can lead to efficiencies and cost savings across the entire value chain** and can create additional revenues from vehicle sales and after-market sales. Most of the value is generated through four core processes. In procurement, supply chain management and manufacturing, efficiencies lead to cost savings of US$ 51 billion, US$ 22 billion, and US$ 61 billion, respectively. In marketing and sales, AI-based efficiencies both reduce cost and generate revenue, leading to a total value potential of US$ 31 billion for this process.

• **While AI-enabled vehicle features can generate substantial industry-wide value in the long term, these features and services will only create limited value at the industry level in the short term.** Nevertheless, generating value from these features and services is important as individual OEMs that outperform competitors with their driver/vehicle features and mobility services can gain substantial market share. These gains in market share by technology leaders are, however, small compared to the risk of losing a significant part of the customer base for OEMs that are falling behind on these features.

Four key success factors will enable OEMs to prepare for the AI transformation and to capture value from AI in the short term: Collecting and synchronizing data from different sources; setting up a partner ecosystem; establishing an AI operating system; and building up core AI capabilities and a core AI team to drive the required transformation.

OEMs need to begin their AI transformations now by implementing pilots to gain knowledge and capture short-term value. They should then establish their AI core to develop an integrated view on AI across the organization. This will enable OEMs to scale up and roll out an end-to-end AI transformation to systematically capture the full value potential from AI and build up capabilities for their long-term ACES strategies.

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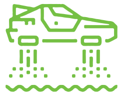

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Our analysis showed that subsidization (Policy 1) always leads to higher social welfare than 'tax-and-subsidize' (Policy 2). Nevertheless, a higher level of automation would be achieved by the latter, and this could lead to important secondary benefits — such as a reduction in accidents and environmental pollution.

We also found that the optimal policy will depend on the market price of AVs and the ability of the industry's infrastructure to service them. Hence, the idea of an 'optimal' policy will change as AVs become more affordable and the infrastructure is upgraded to better serve them over time. For instance, altering sharing arrangements (Policy 3) would not be an ideal approach when AVs first enter the market because the market-share would not be large enough to exploit the benefits of sharing; but, as the market share grows and the infrastructure evolves, this policy becomes increasingly powerful.

Some of our insights might appear to be counter-intuitive. First, it is commonly accepted that 'any increase in traffic will lead to longer travel times'. However, we found that this may not be the case when there is a mix of regular vehicles and AVs on the road. Put simply, it is possible to increase traffic *and* experience shorter travel times under automation. Second, since AV users will experience more free time and comfort when travelling, the induced traffic in the network may increase. Therefore, as the level of comfort increases (and the value of time decreases), automation becomes more harmful to social welfare. This counter-intuitive assertion results from the predicted tendency of AV owners to travel more because of the extra comfort afforded by these vehicles.

While AVs are expected to benefit society in many ways, their high initial cost may hinder their widespread adoption. Therefore we believe government intervention is required to ensure that AVs are affordable for the public. Policies that endorse automation may use subsidization, taxation or the promotion of vehicle sharing between multiple users.

The optimal policy for AVs depends on the price gap between autonomous and regular vehicles, and the ability of an area's infrastructure to service AVs. Therefore, the optimal policy will change with time, as infrastructure is improved and AVs become more cost-effective due to mass production.

In closing

Many forthcoming policies in the realm of vehicle automation remain to be investigated, including changes to traffic rules, taxi regulation and land use changes. Continued research in these areas will allow us to better comprehend the future impact of vehicle automation and provide further tools for policymakers to make effective decisions.

An important next step is to investigate the pricing structure of households in each group of vehicle sharers or 'AV coalitions'. For example, for joint owners of AVs, how should the ownership costs be equitably divided among the members of each coalition to reach an equilibrium where no household benefits from switching to another coalition?

In the meantime, we hope that our analysis and the insights it generates may support government agencies and other regulatory bodies in their study and implementation of policies to optimally control the adoption of AVs. ***RM***



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