Digital Auto Report 2020
Navigating through a post-pandemic world
Digital Auto Report 2020 – Volume 1

✓ Ninth annual Digital Auto Report, developed by Strategy& and PwC
✓ Global consumer survey with a focus on the US, EU and Asia (n = 3,000)
✓ Quantitative market outlook until 2035 based on regional structural analysis
✓ Interviews and survey with >60 industry executives at OEMs and suppliers, leading academics and industry analysts

Volume 1
Anticipating post-pandemic market dynamics

- Market outlook – penetration of technologies and mobility types
- Technology – shifting gears in connected, electric, automated
- Customers – changing mobility preferences: shared no more?
- Regulation – slowdown or acceleration of key policies?

Volume 2
Rethinking business models and investments

- New business opportunities – hype or reality?
- Economic value – market growth and unit economics
- Investment strategy – OEMs vs. VCs vs. Tech players
- OEM survival guide for a post-crisis market reality

Volume 3
Building a software-enabled automotive company

- Capabilities of a software-enabled company
- Deep dive on automated software development and testing
- Capability build-up strategy – a platform approach
The mobility ecosystem is transforming into a fragmented future w/different adoption patterns and use cases by region

Executive summary – Volume 1

- With adjusted technology expectations and changing post-pandemic customer preferences, CASE evolves. Consumers do not expect fully automated cars before early 2030s. Shared mobility growth is slowing down, relevance of seamless mobility remains high.

- Total vehicle parc expected to shrink in Europe (-0.5% p.a.) while growing in the US (+1.1% p.a.) and China (+3.9% p.a.) until 2035, driven by 1) mobility growth (highest in China), 2) customer preferences for sharing (lowest in US) and 3) vehicle disposal rate.

- Regulatory requirements are driving basic connectivity in EU and US (>85% penetration of new cars in 2020), while China is still at 44%. Total connected vehicle parc will pass 50% mark in Europe by 2025; in US as early as 2023 and in China latest by 2029.

- EU and China are leading the e-mobility transformation with expected new car BEV share of 17% and 19% by 2025. US significantly lower with 5% by 2025 given fewer government incentives and attractive ICE alternative in terms of TCO.

- Automated driving will emerge in a broad spectrum of use cases with specific requirements that are difficult to scale. While e.g. L4 pilot projects with people movers are running today, L4 share of new vehicles is expected to reach 17% by 2035 in EU (vs. 16% in China).

- Shifts in individual mobility patterns require a new segmentation in terms of private vs. shared and active vs. passive driving – each with multiple use cases at different automation levels. Shared-active (e.g. rental, subscription) expected to grow strongest in EU (10% of total person kilometers by 2025), while shared-passive (e.g. ride-hailing) is expected to grow significantly more in China (10% vs. 1-3% in US and EU).

- The increasing proliferation of use cases and business models requires many players to re-evaluate their CASE strategies with a fact-based view on available technology, value pool sizes and unit economics as well as investment requirements and right to win (→ covered in our next report volume No 2).

Note: Please refer to respective section for detailed assumptions and sources behind stated propositions.
“With adjusted technology expectations and changing post-pandemic customer preferences, CASE evolves”

S for Shared becomes Smart (Mobility)*

*Smart Mobility describes a transportation ecosystem where stakeholders use data and connectivity to move people and goods sustainably and efficiently. Shared mobility remains as a sub-segment and an important value pool in this ecosystem focusing on people transport with passenger vehicles.

Source: Strategy&
Triggered by the effects of the COVID-19 pandemic, many players will have to reevaluate their CASE strategies.

**Consumer**
- COVID-19 postpones consumer spend during lock-downs. Demand recovery expected with preference for EV.

**Technology**
- COVID-19 shatters old industries and will lead to market shakeout. Digital and remote tech is on the rise.
- COVID-19 digitizes society and increases acceptance and demand for digital – and connected – services.
- COVID-19 modifies competition: Big Tech benefits, asset-heavy OEMs struggle to keep up required R&D invest.

**Regulation**
- COVID-19 imposes new norms for work environments, consumer interactions and international trade.

**Economics**
- COVID-19 cuts topline, accelerating saving needs of OEMs and suppliers as liquidity becomes critical to survive.
- COVID-19 cools down economies, leads governments to subsidize EVs and increases EV market demand.
The acceleration of technology penetration will occur at varying times and speeds globally, as local mobility transforms. Key considerations to anticipate tipping point of exponential technology adoption:

<table>
<thead>
<tr>
<th>Technology</th>
<th>Consumer</th>
<th>Regulation</th>
<th>Economics</th>
<th>Expected tipping points</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Connected</strong></td>
<td>• Connected service content and UX</td>
<td>• “Digitally savvy” share of population</td>
<td>• Scope and timing of enforced connectivity requirements</td>
<td>earlier 2030 later</td>
</tr>
<tr>
<td></td>
<td>• Vehicle system/EE architecture</td>
<td>• “Freemium” segment services</td>
<td>• Scope of data privacy restrictions</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Network infrastructure</td>
<td></td>
<td>• Indirect value capture by OEM</td>
<td></td>
</tr>
<tr>
<td><strong>Electric</strong></td>
<td>• Battery and powertrain performance</td>
<td>• Premium/early adopter segment size</td>
<td>• Emission target levels</td>
<td>earlier 2030 later</td>
</tr>
<tr>
<td></td>
<td>• EV manufacturability and production capacity</td>
<td>• “Rational green” segment size</td>
<td>• BEV/PHEV incentives</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Charging infrastructure</td>
<td></td>
<td>• Diesel/ICE bans/restrictions in cities</td>
<td></td>
</tr>
<tr>
<td><strong>Automated</strong></td>
<td>• ADAS capability by use case</td>
<td>• Premium/early adopter segment size</td>
<td>• Superior total cost of ownership (TCO) of BEV vs. ICE in relevant number of segments</td>
<td>earlier 2030 later</td>
</tr>
<tr>
<td></td>
<td>• Data processing</td>
<td>• Technology openness</td>
<td>• Additional revenues/savings from V2G/V2X charging</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Driver UI</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Network and traffic infrastructure</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Smart Mobility</strong></td>
<td>• Smartphone penetration</td>
<td>• Intermodal openness</td>
<td>• Superior TCO vs. non-AV in first commercial cases</td>
<td>earlier 2030 later</td>
</tr>
<tr>
<td></td>
<td>• Access and fleet availability</td>
<td>• People/traffic density “Frequent user” segment size</td>
<td>• Geographic range and quantity of AV test drive/vehicle approvals</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Private car restrictions/taxes</td>
<td>• Additional value capture from riders</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Passenger transport regulation</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Dynamic pricing for opt. use and availability</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

ADAS = Advanced Driver Assistance Systems; EE = Electric/electronics, V2G = Vehicle to grid, TCO = Total cost of ownership
Note: A tipping point is defined as the start of exponential growth within a segment of the mobility transformation
Source: Expert interviews, PwC AutoFacts®, Strategy&
Total car parc growth strongest in China with high penetration of connected and electric; automation relevant after 2025

### Total vehicle parc and technology penetration (in million, %)

<table>
<thead>
<tr>
<th>Year</th>
<th>New LV sales (million)</th>
<th>Total LV parc (million)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2020</td>
<td>302</td>
<td>14</td>
</tr>
<tr>
<td>2025</td>
<td>308</td>
<td>17</td>
</tr>
<tr>
<td>2030</td>
<td>294</td>
<td>17</td>
</tr>
<tr>
<td>2035</td>
<td>281</td>
<td>17</td>
</tr>
</tbody>
</table>

- **Connected (eCall, % new LV sales)**
  - EU: 86% 100% 100% 100%
  - US: 87% 100% 100% 100%
  - China: 44% 91% 100% 100%

- **Electric (BEV, % new LV sales)**
  - EU: 4% 17% 34% 67%
  - US: 2% 5% 8% 14%
  - China: 4% 19% 33% 55%

- **Automated (L4/L5, % new LV sales)**
  - EU: 0% 0% 7% 15%
  - US: 0% 0% 1% 2%
  - China: 0% 0% 3% 16%

### Assumptions

- **Total vehicle parc** driven by
  - Growing economic mobility demand after COVID-19
  - Build-up of new mobility fleets with high annual mileage
  - Disposal of outdated vehicles

- **Basic connectivity with high penetration** due to regulation in US/EU; share with over-the-air (OTA) capability significantly lower

- **BEV with strong growth in EU/China** due to government subsidies and earlier “total cost of ownership” parity (vs. ICE) than in the US

- **Delay of automated vehicle penetration** at L4/L5 due to technical challenges and investment cuts; L3 with first useful applications before 2025

Source: PwC AutoFacts®, Strategy&

LV = Light vehicles = Cars + light commercial vehicles < 6t GVW
BEV = Battery electric vehicle
ICE = Internal combustion engine
Connectivity will rapidly penetrate total car parc; OEMs need to leverage platforms for scale, while maintaining distinct UX

**Total vehicle parc and connected car share** (in million, %)

**Source:** PwC AutoFacts®, Strategy&

Total vehicle parc expected to shrink in Europe (-0.5% p.a.) while growing in the US (+1.1% p.a.) and China (+3.9% p.a.) until 2035 – connectivity penetration >50% after 2025 in Europe and US.
The shift from conventional to electric powertrains is underway; China and Europe head-to-head in market penetration

New vehicle sales by powertrain (in million, %)

<table>
<thead>
<tr>
<th>Year</th>
<th>FCEV</th>
<th>BEV</th>
<th>PHEV</th>
<th>ICE (incl. HEV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2020</td>
<td>14</td>
<td>3%</td>
<td>93%</td>
<td>17%</td>
</tr>
<tr>
<td>2025</td>
<td>17</td>
<td>1%</td>
<td>74%</td>
<td>10%</td>
</tr>
<tr>
<td>2030</td>
<td>17</td>
<td>1%</td>
<td>55%</td>
<td>10%</td>
</tr>
<tr>
<td>2035</td>
<td>17</td>
<td>4%</td>
<td>11%</td>
<td>67%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Year</th>
<th>FCEV</th>
<th>BEV</th>
<th>PHEV</th>
<th>ICE (incl. HEV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2020</td>
<td>13</td>
<td>2%</td>
<td>93%</td>
<td>11%</td>
</tr>
<tr>
<td>2025</td>
<td>16</td>
<td>1%</td>
<td>74%</td>
<td>10%</td>
</tr>
<tr>
<td>2030</td>
<td>17</td>
<td>1%</td>
<td>55%</td>
<td>10%</td>
</tr>
<tr>
<td>2035</td>
<td>18</td>
<td>1%</td>
<td>11%</td>
<td>67%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Year</th>
<th>FCEV</th>
<th>BEV</th>
<th>PHEV</th>
<th>ICE (incl. HEV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2020</td>
<td>22</td>
<td>4%</td>
<td>93%</td>
<td>1%</td>
</tr>
<tr>
<td>2025</td>
<td>28</td>
<td>19%</td>
<td>74%</td>
<td>6%</td>
</tr>
<tr>
<td>2030</td>
<td>31</td>
<td>33%</td>
<td>60%</td>
<td>7%</td>
</tr>
<tr>
<td>2035</td>
<td>34</td>
<td>55%</td>
<td>32%</td>
<td>9%</td>
</tr>
</tbody>
</table>

Tightening CO₂ emission targets in the EU and new national guidelines in China accelerate BEV penetration in these regions significantly faster than in the US.
Automated driving will not arrive with a *big bang*: Various useful functions and features will pave the way for L4

**New vehicle sales by SAE level** (in million, %)

Before deploying L4 passenger vehicles at scale, players will push the next years for specific automated driving applications in transport / fleets and logistics / industrial areas to recover investments.

*Source: PwC AutoFacts®, Strategy&*
Transformation of mobility refocused towards shared active and passive modes due to COVID-19 and slower automation

**Market penetration by mobility mode** (in ‘000 trillion person-kilometer, %)

<table>
<thead>
<tr>
<th>Year</th>
<th>Shared active</th>
<th>Shared passive</th>
<th>Private active / passive</th>
</tr>
</thead>
<tbody>
<tr>
<td>2020</td>
<td>6%</td>
<td>2%</td>
<td>92%</td>
</tr>
<tr>
<td>2025</td>
<td>5%</td>
<td>3%</td>
<td>87%</td>
</tr>
<tr>
<td>2030</td>
<td>5%</td>
<td>5%</td>
<td>79%</td>
</tr>
<tr>
<td>2035</td>
<td>7%</td>
<td></td>
<td>72%</td>
</tr>
</tbody>
</table>

Source: PwC AutoFacts®, Strategy&

“Global market remains difficult to address with one mobility service given high proliferation of different active & passive driving use cases – new players invest in multi-mode transport platforms.”
This report series lays out in three volumes 1) CASE drivers, 2) economic opportunities, and 3) capability implications.

Volume 1
- Consumer
  - Connected
- Technology
  - Automated
- Regulation
  - Smart Mobility
  - Electric

Volume 2
- Economics
  - Opportunity sizing and investments

Volume 3
- Capabilities
  - Build-up and partnering
Anticipating post-pandemic market dynamics
Consumers seek convenient and safe mobility – private transport modes regain importance”
Survey among 3,000 consumers in Germany, the US and China shows latest shifts in consumer mobility preferences

Key results

- Respondents confirm relevance of connected services – security & navigation most important
- However, willingness to pay overall lower than most OEMs hoped for
- Consumers expect AD vehicles in the early 2030’s; first in transportation, later in private cars
- Two thirds of respondents would use automated vehicles; of those 75% would pay a premium for an automated driving of 5 – 20% per ride
- While new car purchase options lead across regions pre- and post-pandemic, interest in car subscription is growing strongly in China
- Regular cleaning / disinfection has become most important feature for shared mobility offerings to ensure usage during COVID-19
Respondents highlight the importance of connected services – safety and navigation rated as most important features

Connected services – By importance for consumers

- Safety: 80% in Germany, 90% in the US, 93% in China
- Navigation: 75% in Germany, 83% in the US, 92% in China
- Vehicle management: 58% in Germany, 71% in the US, 84% in China
- Vehicle features as a service: 58% in Germany, 68% in the US, 83% in China
- Infotainment/Entertainment: 47% in Germany, 63% in the US, 79% in China
- Mirror smartphone in car: 42% in Germany, 67% in the US, 74% in China
- Lifestyle and comfort: 39% in Germany, 59% in the US, 71% in China

Question: “Which connected service categories are particularly important to you?”

In Germany in particular, safety and navigation rank as most important services.

Winning consumers in other categories requires strong USP and compelling story.
Customers want in-vehicle connected services; however, willingness to pay might be lower than OEMs hope

### Connected services – Willingness to pay

<table>
<thead>
<tr>
<th>Fully-fledged connected service offering</th>
<th>Monthly willingness to pay</th>
<th>vs.</th>
<th>reference prices of other digital &amp; media services</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$ 19.5 at 31% willingness</td>
<td></td>
<td>$ 11.9</td>
</tr>
<tr>
<td></td>
<td>$ 17.6 at 40% willingness</td>
<td></td>
<td>$ 10.0</td>
</tr>
<tr>
<td></td>
<td>$ 4.3 at 58% willingness</td>
<td></td>
<td>n/a</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Spotify subscription²</th>
<th>Mobile voice &amp; data contract</th>
<th>Premium sports stream³</th>
<th>iPhone leasing⁴</th>
</tr>
</thead>
<tbody>
<tr>
<td>$ 34.6</td>
<td>$ 14.2</td>
<td>$ 39.5</td>
<td></td>
</tr>
<tr>
<td>$ 43.6</td>
<td>$ 19.9</td>
<td>$ 35.3</td>
<td></td>
</tr>
<tr>
<td>$ 9.8</td>
<td>$ 10.3</td>
<td>$ 33.4</td>
<td></td>
</tr>
</tbody>
</table>

Question: “Would you like to have Connected Car services integrated in your vehicle and are you willing to pay a surcharge for this? If yes, how much…”

**China** with highest share of consumers (58%) who are willing to pay an extra for connected services.

Capturing this value requires providers to compete partially against other digital services.
Gasoline still most preferred type of powertrain in Germany and the US; hybrid gains popularity and is most popular in China

**Preferred type of powertrain by age (%)**

**ICE – Gasoline & Diesel**

- **Germany**
  - Gasoline: 37%
  - Diesel: 17%
  - Gasoline + Diesel: 54%

- **USA**
  - Gasoline: 53%
  - Diesel: 9%
  - Gasoline + Diesel: 62%

- **China**
  - Gasoline: 31%
  - Diesel: 2%
  - Gasoline + Diesel: 33%

**PHEV & BEV**

- **Germany**
  - PHEV: 24%
  - BEV: 16%
  - PHEV + BEV: 48%

- **USA**
  - PHEV: 23%
  - BEV: 14%
  - PHEV + BEV: 37%

- **China**
  - PHEV: 46%
  - BEV: 22%
  - PHEV + BEV: 68%

**Question:** “Suppose you wanted to buy a car: Leaving aside financial aspects, legal requirements and lack of infrastructure […] – which type of drive do you like best?”

While 68% of Chinese consumers below 40 years prefer electric powertrains over gasoline, only 46% in Germany and 37% in the US share this preference.
Two thirds of respondents would use automated vehicles; of those, 75% would pay a premium for an automated driving service

Automated driving – Consumer attitude, impact factors and willingness to pay

**Source:** PwC Strategy& consumer research 2020; n=3,000 (1,000 DE, 1,000 US, 1,000 CN)
* Average willingness-to-pay a premium for a 5km ride with an automated vehicle instead of having a chauffeur or self-drive

**Attitude towards AV (%):**
- Would use AV: 36, 38, 59
- Would use AV only at low speed/parking: 28, 26, 32
- Would not use AV: 36, 36, 9

**Top 3 Persuasive factors for using AV (% of respondents):**
- Curious about driving AV: 37%, 26%, 23%
- Accident and speeding reduction: 29%, 26%, 23%
- Road traffic safety: 47%, 44%, 41%

**Top 3 Deterrent factors for using AV (% of respondents):**
- Desire to drive: 32%, 22%, 34%
- Loss of control: 22%, 19%, 19%
- Lack of trust in AD technology: 15%, 14%, 15%

**Willingness to Pay**
"Would you be willing to pay a premium for an AV (e.g. car sharing, ride hailing)? If yes, how much more would you pay for a 5 km trip with a base price of 10 €/10$/20¥?"

**Premium**
- Base price: 10, 10, 20
- 2 €, 2 $, 1 ¥
Mobility modes shift due to effects of COVID-19 – use of own vehicle preferred over shared mobility and public transport

Mobility patterns after COVID-19 restrictions (%)

Question: “Assuming COVID-19 restrictions are lifted again, how would you use the following mobility modes compared to pre-COVID-19 times?”

Own car is the clear winner in the US and China. In Germany, the intended increase of car usage is on par with bike and foot. At the same time, Germans move away strongly from shared modes.

1) On the example of transportation to/from work
Source: PwC Strategy& consumer research 2020; n=1,259 DE, n=593 US, n=779 CN; Percentage may not total 100% due to rounding
Shared mobility providers win consumers back with clear disinfection concepts rather than with lower prices

**Attitude towards shared mobility after COVID-19 lockdown (%)**

<table>
<thead>
<tr>
<th>Country</th>
<th>No usage of shared mobility offerings at all</th>
<th>Open towards usage of shared mobility offerings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Germany</td>
<td>42</td>
<td>58</td>
</tr>
<tr>
<td>USA</td>
<td>17</td>
<td>83</td>
</tr>
<tr>
<td>China</td>
<td>2</td>
<td>98</td>
</tr>
</tbody>
</table>

1. Regular cleaning and disinfection by the provider (28%)
2. Lower/cheaper prices (25%)
3. Reliable availability (24%)
4. Offer of gloves and masks in the vehicle (15%)
5. Higher quality/premium vehicles (11%)
6. Unspecified requirement (2%)
7. Unspecified requirement (1%)
8. Reserved parking spots (26%)
9. Extensive geographical coverage (17%)
10. Unspecified requirement (3%)
11. Unspecified requirement (1%)
12. Unspecified requirement (2%)
13. Unspecified requirement (1%)
14. Unspecified requirement (1%)
15. Unspecified requirement (1%)
16. Unspecified requirement (1%)
17. Unspecified requirement (1%)
18. Unspecified requirement (1%)
19. Unspecified requirement (1%)
20. Unspecified requirement (1%)
21. Unspecified requirement (1%)
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24. Unspecified requirement (1%)
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32. Unspecified requirement (1%)
33. Unspecified requirement (1%)
34. Unspecified requirement (1%)
35. Unspecified requirement (1%)
36. Unspecified requirement (1%)
37. Unspecified requirement (1%)
38. Unspecified requirement (1%)
39. Unspecified requirement (1%)
40. Unspecified requirement (1%)
41. Unspecified requirement (1%)
42. Unspecified requirement (1%)
43. Unspecified requirement (1%)
44. Unspecified requirement (1%)
45. Unspecified requirement (1%)
46. Unspecified requirement (1%)
47. Unspecified requirement (1%)
48. Unspecified requirement (1%)
49. Unspecified requirement (1%)
50. Unspecified requirement (1%)

**Question:** “Which requirements should providers fulfill to ensure that you would continue using shared mobility offerings after COVID-19 lockdown?

In Germany, quality/premium vehicles seen as least important factor to return to shared modes – after cleaning, price and availability are most important.
Purchasing a new vehicle remains preferred option across regions; China shows strongest increase in subscription intent

Likelihood to buy/lease/subscribe to a car before/after COVID-19 (%)

<table>
<thead>
<tr>
<th></th>
<th>Before= 1 year ago</th>
<th>after = within next 1-2 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purchase of a new car</td>
<td>24%</td>
<td>68%</td>
</tr>
<tr>
<td>Purchase/lease of a used car</td>
<td>18%</td>
<td>48%</td>
</tr>
<tr>
<td>Lease of a new car</td>
<td>11%</td>
<td>50%</td>
</tr>
<tr>
<td>Subscription of a new car</td>
<td>9%</td>
<td>62%</td>
</tr>
</tbody>
</table>

China, and partly the US, are open towards subscription models.

In Germany, further market education needed to win subscription customers.

Question: “Taking the position of pre-COVID-19, how likely was it that your household would buy, lease or subscribe to a new vehicle in 2020/2021? How likely is it now?”
“Technology progresses fast – yet complexity of autonomous driving has been underestimated.”
In connected services, OEMs are currently rethinking their “build vs. buy strategy” on key technology components.

### Connected services components

<table>
<thead>
<tr>
<th>Enabler</th>
<th>Hardware</th>
<th>Software</th>
<th>Integration</th>
<th>Content/Service</th>
<th>Sales and CRM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cloud infrastructure</td>
<td>Vehicle architecture and ECU</td>
<td>Automotive security</td>
<td>User interface and controls</td>
<td>Vehicle-based services and apps</td>
<td>Offering bundling and pricing</td>
</tr>
<tr>
<td>Mobile/local network</td>
<td>I/O devices (e.g., sensors, displays)</td>
<td>Vehicle OS, over-the-air update and cloud platform</td>
<td>System integration</td>
<td>3rd party content and services</td>
<td>User ID and personalization</td>
</tr>
<tr>
<td>Regulation</td>
<td>3rd party hardware (e.g., VR glasses)</td>
<td>Data analytics</td>
<td>Data interfaces and APIs</td>
<td>Cloud/hybrid services incl. vehicles health services</td>
<td>Customer support</td>
</tr>
</tbody>
</table>

#### Key value blocks
- Cloud infrastructure costs
- MNO costs
- Regional regulations
- Centralized E/E architecture with zonal ECUs
- Sensor fusion and virtual sensors
- OTA update functionality
- Data processing and intelligent data fusion
- Security of data connections
- UI design (e.g. graphical vs. voice only)
- Online-first vs. offline-first
- Open vs. closed APIs
- 3rd party content and app store integration
- Transmission, collection, and analysis of vehicle health data (e.g. based on sensor data)
- Subscription vs. life-time offer model
- Customer identification
- VIN to UID
- Data privacy

#### Current limitations
- Leverage eSIMs for customers and more frequent MNO tenders
- Evaluate sweet spot between complexity reduction and profitability
- Enable expendable vehicle architectures
- Define software-value-add strategy Use virtualization to securely separate domains
- Focus on differentiating adaptive user interface
- Provide and monetize SDKs and interfaces for 3rd parties
- Leverage smartphone integration for non-connected markets
- Bring user sign-up and log-in journey to perfection
- Connect to existing ecosystems (e.g. phone)

---

**Crucial value blocks (own know-how necessary)**
Technology progress in e-mobility must be evaluated in the context of tech trends across various alternative powertrains

### Alternative powertrain developments

#### Internal combustion engine
- **Electrification**
  - Recuperation and boost as standard features with 12V (budget) or 48V
  - Increased electrification of auxiliaries (water/oil pumps, cam phaser, etc.)
  - P2 topology avoiding drag torque

#### Reduction of friction losses
- Coatings and microstructural modifications on cylinder
- Optimization of crankshaft bearings
- Ball bearings for turbocharger

#### Combustion/emission optimization
- Increasing injection pressures
- Variability in valve trains
- Particle filters for most powertrains including DI gasolines
- Variable compression ratio through variable connection rod

### Electric drivetrain (electric motor, inverter, transmission)

#### Efficiency improvement
- Silicon carbide power semiconductor switches (inverter)
- Bar windings and increased notch filling degree in electric motor

#### Cost reductions
- Increased integration of inverter and motor

### High voltage system and architecture

#### Architecture
- Integration of power-units (OBC, DCDC, DC charger)
- Top models up to 800 V, standard in volume 400 V

#### Auxiliaries
- Increasing commoditization of electrified auxiliaries

### HV battery system

#### System design
- Structural integration of housing into vehicle body
- System design incl. recyclability

#### Cell innovation
- Increased cell capacity through larger cells
- Cathode cost reduction by minimization of cobalt content and cobalt-free cells
- Increased anode energy density via silicon
- Intrinsic safe cells by application of solid state electrolytes (polymers, inorganics, blends)
- Dry (solvent-free) processing of electrode coatings

### Fuel cell system

#### Stack
- Increase of power density
- Optimization of catalyst compositions (reduction of Pt) and nano-scale microstructure
- Optimization of bipolar plate coatings

#### Balance of plants
- Stack internal humidification and simplified water mgmt.

#### Tank
- Optimization of fiber winding layout and process
- Mixed materials to reduce costs
- Compressed H₂ as standard for passenger vehicles

---

**Source:** Strategy&
BEVs will become economical for several segments – but extended ranges (600 km+) will not be viable with BEVs

Electric powertrain operating cost break-even timeline (vs. ICE)

There is no fixed point in time when battery electric vehicles offer an operating cost advantage over internal combustion engines – it depends on factors such as the vehicle segment and range
Hardware, software and infrastructure of automated driving are improving, but overall progress slower than expected

**Automated driving technology developments**

**Current status and limitations**

- Radar and camera sensors are developed with a good cost position
- Cheap LiDAR systems do not yet have the necessary performance
- New ADAS computers based on low power tech are under development
- Different driver assistant systems mandatory beginning 2022 in EU
- Test and validation not yet mature
- Motion prediction still not completely solved
- Very large amounts of test data complicate traditional analytics
- So far, there are only a few test tracks that are fully developed for automated driving
- Expansion of 4G by 2022 for motorways in DE as basis for 5G
- For the time being, only pseudo 5G based on 4G (non stand-alone)
While L3 enables various attractive use cases, user experience and system complexity breakthrough is happening at L4

Automated driving SAE levels and AD function mapping

<table>
<thead>
<tr>
<th>SAE level</th>
<th>Narrative definition</th>
<th>Vehicle control</th>
<th>Environment monitoring and user interface</th>
<th>Fallback for dynamic driving task</th>
<th>System capability</th>
<th>Exemplary AD functionalities</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>HIGH</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 Full automation</td>
<td>The system performs all aspects of dynamic driving (driving-mode specific)...</td>
<td><img src="image" alt="System" /></td>
<td><img src="image" alt="System" /></td>
<td><img src="image" alt="System" /></td>
<td><img src="image" alt="System" /></td>
<td>All driving modes</td>
</tr>
<tr>
<td></td>
<td>...under all environmental and road conditions that can be managed by a human driver</td>
<td><img src="image" alt="System" /></td>
<td><img src="image" alt="System" /></td>
<td><img src="image" alt="System" /></td>
<td><img src="image" alt="System" /></td>
<td>• Universal pilot (full autonomy)</td>
</tr>
<tr>
<td></td>
<td>...even if a human driver does not respond appropriately to a request to intervene</td>
<td><img src="image" alt="System" /></td>
<td><img src="image" alt="System" /></td>
<td><img src="image" alt="System" /></td>
<td><img src="image" alt="System" /></td>
<td>• Interactive pilot driving (control via touch/gesture UI)</td>
</tr>
<tr>
<td>4 High automation</td>
<td>The system performs all aspects of dynamic driving (driving-mode specific)...</td>
<td><img src="image" alt="System" /></td>
<td><img src="image" alt="System" /></td>
<td><img src="image" alt="System" /></td>
<td><img src="image" alt="System" /></td>
<td>Most driving modes</td>
</tr>
<tr>
<td></td>
<td>...expecting the human driver to respond appropriately to an intervention request</td>
<td><img src="image" alt="System" /></td>
<td><img src="image" alt="System" /></td>
<td><img src="image" alt="System" /></td>
<td><img src="image" alt="System" /></td>
<td>• Urban/rural/highway pilot with multi-lane change</td>
</tr>
<tr>
<td>3 Conditional automation</td>
<td>The human driver performs remaining aspects of dynamic driving, while the system...</td>
<td><img src="image" alt="System" /></td>
<td><img src="image" alt="System" /></td>
<td><img src="image" alt="System" /></td>
<td><img src="image" alt="System" /></td>
<td>Some driving modes</td>
</tr>
<tr>
<td></td>
<td>...executes both steering and acceleration/deceleration (driving-mode specific)...</td>
<td><img src="image" alt="System" /></td>
<td><img src="image" alt="System" /></td>
<td><img src="image" alt="System" /></td>
<td><img src="image" alt="System" /></td>
<td>• Adaptive cruise control</td>
</tr>
<tr>
<td>2 Partial automation</td>
<td>The human driver performs remaining aspects of dynamic driving, while the system...</td>
<td><img src="image" alt="System" /></td>
<td><img src="image" alt="System" /></td>
<td><img src="image" alt="System" /></td>
<td><img src="image" alt="System" /></td>
<td>• Remote/key parking assistant</td>
</tr>
<tr>
<td></td>
<td>...executes either steering or acceleration/deceleration (driving-mode specific)</td>
<td><img src="image" alt="System" /></td>
<td><img src="image" alt="System" /></td>
<td><img src="image" alt="System" /></td>
<td><img src="image" alt="System" /></td>
<td>• Lane change assistant</td>
</tr>
<tr>
<td>1 Driver assistance</td>
<td>The human driver performs all aspects of dynamic driving, potentially “enhanced” by warning or intervention systems</td>
<td><img src="image" alt="System" /></td>
<td><img src="image" alt="System" /></td>
<td><img src="image" alt="System" /></td>
<td><img src="image" alt="System" /></td>
<td>• Adaptive cruise control</td>
</tr>
<tr>
<td></td>
<td>...executes either steering or acceleration/deceleration (driving-mode specific)</td>
<td><img src="image" alt="System" /></td>
<td><img src="image" alt="System" /></td>
<td><img src="image" alt="System" /></td>
<td><img src="image" alt="System" /></td>
<td>• Driver assisted parking assistant</td>
</tr>
<tr>
<td>0 No automation</td>
<td>The human driver performs all aspects of dynamic driving, potentially “enhanced” by warning or intervention systems</td>
<td><img src="image" alt="System" /></td>
<td><img src="image" alt="System" /></td>
<td><img src="image" alt="System" /></td>
<td><img src="image" alt="System" /></td>
<td>• Lane keeping assistant (system steers)</td>
</tr>
<tr>
<td></td>
<td><img src="image" alt="System" /></td>
<td><img src="image" alt="System" /></td>
<td><img src="image" alt="System" /></td>
<td><img src="image" alt="System" /></td>
<td><img src="image" alt="System" /></td>
<td>• Blind spot monitoring rear/side (system steers)</td>
</tr>
<tr>
<td></td>
<td><img src="image" alt="System" /></td>
<td><img src="image" alt="System" /></td>
<td><img src="image" alt="System" /></td>
<td><img src="image" alt="System" /></td>
<td><img src="image" alt="System" /></td>
<td>• Pre-forward collision braking</td>
</tr>
<tr>
<td></td>
<td><img src="image" alt="System" /></td>
<td><img src="image" alt="System" /></td>
<td><img src="image" alt="System" /></td>
<td><img src="image" alt="System" /></td>
<td><img src="image" alt="System" /></td>
<td>• Front/rear cross-traffic alert with braking</td>
</tr>
</tbody>
</table>

Source: “SAE International Standard J3016”, SAE; Strategy&
Commercially viable automated driving applications at L3 and beyond will start becoming available for specific use cases first.

Automated driving timeline of commercial road availability

People mover
Pre-defined route(s)
7-12 seats

Last mile logistics
Pre-defined route(s)
e.g., parcel station

Robo-taxi
No defined routes
2-6 seats

Owned vehicle
No defined routes
2-5 seats

Current developments
- ADAS technologies require higher development cost and efforts than anticipated
- ADAS sensors still far above target cost, due to small production volumes and sensor fusion/recognition challenges
- Regulation still uncertain with the UN/ECE technical framework and national rules not yet fully in place
- While first L3 vehicles expected for 2021/22, first L4 road applications beyond pilot projects expected for ~2025

Commercial availability (beyond pilot projects)\(^1\)

<table>
<thead>
<tr>
<th>Technology</th>
<th>Level 2+</th>
<th>Level 3</th>
<th>Level 4</th>
<th>Level 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>People mover</td>
<td></td>
<td></td>
<td>30</td>
<td>50</td>
</tr>
<tr>
<td>Last mile logistics</td>
<td></td>
<td></td>
<td>20</td>
<td>40</td>
</tr>
<tr>
<td>Robo-taxi</td>
<td></td>
<td></td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>Owned vehicle</td>
<td></td>
<td></td>
<td>50</td>
<td>100</td>
</tr>
</tbody>
</table>

1) Indicating start of availability. Tipping points of significant adoption expected significantly later in certain fields

Source: Strategy&
Individual mobility splits into four modes of private vs. shared and active vs. passive driving, each with increasing automation.

**Private / shared mobility modes with selected automated driving use cases**

<table>
<thead>
<tr>
<th>PRIVATE 1)</th>
<th>Personally-owned vehicle</th>
</tr>
</thead>
<tbody>
<tr>
<td>L5</td>
<td>Universal pilot</td>
</tr>
<tr>
<td>L4</td>
<td>Urban/rural/highway pilot</td>
</tr>
<tr>
<td>L3</td>
<td>Urban/rural/highway</td>
</tr>
<tr>
<td>L0-2</td>
<td>Private/family driver</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>AUTONOMATION LEVEL</th>
<th>PASSIVE 3) I am a passenger</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L0-2: Private/family driver</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SHARE 2)</th>
<th>Collective vehicle or ride</th>
</tr>
</thead>
<tbody>
<tr>
<td>L5</td>
<td>Robotaxi</td>
</tr>
<tr>
<td>L4</td>
<td>Automated people mover</td>
</tr>
<tr>
<td>L3</td>
<td>Urban/rural/highway</td>
</tr>
<tr>
<td>L0-2</td>
<td>Taxi, ride hailing/pooling</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>AUTONOMATION LEVEL</th>
<th>ACTIVE 4) I am the driver</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L5: Interactive pilot</td>
</tr>
<tr>
<td></td>
<td>L4: Interactive pilot</td>
</tr>
<tr>
<td></td>
<td>L3: Urban/rural/highway</td>
</tr>
<tr>
<td></td>
<td>L0-2: Self drive</td>
</tr>
</tbody>
</table>

1) Includes self-owned, family-owned, credit-financed, long-term leased, personal company car
2) Includes rental, subscription (up to 1 year), ride-hailing, ride-sharing, car sharing, pool car, car club
3) "Passenger" determines mobility purpose and target, passenger selects means of transport and expected time of arrival, mobility system determines detailed routing and actual time/place of arrival
4) "Driver" determines mobility purpose and target, driver determines means of transport and plans arrival time, driver determines detailed routing and actual time and place of arrival through user interface (UI)

Source: PwC AutoFacts®, Strategy&
Seamless smart mobility services require a modular, open API-based technology architecture and platform approach.

Smart mobility technology platform building blocks

Current developments

In contrast to individual mobility, providing smart mobility requires a modular technology and system architecture, capable of integrating various partners across the ecosystem with focus on:

- **Flexibility to integrate multiple modalities** and mobility service providers (with different brands)
- **Cross-platform customer acquisition** and seamless sign-up/-in
- **Region-specific/ local mobility product configuration** and partner management, incl. ride request/ offering brokerage
- **Real-time environment / asset condition-based routing**
- **Predictive maintenance scheduling**
- **Predictive asset lifecycle management**
Regulation aims to accelerate the mobility transformation – but following very different approaches across regions”
**Dynamic regulatory discussions shape CASE trends – impacting EV penetration and speed of AV testing rollout in particular**

### Latest regulatory initiatives and discussions

<table>
<thead>
<tr>
<th>Country</th>
<th>Initiative</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>USA</strong></td>
<td>Announcement to unify AV policies across 38 federal departments enforcing a consistent regulatory approach (01/2020)</td>
</tr>
<tr>
<td><strong>EU</strong></td>
<td>New guidelines on the processing of personal data (EDPB, 02/2020)</td>
</tr>
<tr>
<td></td>
<td>Addition of new advanced test scenarios to rate AEB technology (2020 EU NCAP update)</td>
</tr>
<tr>
<td></td>
<td>Updated guidelines to enforce advanced safety features (01/2020)</td>
</tr>
<tr>
<td><strong>China</strong></td>
<td>Release of the “Strategies for Innovation and Development of Intelligent Vehicles” with focus on creating an ecosystem for AVs in China (02/2020)</td>
</tr>
<tr>
<td></td>
<td>Plans for new changes to the NCAP test program with new safety additions (following the Euro model)</td>
</tr>
</tbody>
</table>

**Heterogeneous regulatory dynamics; focus on commercial dimension, less on sustainability**

- Positive expert sentiment
- Neutral expert sentiment
- Negative expert sentiment

**Note:**
1. The regulation targets a 15% reduction for passenger cars from 2025 onwards and 37.5% reduction from 2030 onwards. (2) Establishes strict requirements for Automated Lane Keeping Systems. (3) Incorporates “lessons-learned based on accumulated field experience in testing prototype ADS-operated vehicles on public roads.” (4) General regulatory sentiment derived from various expert opinions across politics and industry, e.g., automotive associations. AEB = Automated Emergency Braking; AV = Automated vehicle; NCAP = New Car Assessment Program; NHTSA = National Highway Traffic Safety Administration; UNECE = United Nations Economic Commission for Europe

Source: Strategy&
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