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)
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.
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.
- Automated: 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.
- Electric: 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>Connected</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>• Indirect value capture by OEM</td>
</tr>
<tr>
<td></td>
<td>• Vehicle system/EE architecture</td>
<td>• “Freemium” segment services</td>
<td>• Scope of data privacy restrictions</td>
<td>• Effective end consumer pricing</td>
</tr>
<tr>
<td></td>
<td>• Network infrastructure</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Electric</td>
<td>• Battery and powertrain performance</td>
<td>• Premium/early adopter segment size</td>
<td>• Emission target levels</td>
<td>• Superior total cost of ownership (TCO) of BEV vs. ICE in relevant number of segments</td>
</tr>
<tr>
<td></td>
<td>• EV manufacturability and production capacity</td>
<td>• “Rational green” segment size</td>
<td>• BEV/PHEV incentives</td>
<td>• Additional revenues/savings from V2G/V2X charging</td>
</tr>
<tr>
<td></td>
<td>• Charging infrastructure</td>
<td></td>
<td>• Diesel/ICE bans/restrictions in cities</td>
<td></td>
</tr>
<tr>
<td>Automated</td>
<td>• ADAS capability by use case</td>
<td>• Premium/early adopter segment size</td>
<td>• Scope and timing of enforced ADAS safety features</td>
<td>• Superior TCO vs. non-AV in first commercial cases</td>
</tr>
<tr>
<td></td>
<td>• Data processing</td>
<td>• Technology openness</td>
<td>• Geographic range and quantity of AV test drive/vehicle approvals</td>
<td>• Additional value capture from riders</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>Smart Mobility</td>
<td>• Smartphone penetration</td>
<td>• Intermodal openness</td>
<td>• Private car restrictions/taxes</td>
<td>• Superior TCO vs. own vehicle</td>
</tr>
<tr>
<td></td>
<td>• Access and fleet availability</td>
<td>• People/traffic density “Frequent user” segment size</td>
<td>• Passenger transport regulation</td>
<td>• Dynamic pricing for opt. use and availability</td>
</tr>
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<td></td>
<td></td>
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</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>

- New LV sales (million)
- Total LV parc (million)

### Connected (eCall, % new LV sales)

- 2020: 86%
- 2025: 100%
- 2030: 100%
- 2035: 100%

### Electric (BEV, % new LV sales)

- 2020: 4%
- 2025: 17%
- 2030: 34%
- 2035: 67%

### Automated (L4/L5, % new LV sales)

- 2020: 0%
- 2025: 0%
- 2030: 7%
- 2035: 15%

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

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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, %)

![Graph showing total vehicle parc and connected car share](image)

- **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.

Source: PwC AutoFacts®, Strategy&
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, %)

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.
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 [e.g. car sharing, rental]</th>
<th>Shared passive [e.g. ride hailing, (robo-) taxi]</th>
<th>Private active / passive [e.g. own vehicle]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2020</td>
<td>6%</td>
<td>92%</td>
<td>87%</td>
</tr>
<tr>
<td>2025</td>
<td>2%</td>
<td>87%</td>
<td>79%</td>
</tr>
<tr>
<td>2030</td>
<td>3%</td>
<td>79%</td>
<td>72%</td>
</tr>
<tr>
<td>2035</td>
<td>16%</td>
<td>72%</td>
<td>7%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Year</th>
<th>2020</th>
<th>2025</th>
<th>2030</th>
<th>2035</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.3</td>
<td>2%</td>
<td>1%</td>
<td>1%</td>
<td>1%</td>
</tr>
<tr>
<td>6.1</td>
<td>2%</td>
<td>1%</td>
<td>1%</td>
<td>1%</td>
</tr>
<tr>
<td>6.4</td>
<td>2%</td>
<td>1%</td>
<td>1%</td>
<td>1%</td>
</tr>
<tr>
<td>6.7</td>
<td>2%</td>
<td>1%</td>
<td>1%</td>
<td>1%</td>
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</table>

<table>
<thead>
<tr>
<th>Year</th>
<th>2020</th>
<th>2025</th>
<th>2030</th>
<th>2035</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.5</td>
<td>9%</td>
<td>10%</td>
<td>11%</td>
<td>12%</td>
</tr>
<tr>
<td>10.4</td>
<td>89%</td>
<td>88%</td>
<td>87%</td>
<td>86%</td>
</tr>
</tbody>
</table>

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.

Source: PwC AutoFacts®, Strategy&
This report series lays out in three volumes 1) CASE drivers, 2) economic opportunities, and 3) capability implications.

<table>
<thead>
<tr>
<th>Volume 1</th>
<th>Volume 2</th>
<th>Volume 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consumer</td>
<td>Economics</td>
<td>Capabilities</td>
</tr>
<tr>
<td>Technology</td>
<td>Opportunity sizing and investments</td>
<td>Build-up and partnering</td>
</tr>
<tr>
<td>Regulation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Connected</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Automated</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Smart Mobility</td>
<td></td>
<td></td>
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<tr>
<td>Electric</td>
<td></td>
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</tbody>
</table>

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Anticipating post-pandemic market dynamics
Consumers are seeking 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 ranked as most important features.

**Connected services – By importance for consumers**

**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.

<table>
<thead>
<tr>
<th>Service Category</th>
<th>Germany</th>
<th>USA</th>
<th>China</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safety</td>
<td>80%</td>
<td>90%</td>
<td>93%</td>
</tr>
<tr>
<td>Navigation</td>
<td>75%</td>
<td>83%</td>
<td>92%</td>
</tr>
<tr>
<td>Vehicle management</td>
<td>58%</td>
<td>71%</td>
<td>84%</td>
</tr>
<tr>
<td>Vehicle features as a service</td>
<td>58%</td>
<td>68%</td>
<td>83%</td>
</tr>
<tr>
<td>Infotainment/Entertainment</td>
<td>47%</td>
<td>63%</td>
<td>79%</td>
</tr>
<tr>
<td>Mirror smartphone in car</td>
<td>42%</td>
<td>67%</td>
<td>74%</td>
</tr>
<tr>
<td>Lifestyle and comfort</td>
<td>39%</td>
<td>59%</td>
<td>71%</td>
</tr>
</tbody>
</table>

Source: PwC Strategy& consumer research 2020; n=3,000 (1,000 DE, 1,000 US, 1,000 CN)
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>Willingness to pay</th>
<th>reference prices of other digital &amp; media services</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fully-fledged connected service offering</td>
<td>Spotify subscription$^2$</td>
</tr>
<tr>
<td>$19.5 at 31% willingness</td>
<td>$11.9</td>
</tr>
<tr>
<td>$17.6 at 40% willingness</td>
<td>$10.0</td>
</tr>
<tr>
<td>$4.3 at 58% willingness</td>
<td>n/a</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 (%)**

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**

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

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

**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¥?"

- **Base price**: 10
- **Premium**: 2 €/2$/1 ¥

**Top 3 Deterrent factors for using AV (% of respondents):**
- Desire to drive: 32% (DE), 22% (US), 34% (CN)
- Loss of control: 22% (DE), 19% (US), 14% (CN)
- Lack of trust in AD technology: 15% (DE), 14% (US), 13% (CN)

**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*
Mobility modes shift due to effects of COVID-19 – use of own vehicle preferred over shared mobility and public transport

Mobility pattern after COVID-19 restrictions (%)¹)

<table>
<thead>
<tr>
<th></th>
<th>Germany</th>
<th>USA</th>
<th>China</th>
</tr>
</thead>
<tbody>
<tr>
<td>Own bike</td>
<td>35</td>
<td>40</td>
<td>37</td>
</tr>
<tr>
<td>By foot</td>
<td>32</td>
<td>44</td>
<td>43</td>
</tr>
<tr>
<td>Own car</td>
<td>31</td>
<td>67</td>
<td>60</td>
</tr>
<tr>
<td>Public transport</td>
<td>10</td>
<td>22</td>
<td>23</td>
</tr>
<tr>
<td>Shared mobility</td>
<td>7</td>
<td>22</td>
<td>34</td>
</tr>
<tr>
<td>Car-sharing</td>
<td>5</td>
<td>22</td>
<td>25</td>
</tr>
<tr>
<td>Taxi, Uber, ...</td>
<td>4</td>
<td>25</td>
<td>30</td>
</tr>
</tbody>
</table>

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>US</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. ...  
7. ...  
8. ...  
9. ...  

**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>Likely / very likely after COVID-19</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Purchase of a new car</strong></td>
<td>24%</td>
<td>68%</td>
</tr>
<tr>
<td><strong>Purchase/lease of a used car</strong></td>
<td>18%</td>
<td>46%</td>
</tr>
<tr>
<td><strong>Lease of a new car</strong></td>
<td>11%</td>
<td>50%</td>
</tr>
<tr>
<td><strong>Subscription of a new car</strong></td>
<td>9%</td>
<td>62%</td>
</tr>
</tbody>
</table>

**Source:** PwC Strategy& consumer research 2020; n=2,000 DE, n=1,000 US, n=1,000 CN

**Difference to 100%:** no/low likelihood to buy/lease/subscribe a car

**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?”

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

In Germany, further market education needed to win subscription customers.
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 ECUs</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**

### Current limitations
- Centralized E/E architecture with zonal ECUs (see chapter 3)
- 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 developments
- 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 (see Chapter 3)
- 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)

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**Strategy& PwC**

**CRM:** Customer relation management  
**SW:** Software  
**VR:** Virtual reality  
**V2X:** Vehicle-to-x communication  
**HW:** Hardware  
**I/O:** Input/Output  
**MNO:** Mobile network operator

**Source:** Strategy&
Technology progress in e-mobility must be evaluated in the context of tech trends across various alternative powertrains

**Alternative powertrain developments**

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

### PHEV
- **High voltage system and architecture**
  - Integration of power-units (OBC, DCDC, DC charger)
  - Top models up to 800 V, standard in volume 400 V

### BEV
- **High voltage system and architecture**
  - Increasing commoditization of electrified auxiliaries

### FCEV
- **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

**Internal combustion engine**
- **Electrification**
  - Recovery 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

**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

**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

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

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.

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

<table>
<thead>
<tr>
<th>Vehicle segment</th>
<th>Range</th>
<th>Viable powertrains</th>
<th>Evolution of TCO leader</th>
<th>Break-even</th>
</tr>
</thead>
<tbody>
<tr>
<td>A/B Budget 70 kW</td>
<td>Low 150 km</td>
<td></td>
<td></td>
<td>2019</td>
</tr>
<tr>
<td></td>
<td>Mid 300 km</td>
<td></td>
<td></td>
<td>2027</td>
</tr>
<tr>
<td></td>
<td>Long 600 km</td>
<td></td>
<td></td>
<td>2040</td>
</tr>
<tr>
<td>C/D Volume 100 kW</td>
<td>Mid 300 km</td>
<td></td>
<td></td>
<td>2024</td>
</tr>
<tr>
<td></td>
<td>Long 600 km</td>
<td></td>
<td></td>
<td>2035</td>
</tr>
<tr>
<td></td>
<td>Extra-long 800 km</td>
<td></td>
<td></td>
<td>2038</td>
</tr>
<tr>
<td>E/F Premium 250 kW</td>
<td>Mid 300 km</td>
<td></td>
<td></td>
<td>2018</td>
</tr>
<tr>
<td></td>
<td>Long 600 km</td>
<td></td>
<td></td>
<td>2024</td>
</tr>
<tr>
<td></td>
<td>Extra-long 800 km</td>
<td></td>
<td></td>
<td>2028</td>
</tr>
</tbody>
</table>

Main assumptions: electricity and fuel prices as for Germany 2020; H2 price 56€/kg; PHEV driving modes 40% EV mode/60% ICE mode; FCEV driving modes 40% EV mode/60% FC mode

One-time buying incentives not considered

Source: Strategy&
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>5</td>
<td>Full automation</td>
<td>System</td>
<td>System</td>
<td>System</td>
<td>All driving modes</td>
<td>• Universal pilot (full autonomy)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Most driving modes</td>
<td>• Interactive pilot driving (control via touch/gesture UI)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Robo-taxi and automated people-mover (all conditions)</td>
</tr>
<tr>
<td>4</td>
<td>High automation</td>
<td>System</td>
<td>Alternative or conventional user interface</td>
<td>System</td>
<td>Some driving modes</td>
<td>• Urban/rural/highway pilot with multi-lane change</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Robo-taxi and automated people-mover</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Urban last-mile delivery</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Automated valet parking</td>
</tr>
<tr>
<td>3</td>
<td>Conditional automation</td>
<td>System</td>
<td>Conventional user interface</td>
<td>Human</td>
<td>Some driving modes</td>
<td>• Urban/rural/highway assistant (e.g. hands-off traffic jam, intersection movement, single lane change)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Parking chauffeur</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Assisted fleet operations (on-site, off-highway)</td>
</tr>
<tr>
<td>2</td>
<td>Partial automation</td>
<td>System</td>
<td>Conventional user interface</td>
<td>Human</td>
<td>Some driving modes</td>
<td>• Adaptive cruise control</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Remote/key parking assistant</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Lane change assistant</td>
</tr>
<tr>
<td>1</td>
<td>Driver assistance</td>
<td>System</td>
<td>Conventional user interface</td>
<td>Human</td>
<td>Some driving modes</td>
<td>• Adaptive cruise control</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Driver assisted parking assistant</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Lane keeping assistant (system steers)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Blind spot monitoring rear/side (system steers)</td>
</tr>
<tr>
<td>0</td>
<td>No automation</td>
<td>System</td>
<td>Conventional user interface</td>
<td>Human</td>
<td>n/a</td>
<td>• Pre-forward collision braking</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Front/rear cross-traffic alert with braking</td>
</tr>
</tbody>
</table>

SAE level 5: Full automation
- The system performs all aspects of dynamic driving (driving-mode specific)...
- ...under all environmental and road conditions that can be managed by a human driver...
- ...even if a human driver does not respond appropriately to a request to intervene...
- ...expecting the human driver to respond appropriately to an intervention request

SAE level 4: High automation
- The system performs all aspects of dynamic driving (driving-mode specific)...
- ...even if a human driver does not respond appropriately to a request to intervene

SAE level 3: Conditional automation
- The human driver performs remaining aspects of dynamic driving, while the system...
- ...executes both steering and acceleration/deceleration (driving-mode specific)...
- ...executes either steering or acceleration/deceleration (driving-mode specific)

SAE level 2: Partial automation
- The human driver performs remaining aspects of dynamic driving, while the system...
- ...executes both steering and acceleration/deceleration (driving-mode specific)...
- ...executes either steering or acceleration/deceleration (driving-mode specific)

SAE level 1: Driver assistance
- The human driver performs all aspects of dynamic driving, potentially "enhanced" by warning or intervention systems
- ...executes either steering or acceleration/deceleration (driving-mode specific)...

SAE level 0: No automation
- The human driver performs all aspects of dynamic driving, potentially "enhanced" by warning or intervention systems
- ...executes either steering or acceleration/deceleration (driving-mode specific)...

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\(^1\) 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

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1) ADAS = Advanced Driver Assistance Systems
2) 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

**PRIVATE**
- **1)** Personally-owned vehicle
  - L5: Universal pilot
  - L4: Urban/rural/highway pilot, Automated valet parking
  - L3: Urban/rural/highway assistant (for private driver), Parking assistant (for private driver)
  - L0-2: Private/family driver

**SHARE**
- **2)** Collective vehicle or ride
  - L5: Robotaxi, Automated people mover
  - L4: Urban/rural/highway assistant (for public driver)
  - L3: Urban/rural/highway assistant (for public driver)
  - L0-2: Taxi, ride hailing/pooling

### Technology – Smart mobility

#### Differentiating AD use case

- **Passive**
  - I am a passenger
  - L0-2: Private/family driver

- **Active**
  - I am the driver
  - L0-2: Self drive

#### Traditional base use case

- **L0-2**: Car sharing, rental, subscription

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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 is aiming 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

**USA**
- Announcement to unify AV policies across 38 federal departments enforcing a consistent regulatory approach (01/2020)

**EU**
- New EU CO₂ emission targets, applying as of 01/2020

**China**
- Release of the “Strategies for Innovation and Development of Intelligent Vehicles” with focus on creating an ecosystem for AVs in China (02/2020)

**GLOBAL**
- Internationally harmonized and binding UN norms on cybersecurity and software requirements for OEMs (06/2020, UNECE’s World Forum for Harmonization of Vehicle Regulation, WP.29)
- First binding global regulation on level 3 vehicle automation with focus on advancing safety (UNECE’s World Forum for Harmonization of Vehicle Regulations)
- Updated standards for on-road testing of level 3, 4 and 5 prototype ADS promoting a standardized groundwork for AV tech (09/2019)

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

Note: (1) the regulation targets a 15% reduction for passenger cars from 2025 on and 37.5% reduction from 2030 on. (2) e.g. 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