Automated Trucks

The next big disruptor in the automotive industry?

Roland Berger study

Short version – To receive the complete study please contact our US marketing department at linda.saliba@rolandberger.com
Disruption potential
Automated trucks address several challenges that the trucking industry is facing simultaneously: hours-of-service, safety, driver shortage and fuel costs

TCO benefit
In early stages, fast payback of technology investment can only be reached in few applications with high share of truck platooning – significant cost savings expected only long term with driverless trucks

Safety as true driver
As pull from fleet operators will be limited given the slow payback, safety regulation will become a major driver in the adoption of automated trucks

Source: Roland Berger
Hours-of-service, safety, driver shortage and fuel costs are top issues of the trucking industry

Top issues of the trucking industry

Source: ATRI; Roland Berger
Most of the top trucking industry issues can be addressed by automated trucks – Benefits expected also for wider society

Top industry issues addressed by automated trucks

<table>
<thead>
<tr>
<th>Fleet owner impact</th>
<th>Society impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Autonomous technology compensates for driver’s lack of attention</td>
<td>Emission reduction</td>
</tr>
<tr>
<td>Mileage improvements through better aerodynamics</td>
<td>Accident mitigation</td>
</tr>
<tr>
<td>Driver distraction</td>
<td>Safer roads</td>
</tr>
<tr>
<td>Optimized resting times for driver of trailing vehicle</td>
<td>Congestion reduction</td>
</tr>
<tr>
<td>90% of truck accidents caused by human error</td>
<td>Driver wellness</td>
</tr>
<tr>
<td>Driver retention</td>
<td>More rested drivers and reduced sleepiness</td>
</tr>
<tr>
<td>Driver shortage</td>
<td>Changed driver role might attract younger drivers</td>
</tr>
<tr>
<td>Driver shortage</td>
<td>Reduced driving stress and fewer monotonous time periods</td>
</tr>
<tr>
<td>Congestion</td>
<td>Driver wellness</td>
</tr>
<tr>
<td>Smaller distance between trucks reduces road area used</td>
<td>More rested drivers and reduced sleepiness</td>
</tr>
</tbody>
</table>

Source: ATRI, Roland Berger
Automated trucks have the potential to bring a disruptive change to the trucking industry

### Automated trucks – Disruption potential

<table>
<thead>
<tr>
<th>Fuel consumption</th>
<th>Safety</th>
<th>Driver demand</th>
<th>Others</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy consumption heavy duty trucks [tn Btu]</td>
<td>Trucks involved in crashes [per 100 m vehicle-miles]</td>
<td>Number of heavy duty truck drivers [m]</td>
<td></td>
</tr>
<tr>
<td>Base year 2000</td>
<td>Projected development w/o automated trucks</td>
<td>Potential development with automated trucks</td>
<td></td>
</tr>
</tbody>
</table>

- **Fuel consumption**
  - 2000: 3,700, 95% reduction
  - 2020: 5,200, 90% reduction
  - 2040: 7,200, 90% reduction

- **Safety**
  - 2000: 222
  - 2020: 42
  - 2040: 8

- **Driver demand**
  - 2000: 1.6
  - 2020: 1.9
  - 2040: 2.1

- **Others**
  - Reduction of traffic jams
  - Higher driver retention
  - Improved truck utilization
  - Lower transport cost
  - Emergence of new business models

Source: EIA; NHTSA; BLS; Roland Berger
Benefits of automated trucks are twofold: safer and more comfortable vehicle operation and fuel savings from platooning

Benefits from automated trucks

Automated driving

- Increased driver comfort and safety through fully automated vehicle operation

Benefits
- Optimized driver rest periods
- Fuel efficiency gains from predictive driving
- Eliminating human error
- Better vehicle utilization
- Eventually driverless vehicle

Cooperative automated driving

- Improved aerodynamics and fuel consumption through reduced inter-vehicle spacing

Benefits
- Additional fuel efficiency gains

Self-driving trucks

Source: Roland Berger
The technological development towards fully automated trucks takes place in stages – Driver engagement changes with stages

Technological roadmap (SAE stage definition)

<table>
<thead>
<tr>
<th>Stage</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stage 0</td>
<td>No Automation</td>
</tr>
<tr>
<td>Stage 1</td>
<td>Driver Assistance – Automation of individual function, driver fully engaged</td>
</tr>
<tr>
<td>Stage 2</td>
<td>Partial Automation – Automation of multiple functions, driver fully engaged</td>
</tr>
<tr>
<td>Stage 3</td>
<td>Conditional Automation – Automation of multiple functions, driver responds to a request to intervene</td>
</tr>
<tr>
<td>Stage 4</td>
<td>High Automation – Automated in certain conditions, driver not expected to monitor road – Driver has no responsibility during automated mode</td>
</tr>
<tr>
<td>Stage 5</td>
<td>Full Automation – Situation independent automated driving – Driver has no responsibility during driving</td>
</tr>
</tbody>
</table>

Source: SAE; Roland Berger
Each stage of automated trucks requires increasingly complex features that transfer more control from the driver to the truck

Required features by stage of automation

<table>
<thead>
<tr>
<th>Stage 0</th>
<th>No Automation</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; Blind spot detection/ right turn assistant</td>
<td></td>
</tr>
<tr>
<td>&gt; Collision warn system</td>
<td></td>
</tr>
<tr>
<td>&gt; Lane departure warning system</td>
<td></td>
</tr>
<tr>
<td>&gt; Driver monitoring system</td>
<td></td>
</tr>
<tr>
<td>&gt; Traffic sign recognition</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Stage 1</th>
<th>Driver Assistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; Emergency braking system</td>
<td></td>
</tr>
<tr>
<td>&gt; Adaptive cruise control or</td>
<td></td>
</tr>
<tr>
<td>&gt; Lane keep assist</td>
<td></td>
</tr>
<tr>
<td>&gt; Driver-assisted truck platoon (DATP)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Stage 2</th>
<th>Partial Automation</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; Traffic jam/ construction site assistant</td>
<td></td>
</tr>
<tr>
<td>&gt; Highway assist</td>
<td></td>
</tr>
<tr>
<td>&gt; Predictive powertrain control</td>
<td></td>
</tr>
<tr>
<td>&gt; Lane change assist incl. right-turning</td>
<td></td>
</tr>
<tr>
<td>&gt; Intelligent parking assist system</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Stage 3</th>
<th>Conditional Automation</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; Platooning</td>
<td></td>
</tr>
<tr>
<td>&gt; Real time communication between trucks via V2V/DSRC</td>
<td></td>
</tr>
<tr>
<td>&gt; Highway pilot – driver &quot;alert&quot;</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Stage 4</th>
<th>High Automation</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; Highway pilot – no driver responsibility</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Stage 5</th>
<th>Full Automation</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; Truck pilot</td>
<td></td>
</tr>
</tbody>
</table>

Source: SAE, Roland Berger
Autonomous trucks are enabled by an interplay of technology areas including hardware, software and integrated controls.

Key technology requirements automated trucks

**Sensors**
Input about the environment as well as communication with the cloud

**V2X connectivity**
Communication with other trucks (e.g. for platooning) and with infrastructure (e.g. buildings & roads)

**Vehicle control**
Vehicle actuation and output actions

**Integrated controls**
Supervisory controls over system, decision algorithms

**Spatial imaging**
Sensor data fusion for environmental model & object recognition

**Mapping & path planning/control**
Route and motion planning on map data and motion

**Human-Machine-Interface (HMI)**
New driver interaction patterns

Source: Roland Berger
A variety of sensors, connectivity and vehicle control systems are used in automated trucks along with HMI and software modules.

**Technologies used in automated trucks**

**Sensors** monitor the surroundings of the vehicle:
- Radar sensors monitor traffic in front (Stage 1) and to the sides of the truck (Stage 2).
- Front stereo camera adds redundancy and monitors traffic in front (Stage 3).
- Lidar creates high resolution 3D environmental data (Stage 3).
- Internal camera monitors driver to ensure that he can take back control if needed (Stage 3).

**Vehicle connectivity** (V2V/V2I) is not required for automated vehicles in Stage 1 and 2, but platooning depends on V2V communication between paired trucks.

**Spatial imaging** is done by aggregating the inputs from all sensors to develop 3D maps:
- Profile mapping of surroundings includes data about shapes, sizes, distances and speeds.
- Sophisticated algorithms required to process surrounding objects at a high rate.
- Software constantly learns for future adaptation.

**Vehicle control** allows steering of the vehicle:
- Automated steering for lateral control of the vehicle (Stage 2).
- Automated manual transmission (Stage 2) already on significant share of US trucks (~40%).
- Central ECU processes all sensor data (Stage 3).

**V2X connectivity**

**Mapping and path planning/control** uses advanced positioning systems and sensor data to plot, track and control appropriate routes to vehicle destination:
- System processes GPS data along with real time information received from imaging and mapping sensors like cameras and radar.
- Complex software required to determine positions of surrounding vehicles with precision and account for other variables like traffic, road conditions, accidents etc.

**HMI** communicates vehicle information to the driver:
- Informs the driver about the automated mechanical actions of the vehicle.
- Warns or instigates action from driver.
- Displays 3D map that the vehicle uses for its operations to help with driver's visualization.

Source: Expert interviews; Roland Berger
Incremental costs of automated driving increase from Stage 1 to 5 – Total incremental cost of stage 5 truck over 20 k USD

Incremental technologies and vehicle cost per stage [USD per truck]

<table>
<thead>
<tr>
<th>Incremental software</th>
<th>Stage 1</th>
<th>Stage 2</th>
<th>Stage 3</th>
<th>Stage 4</th>
<th>Stage 5</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>~85%</td>
<td>1,800</td>
<td>5,100</td>
<td>6,200</td>
<td>5,900</td>
<td>4,400</td>
<td>23,400</td>
</tr>
</tbody>
</table>

- Processing of sensor data from ACC and/or lane keep assist
- Processing of additional sensor input
- Higher level of environmental recognition required
- Complete automation of sensing process for specific environment
- Ability to correct for unknown variables in every situation is required

<table>
<thead>
<tr>
<th>Incremental hardware</th>
<th>Stage 1</th>
<th>Stage 2</th>
<th>Stage 3</th>
<th>Stage 4</th>
<th>Stage 5</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>~15%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
- Long-range radar
- Short-range radar (lateral sensing)
- Wiring
- Short-range radar (longitudinal sensing)
- Automated steering
- Front camera
- HMI
- Interior camera
- Central ECU
- Lidar
- Connectivity systems

Source: Expert interviews; Roland Berger
Driver and fuel are the largest cost items and will be impacted by automated driving – Additional savings on insurance cost possible

Impact of automated driving on operating costs [USD/mile]

- Driver rests while truck drives automated (Stage 4) and logs more miles
- MPG gains from predictive powertrain control and platooning
- Less accidents drive down insurance premiums
- Only minor savings depending on fleet
- Focus of analysis

Source: Roland Berger
We calculated operating cost benefits and investment paybacks for three representative use cases.

**Use cases – Example USA**

- **a Long-haul**
  - Long distance traffic between warehouse and harbor
  - Trip length 2,000 miles
  - Majority of trip on high traffic highways
  - Likelihood to form a platoon 40%-50%
  - Driver not required any more in Stage 5 (fully automated warehouse with automatic loading/unloading)

- **b Regional – high traffic roads**
  - Short distance traffic between harbor and distribution center
  - Trip length 400 miles
  - Majority of trip on high traffic highways
  - Likelihood to form a platoon 40%-50%
  - Driver not required any more in Stage 5 (fully automated warehouse with automatic loading/unloading)

- **c Regional – low traffic roads**
  - Short distance traffic between regional hub and local warehouse
  - Trip length 400 miles
  - Low share of trip on high traffic highways – Majority on less frequented rural roads
  - Likelihood to form a platoon 10%
  - Driver still required in Stage 5, e.g. for loading and unloading

Source: Roland Berger
Long-haul case allows payback in 3 years for all stages but stage 3 – Payback times too long for regional transportation

Payback calculation for use cases

<table>
<thead>
<tr>
<th>Use Case</th>
<th>Total Savings per Year [000 USD]</th>
<th>Payback Period for Incremental Vehicle Cost [months]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>a) Long-haul</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stage 1: 1.7</td>
<td>Stage 2: 2.3</td>
<td>Stage 3: 2.4</td>
</tr>
<tr>
<td>Stage 4: 8.0</td>
<td>Stage 5: 72.7</td>
<td></td>
</tr>
<tr>
<td><strong>b) Regional – high traffic roads</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stage 1: 1.0</td>
<td>Stage 2: 1.3</td>
<td>Stage 3: 1.4</td>
</tr>
<tr>
<td>Stage 4: 4.7</td>
<td>Stage 5: 42.4</td>
<td></td>
</tr>
<tr>
<td><strong>c) Regional – low traffic roads</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stage 1: 0.1</td>
<td>Stage 2: 0.2</td>
<td>Stage 3: 0.2</td>
</tr>
<tr>
<td>Stage 4: 0.9</td>
<td>Stage 5: 0.9</td>
<td></td>
</tr>
</tbody>
</table>

Benefits from DATP\(^2\) quickly offset initial investments in Stages 1 and 2 and driver cost savings allow quick payback in Stages 4 and 5.

Benefits from DATP\(^2\) offset initial investments in Stage 1 and driver cost savings allow payback in Stage 5 – Slow payback in Stages 2-4.

Limited benefits lead to long payback times.

Source: Roland Berger

1) Incremental vehicle cost: Stage 1: 1,800 USD, Stage 2: 6,900 USD, Stage 3: 13,100 USD, Stage 4: 19,000 USD, Stage 5: 23,400 USD  2) Driver-assisted truck platoon
Up to Stage 3, level of platooning will influence adoption of automated trucks, driver cost savings drive adoption in Stage 4

Impact of platooning on payback times [mo]

<table>
<thead>
<tr>
<th></th>
<th>Long-haul</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mid-term</td>
<td>Long-term</td>
</tr>
<tr>
<td>Stage 1</td>
<td>13</td>
</tr>
<tr>
<td>Stage 2</td>
<td>18</td>
</tr>
<tr>
<td>Stage 3</td>
<td>34</td>
</tr>
<tr>
<td>Stage 4</td>
<td>22</td>
</tr>
<tr>
<td>Stage 5</td>
<td>4</td>
</tr>
</tbody>
</table>

Key insights

> Adoption of automated trucks goes through two distinct phases
  - In the mid-term (Stage 1-3), payback periods increase significantly by stage as cost savings remain flat while per vehicle investments grow
  - Level of platooning has significant impact on payback periods up to Stage 3 – Payback within 3 years can only be reached by operating in platoon mode for over 90% of miles travelled
  - In the long-term, payback periods drop with Stage 4 due to additional driver cost savings – fast progression from stage 3 to 4 expected
  - Long-term adoption less impacted by level of platooning

Likelihood of platoon formation: 45% (base assumption for use case a) 90%
To realize the potential of automated driving several ecosystem challenges need to be solved

Main requirements for self-driving trucks

1. Technological requirements
   - Hardware is largely available with incremental innovation needed
   - Software & integration need advanced development
   - Geo-mapping needed for highly detailed elevation maps for PPC

2. Supply chain development
   - Players are forming partnerships and investing in autonomous trucks technology
   - System integrator required, but still missing/too early to define

3. Legal requirements
   - Legal driving framework needs to be updated
   - Testing of automated trucks must be enabled
   - Liability issues must be clarified

4. Ethical considerations
   - "Dilemma" of fair decision vs. rationale decision
   - Broad dialogue among all stakeholders required
   - Needs to serve as key influence in legal requirements

5. Enabling ecosystem
   - Availability of required infrastructure (e.g., LTE network)
   - Truck driver acceptance of systems and qualification
   - Cyber security standards to enable safe truck operation

Source: Roland Berger
Four key implications for the trucking industry have been derived

Key implications for stakeholders of trucking industry

<table>
<thead>
<tr>
<th>Key insight from analysis</th>
<th>Implication for stakeholders</th>
</tr>
</thead>
</table>
| Safety as real driver behind adoption of automated trucks                                 | > Limited pull from fleet operators due to limited commercial benefits  
> Limited push from OEMs as long as legal issues are not resolved  
> Tighter safety requirements pushes ADAS into the market and drives adoption of automated trucks |
| Roles and responsibilities within the value chain change                                   | > Definition of system architectures and responsibility for system integration remains the domain of OEMs across all stages  
> While OEMs continue to source complete functions from suppliers in Stage 2, a single entity will be required in Stage 3 to handle the higher complexity and interaction between systems (OEM or an ESP)  
> With Stages 4 and 5 being only software driven, and the need to realize scale effects, it is possible that a large software player gains a large share of the revenue and profit pool |
| New business models emerge                                                                | > New business models such as Platoon Service Providers or warehouses with automated loading and unloading functions will emerge |
| Operator models change                                                                     | > Large fleet operators will gain a competitive advantage over owner drivers as they can more easily form intra fleet platoons and are more likely to platoon with peers than with owner drivers |

Source: Roland Berger
While pull from fleet operators and push from OEMs will remain limited, safety regulation will drive adoption of automated trucks.

Drivers of automated truck adoption:

- **Fleet operators**: Limited pull from fleet operators due to limited commercial benefits.
- **Regulation**: Tighter safety requirements pushes ADAS into the market and drives adoption of automated trucks.
- **OEM**: Limited push from OEMs as long as legal and cyber security issues are not resolved.

Source: Roland Berger
Roles and responsibilities within the value chain will change with different stages of automation

Role sharing between OEMs and suppliers

<table>
<thead>
<tr>
<th>Level of integration</th>
<th>Technology-leader OEMs</th>
<th>Technology-follower OEMs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No/function-specific automation</td>
<td>Combined function automation</td>
</tr>
<tr>
<td></td>
<td>No/function-specific automation</td>
<td>Combined function automation</td>
</tr>
<tr>
<td>Vehicle</td>
<td></td>
<td></td>
</tr>
<tr>
<td>System</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Content</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Role of OEMs**
- Complete system understanding
- Integrate fail-operational vehicle safety concept
- Drive ADAS acceptance (regulation/customer acceptance)

**Role of suppliers**
- Holistic ADAS understanding from components (sensors and algorithms) to complete systems
- Infrastructure co-development (V2V, V2I)
- Development lead for affordable and secure ADAS solution
- Complete system competency including sensors and software capabilities

Source: Roland Berger
Platoon Service Providers are expected to emerge that orchestrate platoon formation across fleets

Business model change: Platoon formation options

Matching

Scheduled platoons (inter fleet)
- Warehouse/ Fleet operator
  > Fleet operator selects trucks to form a platoon based on trip schedules

On-the-fly platooning (intra fleet)
- Trucks form ad-hoc platoons on highly frequented corridors – no matching of trip plans

Orchestrated platooning (intra fleet)
- Platoon Service provider (PSP) matches trip schedules

Pairing

Fleet operator
- Trains form platoon for the common part of their trip, monitored by fleet operator

Disengagement

Fleet operator
- Trucks drive independently to final destination

Orchestrated platooning (intra fleet)
- Trucks disengage and keep contact with PSP

Source: Roland Berger; TNO
Large fleet operators will gain a competitive advantage as they are more likely to find platooning partners

Options for platooning collaboration

<table>
<thead>
<tr>
<th>Willingness to platoon with ...</th>
<th>Owner operators</th>
<th>Large fleets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Owner operator</td>
<td>33%</td>
<td>5%</td>
</tr>
<tr>
<td>Any large fleet</td>
<td>13%</td>
<td>20%</td>
</tr>
<tr>
<td>Known fleet</td>
<td>20%</td>
<td>10%</td>
</tr>
<tr>
<td>Own fleet</td>
<td>33%</td>
<td>47%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Willingness to wait for platooning partner</th>
<th>Owner operators</th>
<th>Large fleets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>5%</td>
<td>46%</td>
</tr>
<tr>
<td>No</td>
<td>95%</td>
<td>54%</td>
</tr>
</tbody>
</table>

Key insights

> Platooning outside own fleet bears the risk to improve a competitor's bottom-line

> Large fleets have a competitive advantage as they can platoon within own fleet and also have stronger time latitude and can afford waiting for platooning partner

> Less willingness to platoon with larger fleets

> Unlikely to wait for platooning partner

Source: Auburn University; Roland Berger
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