Shifting up a gear
Automation, electrification and digitalization in the trucking industry
Trucking is the leading mode of freight transportation in many parts of the world, including the United States, Europe and China. But the industry is vexed by issues such as fragmentation, inefficiency, underutilization of trucks, difficulties recruiting new drivers and tightening regulations on emissions.

Fortunately, a number of trends that are currently visible in the industry offer solutions to these issues. Vehicle automation, electrification and digitalization will radically change the trucking industry over the next decades, allowing it to shift up a gear. New business models will emerge, such as the transfer hub model, combining driverless trucks on specific highway routes with conventional trucks for the first and last mile off the highway. The resulting operating cost savings will be significant, shaving 20 to 40 percent off today’s costs.

In this paper, we examine the details of these technological changes and the impact they will have on the industry. As driverless trucks become a reality for highway-based line-haul routes, electric powertrains become viable for short-range applications and new digital solutions based on artificial intelligence (AI) improve utilization and increase transparency, the overall logistics ecosystem will gradually mutate. Trucking companies will face both positive and negative knock-on developments. Fleet sizes will change, the industry will consolidate, new tech players will enter the market and freight rates will come under pressure. At the same time, the development of legislation and public acceptance will be critical for the timing of the industry transformation.

Fleet operators need to start adapting to the coming changes in the industry. To help them master the challenges we suggest some key steps and possible questions that they can ask themselves. The answers to these questions will help them define their strategic direction and take the necessary steps to ensure that they stay ahead of the pack as the industry shifts up a gear.

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1. Key challenges for the trucking industry today
Demand is strong but the industry must address issues such as inefficiency, driver shortages and tighter regulation.

A number of technological trends will address all of these issues and bring about fundamental change in the trucking industry. In the next section we examine advances in automation, electrification and digitalization.

Driving is a complex process where a number of tasks have to be performed simultaneously. First, the trucker monitors the surroundings to check the traffic situation. Second, the vehicle is controlled – i.e. steering, acceleration and braking. And third, there is a need to set the right engine speed. The automation process can relieve the driver of the first two tasks. The vehicle can then be controlled, and the vehicle can be programmed to reach a certain destination and to stop at certain places. The trucker can then be involved in monitoring the traffic situation and the driver can control the vehicle in case an intervention is needed.

2. New technologies
Automation, electrification and digitalization will shake up the trucking industry.

Three technological trends – automation, electrification and digitalization – are set to fundamentally change the trucking industry. Indeed, we can already observe the first fruits of these technological developments today. Several demonstrator projects for automated trucks are already ongoing. For example, the startup Embark has been operating automated trucks on the I-10 freeway between El Paso, Texas and Palm Springs, California since the end of 2017. Likewise, China-based autonomous truck technology startup TuSimple is testing a self-driving truck fleet at a deepwater port in a northern Chinese city. Established truck OEMs are also moving fast towards higher levels of automation, often in partnership with IT solution providers.

In the field of electrification there are multiple examples of technological advance taking hold, both from OEMs and startup companies. Tesla has announced a battery-electric semi-truck focused on short to mid-range applications, with 300 mi (480 km) and 500 mi (800 km) range options. The startup Nikola has announced a hydrogen fuel cell truck for long-haul applications. Established OEMs also unveiled full electric medium-duty trucks for urban pickup and delivery and refuse as well as heavy-duty tractors for short-haul applications.

Automation can already operate in the freight booking space. Several freight booking platforms have emerged in recent years, both from startups such as Convoy and Uber, and from established trucking companies such as the J.B. Hunt 160 platform, CH Robinson and XPO Connect. Below, we examine each of these three areas from a technical point of view and look at some of the figures behind them.

AUTOMATION – DRIVERLESS TRUCKS WILL BECOME A REALITY
The technological roadmap for the development of automated trucks consists of a number of stages, with more and more responsibility handed over by the driver to the automation technology in each stage. At Stage 0 there is no automation and the driver is fully in control. At Stage 1 the technology begins to support the driver with warning signals. At Stage 2 the technology provides automatically controlled in certain situations, such as on less crowded highway stretches, without a driver, at least in certain environments such as the automated trucking space. Stage 3, which lies in the future, is a transition phase. At this stage the vehicle has the technology to drive independently but the trucker needs to be able to take back control quickly if necessary or to respond to a request to intervene. At Stage 4 the driver does not have to monitor the road at all during automated mode. In easier-to-navigate environments such as less crowded highway stretches, the truck can even operate without a driver. Stage 5 is that of full automation, where trucks can operate without a driver in all conditions, including on service roads and in inner-city traffic.

Where is the industry today? Truck OEMs and technology providers are currently rapidly moving into the automated trucking space. OEMs are working on vehicles with Stage 3 and Stage 4 capabilities. Startups such as Embark in the United States and TuSimple in China have exhibited initial Stage 3 capabilities with
A technological roadmap for self-driving trucks

STAGE 0 
No automation

STAGE 1 
Driver assistance

STAGE 2 
Partial automation

STAGE 3 
Conditional automation

STAGE 4 
High automation

STAGE 5 
Full automation

TODAY

2020

2022

2025

2025+

A: From no automation to full automation

STAGE 0 – From no automation to full automation

A technological roadmap for self-driving trucks

STAGE 0
No automation

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Driver assistance

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STAGE 3
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High automation

STAGE 5
Full automation

TODAY

2020

2022

2025

2025+

Source: SAE, Roland Berger

aftermarket solutions in pilot applications. Partnerships of these startups or OEMs with IT solution providers will accelerate the development of Stage 4 and 5 capabilities. Specialized technology companies are also busy working on specific areas of automated vehicles, such as video safety technology, next-generation vision technologies, high-definition mapping, deep learning, artificial intelligence and computing and processing technology – Stages 4 and 5 will require large amounts of data to be processed in the truck and thus rely on advanced processing power.

Looking ahead, the development of automated trucks will go from confined environments such as harbors, terminals and mines, where automated trucks already operate today – Rio Tinto uses self-driving trucks in its open pit mines in Pilbara, Australia, for example – to unconfined environments, where conventional and automated vehicles will operate next to each other. This latter environment poses multiple technological challenges, and tech companies as well as OEMs are working on business models that allow operation of driverless trucks in semi-controlled environment with Stage 4 technology, before fully automated trucks become available.

The technology required for a Stage 4 driverless truck is expected to be ready by the middle of the next decade. This includes numerous hardware and software components. Thus, sensors monitor the surroundings of the vehicle – radar sensors keep track of traffic in front and to the sides while a front stereo camera adds redundancy and monitors the traffic in front. Multiple Lidar systems create high-resolution 3D environmental data. Data from these sensors is then processed on a computing platform. Spatial imaging occurs by means of aggregating the inputs from all sensors to develop 3D maps of surroundings, including information about shapes, sizes, distances and speeds. Algorithms for mapping and path planning/control use sensor data to plot, track and control appropriate routes to the vehicle’s destination.

Stage 5 requires highly complex technology and software algorithms, which means significant R&D expenses. By contrast, Stage 4 driverless trucks can be considered a mid-term opportunity in financial terms. We estimate the additional hardware cost for a Stage 4 truck to be approximately USD 15,000 in 2025, with the computing platform and redundancy systems for braking, steering and energy supply being the largest items. The cost of sensors is expected to have come down significantly by this date, accounting for only about USD 1,000 per truck (Lidar systems today cost about USD 7-8,000, down from USD 75,000 a few years ago). The development cost for a Stage 4 truck, covering software development, prototypes and testing, is considerable, estimated around USD 15 billion.

Investments of this magnitude can likely only be carried out by large players such as global truck OEMs. The development cost share per truck depends strongly on the amortization model: We estimate it at about USD 5,000 per vehicle for those OEMs that can reach a minimum scale of 225,000 automated units. On top of the material and development cost, OEMs will charge a margin. We consider an initial margin level of up to 50 percent probable, as competition will be limited in the early years and OEMs target price their applications, allowing fleet customers to reach payback within the three years typically expected of such investments. In total, the incremental price of the technology in 2025 is an estimated USD 10,000 per truck, about 20-25 percent above the projected base vehicle price at that time. By around 2030, when sufficient scale effects have been achieved and initial development costs have been amortized, the price may go down to about USD 15,000.

The actual timing of when driverless trucks will appear on our roads will not depend so much on the availability of the technology, but rather on legislation. Some
Shifting up a gear – The truck platooning concept

The picture is different for short-range applications such as drayage trucks. Less battery capacity is required based on diesel and electricity price projections from the US Energy Information Administration. Batteries are the major cost contributor for electric trucks, and we expect battery prices for commercial vehicles to come down from around 300 USD/kWh to 100 - 140 USD/kWh by 2025. The required battery capacity depends on the application and operating range of the vehicle.

Electric trucks with an operating range of up to 250 miles (400 kilometers) provide a TCO benefit and payback that is short enough for fleet operators.

Concepts are also being developed for platoons with a driver in the lead truck only, followed by a driverless second truck. Technically, in such a scenario the second truck would need to be equipped with Stage 4 technology as it has to be able to drive independently should the platoon break up. However, if Stage 4 technology is required, then the entire platoon might as well operate with no drivers (if not otherwise mandated by regulation). Platoons with a driver in the lead truck may therefore be an interim phenomenon only, building acceptance for fully driverless platoons later on.

**ELECTRIFICATION – ELECTRIC POWERTRAINS WILL BECOME VISIBLE FOR SHORT-RANGE APPLICATIONS**

Over the past two years, many incumbents and startup truck manufacturers have increased their focus on electric powertrains. Various factors drive truck electrification, including fuel efficiency and CO₂ emissions regulation, corporate sustainability targets and a “green image”, city restrictions on diesel vehicles and total cost of ownership (TCO) benefits. Some factors are more relevant for particular markets than others. For example, the Chinese market is mainly driven by the need to resolve the local emissions problem. The Chinese government also supports the development of electric vehicle technology in the hope of leapfrogging Western OEMs, as local manufacturers are struggling to compete on combustion engine technology. By contrast, the main aspects driving developments in Europe are both TCO developments, such a battery would still cost in excess of USD 150,000 in 2025, while the annual operating cost savings would amount to USD 18,750. Payback on the incremental investment would therefore be longer than the average first-owner usage time of five years. In addition, a battery of this size would weigh about ten tons and bring a significant payload penalty.

Some simple calculations show why. A long-haul truck with a range of 750 miles (1,200 kilometers) would need a battery capacity of 1,500 kWh. Given current technology, such a battery would still cost in excess of USD 150,000 in 2025, while the annual operating cost savings would amount to USD 18,750. Payback on the incremental investment would therefore be longer than the average first-owner usage time of five years. In addition, a battery of this size would weigh about ten tons and bring a significant payload penalty.

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Electric trucks with an operating range of up to 250 miles (400 kilometers) provide a TCO benefit and payback that is short enough for fleet operators.
to support the lower operating range, making electrification a viable option. Trucks with an operating range of up to 250 miles (400 kilometers) provide a TCO benefit and investment payback that is less than five years, in other words, short enough for fleet operators.

One additional complication needs to be considered, however. Used trucks make up a significant share of drayage trucks. While fleets typically replace their long-haul tractors every three to five years, a sizeable proportion of the drayage truck fleet is over ten years old. The economics of an electric truck only work when compared to a new diesel truck. The operating cost of a used dray truck is significantly lower as the equipment is largely depreciated. The electric truck would provide a lower fuel cost than the used, less fuel-efficient truck, but the investment does not typically achieve payback within the remaining lifetime of the truck. This further limits the potential of electric trucks. We estimate that sales volumes for battery electric Class 8 trucks will reach 10-11,000 in the United States by 2025. Larger numbers are expected for medium and light-duty trucks with urban applications, such as delivery trucks and refuse haulers. These vehicles require smaller battery capacities and their return-to-base, commercial-hours only driving pattern makes them suitable for depot charging. The low annual mileage of urban truck applications, however, can be a challenge when fleet operators aim for fast payback. Inner city restrictions planned in many cities, especially in Europe, might well turn out to be the real driver behind electrification of these applications.

**DIGITALIZATION – NEW DIGITAL SOLUTIONS WILL IMPROVE UTILIZATION AND INCREASE TRANSPARENCY**

Around 20 percent of trucks in the West currently travel empty. Sub-optimal route planning, driven by complexity, leads to empty runs. For instance, a truck might have various options to pick up loads on a given day. At the destination of each trip, several options may exist to pick up a new load. However, this could involve waiting times or empty trips to the next pickup point, the number of possibilities increasing with every day. Truck dispatchers need to decide on routes taking into consideration the length and pricing of the trips, the number of empty miles to the next shipment and expected waiting time for that shipment. This is a highly complex task that involves many uncertainties and requires coordination of a large number of moving elements. Artificial intelligence (AI) is the key to solving the “dispatcher’s problem”. Digitalization is set to automate today’s largely manual, telephone-based freight capacity and demand matching processes using data analytics and AI algorithms. We expect to see freight booking and optimization platforms emerging and disrupting the industry in the same way that booking platforms have disrupted the travel industry. This development will initially apply primarily to standardized freight, which accounts for approximately 25-30% of today’s freight volumes. Many firms, both large trucking companies and startups, have launched online platforms in recent years. Convoy or J.B. Hunt 360 in the US and Sendner or InstaFreight in Europe are such examples. However, integration with transportation management systems (TMS) will be critical for large-scale adoption. Ultimately, booking platforms will replace intermediaries, such as third-party logistics (3PL) companies and brokers, and eliminate their margins, today at 15-20 percent. Full truckload business with standardized freight (dry van business) will be most suitable for booking platforms, while less than truckload business and specialized freight will likely be less impacted. We expect that those booking platforms that reach critical mass in terms of the number of freight forwarders and coverage will attract the most customers, eventually pushing other platforms out of the market in a “winner takes all” scenario.

**3. The business model**

Transfer hubs and platooning combine to deliver substantial end-to-end savings for operators.

The technological changes outlined in the previous chapter have the potential to reshape the trucking industry’s business model. Specifically, for the second half of the next decade, we foresee a scenario that combines electric drayage trucks and automated long-haul truck platoons, both optimized through booking platforms. This will lead to significant overall savings in operating costs.

Automated driving on highways is less complex than driving on service roads or in inner-city traffic. The business model that will likely emerge therefore combines conventional trucking for the first and last mile with automated driverless trucking for the middle mile on the interstate. The change between the two modes will take place in “transfer hubs” that are located next to the interstate with direct access to them. These hubs will require little infrastructure and basically consist of dedicated areas where trailers can be switched from one truck to the other. The trip between two transfer hubs can be done in a platoon. Once the automated truck has pulled the trailer to the destination hub, an electric truck with a driver will take over and pull the trailer to its final destination. 

**Dr: Combining conventional and autonomous trucks**

*The transfer hub concept*

![Diagram](https://example.com/diagram.png)
Self-driving trucks (ideally traveling in platoons) have much lower operating costs on the long-haul than conventional trucks. Today the average cost per mile for a Class 8 truck is around USD 1.55 (or USD 0.96 per km), excluding the cost of empty miles, compared to an estimated USD 0.83 (USD 0.52 per km) for a driverless truck traveling in a platoon between transfer hubs. In the conventional model, the human driver is the single largest cost item, accounting for almost half of the cost, followed by fuel at almost a quarter, then equipment and maintenance. Insurance and infrastructure costs (tolls) are less significant.

Platooning reduces the fuel cost due to the lower air drag, while equipment cost goes up slightly due to the depreciation of the additional technology required for platooning. On an annual basis, fuel savings from platooning can add up to USD 2,400 per truck. With Stage 4 automation, where the vehicle functions without a driver on the long-haul section between transfer hubs, the cost of the driver is fully eliminated. Maintenance cost is reduced due to less wear and tear (the result of better driving) and less unplanned downtime (the result of fewer accidents). The insurance cost is expected to fall in line with the lower probability of accidents. On the other hand, equipment cost will increase as the additional technology means greater annual depreciation. Also, the trucks using the transfer hubs have to bear the expense of the hubs – largely real-estate expenses and personnel costs.

If the long-haul savings amount to 72 cents per mile (45 cents per km), what, then, are the ultimate end-to-end savings for fleet operators? The figures vary by lane and depend on how long the drays and the long-haul section are. Our cost model is based on a scenario in which electric drayage trucks pull the trailer from and to the transfer hubs. We model three different lanes and calculate the total cost per load for the entire trip from origin to destination. For each lane we define potential locations of transfer hubs, assuming that they would be located in areas with sufficient industrial production or metropolitan areas.

The majority of the cost-out effect comes from the elimination of the driver on the section between the hubs. Fuel cost savings from platooning and electrification are small in comparison to the driver cost savings on the long-haul section. Total savings range from 22 percent for a short lane with long drays to 40 percent for a long lane with short drays. As the implementation of transfer hubs will happen gradually and the number of hubs will be limited at the beginning, longer drays will be required to reach the next hub. Savings will therefore be closer to the 22 percent level initially or even lower, increasing over time as the transfer hub network grows.

![EXAMPLE 1](Origin to hub 50 mi (80 km) Hub to hub 300 mi (480 km) Hub to destination 100 mi (160 km))

In the transfer hub model total operating cost savings range from 22 percent to 40 percent.

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**EXAMPLE 1**

- **Origin to hub**: 100 mi (160 km)
- **Hub to hub**: 300 mi (480 km)
- **Hub to destination**: 100 mi (160 km)

**EXAMPLE 2**

- **Origin to hub**: 50 mi (80 km)
- **Hub to hub**: 300 mi (480 km)
- **Hub to destination**: 50 mi (80 km)

**EXAMPLE 3**

- **Origin to hub**: 50 mi (80 km)
- **Hub to hub**: 1,000 mi (1,600 km)
- **Hub to destination**: 50 mi (80 km)

**E Shorter drays and longer lanes = bigger savings**

Operating costs for sample trips [USD per load]
The changes taking place in the logistics industry will ultimately create a very different logistics ecosystem to that which we are familiar with today. This "endgame scenario" covers two distinct spheres: long-haul transportation and urban distribution. While the overall trends of automation, electrification and digitalization apply to both spheres, the drivers behind these trends and the resulting solutions differ.

In long-haul transportation, the focus will be on reducing operating costs, while in urban logistics, the main lever is higher customer expectations in terms of delivery speed, information and flexibility. The standards set in the e-commerce space are progressively transferring to other areas such as food retail. Retailers intend to meet growing customer expectations by increasing delivery speed in urban areas and setting up innovative delivery modes.

New warehouse concepts (peri-urban and urban) are emerging to face space and speed constraints of urban logistics. Peri-urban warehouses (25,000 m²) will be highly automated to deliver huge volumes while urban warehouses (below 5,000 m²) will remain manual to keep them as flexible as possible.

Source: Roland Berger
4. Implications for the trucking industry
Larger freight volumes, industry consolidation and pressure on freight rates lie ahead.

What do these trends and developments mean for the trucking industry? We identify a number of effects, from changes in truck fleet size and composition, to industry consolidation, the emergence of new tech players and increased pressure on freight rates. Legislation and public acceptance of autonomous vehicles will also have a fundamental impact on the speed of adoption.

TRUCK FLEET SIZES AND COMPOSITION WILL CHANGE
While freight volumes are projected to continue growing, the size of the truck fleet required to handle these volumes depends on the adoption of the transfer hub model. As automated trucks can, at least theoretically, operate 24/7, their utilization is almost twice as high as that of trucks with drivers, who need to rest once they hit the legal driving limit. Fewer automated trucks are required to carry the same freight. The number of conventional sleeper cab tractors will go down with increasing penetration of the transfer hub concept. At the same time the number of automated trucks will go up, and the number of drayage trucks will increase. We estimate that by 2035, 20-25% of the freight volume in the US could be handled through transfer hubs, reducing the overall truck fleet by 6%. By then, automated trucks will account for 10-15% of the trucks on the road.

INDUSTRY CONSOLIDATION IS INEVITABLE
Investing in automated trucks is expensive. They cost around 20-25 percent more than conventional trucks and require large control centers and investments in IT infrastructure. For this reason, only large fleet operators are expected to adopt driverless technology. Smaller players, especially the owner-driver segment, will face price pressure from booking platforms without having the cost-saving potential of automated trucks available, leading to consolidation in the industry in all regions.

NEW TECH PLAYERS WILL ENTER THE MARKET
New tech players will continue to enter the industry, driving the development of automated truck technology. While these players are not seeking to become integrated trucking operators themselves, they are likely to operate individual lanes of automated trucks as sub-contractors to large trucking companies that continue to own the customer interface. Traditional players will probably lose revenues to these new players as a consequence, unless they build up their own capabilities around the operation of automated truck fleets.

FREIGHT RATES WILL COME UNDER PRESSURE
The elimination of the driver will eventually allow operating costs to come down significantly. However, the cost-out effect will not fully hit the bottom line of trucking companies. Once digitization increases transparency over available freight capacity and rates, and booking platforms become integrated with transportation management systems (TMS), freight rates will increasingly come under pressure. The operating cost savings from truck automation will at least partially be passed on to end customers.

LEGISLATION AND PUBLIC ACCEPTANCE WILL BE CRITICAL
The actual timing of when driverless trucks appear on our roads will depend not so much on the availability of technology as on legislation and public acceptance. In the United States, while some states are relatively advanced when it comes to driverless truck legislation, others have not yet decided which direction to take. Various stakeholder groups are trying to make their voices heard. Tech companies, OEMs and large shippers are in favor of automated truck technology and are lobbying for this, while labor unions (Teamsters) are trying to slow down adoption.

5. Our recommendations
Fleet operators must prepare for the challenges ahead.

While automated trucks won’t become reality before the middle of the next decade, fleet operators should already be preparing for the industry to shift up a gear. Players should be asking themselves a number of questions, the answers to which will help them master the changes that lie ahead.

Choose your direction: The first task for fleet operators is to decide what fundamental direction they want to take their business in. Should your focus remain on owning and operating trucks, or shift to asset-light services and supply-chain expertise? In the future, we will see a much clearer separation of asset-heavy and asset-light players. If you are an asset-heavy player and you want to extend your offering into digital services, for example, you might consider setting up a freight booking platform.

Define your competitive position: Fleets that want to become significant players in the automated and digitized logistics world need to define their future competitive positioning and differentiation potential. While truck automation is still a few years off, other forms of automation, such as warehouse automation, are more immediate. Could this be your first step towards becoming an automated, digitalized player?

Transform your customer interaction: Transforming your customer interaction in line with today’s digital world will ensure continued customer loyalty. Should you be looking at integrating your services with a booking platform or developing your own platform, perhaps?

Build the infrastructure: Players that wish to run their own fleets of automated trucks need to adapt their existing infrastructure for automation. Is now the time to consider setting up your own transfer hubs? Is your existing warehousing network sufficiently robust when viewed against the expected upcoming changes?

Prepare for disruption: Finally, organizations need to prepare themselves for the coming disruption. It is vital to ensure that you manage the transition properly, for example through workforce transition plans. You must also ensure that you have the necessary financing for the required investments. Do you have a robust execution plan in place for taking the organization with you through the transformation?

As we have seen, automation, electrification and digitalization are set to cause major disruption in the trucking industry. The precise timing of this technology-driven transformation is as yet unclear, as it depends on how legislation develops and whether the public can be convinced that autonomous trucks are a safe addition to our roads. What is clear, however, is that the shifts will have far-reaching implications for fleet operators, changing operating practices and rewriting the underlying economics. To stay ahead of the pack, trucking companies need to be proactive and start preparing now for the road ahead.
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WE WELCOME YOUR QUESTIONS, COMMENTS AND SUGGESTIONS

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