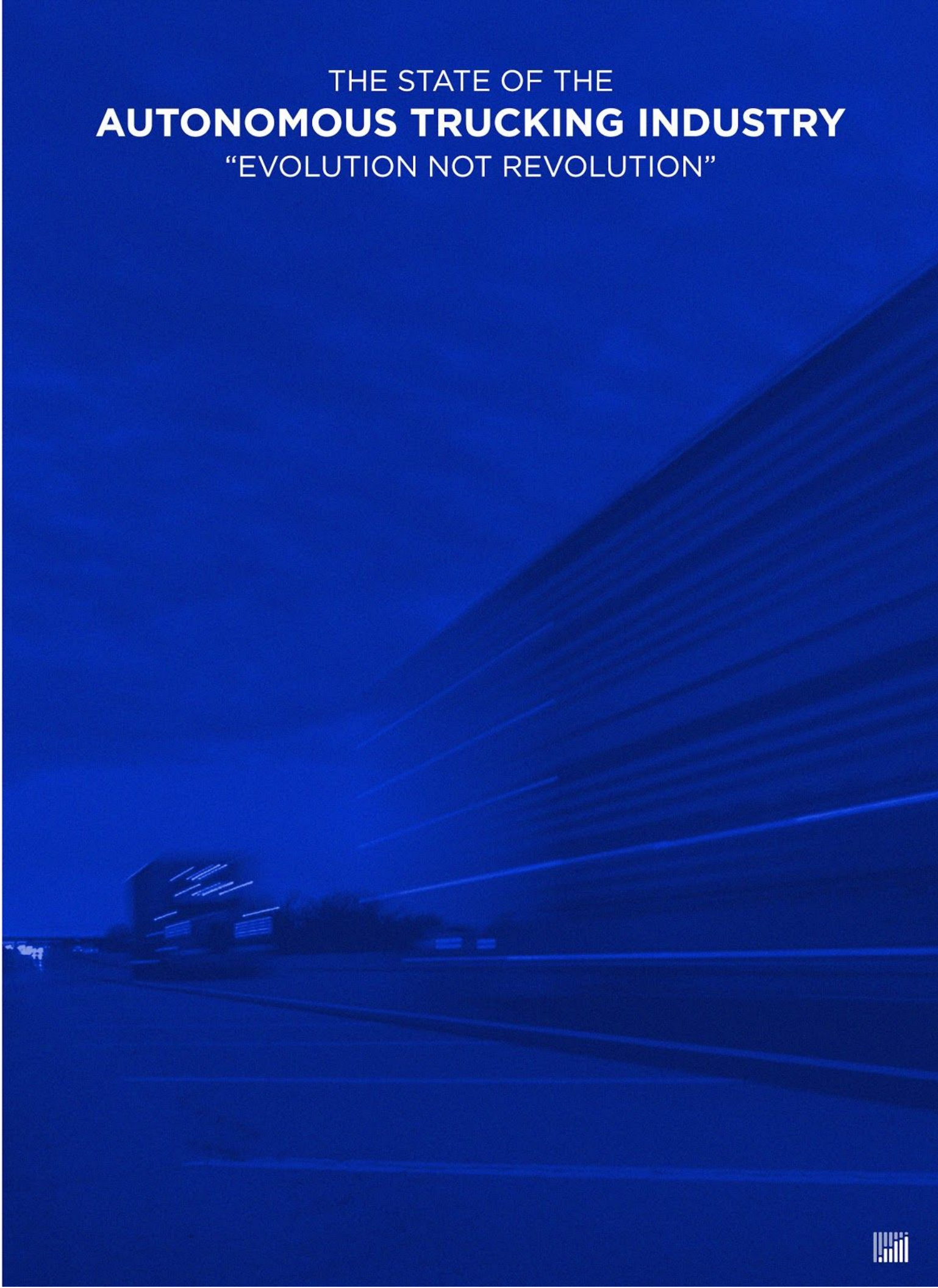
MAY2019

THE STATE OF THE
AUTONOMOUS TRUCKING INDUSTRY
"EVOLUTION NOT REVOLUTION"



FREIGHTWAVES FREIGHTINTEL RESEARCH

Executive Summary

The Research Team at Freightwaves believes that a fully autonomous (i.e. no human operation; defined as Level 4 or 5) future for trucking is more than a decade away, at a minimum. **A forecasted timeline for the development and successful rollout is speculative; but more likely 20 to 30 years (or more) away.**

However, that forecast is not because the technology doesn't currently exist – it mostly does in early stages or is on the horizon. Instead, it **hinges more on a prolonged regulatory and adoption curve as the industry moves from a venture capital (VC)-backed proof-of-concept stage to commercial viability**. The **heavily fragmented nature of the trucking industry will likely serve as a meaningful obstacle to adoption** as well, because 91 percent of fleets in the United States are comprised of eight trucks or less. In order **to achieve widespread autonomous trucking (AT) adoption, both truckers and shippers will need to see a high probability, concrete path to a positive return on investment (ROI)**.

Nevertheless, we believe that **semi-autonomous trucks (defined as Level 2 or 3) will begin to make significant strides over the coming years in certain geographies and on heavily trafficked long-haul lanes, whether in the form of platooning or simply increasing driver assistance** as we will explain later. Key prerequisites would be that a carrier has a presence, AT is approved and adoption makes financial sense.

There is no doubt that **fully autonomous trucks**, whenever they arrive, **will likely ultimately prove to be a devastating deflationary force that results in a massive wave of human truck drivers losing their jobs** (there are approximately two million truck drivers in the U.S. at this time, and the number is growing). **For carriers and shippers** on the other hand, **this outcome is likely to represent a step-function higher in profitability**.

Until that day, the evolution from semi-autonomy to a fully autonomous future may just mean a higher quality of life for truckers as the long-term unfilled supply of truckers in the U.S. continues unabated (currently an unfilled supply of 50,000 drivers, which is forecast to reach approximately 200,000 by 2025). In other words, **truckers will remain in the driver's seat but begin to transfer many of the monotonous, dangerous and grueling tasks to computers – but not the whole operation**. **Truckers will** be needed for the foreseeable future to **carry out first- and last-mile duties**, as well as to problem solve, for basic truck maintenance and to potentially help operate the autonomous systems.

In the following report, we will analyze the industry from a high level, breaking down the major issues at hand, as well as outlining the top players and their current strategies across original equipment manufacturers (OEMs), hardware and software.

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Key Highlights

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Will autonomous trucks result in devastating job losses?

Quick Reference Table for AV/AT Levels		
Levels	**Description**	**Example**
0	No Automation	No driver assistance; almost every car pre-2010
1	Driver Assistance	Adaptive Cruise Control; car can help steer, brake or park - but not all three
2	Partial Automation	Two or more advanced driver assistance systems (ADAS) and must be coordinated.
3	Conditional Automation	Essentially full-autonomy except under certain adverse weather, traffic and other conditions when control of car must be turned back over to human driver.
4	High Automation	Full autonomy except outside of certain geographic restrictions. Car still has pedals and brakes in case of emergency.
5	Full Automation	Capable of complete hands-off, driverless operation under all circumstances. No pedals, brakes, etc.

Why Are Trucks (Specifically Long-Haul) Inherently Ideal for Autonomous Driving?

Long-haul ("LH") semi-autonomous trucking technology is already here. The technology works and from all accounts is equal to or superior to autonomous driving for retail vehicles. The primary reason for this is that there are major economic incentives and cost savings at stake for both shippers and carriers. According to an AT technology expert we spoke with, there are a few other **crucial considerations that favor ATs over autonomous vehicles (AVs)**. These include the fact that trucks simply travel many more miles than cars and there are real economic benefits and cost savings because drivers are being paid while in the cab.

Long-haul trucking routes (more than 250 miles) are ideal for autonomous technology, given that they operate on open highways at consistent speeds where conditions are generally much easier and more predictable compared to last-mile conditions in densely populated urban environments where a driver must contend with far more traffic, turns, pedestrians, objects and distractions.

Finally, **long-haul trucking routes are ideal for autonomous trucks because it is a grueling job where the turnover is the highest in the trucking industry and the unfilled supply is most acute**. LH trucking can be very taxing on one's personal/family life and health given it often requires hundreds of days away from home per year.

That said, we would make one important distinction and disclaimer with regards to AT vs. AVs that we heard from an AT technology source. **While AT may indeed have a more predictable *environment,* AT is not without its challenges. Chief among those challenges is that you are moving a 40-ton truck rather than a 1- to 2-ton vehicle.** In the former case, the stakes are much higher, because the consequences become dire if a 40-ton truck crashes at very high speed.

Who is Behind the Major Push for Autonomous Trucks?

The short answer is **both carriers and shippers have a major economic incentive**. **Carriers' incentives include lower labor costs and shippers' incentives include reduced shipping cost per mile.** Whether this potential windfall and surplus is ultimately passed on by these players to end consumers is unknown and very difficult to forecast, because it is likely to be a byproduct of competitive response.

For carriers, the economic incentive is fairly self-explanatory – **truckers' salaries represent over 40 percent of total costs**. For a low-margin, capital-intensive industry, savings this material are far too big to ignore.

For shippers, the answer is a bit more nuanced and we feel bears more explanation. Stepping back to a 40,000 foot macro level, the U.S. economy totals $20 trillion; two-thirds of that amount is consumer spending. Within this figure, 70 percent of U.S. goods are shipped by truck and this percentage is increasing as e-commerce as a percentage of overall consumer spending continues to climb.

Drilling down on a micro level, we think Amazon is a major driving force that bears watching. For example, consider that Amazon spent $28 billion on shipping in 2018 (up nearly 30 percent year-over-year in-line with its revenue growth). Amazon has set the industry standard in terms of speed and convenience with its free two-day shipping (and soon to be one-day shipping) on nearly all items for its more than 100 million Prime members. Of this, we estimate that trucking hauled a large percentage of these goods. **Amazon will benefit from both vertical integration and increasingly autonomous trucks.**

For greater context, we stress that Amazon's shipping expenses swamp the revenue of nearly 80 percent of the companies in the Standard & Poor's 500 (S&P 500), making it about the 100th-largest company in the S&P 500 by comparing its shipping expense with others' revenue. If you are looking at what company sets strategy and capacity on the margin, look no further than Amazon.

As long-time followers of Amazon as a company and a stock, FreightWaves staff believe that Amazon will need to increasingly focus on improving margins and entering new high Total Addressable Markets (TAMs) as its core ecommerce revenue inevitably begins to slow from a 20-year compound annual growth rate (CAGR) of more than 25 percent, as the law of large numbers begins to set in with its revenue topping $230 billion in 2018.

Amazon has already focused on improving margins at Amazon Web Services (AWS) and its advertising. The next in line may be Amazon Logistics Services (ALS). One such way to do so that is largely within its control is to increasingly vertically integrate and automate shipping. By doing so, Amazon would effectively transfer some of that more than $30 billion from someone else's bottom line to its own. Additionally, in order to just keep its revenue growth moving higher, Amazon needs to ensure that it's always expanding its shipping capacity ahead of time so as not to be overwhelmed by demand. Amazon's recent announcement on its latest earnings call that it is moving to broad-based free 1-day shipping for its Prime members (and investing $800 million to do so), reaffirms our conviction in this view and raises the stakes even higher.

And, lest we forget, **many other large shippers** (such as PepsiCo and Anheuser-Busch) **have a vested interest in AT, given trucking costs are a very**

material line item and they stand to reap benefits to margins in addition to better visibility and less volatility around their profitability. This is a particular area of focus this late in the economic cycle and for more mature companies where revenue growth has plateaued and they are now focused on expense control.

Finally, **cheap and plentiful venture capital investment in this arena is fueling the fire**, growing exponentially and looking to position themselves ahead of the crowd as investors seek to solve a significant, real issue with a windfall payoff. In FreighTech alone, the year-to-date mergers and acquisitions (M&A) and VC investment is tracking in billions of dollars.

Knock-on Effects from AT – Carrier Fragmentation Should Reverse Under Autonomous Trucks

We think **trucking will undoubtedly become more concentrated by way of M&A as the industry increasingly moves to an autonomous world**. **Trucking** today is **hugely fragmented and suffers from diseconomies of scale**. The inability to effectively scale stems from having to manage massive fleets of human drivers. With this barrier gradually removed in an autonomous world, not to mention exponentially more data/transparency regarding fleets, improving balance sheets/cash flows as labor costs shrink and margins increase, and greater access to cheap capital given improving creditworthiness, consolidation is very likely to follow in our view.

Looking across most industries, when technological disruption ensues, the industry in question generally sees the pendulum swing towards more of a winner-take-all market where small companies struggle to keep up with the technological prowess and spending power of the leaders. We believe **trucking market share will concentrate in the coming years**.

What Happens to Brokers in a AT world?

Should carriers begin to consolidate in an increasingly automated world, we would expect brokers to follow suit. This is the usual playbook of industries after a consolidation wave ensues. Harkening back to **Porter's Five Forces, as customers and suppliers get bigger, brokers will need to get bigger themselves to increase their bargaining power versus a concentrated carrier base in order to stem potential fee compression**.

Amazon's recent entry into the brokerage industry and aggressive price-cutting represents another significant tail-risk to the broker business model worth watching that is beyond the scope of this report.

Autonomous Trucks are Advantageous from Both Economic and Safety Standpoints

While it may seem obvious, **running a truck autonomously is advantageous to a human-operated truck** for numerous reasons, starting with **massive potential cost savings because drivers will not be paid**.

Other less obvious reasons include the fact that humans are only allowed to drive a truck for 11 hours per day due to Federal hours-of-service regulations, while a fully autonomous truck can operate 24/7. This means that an **AT traveling at an equivalent speed can cover 2.5 times more mileage per day relative to a human-operated truck**. In broad terms, this effectively means that an autonomous truck can traverse the U.S. in just two days compared to five days for a human-operated truck. This puts **autonomous trucks close to on par with air freight**. This would materially change the value proposition for shippers looking to ship cross-country, because air freight has traditionally commanded a premium due to its speed advantage.

Autonomous trucks also have the potential to drive rapid and immense improvements in productivity and asset turns given much higher utilization in an existing truck fleet. A common industry rule of thumb is that trucks last one million miles. In AT, replacement cycles are forecast to shorten from ~10 years to ~3 years given annual miles traveled per truck may climb to 300,000 from 100,000. Carriers tend to be maniacal about effectively managing both of the former key metrics given the low-margin, capital-intensive nature of the industry.

Putting some numbers together at a macro level, the **long-term potential labor savings from autonomous trucks just in the U.S. is generally estimated to be in the range of ~$75 to $125 billion annually**, a figure we believe to be reasonable.

Turning to safety, **ATs are more efficient both in terms of fuel economy** (as the truck stays in its lane better **and operates at a smoother, more consistent speed with reduced drag) and in terms of timeliness** (autonomous trucks don't take breaks, get lost or go off course, etc.).

From a statistical standpoint, there are said to be **more than 400,000 accidents per year in the U.S. involving trucks, resulting in more than 4,000 casualties per year**. Per Starsky Robotics, close to 0 percent of human truck drivers are not involved in an accident within a five-year period. Furthermore, on top of the loss of human life, **truck accidents can often have major consequences in terms of economic loss and lost productivity due to traffic jams**.

Regulatory Landscape: Where is AT Even Legal Today?

You can have the most amazing AT technology the world has ever seen, but if you don't have approval to operate and implement it commercially, it's a non-starter. So where are we today from a regulatory standpoint in regard to AT? According to one of the experts with whom we spoke, **AT is currently legal from a testing standpoint in 15 to 20 states and commercially deployable in six to seven**. We expect the former numbers to continue to steadily grow over time.

In addition, **not only is federal and state legislation critical to commercial acceptance, but public acceptance will be crucial as well**. To demonstrate this, one need look no further than the Uber AV accident in Arizona.

Meet the Players: Segmenting the Autonomous Trucking Industry into OEMs and FreightTech

From a high level, the autonomous truck market can be broadly separated into truck manufacturers (OEMs) and hardware and software technology players. A few players, such as Tesla, are taking an integrated approach across all three.

Major legacy truck OEMs participating in the AT market include Daimler, Navistar, Paccar, Peterbilt, Tesla and Volvo.

Nearly all of the major AT software players are relatively new and VC-funded. These include Embark, Ike, Kodiak Robotics, Locomation, Starsky Robotics and Tu Simple, among others.

Google's Waymo is essentially an integrated hardware and software company, as is Tesla, though Tesla uses its own semis while Google uses Peterbilt trucks.

Given current public and private valuations in Software-as-a-Service (SaaS), where companies can often fetch valuations of 10-25x revenue (or higher), we believe **much of the value in terms of equity market capitalization may ultimately accrue to the software players, given their recurring revenue bases and capital-light business models**.

TuSimple

Most industry experts would point to **TuSimple (TS) as the leader in the AT space**. **TS has the highest valuation to date – $1.1 billion as of the latest round – making TuSimple the first "unicorn" in AT.** TS is tackling true Level 5 full autonomy right

from the get-go (human-less driving from depot-to-depot, in complex surface street driving and all weather conditions).

TS is based in both San Diego and China, has over 400 employees, and boasts a competitive advantage in the form of "the industry's first 1,000-meter perception system." The latter is more than three times further than its nearest competitor and provides the AT with 35 seconds of reaction time at highway speeds, enabling a far more efficient and safe autonomous system.

TuSimple also already has commercial customers to boot and so is one of only a handful generating revenue.

Embark

Embark is a **much smaller number two player in fully autonomous trucking** with a valuation of ~$60 million per the latest funding round and has 32 employees. Embark is led by Co-Founder and CEO Alex Rodrigues, who is just 23 years old. To date, Embark has announced and implemented a revenue-generating partnership with Ryder and Electrolux to move Frigidaire freight autonomously on the highways while relying on Ryder's trucks and drivers to ferry freight between the warehouses and interstate.

Embark differs from TuSimple in that its trucks are fully autonomous only on highways (today, at least).

Starsky Robotics

Starsky Robotics is the number three player in AT with a valuation of ~$55 million per the latest funding round and has 21 employees. **Like Embark, Starsky is working on trucks that are fully autonomous on the highway but require human operation for the first and last miles.**

For the first and last miles, however, Starksky aims to have its trucks be "tele-operated," or remotely operated by a human driver at another location. "What we're hoping to do is to make truck driving go from a job where you're spending weeks in isolation to an office job," stated CEO and Co-Founder Stefan Seltz-Axmacher.

Locomation

Locomation differs from the companies above in that they are **taking on the autonomous platooning market before going after full autonomy**. FreightWaves

staff think Locomation is a very exciting and leading software company within platooning and Autonomous Relay Convoying (ARC).

FreightWaves staff spoke with its Co-Founder and CEO Cetin Mericli (PhD). He was able to give a detailed, inside view on the state of AT and the technology for platooning. Locomation feels the race to full autonomy in trucks, much like robo-taxis, is more crowded and farther away from commercialization, so Locomation is taking its own path. This belief is strengthened by the fact that its autonomous platooning technology is perfectly suited for trucks as well as his team's background, composed of five former employees of the Carnegie Mellon National Robotics Engineering Center with collectively over 100 years of experience in autonomous vehicles and robotics.

Potential Cost Savings with Autonomous Trucks

Before writing about the cost savings of AT, a delineation between the **two most common methods that AT companies are using to attack the market** is provided. These are **platooning and fully autonomous trucking**. Both camps seem to believe the other is chasing an unrealistic pipe dream, with Daimler citing "There is no 'business case' for platooning." On the opposite side, the platooning camp believes full autonomy could be decades away and has no viable commercial business model.

Each of these approaches will evolve from semi-autonomy (limited human intervention) to full autonomy, likely over the coming decades. What this means from a practical standpoint is that **human drivers will still operate the trucks in the beginning, even though they will be assisted by autonomous functions**. Moreover, the trucks will still have steering wheels, pedals and the like for emergency human intervention, should it be needed.

In the following sections, we will dive a little deeper into what this all means.

Specific Numbers Around The Cost Savings

To break it down from the highest level possible, there are basically **two buckets of cost savings – fuel savings and labor savings**. The first bucket is achievable through both platooning and full AT by way of efficiency gains (more consistent speeds, more efficient lane maintenance, less breaking, reduced drag). To achieve the second bucket, you either have to start removing drivers or start moving more freight with fewer people. **Full autonomy is pursuing the removal of drivers and platooning is pursuing both options.** The amount of cost savings available depends

on the degree of fuel and labor savings, which are dynamic and will move sharply higher over time as technology advances.

Another fact to keep in mind – the **AT labor savings curve is exponential and not linear** – the slope of the cost savings line is flatter in the beginning at Levels 2-3 autonomy and then steepens dramatically as you cross over to Levels 4-5 autonomy. What this means in practice is that the **savings aren't huge until you start removing drivers from the trucks**. The savings at first are just from fuel efficiencies. Then you remove the driver in Truck 2 from a platoon. Then you eventually remove the driver in Truck 3 from a platoon. And, finally, you eventually remove the driver in Truck 1 from a platoon and thus have a fully autonomous platoon (and ATs in general).

FreightWaves also notes, as explained by one of the VC experts with whom FreightWaves staff spoke, *"There are real economic benefits with AT, it's not just a nice-to-have. And everyone has their own prediction as to how much money it will save and that's all based on taking the driver costs out of the truck. Now some of that will come back in the form of higher technology costs to service the autonomous system. And it's one of those things, we're really not talking about specific costs yet because it doesn't exist so all we can do is guess."*

If the potential cost savings can be simplified as much as possible – keeping in mind these are simply estimates that could be wildly wrong – they would be as follows.

Fuel savings: 10 percent in the short-term based on today's state-of-the-art platooning technology; long-term is unknown and dependent on technological innovation. While 10 percent fuel savings might not sound like much, remember this is a razor-thin margin industry where the average truck gets just 6.5 miles to the gallon.

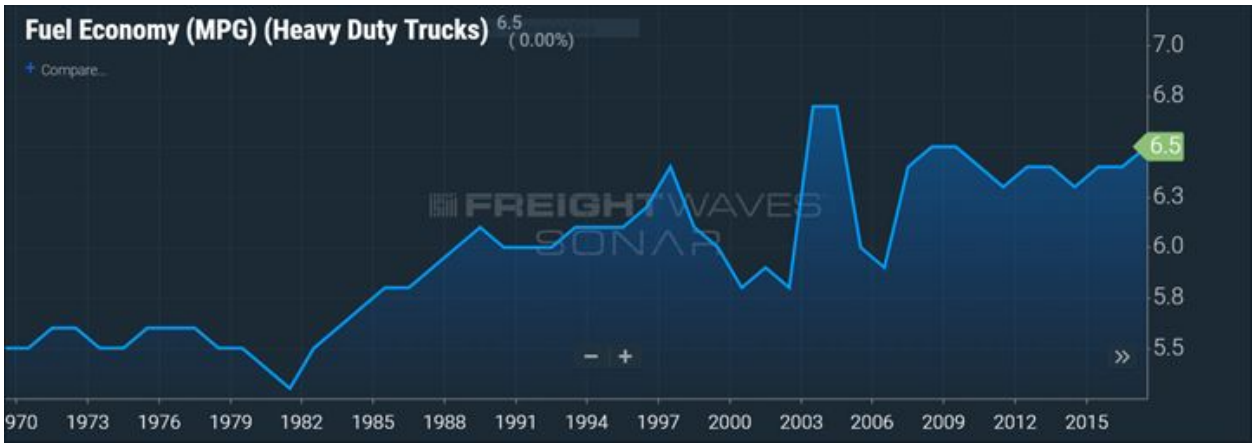
Labor Savings: 50 percent in the short-term based on today's state-of-the-art platooning technology where you are moving twice the freight with the same number of people; medium- term, 50 to 75 percent once at least one human driver is removed and/or one more truck is added to the platoon; long-term 90 to 100 percent labor savings once human drivers are completely removed and full autonomy is reached.

Next, in terms of dollars at stake, after talking to various industry sources, FreightWaves staff estimate that carriers spend an average of $110,000 per year per driver all-in in terms of trucker compensation. This means total available cost savings at full autonomy is straightforward, because you are completely removing the human driver – fleet size x $110,000.

This will be elaborated on in more detail in coming sections.

		Human-Operated
Hiring Costs All-in*	$	10,000
Average Truck Driver Salary*	$	75,000
Benefits**	$	25,000
Total Annual Labor Cost per Driver	$	110,000

*Assumes $75k per driver, $10k per driver in hiring cost, and 100% turnover, which are industry standards and/or averages per our trucker recruiting source TenStreet.
**Freightwaves internal estimate.
***Locomation estimates of 50% decline in labor costs and 8% reduction in fuel consumption.



Incremental Capital Expenditures Associated with an Autonomous Truck

According to AT start-up Tu Simple, the all-in cost of one of its autonomous trucks is $200,000. This figure is composed of $150,000 for a new truck, plus $50,000 for retrofitting the truck with autonomous equipment (such as sensors, cameras, Lidar, etc.). The $50,000 can be viewed as an incremental capital expenditure relative to a human-operated truck. TuSimple cites an attractive pay-back period of two years, though concrete data to support this estimate is sparse.

For the time being, new trucks are likely to be retrofitted with semi-autonomous technology and then later, down the road, that technology will be pre-installed. We would stress that it is important to remember that this $50,000 figure is simply the cost of retrofitting an existing truck with an AT system today. Like other technologies, as they progress along the adoption curve and mature, costs generally come down over time as they scale and penetrate. We're not predicting this by any

means, but it could drive already-attractive ROIs and payback periods up and down, respectively, in the future.

In terms of generating a payback on retrofitting a truck to be autonomous, one can think of trading $50,000 in capital expenditures for lower operating expenditures in the form of reduced labor costs. There will be a smaller and not totally offsetting subscription fee for the AT software as an incremental operating expense for the carrier. In order to generate a payback and a return on investment, the initial requirement that must be in place is regulatory approval of ATs in whatever jurisdiction or geographic area that a particular carrier or fleet operates. In other words, retrofitting your entire fleet (or even a portion of it) likely doesn't make sense if your fleet operates in a state (or states) where AT isn't legal.

Incremental Operating Expenditures Associated with an Autonomous Truck

In addition to the ~$50,000 in incremental capital expenditures, a carrier will likely have to pay ongoing subscription or licensing fees to the AT software companies to use their intellectual property. And the software companies will want subscription fees to be recurring in exchange for the billions of dollars (in aggregate) and the years spent in development.

How often these fees are charged and what the fees will be are largely unknown. In other words, **absolute dollar costs are not forecastable at this point because the AT software companies' business models and commercialization barely exist**. To the degree that monetization is already taking place, it is very small and undisclosed. We suspect the software companies will be willing to strike deals to obtain their early commercial customers and gain more pricing power over time as their software is proven.

What is the Potential Impact of Full Autonomy on Carriers' Margins?

The **number one line item cost for a carrier is labor, representing 40 percent of total costs on average**. With operating ratios (ORs) of ~90 percent for major trucking companies, this means that **ATs represent a game-changer in terms of profitability and potentially the valuations awarded by investors to the carrier stocks** themselves.

In theory, this means a fully AT future could mean operating margins of approaching 50 percent rather than 10 percent for trucking companies, or a 5x increase. Here is the quick high-level math. If we assume operating ratios of 90 percent, and labor

costs at 40 percent of operating costs, then you get to labor costs (all-in trucker compensation) of 36 percent of sales (90 percent OR x 40 percent Labor = Labor Cost of 36 percent of Sales).

In reality, this number is likely substantially less than 50 percent for a very long time. That being said, a **slow evolution to semi-autonomy would lead to a step-function higher in margins for carriers**. Should this scenario begin to play out, **we would expect publicly traded truck carriers' stocks to re-rate substantially higher as they come to be viewed as higher quality, less cyclical businesses with twin momentum from concentrating market share and escalating margins**.

The Rub with Full Autonomy

The **economic benefits and cost savings associated with fully AT are clear – complete removal of driver labor costs**. **The trouble with full autonomy is that you need huge amounts of data and miles driven to improve and perfect the autonomous system to be ready for primetime and commercialization.** So full autonomy is like a Hail Mary pass – low probability but with a huge payoff if you connect. **Along the way, as you work out the kinks, you are likely to face tremendous cash burn.** Why? Because operating an autonomous truck cost between $1,300 and $2,500 per day (labor, fuel, etc.) until you remove the human driver (based on driving 500 miles per day and 1,000 miles per day, respectively). And you need a human driver to actually sit in the driver's seat in case of emergency when testing, as well as a systems engineer in the cab to monitor the autonomous system.

Therefore, you need an investor base that can stomach a tremendous amount of losses and be patient. **Because of these dynamics, it strikes us as making more sense to incubate a fully AT company within a large OEM instead of a stand-alone company**, much like Google's "Other Bets," which are funded by the highly profitable and cash-generative core search business. It totally depends though and is a strategic decision left up to the companies; for example, Daimler decided to buy (vs build) with its latest acquisition of Torc.

Within the current landscape of **existing AT companies, the typical business model is** basically as follows – **produce ATs that can drive themselves on highways, but that require humans to get on and off the exits and to navigate around densely populated cities. Most don't actually produce the autonomous truck themselves; instead they are relying on legacy OEMs** like Peterbilt and Navistar, **while creating self-driving autonomous systems software that can be placed in those trucks**.

That being said, **many of the AT vehicle software start-ups are basically just looking to prove out a "proof-of-concept" model** where once the software is ready for commercial viability, t**hey will just license it out rather than building out their own huge fleets**.

Another major problem with full autonomy is not just commercial viability/adoption; we are still a long way from a technical standpoint. In terms of Level 4 and 5 full autonomy, you are basically talking about science fiction where computers reach The Singularity (a state where AI surpasses humans in terms of intelligence).

Regarding the challenge of reaching full autonomy, one good example that we found insightful and helpful is the following. In Level 5 autonomy, an autonomous truck (or vehicle) must be able to distinguish between a true stop sign and a human wearing a t-shirt with a stop sign on it. As an engineer, you then have to multiply and extend this scenario out across hundreds or thousands of similar quandaries.

Furthermore, teaching a computer to play chess better than a human is one thing (i.e. AlphaGo in Google's Deep Mind division), but teaching one to drive better than a human is far harder and the stakes are much higher. Full autonomy essentially has to be perfect because human lives are at stake. For example, a source told us that he believes Uber's self-driving car accident in Arizona in which a 49-year old woman was killed set the entire autonomous driving industry back almost two years.

Platooning

Platooning is the wireless linking of two or more trucks in a convoy on the highway using WiFi, radar and GPS positioning. In its simplest form, platooning is just implementing adaptive cruise control in a truck convoy without actually replacing any human drivers. In common parlance and everyday life, platooning has long been described as "caravanning."

Platooning has been around for years and has its own merits aside from just removing driver labor costs once autonomous technology is applied (i.e. safety improvements and fuel savings). In fact, platooning started out as simply a way to save fuel by traveling as a convoy to reduce drag. This is similar to drafting in NASCAR or the Peleton in the Tour de France.

Autonomy and significant cost savings come into play with platooning when you start moving more freight with the same number of people (possible today with ARC technology) or removing drivers altogether (possible in the future). Over time, platooning will evolve to become two or more trucks with no human

drivers. This is likely to take place over the years and in stages, as described in the next section below.

To elaborate on the potential cost savings of semi-autonomous platooning, consider the following. For a traditional long-haul trucking team, you have one 80,000-pound truck and two human drivers who can each drive 11 hours per day according to Federal hours-of-service regulations. When the first driver reaches his/her limit, the drivers switch places. Thus, to sum things up, you are moving one 80,000-pound truck with two people.

Conversely, in **Autonomous Relay Convoying (ARC)**, you have two 80,000-pound trucks and two human drivers who can each still only drive 11 hours per day. ***The critical difference is that with ARC, the follower Truck 2 is fully autonomous/driverless so the human driver in Truck 2 is disengaged and considered "off-duty" (and to be clear, in the sleeper berth and not the cab counting against HOS).*** Only the first driver in Truck 1 is considered "active/on-duty." When the 11-hour limit is reached, the two trucks switch places and Truck 2 is now active/on-duty and Truck 1 is now off-duty/fully driverless. Thus, to sum things up, you are moving two 80,000-pound trucks with two people (or 160,000; hence, twice the freight with the same number of people).

With current ARC platooning technology, you are looking at 50 percent labor savings. The reason for this is simple: you are moving twice the freight with the same number of people. As technology improves, we will begin to see platoons move three times the freight with half the people. And, eventually, we will reach full autonomy where we are moving freight with no people, whether in platoons or one truck at a time.

In the pictures below from Locomation, the ARC process is described in more intricate detail.

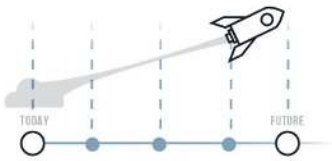
Here's how it works:

- Two manually driven trucks leave the dock, pass through urban obstacles, and get on the highway.
- The trucks then connect, forming a convoy. Vehicle-to-vehicle (V2V) communication combined with robust sensing allows the follower truck to react almost instantly to the lead truck's activity. With the trucks connected in this way, the follower truck can safely follow in close proximity.
- With both trucks equipped with ARC technology, the system can also assist the lead truck.
- When ARC is active, only the lead driver is engaged and driving while the follower is driven by the ARC system and its driver is off duty. The follower truck in ARC is fully driverless (SAE Level 4).
- At set intervals, the trucks swap places. The second driver now assumes control of the convoy while the new follower driver disengages and goes off duty.
- A shadow autonomy stack in the lead truck generates driving actions without actually putting them into action. These actions are recorded and can be compared to the driver's actions to produce valuable data for testing higher levels of autonomy.

The result is improved safety, significant labor cost savings, and a reduction in fuel consumption (due to reduced aerodynamic drag). This translates into huge overall cost reductions.

What We Are Doing

The future is autonomous and Locomation has what it takes to achieve it. We're deploying our Autonomous Relay Convoying (ARC) technology into the industry that needs it most—trucking.



At the current pace, it will easily take a decade before any industry sees fully driverless vehicles. We're changing the course by deploying commercial-grade autonomy benefits today with a clear roadmap to higher levels of autonomy in the near future.

As we work towards Locomation technology that comes pre-installed on every carrier, we are making short-term autonomy solutions available as retrofit kits.

How We Are Doing It

Trucks driven in urban environments will remain in manual operation until they reach a highway where the formation of a convoy via V2V link is possible.

Our ARC system simultaneously assists the leading truck driver while also fully operating the follower L4 truck, a carrier whose driver is not engaged and is considered "off-duty."

Once the leading driver has maxed out the active driving limit, the trucks switch places so that the second driver now assumes control of the convoy while the new follower driver disengages and goes off duty.

Platooning Will Likely Unfold in Stages

Most industry experts believe platooning will unfold in stages, as described below. As platooning transitions through these stages, the number of human truck drivers eventually falls to zero and the number of trucks in the platoon grows.

Stage 1 Platooning:
Commercial Deployment: Now.
Human Drivers: 2
# of Trucks in Platoon/Convoy: 2
Labor Savings: 50 percent; moving twice the freight (or two trucks) with one driver team.
First and Last Mile: driven by humans in each truck.

Human drivers are present in both Truck 1 and Truck 2, but only the driver in Truck 1 is actively driving and having hours counted against his/her federally mandated 11 hours of service. Once the convoy drives for 11 hours, Trucks 1 and 2 switch places, with Truck 2 becoming the driver. This way, you are looking at carrying twice the freight, or up to 160,000 pounds with a team of two drivers.

Stage 2 Platooning:
Commercial Deployment: Unknown. Most believe within the next five to ten years.
Human Drivers: 0
# of Trucks in Platoon/Convoy: 2 or more
Labor Savings: 75 percent (or more); moving twice (or more) the freight (or 2+ trucks) with 0 drivers instead of 2+.
First and Last Mile: driven by humans in each truck.

Stage 3 Platooning – Full Autonomy:
Commercial Deployment: Unknown. Most believe within the next twenty to more than thirty years.
Human Drivers: 0
# of Trucks in Platoon/Convoy: 2+
Labor Savings: 90 percent (or more); moving twice (or more) the freight (or 2+ trucks) with 0 drivers instead of 2+.
First and Last Mile: humans not required. Depot-to-depot driverless autonomy.

Will Autonomous Trucks Result in Devastating Job Losses?

The short answer is it depends on whether we are talking about the short-term or long-term.

In the short- to medium-term (e.g. in the next decade), it is a virtual certainty that there will actually be *more* truck drivers, when measured on a normalized basis (i.e. outside of a potential deep recession where almost all industries would see job losses).

The long-term answer is yes. **We will eventually see devastating truck driver job losses, almost certainly. There's just too much money at stake.**

The consequence of full autonomy could ultimately lead to a near-complete dislocation of the more than two million human truckers in the United States, displacing a trucker population with an average age of 55 that largely lacks college degrees. This obviously has potentially profound social consequences that will have to be sorted out by the politicians as truckers make up the #1 occupation in over half of all U.S. states.

One note of caution, however. We would point out that industrial autonomation in the form of robotics has been around for more than 50 years in auto manufacturing and not all humans in those factories have lost their jobs. It is quite possible that humans are simply reassigned to different tasks within the trucking ecosystem, though unlikely in a big enough number to offset losses.

In the short- to medium-term, our base case assumes a semi-autonomous future, meaning autonomous trucks won't be doing "dock to dock" runs for a very long time. In such a scenario, **human drivers will still be needed for the first and last miles in densely populated urban environments as well as for operation of the AT systems and basic maintenance**. Due to the former, **we see the U.S. trucker population as stable to growing in the next 10 years**.

There is another important consideration within semi-autonomy that will affect the demand for drivers, and thus the eventual supply. This comes in the form of a fundamental question without an easily identifiable solution in regard to elasticity. An elastic good in classic economics is a good or service where, as the price falls, people will buy more of it and vice versa (the vast majority of all goods/services fall in this camp). An inelastic good is one for which people will demand relatively the same amount no matter how much the price increases or drops (i.e. life-saving pharmaceuticals).

That is to say, we can ponder whether falling trucking rates will actually stimulate more demand for purchasing goods, and thus lead to more demand for human operators to steer the first and last miles or to sit in the driver's seat to man the truck while the semi-autonomous systems do the work (for as long as they are needed). Uber is one such notable, sanguine player regarding human trucking jobs actually *increasing* in the future because of demand elasticity.

And then there is also the question of whether average driver pay will then fall with semi-autonomy because: platooning should alleviate (at least partially) the acute long-haul driver unfilled supply; and less skill per driver is required as functions and operations increasingly automated. Therefore, **even if the number of drivers doesn't fall in the short- or medium-term, perhaps truckers' aggregate compensation will fall as the unfilled supply is reduced and necessary skills required fall**. We do not have an answer to this last question but consider it an important one to consider.

Conclusion: How Far Off is Fully Autonomous Trucking? Really far. But Semi-Autonomous is Here to Stay.

The **vast majority of industry experts** we came across in our research and with whom we spoke **agree that fully autonomous trucks are a decade away (at minimum) just in terms of being technologically feasible. Even then, full autonomy would likely just apply to a minority of the total fleets in question at first because the entire human trucking fleet would have to be displaced and turned over. Turning over the full fleet will likely take another decade or more. Thus, when you include the time needed to entirely displace the human fleets and reach full penetration, we think it will take 20 to 30 years to reach full autonomy and 100 percent penetration** if we had to hazard a guess.

Fully autonomous trucks and full penetration remain years away because of safety testing, the need for state and federal regulations, and the general

complexities and technical advancements needed to reach artificial general intelligence in AT.

However, just because full autonomy likely remains a pipe dream, that doesn't mean a semi-autonomous future won't begin to increasingly catch on. **In our view, this journey is likely to start with platooning, grow with increasingly automated driver assistance functions, and end with full autonomy.**

Key Autonomous Trucking Industry Terms

Autonomous Vehicle/Truck (AV/AT) – An autonomous vehicle is a vehicle that can guide itself without human operation.

LiDAR – LiDAR is made of laser diodes shooting laser rays and measuring the distance to the nearest solid object the laser ray reflects from. Most LiDARs today are spinning towers with mechanical parts, though the biggest expectation in the industry surrounds the so-called Solid State LiDAR, where the laser beam is steered electronically without any mechanical parts involved. Solid State LiDAR should reduce the prices of the LiDARs substantially and would also make them more durable.

Appendix A

Levels of Automation: 0-5 (Source: Society of Automotive Engineers [SAE]; CNET)

Level 0 – No Automation
A car has no automated assistance technologies, though it may feature traditional fixed-speed cruise control hardware or warn of an impending crash (without intervening). A vehicle that fits into this category relies on a human to dictate every driving action.

- Examples: Your uncle Rick's 2005 Honda is a Level 0 vehicle**.**

Level 1: Driver Assistance
Most modern passenger cars qualify as capable of Level 1 on the SAE scale. To meet this requirement, a vehicle must have at least one advanced driver-assistance feature – adaptive cruise control, for instance. Mobility is still supervised by a human, but for convenience, the vehicle is capable of maintaining its own speed under certain circumstances. Lane-keeping tech also falls into this category.

- Examples: Any model with adaptive cruise control or lane-keep technology is at least a Level 1 vehicle.

Level 2: Partial Automation

- A Level 2 vehicle has two or more advanced driver assistance systems (ADAS) that can at times control the braking, steering or acceleration of the vehicle. Examples of qualifying ADAS includes adaptive cruise control, active lane-keep assist or automatic emergency braking, and these technologies must be applied in a coordinated fashion.
- Such individual assist features vary in sophistication, but are increasingly common, and are available on nearly all but the most budget-minded vehicles in 2019. However, it's the coordination between two or more of these assist technologies that helps them qualify for Level 2 status.
- Importantly, in a Level 2 vehicle, a human driver must still actively monitor the vehicle's progress and be ready to intervene at any time.
- Examples: General Motors Super Cruise, Mercedes-Benz Distronic Plus, Nissan ProPilot Assist, Tesla Autopilot.

Level 3: Conditional Automation

- The jump in complexity between Levels 2 and 3 is huge compared to the jump between 1 and 2. A Level 3 vehicle is capable of taking full control and operating during select parts of a journey when certain operating conditions are met.
- For example, a vehicle that is capable of managing itself on a freeway journey, excluding on- and off-ramps and city driving, might be considered Level 3

automated. This level of automation requires advanced sensor packages, hardware backups and sophisticated software to keep occupants safe.

· The driver must remain vigilant, even when the vehicle is self-driving, in the event of a failure. Even with Level 3, a driver monitor system is all but a prerequisite to ensure that the person in the driver's seat is sufficiently alert to take over when conditions dictate.

· Google achieved Level 3 autonomy back in 2012 with its test vehicles but found that human drivers were too trusting and slow to retake control from the system in the event of trouble. This observation ultimately led Google to decide against taking the tech to market, so it's pursuing full Level 5 automation through its Waymo division.

· Examples: Audi aims to sell the first Level 3-capable vehicle to the public, but its Audi AI Traffic Jam Pilot system in the new A8 sedan is still awaiting legal approval in many countries, including the U.S.

Level 4: High Automation

· Level 4 is where things start getting a little "Minority Report," and where bona-fide autonomous driving systems kick in. A Level 4 vehicle is capable of completing an entire journey without driver intervention, even operating without a driver at all, but the vehicle does have some constraints. As an example, a Level 4 vehicle may be confined to a certain geographical area (i.e. geofenced), or it could be prohibited from operating beyond a certain speed.

· A Level 4 vehicle likely still maintains driver controls like a steering wheel and pedals for those instances in which a human may be required to assume control.

· Examples: There are no Level 4 production vehicles available to consumers.

Level 5: Complete/Full Automation

· Level 5 is the ultimate goal of self-driving vehicle developers. A Level 5 vehicle is capable of complete hands-off, driverless operation under all circumstances. This is the level where there are no provisions for human control -- no steering wheel, no pedals, no joysticks.

· A Level 5 autonomous vehicle is unconstrained geographically and theoretically able to travel at all speeds in safety, thanks to advanced software and vehicle-to-vehicle and vehicle-to-environment communications

Appendix B

Sources and Articles for Further Reading:

Forbes, May 31, 2019, Robo-Rigs: The Scientist, The Unicorn And The $700 Billion Race To Create Self-Driving Semi-Trucks

Medium, March 27, 2019, Paving the Way to Autonomy

CNet, March 29, 2018, Self-driving cars: A level-by-level explainer of autonomous vehicles
Your guide to understanding the road to self-driving vehicles, as defined by the Society of Automotive Engineers.

McKinsey, December 2018, Distraction or disruption? Autonomous trucks gain ground in US logistics

What are the different levels of Autonomous Vehicle? – Geospatialworld.net YouTube

How Amazon Demand Drives Autonomous Truck Tech – CNBC YouTube

Could driverless vehicles spell the end of the road for truck drivers? – PBS YouTube

Company Websites

https://www.tusimple.com/

https://www.starsky.io/

https://embarktrucks.com/

https://locomation.ai/