

Uber Freight

The future of self-driving technology in trucking

A road map for evolving
freight transportation with
autonomous trucks

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After a decade of development, self-driving technology is starting to hit the roads

In 2021, self-driving vehicles traveled approximately 4 million miles in California alone, doubling the previous year's record.¹ The trucking industry is well positioned to reap the benefits of this technology, which will be enjoyed by truck drivers, carriers, shippers, and road users.

The first, and most important, benefit is better road safety. In 2019, more than 5,000 lives were lost in large truck crashes, including 892 truck occupants.² About one-third of these accidents occurred on interstates, freeways, and expressways. Vehicle- and environment-related factors accounted for only 13% of these crashes. The remaining 87% were caused by drivers' performance/non-performance (21%), decisions (38%), and recognition (28%).³

While the safety benefits are likely to be welcomed by all, some state that the effects this technology will have on the trucking industry as a whole, and on truck drivers in particular, are less fully understood. At Uber Freight, we envision a bright future for the trucking industry,

one where truck drivers and self-driving trucks connect long-haul and local-haul routes, thus complementing each other on capabilities and preferences. We think this model will support the growth in truck freight demand, create safer roads, provide better truck-driving jobs, and make goods more affordable and available for everyone.

In this paper, we demonstrate why trucking is the faster route to commercialize and scale self-driving technology. We then lay out the hub-to-hub model, which will allow autonomous trucks (ATs) to operate alongside those driven by people. This model achieves synergies that benefit carriers, drivers, and autonomous vehicle (AV) developers. We show that autonomous trucking will not be a dispensable service that simply aims at reducing the cost of trucking. Instead, it will become an essential component of supply chains that helps satisfy the growing demand while offering drivers better working conditions. Finally, we outline our predictions for how this technology will unfold over the coming years.

Trucking is primed for self-driving technology

A trillion-dollar market⁴

Surface freight transportation in the US is a \$1.06 trillion market.⁵ Trucking constitutes the largest share of this market, as it moves about 64% of the total US freight (by tonnage) and approximately 80% of the total inland freight.⁶ In 2021, for-hire trucking carriers made \$384 billion in total revenue.⁷ Private trucking fleets constitute an equally large market, which brings the total trucking market size close to \$800 billion. Globally, the total addressable market (TAM) of freight (\$4 trillion) is comparable to that of ridesharing and delivery (more than \$5 trillion each).⁸

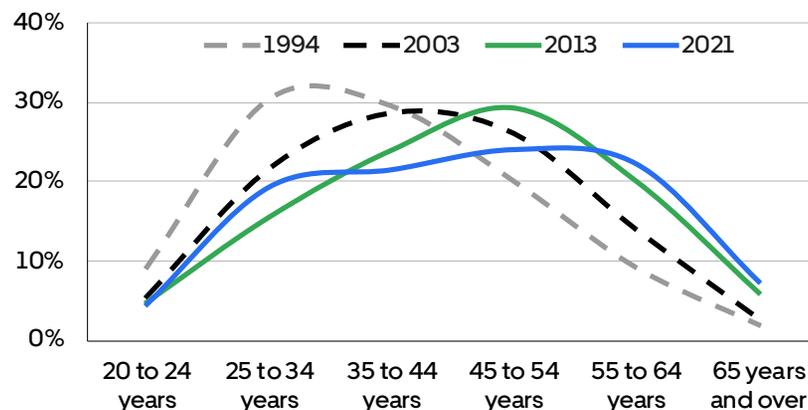
Autonomous trucking solves bigger pain points

Despite growing demand, the trucking industry continues to bleed skilled labor as experienced drivers retire or choose other careers. The American Trucking Associations (ATA) estimates that the US needs to fill one million jobs cumulatively between 2020 and 2030.⁹ Approximately 80% of these are due to retirements, early exits, and drivers pushed out of the industry. The remaining 20% are needed to support growth in freight demand.

The trucking industry has also struggled with attracting younger drivers to the workforce. Figure 1 shows how the truck-driver population in the US has been aging with time. Lifestyle issues, notably time away from home, are among the primary factors behind this trend. Potential truckers have to wait until they are 21 to get their interstate CDL license,¹⁰ the hours are long and grueling, and trucking keeps drivers away from home for up to 200 nights a year.¹¹

On the other hand, other sectors, such as construction, manufacturing, and warehousing, can offer blue-collar jobs under more favorable conditions. Over the past decade, parcel delivery employment has doubled and warehousing employment has almost tripled.¹³

Figure 1. Aging population of truck drivers¹²



In previous years, market dynamics alone were not enough to bring drivers back. On the demand side, shippers still prefer trucking to rail and rail+trucking, called intermodal, as trucking offers superior benefits in terms of speed and reach. On the supply side, new carriers face various constraints such as tightening regulations and high capital costs. In addition, small fleets pay 10% more than large fleets (per mile) to operate their trucks.¹⁴ This makes it difficult for them to sustain themselves, except in tight markets like the one we saw in 2021.¹⁵

Driver shortage and retention were among the top 10 issues facing the trucking industry for 10 years in a row.¹⁶ These aren't the only pain points, however. The industry grapples with driver compensation, safety, and facility-delay issues. Self-driving technology will improve drivers' lifestyle and spare them hours spent away from home. It will also address most of the other issues shown in Table 1.

Table 1. Trucking industry pain points and how autonomous trucking can help mitigate them

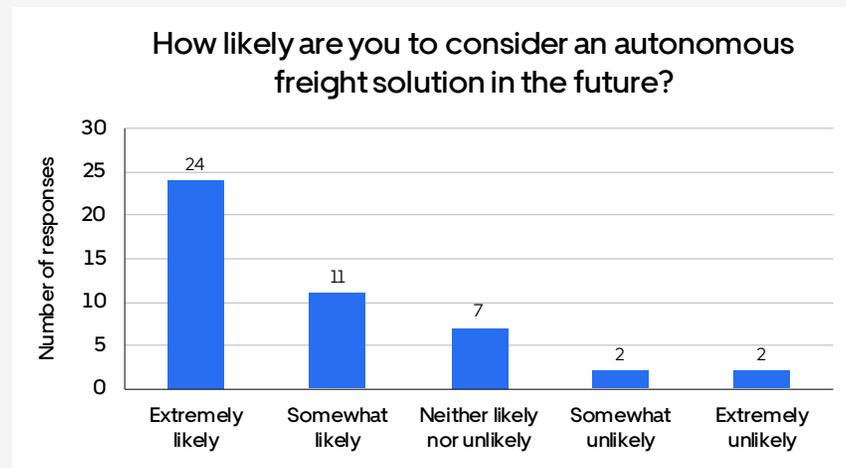
Trucking industry pain points	Rank	How autonomous trucking can help
Driver shortage	1	Provide additional capacity where it's most needed and offer a better lifestyle to truck drivers.
Driver retention	2	
Driver compensation	3	Increase drivers' rate per mile using the hub-to-hub model (see the next section).
Lawsuit abuse reform	4	Reduce the number of trucking accidents, 87% of which are caused by human error, ¹⁷ and, therefore, improve safety and lower insurance costs.
Compliance, safety, accountability	6	
Insurance cost/availability	9	
Limited truck parking	5	Reduce the need for truck parking, because ATs will be exempted from hours of service constraints.
Detention/delay at customer facilities	7	Eliminate detentions and unnecessary delays with drop-and-hook operations, described in the next section.
Transportation infrastructure/congestion/funding	8	Route and schedule ATs to operate during off-peak hours, thereby decongesting roads.
Diesel technician shortage	10	Accelerate the adoption of electric trucks, due to the lower cost of waiting to recharge.

Uber Freight has been leveraging technology to address some of these issues. For example, the Uber Freight app provides carriers of all sizes with easy and convenient access to freight, allowing them to operate profitably in the marketplace. In addition, Uber’s facility ratings have been helping shippers to improve their facilities by reducing detentions, layovers, and unnecessary delays, and Uber Freight has also laid the groundwork for seamless trailer handoffs between autonomous trucks and human drivers with Powerloop, a drop-and-hook trailer solution. Finally, Uber Freight’s Carrier Wallet solution and Freight Plus program offer faster payments, fuel discounts, and rewards to carriers. Autonomous trucks present an opportunity that complements these efforts by giving drivers a better lifestyle and more profitable loads (see the “What about trucking jobs?” section).

Enthusiastic early adopters

The commercialization of autonomous vehicles at scale requires customers’ acceptance and trust in this technology. According to a 2022 survey¹⁸ of Uber Freight and Transplace’s biggest shippers,

Figure 2. Autonomous trucking survey results collected from a sample of Uber Freight/Transplace shippers



the majority of shippers indicated that they are either extremely likely (52%) or somewhat likely (24%) to consider an autonomous freight solution in the future. While this survey (see Figure 2) was based on a small sample, it clearly shows that shippers are more likely to adopt autonomous technology compared with the general population.

The path of least resistance

Self-driving development is an incremental endeavor. SAE International (formerly known as the Society of Automotive Engineers) and the National Highway Traffic Safety Administration (NHTSA) recognize 6 levels of automation.¹⁹ At Levels 0, 1, and 2, the driver must be engaged at all times. The vehicle supports the driver with basic features, such as automatic steering, acceleration, deceleration/braking, and cruise control. Levels 3 and 4 include additional features that allow the vehicle to drive under certain conditions. However, at Level 3, the driver must be ready to take over when the feature requests. Finally, at Level 5, the vehicle can drive under all conditions without any assistance.

Level 5 is the automation north star. However, it is unattainable within the coming years. Current self-driving developers are focusing on Level 4, where the vehicle can drive under most conditions along

specific corridors. Remote operators will handle the remaining edge cases, where human intervention is needed.

Think of all the complexities that a self-driving vehicle needs to handle on an urban trip. First, urban streets are far from uniform. Lanes vary by width, speed limit, and geometry. Some streets have side parking, shoulders, or sidewalks while others do not. Roundabouts and intersections are even more complex, whether they are controlled by traffic lights or stop signs. And while some turns are protected, others are not. Furthermore, urban streets can be jammed with pedestrians, bicyclists, and smaller delivery vehicles.

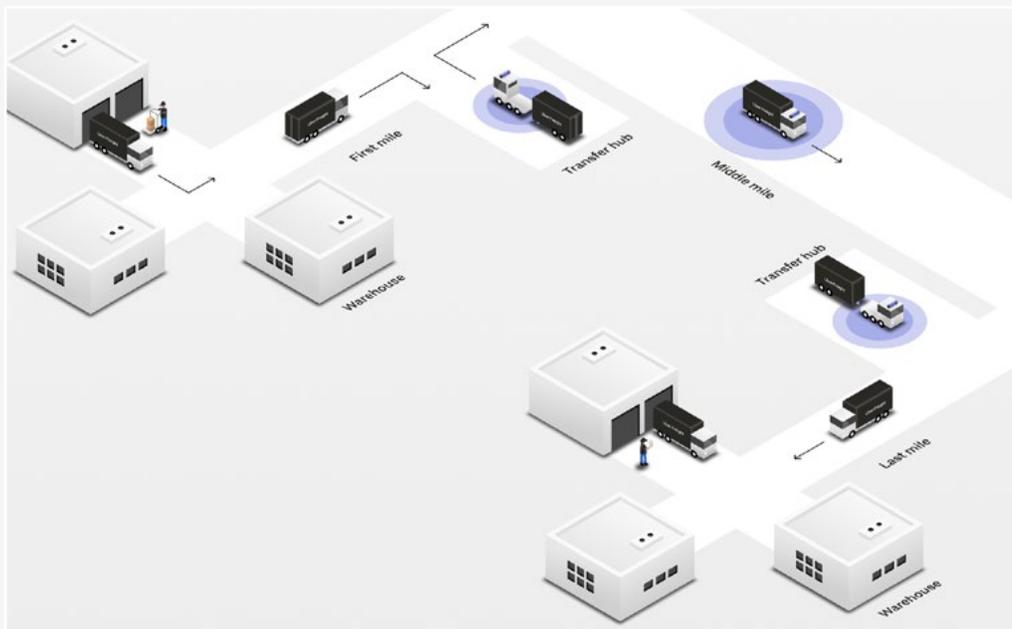
Because of this complexity, highway driving is a more tractable and well-defined problem for AT developers. The US interstate highways are much more uniform because they are regulated and maintained by a single agency: the Federal Highway Administration (FHWA). The FHWA imposes uniform standards covering controlled access, minimum and maximum speed limits, and lane geometry. For example, most interstate highways have a posted speed limit of 65-70 mph. This makes long-distance trucking a feasible first step toward autonomy.

But don't autonomous trucks still need to navigate complex urban streets for the first and last mile?

The hub-to-hub model

For the foreseeable future, most ATs will operate under a hub-to-hub model. Human drivers will handle the trip ends, which involve complex urban streets and many manual operations at facilities, such as loading, unloading, gate entrance, and documentation. ATs will service the middle part of the trip (see Figure 3).

Figure 3. The hub-to-hub model



Under this model, a driver picks up a preloaded trailer from the shipper's facility and delivers it to a transfer hub located close to the highway. We refer to this as the first mile. The trailer then gets hooked to an AT, which drives on the highway to another transfer hub located near the receiver's facility. This step is referred to as the middle mile. At the second transfer hub, another driver picks up the trailer and delivers it to its final destination. This is the last mile.

Dropping and hooking trailers, which we refer to as drop-and-hook, can minimize cost, boost efficiency, and improve the drivers' experience. While it is not strictly required at shippers' and receivers' facilities, it will save drivers time by eliminating the need to wait for loading and unloading, and therefore reduce the cost of the first and last miles. However, drop-and-hook is required at transfer hubs in order to maximize the uptime of ATs and improve asset utilization.

Eventually, ATs will be able to provide a depot-to-depot service, including the first and last miles. While some carriers and AT developers might adopt this model earlier along specific routes and with specific shippers, scaling it is expected to take several years. ATs will need to not only drive through complex urban environments but also handle manual operations at facilities that will require human intervention for the foreseeable future.

The hub-to-hub model will bridge the gaps

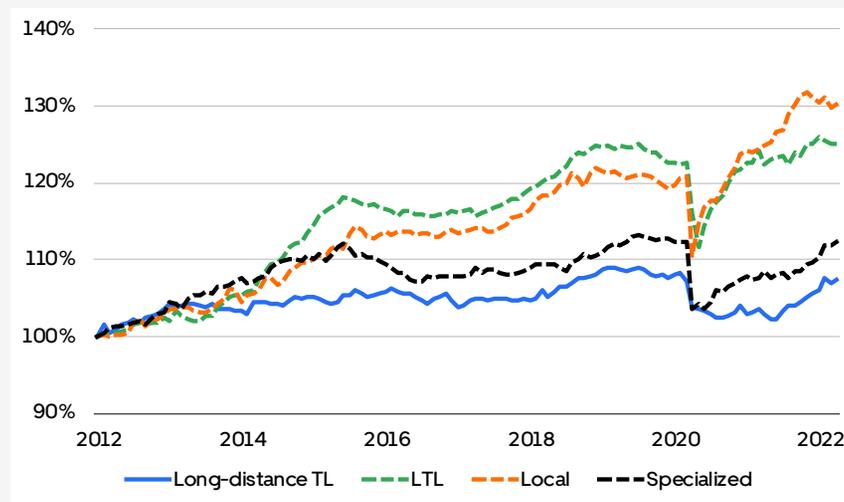
The hub-to-hub model allows AT developers and carriers to launch commercial operations earlier, before transitioning to a depot-to-depot service. At the same time, it adds capacity where it's needed most—in long-distance trucking—and provides a better lifestyle to truck drivers.

This model is a stepping stone toward full autonomy. It allows AT developers to start generating revenues in their early years of operation. This will provide them with a revenue stream that can sustain the development of self-driving technology instead of relying exclusively on external investment, in order to expand their capabilities beyond highway driving.

This approach also cuts mapping costs by 2 orders of magnitude. Self-driving vehicles need high-definition maps in order to determine their exact location with respect to the surrounding environment and plan their next move accordingly. The mapping process is time-

consuming and costly. With the hub-to-hub model, self-driving providers will only need to map the highway segments on which they operate. According to FHWA, the total length of the US interstate highway system is 46,876 miles,²⁰ which is only about 1.2% of the US public roads, but carries a quarter of vehicle-miles.²¹ In contrast, mapping urban streets is more complicated because they have more features, and a single large city like Los Angeles can have 6,500 street miles,²² almost 14% of the entire US interstate system.

Figure 4. Employment growth in various trucking sectors²³



The advantages of the hub-to-hub model are not limited to self-driving developers; they help drivers as well. As shown in Figure 4, truck drivers are becoming more inclined toward local—rather than long-distance—freight. This has been attributed to various factors, including the evolving preferences of younger drivers who like to stay closer to home. The hub-to-hub model will allow drivers to only serve short hauls and return to their homes and families every night.

Finally, drop-and-hook operations at transfer hubs and shippers' facilities will save drivers time and boost the system's efficiency. By

eliminating the need for appointment windows, carriers will be able to maximize the uptime of ATs, an expensive asset that should keep moving rather than waiting at facilities to load and unload.

The hub-to-hub model requires a hybrid network of human drivers and self-driving trucks. It also requires seamless drop-and-hook operations, in addition to reliable technologies for tracking, dispatching, and planning. Uber Freight's Powerloop program gives carriers access to a pool of trailers that allow the hub-to-hub model to operate smoothly and efficiently.

Economics of the hub-to-hub model

Autonomous trucks will cut freight costs substantially in the long term. Currently, carriers spend about 34%–44% of their total operating costs on driver wages and benefits.²⁴ Therefore, different studies have estimated the savings to be between 30% and 45% of total operating costs.²⁵

To achieve this, ATs need to drive on urban streets and handle a lot of edge cases. For the coming years, however, ATs will operate under the hub-to-hub model, which will transform the cost structure by reducing some costs and adding others, as shown in Figure 5.

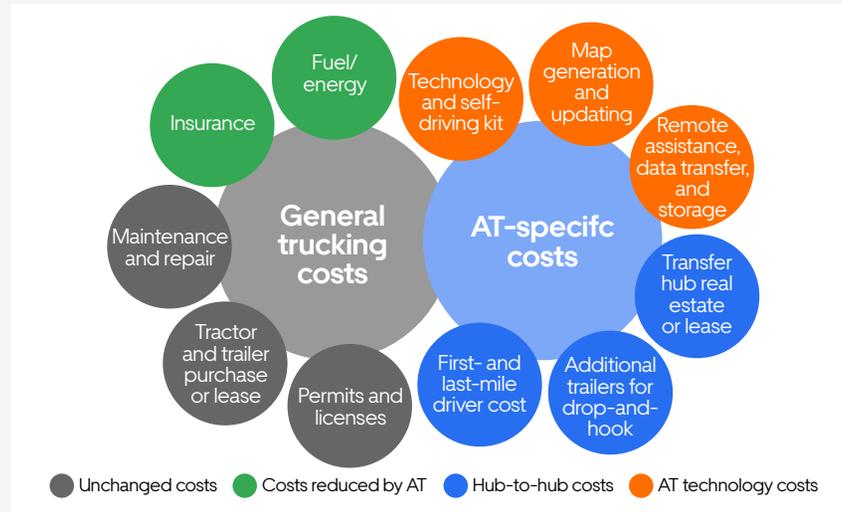
Under this model, we can divide the cost of a trip into 3 components: the first- and last-mile costs, which are handled by a human driver, and the middle-mile cost, which is driven autonomously. The middle-mile cost includes:

- Truck operating costs such as fuel, tractor and trailer depreciation, maintenance, permits, insurance, and tolls
- Transfer hub acquisition, lease, and operating costs
- Autonomous technology costs, such as sensors, mapping, remote assistance, data transfer, and storage

Truck operating costs

The American Transportation Research Institute (ATRI) provided a breakdown of trucking costs for different fleet sizes in 2020.²⁶ These costs vary significantly across carriers. Large fleets incur lower costs (per

Figure 5. Total operating costs of trucking under the hub-to-hub model²⁹



mile) than smaller ones across all cost components. In our analysis, we consider the operating costs of large fleets to estimate a lower bound of the total cost per mile. These costs are shown in Figure 6.

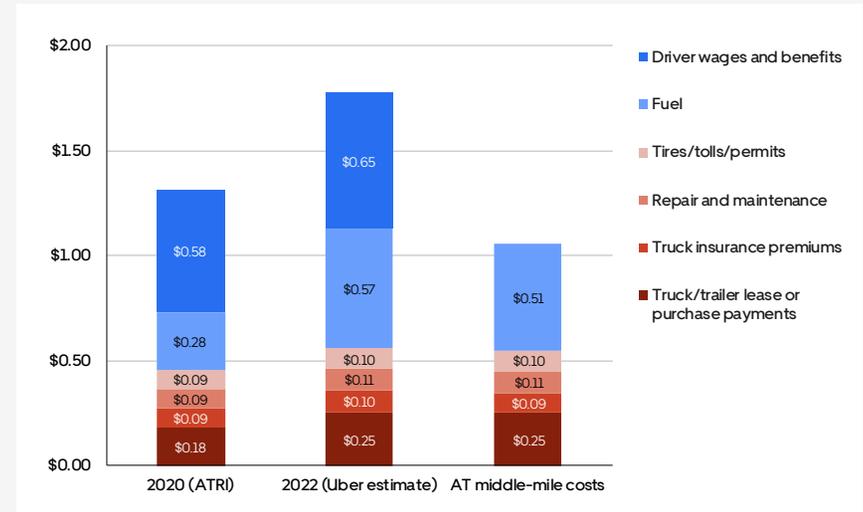
The operating costs of trucking have increased substantially between 2020 and 2022. For example, the price of diesel has doubled,²⁷ and the price of labor has increased by about 10%. Therefore, we need to apply relevant inflation factors to these costs to estimate their 2022 counterparts.

Yet as the technology matures, ATs will decrease some of the truck operating costs, such as fuel and insurance, due to optimized driving patterns and fewer accidents.²⁸ Therefore, we estimate the operating cost of an AT at about \$1.06 per mile, which is about 72 cents per mile cheaper than a human-driven truck.

Hub-to-hub costs

These costs are associated with the leasing, acquisition, and operation of transfer hubs. They are generally low compared with other cost

Figure 6. Per-mile operating costs of trucking for large fleets in 2020 (ATRI) and 2022 (Uber Freight calculations based on ATRI)³⁰



components. For example, if a transfer hub costs \$5,000 per month and handles 20 loads per day, and if the average length of haul is 500 miles, the resulting cost will be less than 2 cents per mile.

If workers are required at the transfer hubs (for maintenance, security, etc.), they might increase this cost substantially. For example, having 2 workers at each facility available for 24 hours a day will result in a daily cost of about \$1,920.³¹ This is where the utilization of transfer hubs becomes essential. If each transfer hub processes 20 loads per day, the cost will be as high as 19 cents per mile. However, if each transfer hub processes 100 loads per day, then the labor cost will be lower than 4 cents per mile.

However, AT carriers will need access to additional trailers for drop-and-hook operations at transfer hubs. Ideally, 3 trailers per tractor will be available: at the origin, at the destination, and in transit.³² If 2 additional trailers per tractor are needed, the added cost (including maintenance, insurance, etc.) can be as high as 26 cents per mile.³³

Therefore, the additional cost per mile associated with the 2 trailers and the 2 transfer hubs (on both ends) is about 30 cents per mile.

Self-driving technology costs

These include sensors, mapping, data storage and transfer, and remote operations. These costs are difficult to quantify, because they depend on the technology maturity and will generally decrease with time. The sum of operating, hub-to-hub, and technology costs constitute the total cost per mile of the autonomous middle mile.

First- and last-mile driver costs

These are the largest cost components of the hub-to-hub model and will be discussed in more detail in the following section.

The hub-to-hub model will also be profitable

The major cost component associated with the hub-to-hub model relates to the first and last miles. How will this impact the profitability of ATs operating between transfer hubs?

There are different ways in which we can procure and price first and last miles. For simplicity, we analyze 2 models: local-haul pricing and hourly driver pricing. Our analysis is based on the break-even points: At what price point will the combined cost of the first, last, and middle miles be equal to the cost of a human driver³⁴ serving the entire haul?

Local-haul pricing

The simplest approach is to treat the first and last miles as 2 separate local hauls. For example, a load going from Dallas to Phoenix will be divided into 3 hauls: a local haul in Dallas, an autonomous haul from Dallas to Phoenix, and a local haul in Phoenix. The total price is the sum of the 3 individual linehaul costs. We exclude the cost of fuel from our analysis because it is usually passed to the shippers in the form of a fuel surcharge.

This approach favors long hauls. To illustrate this, we consider the following example with 2 lanes: Dallas to Houston and Dallas to

Phoenix, which are 241 and 1,068 miles long, respectively. On both lanes, the combined price of the first and last miles was approximately \$600 in 2021,³⁵ assuming a \$76 reduction in price due to drop-and-hook, based on the hourly earnings of local truck drivers in 2021.³⁶ On the Dallas-Houston lane, this is almost equal to the total linehaul cost from Dallas to Houston. To achieve break-even, ATs need to have a cost of \$0.70 per mile.

On the other hand, the Phoenix-Dallas lane is more profitable for AT carriers. Because it is a longer haul, the combined price of the first and last miles is a smaller fraction of the total linehaul price as shown in Figure 7. Autonomous trucks can achieve break-even, even when their cost is as high as \$2 per mile.

Table 2. Characteristics of the lanes used in the hub-to-hub example

Lane	Dallas to Houston	Dallas to Phoenix
Length (miles)	241	1,068
Linehaul price (2021 average)	\$793	\$1,798
Linehaul price (opposite direction)	\$761	\$3,061
Local-haul price (Dallas)*	\$417	\$417
Local-haul price (Houston/Phoenix)*	\$334	\$328

*The local prices usually assume live loading and unloading. We applied a \$76 reduction to these figures in our assumptions.

The above conclusion holds for the majority of lanes on the Uber Freight network. We have calculated the autonomous middle-mile break-even rate per mile for Uber Freight’s top lanes, at which the combined cost of the first-, middle-, and last-mile segments is equal to the linehaul cost with a human driver. The results, shown in Figure 8, indicate that:

- The feasibility of the hub-to-hub model improves with longer hauls
- More than 80% of these lanes have a break-even price exceeding \$1 per mile, and about 40% of them have a break-even price exceeding \$2 per mile

Figure 7. Cost of the first and last mile (in gray) and the AT break-even revenue (in green) using the hub-to-hub model. We assume a \$76 reduction in the cost of local hauls because of time savings resulting from drop-and-hook operations.

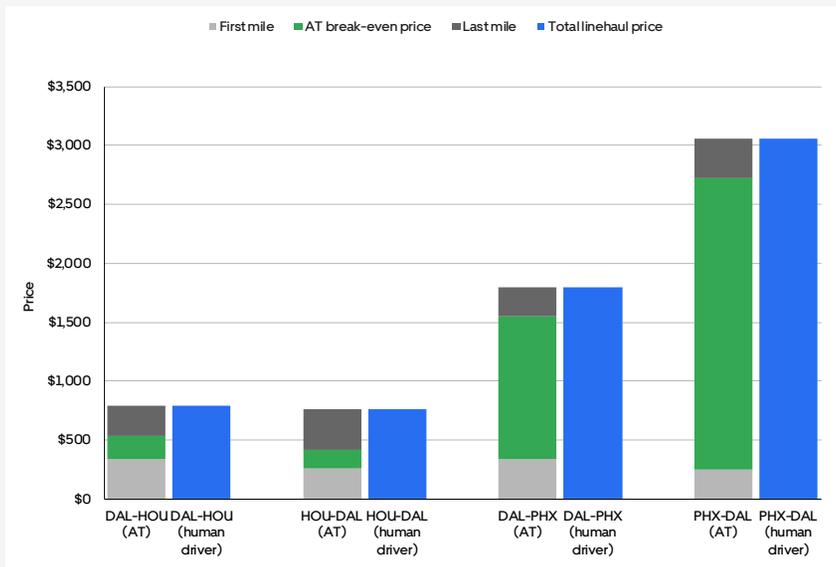
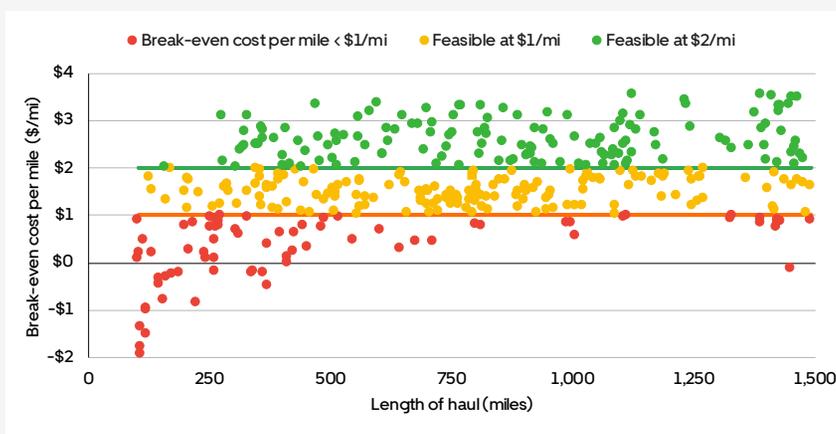


Figure 8. AT break-even rate per mile (excluding fuel) as a function of linehaul distance



Based on our analysis in the “Economics of the hub-to-hub model” section, a total middle-mile cost of \$1-\$2 (excluding fuel) can be achieved as the technology matures. The truck operating costs and the hub-to-hub costs constitute about \$0.86/mile. In order to achieve a middle-mile cost of \$1/mile, the AT technology costs should be \$0.14/mile. However, even if these costs are as high as \$1.14/mile in the early years of operation, the total cost of the middle mile will be about \$2/mile.

Under this model, the high cost of the first and last mile is partly due to the added friction at facilities. For example, drivers might not show up on time (or at all) to pick up a scheduled load, either at the shipper’s facility or at a transfer hub. Since each load is divided into 3 separate segments (the first, middle, and last miles), the probability of such events occurring is magnified. Some of these costs are implicitly included in the first- and last-mile prices shown in Table 2, which uses data from various loads, including those with driver delays and no-shows.

Hourly driver pricing

In the second approach, drivers who are paid hourly are hired at each transfer hub in order to handle first-/last-mile transportation. Preferably, these drivers can drop and hook trailers at both the shippers’ facilities and the transfer hubs rather than waiting to load and unload. With this approach, the combined cost of the first and last miles will be almost cut in half compared with local-haul pricing.

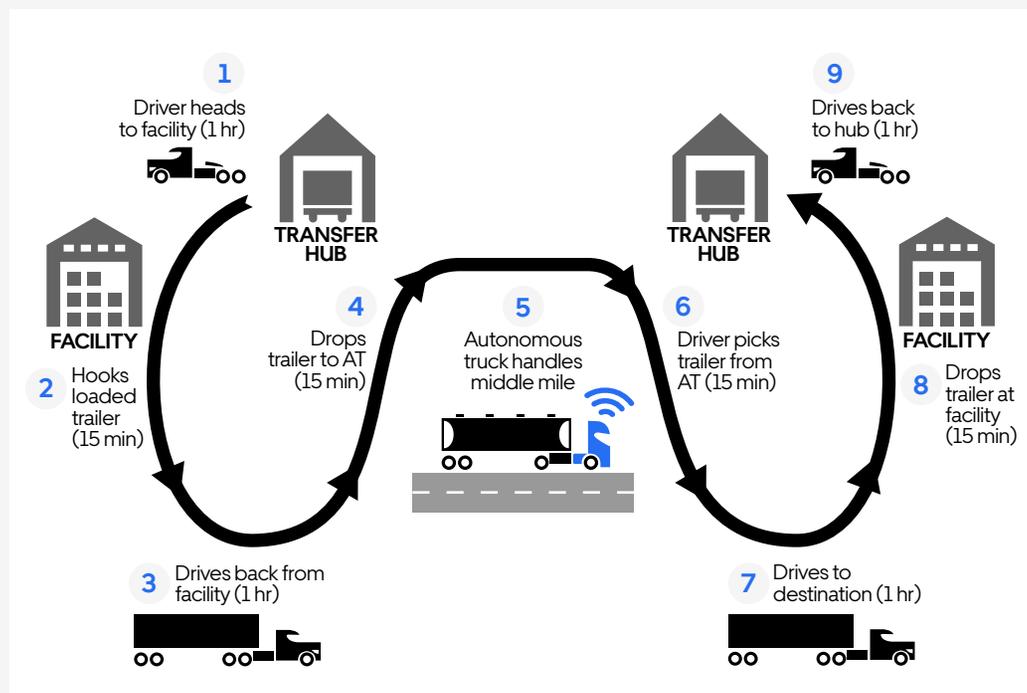
To demonstrate this, we provide the following example, which is representative of typical hub-to-hub operations. We assume that each transfer hub is located about 25 miles from the shippers’ facility. Trucks can travel at a speed of 25 mph between the transfer hubs and the facilities. At these facilities, as well as at the transfer hubs, drivers are able to drop and hook trailers, and each drop-and-hook operation takes about 15 minutes.

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In that example, about 5 hours are needed per load: 4 hours of driving and one hour for all 4 drop-and-hook operations as shown in Figure 9. Using the average hourly earnings rate for local freight drivers³⁷ and a 20% overhead cost, the total labor cost required at both ends is approximately \$156. Labor cost is approximately 45% of the total operational cost of trucking.³⁸ Therefore, the total cost of the first and last miles will be around \$345 per load, approximately half the cost of 2 local hauls.

The above analysis assumes that trucks are traveling empty to the source facility and from the destination facility. However, if enough loads are available in both directions, drivers can return with a backhaul. That way, the time required per load for the same example above can be cut to 3 hours.

Figure 9. Example of a journey of a load and expected time at each step



Unfortunately, in the near term, not all facilities can support drop-and-hook. Instead, drivers might have to wait for live loading and unloading at these facilities. If we assume the average loading and unloading time to be 2 hours, the total time required per shipment will be about 8.5 hours. This translates to a total first-/last-mile cost of \$455, still substantially cheaper than local-haul pricing.

How much freight can be moved with the hub-to-hub model?

In the previous section, we showed that the hub-to-hub model will be economically feasible on many lanes if AT developers can achieve a middle-mile cost between \$1 and \$2 per mile. In this section, we quantify the size of the opportunity associated with this model. Instead of limiting our analysis to a single number, we provide a range, which depends on the level of maturity of the technology.

Combination trucks³⁹ travel more than 177 billion miles annually in the US.⁴⁰ These include both loaded and empty miles for long-distance and local freight. We estimate that long-distance freight accounts for 135 billion miles per year. These are mostly distributed along the US interstate corridors as shown in Figure 10.

Figure 10. Mapping 2022 US truck shipments on the US interstate network using data from the Freight Analysis Framework⁴¹

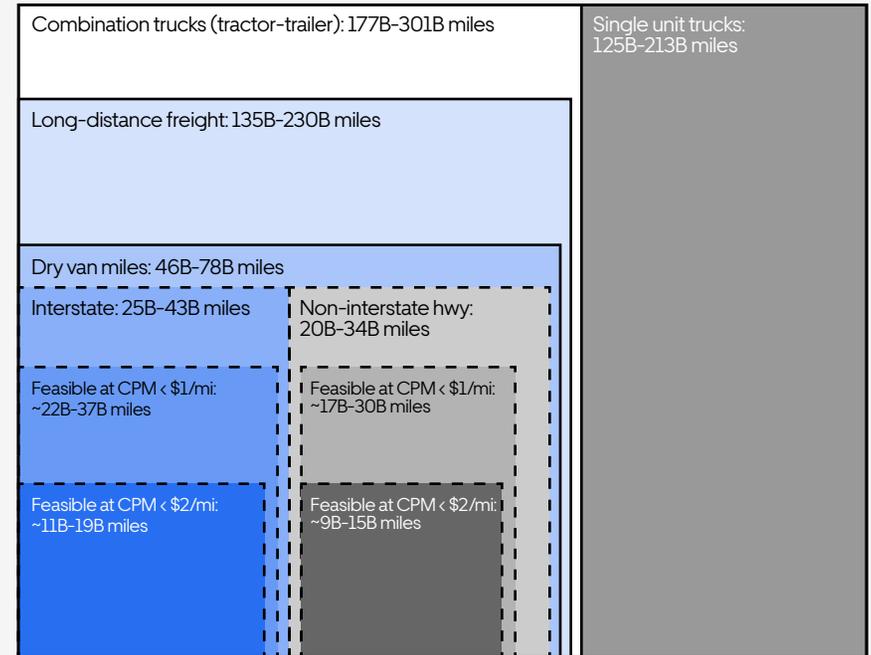


Due to technological limitations, early operations will focus on dry van trailers. In addition, these trailers are more convenient for drop-and-hook operations. Long-distance dry van freight amounts to 46 billion miles per year in the US. And using Uber Freight's data, we find that 98% of these miles are driven on the highways, with a speed limit of 50 mph and above.

Even if ATs were to operate on interstate highways only, they would still be able to capture a sizable fraction of miles traveled. This is because most of the lanes can be rerouted on the interstate system with a small increase in distance traveled. For example, 54% of the lanes can be rerouted within 10% of the optimal distance, and 45% can be rerouted with 5%. Route deviations will likely be tolerated by AT carriers, because ATs can achieve lower operating costs and be exempted from hours-of-service (HOS) limitations.

Finally, by applying the above assumptions on the economic feasibility of different lanes (shown in Figure 8), we can quantify the total addressable market of ATs as shown in Figure 11.⁴²

Figure 11. Total addressable market of autonomous trucking under the hub-to-hub model⁴³



What about trucking jobs?

There are more than 3.5 million truck drivers in the US.⁴⁴ While many studies warn of automation’s dire effects on the labor force, they usually rely on unrealistic assumptions. The majority of these studies assume a rapid transition to autonomous vehicles, both in terms of technology development and market penetration. However, this is unlikely to occur given the high cost and technological challenges that will be overcome incrementally. In addition, the trucking industry is large and fragmented, which means that disruptions of this scale will need time to propagate. For example, even cheaper technologies, such as basic safety features, took years to scale.

In the following sections, we discuss the positive effects self-driving technology will have on the trucking industry, and particularly on drivers.

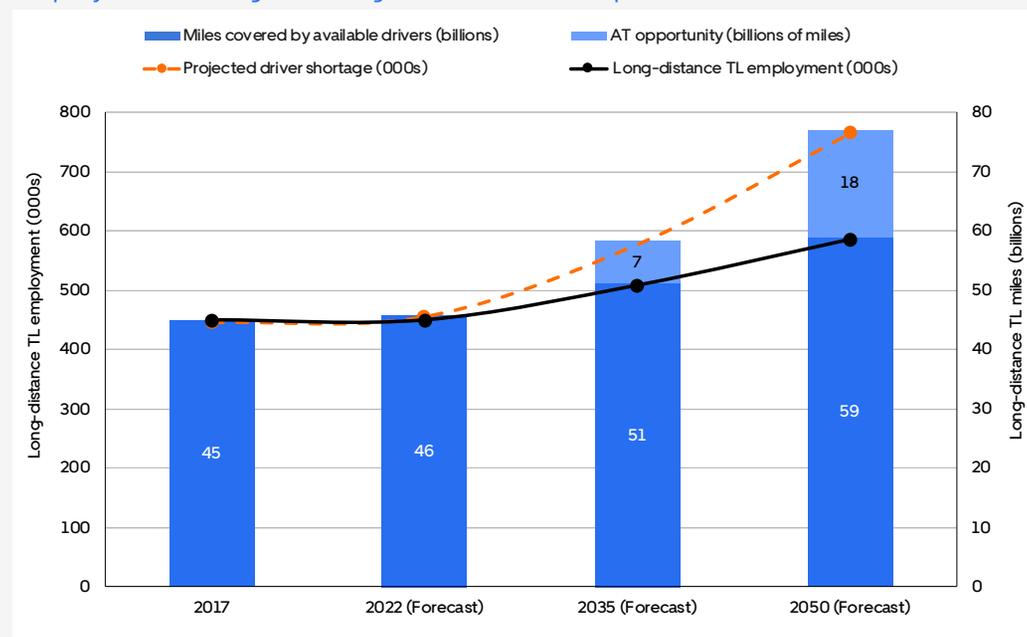
Autonomous trucks will fill gaps in the labor force

The freight industry will continue to grow over the coming decades. According to the Freight Analysis Framework (FAF), trucks are expected to move 19 trillion tons of freight annually by 2050. This represents a compound annual growth rate of 1.5% per year. Similarly, trucking employment has been growing at a rate of 1.5% per year over the past decade.⁴⁵ Assuming this growth persists, both trucking employment and trucking tonnage are expected to grow by more than 50% by 2050.

While total trucking employment is expected to grow on par with the total trucking ton-miles, looking at the long-distance truckload sector paints a different picture.⁴⁶ Over the past decade, employment in this sector has only grown by 0.95% annually. This means that at a similar rate, long-distance truckload employment in 2050 would be only 30% above its current level.

This creates a mismatch between supply and demand. As shown in Figure 12, while long-distance truckload miles are expected to grow by 69% by 2050, employment in this sector will only grow by 30%. We estimate that at least 69,000 additional drivers will be needed to cover 7 billion dry van miles by 2035, and 180,000 drivers will be needed by 2050 to cover 18 billion miles. These figures are of the same order of magnitude as the total addressable market of the hub-to-hub model estimated in the “How much freight can be moved with the hub-to-hub model?” section.

Figure 12. Expected growth in US dry van long-distance freight mileage and trucking employment⁵⁰ using a similar growth rate as in the past decade



This mismatch will be exacerbated by the looming cliff of hundreds of thousands of truck driver retirements over the next decade. This will have adverse effects on supply chains in the US and globally. For example, in 2021, long-distance truckload employment dropped

by 5%, while freight demand has increased by only 2.4% compared with their pre-pandemic levels.⁴⁷ This has led to the tightest truckload market in recent history. Dry van spot rates increased by more than 70% year-over-year in May 2021.

The effects of a driver shortage will not be limited to the freight and logistics industry but can extend to the broader economy. In 2021, the “sustained breakdown of supply chains” was deemed by economists as one of the top factors contributing to long-term high inflation.⁴⁸ Supply chain issues were also the leading constraints hindering manufacturing growth in 2021.⁴⁹ These issues resulted in inventory shortages, order cuts, and higher prices. Finally, end consumers also felt these shortages, as retailers were struggling to fill their empty shelves throughout the year.

Therefore, autonomous trucking will not simply replace trucking jobs but rather fill gaps in employment in order to keep our supply chains moving.

Autonomous trucks will provide better jobs for truck drivers

New technologies have not reduced overall employment in the past. However, they have changed the nature of these jobs and the tasks performed. For example, the introduction of automated teller machines (ATMs) has had positive effects on bank teller jobs.⁵¹ While the number of employees per branch dropped, efficiency gains caused the number of branches to increase. As a result, more tellers were needed to work in customer support.

Self-driving technology will also transform the nature of trucking without necessarily reducing the overall employment in this sector. By tackling the long-haul middle mile, self-driving trucks will enable drivers to shift toward local hauls. This will boost demand for skilled drivers in the local freight sector, which is the most preferred among truckers as shown in Figure 4. It will also allow drivers to have a say in where and how they work and allow them to stay closer to their homes and families. On the other hand, drivers who prefer long-haul trucking will still be able to serve loads that cannot be addressed by ATs, due to technological limitations, regulatory constraints, or adverse weather.

In addition, ATs will create new jobs. Since Level 5 automation is still years away, skilled drivers will provide remote assistance to handle AT disengagements and edge cases. Employees will also be hired to develop, maintain, and operate transfer hubs and self-driving trucks.

Finally, ATs will accelerate the widespread adoption of drop-and-hook, which will spare drivers many unpleasant experiences, including waiting at facilities to load and unload, detentions, and layovers. Since the majority of company drivers are paid by the mile,⁵² they are not being paid while they rest or wait at facilities. Therefore, facilities do not have a strong incentive to improve service for drivers. Even drop-live loads will allow drivers to better plan their time; if an appointment is not ideal, they could run other loads instead of waiting at the facility to unload.

Autonomous trucking will expand incrementally

Over the coming years, autonomous trucking will expand gradually throughout the US interstate system. In the short term, weather, regulations, and autonomy capabilities will dictate the lanes on which ATs will operate. In the long term, commercial opportunities and technological developments will drive expansion strategies.

Early expansion: navigating the maze of regulations and weather

A patchwork of state laws

The US DOT has adopted a hands-off approach with respect to regulating autonomous vehicles. As a result, testing and deployment are regulated by a state-centric patchwork of laws. As of 2021, 40 states in addition to Washington, DC, have either passed autonomous vehicle legislation or are operating under executive orders.⁵³

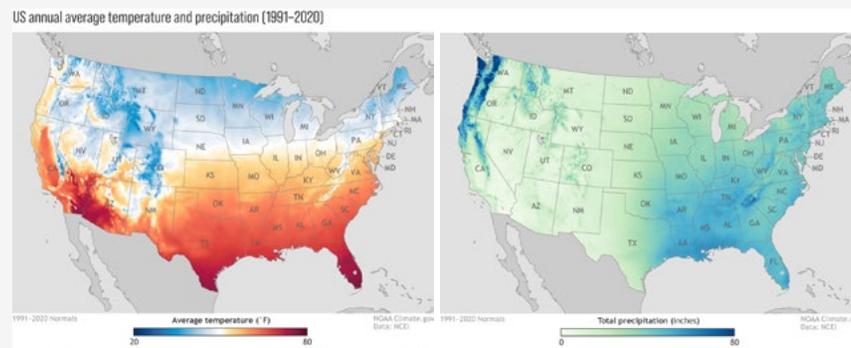
This fragmentation has led self-driving developers to favor some states over others for their testing and development efforts. As an example, state law in Texas allows an automated motor vehicle to operate regardless of whether a human operator is present in the vehicle, as long as certain requirements are met. Similarly, Arizona has adopted a permissive approach where automakers need only to notify the Arizona DOT before testing, as long as their vehicles comply with state and federal laws governing motor vehicles. Other states such as California adopted a more hands-on approach, by developing a comprehensive framework to regulate testing and operations. In 2016, Arizona, California, New Mexico, and Texas established the I-10 Corridor Coalition,⁵⁴ to help provide a streamlined, end-to-end, and connected vehicle experience, and enable better freight and passenger movement along the corridor in a connected vehicle environment.

Weather

A fully autonomous truck in the future would need to handle a wide range of weather conditions, ranging from light to heavy rain, to snow, fog, and freezing temperatures. However, in the short term, weather-related constraints will play a major role in shaping expansion strategies. Weather conditions vary widely by state, as shown in Figure 13. Deployment in many northern states is infeasible in the short term because

of freezing temperatures and snow. Precipitation also renders southeastern states inconvenient. This leaves us with states in the West and Southwest that have consistently high temperatures and low precipitation, particularly Arizona, California, New Mexico, and Texas. Fortunately, these states happen to be the same regulation-friendly states working on the I-10 Corridor Coalition.

Figure 13. Average temperature and precipitation in the US⁵⁵



Short-term opportunity: Show me the money

In the initial stages of commercial deployment, AT developers will need to prove that their technologies are safe, feasible, and capable of generating favorable unit economics. This stage might involve busy lanes with convenient weather and friendly regulations. The Dallas-Houston lane, on which Waymo and Aurora have both chosen to operate their pilots, checks all the boxes. In 2022, we estimate that this corridor will handle 0.36 billion to 0.66 billion miles of dry van freight.⁵⁶ Other potential lanes include:

- The remaining legs of the Texas Triangle: Dallas-San Antonio, and Houston-San Antonio, which combined with the Dallas-Houston lane handle 1.13 billion to 2.06 billion miles of dry van freight
- Los Angeles-Phoenix, with about 0.34 billion to 0.61 billion miles of dry van freight
- Los Angeles-San Francisco (regulation permitting), with about 0.66 billion to 1.20 billion miles of dry van freight

Texas and California are Uber Freight’s earliest and most mature markets. In 2021, Uber Freight alone (excluding Transplace) had more than 17 million truck-miles traveled between Austin, Dallas, Houston, and San Antonio, and 41,000 loads going exclusively between these markets. In addition, Uber Freight had about 20 million truck-miles traversing the I-5 corridor between Fresno, Los Angeles, and San Francisco, and 45,000 loads between these markets. This gives Uber Freight a strategic advantage to be the platform of choice for early deployment and commercialization.

Figure 14. Mapping of Uber Freight’s loads in 2021 (excluding Transplace) on the US interstate network: shipment movements span the entirety of the interstate network, with heavy presence in corridors that are strong candidates for early deployment



Long-term opportunity: See the forest and the trees

As the technology matures and the costs decrease, self-driving developers and carriers will start shifting their focus toward long-term commercial opportunities. At this stage, long-haul lanes will be preferred, as discussed in “The hub-to-hub model will also be profitable.” At this stage, self-driving developers and carriers will need to consider how each lane fits into their network and long-term expansion

strategy. For example, if a carrier were to expand AT operations to a new corridor, they would need to consider how much additional volume could be unlocked on the carrier’s extended network, how many empty miles their trucks would drive, and what the total return on investment of expanding on that particular corridor would be.

In Table 3, we analyze some of the key routes that carry long-term potential for ATs, based on data from the Freight Analysis Framework that we loaded on the US interstate network.

Table 3. Freight corridors with the biggest long-term opportunities for commercial expansion

Corridors	Opportunities
I-10/I-20 extending from Dallas to Los Angeles/ Houston to Los Angeles through El Paso and Phoenix	<ul style="list-style-type: none"> • Check all the boxes for regulations, weather, and short-term and long-term opportunities • A total addressable market of 160 billion ton-miles of freight as of 2022, which is more than 8% of the total US interstate ton-miles (based on our network model shown in Figure 10)
I-5 starting with the LA–San Francisco lane, and extending north toward Portland and Seattle in the future	<ul style="list-style-type: none"> • The busiest North–South corridor on the West Coast, and it connects to I-10 at Los Angeles • Carries approximately 86 billion ton-miles annually, which is 4.5% of the total US interstate ton-miles
I-40, connecting the 2 coasts through the south-central portion of the United States	<ul style="list-style-type: none"> • Falls on the optimal path connecting Los Angeles, the major import hub in the US, to key freight clusters such as Atlanta, Chicago, Indianapolis, Memphis, Nashville, and St. Louis
I-35 and I-45 connecting the Texas Triangle to Oklahoma City	<ul style="list-style-type: none"> • Give access to the busy I-40 and I-44 corridors, connecting Los Angeles to the Midwest and Northeast
I-95 extending from Miami to the Northeast	<ul style="list-style-type: none"> • Serves the most populated cities along the East Coast
I-75/I-65 extending from South Florida to Chicago	<ul style="list-style-type: none"> • Pass through major freight markets such as Atlanta, Nashville, Louisville, and Indianapolis

Conclusion

The future of trucking will consist of a hybrid model whereby drivers and ATs share the roads and keep America moving. ATs will fill gaps in trucking supply and complement the role of truck drivers rather than competing with them.

Uber Freight, being the preferred network for carriers in the US, is uniquely positioned to be also the preferred network for ATs. First, Uber Freight has developed key partnerships with leading technology players in the AT industry. In addition, we have developed all the necessary capabilities and tools to be the best AT network for both shippers and carriers.

Uber Freight can introduce ATs as a new mode into a shipper's network seamlessly and efficiently.

- **Deep trust with shippers:** With its acquisition of Transplace, Uber Freight is the trusted partner for shippers and their network of choice. We can partner with shippers to deploy ATs more strategically and help them achieve their profitability, sustainability, and network resiliency goals.
- **Key, strategic partnerships with autonomous trucking technology developers:** Uber Freight has executed a long-term, strategic partnership with Waymo to secure billions of autonomous miles to serve its customers on its network as well as a deep technical integration across platforms to further the mode of autonomous transportation for its shippers. Additionally, Uber Freight is currently running a multiphase pilot program with Aurora where Uber Freight is also learning how to integrate the Aurora Driver into its digital freight network.

- **Richest freight data:** Uber Freight has a rich database covering \$17 billion of freight under management. This data can help Uber Freight and shippers deploy this technology in an optimized manner, by informing decisions on where, when, and how shippers can accommodate ATs in their networks.
- **Largest carrier base:** The hub-to-hub model requires both technology and skilled drivers to handle the first and last miles. Uber Freight, combined with Transplace, provides access to the largest carrier base in the US, with over 130,000 active carriers. Therefore, Uber Freight can seamlessly handle the entire journey of a load, from the first mile to the last mile. In addition, Uber Freight's carriers will provide the required backup whenever an AT cannot service a load for any reason, including due to adverse weather conditions or unforeseen downtime.
- **Drop-and-hook capability:** Uber Freight's drop trailer pool system, Powerloop, helps carriers and shippers of any size tap into the efficiencies of drop-and-hook loads. Powerloop is crucial for the hub-to-hub model, as it has the potential to reduce dwell time by 30% and keep ATs highly utilized.

On the other hand, Uber Freight can help carriers of all types benefit from this technology.

- **Largest demand base:** Uber Freight provides carriers with access to \$17 billion of freight under management. This covers the entire US interstate network as shown in Figure 14. The scale of Uber Freight's network makes it a top choice for self-driving developers and carriers who want to expand their networks and grow their business successfully.

- **Integration with autonomous trucking technology developers:** In partnership with major AT players, carriers on the Uber Freight network will also have increased access to ATs, and higher efficiency through the seamless experience across one integrated platform between Uber Freight and its AT tech partners.
- **Pioneering customers:** Uber Freight's large customer base includes shippers ranging from small and midsize businesses to large enterprises. Many of these customers are all early adopters of new technologies and supply chain innovations.
- **Unmatched technology:** Uber Freight has already been leveraging state-of-the-art technology to provide carriers with easy and convenient access to freight, support them financially, and improve their experiences at facilities. In the future, Uber Freight imagines a world where smart scheduling, combined with the efficiencies of transfer hubs, will enable short-haul drivers to move a higher volume of freight within their working hours than they can today. In addition, by providing the right load at the right time, and guaranteeing predictability and consistent demand, we can help AT carriers maximize their AT asset utilization and return on investment.

At Uber Freight, we want to deploy data and algorithms to do the right thing—by deploying autonomous trucks in a way that is beneficial to shippers, self-driving developers, carriers, and their truck drivers.

The Uber Freight team

Author



Mazen Danaf

Senior Economist and Applied Scientist

Mazen's work focuses on analyzing the freight transportation landscape, and producing long-term forecasts based on supply and demand dynamics. He is also a research affiliate with the Intelligent Transportation Systems (ITS) Lab at MIT, where he completed his PhD in 2019. His research falls at the intersection of smart mobility, economic modeling, and machine learning.

Contributors



Laurent Hautefeuille

Head of Business Development and Strategy & Planning



Olivia Hu

Senior Business Development Manager



Bar Ifrach

Senior Director, Head of Marketplace, Applied Science, and Data Science



Mike Place

Product Manager

Endnotes

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