

Robotaxis and the Road to Profitability

As technology improves, dense cities are a must for Waymo

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Introduction

Despite operating in just one area, robotaxi operator Waymo raised \$2.5 billion in fresh funding in June 2021, thereby bringing the company's total amount raised to more than \$5.7 billion. We believe such an aggressive raise suggests Waymo is gearing up to expand its service to additional locations. While years of operating subscale in a limited suburban location has helped to advance Waymo's technology, it has not led to a commercially viable model. As a result, we expect the company is preparing to transition to a larger, more densely populated city—likely San Francisco, where higher ride volume can drive better operating metrics, and where it would come into more direct competition with Cruise, another robotaxi company.

Waymo is the first company to commercialize robotaxis and has operated an autonomous ride-hailing service in a limited, geofenced part of Phoenix since October 2020. However, while Waymo has made progress automating vehicles and is largely regarded as the leader in autonomous driving, the company has failed to scale or expand despite several nearby areas possessing similar weather and traffic conditions. We believe this reflects the poor economics of operating a ride-hailing model in suburban and less dense areas where ride volumes are low and car ownership is popular. Both Uber (NYSE: UBER) and Lyft (NASDAQ: LYFT) generate most of their profits from large cities, including New York City and San Francisco, where trips are frequent and prices remain relatively high. While suburban locations provide safe testing grounds for robotaxis, dense cities' higher utilization rates will be necessary to achieve profitability.

Relative to lower-density areas, operating autonomous vehicles in dense cities presents numerous complications. Existing robotaxis in suburban areas face interference when driving into sunlight, which results in limited service at dusk and dawn. Also, both inclement weather and complicated driving scenarios such as unprotected left turns and highway merging remain a struggle. Robotaxis in dense cities face all of these issues, too, but must also contend with denser traffic, double-parked vehicles, challenging intersections, and unpredictable cyclist and pedestrian behavior, among other things. These issues limit both routing and opportunities to service highly profitable trips within urban centers. Nonetheless, the industry is progressing. Based on our analysis of miles driven per disengagement, we expect the robotaxi industry—led by Waymo and Cruise—to achieve human-like levels of safety by the middle of the current decade and superhuman levels by decade's end. While it may yet be years before Waymo can scale in a large city, we nonetheless believe this is Waymo's core rationale behind seeking such a large funding round.

Larger revenue opportunity in densely populated cities

	Dense city	Less dense city
Sample city	San Francisco, CA	Indianapolis, IN
Population	874,961	877,903
Square miles	46.9	361.5
Annual TNC and taxi trips per person	111.6	34.9
Annual TNC and taxi trips	97,645,648	30,616,867
Robotaxi market share	50.0%	50.0%
Annual robotaxi trips	48,822,824	15,308,434
Price per trip mile	\$1.00	\$0.75
Average trip length (miles)	4.4	7.7
Revenue per trip	\$4.40	\$5.78
Annual revenue	\$214,820,425	\$88,406,204

Sources: PitchBook Emerging Tech Research, Schaller Consulting, Ride Guru

Our analysis compares the revenue and profit opportunity of launching a robotaxi service in two cities: population-dense San Francisco and less dense Indianapolis. To construct this analysis, we assumed the business objective for both robotaxi endeavors is to achieve roughly 50% market share of transportation network company (TNC) and taxi trips per city. To achieve this objective, we set the ride cost to \$1.00 per mile for San Francisco and \$0.75 per mile for Indianapolis, based on the relative cost of transportation within those cities. Finally, we assume that residents in San Francisco currently take an average of 93.0 TNC and taxi trips per year, and that figure increases by 20% to 111.6 as robotaxis scale at a lower price point. For Indianapolis, we assume residents average 23.3 TNC and taxi trips per year—approximately one quarter of annual trips per person in San Francisco—but that number increases by 50% to 34.9 once a cost-effective robotaxi option is made available.¹

1: "The New Automobility: Lyft, Uber and the Future of American Cities," Schaller Consulting, Bruce Schaller, July 25, 2018.

This analysis reveals the limited available market opportunity in suburban areas. Whereas the model shows an annual market opportunity of \$214.8 million in San Francisco, the opportunity in Indianapolis is just \$88.4 million. This difference in revenue is driven primarily by the difference in annual TNC and taxi trips per person between urban and suburban areas. Residents in suburban environments tend to have higher rates of car ownership, thus resulting in reduced demand for TNC solutions. As we demonstrate in our cost analysis, unlocking this demand will likely require millions of dollars in investment per city. It will take years of investment in those regions to ultimately unlock the demand, during which time vehicles will likely be underutilized. As such, robotaxi developers seeking to penetrate suburban markets face a chicken and egg problem, wherein underlying demand needs to be unlocked by significant investment in operating autonomous mobility services.

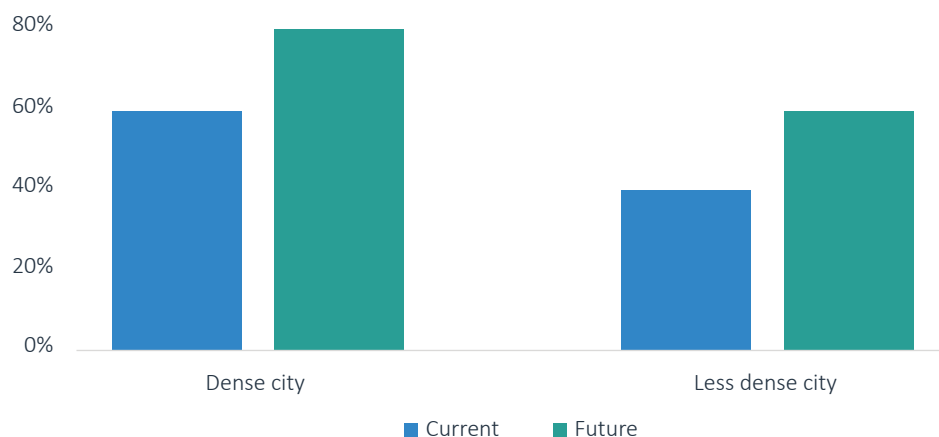
Cost analysis further favors cities due to higher utilization, better unit economics

Next, we conducted a cost analysis to determine the differences between scaling a robotaxi service in densely populated cities versus less dense cities. Here, the differences prove even more striking and indicate that robotaxi companies seeking to scale in suburban areas will face difficulties in generating a profit.

The utilization rate tips the scales in favor of densely populated urban areas. In addition to boosting top-line revenue, the higher utilization rate inherent to dense urban areas reduces downtime and mileage resulting from traveling to pick up passengers between trips, which incurs additional repair, maintenance, and depreciation costs.

We model robotaxis to complete 30 trips per vehicle per day in both dense and less dense cities. However, we model the utilization rate—time spent with a passenger in the car—at 60% in dense cities and 40% in less dense cities. We believe these figures align with utilization rates of existing ride-hailing services in both dense and less dense cities. Over time, we expect utilization rates will improve concurrent with increased demand, better routing capabilities, predictive analytics tools, and enhanced core technology that will enable trips in more-challenging conditions such as inclement weather. At scale, we expect the robotaxi utilization rate will rise to 80% in dense cities and 60% in less dense cities.

Robotaxi utilization rate proportion



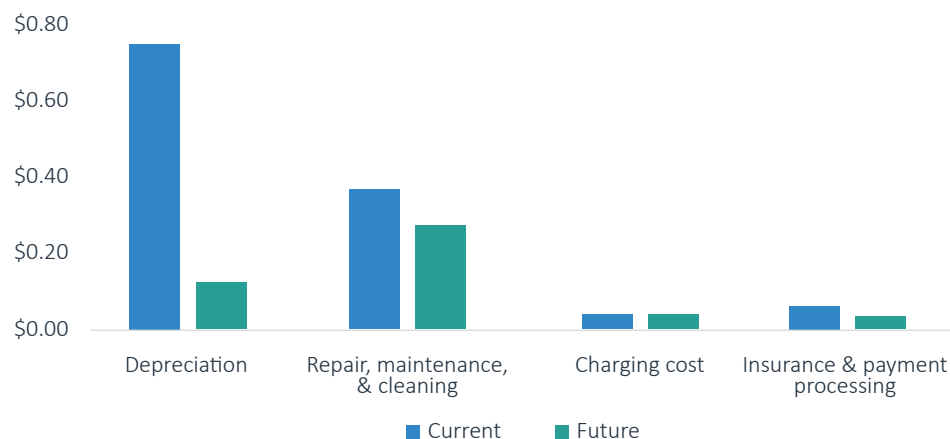
Source: PitchBook

We model current repair, maintenance, and cleaning costs at \$0.37 per mile and expect this figure to decline by approximately 25% to \$0.24 per mile at scale. This translates to an average of \$2.09 per trip in dense cities and \$4.88 in less dense cities. The utilization rates drive this difference.

Currently, the upfront vehicle cost is one of the largest cost components for robotaxis. We estimate that robotaxis cost approximately \$150,000 each, which includes the upfront cost of the vehicle, onboard computer chips, and multiple lidar, radar, and camera sensors. In the mid-to-late 2020s, we anticipate the cost of robotaxis will drop significantly, driven by three primary factors: a decline in battery and electric vehicle manufacturing costs; significant hardware price compression as compute costs decline and cheap, solid-state lidar hits high-volume production; and vertical integration as robotaxi developers assume greater ownership over the manufacturing process to drive down costs. Ultimately, we expect the cost of robotaxis will drop from approximately \$150,000 today to \$50,000 once at scale.

While this cost decline is significant, annual depreciation tends to favor dense cities due to their higher utilization rates and shorter trip lengths. We expect robotaxis in less dense areas to drive farther on average than robotaxis in dense areas, thanks to both the reduced utilization rate of 60% versus 80% in dense cities and the longer average trip lengths of 7.7 miles versus 4.4 in dense cities. In addition, due to the lower utilization rates, many more vehicles will be required to fulfill demand. We estimate that robotaxis in dense urban areas will average 12,727 trips annually, while robotaxis in less dense areas will average just 5,455 trips annually. We expect 0.8 robotaxis will be sufficient to fulfill 10,000 annual trips in dense areas, while 1.8 robotaxis will be required per 10,000 trips in less dense areas. At scale, vehicle depreciation cost will total \$0.69 per trip in dense cities and \$1.28 per trip in less dense cities.

Robotaxi costs (\$) per mile



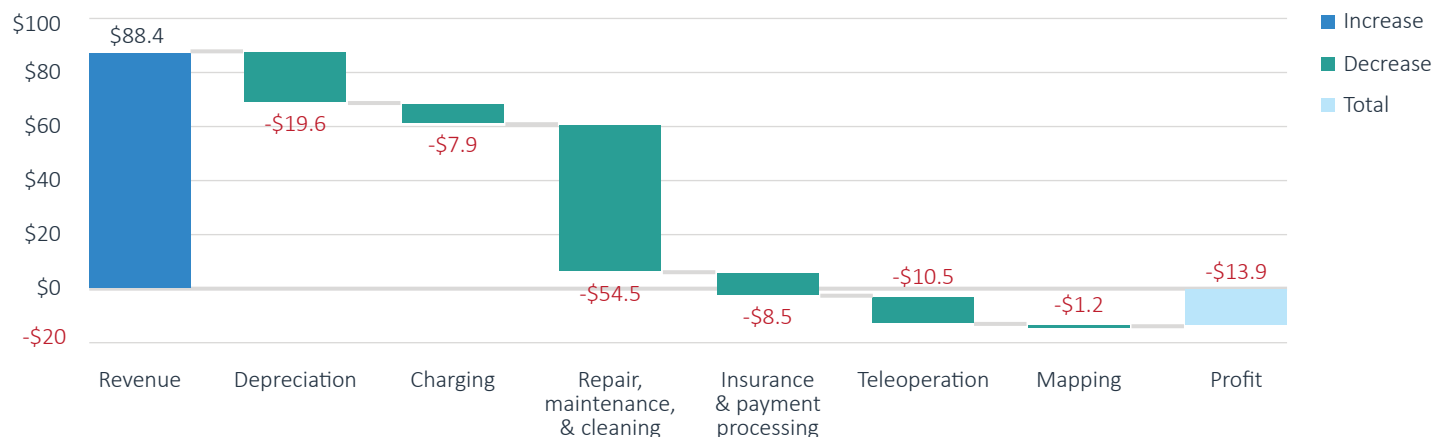
Source: PitchBook

Mapping is another key cost component of operating a robotaxi service. While future robotaxi companies may have reduced reliance on mapping, current leading robotaxi companies depend upon high-density maps that require frequent updates. At scale, we expect annual mapping costs will total \$1.1 million per city. This figure consists of purchasing and running a fleet of mapping vehicles, drivers, and an engineer team to annotate the data.

Finally, teleoperations will significantly affect the profitability of robotaxi operations. In situations wherein robotaxis become stuck or unable to drive autonomously, teleoperators should be able to remotely take over and safely guide the vehicle. Most leading robotaxi companies are developing teleoperation capabilities as a key part of their go-to-market strategies. We assume that, at scale, one teleoperator can oversee 10 vehicles in dense urban areas and 20 in less dense areas. The advantages of dense urban areas—such as fewer vehicles needed to service demand—are more than offset by the advantages of less dense areas—such as the less-complicated environments, which necessitate fewer teleoperators. However, while less dense cities have the advantage of lower teleoperation costs, other cost considerations still tilt the balance in favor of dense cities.

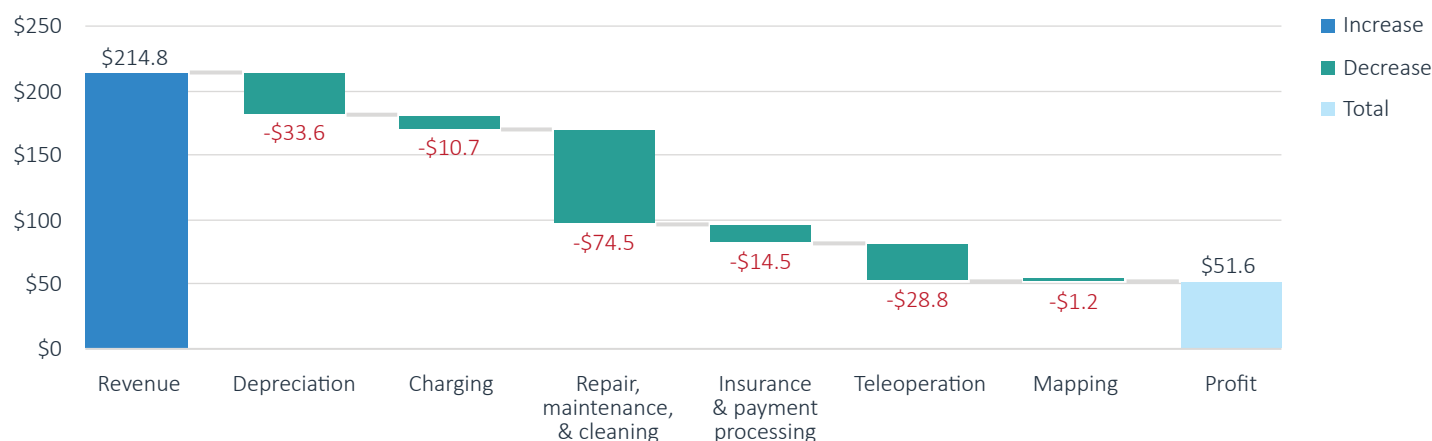
Robotaxis must deploy in densely populated cities

Less dense city robotaxi operating profit (\$M)



Source: PitchBook

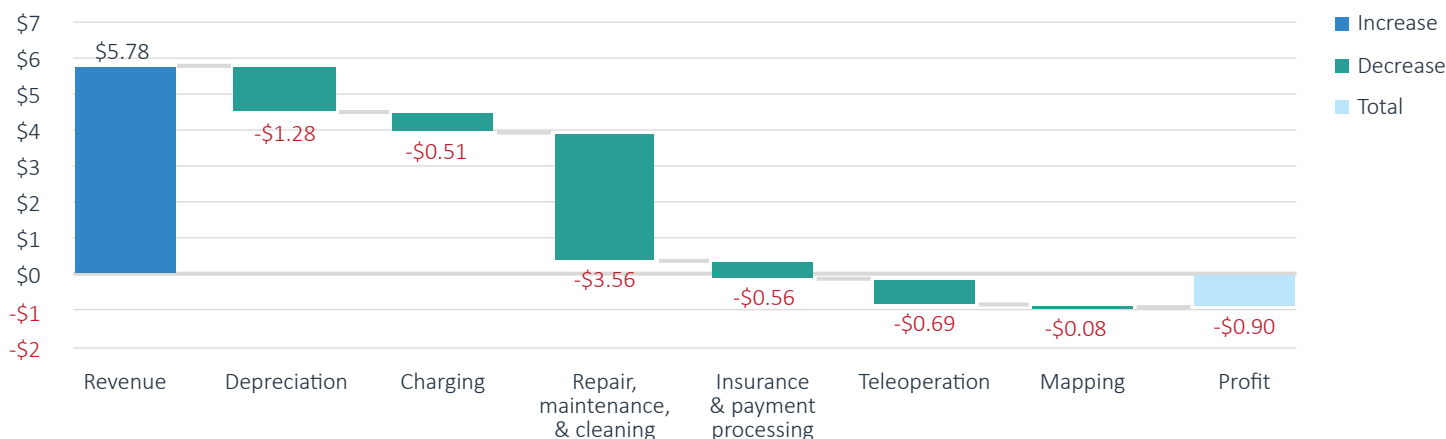
Dense city robotaxi operating profit (\$M)



Source: PitchBook

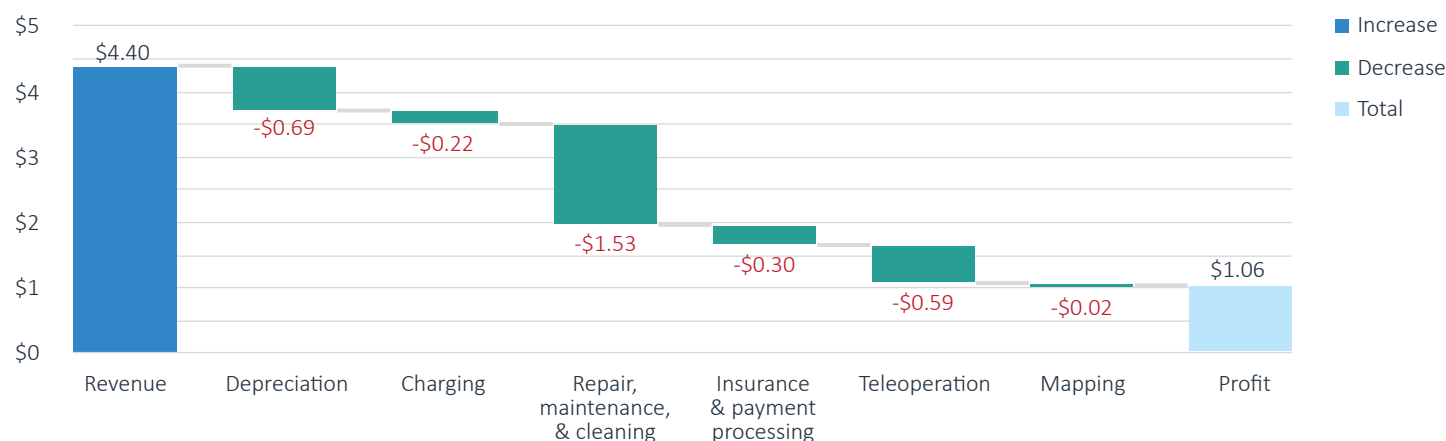
Our model shows a striking difference between dense cities and less dense cities. When layering the operating costs of depreciation, charging, repair, maintenance, cleaning, insurance, payment processing, teleoperation, and mapping, robotaxi operators can expect to generate a contribution margin of 24.0% in dense cities and a contribution margin loss of -15.7% in less dense cities. Using real cities as an example, we estimate that a robotaxi operation in San Francisco with 50% market share would generate approximately \$214.8 million in revenue and an operating profit of \$51.6 million, while a robotaxi operation in Indianapolis with 50% market share would generate \$81.4 million in revenue and a loss of -\$13.9 million.

Less dense city robotaxi unit economics (\$ per trip)



Source: PitchBook

Dense city robotaxi unit economics (\$ per trip)



Source: PitchBook

The implications of this analysis are clear: Robotaxis must deploy in dense cities to be profitable at scale. Robotaxis deployed in suburban areas face an uphill battle in unlocking enough demand to make the investment worthwhile and then will face ongoing issues in achieving profitability. On the other hand, dense urban environments provide massive positive unit economics. Deploying in cities enables more trips, higher prices, and improved utilization—all key drivers of profitability. By drawing car and public transit commuters, robotaxis in dense urban environments could significantly expand the market for ride-hailing—all while generating positive contribution margins.

San Francisco will pit Waymo directly against Cruise

We expect Waymo will deploy in a dense urban area such as San Francisco and scale out its product city by city. Expanding in San Francisco will put Waymo in direct competition with Cruise. Both Waymo and Cruise have applied for permits to charge passengers for rides in the San Francisco area. However, as of June 2021, only Cruise has received authorization to charge for driverless rides.

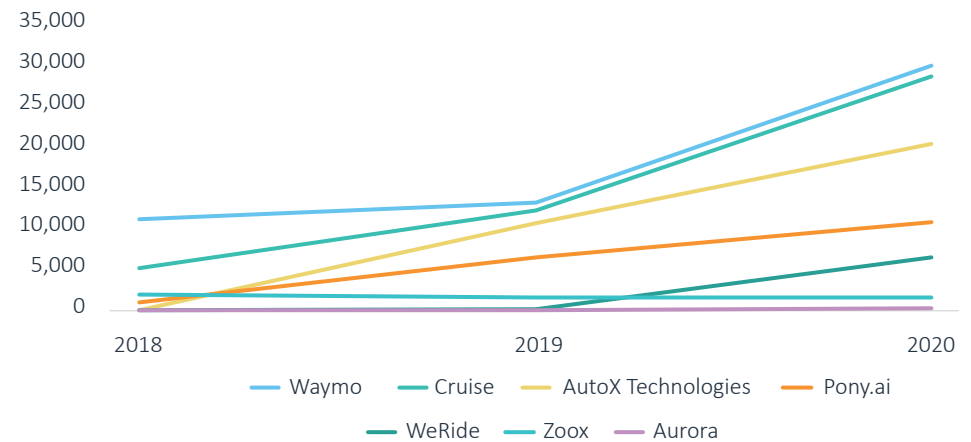
Dense urban environments represent an operating design domain (ODD) that is orders of magnitude more complex than suburban environments. Dense urban areas are full of traffic, pedestrians, and novel situations such as double-parked delivery vehicles, unprotected left turns, and partial visual obstructions—situations that many humans find at least somewhat difficult and have proven challenging for robotaxis. Given that the bulk of Waymo's testing has taken place in suburban environments, it remains unclear how Waymo's technology will fare in a densely populated city.

Thanks to the startup having spent the past five years test-driving millions of San Francisco miles,² Cruise could be better positioned than Waymo to tackle the city's dense urban environment. In June 2021, Cruise secured a \$5.0 billion line of credit from General Motors (NYSE: GM) to purchase purpose-built autonomous electric shuttles, which GM expects to begin producing in early 2023. Its backing from Honda (TKS: 7267) and GM makes Cruise well positioned for vertical integration to further drive down component costs, which should help it commercialize.

2: "Cruise Beats Out Waymo in California AV Testing Miles in 2020," *The Detroit News*, Riley Beggin & Kalea Hall, February 9, 2021.

Robotaxi developers testing on California roads are required to disclose the number of miles traveled on public roads, as well as numbers of disengagements—or situations wherein a safety driver has to manually take over control of the vehicle. While not a perfect measure, miles per disengagement can provide some clues as to the technological progress of the industry.³ We note that Waymo and Cruise report similar miles per disengagement in California.⁴

Robotaxi miles per disengagement



Source: California DMV

Robotaxis are 5-10 years away from human-like performance

Using miles per disengagement as a proxy for assessing the general technological progress of the industry, we have assembled a basket of companies that have disclosed data via this measurement over the past three years. As expected, industry leaders Waymo and Cruise hold the top rankings, though Alibaba-backed (HKG: 09988) AutoX has achieved significant traction in a short time. As of 2020, the industry has reached an average miles per disengagement figure of 14,005.⁵

These numbers do not compare favorably with human driver performance. According to the National Highway Traffic Safety Administration, on average, people in the US drive 1.7 million miles between accidents resulting in injuries or fatalities and 482,800 miles between all accidents.⁶ As any collision involving autonomous driving will likely face elevated levels of scrutiny, we believe the 1.7-million-mile figure is the level of safety robotaxis should seek to achieve.

3: Caveat: Miles per disengagement is not a perfect measure of safety, as the figures can be manipulated. For example, robotaxis testing on easy-to-navigate streets, in which vehicles encounter fewer novel situations, could have artificially inflated miles-per-disengagement figures. Meanwhile, robotaxis undergoing more-robust testing environments such as urban areas could show a poorer miles-per-disengagement figure, which might misrepresent the fleet's true capabilities.

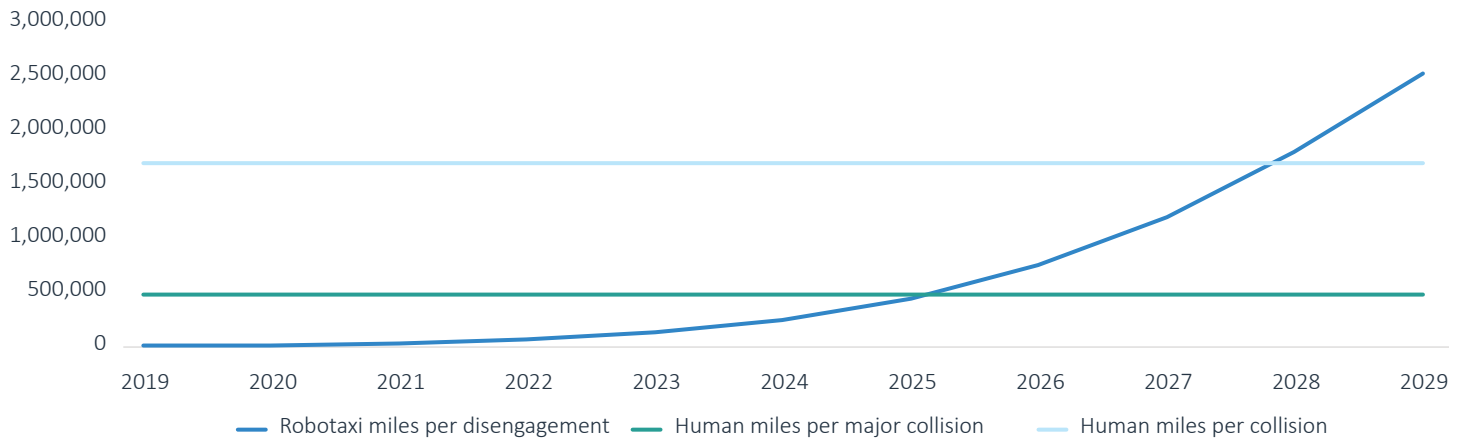
4: "Disengagement Reports," California DMV, 2021, accessed on June 15, 2021.

5: Ibid.

6: "Traffic Safety Facts Annual Report," National Highway Traffic Safety Administration, May 2021.

Robotaxis have a long way to go before they can displace human drivers. On average, the industry appears to be improving miles per disengagement at a rate of 120% to 130% per year. At this rate of progress, we forecast the robotaxi industry will achieve human-like performance of approximately 482,900 miles per disengagement between 2025 and 2026 and superhuman performance of 1.7 million miles per disengagement in 2028.

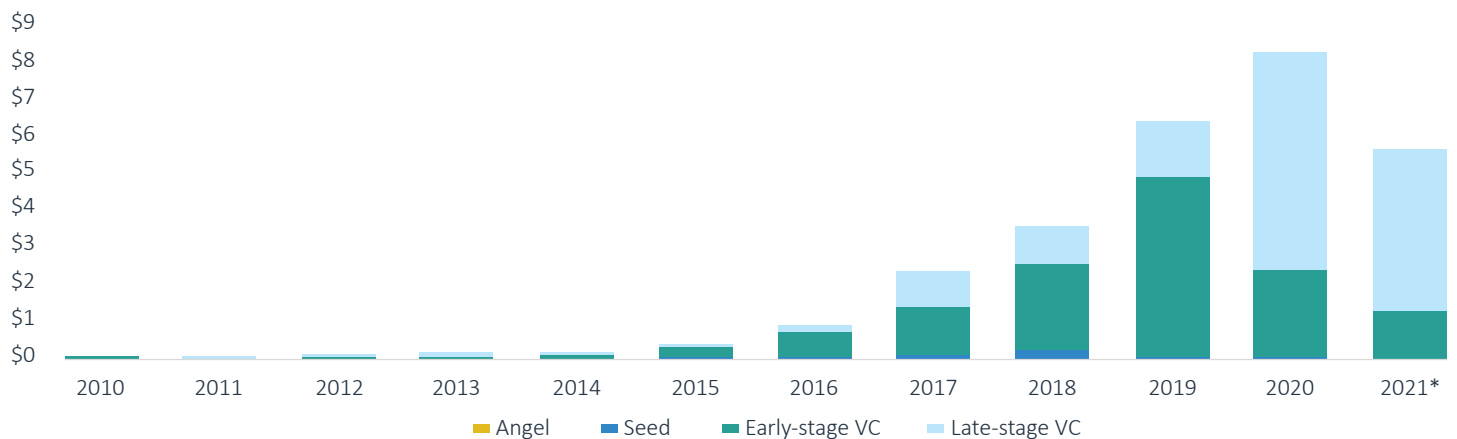
Projected robotaxi miles per disengagement



Source: PitchBook

Financial implications

Autonomous driving VC deals (\$B) by stage



Source: PitchBook | Geography: Global
*As of June 4, 2021

Waymo faces pressure to deliver on the billions of dollars in investment it has raised. Dense urban environments will be key to providing future returns. Thus, Waymo's success or failure to compete with Cruise and successfully commercialize in San Francisco could both determine the company's future and hold significant implications for future funding of the autonomous driving industry.

So far, investment in autonomous driving has been strong. As of June 2021, \$5.7 billion in VC has been invested into the industry—a figure on pace to exceed the previous year’s record of \$8.3 billion. The majority of capital has gone toward late-stage companies in the space.

The leaders in autonomous driving continue to raise huge amounts of capital. In May 2020, Waymo raised \$3.0 billion of Series A venture funding in a deal led by Silver Lake Management, Mubadala Capital-Ventures, and Canada Pension Plan Investment, which put the company’s pre-money valuation at \$27.8 billion. Additional investors included a suite of automotive and financial investors. In June 2021, Waymo announced it raised a \$2.5 billion round largely from its existing investor base and at an unknown valuation. Meanwhile, in January 2021, Cruise raised \$2.8 billion in corporate financing from General Motors, Honda, Walmart (NYSE: WMT), and Microsoft (NASDAQ: MSFT). In June 2021, Cruise secured a \$5.0 billion credit line from General Motors to purchase purpose-built autonomous electric shuttles.

Even while the leaders raise the bulk of capital, VC investors are still willing to back new entrants tackling the self-driving problem in different ways. Raquel Urtasun, former Chief Scientist at Uber ATG, recently launched the startup Waabi, which uses an artificial intelligence-first (AI) approach that leverages deep learning and places a greater emphasis on simulators as opposed to on-road testing. In June 2021, Waabi raised an \$82.7 million Series A led by Khosla Ventures, with participation from Uber, Aurora, Radical Ventures, and BDC Capital, among others. In 2019, Zoox co-founder Tim Kentley Klay founded the startup HYPR, which leverages reinforcement learning that enables cloud-connected vehicles to write their own code and teach themselves to drive.

Appendix: Robotaxi profitability model

	Dense city			Less dense city		
Sample city	San Francisco, CA			Indianapolis, IN		
	Robotaxi testing	Scaling current tech	Scaling future tech	Robotaxi testing	Scaling current tech	Scaling future tech
Population	874,961	874,961	874,961	877,903	877,903	877,903
Area (square miles)	46.9	46.9	46.9	361.5	361.5	361.5
Annual TNC and taxi trips per person	93.0	111.6	111.6	23.3	34.9	34.9
Annual TNC and taxi trips	81,371,373	97,645,648	97,645,648	20,411,245	30,616,867	30,616,867
Robotaxi market share (%)	0.5%	50.0%	50.0%	0.8%	50.0%	50.0%
Annual robotaxi trips	406,857	48,822,824	48,822,824	163,290	15,308,434	15,308,434
Price per trip mile	\$3.00	\$1.00	\$1.00	\$2.50	\$0.75	\$0.75
Average trip length (miles)	4.4	4.4	4.4	7.7	7.7	7.7
Revenue per trip	\$13.20	\$4.40	\$4.40	\$19.25	\$5.78	\$5.78
Annual revenue	\$5,370,511	\$214,820,425	\$214,820,425	\$3,143,332	\$88,406,204	\$88,406,204

Source: PitchBook Emerging Tech Research

Note: Model excludes potential impacts of municipal fees and inclement weather.

	Dense city			Less dense city		
Sample city	San Francisco, CA			Indianapolis, IN		
Costs	Robotaxi testing	Scaling current tech	Scaling future tech	Robotaxi testing	Scaling current tech	Scaling future tech
Total vehicles to service demand	43	5,115	3,836	45	4,210	2,807
Trips per vehicle per day	20	20	30	20	20	30
Utilization rate (%)	60.0%	60.0%	80.0%	40.0%	40.0%	60.0%
Annual miles traveled per vehicle	70,000	70,000	70,000	70,000	70,000	70,000
Vehicle operational life (miles)	200,000	200,000	400,000	250,000	250,000	500,000
Vehicle operational life (years)	2.9	2.9	5.7	3.6	3.6	7.1
Vehicle cost	\$150,000	\$150,000	\$50,000	\$150,000	\$150,000	\$50,000
Annual depreciation per vehicle	\$52,500	\$52,500	\$8,750	\$42,000	\$42,000	\$7,000
Total annual depreciation	\$2,237,713	\$268,525,531	\$33,565,691	\$1,885,999	\$176,812,408	\$19,645,823
% of revenue	41.7%	125.0%	15.6%	60.0%	200.0%	22.2%
Charging & fuel	\$119,345	\$14,321,362	\$10,741,021	\$125,733	\$11,787,494	\$7,858,329
Repair, maintenance, & cleaning	\$1,103,938	\$132,472,595	\$74,515,835	\$1,163,033	\$109,034,318	\$54,517,159
Insurance & payment processing	\$447,543	\$32,223,064	\$14,500,379	\$345,766	\$22,101,551	\$8,545,933
Total annual charging, repair, maintenance, cleaning, payment processing, & insurance costs	\$1,670,826	\$179,017,021	\$99,757,235	\$1,634,532	\$142,923,363	\$70,921,421
% of revenue	31.1%	83.3%	46.4%	52.0%	161.7%	80.2%
Annual teleoperation costs	\$1,598,366	\$191,803,951	\$28,770,593	\$1,683,928	\$157,868,221	\$10,524,548
% of revenue	29.8%	89.3%	13.4%	53.6%	178.6%	11.9%
Annual mapping costs	\$2,958,333	\$3,916,667	\$1,166,667	\$2,958,333	\$3,916,667	\$1,166,667
% of revenue	55.1%	1.8%	0.5%	94.1%	4.4%	1.3%
Operating profit	-\$3,094,727	-\$428,442,744	\$51,560,239	-\$5,019,461	-\$393,114,454	-\$13,852,255
% of revenue	-57.6%	-199.4%	24.0%	-159.7%	-444.7%	-15.7%

Source: PitchBook Emerging Tech Research

Note: Model excludes potential impacts of municipal fees and inclement weather.