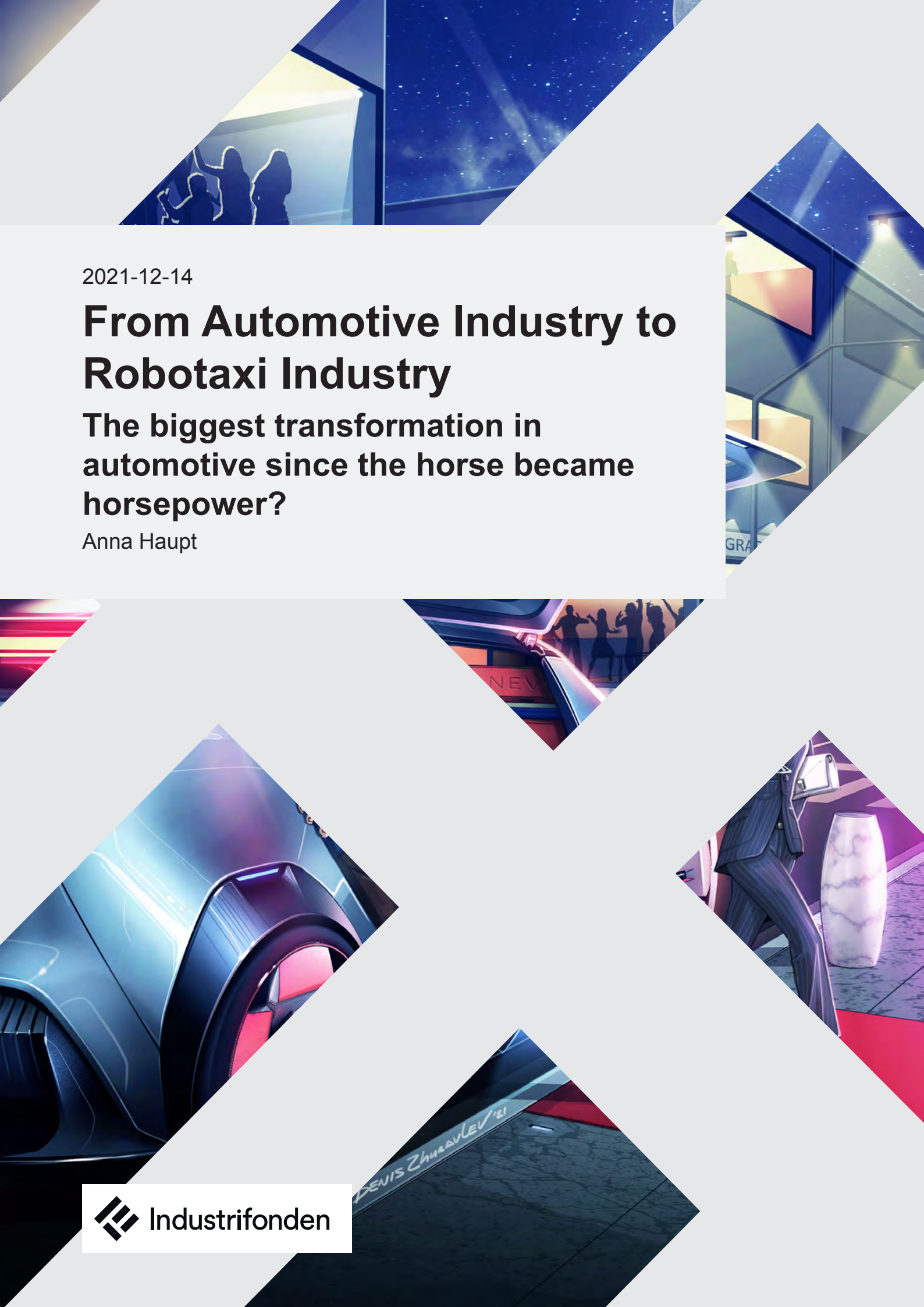




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From Automotive Industry to Robotaxi Industry

The biggest transformation in automotive since the horse became horsepower?

Anna Haupt



Industriefonden

About Industrifonden

Industrifonden sees today's science and groundbreaking technologies as the foundation for the industries of tomorrow. That is why we seek out the most transformative ventures to invest in. Those with the power to change the way we live for the better and those that have a real, meaningful impact on society.

We partner with entrepreneurs, innovators, and scientists whose discoveries are laying new ground for our future – for industries that may not even exist yet. We invest in early growth stages, seed to A-round funding. Initial investments are typically 10-50 million SEK, but we have the power to invest considerably more during our holding period.

We believe in being an active investor; in sharing our 40 years' experience of scaling and growth. However, we do not take an operational role in our portfolio firms.

Our portfolio of companies spans the Nordics, but all have a Swedish connection.

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Anna Haupt is one of two inventors of Hövding – the airbag bicycle helmet, which she founded in 2005 and took from idea to a listed company with 400 dealers around Europe and Asia. The years before joining Industrifonden, Anna devoted to the automotive industry. At Nevs (formerly Saab), she was part of the management team and responsible for the development of a mobility system of self-driving vehicles for urban environments. A product she took from idea to first driving prototype, including app and fleet management system. Anna Haupt has a master's degree in Industrial Design from LTH, Lund University.

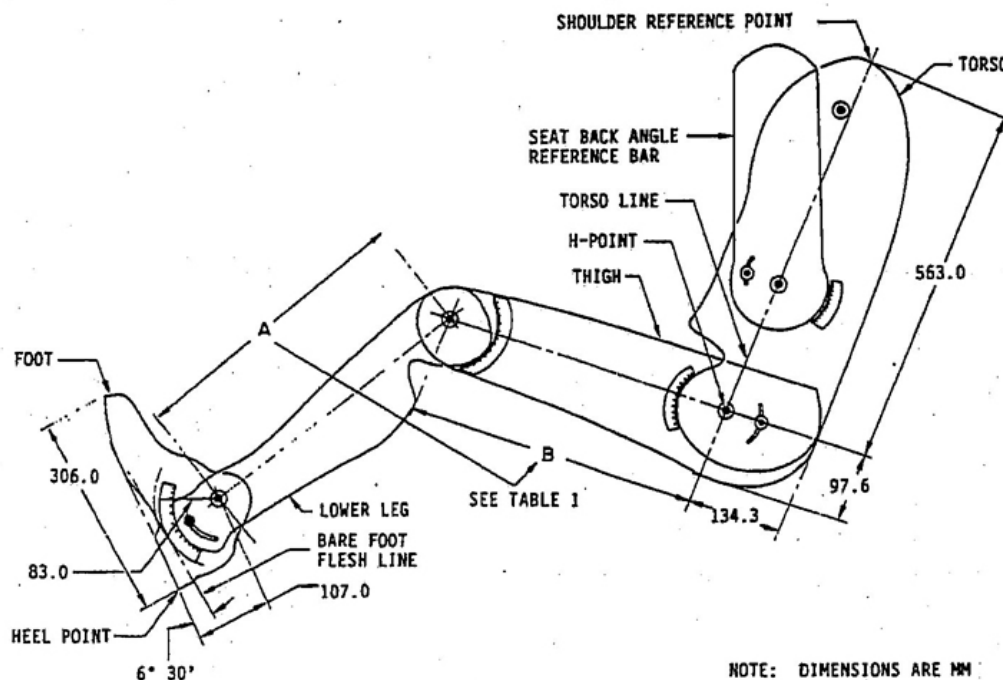
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Introduction: Understanding the automotive industry mindset – a love story

The year 1886 is regarded as the birth year of the modern car, when German inventor Karl Benz patented his Benz Patent-Motorwagen. The automotive industry has since then developed from a horse-carriage-without-a-horse to an autobahn optimized driver experience with aerodynamic perfection. The core business model has always been private ownership.

Optimized "driving experience" has been the goal for every automotive company since the beginning. The driver's reclined position and the feeling of being in control of the horsepower, has been the center and focus of car design, interior as well as exterior. The driver's position affects vehicle height, door placement, angle of vision and windscreen, ingress/egress, instrument panel, exterior lighting, passenger roominess, wheelbase, and more. Engineers have to a large extent designed the cars based on their own experiences and premises behind the wheel.



Drawing of a driver's position

It's been this "love to drive"—the feeling of freedom, of raw power, the sound of an accelerating engine—that has attracted talented engineers to devote their whole lives to car development. The ones who love to drive want to work with cars. The automotive industry has for many years been a club for car lovers, generating a homogeneous composition of insights – a *status quo* in the working environment.

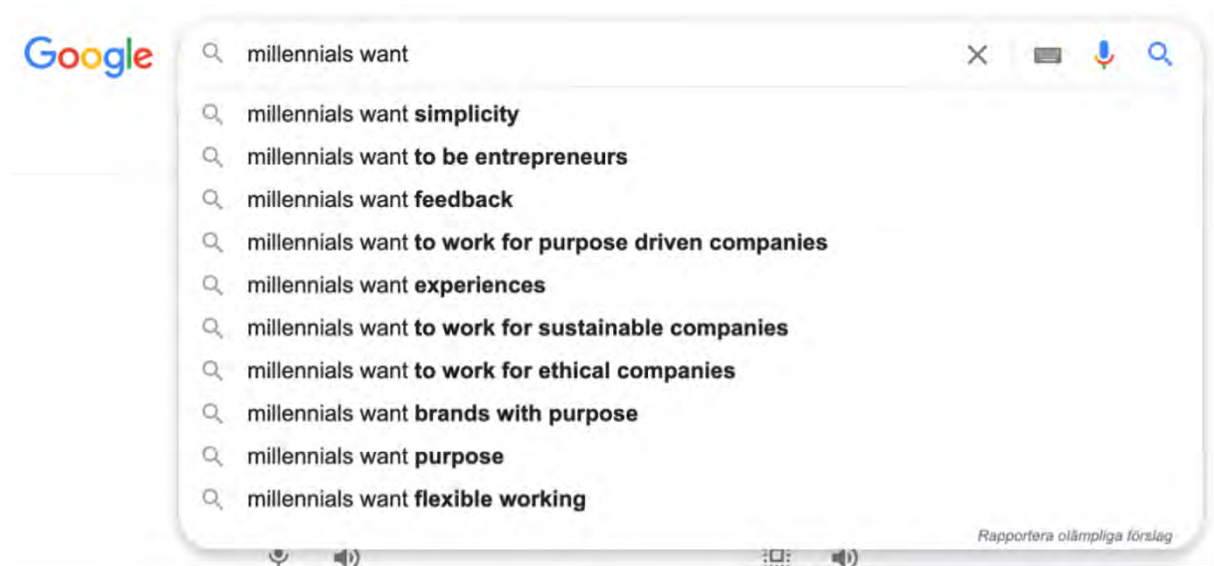
The growing awareness of climate change in society, in combination with the obvious relation between traffic jams, pollution and cars, has ignited a push for the delivery of smarter and more environmentally-friendly environmentally friendly mobility solutions to cities. Preferably from the automotive industry, since they control the vehicle manufacturing know-how. But the automotive industry stands perplexed: what is

demanded from them is true disruption and a completely new mindset in terms of car design, user needs and new business models. Simultaneously, the development of autonomous driving (AD) software, developed by software companies, is pushing the automotive industry towards the terrifying insight that their holy grail, the perfect driving experience—the love to drive—may soon be redundant for the masses.

A transforming view on automotive industry

Today, the privately owned car stands still 95% of the time, using city streets and expensive land for parking. During peak hours the roads are filled with them—one person per car—driving 10 km/h¹, in or out of the city, creating congestion as well as pollution.

To many, the car is a personal statement, closely connected to style and image. Car brands buy reports and analysis tools to identify their target groups², and invest billions on marketing and brand building. For more than a hundred years, buying a certain car brand, has made you a certain type, or confirmed your type. Late millennials (born during the 90's or according to some, stretching into the beginning of the 2000 first decade) are moving towards a different buying pattern than older generations. Late millennials never bought an LP or a CD record. Instead, they *rent* bags, clothes and equipment, they *stream* music, films and TV series. They consume experiences, they do not focus on ownership to the same extent. They don't express themselves with things. To them, and to the next "Greta generation", what matters is a sustainable and life-worthy future. Younger generations are starting to question the prioritization of space for car usage and car ownership in urban environments.



Google's pre-selected suggestions on what millennials want.

Source: screenshot August 2021

To cities, cars are a major burden. While waiting for the automotive industry to innovate the burden away, city councils and law makers are doing what they can to reduce traffic and to create a pull for mobility innovation. The Swedish Transport Agency is just *waiting* for car developers to approach them with autonomous pilots for approval. In the city of Beijing, you must win a lottery in order to get the right to a license plate. If you have the

¹ <https://www.latimes.com/nation/la-na-new-york-traffic-manhattan-20180124-story.html>

² http://www.sigma-online.com/en/Home/SIGMA_Global_Milieu_Research_eng.pdf

luck to win the lottery and buy a car, you are allowed to drive it only certain days (e.g., the odd-even license plate policy, the yellow label car policy, the end-number policy) and there is nowhere to park. Milan, London and Paris have banned cars from some streets in central areas. Recently, cities started to investigate the “15-minute city” concept³, i.e., decentralizing services and workplaces to smaller hubs, closer to where people live. The ineffectiveness of traffic has been around for many years, with no solutions delivered from the source of the problem—the automotive industry. Governments as well as citizens around the globe are gradually losing patience.

Facing three trends

Three trends are pushing the automotive industry towards disruption. *Electrification*, through the newcomer Tesla. *Autonomous drive*, through software companies like Google/Waymo and *Shared Services* (read: *shared rides*) through companies like Uber and Didi Chuxing. None of the trends would individually disrupt the automotive industry, but the three combined create the building blocks for a new, potentially superior mobility service: “robotaxi”⁴. The automotive industry has not initiated any of these trends, but it will have to understand and adapt to the robotaxi development in order to survive. Will the “Love to drive” mindset within automotive become a “Die for love” situation for the industry? Or will it adapt in time and survive the transformation?

What does “robotaxi” mean?

A Robotaxi is a taxi service using digital, non-human drivers to drive the vehicles. The business model for a robotaxi service requires a fleet of vehicles to be connected to a fleet management system for optimized availability, utilization and for positive environmental effects, such as reduced congestion and pollution in urban areas. A robotaxi service system will likely partner up with local authorities or be procured as part of public transportation systems, to varying degrees, to optimize service level and traffic flow. The robotaxi service and its partners will encourage the users to *share rides*, which is key for reduced congestion, using different incentives.

As with all hyped words, “robotaxi” will be used for a variety of services wanting to be cool. What’s important to understand is that a robotaxi is not a privately owned car rented to another private person at the car owner’s convenience. The sustainability benefits and big revenue streams from robotaxi services cannot come from individual vehicles, but require a critical mass.

Electrification: Did ‘Macho’ make the automotive industry a fossil fuel friend?⁵

In the beginning of the 1900’s, when the car was a new invention, there were two engine solutions competing to win the car application race—the combustion engine driven by fossil fuel and the electric engine. The combustion engine car was dirty, noisy and tricky to ignite with a crank in the front of the car. The electric engine was quieter, cleaner, made the trip more convenient and was easy to start. But battery capacity was

³ <https://www.bbc.com/worklife/article/20201214-how-15-minute-cities-will-change-the-way-we-socialise>

⁴ <https://en.wikipedia.org/wiki/Robotaxi>

⁵ Marçal (2020)

weak and could perhaps not evolve fast enough to compete with the combustion engine car and its rapidly expanding petrol station infrastructure outside cities.

Electric cars could have had a chance to be superior in urban, shorter distance environments where charging was not a problem. But the combustion engine's PR people succeeded in launching the idea that electric cars are for women, since they were so comfortable, quiet and clean. And everybody knew that products made for women are not for *real* men to use (while the opposite was okay). The battle was won by the dirty combustion engine, and it succeeded in keeping the lead for about a hundred years or so, until Tesla was born and ignited the start of the next revolution.



"It is now possible for the owner of an electric car to install his own charger at home in the stable" Source: New York Times, 1911, cited in Kilson (2016)

Painting the future of mobility

Electrification, autonomous driving and shared services are the three important ingredients for inventing urban mobility solutions that will solve the two major challenges for urban and metropolitan areas: congestion and pollution. It can also solve mobility challenges in rural areas: poorer public transport due to the long distances involved, and fewer people.

Environmentally-friendly, multipurpose-designed, self-driving vehicles, connected as a fleet to an operator and a fleet management system with algorithm-based route planning, will enable for the user to order a ride, on-demand, from A to B within a city or an area.

The elimination of a human driver makes the operator's cost to go down by approx. 40%, according to public transportation companies in Sweden and interviews with taxi companies, and the price per trip should then become cheaper. Cities can to a greater extent than what is done today, ban privately owned, human driven

cars from city centers by providing a superior public transportation system that includes self-driving vehicles enabling door-to-door or last-mile mobility to citizens and goods at any time. Seamless mobility, available to all.

Key components of such a system are:

- The purpose-built vehicle and its digital driver (AD, autonomous drive) system;
- The fleet management system including route optimization, predictive travel planning, cleaning, service, over-the-air software (SW-OTA) and maintenance;
- The mobility service (including app user interface(s)); and
- An existing infrastructure interface.

Level 4 digital drivers exist today (see chapter 'Autonomous maturity and self-driving levels' below). Purpose-built vehicles exist in low-volume prototypes. Fleet management systems exist. Apps for ordering transport exist. The ecosystem putting all these together does not exist—yet.

These completely new mobility business models will cannibalize the very core of the automotive industry—private car ownership. Which is why the push for these new businesses is not coming from within the automotive industry itself, but from its challengers. But the main component of such a mobility system is the purpose-built vehicle, designed for mass-production. Developing and manufacturing a safe and secure vehicle in high volumes is not easy, nor cheap, and the knowledge on how to do it is to be found in the reluctant automotive industry, which is why full-scope, user optimized solutions are yet to be launched.

Prerequisites for new business models

One advantage of self-driving vehicles is that they can move between, and to, the customers by themselves, which traditional carpools cannot offer. Also, autonomous fleets do not need to pay a human driver, which car-hailing and taxi companies have to today. A disadvantage is that the model relies on vehicles that are expensive to manufacture for a few more years and they may also need to update part of the sensor suite (hardware) several times during its lifetime. For an operator, utilizing the vehicle fleet many hours of the day, this is manageable, but it's not as suitable for private ownership. Which is why self-driving fleets will be operated in dense areas with many people in need of transport.

What role will the traditional car manufacturers take in this new eco-system? Will they rethink their business models, or will they simply become a hardware contract manufacturer with minimal margins into this emerging new ecosystem, like Foxconn within the smartphones segment?

The definition of premium and performance

The definition of a premium, high performance automotive brand historically, has been about attributes such as leather seats, flat, big and wide tires, double exhaust pipes, 0-100 in x seconds, perfect "fit and flush" and highway adapted comfort. It has been about engine performance and a luxurious interior, optimized for a driver. Human driven, high-performance sports cars (e.g., Lamborghini or Koenigsegg) is a niche segment that will probably survive the mobility transformation, like the horse also survived the last big mobility transformation. Horse riding became a hobby for horse lovers.

"Premium" for mobility users though, is something different and the future definition of premium is a hot topic in automotive today.

MaaS and stepwise emerging ecosystems

MaaS stands for Mobility as a Service. In order to claim to be a real MaaS, more than one transport method is required on the platform. E.g., taxis, buses and e-scooters that are sharing the same MaaS platform.

Will robotaxi fleets become a public transport competitor, or will they become the public transport 2.0? The optimized business models for autonomous city mobility are yet defined. What most sector analysts agree on though, is that self-driving cars will not to be privately owned. The point is to *share vehicles as well as share rides*. As mentioned, cars are standing still 95% of the time. And when used, most cars move just one occupant. It's not sustainable and cars take up a lot of city space that could be used for other things.

The automotive industry is one of the biggest consumer markets globally. As this shrinks and new business models replace sold vehicles to sold kilometers, the robotaxi industry could grow to be worth 2 trillion USD by 2030⁶. A fully functional fleet of self-driving vehicles, managed by a fleet management system, making the vehicles always appear where the mobility need is high, requires an ecosystem of partners. In this ecosystem of robotaxis, vehicle fleet density prediction is key, to be able to predict where and when you are needed, during the 24 hours of the day. The higher the accuracy in predicting mobility need, the shorter the waiting times for users, enabling a higher service level and higher usage attractiveness. The solution itself would be able to radically reduce the number of cars as well as replace busses and small trucks in a city, which is the incentive for cities.

Several areas of expertise are required to assemble the full puzzle; these will likely include vehicle manufacturers, operators, AD developers, route optimizing developers, user app developers, the city and its infrastructure interface (roads, charging stations, traffic signs, traffic lights, etc.), regional regulators and national law makers. It may seem to be a complex puzzle to put together. But when some stakeholders within automotive industry say "full AD is many years away", they have an agenda and they are not referring to robotaxi, but to level 5 fully autonomous, privately owned vehicles that can drive themselves anywhere, under any conditions. These stakeholders within automotive industry still regard AD as the endgame on an evolutionary path passing a number of ADAS (advanced driver assistance systems) feature steps. They do not regard AD as the revolutionary leap it is—a business enabler and a tool for superior mobility, developed and optimized explicitly for its ODD⁷ (operational design domain), giving AD the opportunity to cut many years of development time and reach the market as we speak.

Expected steps towards a mature AD mobility ecosystem

Robotaxi operations will grow and mature gradually over time, simultaneously as it is utilized, in terms of operational geographic size as well as in vehicle maximum speed and ODD complexity. We will see existing AD pilots – already today using all necessary pieces of the ecosystem puzzle performing in MVP versions – gradually mature into more and more advanced mobility services, spreading over bigger and bigger areas, moving into city centers from suburban test environments, adding more advanced and optimized vehicles. The

⁶ According to UBS analysts, cited in <https://www.bloomberg.com/news/articles/2019-05-23/robo-taxi-industry-could-be-worth-2-trillion-by-2030-ubs-says>

⁷ An Operational Design Domain (ODD) is. [a] description of the specific operating domain(s) in which an automated function or system is designed to properly operate, including but not limited to roadway types, speed range, environmental conditions (weather, daytime/nighttime, etc.), and other domain constraints. https://itlaw.wikia.org/wiki/Operational_Design_Domain

optimization will happen simultaneously and in parallel within the different fields building the complete ecosystem.

- Legislation will evolve side by side with AD pilots. The willingness to innovate legislation has developed over time and is in good shape among authorities within the field.
- An AD optimized vehicle will “package protect” for continuous hardware updates for sensor suite and interior, parts with a shorter lifetime than the vehicle itself. AD vehicle start-ups will evolve and integrate user-centric features such as complete privacy, shared privacy and socializing settings. E.g., hi-fi sound systems in combination with interior disco lighting, which up until now has been impossible (illegal) due to driver disturbance. Safety features will be added on gradually as start-ups learn. The design of the autonomous vehicle will play an important role for the potential profit of the ecosystem. If designed correctly, the autonomous vehicle will enable for a radically higher utilization of the fleet. The most mature start-ups will be acquired by the big OEM’s and be upgraded for mass-production.
- Robotaxis will be able to provide a higher level of personal security than traditional public transportation. This is especially important to many user groups during nighttime, which happen to be a perfect combination, when one considers fleet-utilization optimization. When vehicle fleet utilization is low, the demand for individual travel is high.
- User behavior and travel patterns from pilots will develop fleet management algorithms, pricing and campaigns. As fleet management develops, it will gradually become more and more predictive, and vehicles will appear where and when you need them. The development of vehicle fleet optimization during the 24 hours of the day has an unknown potential, but the company who can best optimize and weigh vehicle fleet density with prediction of user mobility need, will probably be one of the winners of the AD ecosystem market.
- Climate change and extreme weather will push politicians to learn about future mobility and adapt traffic infrastructure (e.g., AD priority lanes, facilitate build-up of charging and fleet service infrastructure) for smoother and faster transition to AD optimized traffic environment. AD priority lanes will work as carrots for tech-sceptic people, when they realize that robotaxis are whizzing past the slower, congested human driven car lanes they are using themselves.
- Smart traffic light technology is on its way, but as with any infrastructure update, it will take years before we reach to a level when we can really see Vehicle to Infrastructure (V2I) being applied. Therefore, AD pilots today are relying on existing, local infrastructure pillars.
- Countries that have not yet digitized their traffic sign databases, will do so over the next coming years and make them available through secure cloud solutions or for download.
- Public transport operators will add AD mobility to their fleets, initially focused on low density, low complexity areas on the countryside to push operating costs down and raise service levels in these areas. Much later, they will understand the potential of urban, individualized AD services.
- Innovative taxi companies, who are already are using fleet management optimization and user apps, will build consortia and invest in AD vehicles with the goal of becoming robotaxi operators.
- Remote driving companies (most of them now delivering technical solutions to the mining industry) will fill an important role while AD software is being brought to maturity, contributing with back-up

drivers remotely from fleet management control towers.

- During a transition period, taxi drivers will be trained by the operator companies to become back-up drivers, supervising autonomous vehicles remotely. In some cases, one driver per vehicle, and gradually, depending on AD maturity, up to many vehicles per back-up driver. It may take time before AD vehicles are smart enough to take illegal yet correct decisions in traffic (so-called extreme cases). E.g., if an accident has happened and the police were redirecting traffic flow to the wrong side of the road. In those situations, when the AD vehicle must maneuver to the other side of the road, a remote, human back-up driver is the fastest and easiest solution, until the AD system can handle those circumstances. The most advanced AD systems today are smart enough to take responsibility for the decision when to hand over responsibility to a human driver in a controlled and calm manner (meaning without time pressure) within its ODD. It is also a hygiene factor for increased degree of ecosystem maturity over time that it can do so.
- AD companies are training algorithms to handle and understand one geographic area at a time. They are locally focused, and we will see either the AD companies gradually spread over wider geographic areas, or locally adapted companies, specialized on certain markets or certain conditions.
- End-user payment methods will transform from simple, single-use tickets based on distance and the number of accepted (by users) co-passengers in the vehicle, to flat rate subscriptions as endgame. Initially rides will be ordered through apps. But as vehicles become more predictive in their behavior, one can imagine a future where the vehicles are available as a service to the citizens to use completely seamlessly, like a free-floating pod conveyor belt, or like a blood stream of blood cells on the roads. Jump in, jump off, and the vehicle know where you are heading, you just have to confirm.
- Initially, vehicles will not use the advantage self-driving vehicles have, to connect themselves vehicle to vehicle (V2V) in dense traffic into a “virtual train”. But this too will be added onto the robotaxi system as a feature called platooning, with time. Platooning is today most relevant for heavy-duty vehicle development, due to aerodynamic efficiency and energy saving possibilities.

Current landscape

It's difficult to accurately determine the amount of money being shoveled into these new technologies, but a study by the Brookings Institute estimated that investment in the autonomous technology ecosystem was at least 80 billion USD, in 2016-2018 alone.⁸

Pilots and trials have been in operation for some years now, in numerous set-ups. Below are a few of the bigger ones:

Waymo One (Alphabet Inc.) – Developing a digital driver and mobility service

⁸ Deloitte Review (2018)



Waymo One is an ongoing pilot in Phoenix City. Since December 2018, Waymo has been driving autonomously with 400 vehicles within a geofenced area, enabling for self-driving mobility to the public. They had more than 20 000 people signed up as test-users before the service was even launched. In the beginning Waymo used back-up drivers in the vehicle but not do not any more.

Waymo still lacks a purpose-built vehicle, so they are forced to use the Chrysler Pacifica: a traditionally designed car, optimized for human drivers.

AutoX – Developing the digital driver



AutoX was the first US based company to get a permit to drive without a human back-up driver on public California roads. AutoX has pilots in California as well as in Shanghai, offering a robotaxi service in speeds up to 70km/h in complex city traffic.

Partner AutoNavi (owned by Alibaba) is the mobility service provider, delivering the user app.

AutoX lack a purpose-built vehicle to its services.

Navya – developing a purpose-built vehicle



Navya has built a mobility shuttle for autonomous driving. It has produced in small volumes (170 to be exact, in mid-2021) and sold to 22 countries for autonomous operations in low speeds.

Navya lacks the knowledge to build high speed vehicles in mass production. At this point they are focusing on developing vehicle design and testing in small scale.

Zoox – developing a self-driving mobility service including own purpose-built vehicle



Zoox's plan is to provide autonomous mobility-as-a-service in dense urban environments. They will handle the driving, charging, maintenance and upgrades for the fleet of vehicles. They are in prototype phase. In 2020, Zoox joined forces with Amazon.

Tesla – electrification packaged in traditional car design

Tesla uses traditional automotive industry business models (private ownership) and adds to this, charging infrastructure, Software over-the-air updates (SW-OTA) and other SW features that extend the “car ownership

experience”. They are also discussing whether to add a feature that allows you to rent your Tesla to others, which they call robotaxi.

They are building their brand on excellent performance – acceleration, speed and (rocket-) power. Maybe traditional macho values were necessary to finally wash the female touch off the electric machine?

Tesla has so far not revealed any plans to release a vehicle optimized for real robotaxi services.

Apple – project Titan, what is it?

Apple has applied for a permit to drive autonomously in California. There are rumors that Apple is developing a self-driving, electric vehicle, and there is even a Wikipedia page summarizing all these rumors, year by year⁹. Fans and reporters in the automotive media are speculating about car manufacturing sites. They have the knowledge to integrate software and hardware into seamless perfection, could they be working on the user experience for robotaxis that we are waiting for?

Robotaxi mobility – the components needed for a fully functional system

The vehicle (and vehicle manufacturer)

Traditional vehicles are designed for an optimized *driver* experience, passengers being second priority. Robotaxi vehicles are designed for shared mobility where all occupants are passengers, with needs of equal value.

Many companies are exploring the field of autonomous mobility vehicle design. The completely different set of user needs will affect a range of design decisions. Will a city of self-driving vehicles need vehicle safety systems such as seat belts? A self-driving vehicle does not need a front and back – will fellow road users want to see the vehicle direction intention, or could the car be bidirectional? Robotaxis will pick up and drop off people by the roadside many times a day; will this affect steering radius capabilities? Will a fleet of electric robotaxi vehicles become a battery supply for the city grid, by making the vehicle charging system bidirectional? Lacking the mechanical steering wheel, will a redundant steer-by-wire system be required? Packages and goods do not need active and passive safety features, will vehicles transporting only goods be simpler and cheaper to produce when there is no human to protect?

Some start-up companies have ambitions to become future big players within this field (Navya, Easymile, Zoox). Their biggest challenge will be the manufacturing, engineering and financing of the transformation from small scale to mass production. Big OEMs like Toyota (E-palette concept) and Tier 1s like Continental are exploring the area. Their challenge is to think outside the box and to get the internal funding for a future business that will cannibalize its main business.

Below is a short summary of the difference in mindset between traditional car design and robotaxi vehicle design.

⁹ https://en.wikipedia.org/wiki/Apple_electric_car_project

Multiple user needs

A robotaxi is a people-mover and will have to be able to handle multiple user needs. These include the need for privacy, need for socializing with friends and family, need for bringing packages, trolleys or wheelchairs. To optimize utilization of each vehicle during the 24 hours of a day, the vehicle interior benefits from being flexible with the ability to change settings between different user modes. To be relevant as a mobility partner to a city, the robotaxi operator has to offer a democratic solution, available to all.

Shared privacy

Sharing rides—and not only sharing vehicles—is important for reducing congestion during peak hours. The key is to make the interior design secure for, and between, passengers who are strangers to each other. A traditional public transport vehicle, like a bus or a subway car, uses the many people as a personal protection between passengers. In a small, intimate space like a robotaxi, the interior design must be able to offer security between occupants—upon user request.

Materials

Robotaxi vehicle design is closer to public transport vehicle design than to traditional car design. The vehicles will need to be easy to clean and maintain, using removable and changeable parts made in robust, solid, sustainable and recyclable materials.

Shorter trips

The robotaxi will be designed for short trips on urban roads, since the vehicle fleet never leaves the territory, it is operating in.

Since you are sharing rides with others, while the trip is shorter, the reclined position is straightened up to a more upright position, affecting vehicle height. This also has to do with integrity; people don't want to lie down close to a stranger.

Vehicle production

Mass production of cars is expensive and complex. Lemons are simply not allowed when a failure can be fatal. Investments in tooling and equipment are extensive and most of the production is automatized. Start-up companies have a huge challenge switching from prototype scale to mass production. The newest car player on the market, Tesla, had big problems to keep budget and timeline (they didn't), despite strong investors. Elon Musk referred to the challenge as "production hell".

Who wins this design race is yet to be revealed. The automotive industry is in no hurry. But society and the climate are, so when the solution is launched, the billion-figure target group will have waited long for sustainable mobility already.

The digital driver (and its developer)

Autonomous driver development, often referred to as the 'digital driver', is divided into five subcategories: localization, perception, planning, vehicle motion control and coordination. The autonomous driving company takes responsibility for some of these, and the vehicle manufacturer for some, including integration on the electrical platform. A close partnership is optimal.

Autonomous maturity and self-driving levels

The level of autonomy in self-driving systems are described by the SAE standard levels 0 to 5 (see picture below). Level 0 to 2 are human-driver-support systems. Level 3 is a mix between human driven and machine driven and is considered to be challenging to use in reality, since humans are an unreliable back-up system for a machine. Level 4 and 5 are systems where the digital driver has full responsibility for the driving. The difference between level 4 and 5 is that level 4 has limitations, such as a steering wheel where a human can take over when the digital driver asks for it without rush, or it drives in all conditions, but only within a certain area. While level 5 can drive everywhere, in all conditions.

There are several companies at driving level 4 now, but no company is officially offering level 5 yet. Level 4 is enough for robotaxi operation.



SAE J3016™ LEVELS OF DRIVING AUTOMATION

	SAE LEVEL 0	SAE LEVEL 1	SAE LEVEL 2	SAE LEVEL 3	SAE LEVEL 4	SAE LEVEL 5
What does the human in the driver's seat have to do?	You are driving whenever these driver support features are engaged – even if your feet are off the pedals and you are not steering			You are not driving when these automated driving features are engaged – even if you are seated in "the driver's seat"		
	You must constantly supervise these support features; you must steer, brake or accelerate as needed to maintain safety			When the feature requests, you must drive	These automated driving features will not require you to take over driving	
What do these features do?	These are driver support features			These are automated driving features		
	These features are limited to providing warnings and momentary assistance	These features provide steering OR brake/acceleration support to the driver	These features provide steering AND brake/acceleration support to the driver	These features can drive the vehicle under limited conditions and will not operate unless all required conditions are met	This feature can drive the vehicle under all conditions	
	Example Features	• automatic emergency braking • blind spot warning • lane departure warning	• lane centering OR • adaptive cruise control	• lane centering AND • adaptive cruise control at the same time	• traffic jam chauffeur	• local driverless taxi • pedals/steering wheel may or may not be installed

The Levels of Driving Automation

Source: SAE (2018)

Components of a digital driver

- Localization – Where am I?
- Perception – What do I see?
- Planning – Where do I go?
- Vehicle motion control – How do I control and secure the vehicle movements?
- Coordination and multi-vehicle coordination – My relation to traffic surroundings

The user app (developer and operator)

The user app is developed and managed by the fleet operator. The fleet operator is close to the end-user, and responsible for customer service, route planning and payments. The operator will own much of the incoming user data, which will be used for improved product development, targeted campaigns and as assets for third party acquirement. A robotaxi operator is a mix between a traditional taxi service and public transport. Many taxi and ridesharing companies, like Uber and Didi Chuxing, are investing in autonomous driving in a bid to reduce the cost and complexities associated with having a human driver.

Public transportation companies are also investing in AD. SL (Stockholm public transport) has a collaboration with Nobina, driving autonomous buses in Barkarby. Public transport company Ruter in Oslo has driven more than 33 000 km with autonomous Navya buses and Toyota cars since 2019.

Apart from the obvious app features like the ability to order a ride, the user interface of a robotaxi service will have to be integrated into the vehicle user interface system (screens etc) seamlessly. Should the car door be possible to open through an app? How do you secure the right vehicle to the right person at a queue situation outside a building? How much of a person's travel behavior should be remembered to next time vs integrity?

The operator will design the different payment methods, such as pay-per-km, flat rate subscriptions or monthly fees. The operator will also design the route planning system, whether fixed routes or on demand is best for a certain area or hour of the day.

Emergency staff may require a user app of their own, controlling some vehicle features in case of an emergency.

The fleet management system

A wide range of components are included in a fleet management system. From basic needs such as cleaning, charging and maintenance of the vehicles, to the algorithms for route optimization and integration with the city's infrastructure.

Over a longer period, perhaps years, remote driving/remote operation possibilities could be used as a back-up for the digital driver, when illegal maneuvers are needed, e.g., driving on the wrong side of the road to avoid an obstacle. Many self-driving operators use human back-up drivers inside the vehicle today. Remote operation, however, allows one operator to supervise several/many vehicles simultaneously.

Most components of a fleet management system are already in use within the (public and goods) transport sector.

The infrastructure interfaces

A city provides a robotaxi fleet with roads, traffic lights, traffic signs, road works, charging stations and parking availability, sometimes through partners. The city might also provide special fast lanes for shared mobility and other encouraging regulations and carrots to incentivize people to take on sustainable travel behavior.

Existing infrastructure interfaces are good enough for a robotaxi fleet to enter the market but can, and will be, improved for increased efficiency over the coming years through smart city¹⁰ development, e.g., smart traffic lights that communicate with their surroundings.

Local regulations for a robotaxi operator

Cooperation with local public service providers will likely be mandatory for a robotaxi operator to be able to reach the public in many European cities. Most European countries are regulating new mobility's right to enter a city, although to varying degrees. Sweden/Stockholm is a fairly deregulated area, while Norway/Oslo is highly regulated and a cooperation with Ruter (Oslo public transportation) would probably be necessary for a player who would want to enter the Oslo mobility system.

Legal maturity

Since 2018, KPMG has produced an annual "Autonomous vehicles readiness index", in which they rate countries based on self-driving maturity. In 2020 Sweden was placed sixth, after Singapore, The Netherlands, Norway, United States and Finland. The indicators of the report are organized into four pillars: policy and legislation, technology and innovation, infrastructure and consumer acceptance.

The Swedish Transport Agency has sole responsibility for autonomous pilot approvals and, later on, autonomous mobility systems for the Swedish market. The Swedish Transport Agency operates in the service of society and of its development. Their analysis is that self-driving systems will benefit society through reduced congestion, pollution and offer suburban areas mobility with a higher service level. In dialogue with them, it is clear that they had expected the automotive industry to act sooner. They have been ready to handle applications within the field of autonomous mobility for some time.

The moral compass of a self-driving vehicle – an attractive topic of discussion

Philosophers love to talk about the hypothetical moral dilemma a self-driving vehicle might face, by exemplifying a story with a car that must choose to crash into an old lady or a trolley with a baby. People prefer to believe to be smarter than machines and are trying to identify situations unmanageable for AD vehicles.

AD developers say though, that these imaginary moral challenges are nowhere to be found in reality, according to millions of kilometers of data collected so far. If a self-driving vehicle is confronted with a potential accident

¹⁰ European Commission, no date

situation, the vehicle will calculate risks based on likelihood, speed, deceleration and alternative maneuvers. A self-driving vehicle will try to minimize risk of injury based on probability, while a human driver risk being prejudiced or take bad decisions due to tiredness, screaming children in the back seat or by being affected by alcohol. The World Health Organization estimates that there are 1.35 million road deaths and 50 million injuries annually. With human error responsible in around 95 percent of cases, autonomous vehicles have the potential to reduce these casualties dramatically¹¹.

Industrifonden's investment hypothesis

We will invest in key solutions that could have been expected from the automotive industry and look for an optimized user experience on an ecosystem level:

The missing piece in a complete, seamless robotaxi ecosystem, is a contribution from the automotive industry—the purpose-built, mass-produced vehicle, available to operators to a realistic cost.

As long as the automotive industry continues to hold the autonomous revolution back, while society is screaming for sustainable, urban transport innovations, we believe that companies who deliver smart solutions in this field have a prosperous future ahead.

In order to be successful in this new, emerging industry, it is important to have a clear picture of the complete puzzle and how to contribute to the ecosystem. The closer to the robotaxi end-user you are with your product, the higher the quality of your input usage data will be, and the better your ability to develop your products and continue to be relevant in a fast-growing, rapidly changing market.

Industrifonden will be interested in companies that deliver core components to the robotaxi mobility ecosystem. We are looking for founders with a true passion to revolutionize the automotive industry. The company should strive towards offering cities a sustainable and democratic mobility solution, with the aim of reducing the number of cars on the roads.

¹¹ KPMG (2020)

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