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Autonomous cars: The next revolution looms

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Introduction

If only technical issues mattered, driverless vehicles would soon be common place: After 40 years of research the technology is close to leaving the prototype stage: Late in 2007 six autonomous vehicles successfully completed a 90 kilometer test course of simulated urban traffic.[1] The completely driverless cars had to obey California Driving Rules, watch traffic lights, avoid other cars, negotiate their turn at four-way intersections, etc.

Despite of these successes, little progress will be made (except, unfortunately, on the battlefield) as long as our societies continue to ignore the huge social, economic and environmental benefits of this technology.

In the following, we examine how automated vehicles will fundamentally change our transportation infrastructure and provide the opportunity to make our societies better – less dependent on oil, less-resource consuming, with less carnage on the roads and with more freedom for the old, young and underprivileged.

Towards car-sharing

From an economic perspective, privately owned cars are extremely underutilized assets: They sit idle almost all of the time, aging and wasting space on a parking lot or in a garage. This will change: A car that can drive a passenger into town on its own does not need to wait there until the passenger needs it again. It can drive others in the mean time.

Car-sharing organizations and rental car companies are best positioned to take advantage of this new capability: They will develop novel mobility services based on autonomous cars. Once their fleets reach a certain size, they will be able to offer almost instant transportation services to anyone: Whenever you need a car, it will arrive at your doorstep in just a few minutes. Initially, such services will be most viable in high-density urban areas where space is at premium and many residents don't own a car. As such services grow, as mobility providers optimize their business models and as network effects kick in, the costs of renting will fall dramatically. It will not take long until the costs will fall below the costs of owning. This will entice more and more consumers to stop buying their own cars but rather rely on shared car ownership. This effect is self-reinforcing and will lead to huge economic, life-style and resource-conservation benefits for society.

Key benefits of autonomous cars

- Greatly reduced mobility costs through car sharing
- Simplify introduction of alternative fuels
- Greatly reduced traffic fatalities
- Better road utilization, fewer roads needed
- Combat climate change (higher passenger-mile per-gallon)
- Elderly can live on their own much longer
- Revolutionize product distribution
- Improved disaster response (hurricane, epidemics etc)
- Optimal integration of private and public transport

The following factors drive down the costs. Combined, they should easily be able to halve the average mobility-cost per household.

Increased utilization rate

When vehicles are shared, their utilization rate (the average number of hours it carries passengers) increases which in turn decreases the capital costs per kilometer. Shared vehicles should be able to achieve an increase in utilization per vehicle by a factor of at least 5, maybe even 10. But the capital costs per kilometer will be reduced by an even larger factor because rental vehicles will differ from privately owned vehicles and are – on average – much less costly (see next section). The ability to manage fleets of cars instead of an individual car will also reduce maintenance costs and increase the life-span of a vehicle.

Vehicle differentiation

Today's privately owned cars are general-purpose tools. All of our car models are designed to accommodate many different usage scenarios: Commuting alone, short distance shopping trips, taking the whole family on vacation, long distance travel, etc. As a consequence privately owned cars show little differentiation in such crucial attributes as number of seats, range, weight, energy source, speed range. When cars are shared, in contrast, the customer chooses the appropriate vehicle for each trip. There is no need to request a five-seater with a range of 400km for the lonely 15 minute morning commute. Thus cars in a rental fleet will be optimized for a particular usage scenario: Small passenger cars for short-range city trips, vans for the holidays, limousines for showing off.

Most trips occur within the city and cover only a short distance. Mobility providers therefore will operate a large number of small, lightweight, short-range cars which can only transport one or two passengers. While this reduces capital cost and consumes less of our precious natural resources, it also leads to a large jump in fuel efficiency! Switching the average trip to a smaller, lighter car has a much larger potential to increase fuel efficiency than all current technical efforts to develop slightly more efficient engines.

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In the same vein, barriers to the introduction of low emission vehicles and of electric vehicles will fall: Private car owners hesitate to purchase electric vehicles because of their limited range. This is no concern for the short-range part of a car fleet which can easily include electric vehicles. Today one of the major obstacle for the adoption of alternative fuels is the need to invest in distribution systems on a national scale. The problem becomes much more manageable when the fleet contains thousands of short-range vehicles which never leave the city. Local distribution systems can then target specifically this market segment and compete heads-on with the established players.

Thus automated vehicles turn out to be a very green technology. They may actually be a potent technology to combat climate change. Many of the traditional assumptions governing the commercial viability of green automotive technology become obsolete.

Better public transport

Automated cars are ideal for delivering passengers to or from public transport systems. They can coordinate pickup and delivery with the actual timetable of the public transportation system.

Furthermore, when cars are rented, the mobility provider will establish the necessary information technology infrastructure required for coordination. The service provider will be able to anticipate and coordinate travel plans and to avoid congestion through intelligent routing. When traveling longer distances, providers may offer the option to switch to a more public mode of transportation. For example, instead of renting a two-seater to travel from New York to Washington a two-seater may pick up the travelers at their home, drive them a few miles to a gathering location, where the passengers may need to wait for a few minutes until they can change into a larger capacity automated vehicle - a bus. Of course, they are unlikely to have to step out into the cold; they will wait in their car - continue to watch their in-flight movies until the bus arrives (and when they sit down in their seats in the bus, their movie will continue right where they left off). As they reach their destination, their bus may drop them off next to another two-seater which brings them to their final destination. There would be little need for scheduling as the provider could assemble the buses based on actual demand. In this way, the distinction between public and private transportation will become quickly blurred.

Increased road utilization

Rental cars will improve the utilization of scarce transportation infrastructure:

Autonomous cars cause less congestion. Such cars can coordinate their actions on crowded street much more efficiently than human drivers (who tend to start switching lanes, thereby making the problem worse). When waiting at a stop light, all automated vehicles can easily synchronize their actions: As the stop light turns to green, all waiting cars can start moving immediately; they don't need to wait until the car in front has visibly moved out of the way. In cities, this will make a large difference and thus increase the capacity of existing roads. The ability to reduce congestion and increase the capacity of roads has important implications for infrastructure planning. Many roads which are being planned today because of an anticipated increase in traffic may turn out not to be needed any more when automated vehicles become the main stream. Automated vehicles will reduce worldwide infrastructure investments by billions of dollars worldwide.

Rented automated cars have another efficiency advantage: Their rental costs will be lowest when transportation demand is low, i.e. late at night, highest during the peak commute times. When commuters use rental cars, congestion pricing will no longer need to be instituted on the road, it will occur on the car with the added benefit that commuters will have an incentive to car-share part of the way. Long distance travelers who are flexible (students, vacationers etc.) may elect to drive during the night - when costs are lowest. Cars for long-distance travel might even be convertible into sleeper-cars. The economics of automated cars ensure a more efficient distribution of the load on our traffic infrastructure and reduce the demand for peak capacity.

This provides enormous cost and energy saving potential which far exceeds any possible improvements which may still be reached in the fuel efficiency of current cars. Automated vehicles are a very green technology!

Safety

Worldwide, every year more than 1 million people die on the road. Traffic accidents are a major cause of death for young adults. They cause unspeakable grief and impose a large financial burden. While intelligent cars will never completely eliminate traffic accidents, they will greatly reduce traffic fatalities. Humans are no match for automated cars because technology is not susceptible to many of our shortcomings: Automated cars never tire, are always alert, don't drink and have no emotions which might take over at the wrong moment. Moreover, automated cars have extremely short reaction times to external events. They are not measured in seconds but in thousands of a second. They can process a much wider range of information about what is happening around the car; there is no limit to the number and type of sensors. They are also able to communicate among one another. In the same instant that a car hits the brakes it can notify the neighboring cars of this action which can then react almost without delay.

The potential to increase car safety by several orders of magnitude is clearly there. It is up to our society to encourage industry to reach such a safety level. Every child that dies on the road, every youth that ends their live in a car wreck on Friday night is a death too many. Automated cars have the potential to greatly reduce the carnage on our roads, a phenomenon we have grown strangely accustomed to.

Liability trap

But automated cars won't be without their own failures. While we accept thousands of lives ending on the

streets every year because of drunk driving, a single fatality caused by an automated car could provoke a media frenzy and lead to huge liability claims. As long as the car industry must fear that every accident involving an autonomous car will become a feast for litigation lawyers, no such cars will be built and traffic fatalities will continue to be a leading cause of deaths.

This liability trap is an obstacle which car companies can not overcome. It needs concerted legislative action which requires autonomous cars to pass the highest safety standards and then provide clear liability limits. Such safety standards, for example, would require that their fatality rate, is by the factor of at least a 100 lower than the fatality rate of a human driver. Safety institutions must develop agreed upon standards for measuring the safety of such cars. Exacting tests will need to be developed to ensure that autonomous cars behave appropriately. Real-world testbeds will need to be set up with real cars (possibly remote-controlled). Extreme situations will need to be tested - similar to crash tests.

Real-time simulation testbed

But extensive testing in a real setting is very hard. Therefore a real-time autonomous car simulator will need to be developed. Such a simulator will feed the car with simulated sensor information. The car in turn will respond with commands for the drive train, motor etc. These commands need to be returned to the simulation environment which then calculates the speed, location and other physical properties of the car at any moment. Such a simulation environment will have the great advantage of being able to test the behavior of the car in extreme situations (e.g. half of the sensors fail, heavy rain etc.). Such a simulation environment will force car makers, sensor builders and safety bodies to agree on a standard for modeling car control and behavior which would also improve the interoperability of components and thus reduce overall costs. Furthermore, such a simulation environment will provide a boost to autonomous car research: The current rush of countless university research groups gobbling up their own autonomous car prototype, encountering the same problems over and over, could give way to more productive research where different sensor arrangements and command and control strategies could be tested. Advantages and weaknesses of different algorithms could be investigated in detail. At the same time, the development of a real-time simulation environment for automated cars poses interesting computing challenges which will advance basic research.

In the United States, more than ten thousand people are killed each year in alcohol-impaired driving crashes[2]. Such accidents could easily be prevented with autonomous driving technology. Every year which we can speed up the introduction of such cars, we will be able to save this many lives in the United States alone.

Implications for the automotive industry

Autonomous vehicle technology may rejuvenate the automobile industry. It presents many opportunities for new products and services. But established players may find it hard to adjust. The shift towards the rental model will greatly shrink the overall number of vehicles in service, thus dramatically reducing demand in the long term (in the short to medium term demand may actually pick up as a stock of automated cars is built up). Marketing will be turned upside down. Professionally managed car fleets will be less interested in design and brand appeal. They will aim to reduce average lifetime operating costs and focus on maintenance, improved fuel efficiency, fleet integration, etc. They will certainly want to have their say during development. We may find that car marketing will take some cues from the way Boeing and Airbus market commercial airliners.

Fleet managers will always have very specific needs for their cars. As they usually order larger numbers, there will be significant demand for customization. This includes furnishing the interior in the mobility provider's style, adding technology for monitoring, billing, passenger authentication, adding devices to simplify maintenance, etc. While it is possible that established car vendors perform these services, these needs will also lower the barriers for new entrants to the market.

Autonomous cars conserve resources

- Car sharing greatly reduces total number of cars
- Smaller average car size increases mileage
- Fleets simplify introduction of alternative fuels
- Can meld public and private transport
- Improved road utilization
- Fewer roads needed
- Inherent congestion pricing

Some established segments of the car industry will shrink: Fewer gas stations will be needed because it won't be left to chance when and where a car needs to refuel. The dealer networks will shrink dramatically or even vanish. Repairs will be managed by the car fleet which will pay close attention to maintenance costs and durability. The number of repair shops will greatly fall.

New Services and business models

Automated cars are robots. They may become the first major intrusion of robots into our daily lives and into the consciousness of the public. They will change our world view and the way we think about ourselves. For a time, there will be a discussion about whether autonomous cars take away human freedom to drive. This may be a political issue for a while. But commuters will be quite happy to release the steering wheel and it is only a question of time until a broad consensus emerges that humans should only drive cars for fun and certainly only in places where they can not endanger the lives of others.

Automated cars will lead to the emergence of many kinds of new services, most of which we probably can not anticipate today.

New products will arise in logistics and around the delivery of all kinds of products. Supermarkets may use them to deliver their wares to your home (which requires suitable receptacles/receiving mechanisms). Meals on wheels and other services to the elderly may become much more ubiquitous thus enabling the elderly to live on their own for much longer.

Lower distribution costs also increase the ability to rent or share products. Why own a bike when you only use it a weekend or two in a year? Just call the bike shop and your favorite bike will be at your doorstep on Saturday morning. Need special tools - they are just a call away. No need to own a lawn mower; they will arrive at regular intervals. Thus greatly reduced local transportation costs and short delivery times may mean that fewer items need to be purchased for yourself. The storage business could also benefit from the ability to transfer goods automatically between storage site and usage location.

Automated cars imply that machines can move by themselves to the destination where they are needed. This is attractive for agricultural machines and in construction. A logical step is to operate more and more machines by remote control. Smaller special purpose autonomous machines may emerge which only operate in bounded areas such as a construction site or a field. Roving 'inspectors' may become popular - small robots equipped with a camera which can be remotely controlled and feed images about a site from whichever angle and position is needed. Automated vehicle technology will be applied for many smaller autonomous machines. There is a huge potential for them on factory floors, warehouses, hospitals and practically everywhere. Automated vehicle technology will be applied to an incredible variety of moving systems.

Emergency response

Automated cars may also perform a special role in an emergency. They might be able to switch into emergency mode and deliver anybody to the nearest hospital or first aid team at maximum speed. When an earthquake occurs, a hurricane approaches etc. evacuation can be more orderly and faster. In cases of disease outbreaks autonomous cars could help limit the spreading of a disease. Unfortunately, automated vehicles also have offensive capabilities. No wonder that the military is so interested in this technology.

Action items for faster introduction

Governments

- Legal framework to remove liability trap
- Legal framework for inter-car communication
- Legal framework to ensure open access
- Review long-term infrastructure investments
- Encourage testbeds

Industry

- Update scenario planning to include autonomous vehicles
- Adapt portfolio strategy
- Create real-time autonomous vehicle simulator testbed
- Standardize autonomous car component interfaces
- Establish limited local testbeds
- Experiment with autonomous devices on different scales

Academia

- Build economic models of autonomous car fleets to understand evolution paths and success factors
- Fundamental research for real-time simulator
- Algorithms and tools for autonomous cars

Driver Assistance Systems?

At present a large part of the automotive industry and of research funding institutions (especially in the European Union) assume that the best path towards autonomous vehicles is via driver assistance systems. But this focus may be a detour. Driver assistance systems need to solve many hard problems which are not relevant for autonomous systems. They require a strong focus on human-computer interaction and often need to evaluate the intentions of the driver and his alertness state. They are mostly built to handle specific situations - parking, lane assist on highways etc. - and are then optimized for that situation. They don't need a general model of the road and of driving as fully autonomous systems do - instead they need a powerful model of the driver - which autonomous vehicles don't need. With the recent advances in fully autonomous vehicle technology, it seems that research funds will be put to better use on the direct route rather then on the detour of driver assistance systems.

Conclusion

Autonomous cars will greatly impact on our lives. They will make driving safer, more convenient, less energy-intensive and cheaper. They will greatly reduce our CO2 footprint, enhance our freedom and reduce the risk of dying in a traffic accident. They will force us to confront philosophical issues about us and the machines we have created and they will change patterns of work, life and economic organization. Although the benefits are obvious, the current legal framework is still hindering the further evolution of this technology and may thus be responsible for hundreds of thousands of deaths per year which would have been prevented if autonomous cars had reached maturity earlier.

It is time to seriously consider this technology and to put it into service to the benefit of our societies.

About the author

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1 Urban Challenge. http://www.darpa.mil/GRANDCHALLENGE/index.asp

2 2007: 12998 fatalities, 2006: 13491 fatalities. Source: Traffic Safety Facts, Research Note, NHTSA, August 2008, http://www-nrd.nhtsa.dot.gov/Pubs/811016.PDF.