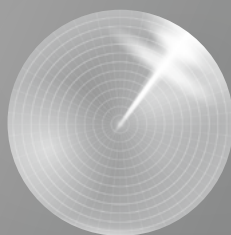




SELF-DRIVING VEHICLES IN LOGISTICS

A DHL perspective on implications and
use cases for the logistics industry

2014



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PREFACE

Next time you are stuck in slow-moving traffic, you'll possibly want to trade your conventional vehicle for an autonomous model. Maybe you would like to read a newspaper, look out at the scenery, or even take a refreshing nap. A switch like this may be possible one day, freeing each driver to do something more productive and enjoyable with their time.

Unlike human drivers who sometimes cannot react fast enough to a sudden road hazard ahead, driving assistants or self-driving vehicles are programmed for constant vigilance and safety. In addition, these systems can find the swiftest route to avoid traffic congestion, reduce motoring costs, and minimize environmental impact, achieving an overall experience that's safer and greener for everyone.

We invite you to join us on a journey to discover the incredible potential of autonomous vehicles.

This trend report examines the distance that needs to be covered before self-driving technology reaches full maturity, and addresses the challenges of regulations, public acceptance, and issues of liability. It also shines the headlights on various best-practice applications across several industries today, and takes a detailed look into the existing technology that's successfully used today as well as some future applications for self-driving vehicles in the logistics industry.

You will learn that logistics provide some of the most ideal working environments for self-driving vehicles. Examples include warehouses and other private and secure indoor locations where goods (not people) are loaded and transported, and relatively isolated and remote outdoor locations where harsh conditions and long hours can put human drivers at risk.

It's no surprise then that the logistics industry has been deploying self-driving vehicles for several years, and is adopting advances in self-driving technology more rapidly than many other industries.

The road to the future is going to be extremely interesting. Sit back, buckle up, and we hope you enjoy this trend report!

Sincerely yours,



A handwritten signature in black ink that reads "Matthias Heutger".

Matthias Heutger



A handwritten signature in black ink that reads "Markus Kückelhaus".

Dr. Markus Kückelhaus

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1 UNDERSTANDING SELF-DRIVING VEHICLES

This introductory chapter sets the scene by providing some common ground for understanding the topic of self-driving vehicles. It offers a technical definition, describes the current developmental status, and reviews the benefits and technological requirements of autonomous driving. This chapter also highlights some key challenges and concerns about driverless vehicles, exploring how society will regulate these vehicles, whether the general public will accept these vehicles, and what changes will be required to insure these vehicles.

1.1 Definition and context

Self-driving vehicles have been defined as “vehicles in which operation occurs without direct driver input to control the steering, acceleration, and braking”,¹ according to the National Highway Traffic Safety Administration. In this type of vehicle, the driver is “not expected to constantly monitor the roadway while operating in self-driving mode”.

This definition assumes that the vehicle will always have a driver. However, this isn't essential – autonomous technologies are already able to perform all of the required functions for a vehicle to move safely from A to B without anyone on board at all.

The widespread adoption of driverless vehicles may seem a distant vision – something we would expect to see in a futuristic movie perhaps. However, the reality is that some of the world's leading automotive and technology companies are already showcasing first prototypes and discussing the advent of “the next automotive revolution”. First trials of fully driverless vehicles are already underway. And if you look closely at the vehicles on our roads today, you'll find that many adopt a number of the key technologies required for autonomous driving.

The race to bring self-driving vehicles to our roads has begun, and it is not just the automotive manufacturers that are leading the charge – as early as 2011, the US tech giant Google famously debuted its version of a driverless car which has since been spotted doing many test rounds on the streets of the US.



Figure 1: An advertisement for America's Electric Light and Power Companies, 1950s; **Source:** Computer History Museum

Beyond testing, how long will it take before we see the first autonomous vehicles on public roads? Some industry analysts predict this could happen within the next three years.

1.2 Key benefits

The hype surrounding autonomous driving clearly suggests that there must be advantages to be gained from investing in driverless vehicles. And these benefits will increase exponentially as more and more people adopt this method of transportation.

Imagine a world where our streets and highways are full of driverless trucks and cars moving in perfect sync with each other. Road traffic accidents caused by human error will become a thing of the past. Our daily commute to work will be stress-free and safe – we'll get into our cars, enjoy a cup of coffee, read the latest news, interact with other passengers, and even catch up on some sleep! The American public had this dream already some 70 years ago (see Figure 1). We'll arrive relaxed and refreshed at our destination and step out of our vehicles and directly in through our office door. We'll leave the car to find an available parking space autonomously.

¹ <http://www.nhtsa.gov/About+NHTSA/Press+Releases/U.S.+Department+of+Transportation+Releases+Policy+on+Automated+Vehicle+Development>

Improved safety: Research indicates that up to 90 % of road traffic accidents are caused by the driver. Advocates for driverless vehicles use statistics like this to argue that autonomous systems make better and faster decisions than humans. They also claim that self-driving vehicles will always monitor and adapt to varying traffic and weather conditions, and will avoid obstacles in the road, doing all this with more diligence, speed, and safety than human drivers.²



Figure 2; Source: Construction Skills Training

Higher efficiency: Traffic can flow faster and congestion can be reduced with autonomous driving. Using vehicle-to-vehicle communication, autonomous systems can set high speeds and intelligently avoid busy routes. With fuel efficiency achieved by optimized driving and by convoying, owners of driverless vehicles can reduce their carbon footprint and motoring costs by approximately 15 %.

In addition, the all-too-familiar time limitations placed on freight trucks will be removed; they will be able to travel 24/7 without requiring driver rest time and – compared with today's driving – could achieve overall cost reductions in the region of 40 % per kilometer.³



Figure 3; Source: Thinkstock

Lower environmental impact: With fewer cars and more efficient fuel consumption, autonomous systems are programmed to minimize environmental impact. Self-driving vehicles can achieve lower emissions. This of course benefits the environment and puts less stress on the road network.⁴



Figure 4; Source: Hutchinson

² http://www.bosch-presse.de/presseforum/download/de/7966ks-d_Anlage_Befragung_Fahrerassistenz.pdf

³ <http://irandanesh.febpc.com/FileEssay/barnamerizi-1386-12-8-bgh%28353%29.PDF>

⁴ <http://www.daimler.com/dccom/0-5-876574-49-1691209-1-0-0-1727129-0-0-135-0-0-0-0-0-0-0.html>

Greater comfort: In an autonomous vehicle, the driver becomes a passenger. He or she doesn't have to watch the road ahead but can rest and enjoy other activities. This also makes self-driving vehicles a very attractive form of transportation for the elderly, underage, people with physical disabilities, and even the intoxicated. Parking a car used to be stressful and time consuming ... but now the self-driving vehicle can find a parking space and, later, return to a specified pickup point all on its own!



Figure 5; Source: MotorTrend Magazine

After evaluating the initial key benefits of self-driving vehicles, the following section provides an overview of existing technology.

1.3 Technology overview

Autonomous technologies have been used productively in a number of different applications for many years. One of the most obvious uses is in aviation – it is considered normal for airlines to deploy auto pilot technology as standard equipment. Other examples include the fully automated metro and shuttle trains that operate in multiple cities and airports around the world.

As with many technological developments, the military sector was an early adopter of self-driving vehicles. A significant example is the military use of autonomous technologies for mine sweeping. This has saved countless lives

by keeping soldiers and civilians out of danger until mines have been detected and safely detonated or disabled.

As seen in Figure 1, people have been thinking about self-driving vehicles for several decades already. Autonomous vehicles were on display as part of the GM Futurama Exhibit at the 1940 New York World's Fair and, by the 1950s, both GM and Ford had running prototypes.⁵

Several simple autonomous features such as an **anti-lock braking system** and **cruise control** can be found in most current vehicles. Beyond these supporting functions, already there are many advanced features that can take over an element of primary control. An example is **adaptive cruise control** which has been included over the past couple of years in selected vehicles. This technology maintains a specified distance between the conventional or driverless vehicle in front (see Figure 6).



Figure 6: Audi's Adaptive Cruise Control helps to keep a safe distance from the vehicle in front; Source: Hearst Communications

Advanced technologies such as this are extremely helpful to drivers, but they fall short of enabling a fully autonomous experience.⁶

To achieve a vehicle capable of driving itself, four basic interdependent functions are required. These are **navigation, situational analysis, motion planning, and trajectory control**⁷, described in further detail in the following section.

⁵ <http://www.wisburg.com/wp-content/uploads/2014/09/%EF%BC%88109-pages-2014%EF%BC%89MORGAN-STANLEY-BLUE-PAPER-AUTONOMOUS-CARS%EF%BC%9A-SELF-DRIVING-THE-NEW-AUTO-INDUSTRY-PARADIGM.pdf>

⁶ <http://www.mrt.kit.edu/z/publ/download/2014/ZieglerAI2013ITSMag.pdf>

⁷ <http://www.mrt.kit.edu/z/publ/download/2014/ZieglerAI2013ITSMag.pdf>

Navigation

Navigation is essentially route planning. More specifically, it creates and recalculates a digital map that includes information on locations, road types and settings, terrain, and weather forecasts.

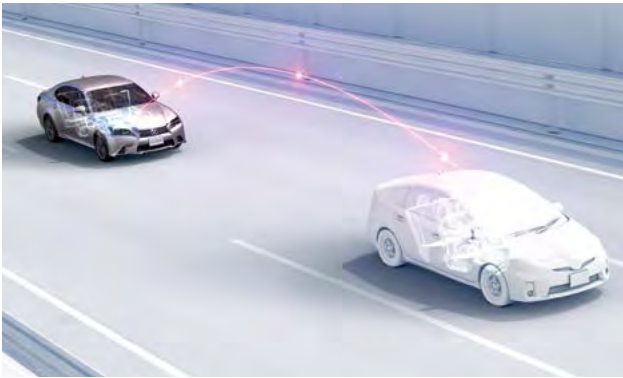


Figure 7: Safety-related information is instantly communicated with V2V communication; **Source:** MotorTrend Magazine

Nowadays, vehicles complete route planning using **global positioning system (GPS)**. In the fully autonomous vehicle, however, navigation is enhanced by integrating **vehicle-to-vehicle (V2V)** communication (see Figure 7).

This describes the ongoing exchange of data between vehicles via communication systems such as wireless local area networks (WLANs). With V2V communication, the autonomous system can recognize critical and dangerous situations at an early stage, and receive the required safety-related information within a fraction of a second.⁸

Situational analysis

Situational analysis monitors the environment through which the vehicle is moving to ensure the autonomous system is aware of all relevant objects and their movements.

Visual image recognition techniques, broadly defined as **video cameras**, identify relevant objects in the environment such as other vehicles, pedestrians, traffic signs, and traffic lights (see Figure 8).⁹ Additionally, precise positioning data can be obtained using **markers** embedded in the infrastructure. This solution is often deployed in warehouse applications (described in more detail in Chapter 3) – with markers it is possible to successfully track the position of all moving vehicles in a defined area, and detect any obstacles in their way.

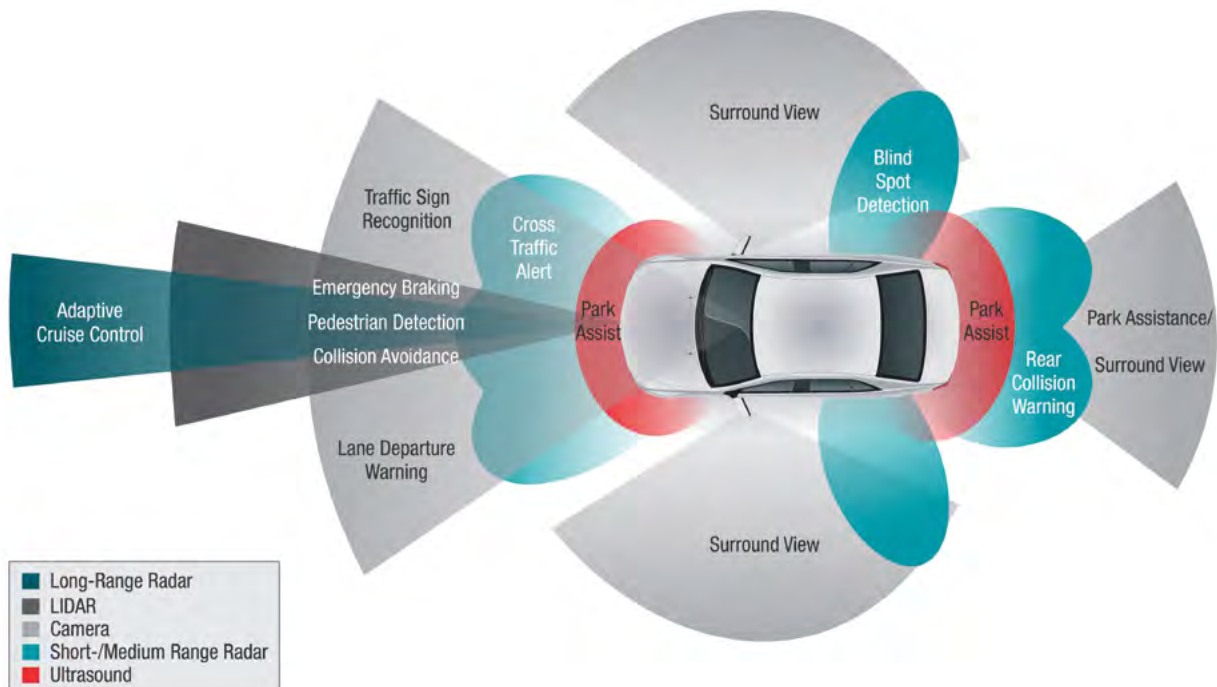


Figure 8: Situational analysis using various different sensors; **Source:** Texas Instruments

⁸ <http://www.heise.de/ix/artikel/Sichtweite-erhoehen-820516.html>

⁹ <http://www.mrt.kit.edu/z/publ/download/2014/ZieglerAI2013ITSMag.pdf>

A downside is that this solution requires considerable investment. Other key techniques are to use **radar** and **ultrasonic sensors**. These solutions create images with electromagnetic waves and ultrasonic waves, respectively. While visual image recognition depends on good weather, radar and ultrasonic technology can work reliably in difficult weather conditions such as fog or heavy rain.¹⁰

One further technique is to use a remote sensing technology known as **LIDAR** (light detection and ranging). The principle is comparable to radar systems but this technology works with laser pulses (optical detection) instead of electromagnetic waves. The LIDAR system creates a rapid series of 360° profiles; it matches each of these to each other to detect any deviation such as movement (see Figure 9). Although LIDAR is a state-of-the-art system, it is just one of several recognition technologies that make autonomous driving possible.¹¹



Figure 9: Using LIDAR to scan the environment;
Source: DriverlessCar.com

Motion planning

Motion planning monitors the vehicle's movements. It does this by using sensors that determine a precise course of motion within a defined period of time. This course must ensure that the moving vehicle remains in its lane

and continues in the correct direction as defined by the navigation system, so that the vehicle avoids collision with the static and dynamic objects that are identified by situational analysis.

Direction is determined by the current position of the vehicle and the route of the road, avoiding any detected static objects. Decisions have to be made about adapting speed and direction, and these are based on a myriad of variables. The appropriate speed, for example, depends on the width of the driving lane, the preferences and schedule of the passengers, the speed limit on a particular stretch of road, and much more. And one of the main challenges is to avoid not just static objects but also dynamic objects, as this requires prediction of their future movements (see Figure 10).

Obviously, the more dynamic an object is, the more difficult it is to predict its future movements. For example, it is not always easy to know which way a bicyclist or pedestrian is likely to turn next. To improve predictive ability, this technology would have to analyze indicators such as the bicyclist's hand signals or the pedestrian's facial expressions. This level of capability is not yet available in today's video recognition systems or even through rapid vehicle-to-human interaction.¹²



Figure 10: A vehicle with motion planning can predict what will happen next; **Source:** Thinkstock

¹⁰ <http://faculty.nps.edu/jenn/Seminars/RadarFundamentals.pdf>

¹¹ <http://www.wisburg.com/wp-content/uploads/2014/09/%EF%BC%88109-pages-2014%EF%BC%89MORGAN-STANLEY-BLUE-PAPER-AUTONOMOUS-CARS%EF%BC%9A-SELF-DRIVING-THE-NEW-AUTO-INDUSTRY-PARADIGM.pdf>

¹² <http://www.mrt.kit.edu/z/publ/download/2014/ZieglerAI2013ITSMag.pdf>

Trajectory control

Trajectory control manages the execution of pre-planned changes in speed and direction, while also observing and maintaining driving stability. The actions in accelerating or braking and in adjustments to the steering are performed by the autonomous system.



Figure 11: Trajectory control ensures driving stability during changes in vehicle speed and direction; **Source:** Thinkstock

Driving stability is measured by comparing the expected with actual changes that occur after a speed or direction intervention. If there is high deviation between the expected and actual changes, the autonomous system makes an adjustment to return to a stable driving mode.¹³

As stated earlier, to achieve a vehicle capable of driving itself, all four of these functions are required. The vast majority of the related technology already exists. But the real challenge is to make accurate and detailed identification and prediction in the self-driving vehicle's environment. Objects move, weather changes ... anything can happen in the blink of an eye.

1.4 Regulations, public acceptance & liability

Beyond technological capability, some key challenges to the introduction of driverless vehicles include regulatory pressures, public acceptance, and liability. As with any new method of transportation, the regulatory environment plays a crucial role in its adoption.

Public opinion has a significant impact too, particularly if there are any negative perceptions of self-driving vehicles. In addition, there must be greater clarity on issues of liability.

Regulations and on-road approval

Autonomous driving on public roads is currently restricted by law. According to the Vienna Convention of Road Traffic, which is ratified by over 70 countries as the foundation for international road traffic regulation, a driver must be present and in control of a moving vehicle at all times.

However, this convention dates back more than 45 years, and clearly road transportation issues have moved on since then! In May 2014, an expert committee of the United Nations added a new rule to the Vienna Convention:

“Systems that autonomously steer a car are permissible if they can be stopped by the driver at any time¹⁴”

This recent addition represents a significant step forward in the development of automated driving, and a number of countries are now reviewing national legislation to allow self-driving vehicles in specific circumstances where automated technology is proved to be sufficiently mature and safe. Early policy reviewers – and therefore the countries that are likely to feature early adoption – include the USA, UK, and New Zealand.

¹³ <http://www.mrt.kit.edu/z/publ/download/2014/ZieglerAI2013ITSMag.pdf>

¹⁴ <http://www.ferchau.de/news/details/revolutioniert-un-konvention-autonomes-fahren-3212/>

Public acceptance and ethical difficulties

Several studies have attempted to measure public acceptance of autonomous driving, with substantial research undertaken in Germany and the USA. Findings suggest that people have mixed feelings about self-driving vehicles. A study by Bosch in 2013 found strong support for the comfort that autonomous driving will provide travelers, compared with the stresses of conventional driving.¹⁵ On the other hand, studies also suggest that more than 60% of us believe we can make better decisions behind the wheel than any computer.

Would you travel in car without a driver and without any means of intervention? Currently 40% of us say yes. This number increases to more than two-thirds if there is an option for someone inside the car to re-take control in the event of an emergency.¹⁶ Would you trust your children to travel in a self-driving vehicle to school? Three out of four people say no, they would not.¹⁷ Would you be prepared to pay extra for a vehicle that includes self-driving technology? Surprisingly, more than half of us (57%) say no.¹⁸

These findings suggest that there is still some skepticism about self-driving vehicles among the general public. However, more than half of us (52%) say we believe autonomous driving is a transport method of the future, and anticipate its full acceptance over time.¹⁹

The biggest hurdle to public acceptance is probably ethics (see the Dilemma box). As we prepare self-driving vehicles for the open road, we must define in precise detail how the

vehicle will react in various situations, recognizing that passengers, other road users, and pedestrians could be hurt because of the self-driving vehicle's decision.²⁰

Isaac Asimov, the Russian-American biochemist, non-fiction author, and one of today's best-known and most prolific science fiction writers addressed this dilemma more than 60 years ago in his book "I, Robot", which subsequently inspired a blockbuster movie of the same name. He describes in several short stories how autonomous systems seem to be behaving in arbitrary and incorrect ways but, by the end of each tale, it becomes clear that these systems are only behaving in exact accordance with the laws that were programmed by human beings.¹²

Dilemma:

You are driving downhill on a narrow mountain road between two big trucks. Suddenly, the brakes on the truck behind you fail, and it rapidly gains speed. If you stay in your lane, you will be crushed between the trucks. If you veer to the right, you will go off a cliff. If you veer to the left, you will strike a motorcyclist.

What do you do?

What should the autonomous system tell a self-driving vehicle to do?

¹⁵ http://www.bosch-presse.de/presseforum/download/de/7966ks-d_Anlage_Befragung_Fahrerassistenz.pdf

¹⁶ [http://www.ey.com/Publication/vwLUAssets/Autonomes_Fahren_-_die_Zukunft_des_Pkw-Marktes/\\$FILE/EY-Autopilot-2013-Praesentation.pdf](http://www.ey.com/Publication/vwLUAssets/Autonomes_Fahren_-_die_Zukunft_des_Pkw-Marktes/$FILE/EY-Autopilot-2013-Praesentation.pdf)

¹⁷ <http://www.insurance.com/auto-insurance/claims/autonomous-cars-self-driving.html>

¹⁸ <http://deepblue.lib.umich.edu/bitstream/handle/2027.42/108384/103024.pdf>

¹⁹ [http://www.ey.com/Publication/vwLUAssets/Autonomes_Fahren_-_die_Zukunft_des_Pkw-Marktes/\\$FILE/EY-Autopilot-2013-Praesentation.pdf](http://www.ey.com/Publication/vwLUAssets/Autonomes_Fahren_-_die_Zukunft_des_Pkw-Marktes/$FILE/EY-Autopilot-2013-Praesentation.pdf)

²⁰ <http://www.thesatellite.com.au/news/should-robot-cars-be-allowed-kill-you/2339399/>

Liability – shifting from drivers and vehicle owners to manufacturers

As vehicles gradually become more automated, liability is a further concern that must be addressed. If a self-driving vehicle is involved in a road traffic accident, who has liability for the damage caused – is it the person inside the vehicle, the vehicle owner, or the manufacturer?

At present, liability for the vehicle is based on the fact that the person using that vehicle is responsible for its safe operation.

According to current regulatory frameworks:

- Liability for damage to property and person is with the driver or vehicle owner
- Liability for the vehicle – accountability for manufacturing errors including constructional defects, manufacturing defects, and faulty instructions – is with the manufacturer

Currently the insurance characteristics of self-driving vehicles are, however, nonexistent. With a fully self-driving vehicle, liability alters. There can be no such thing as driver liability. And so long as the vehicle owner can prove correct maintenance of the vehicle, liability for damage to property and person shifts to the manufacturer.²²

There are a couple of options for manufacturers to reduce their liability. Although very difficult to achieve, a manufacturer could avoid liability for constructional defects by verifying safety to Automotive Safety Integrity Level (ASIL), a risk classification scheme to assess the functional safety level of a road vehicle, and by requiring safety standards to be in line with ISO 26262. Alternatively, the manufacturer may be able to insure its liability – this will require the support of insurance providers convinced by the evidence that autonomous driving results in fewer, and less lethal, accidents than conventional driving.²³

Clearly, it will be necessary to overcome obstacles of regulation, public acceptance, and liability before fully autonomous vehicles arrive on our roads. Notwithstanding this, some countries have already addressed issues of regulation and enabled self-driving vehicles on their streets, at least for initial trials.

To achieve public acceptance, a change of thinking is required. People will have to get used to the imagination of a computer being in full control of their vehicles. There is clear evidence that adoption of this new mindset is already underway, step by step.

Added to this, there must be a willingness to transform the status quo. Insurance companies are now recognizing the need to evolve towards a self-driving future. By modifying and extending the existing terms of insurance, vehicle insurance companies may play a crucial role in accelerating the adoption of autonomous vehicles.

²¹ <http://www.bookrags.com/studyguide-i-robot/#gsc.tab=0>

²² http://www.ftm.mw.tum.de/uploads/media/07_Lutz.pdf

²³ http://www.ftm.mw.tum.de/uploads/media/07_Lutz.pdf

2 CURRENT DEPLOYMENT AND BEST PRACTICE

Already, self-driving vehicles are deployed in a range of applications across a number of different industries. These working examples provide inspiration for the use of autonomous driving in logistics, and also highlight best practice.

2.1 Military & industry applications

As previously mentioned, minesweeping represents one of the very earliest autonomous driving applications. Today the US military continues to test self-driving vehicles. The defense contractor Lockheed Martin has deployed driverless convoys of off-road trucks through uninhabited and difficult terrain in Fort Hood, Texas (see Figure 12). Using GPS and laser sensors, these vehicles keep close to each other and captured the terrain to follow the route. It's not clear yet when driverless vehicles such as these could be used in real operations.²⁴

Another early adopter of autonomous driving is the aerospace industry. The Mars Rover Curiosity is an autonomous extraterrestrial vehicle developed by NASA (see Figure 13).



Figure 12: Driverless convoys moving through challenging terrain; **Source:** Foundation Media

It uses an autonomous way-finding routine, evaluates the area ahead, and decides independently which route is the safest. To achieve this routine, the Mars Rover Curiosity must suspend its journey at regular intervals of no more than a few meters, and take pictures using hazard detection and navigation cameras. The vehicle takes several sets of stereo recording, from which its on-board computer creates a map identifying all potentially dangerous obstacles. Its software then evaluates all possible ways to reach a predetermined target point and selects the route that seems most appropriate.²⁵



Figure 13: The unit designed to move autonomously on the surface of Mars; **Source:** NVIDIA Corporation

²⁴ <http://www.techtimes.com/articles/3118/20140203/lockheed-martin-successfully-tests-self-driving-military-trucks.htm>

²⁵ <http://www.raumfahrer.net/news/raumfahrt/30082013201308.shtml>

Agriculture is another industry in which autonomous driving has a valuable niche, using self-driving tractors in a number of different applications. For example, Fendt, a German manufacturer of agricultural tractors and machines, has launched Fendt GuideConnect – a system that connects two tractors via satellite navigation and radio communication to form one unit. One of the two vehicles is unmanned and performs the same working procedure as the manned vehicle (see Figure 14). Both tractors turn together at the end of a field, and avoid obstacles and deviations. The obvious benefit is that agriculturalists can improve the productivity and efficiency of their operations.²⁶



Figure 14: Fendt GuideConnect – two tractors, one driver; **Source:** Euromediahouse

2.2 Consumer applications

Closer to home, some of our appliances – including lawnmowers and vacuum cleaners – are beginning to feature autonomous driving technologies. The HomeRun vacuum cleaner from consumer electronics company Philips runs autonomously through the house and vacuums the dust and dirt beneath it into a built-in receptacle (see Figure 15). When the batteries run low, HomeRun drives itself back to a charging station; once re-charged, it resumes the housecleaning task. Infrared sensors on the bottom of the unit continually monitor the environment to prevent, for example, an accidental fall down a staircase.²⁷



Figure 15: A labor-saving device that can vacuum your house while you are out; **Source:** infoboard.de

The consumer robotics and artificial intelligence startup, Anki, catalyzed by the Carnegie Mellon University in Pittsburg (PA), USA, recently released its first product – a model car that runs autonomously. The route is rolled out and several cars can be placed on this track. Players can choose to race against other players, or against the autonomous car which not only detects the other model vehicles on the track but also has strategies to win the game (see Figure 16). Additionally, two or more self-driving vehicles can work together to compete against the human players ... so watch out!²⁸



Figure 16: The Anki challenge – can your driving skills outpace a computer?; **Source:** TouchArcade.com

²⁶ <http://www.agcocorp.com/GuideConnect.aspx>

²⁷ <http://infoboard.sprachakt.com/philips-staubsauger-roboter-homerun-fc9910/>

²⁸ <https://anki.com/en>

2.3 Automotive applications

There are many different categories of autonomous driving technology in use today in the automotive industry. A very popular application, available as an optional accessory in many new cars, is the **parking assistant system**. This detects the immediate environment and autonomously parks the vehicle in a parking space.

The **Bosch Park Assist**, for example, parks the car automatically with great accuracy and within a few seconds, even into tight parking spaces (see Figure 17). This system takes entire control of the steering, freeing the driver to focus on other traffic and to control the parking operation via acceleration and braking. Drivers can choose either parallel parking or parking at a right angle to the road. Tests indicate that today's parking autopilots are superior to human drivers in terms of speed and precision.²⁹



Figure 17: Taking the stress out of parking with Bosch Park Assist technology; **Source:** Bosch Auto Parts

Volvo's Autonomous Valet Parking offers the 'next big thing' in parking assistance. Similar to traditional valet parking, this system enables a vehicle to be parked once the driver has stepped out of the vehicle (see Figure 18). The driver can communicate with the system via a mobile device such as a smartphone, directing it to a preferred parking place and summoning the parked vehicle to leave the car park to collect them when required. During its driverless journey, the vehicle avoids other cars and pedestrians. Development continues on this system and elements of it should show up on production lines soon.³⁰



Figure 18: Volvo's autonomous self-parking car; **Source:** Dealer.com

Another parking application is the so-called 'robot valet'. Serva Transport Systems has launched **Ray**, a self-driving automated parking device, currently in use at Germany's Düsseldorf Airport (see Figure 19). Based on laser navigation, the driverless robot parks cars of different sizes moving in and out of nearly 250 automated parking spaces at the airport. It collects and retrieves each vehicle in robot arms on request from a kiosk inside the terminal building or remotely via a mobile phone application. This system achieves a 60 % parking capacity increase compared with traditional use of the same parking area.³¹



Figure 19: Ray – an automated system that improves parking space utilization by 60 %; **Source:** MV Media

²⁹ http://www.bosch-automotivetechology.us/media/db_application/downloads/pdf/comfort_1/en_5/einparkenleichtgemachtparkassistenzenstemevonbosch.pdf

³⁰ <http://www.slashgear.com/volvo-self-parking-car-is-the-valet-you-dont-pay-21287523/>

³¹ <http://serva-ts.com/product.2.0.html>

By 2014, almost every car manufacturer and supplier had started to experiment with autonomous driving technology – BMW, Bosch, Continental, Delphi, Fiat, Ford, General Motors, Renault-Nissan, Tata, and Toyota. Several had already launched test cars and deployed these in designated approved areas and closed environments.

On the open road, a number of high-end vehicles including the Mercedes S-Class Intelligent Drive³², BMWi3³³, and Hyundai Genesis³⁴ are now equipped with a **highway pilot** feature (see Figure 20), specifically developed to assist drivers when they encounter traffic congestion on highways. This feature is activated in heavy road traffic, and autonomously keeps the vehicle in its lane, brakes, and accelerates up to 60 km/h (37 mph).³⁵ This maximum speed is likely to increase incrementally over time and, technically, this application can support velocities in excess of 100 km/h (62 mph).



Figure 20: Hyundai Genesis proves autonomous driving technology; **Source:** PSFK Labs

The highway pilot application is likely to evolve to allow lane changing and overtaking – this kind of enhancement is being developed by Nissan and others, and is expected to become available by 2018.³⁶ As a next step, highway pilots may guide the vehicle on an access road to merge into and safely join the flow of highway traffic. Then it seems only

a small additional step to achieving a fully self-driving vehicle capable of controlling all safety-critical functions for an entire journey – and all the driver has to do is pick a destination!

A remarkable example of a self-driving vehicle is the **Google Self-Driving Car**. Powered by Google Chauffeur software, this car is capable of driving itself on both highways and urban streets (see Figure 21). It is equipped with a steering wheel and pedals, so a driver can always take over control.



Figure 21: The extraordinary Google Self-Driving Car; **Source:** mobiFlip.de

From mid-2011 to early 2014, these cars have covered a total of 1.25 million kilometers (nearly 700,000 miles), mostly in California, District of Columbia, Florida, Michigan, and Nevada, USA.³⁷

In a promotional video, Google invites a visually impaired man to take a ride in the self-driving vehicle, demonstrating that the car provides all the required “seeing” functions, and delivers new freedom of mobility to people with disabilities.

Building on the success of this self-driving vehicle, Google took a further step to develop the fully self-driving **Bubble Car**.

³² <http://www.mrt.kit.edu/z/publ/download/2014/ZieglerAl2013ITSMag.pdf>

³³ <http://www.ce.org/Blog/Articles/2014/January/Autonomous-Driving-The-Auto-Pilot-of-the-Highway.aspx>

³⁴ <http://www.psfk.com/2014/07/hyundai-smart-tech-self-driving-cars.html>

³⁵ <http://www.autogazette.de/mercedes/s500/autonom/wettlauf-um-vorherrschaft-beim-autonomen-fahren-470964.html>

³⁶ <http://europe.autonews.com/article/20140716/COPY/307169922/ghosn-offers-autonomous-car-reality-check>

³⁷ <http://googleblog.blogspot.de/2014/04/the-latest-chapter-for-self-driving-car.html>

This prototype is currently being tested on private sites – it doesn't have a steering wheel or pedals; it only has buttons for starting, pulling over, and emergency stops (see Figure 22). This is an impressive statement of full automation!



Figure 22: The Google Bubble Car – an impressive statement of full automation!; **Source:** Fast Company

The Bubble Car is powered by an electric motor with a maximum speed of about 40 km/h (25 mph), to limit potential damage in any accident. With a range of about 160 kilometers (100 miles), this eco-friendly vehicle is well suited to urban commuting.³⁹

But over the past 12 months, it's the traditional car manufacturers – rather than Google – that have made the most progress with self-driving technology.

Audi's RS7 prototype is the world's most athletic self-driving car. Audi has been testing various stages of automated vehicles for years and, in 2014, it was the first car manufacturer to receive a California license for self-driving vehicle testing. And in October 2014, at the final of the German Touring Car Masters (DTM) event, Audi amazed thousands of motor sports enthusiasts by demonstrating the driverless RS7 achieving speeds of up to 240 km/h (150 mph) around Germany's Hockenheimring racing circuit (scan Figure 23 to watch a video of the highlights).⁴⁰



Figure 23: Scan the QR code to watch a video of the high-speed self-driving Audi RS 7; **Source:** Warspeed.com

In 2013, another self-driving vehicle, the **Mercedes-Benz S500 Intelligent Drive**, undertook a very special journey. Equipped with a series of video and radar sensors, it retraced the route of the world's very first long-distance automotive journey undertaken in 1888 by Bertha Benz, wife of inventor Carl Benz (see Figure 24). For safety and legal reasons, a driver accompanied the vehicle for this 125th anniversary event, and on two occasions – after the car had safely stopped behind obstacles – the driver's intervention was required to restart the vehicle.



Figure 24: During the 2013 Bertha Benz Memorial Drive; **Source:** SoftNews NET

Technically, the car could have automatically navigated around these obstacles but for this journey the autonomous system had been configured to keep the vehicle in its lane.

³⁸ <http://www.autoguide.com/auto-news/2012/03/google-self-driving-car-chauffeurs-legally-blind-man-video.html>

³⁹ http://www.nytimes.com/2014/05/28/technology/googles-next-phase-in-driverless-cars-no-brakes-or-steering-wheel.html?_r=1

⁴⁰ <http://www.wired.com/2014/10/audis-self-driving-car-hits-150-mph-f1-track/>

These two incidents demonstrated that obstacles were efficiently identified, braking was gently and appropriately applied, and the command to stay in lane was followed – great evidence that cars like this are ready and able to perform safely and reliably on highways and in urban areas.⁴¹

An obvious next step is the introduction of fleets of fully self-driving vehicles. With this in mind, Volvo is undertaking a multiple vehicle test called **Drive Me** – the manufacturer plans to test a fleet of some 100 self-driving Volvo vehicles in everyday driving conditions on approximately 50 kilometers (31 miles) of the roads around Gothenburg, Sweden (see Figure 25). Volvo hopes to complete all testing by the end of 2017 and anticipates commercial use of fleet technology in 2018.⁴²



Figure 25: The Volvo Drive Me Pilot; Source: CHIP Digital

2.4 Public transport applications

Other examples of best practice in autonomous driving can be found in public transport applications. With its partners, the UK-based RDM Group is working with Oxford University to produce futuristic **LUTZ Pathfinder pods** – driverless public transport vehicles that can carry two passengers autonomously at speeds of up to 11 km/h (7 mph). Trials are due to begin in early 2015 in the UK city of Milton Keynes. These electrically powered pods will move passengers around main locations of interest in the urban environment, and by mid-2017 there should be about 100 fully autonomous pods serving the city on specially designated sidewalk routes (see Figure 26).⁴³

Joint venture partners United Technical Services (UTS) and 2getthere are collaborating to deliver three different versions of a rapid-transit **Automated People Mover** – personal vehicles, group vehicles, and freight vehicles. Each is constructed to run as an on-demand nonstop transportation system between any two points on a network, at a maximum speed of 40 km/h (25 mph). The personal vehicle carries up to 6 people; the group vehicle carries up to 20; and the freight vehicle conveys a total weight of up to 1,600 kg (3,500 lb). With a 1.5-hour charge time, these electric vehicles have a range of 60 km (37 m).⁴⁴



Figure 26: Milton Keynes will have its first driverless public transport pods in 2015; Source: dotTech.org

⁴¹ <http://www.mrt.kit.edu/z/publ/download/2014/ZieglerAl2013ITSMag.pdf>

⁴² <https://www.media.volvocars.com/global/en-gb/media/pressreleases/145619/volvo-car-groups-first-self-driving-autopilot-cars-test-on-public-roads-around-göteborgHQeBorA>

⁴³ <http://www.birminghampost.co.uk/business/business-news/midland-firm-chosen-make-uk-7115011>

⁴⁴ <http://www.2getthere.eu/>

The group vehicle is already in use at Amsterdam's Schiphol Airport in the Netherlands, and both personal and freight vehicles have been in operation in Masdar City, Abu Dhabi, UAE, since 2010, achieving a record 1 million passengers by May 2014.

In a separate solution, 2getthere has delivered one of the first people-mover systems in the Netherlands. Called the **ParkShuttle** system, this self-driving vehicle operates without a driver, finding its way automatically and moving on a simple ground-level asphalt road (see Figure 27). It is ideally suited to short-distance public transport.⁴⁵



Figure 27: A self-driving ParkShuttle system in Rotterdam; **Source:** Academic

Since 2011, another people mover has been in use for business parking at Heathrow Airport in the UK. The **Ultra Pod** by Ultra Global PRT operates as an autonomous guidance, navigation, and control unit seating up to 6 passengers with luggage (see Figure 28). This electric vehicle recharges autonomously at battery points while waiting for passengers, and it can be booked via smartphone.⁴⁶



Figure 28: The Ultra Pod carrying passengers at Heathrow Airport; **Source:** Airspan

Another successful self-driving shuttle is the **Navia** by Induct Technology. This people mover is deployed at several campuses around the world – in Singapore, France, the UK, and the USA – and doesn't require any special infrastructure (see Figure 29).⁴⁷ With a maximum speed of 20 km/h (12.5 mph), the Navia carries up to 8 passengers and can be summoned using a mobile device. Passengers select their destination using an onboard touch screen. This self-driving electric vehicle recharges itself at docking stations or can be charged via induction.⁴⁸



Figure 29: The self-driving Navia shuttle; **Source:** Induct Technology

⁴⁵ <http://www.2getthere.eu/wp-content/uploads/Personal-Rapid-Transit-Innovation-Lasting-R.-Lohmann.pdf>

⁴⁶ <http://www.ultraglobalprt.com/wheres-it-used/heathrow-t5/>

⁴⁷ <http://induct-technology.com/en/products/navia-clients-and-technological-partnerships>

⁴⁸ <http://induct-technology.com/en/products/navia-the-100-electric-automated-transport>

3 THE IMPLICATIONS FOR LOGISTICS

The previous chapter explored best practice in the application of self-driving technology in a number of different industries. Now this chapter focuses on current and future implications of driverless vehicles in the logistics industry.

There is a strong case for suggesting that the logistics industry will adopt self-driving vehicles much faster than most other industries.

The reason for this is that different rules apply when a vehicle is moving around in a secure, private zone. Also, liability issues are less pressing when that vehicle is transporting goods instead of people.

These conditions are typical of many logistics applications – for example, vehicles often move materials in private warehouses and controlled open-air sites.

Already today there are numerous applications of autonomous technology in logistics, providing further evidence that driverless vehicles are safe and successful in closed environments.

It's the next evolutionary step to start applying this technology to outside premises and on public streets. Beyond **warehousing operations**, analysts expect many more applications in future along the

entire supply chain, particularly in **outdoor logistics operations**, **line haul transportation**, and **last-mile delivery** (see Figure 30).

This chapter provides a possible roadmap for this evolution – it starts with indoor and outdoor solutions that are being applied today, and travels on towards some visionary concepts for the future of logistics.



Figure 30: Overview of self-driving vehicle applications in logistics

3.1 Warehousing operations

For many years now, dedicated warehouses have been deploying autonomous vehicles that handle products of all shapes and sizes, and move around the warehouse environment as directed. However, most of these self-driving vehicles stop when they encounter an obstacle, and won't move again until the object is removed or a driver takes manual control. Also most of these vehicles can only follow a predefined route and require a relatively expensive and inflexible infrastructural investment due to the challenges of indoor navigation.

As described in Chapter 1, robust navigation and situational analysis capabilities are essential for autonomous vehicles. To get past the hurdle of indoor navigation, early solutions used **wire technology**, where the vehicle is fitted with a radio sensor that receives radio waves transmitted by a wire that is embedded in the floor of the warehouse.⁴⁹ Improving on this, **guide tape technology** used markers such as colored images around the aisles

that a camera on the driverless vehicle recognizes for navigation. Other similar tactics included using magnets and sensors to guide the vehicle in the right direction.⁵⁰

However, physical markers and wires proved to be inflexible and often costly. Therefore the best and most common method today and in the future is to rely on a mixture of **depth cameras and lasers** on the vehicle; these devices constantly scan and capture the environment to identify the vehicle's position and any obstacles. **Vision guidance technology** relies completely on cameras that perform 360-degree depth scans of the environment in order to create a 3D map which the vehicle then uses for navigation.⁵¹

These are the next generation of self-driving vehicles in warehouses and they have complete, flexible navigational authority, enabling a much larger range of potential applications and autonomy. A number of current and prospective solutions for autonomous warehouse processes are provided below, solutions that could help to achieve the future scenario illustrated in Figure 31.



Figure 31: Warehousing operations of the future

⁴⁹ <http://de.scribd.com/doc/53734878/Automated-Guided-Vehicle>

⁵⁰ <http://www.robotiq.com/index.php/applications/how-to/278-building-a-magnetic-track-guided-agv>

⁵¹ https://pure.ltu.se/portal/files/40122324/mum_preprint.pdf

Autonomous loading and transport

Self-driving vehicles in warehouses have the ability not just to transport goods but also to combine other process steps such as loading and unloading in order to increase the overall efficiency of an entire process. In addition to providing efficiency gains, self-driving vehicles can also significantly increase safety in transport and loading processes.

One example solution is the **KARIS PRO System** developed by the research and education institute KIT in Germany. This system deploys a flexible and scalable number of small autonomous vehicles that either transport small goods alone or connect with other vehicles to form a flexible conveyor system (see Figure 32).

Each of these vehicles separately navigates itself using laser technology and monitors the environment to ensure safe human-machine interaction. It recognizes when an adjustment is needed and, when there is heavy traffic on a particular route, the vehicle simulates new alternative formations and connects with other units accordingly (for example, it may switch transporting goods to creating a continuous conveyor belt, pairing two, four, or even more units). None of this involves costly reconfiguration and therefore this solution provides the benefits of easy and cost-sensitive deployment.⁵²



Figure 32: Small autonomous vehicles in the KARIS PRO System; **Source:** Karlsruher Institut für Technologie



Figure 33: The highly flexible Open Shuttle; **Source:** Handling-Network.com

Another example of autonomous transportation in the warehouse is the **Open Shuttle** developed by KNAPP. Using laser navigation technology, this free-moving vehicle can be deployed for transport and picking activities involving cartons and containers – this makes it ideal for many kinds of low-throughput transportation (see Figure 33). This technology is particularly suited to complex transport networks.

The Open Shuttle reacts dynamically to any obstacle it encounters in the warehouse, and plans alternative routes, taking order parameters into consideration to ensure optimal throughput. Companies can start with a basic system and later scale this to meet additional performance requirements.⁵³

⁵³ http://www.mhpn.com/product/open_shuttle/agvs

For tight, crowded warehouse spaces, an even more flexible and intelligent solution is required for autonomous transportation. One solution is called **RoboCourier** developed by Swisslog. It also uses laser navigation technology and a 360-degree turn range to allow the vehicle to navigate seamlessly through tight spaces, doors, and crowded hallways (see Figure 34). It can even request an elevator which means it can navigate autonomously between multiple levels of a building.⁵⁴ The RoboCourier is currently deployed in the life sciences and healthcare industry where it is handling the transportation of laboratory samples, pharmacy supplies, medical devices, and other items inside a hospital building. It carries the items in a container which can be sealed, protecting drugs and other materials that need to be transported safely and securely.



Figure 34: The RoboCourier gives medical staff more time to focus on patients; **Source:** Vogel Business Media

The **MultiShuttle Move**, jointly developed by Fraunhofer IML and Dematic, describes a swarm of self-driving vehicles handling small load carriers and pallets, and operating almost anywhere. Vehicles communicate and coordinate tasks among themselves each using radio interface communication and laser navigation technology. The overall system is able to adapt its capacity to seasonal and daily fluctuations, and to changing orders, customer preferences, and product structures.



Figure 35: Swarming vehicles move swiftly and autonomously around the warehouse; **Source:** Fraunhofer-Institut für Materialfluss und Logistik IML

The swarm can switch performance between storage and transport processes and adapt to specific operational locations including under shelves, on packing floors, and in picking spaces, receiving bays and shipping areas (see Figure 35). The MultiShuttle Move consists of a bottom chassis and a shelf chassis; it is therefore able to move on floors and also in high-bay racking, making this system ideal for picking a designated load from one height and moving it to another height. After deployment, minimal effort is required to achieve system extension or layout changes, since the vehicles autonomously adjust their routes and adapt to changing conditions.⁵⁵

⁵⁴ <http://www.swisslog.com/en/Products/HCS/Automated-Material-Transport/RoboCourier-Autonomous-Mobile-Robot>

⁵⁵ <http://www.fraunhofer.de/de/presse/presseinformationen/2012/maerz/schwaermen-und-transportieren.html>

The Jungheinrich **Auto Pallet Mover** travels to pre-defined locations using laser navigation technology. This self-driving pallet mover can be used throughout the warehouse, from receiving goods all the way through to transition points close to the shelves (see Figure 36). A separate control system ensures infrastructure planning, vehicle coordination, and traffic flow optimization. Extensive safety features contribute to collision-free operation in any warehouse environment. The Auto Pallet Mover can be used not only as an entirely self-driving system, but also in combined procedures with manual vehicles.⁵⁶



Figure 36: A new way to move pallets in the warehouse environment; **Source:** International Forklift Truck of the Year

Logistics processes are conveniently automated by BALYO's recently launched **MOVEBOX** automation kits. These solutions convert regular electric forklifts into self-driving vehicles that can position themselves to pick up and deliver pallets as directed (see Figure 37). Navigating via geo-guidance, these vehicles do not require a new infrastructure.

The MOVEBOX goes beyond pure navigation to also integrate features such as barcode scanning, pallet detection, and pallet stacking, as well as autonomous stops and slow-downs. Deployed as a hybrid solution, it enables an operator to take manual control of the vehicle to accomplish regular manual tasks and, once this is finished, the vehicle can revert to self-driving mode and resume its autonomous tasks.⁵⁷

A current research project called **FTF out-of-the-box** is a good example of an autonomous forklift that is being developed by Germany's Jungheinrich AG, Götting KG, the University of Lübeck, and IPH Hannover. Using vision guidance, this forklift is equipped with an innovative 3D camera and intelligent image recognition software. This enables the vehicle to recognize its environment, identify humans and obstacles, and move autonomously through the warehouse. This forklift creates a map of the warehouse on its own, following a human-guided introductory tour.⁵⁸ An excellent logistics deployment for this forklift would be in a goods receiving area. Imagine there is a pallet on the floor that has already been identified and assigned a storage location. By pointing at it, an employee instructs the forklift to pick up this pallet, drive to the target location, and put the pallet on the floor or into the rack. Once finished, the forklift returns to its starting position. By using several of these forklifts, a single employee can handle the entire receiving area of a warehouse.

All the above systems make the process of loading and transport within warehouses safer and more efficient. Equipped with sensor technologies, these driverless vehicles can also be deployed in a mixed human-machine environment – in this way, they provide a high level of flexibility that allows users to move step by step to a fully autonomous solution.



Figure 37: An ingenious way to turn a regular forklift into a self-driving vehicle; **Source:** BALYO

⁵⁶ <http://www.jungheinrich.com/en/automatic-industrial-trucks/driverless-transport-systems/>

⁵⁷ <http://www.balyo.com/en>

⁵⁸ <http://www.ftf-out-of-the-box.de/>

Assisted order picking

Looking ahead from the task of moving items from A to B, it is interesting to consider the warehouse commission area. When undertaking manual order picking, carts can become very heavy. Non-ergonomic cart handling slows things down. Furthermore, transportation to and from drop-off locations is usually time consuming. With autonomous technologies, the assisted picking cart of the future can autonomously follow the picker as he or she moves through the rack system. Before the cart reaches full capacity, the picker simply sends it to the drop-off location or directly to the packing area. Meanwhile, and initiated in advance, another replacement picking cart joins the picker, ready for new products to be placed on it. The main benefit of this application is a more efficient and ergonomic picking process.

One example of this is **FiFi**, an assisted order picking pilot developed by BÄR Automation and KIT. This intelligent self-driving vehicle follows the order picking process using vision guidance, and responds to human gestures (such as a waving hand) that indicate an instruction to follow the order picker (see Figure 38). FiFi can also transport loads autonomously to specified hand-over points.⁵⁹



Figure 38: The assisted order picking pilot FiFi; **Source:** Karlsruher Institut für Technologie



Figure 39: The self-driving order picking system Kiva; **Source:** Wonderful Engineering

A different and highly innovative approach to assisted order picking is the **Kiva** warehouse automation system which was acquired by the online retail giant Amazon in 2012.⁶⁰ Kiva aims to increase picking efficiency by mobilizing the shelves of a warehouse through an autonomous vehicle which fixes itself onto the bottom of a shelf and then transports the entire shelf to an order picker (see Figure 39). This allows the order picker to stay in one spot while Kiva does the moving around. With intelligent control software, large fleets of Kiva vehicles can follow barcode stickers positioned on the warehouse floor, significantly reducing the picking cycle time. Unlike other material handling systems which are designed to handle products of a specific size, Kiva can automatically transport multiple types of product around the warehouse.⁶¹

From these many examples, it is clear that autonomous technology has not merely arrived but also made huge progress over several years in closed environments in the logistics industry. In warehouses and other indoor locations, self-driving vehicles have proved capable of improving process and increasing safety. The next section focuses on driverless vehicles in outdoor applications.

⁵⁹ http://www.ifl.kit.edu/projekte_fifi.php

⁶⁰ http://dealbook.nytimes.com/2012/03/19/amazon-com-buys-kiva-systems-for-775-million/?_r=0

⁶¹ <http://www.kivasystems.com/>

3.2 Outdoor logistics operations

As mentioned at the beginning of this chapter, autonomous driving is most easily achieved in closed, private environments where processes are clearly defined. So there are significant challenges to applying autonomous technology to outdoor logistics operations where public roads, open environments, and multiple players can have unpredictable impact and influence. This section takes a first step outside to look at yard, port, and airport logistics and reveal the potential benefits of driverless vehicles as illustrated in Figure 40.

Many companies are looking for ways to reduce congestion and improve safety in **yards**. The combination of classic forklifts and trucks as well as pedestrians in the yard environment can make maneuvering difficult, dangerous, and inefficient.

Therefore self-driving vehicles could provide a great solution by executing all types of yard logistics including maneuvering and repositioning transport items such as pallets and swap bodies.

A research project called **SaLsa**⁶² aims to safely test autonomous transport vehicles in yards. With sensors installed in the yard infrastructure, these vehicles detect other objects and their position which allows the combined operation of automated vehicles, forklifts, and people in an efficient and safe manner.⁶³

Similar to transportation in yards, container and unit load device (ULD) transportation in **harbors** and **airports** can be automated as well.



Figure 40: Outdoor logistics takes self-driving vehicles beyond the closed environment of traditional warehouse operations

⁶² Collaboration between Götting KG, InnoTec DATA GmbH & Co. KG, ifm electronic GmbH, the Institute for Information Technology OFFIS e.V. and the Fraunhofer Institute for Material Flow and Logistics

⁶³ http://www.iml.fraunhofer.de/en/fields_of_activity/automation_embedded_systems/research/SaLsa.html



Figure 41: From A to B by the fastest possible routes in the Altenwerder Harbor Container Terminal; **Source:** Hafen Hamburg Marketing

One pioneering example is at the Harbor Container Terminal Altenwerder in Germany, which is one of the most modern container handling facilities in the world. Container handling is almost completely

automated. A total of 84 driverless vehicles transport containers between the wharf and the storage areas via the fastest possible routes (see Figure 41). Navigation is performed using 19,000 transponders that are installed in the ground.⁶⁴ This greatly increases the speed and efficiency of container handling in comparison to traditional transport methods using trucks and cranes.

At airports around the world today, it is typical for cargo transporters to manually transport ULDs with dollies and ULD transporters (see Figure 42).

But this could be more efficiently performed using autonomous technologies. For example, self-driving dollies could carry ULDs to and from the airport terminal gate and each plane. The next step might be the automated handover to a self-driving ULD transporter which automatically loads and unloads each plane.



Figure 42: ULD transporter and dollies

⁶⁴ <http://www.oelcheck.de/en/knowledge-from-a-z/lubricants-on-duty/fahrzeugeverkehr/sca-preventive-maintenance-at-the-worlds-largest-container-terminal.html>

3.3 Line haul transportation

Taking one step further into the world of outdoor logistics operations, this section reviews line haul transportation, mainly focusing on long-distance intercity freight transportation where trucks are the typical vehicle in use.

In a public environment like this, there is a constant risk of road traffic accident, even for the most experienced truck drivers, as no-one can control all factors such as another driver's error of judgment or the onset of treacherous weather conditions.

Accident scenarios often illustrate the difficulty of performing a sudden maneuver with a large truck – these vehicles are intrinsically heavy, and may also be

transporting heavy cargo. Any collision often results in disastrous damage to other road users.

Autonomous technology can help drivers to react faster to oncoming dangers and calculate the safest maneuver, taking into account the truck's current status and the driving conditions.

This could drastically reduce the number and severity of accidents, and therefore self-driving vehicles have the potential to play a significant and useful role in reducing driver error and avoiding accidents. Figure 43 illustrates a scenario for line haul transportation with the use of driverless vehicles.



Figure 43: Autonomous driving in line haul transportation can reduce the number and severity of accidents

Assisted highway trucking

As outlined in Chapter 2, driver assistance systems are already available in many modern private vehicles. Although limited in their current application, similar types of autonomous support system are available to today's line haul drivers. For example, to create a safer highway environment, there are driver assistance systems that inform and alert the driver about safe driving distances, help to maintain and control the optimum speed, apply emergency braking, and provide data to compensate for vehicle blind spots.

An obvious progression from these assistance systems is the advent of an **assisted highway trucking system**. A truck equipped with this system will stay in lane automatically, keeping a safe distance from the vehicle in front, and obeying the truck's maximum speed and/or prescribed speed limits along the highway. The driver would still be required to perform tasks such as merging into traffic, overtaking, and leaving the highway although in future these functions could also be automated, as in the Mercedes-Benz showcase example (see Figure 44). With this type of system, the driver must be available and prepared to resume manual control at any time and at short notice.

Looking into the future, standard line haul transportation could be further enhanced with trucks that can travel the majority of the journey without the intervention of a driver, or even complete the entire distance with no driver on board.

In many developed countries, there are not enough long-distance drivers in the trucking industry, and this scarcity is increasing because of demanding hours, long periods of time away from home, and the dangerous nature of the job. These challenges can be answered by autonomous technology. Imagine the following scenario: After a truck has completed loading at a warehouse, it is manually driven to the entrance of the highway. From here, the driver activates the autonomous highway trucking system. The driver is not required to actively steer the truck, as the vehicle has a radar with a range of 250 meters (820'), proximity sensors with a range of up to 70 meters (230'), and various cameras to identify pedestrians and other obstacles. The driver is now free to rest and work on other tasks during the journey and, once the truck nears its destination in an inner city area, the driver can retake manual control for the final part of the trip.⁶⁵ Testing indicates that this degree of self-driving reduces the number of accidents. Also, as automation ensures optimal vehicle operation and routing, it helps to cut fuel consumption by 5–10%.⁶⁶



Figure 44: A prototyped assisted highway trucking system is the Mercedes-Benz Future Truck 2025; **Source:** The Car Connection

⁶⁵ <http://next.mercedes-benz.com/en/autonomous-truck-logistics-en/>

⁶⁶ <http://www.greencarcongress.com/2014/07/20140704-futuretruck.html>

For long haul trips that often require multiple days of driving, the driver may not have to accompany the truck at all. The driver could drive the truck manually to the entrance of a highway and hop out. The truck would then drive autonomously and non-stop until it approaches its destination. Here another driver would be waiting to get in, and then drive the truck manually to the depot or inner city destination.

Of course, it is technically feasible to have a fully autonomous truck that does not require any manual driving at all. One example of this is the trialing of autonomous vehicles in closed environments in the mining industry. This is an ideal application as the transportation of materials in tough and dangerous terrain can put truck drivers at high risk. Caterpillar is already supplying driverless trucks to mining companies in Australia (see Figure 45). For example, BHP Billiton is currently trialing nine driverless trucks at its Jimblebar mine in Western Australia.⁶⁷



Figure 45: Self-driving truck at a mining site in Australia; **Source:** Carnegie Mellon School of Computer Science

Convoying systems

Another opportunity for autonomous driving in line haul transportation is truck convoys. In this application, the driver of the first truck retains control of all steering functions and sets the pace. Drivers in the following trucks and other vehicles are not required to provide any steering, acceleration, or braking intervention – technically, once underway in the convoy these vehicles can manage without their drivers.⁶⁸

The convoy moves from one highway service area to another, picking up and decoupling trucks as required at each location. As with assisted highway trucking, this system reduces accident rates and can cut fuel consumption by about 15%. It also keeps drivers relaxed and comfortable. In fact, convoying time could be counted as rest time, therefore extending the productivity potential of each driver.⁶⁹

One of the first successfully tested convoy systems on public roads took place in Barcelona, Spain, as part of the Sartre project. The convoy was led by one Volvo truck, with its driver providing the steering function for the four vehicles that followed behind (see Figure 46). Besides Volvo, several other truck manufacturers, including Daimler and MAN, are already developing similar solutions for commercial use.⁷⁰



Figure 46: A Volvo convoy during the Sartre project; **Source:** Ricardo

⁶⁷ <http://www.catminestarsystem.com/articles/autonomous-haulage-improves-mine-site-safety>

⁶⁸ Bishop, R. A survey of intelligent vehicle applications worldwide; Intelligent Vehicles Symposium, 2000. IV 2000. Proceedings of the IEEE

⁶⁹ <http://www.greencarcongress.com/2012/05/sartre-20120528.html>

⁷⁰ <http://www.sartre-project.eu/en/Sidor/default.aspx>

3.4 Last-mile delivery

This section leaves the highways and moves toward the most visionary application of self-driving vehicles in logistics. The last mile of delivery is often the least predictable part of the entire journey. The environment is likely to be both complex and dynamic, particularly in congested urban areas that are full of trucks, cars, cyclists, pedestrians, and more, with everyone moving in different directions at different times for different purposes. This poses huge challenges for the self-driving vehicle.

A key question is whether the autonomous vehicle will be able to understand the environment and react appropriately? For example, if the last mile occurs on congested city streets, surrounded by many other moving vehicles and people and with various complex intersections and traffic rules, will the sensors and autonomous technology of today be able to cope?

Despite these challenges, the last-mile environment typically presents a particular advantage for self-driving vehicles. In cities, traffic normally moves very slowly and in accordance with low speed limits. This of course is ideal for today's self-driving vehicles as autonomous technology is best executed at low speeds, allowing driverless vehicles to identify, monitor, and navigate their environment accurately and react in an appropriate timeframe to any emergency.

This section gives an overview of the future of last-mile delivery, using autonomous technology to improve the safety and efficiency of driverless vehicles, and to support delivery personnel as they cope with rapidly increasing parcel volumes caused by the growing popularity of e-commerce (see Figure 47).



Figure 47: The typically complex environment for last-mile delivery

Support vehicles for letter and parcel deliveries

A significant inefficiency in the process of delivering letters and parcels to their final destination is the need for long-distance walking. This occurs each time the delivery person fails to locate a parking space close to the recipient's mailbox or front door. When this happens, they have to park their delivery vehicle wherever they can, and then cover the distance on foot, which obviously uses extra time and can be hard work, especially if the letters and parcels are heavy. Once the delivery has been made, they have to walk all the way back to the vehicle again.

One potential use case is a self-driving vehicle that follows the delivery person during the delivery of multiple items in one area. This type of vehicle for assisted deliveries could be equipped with a number of assistance systems to make the delivery job easier.

Here's how a driverless vehicle for assisted deliveries could be deployed. In the morning, the delivery person drives the vehicle out of the depot to the first point of delivery, and steps out of the vehicle. Thanks to an intelligent spatial concept that uses ergonomic design, the delivery person finds it easy and efficient to locate in the vehicle the correct parcels and letters required for delivery in a particular area. After extracting and delivering each item to each recipient, the delivery person now starts walking to the next delivery area and the driverless vehicle follows autonomously.

If there is a big distance between one destination and the next, the delivery person can choose to get back into the vehicle and drive. When the support vehicle is nearly empty, a second one (loaded with more parcels and letters) arrives autonomously; this means there is no need to drive back to the parcel center to reload.

This type of delivery-assistance vehicle would be perfectly suited to support urban delivery processes. The biggest advantage is its potential to increase the productivity of each delivery person, making their job easier and at the same time more attractive.

Parcel station loading

Machine-to-person handover of parcels and letters may be beyond the current capability of autonomous technologies – there are many variables and the environment is typically complex and dynamic. Instead, machine-to-parcel station handover is certainly achievable.

In Germany, Deutsche Post DHL has established around 3,000 Packstations in central locations to serve multiple customers, as well as a growing number of Paketkasten in private homes to serve a single household. At the moment, a delivery agent is responsible for loading the right letters and parcels into the standardized delivery points. In future, this could be done by autonomous vehicles equipped with a specific attachment for parcel loading and unloading – making the process faster and enabling greater flexibility of delivery times.

Self-driving repositories

Another interesting solution for the future of last-mile delivery is the concept of the “self-driving Packstation”. While today, the customer must go to this central repository, in future the Packstation could autonomously come (closer) to them. The same is true for a municipal library bus – it could stop at designated locations at certain times and open its doors to the public ... all without a driver. Self-driving repositories could become a model for mobile delivery of the future.

Autonomous shared cars

Self-driving vehicles for private use could similarly be deployed as shared resources. They could, for example, provide crowd-sourced fulfilment of first- and last-mile delivery.

The idea of a shared self-driving shopping car, for example, has several benefits. Customers can order goods online and instead of collecting an order themselves or arranging a home delivery service, they can book an autonomous shopping car.

If they need a ride home after work, they can instruct the shopping car to visit the store, wait while the purchased goods are loaded into the trunk, and then arrive at the required time outside their office. The driverless vehicle would continue to the customer's home and wait while they unpack their items. Then the autonomous shared shopping car could set off in the direction of its next booking.

These ideas may sound far-fetched, yet Volvo is already thinking along these lines. The company has developed a **Volvo on Call app**, which can give anyone access to a shared vehicle (see Figure 48). How would this be useful? Volvo plans to deploy its cars as mobile delivery stations.



Figure 48: The Volvo on Call app enables shared access to a trunk;
Source: Blogspot

A delivery company would buy the right to access the trunk of a car. It would put its parcels and other items into the trunk. Then the delivery company would check the required location and time of delivery with the customer. Once this was agreed, a human would drive the car to the agreed place. Using the Volvo on Call app, the customer would receive and use a digital key to open the trunk and collect their parcel.

The car would then self-lock and the customer would receive a delivery confirmation. This solution saves time and provides handover and verification without the need for direct interaction between the driver and the customer.⁷¹

Self-driving parcels

A futuristic solution for the fully automated delivery of goods is the self-driving parcel. This would be able to control its own integrity (ensuring the correct temperature and appropriate handling throughout its journey) and find its own way directly to the recipient (see Figure 49).



Figure 49: One day we could open the door to a self-driving parcel;
Source: Prestigeifilm

Here is a glimpse into this fascinating future. An autonomous truck offloads a number of parcel-sized autonomous vehicles close to their final destination. With swarming capabilities similar to those of the MultiShuttle Move (see section 3.1.1), these parcel-sized autonomous vehicles could even interact with each other and intelligently determine their last-mile journeys. Each one would drive to its final delivery point, travelling on sidewalks, mounting steps, and climbing rails. To keep their contents safe, these parcel-sized vehicles would be electronically locked and, for theft protection, would have a GPS-location function.

Once a vehicle reaches the destination house, it would be able to access the building via a small gate similar to a cat flap. A “smart home” device would control this gate, so that only approved parcels could enter. When the recipient arrives home, they can unload their parcel and, simply by using a smartphone app, send the vehicle back to the delivery service company.

⁷¹ <https://www.media.volvocars.com/global/en-gb/media/pressreleases/139114/volvo-cars-demonstrates-the-potential-of-connected-cars-with-deliveries-direct-to-peoples-cars>

CONCLUSION AND OUTLOOK

Providing a wide range of crucial benefits including improved road safety, greater fuel efficiency, and reduced environmental impact, self-driving vehicles are sure to impact our daily lives. We are only just beginning to understand the magnitude of this impact.

In the near future, we are likely to see enhancements to existing driver assistance functions, with a particularly strong focus on safety.

Next, we can anticipate the introduction of autonomous driving in specific situations – for example, on congested highways and with strict low speed limits at first, although speeds will be allowed to increase over time. In parallel or soon after situation-specific autonomous driving, we should see an increase in low-speed driverless passenger transportation vehicles in non-public areas.

Looking further into the future, we could start to see the first fully autonomous highway journeys, 24/7. These vehicles will come when called, travel in convoy, communicate with each other, and even follow you around!

Several improvements can be anticipated, including greater precision in digital mapping, better algorithms to predict the behavior of other road users, and additional system flexibility for easier integration and deployment.

Alongside technology development, we may see a gradual reduction in current legal and liability framework gaps, along with more widespread public acceptance of autonomous driving.

Despite the current technical, regulatory, and societal hurdles to the uptake of driverless vehicles, some compelling use cases have already emerged in many different industries, clearly indicating a broad willingness to develop and deploy autonomous technology. And if any organizations in any industries dare to adopt a revolutionary approach, the pace of development could increase dramatically.

There is no doubt that self-driving vehicles will change the world of logistics. In this, as well as in many aspects of our personal and business lives, the question is no longer “if” but rather “when” autonomous vehicles will drive onto our streets and highways. As the speed of adoption increases, particularly in the ideal working environments of the logistics industry, it is clear that logistics service providers can have a key role to play.

At DHL, we are prepared to innovate and navigate this road to the future of logistics; we are ready to take a front seat. Along with our partners and customers, we plan to maintain pole position in the world of self-driving vehicles.

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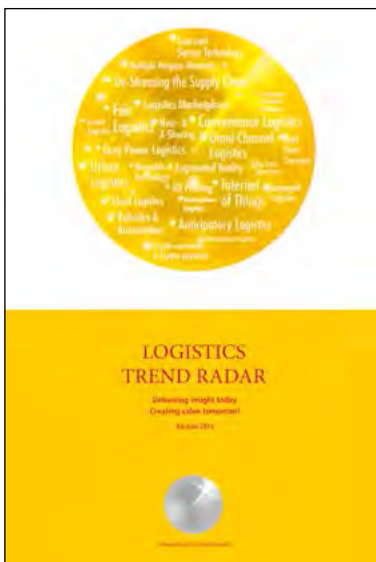
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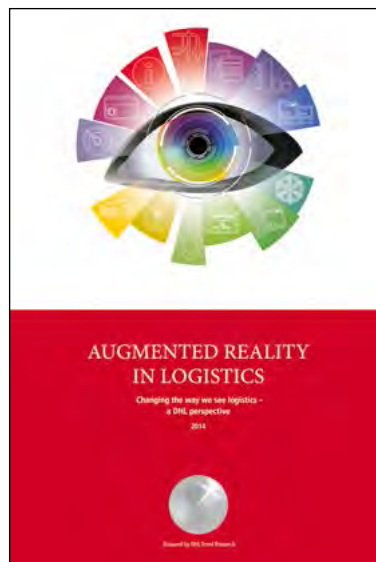
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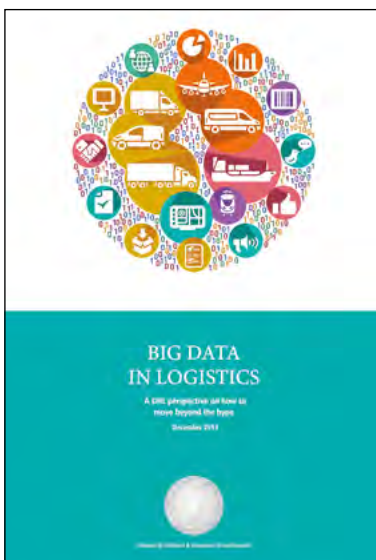
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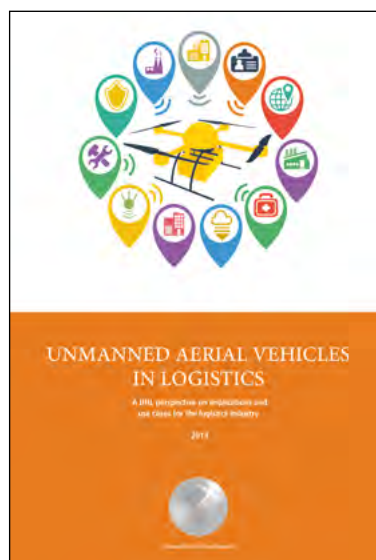
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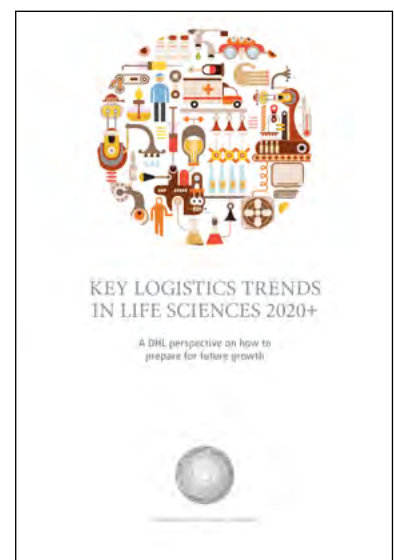
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