Automated container terminals and self-driving cars: Industry outlook

AUTHORS

JARI HÄMÄLÄINEN
PEKKA YLI-PAUNU
PERTTI PEUSSA

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Executive summary

In recent years, the development of autonomous cars has progressed rapidly, while automation has increasingly been gaining ground at selected container terminals. This white paper outlines the key differences and similarities between the two fields and examines the influence that the development of autonomous road vehicles is expected to have on the future of container terminal automation.

In both autonomous cars and terminal automation, the level of automation is increasing stepwise. The two areas share many common drivers towards automation but differ markedly in several respects. The underlying operating differences in basic technical approach (most notably that of autonomous road vehicles vs. a centralised terminal infrastructure) will remain for the foreseeable future.

Arguably the single most important long-term enablers for autonomous road vehicles will be Artificial Intelligence (AI) and especially machine learning, which are the core technologies required for accurate real-time situation analysis and safe decision making in complex open traffic environments. It is the view of the authors that the exponential growth of these technologies in the car and Information & Communication Technology (ICT) industries will create significant openings for adapting and integrating new capabilities into terminal automation, thus speeding up the development of our industry.

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1. Drivers for automation and expected impact

SCOPE OF DISCUSSION

This white paper is intended as a high-level overview on the current state of autonomous vehicle development and terminal automation – as well as the differences and potential synergies between the two – for readers in the container handling and logistics industries. Automation is progressing step by step in container terminals as well as in the car industry. However, in both fields, this is not just incremental product development, but a major transition that will likely have a substantial effect on the world at large.

At the time of writing (late 2018), both areas are undergoing fast development, with autonomous vehicle research benefitting particularly from recent progress in powerful and accessible AI / machine learning capabilities. Instead of focusing on individual solutions, products or research projects by various manufacturers, the paper aims to facilitate analysis and discussion of how advances in self-driving vehicle development might benefit the container handling industry, as proven, cost-effective technical solutions become available for customisation and adaptation.

THE CAR INDUSTRY AND SOCIETY

Over the last several years, manufacturers have been introducing progressively more advanced driver assistance features into mass-production cars. The purpose of these technical features is to aid the driver in their journey from A to B while making driving more enjoyable and safe. In this way, car manufacturers develop their products incrementally in order to keep the industry and their business evolving. The next goal is to increase the productivity of the driver or society. At levels of automation where no driver is needed, people will be able to spend their time on something more productive or interesting during the journey. Once the majority of cars are self-driving, this can be expected to have a major societal impact.

> Automation is likely to have a substantial effect on the world at large.

An even more significant effect on society and global business may result from various kinds of mobility as a service (MaaS) offerings. For example, driver salaries are often the single biggest expense for taxi and truck companies. Once equipped with self-driving fleets, their business is expected to get a major economic boost.

> The biggest societal impact of autonomous vehicles may ultimately result from a new type of sharing economy.

Also, self-driving cars will likely become a reality in MaaS applications much sooner than they are generally available to consumers all around the world. For example, self-driving public transportation, valet parking and local taxi services can be offered in selected areas when the weather allows long before global fleets of self-driving cars are feasible. Development in this field is already well underway; in 2018, former Google company Waymo announced the order of 82,000 vehicles from Chrysler and Jaguar for a large-scale pilot programme of an autonomous commuting service in Phoenix, Arizona.

Paralleling the development of MaaS offerings, the biggest societal impact of autonomous vehicles may ultimately result from a new type of sharing economy. Once the consumer does not have to own their car, but can get a drive when needed (from a fleet of self-driving cars), the number of cars worldwide can be expected to decrease significantly. This may ultimately impact a diverse range of seemingly unconnected businesses and services. Even the earnings model of car manufacturers may change from selling vehicles to a service-based model in which customers pay for kilometres travelled.

CONTAINER TERMINALS AND THE GLOBAL LOGISTICS CHAIN

Currently, automation is accepted as the primary way for terminals to develop their competitiveness in the future. The benefits of automation include safety, reliability, predictability and improved operations. Terminal automation as such does not radically change the current business models of the logistics industry, but the ever-growing software and service business, as well as the development of open and transparent global logistics chains does do so.

> Terminal automation sets the stage for a fully transparent global logistics chain.

The increase of automation levels at container terminals parallels the automatisation that has taken place in many other industries over the last decades. In addition to the obvious safety improvements that arise from keeping people out of the operating area of heavy machinery, automation enables terminals to do more container moves with the available number of people. When combined with the rapid advance of digitalisation and new developments such as blockchain, terminal automation sets the stage for a fully transparent global logistics chain that can be expected to have a major disruptive impact on how goods and materials are transported and delivered worldwide, and how businesses make a profit from it.

2. Terminology and definitions

> "The Society of Automotive Engineers (SAE) defines six progressive levels of driver assistance technology.

KEY TERMS

In a discussion of automated vehicles and equipment, it is useful to provide some clarification of the basic concepts in use. In everyday language, terms such as automated, automatic, autonomous, highly automated and self-driving are used interchangeably; however, more careful definitions are usually required when addressing the specific capabilities and development possibilities of such systems.

The automotive industry usually uses the terms autonomous or self-driving when referring to the ultimate design goal of creating road vehicles that would eventually be able to handle any driving situation as well as or better than a human driver. The United States Department of Transport refers to the same concept with the term highly automated vehicle (HAV).

By contrast, the container handling industry deals with terminal automation and automated container handling equipment, with little foreseeable need to create fully autonomous vehicles in the future. Furthermore, it is important to note that various levels of automation can be deployed to support operational and business goals, but they do not necessarily need to lead to fully autonomous vehicles.

To gain a more nuanced understanding of current solution levels and future development prospects, it is worth examining the definitions of progressive automation levels for both of these areas.

LEVELS OF DRIVING AUTOMATION

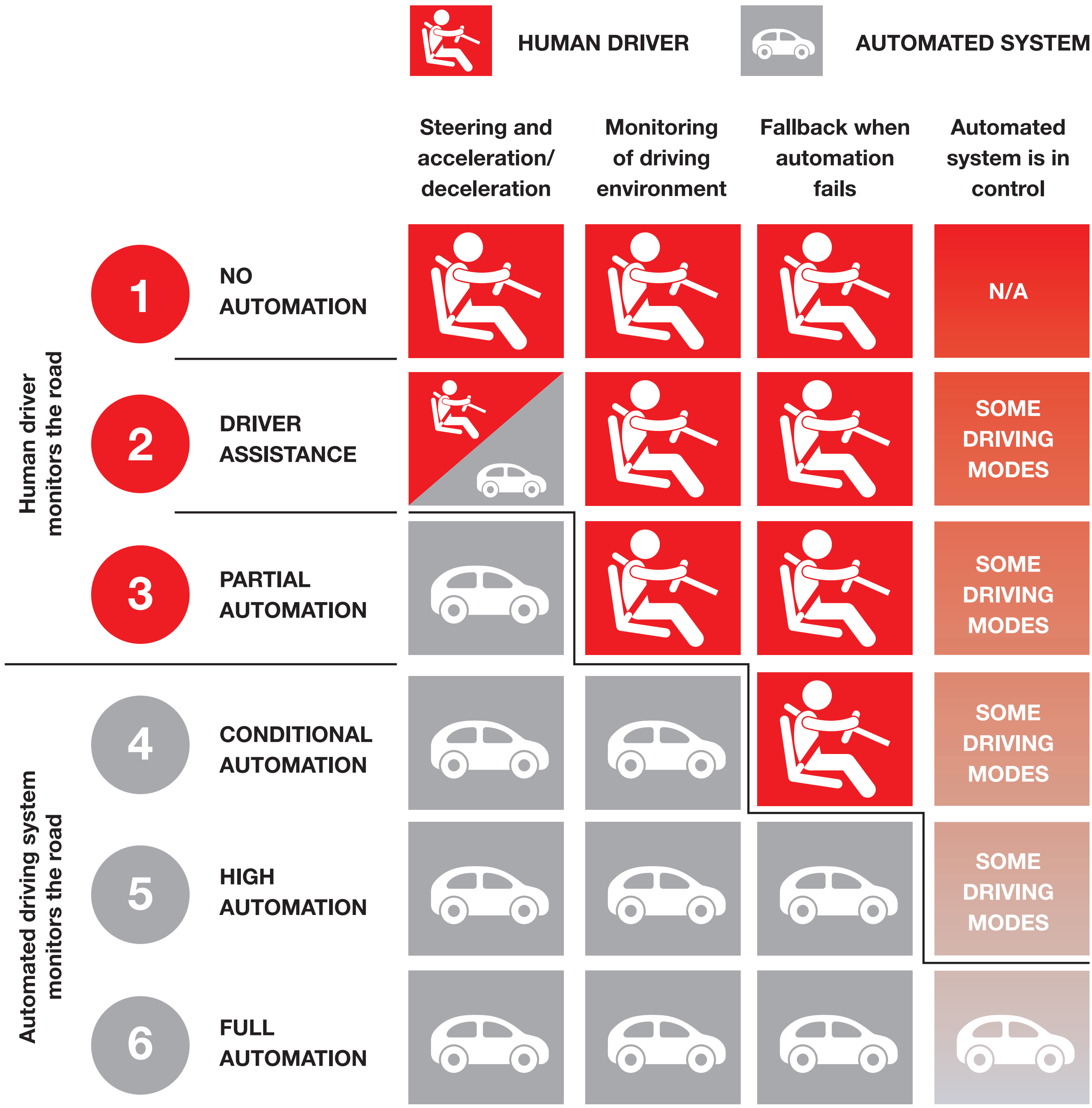
The Society of Automotive Engineers (SAE) defines six progressive levels of driver assistance technology, from manual driving to fully autonomous operation:

Level 0
The human driver does all the driving.

Level 1
An advanced driver assistance system (ADAS) on the vehicle can sometimes assist the human driver with either steering or braking/accelerating, but not both simultaneously.

Level 2
An advanced driver assistance system (ADAS) on the vehicle can control both steering and braking/accelerating simultaneously under some circumstances. The human driver must continue to pay full attention ("monitor the driving environment") at all times and perform the rest of the driving task.

THE 5 LEVELS OF DRIVING AUTOMATION



Source: Society of Automotive Engineers / National Highway Traffic Safety Administration
https://www.nhtsa.gov/technology-innovation/automated-vehicles-safety

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Level 3

An Automated Driving System (ADS) on the vehicle can itself perform all aspects of the driving task under some circumstances. In those circumstances, the human driver must be ready to take back control at any time when the ADS requests the human driver to do so. In all other circumstances, the human driver performs the driving task.

Level 4

An Automated Driving System (ADS) on the vehicle can itself perform all driving tasks and monitor the driving environment – essentially, do all the driving – in certain circumstances. The human need not pay attention in those circumstances.

Level 5

An Automated Driving System (ADS) on the vehicle can do all the driving in all circumstances. The human occupants are just passengers and need never be involved in driving.

> The automation level can be selected based on the existing systems, operating environment and business goals of the terminal.

AUTOMATION LEVELS IN CONTAINER TERMINALS

In container terminals, automation is also progressing stepwise from traditional manual operation through various process automation, remote control and operator assistance solutions, to eventual fully automated operation. The desired automation level can be selected based on the existing systems, operating environment and business goals of the terminal. Typically, process automation is deployed prior to – and alongside – automated equipment as the first step in gaining the benefits of terminal automation.

Kalmar defines several progressive levels of automation for container handling equipment. It should be noted that the levels detailed below are indicative and based on an application of an automated rubber-tyred gantry crane (AutoRTG) system. However, they are generally applicable to various other types of container handling equipment.

Level 0: Manual operation with process automation
In the traditional operating mode, a human driver controls all equipment functions. Process automation adds another dimension to terminal automation, as it can be deployed prior to, or alongside, different automation levels for the actual equipment. Even with a human driver still controlling the equipment, terminal performance can be improved with various process automation, fleet management and operator assistance solutions.

Examples of process automation solutions include automatic identification and tracking of containers and trucks in the yard; automated job allocation to equipment operators; telemetry for horizontal transportation equipment; and stack profiling for preventing collisions between the crane spreader and the container stack.

Level 1: Remote control
The most basic level of terminal equipment automation is remote control, which already improves efficiency and safety by bringing operators from the container yard into a control centre. For many types of equipment (e.g. RTGs) remote control enables a single operator to control multiple cranes. Remote control provides the possibility of optimising the manning level of the terminal based on the true amount of moves needed, instead of the number of operational cranes, as the operators are located in an office environment at remote control desks, able to take control of any crane in the terminal. Remote control also offers other benefits such as eliminating the time needed for operators to commute to and from the cranes in the yard.

Level 2: Supervised automatic moves

At the next level of automation, crane operation is fully integrated with the Terminal Operating System (TOS), so jobs are handled in an integrated solution and not in a separate equipment-specific system. Connection of the control desk to the crane is automatic once the job arrives. At this level of automation, an RTG crane executes automatic gantry and trolley moves to the target location, as well as automatic hoisting in the stacking area, all under the operator's supervision.
In many cases, supervised operation makes operation faster while reducing the potential for collisions against other containers. As the crane automatically positions itself accurately over the target container, this saves valuable seconds on each move. The automated moves are also smoother, resulting in less wear and tear on equipment and containers. This level of automation (supervised operation with automatic gantry steering) is the desired option for new RTG installations.

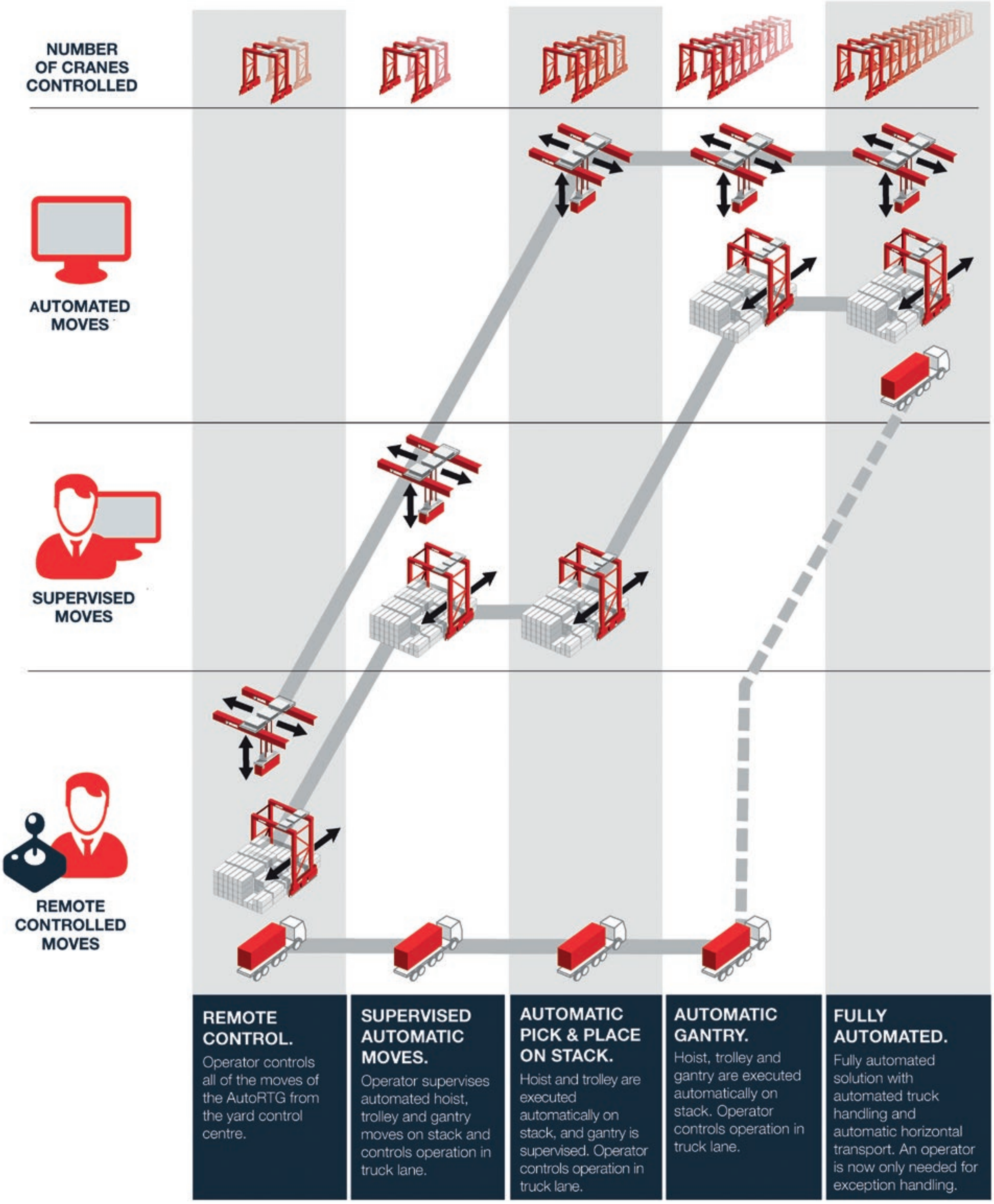
Level 3: Semi-automated operation

More advanced automation features can be added for higher efficiency and performance, and at this level, remote operators can control even more cranes per person. In semi-automated RTG operations, the crane executes automated trolley movements in addition to automated container pick and placing in the stack area. This level of automation significantly decreases the required operator time per container move. Gantry movement takes place under operator supervision, while truck lane operations and exception handling are accomplished by remote control. Trolley, hoist and gantry movements as well as stack housekeeping can also be automated, with the operator remote controlling the crane only in the truck lane.

Level 4: Fully automated operation

Finally, in a fully automated setup, all crane functions including hoist operation, container picking and placing, gantry moves and truck lane operation are automated. If needed, an operator can still step in to manage exceptions remotely. With a fully automated system, operator time per crane move is minimised, and stack housekeeping can be fully automatic. This level is standard for automated container handling equipment that can operate in a fully segregated automation area without people. Examples include automated stacking cranes and Kalmar AutoStrad™ straddle carriers that have already been in operation at various terminals for years.

” In a fully automated terminal, all crane functions including hoist operation, container picking and placing, gantry moves and truck lane operation are automated.



Automation levels in an AutoRTG terminal
Note: The depicted automation levels are illustrative and specific to an automated rubber-tyred gantry crane installation. Exact functionality at increasing levels of automation will depend on the type of automated container handling equipment and terminal concept.

3. Where we are now

AUTOMATED CONTAINER TERMINALS TODAY

Automated container terminals have already been in production use for over two decades. The world's first automated terminal was ECT Delta in the Netherlands, operational since the early 1990s. It was followed by the HHLA CTA Terminal in Hamburg, Germany in 2000. In 2005, the first stage of Patrick's AutoStrad™ straddle carrier terminal went live at the Port of Brisbane, Australia. Over the years, Patrick has continued to provide high performance levels while simultaneously becoming one of the world's safest container terminals. Today, some degree of automation is the standard for all newly built container terminals.

There are several reasons why container terminal automation has, until now, developed further than roadgoing autonomous vehicles. Firstly, the operational area is limited to the terminal domain, which simplifies deployment. Secondly, a terminal site is always relatively flat and it is easy to manage the full infrastructure within the area, from fences, gates and lamp masts to traffic signs, communication, cabling, and navigation markers. The majority of container terminals are also located in warm countries without the difficult winter conditions (snow, ice, low temperatures) that can complicate the operation of automated equipment.

> "The greatest demand for automation solutions will come from the existing manually operated terminals around the world.

Thirdly, equipment decision making is centralised and executed in layers that integrate the actual equipment control, the management of the fleet of machines at the terminal (Terminal Logistics System, TLS) and the overall operations of the terminal (Terminal Operating System, TOS). Finally, the manufacturing volumes for container handling machines are significantly smaller than those of the automotive industry. This has made it possible to deliver automation projects one by one to various customers without needing to wait for a global standardised solution.

Today, automation is generally accepted as the primary way of improving the competitiveness, predictability and safety of container terminal operations. It is unlikely that any new terminals will be built for traditional all manual operation, but the greatest demand for automation solutions will come from the large number of existing manually operated terminals around the world, as they continue to seek competitive advantage in a high-pressured global business environment.

AUTONOMOUS CARS TODAY

At the time of writing, autonomous cars are still at the experimental stage. Almost always, a human is in the driver's seat, even if the car is driving autonomously. The level of automation is increasing feature by feature, but despite fast progress in enabling technologies, we are still a long way from globally available commercial autonomous cars. The main challenge that technology developers are addressing is enabling autonomous vehicles to deal with the endless variety of driving situations and exceptions that can be encountered in traffic conditions around the world. Ultimately, this problem will be solved by machine learning models that are able to utilise vast pools of real-world training data gathered around the world.

A major difference with container terminal automation is the global operational area required of autonomous cars. Differences in national legislation, driving culture and weather conditions (fog, rain, dust, snow, sunshine etc.) pose massive challenges for the development of self-driving vehicles. Many production cars already have technically impressive driver assistance features that include various degrees of driving automation, and several major car manufacturers and technology companies have announced ambitious plans to bring fully autonomous vehicles to market over the upcoming years.

Equipment manufacturers are progressing stepwise in adding automation features to vehicles, with the key technical capabilities under development including sensor fusion and machine learning for localising the vehicle and mapping the environmental context around it.

A defining aspect of automated car development is that decisionmaking and navigation capabilities will likely be decentralised in each individual vehicle, at least for the foreseeable future. As a consequence, advances in onboard sensoring and processing capacity will incrementally enable new driver assistance features that evolve towards the ultimate goal of truly autonomous cars.

LEGISLATION AND INDUSTRY REGULATION

A major challenge for the development and adoption of autonomous road vehicles is that existing legislation and safety standards generally do not address self-driving vehicles. As a result, questions of liability, safety certification and applicable safety levels need to be reconsidered for autonomous cars. Changes in legislation and/or industry standards usually take several years to implement, but the speed of technical development in the field has outpaced the capability of policymakers to adjust the regulatory framework.

> "The container handling industry already works within a tightly defined framework of industrial standards and occupational safety legislation.

In the United States, Federal Motor Vehicle Safety Standards outline the requirements for minimum safety performance, objective testing and manufacturer self-certification. However, the federal level has no safety standards for autonomous vehicles, so references to a driver can be interpreted either as requirements towards an autonomous driver (AI), or a human driver/steward overseeing the operation of the vehicle.

The U.S. Department of Transportation Automated Vehicles Policy from late 2016 is not a rulemaking initiative but an agency guidance document that outlines steps for the deployment of self-driving vehicles, defined as highly automated vehicles (HAV). The document sets out recommendations and best practices in several areas, including requirements for pre-deployment testing, a model for a future state-level legislative framework, as well as guidance on the applicability of existing and new regulatory tools.

Meanwhile, various states have progressed with their own legislation to facilitate the adoption of autonomous vehicle testing, and the majority of states already provide some provision for self-driving vehicles on public roads; however, these state-by-state laws differ on even basic concepts such as how to define the "operator" of the vehicle. Most notably, California, Arizona and Nevada have updated their laws to allow the testing of autonomous vehicles without a human driver inside.

The EU faces a similar situation, in which member states are forging ahead with national regulations in attendance of a union-wide framework on autonomous cars. No well-defined acceptance procedures exist for road vehicles at higher levels of automation, but the topic is under active discussion in several countries, as manufacturers and research organisations proceed with their development efforts. In Finland, autonomous cars at any SAE automation level may be temporarily tested in traffic subject to a test permit, provided that the car has a human driver either inside or outside the vehicle.

By contrast with autonomous road vehicles, the container handling industry already works within a tightly defined framework of industrial standards and occupational safety legislation. However, the challenge here is similar in that no safety standards or laws exist yet specifically for container terminal automation, so applications need to be based on interpretations of existing norms and regulations.

4. Technology considerations

CLOSED/CONTROLLED VS. OPEN/UNCONTROLLED ENVIRONMENTS

Container terminals are closed environments, which has made it possible to deploy extensive automation at many terminals. The car industry and mobility as a service providers are attempting to start with a parallel approach, since it is easier to introduce commercial operation for self-driving cars in limited areas and applications (e.g. shopping centre valet parking or public transportation in a selected city), rather than globally.

The major challenge that the developers of autonomous/self-driving cars are tackling today is ensuring the safe and consistent operation of the vehicles in the infinitely variable open environment of road traffic. In controlled or semi-controlled environments (such as people mover systems at airports or corporate campuses) self-driving vehicles have been operating safely and reliably already for many years. The complexities of open and uncontrolled environments will require vastly more advanced capabilities, as manufacturers and system designers need to address an endless range of factors ranging from differences in traffic culture, national legislation, weather conditions and road infrastructure.

Driving on a straight road is a relatively simple task to automate, but self-driving cars will also need to cope with snow, darkness, animals of various sizes, unpredictable and sometimes irrational people in traffic, various road surfaces, and traffic conditions that range from a desert highway to a rush-hour roundabout in Paris or the organised chaos of traffic in Mumbai.

This infinite amount of exceptional situations is the main source of complexity in enabling global fleets of fully autonomous cars. It seems likely that the only way to make significant progress with these cases is to harness existing cars and humans to automatically gather and/or crowdsource data from a vast range of situations and feed this data into machine learning applications to create models that can react to such situations. Thus, it is only the current exponential growth of technology (and especially AI and machine learning) that offers any reasonable chance of making autonomous cars a reality in the next few decades.

At container terminals (ports, intermodal terminals or industrial logistics centres), the main challenges of automation are, firstly, continuously increasing the reliability and performance of load handling and, secondly, the fluid collaboration between load handling equipment, other vehicles (trucks, trains and container vessels) and especially people (operators, service personnel).

Industrial applications also have different safety requirements than commercial vehicles. Container terminal automation takes place in a closed area with safe access control systems built to well-defined industrial safety standards, though development is moving towards operations in which automated and manual machines can work alongside humans. Conversely, the car industry will always need to operate in so-called mixed mode as conventional vehicles, smart cars and people move together in open traffic.

Paralleling the autonomous vehicle industry, terminal automation also meets its greatest design challenges at the interfaces between humans and automated equipment, such as when loading road trucks by automated RTG cranes. In such an environment, there are still numerous variables and exceptional cases that need to be tackled one by one, but the magnitude of the challenges is limited compared to the uncontrolled environment of a global fleet of autonomous cars. At terminals in which the container handling equipment does not need to physically interact with people, the degree of automation is already several levels ahead of sites that must integrate people with automated machines.

> ” Autonomous vehicles rely on a wide range of sensoring solutions, with development continuing at a fast pace.

SENSORING AND PERCEPTION

Autonomous vehicles rely on a wide range of sensoring solutions, and this area is already relatively advanced, with development continuing at a fast pace. The solutions are based on the concept of sensor fusion, combining inputs from numerous systems from inertial measurement units, cameras and GNSS devices (Global Navigation Satellite Systems, including GPS) to radar, ultrasonic and Light Detection and Ranging (LIDAR) sensors. The vast amount of data generated by these systems is then handled with artificial intelligence (AI) such as machine learning / deep learning methodologies to enable the autonomous solution.

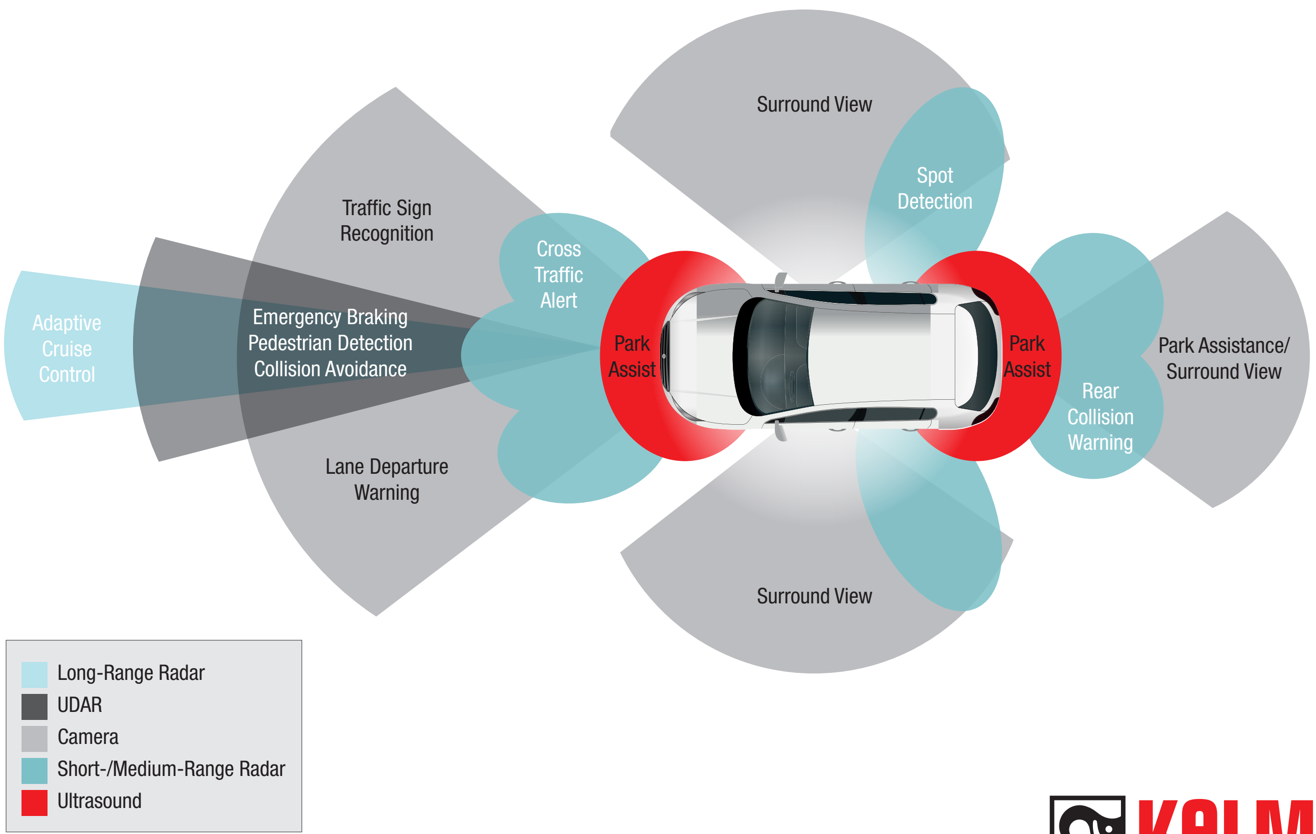
In the development of autonomous cars, the primary sensoring technology varies from manufacturer to manufacturer. For example, Tesla focuses mainly on camera-based systems while Waymo depends more on LIDAR technology. At automated container terminals, the need for advanced sensoring also extends from vehicle movement to the handling of the actual containers, which can utilise various technologies such as laser scanners.
Irrespective of the technical solutions used, both fields share the common goal of enabling the solution to build a sufficiently detailed real-time picture of the environment in order to ensure safe and efficient

operation in any expected conditions. Thus, it is useful to extend the concept of sensoring to the wider concept of machine perception in both contexts.

As a high-volume mass market, the car industry is developing sensors, actuators and cameras at a remarkable pace to boost the development of autonomous vehicle systems. The major auto manufacturers are investing heavily in this field, typically depending on an ecosystem of specialised hardware and software subcontractors for the huge range of subsystems required. Container terminal automation also depends on the sensor fusion of data from satellites, radar, magnets, transponders, cameras and laser scanners, with the exact combination selected on a case-by-case basis. By contrast with the car industry, these systems are usually built from safety-rated products designed specifically for industrial purposes, instead of high-volume bulk components.

The rapidly developing mass-market sensor technology in the car industry will also boost innovation in industrial applications, while simultaneously lowering component prices. Container terminals therefore have the possibility of adapting these innovations very quickly to their own sensing and perception systems, so this area holds the potential for fast improvement already in the short and medium-term future.

Sensor fusion in autonomous cars
Source: Society of Automotive Engineers



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MAPPING AND LOCALISATION

Another area of rapid development in the car industry is creating and maintaining the highly detailed, dynamic 3D HD maps required by autonomous vehicles. Currently technology companies have large fleets of cars scanning the global roads continuously, but in the future new on-vehicle sensors will enable the increasing use of crowdsourcing for the distributed collection of dynamically changing map data.

The ETSI (European Telecommunications Standards Institute) has defined an LDM (Local Dynamic Map) framework for managing vehicle sensor and map data, which has subsequently been standardised as ISO standard 18750. Local Dynamic Map information encompasses several levels from permanent and transient static data (map features, roadside infrastructure) to transient dynamic data (e.g. congestion and traffic signal phase) and highly dynamic real-time data such as vehicles and detected pedestrians.

In current terminal automation solutions, map data is relatively static, with a possibility for updates through various configuration actions. Adopting dynamic HD-level mapping technologies holds the promise for great improvement at future container terminals. In addition to changes in terminal infrastructure, such dynamic 3D maps could include data such as the position of people or service vehicles moving in the area, or even holes in the asphalt that should be avoided by equipment. Even though the terminal infrastructure design remains as the basis for the environment map, it is possible to adapt features of dynamic maps from smart/autonomous traffic to enable more dynamic changes in terminal layout maps.

CONTROL

Independently operating self-driving vehicles – and even today's cars with advanced driver assistance features (e.g. Tesla) can rightly be described as computers on wheels, instead of cars that include computers. Alongside sensoring/perception technology, the key development area today is the processing required for the vehicle to safely and reliably make sense of its environment and respond optimally to the infinitely variable situations that can be encountered in different traffic and weather conditions.

Arguably the single most important long-term enabler for autonomous road vehicles will be AI, which is the core technology required for accurate real-time situation analysis and safe decision making in complex open traffic environments. Resultantly, a key challenge for autonomous vehicle developers is managing the massive system complexity required by high-level sensoring and AI deployments on individual vehicles.

By contrast, automated container terminals already utilise a range of highly reliable, field-proven solutions for equipment guidance, navigation and control. Positioning/navigation technologies range from infrastructure-based systems such as magnetic markers and radar beacons to various on-equipment solutions. However, automated container terminals operate with a different set of design requirements, as the equipment is, by default, always controlled centrally and the scope of operations is limited to the terminal.

Despite these differences in the underlying concept, the current rapid development of AI for autonomous vehicle solutions is also a major opportunity for the container handling industry, as the exponential improvement and affordable availability of both on-vehicle and server/cloud-based AI processing capacity will open up new possibilities for centralised automated solutions in the container terminal environment. As the technology for high-level AI becomes accessible and increasingly commoditised, the cost or availability of raw processing power is no longer a design constraint. Instead, the challenge becomes one of identifying successful solutions in other fields and applying them creatively to the specific requirements of the logistics industry.

Algorithms vs. machine learning

In any automated or autonomous system, some control and decision making is always possible with algorithms created by software developers. However, when the set of required rules and potential exceptional cases gets large enough, the only possibility will be to utilise various kinds of machine learning. Rather than hard coding system behaviour into fixed rules, machine learning allows developers to focus on gathering a lot of learning data and creating models based on it. Currently there are several multilayer deep learning technologies available, and new ones coming in the future, so one needs to have the competence to select the right method for each problem. A combination of fixed algorithms and various machine learning techniques is the standard approach for complex problem sets such as those encountered in autonomous cars and vehicles.

At the highest level, the key difference between self-driving cars and automated container terminals is that in current terminal automation, most of the control and decision making is based on pre-programmed software-coded algorithms, though in the future machine learning techniques will increasingly be used to support and improve control and decision making. By contrast, in self-driving cars, it is impossible to get far with pre-coded algorithms, so machine learning is a key success factor both now and in the future.

> ” Artificial intelligence for autonomous vehicle solutions is also a major opportunity for the container handling industry.

One should also remember that AI is already in widespread use in many small applications, both in passenger cars and terminal automation. In vehicles, AI is used e.g. for automatic traffic sign recognition, detection of animals in order to avoid accidents, and automatic lane monitoring. In container handling, successful production deployments already include solutions such as optical character recognition for container identification, license plate recognition at automatic truck kiosks, and automatic damage detection for containers.

Infrastructure

Infrastructure for self-driving cars is rarely given much attention in public discussion, and is often viewed almost as a "nice to have" add-on. The current focus of self-driving cars is to make them standalone products that can drive autonomously, and manufacturers cannot count on a global infrastructure being available solve the problems associated with car operation and control. As a result, smart traffic infrastructure will probably add value to autonomous cars on a case-by-case basis. For example, when self-driving cars are used in predefined applications in constrained areas (e.g. automatic “valet parking” at shopping centres), the location can be equipped with the necessary infrastructure to enable such a mobility service. Even though various kinds of sensors in traffic lights, traffic signs, roads etc. may add value beyond the standalone decisionmaking in the cars, the global self-driving car industry does not expect infrastructure-based solutions to solve its major design problems.

By contrast, in the limited area of a container terminal, it is straightforward to build the local infrastructure to enable automated applications. Whereas autonomous cars are basically designed to operate on their own in open environments, terminal automation can be designed with a specific infrastructure in which most of the obstacles except people and vehicles are known and defined beforehand.

Communications

Vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) machine communication – also known as Connected Driving – hold tremendous potential for boosting the safety and efficiency of both manually driven and automated cars. In the future, cars and infrastructure may start sharing relevant information with each other wirelessly, such as the vehicle's own state, speed, location, traffic light status, approaching emergency vehicles, slow vehicle warnings, platooning coordination etc.

In order to reach this type of functionality, the vehicles and infrastructure require several levels of static and dynamically updated map data. The standards and base technology for Connected Driving already exist in the previously mentioned ISO standard 18750, so the capability could theoretically be introduced to new cars, trucks, buses and motorcycles at any time. Despite this, the industry has until now been slow to embrace the concept. Since both manually driven and automated vehicles stand to benefit from Connected Driving, its eventual impact may turn out to be larger than that of automatic driving alone.

In connected cars, continuous high-speed data connectivity is required for real time map updates, as well as to enable smart features that assist drivers by enabling faster reactions than those of a human driver. This kind of smart traffic communication is one of the basic building blocks of autonomous driving. 5G and modern mesh/swarm communications will improve the connectivity of both V2V and V2I communication, thus leading to advances in safety and traffic efficiency.

At container terminals, all automated operations are, by default, based on real-time connectivity, so future technology improvements will also add value to terminal applications. At terminals, cables and fibre-optic connections can be used for certain machines, but many operations depend on reliable high-speed wireless communications. Wifi can currently be used for some applications, but 5G data communications are expected to provide significant new possibilities for connectivity at all automation levels. In the future, machines may also communicate with each other to a greater extent.

MAINTENANCE ASPECTS

Smart maintenance – in which systems are equipped with advanced monitoring, diagnostic and telemetry features – will be essential for all kinds of autonomous vehicles. Sensors and systems on the vehicle will be collecting condition data that will be used for smart decisionmaking about the most optimal time of maintenance.

At automated container terminals, the focus of maintenance shifts from ad-hoc repairs to preventative maintenance. It is notable that even as automation increases the predictability and availability of container handling equipment, it also requires a more stringent service programme that focuses on preventative maintenance tasks and continuous monitoring of equipment condition. At manual terminals, human operators can often compensate for small deficiencies or malfunctions in equipment, but automated machines always need to be at full performance for the system to deliver its expected potential.

Automated container terminals require more – not less – attention to maintenance, to ensure that machines are not broken and unavailable, because there is no human driver or operator there to notice basic faults before they develop into more serious malfunctions. It is reasonable to assume the smart and predictive maintenance programs will also be essential for self-driving cars. On the other hand, automatisation goes hand in hand with the ongoing trend towards electrification. A detailed discussion of electric cars is beyond the scope ▶

of this paper, but it should be noted that in both cars and container handling equipment, electric drivelines feature a completely different maintenance paradigm, potentially offering higher reliability and lower lifecycle costs. However, the level of technical competence required to service and maintain automated/electric equipment is also very different from traditional vehicles or machines.

SYSTEM APPROACHES: AUTONOMOUS VEHICLES VS. CENTRALISED DECISION MAKING

Autonomous container handling equipment has always been – and is likely to remain – centrally controlled, even as the intelligence of the equipment increases rapidly. Though the ultimate goal is an automated system that will be able to handle any conceivable situation, remote control or teleoperation will still be needed for exception handling far into the foreseeable future.

The development of autonomous cars is currently focused almost exclusively on vehicles that distribute the decision making and processing to each individual vehicle, at least if the discussion is limited to private cars and new mobility services instead of a larger context of future public transportation infrastructures. Whether autonomous cars can actually succeed in fulfilling many of the expectations set for them (reduced traffic congestion, improved sustainability, less need for parking in city centres etc.) without shifting the underlying design approach to a centrally managed system remains a space for some debate. However, such a major paradigm shift on a global scale seems highly unlikely, as long as individual transport and freedom of mobility remain the prevailing core values for consumers/road users and vehicle manufacturers.

EXPONENTIAL TECHNOLOGY GROWTH

Exponential technology growth has been with us for decades, from the processing power of integrated circuits to memory capacity and communications technology. A high-capacity hard disk in 1956 might have been 5 MB in capacity; today, our portable drives hold Terabytes of data for a tiny fraction of the cost. The wireless data speed of GSM in the 1990s was 9.6 kbps, while 5G will reach speeds of 10 Gbps with sub-millisecond radio latency in the next decade. As impressive as these figures are, they don't even begin to address the potential of how various new applications can accelerate the development of other industries.

As far as technology is concerned, many commentators have posited that we have already moved well into the "second half of the chessboard" – the point where the speed of exponential change becomes difficult to understand. This has particular relevance to the

"Exponential development means inevitable business change. The winners will be those that are the fastest to adapt to the ongoing change in the world.

accelerating onset of digitalisation and how it will affect global maritime container logistics. Exponential technology growth in computing power, memory, data communications and cameras will drive the adoption of new solutions at speeds that may be impossible to estimate beforehand.

The exponential growth of digital technology – and especially AI / machine learning – is currently the key enabler of autonomous vehicle development. However, this development also brings with it much wider implications. Exponential development means inevitable business change, and the winners will be those that are the fastest to adapt to the ongoing change in the world.

In a world of exponential development, well-run established companies are actually the ones that are most at risk as new entrants shake up the business models. Most often, the biggest change happens in the creative crossing of existing industries. So the question becomes, does the container handling industry dare to challenge itself and utilise the advances of other fields (including autonomous car development) or does it choose to wait to be disrupted? And what is the future of the car manufacturers that have ruled their markets for a hundred years or more? Can they cope with challenges from new service providers, or will they themselves shift towards MaaS business models?

KALMAR

5. Safety

FUNCTIONAL SAFETY

Autonomous cars and automated container handling equipment need to conform to strict existing safety requirements as well as highly demanding safety expectations from stakeholders within and outside their own industries.

A key concept for system designers is that of functional safety, which refers to the automated, predictable and correct response of a system to its inputs, or to the system having a fail-safe design in case of malfunction. In road vehicles, the core risk classification scheme is the Automotive Safety Integrity Level (ASIL), which is adapted from more general industrial safety level standards. Defining the ASIL of a given system or product involves an analysis of the severity, exposure and controllability of the hazards in a vehicle operating scenario. The desired safety goal for the hazard then defines the required ASIL.

ASILs are classified to four levels, with ASIL D dictating the most stringent integrity requirements and ASIL A the least demanding. The development and certification of software and hardware-intensive advanced driver assistance solutions to ASIL D has proven to be a challenge for equipment manufacturers; as system complexity in autonomous vehicles increases, this challenge is likely to remain.

STANDARDISATION AND INDUSTRY NORMS

Automotive safety standards set out a comprehensive and detailed framework that manufacturers must follow for commercially available road vehicles. The difficulty is that no industry-wide standards exist yet for autonomous cars. Even as several states in the US forge ahead with legislation that approves self-driving cars without a safety driver behind the wheel (though usually with a remote operator and/or special permits), the industry must do its best to adapt current systems to existing standards.

The key safety standard for road vehicles is ISO standard 26262, titled "Road vehicles - Functional safety", which defines the above-mentioned ASILs. An ASIL is calculated as Severity x (Exposure x Controllability), thus taking into account the possible consequences and likelihood of a system failure, as well as whether a driver would be able to take action to prevent injury.

ISO 26262 is adapted from the IEC 61508 functional safety standard that provides a more general framework for designing and deploying automatic protection systems. IEC 61508 utilises a risk class matrix that rates various

> Manufacturers and system designers must embrace a philosophy of humanised automation.

hazards on the likelihood of their occurrence (from Frequent to Incredible) as well as their consequences (from Catastrophic to Negligible). Though similar in overall concept, there is no direct mapping between the SILs defined in IEC 61508 and the ASILs of ISO 26262, with the latter involving a more complex risk mapping with three separate dimensions (severity, exposure and controllability).

In the field of industry, a key safety standard is ISO 13849, "Safety of machinery – Safety-related parts of control systems", which also refers to IEC 61508. ISO 13849 provides safety requirements and guidance on the principles for the design and integration of safety-related parts of control systems, including the design of software. For these parts, it specifies characteristics that include the performance level required for carrying out safety functions. The standard can be applied to systems with high demand and continuous operation, irrespective of the type of technology and energy used.

HUMAN FACTORS

In both autonomous cars and terminal automation, it is easy to get fixated on the questions of technology, and forget that in both fields, manufacturers are designing solutions for people, in a stepwise approach to help them in their work, business and free time. To gain wider adoption, any solution must ultimately address the needs, goals and values not only of its immediate users, but also of other stakeholders and society as a whole.

In all dealings with automated and autonomous machinery, the most complex issues always arise at the interfaces where people need to work with and/or share space with automated equipment. Beyond the obvious requirements for safety, the demands extend much deeper into questions of how we interact with our machines. Whether designing self-driving vehicles or automated container handling equipment, manufacturers and system designers would do well to embrace a philosophy of humanised automation, all the way from enabling the safe and seamless operation of machines and people in the same area, to top-notch user experiences that ensure our systems serve our needs, and not vice versa.

SECURITY

In addition to occupational and consumer safety aspects, automated equipment, self-driving cars and any type of autonomous system also raise a wide range of new questions related to security. New threats ▶

will inevitably surface, and new solutions will need to be found to address them.

Potential threat scenarios may range from intentional unavailability of systems, to safety hazards created on purpose. How do we stop malicious actors from hacking an autonomous car in order to kill a pedestrian on purpose – or a terrorist from using one to deliver a bomb? What completely unexpected threats might be made possible by the new technology being deployed at the cutting edge of development? Especially in the open, global operating environment expected of autonomous cars, the security discourse is likely to become extremely complex as the deployment of self-driving vehicles progresses further.

HIGH-LEVEL SOCIETAL QUESTIONS

Even though we are still awaiting a major breakthrough in the adoption of autonomous road vehicles, the rapid development in the field has already called for a wide-ranging debate on how to define the responsibilities, liabilities and accepted risk levels of self-driving cars. When algorithms and "smart" machines perform decision making in life-or-death situations, the question of who is ultimately to be held accountable becomes extremely complex and laden with legal, political and moral dimensions.

In a few highly publicised incidents over the last years, autonomously driving cars or advanced driver assistance systems have been involved in road accidents resulting in loss of life. Paradoxically, the further autonomous vehicle control systems advance and the safer they become, the harder it will be to assign responsibility on the occasions that they do fail. Can unequivocal blame be laid on the car manufacturer, software designer, or some other party further in the system development chain? Or does the responsibility for the safety of the vehicle and its occupants ultimately always rest with a human driver/steward who should theoretically be ready to step in if the autonomous functions of the car fail to cope with a given situation – even if at highway speeds there is no realistic chance of a human being able to react and take control fast enough?

As a society, we need to make difficult decisions on our expectations and demands of autonomous vehicles, and how we measure the fulfilment of these demands. Should we expect self-driving cars to be as safe, or safer than human-driven automobiles per kilometre travelled? Or safer than trains, or commercial air traffic? How do we deal with an autonomous car accident that a human driver couldn't reasonably have averted? When loss of life occurs, can an autonomous car manufacturer defend itself by stating that even after the accident, the car in question has already been safer on average than traditional vehicles?

For automated container handling equipment operating in the closed environment of a container terminal, the moral issues are not quite as daunting, but manufacturers and software developers still need to deal with the formidable task of ensuring the safety of their systems, even as the complexity of automation deployments increases. As development is extended to ecosystems involving multiple parties with specialist knowledge, it becomes an increasingly challenging task to not only design but also to certify systems to whatever safety level is required.

For evaluating safety levels and identifying areas for further improvement, modelling, simulation and real-world data are essential. In terminal automation, the ultimate responsibility for accidents is often focused on the equipment/system manufacturer, which can create pressure for over-engineering or hinder the adoption of new solutions. Ultimately, we want to create solutions that are smartly safe – i.e. designed for human needs, rather than over-engineered based on other aspects such as legislation or the opinions of engineers.

In both autonomous cars and terminal automation, solution development relies on vast amounts of data being gathered on the autonomous/automated machines, as well as their operating environments and conditions. AI guidance and collision avoidance systems require massive real-world datasets to train their algorithms, and autonomous car manufacturers make a point of advertising the millions of kilometres their vehicles have driven without incident. To further accelerate the development of safety in autonomous vehicle design, an open, industry-wide culture of proactively sharing safety-related data would enable all manufacturers – and ultimately society as a whole – to benefit from the experiences of others. However, competitive pressures and the proprietary interests of each manufacturer may render such an ideal scenario unfeasible in practice.

Likewise, a global pool of source data for machine learning could help developers solve the vast amount of exceptional cases faster in order to create a significant number of fully automated terminals all around the world. For example, gathering data from twistlock operations, container moves, truck alignment, routing, and navigation operations would enable continuous self-learning based on actual operational data. Finally, real-world data on safety hazards and near-miss cases would enable improvement of safety throughout the industry.

Future prospects

TOWARDS THE AUTONOMOUS WORLD

At the time of writing, the development of or autonomous cars is proceeding at an impressive pace, with many of the world's leading car manufacturers and technology companies making huge research and development investments in the field. For example, Volvo has announced that it intends to bring its first unsupervised autonomous vehicles to the market by 2021. The stepwise adoption of more advanced driver assistance features in commercial cars will eventually lead the way to the ultimate goal of an autonomous car that meets the technical, safety, price and performance demands of the mass market.

How much of – and when – this projection actually becomes a reality remains to be seen; manufacturers are happy to provide quite ambiguous estimates of when their autonomous cars will arrive, or even what the term 'autonomous' specifically means in the context of a press release. It is well understood that building a vehicle that can consistently navigate suburban streets in sunny Arizona is quite different from equipping a vehicle to do the same on a rural road in northern Sweden, while safely dealing with snow, fog and reindeer crossing the road.

By contrast, the container handling industry is already years or decades into the successful production use of automated solutions. Automation is generally accepted as the primary way for terminals to improve their operations over the upcoming years, and as solutions develop, the benefits of incrementally deployed process and equipment automation will become increasingly accessible to terminals of all sizes.

> ” The greatest value of terminal automation will come when it is eventually combined with the new digitalised and connected logistics chains.

However, the greatest value of terminal automation will come when it is eventually combined with the new digitalised and connected logistics chains that are rapidly taking shape around the world.
It remains to be seen how much autonomous and automated operation will change the roles and value creation in the global logistics business, but a fully digitalised, transparent supply chain holds great promise for not only the container shipping business but also the whole global economy.

Eventually, autonomous container handling equipment, cars, trucks, vessels and trains will all work smoothly together, transporting containers between automated terminals. In the future, even the containers may become smarter and more connected thanks to advances in the Internet of Things (IoT). Simultaneously, the surrounding infrastructure will also be connected with every car, machine, container and device, enabling cybersecurity threats to be tackled resiliently.

> Software reliability may prove to be one of the most severe limiting factors for autonomous car adoption.

In this autonomous world, we will see fewer human-coded algorithms, as developers focus on self-learning models and the harnessing of big data from various sources including crowdsourcing. This will aid systems in coping with the never-ending exceptional situations encountered in the real world. System intelligence will move from the cloud to the edge, making cars and machines more intelligent and enabling them to make more independent decisions. Standardisation and openness will increase, and ports, intermodal terminals and other industry facilities will adopt and integrate mass-market technology from the auto industry into terminal automation.

DEVELOPMENT DRIVERS VS. INHIBITING FACTORS

When trying to predict the future of autonomous vehicles from today's vantage point, it is worth considering some of the potential factors that may inhibit their wider adoption. Many of the utopian scenarios with which autonomous cars are currently marketed may also need some re-evaluation when subjected to real-world constraints. By contrast, the container handling industry is in a relatively advantageous position in that solution development is mostly contained to the limited and controlled environment of the terminal, so many of these challenges are not felt as acutely.

Software reliability may well prove to be one of the most severe limiting factors for autonomous car adoption. Developers are faced with the formidable task of designing vehicles whose AI capabilities will eventually allow them to function reliably, safely and predictably in chaotic inner-city environments or rough rural conditions. Susceptibility of the car's sensing and navigation systems to different types of weather (such as snow), let alone deliberate interference such as jamming or spoofing will remain a concern. The avoidance of large animals requires instant recognition and tracking, and software that is optimised for caribou, deer, and elk may prove ineffective with kangaroos.

Autonomous cars will also require very high-quality specialised maps to operate properly. If and when these maps are inaccurate or out of date, the vehicles need to be able to fall back on reasonable failsafe behaviours. Competition or interference in the radio spectrum required by the car's communication systems may pose problems, and current road infrastructure may need extensive, costly modifications for autonomous cars to function optimally.

The total cost of ownership (purchase, maintenance, repair and insurance) of autonomous vehicles is still unknown, even if novel cost-sharing models may some day change the basic paradigm of private car ownership. Finally, differences of opinion on how governments and lawmakers should respond to the development of autonomous cars may cause delays in their acceptance for the road. Irrespective of which path is chosen, the regulatory and standardisation framework will be one of heated discussion and intense debate.

Autonomous cars have been predicted to have a huge impact on almost every area of business. Disruptive change is taken as a given, even if the specific predictions of what this change involves are sometimes in direct contradiction. Often, the public debate conflates arguments about autonomous vehicles with those regarding electrification or new models for vehicle sharing. On one hand, mobility as a service (provided by autonomous vehicles) is expected to decrease private ownership of cars; on the other, autonomous cars may attract new owners who have previously felt uncomfortable with the idea of driving. Mobility as a service is seen as a way to introduce self-driving cars more rapidly into markets, because the operation can be limited rather than global.

Autonomous cars are predicted to decrease traffic congestion, vehicle emissions and the need for parking in city centres; at the same time, it remains difficult to see how this may come to pass if huge fleets of roving autonomous vehicles are required to serve the on-demand mobility needs of the working population. It is equally easy to conceive of a situation in which the adoption of self-driving vehicles actually increases traffic in city centres. If an autonomous car can roam the streets and park on its own after dropping off the driver at the destination – as currently advertised by e.g. Volvo – does the car owner have any incentive to park the car at all? Why not let it drive around for the day, and have it pick you up after work – or send it back home to the suburbs for parking, effectively doubling the daily commute distance?

If the promises of car manufacturers come true, autonomous cars have the potential to hugely improve the safety of road traffic, but even this positive development may have unexpected side effects. How will our healthcare system deal with a significantly smaller number of organ donors from traffic accident deaths? Will our pizza taxis become automated for last-mile delivery? If self-driving cars become mobile hotels or replacements for medium-haul flights, what does it mean for the hotel and airline businesses?

KEY OPPORTUNITY: SELF-DRIVING CARS BRING NEW CAPABILITIES TO THE TERMINAL INDUSTRY

The rapid mass-market development of supporting technologies for autonomous cars (AI, sensoring, guidance technology etc.) is the major opportunity from which container terminal automation providers can benefit today and in the near future. Instead of needing to develop proprietary technologies from scratch, or systems based on expensive industrial components, the industry can adapt and reuse many of these new solutions for its own specific applications.

This opportunity is particularly powerful if it can be combined with open standards and interfaces that allow for the creation of wider business and technology ecosystems beyond the borders of individual companies. Within the terminal industry, Kalmar has taken the first steps to facilitate this kind of development with its Kalmar Key initiative; whether automotive companies and technology providers are able to converge on a workable set of open standards to benefit the growth of self-driving cars will likely be a key success factor for the entire wider industry in the years to come.

The future of self-driving cars:

- Continued development of new driver assist features
- MaaS services with autonomous cars, first in limited areas
- Development of support infrastructure
- Communications network development
- HD maps and crowdsourcing
- Eventual global deployment of autonomous cars, perhaps area by area

TIMELINE

Step 1
Sensoring part solved first

Step 2
Mapping evolves relatively quickly

Step 3
Autonomous control approved for limited areas and services

Step 4
Global operations
(exact timeframe unknown, probably decades)

´THE FUTURE OF CONTAINER TERMINALS

- More mixed mode traffic with manual and automated vehicles together
- Sensor fusion and AI based container handling, obstacle detection and control
- AI helps container handling operations, routing, path and storage planning, safety, ship & truck operations
- Dynamic maps at terminals
- Wireless communications evolution fulfilling even the most demanding requirements and enabling flexibility for retrofit terminals
- Sensors, cloud services, computing power face exponential growth enabling improvement with automation and digitalisation
- Eventually moving towards fully automatic and autonomous logistics and transparent end-to-end logistics chain
- Centralised control remains even as intelligence moves from cloud to the edge (machines and their sensors)
- Once regulations for self-driving cars are solved, same framework may be adapted to terminals

Summary

Autonomous cars and the automation of container handling equipment share many common drivers but differ markedly in several respects. In both fields, development proceeds stepwise towards full automation, but a global mass market (car manufacturing) can benefit from greater economies of scale in technology development than a comparatively specialised industry such as our own. The underlying differences in basic technical approach (autonomous control of self-driving cars vs. centralised control of terminal automation) will remain for the foreseeable future.

The approach to system safety is also very different between the two fields. The container terminal business needs to adhere to a strict set of pre-existing industrial safety regulations, whereas a high-volume market led by the world's largest major industrial and software companies might simply forge ahead with the development of self-driving cars and expect legislation to catch up. For better or for worse, the terminal business does not have this option.

The general trend is towards increasing autonomy in AI systems, and increased autonomy always introduces increased chances of error. Problems related to AI safety are most likely to manifest in scenarios in which the AI system exerts direct control over its physical and/or digital environment without a human in the loop – for example, automated industrial processes, self-driving cars or cleaning robots.

Container terminals were among the first leaders in automated work machines, and they have been able to build extremely reliable and well-performing solutions with simpler technology in the closed environment of a container terminal. Now, terminals have the unique opportunity of picking the best of the new technologies being developed by the mass-market car industry, and harnessing them for their own purposes. However, due to significantly different operative business logic, the key challenge will be learning to adapt and customize these capabilities to the port environment. As for what kinds of next-generation solutions we are able to create, the only limits will be in our imagination and our capability to apply these technologies in our own field.

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AUTHORS

JARI HÄMÄLÄINEN

Director, Terminal Automation, Kalmar, (Dr. Tech.) has a background from the telecommunications and software industries, with over 300 patents in 40 global patent families helping smartphone users in their daily business and pleasure. He has been working for Kalmar since 2012 and is currently leading Kalmar software and automation systems development, simulations lab and test yard automation operations. He is also project director of the Kalmar AutoRTG product development.

PEKKA YLI-PAUNU

Director, Automation Research, Kalmar, (Lic. Tech.) has background from automation research in VTT and from factory automation/robotics projects. Pekka has started his career in Kalmar in 2003, and has worked in various automation R&D management roles. Currently, Pekka is focusing on automation applied research projects and building technology strategy and roadmap for coming years.

PERTTI PEUSSA

Principal Scientist and Senior Project Manager (IPMA C), VTT, (Lic. Tech.) has joined VTT already in 1988 and often works as a project manager in industrial contracts dealing with smart machines, environment perception, and automated driving, from which he has about 25-years experience. He has also worked as a research group leader and research manager but now project management is his priority.

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