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Intralog
Towards an autonomous system for handling inter-terminal container transport

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Summary

As part of the National Transition Board Practice Research Raak/SIA program, the INTRALOG (intelligent Truck Application in Logistics) project investigated the practical application of zero emission Automatic Guided Trucks (AGTs) for the transport of containers in the Harbour Industrial Cluster (HIC) in the port of Rotterdam. The introduction of zero emission autonomous trucks is facing a couple of barriers and challenges which are discussed in this paper.

Autonomous driving is still under development and the application of batteries in heavy trucking is not yet feasible, because of their relatively low energy density versus fossil fuels. Carrying heavy batteries reduces the payload and therefore complicates the financial feasibility of electric propulsion with batteries.

Analysis of the container flows at the port area of Rotterdam has shown a big difference based on distance, closed track or open road, type of energy, and energy distribution. In terms of organization, five different situations can be distinguished: (i) Central Exchange Route (CER), (ii)Inter-terminal, (iii) DCs (Distribution Centres) in HIC, (iv) (intermodal) inland terminals in the Netherlands and (v) the long-distance transport. The CER proves to be an ideal solution to start the introduction of zero emission AGTs. In terms of innovative technology all lights for actual implementation have been switched into green. However, the major challenge now emerging at the Port of Rotterdam is how to mobilize all key stakeholders in such a way that the estimated benefits outweigh estimated costs and really leads to the implementation of this new autonomous and zero emission system in practice.

Key words: Autonomous truck driving, zero emission, freight transport, heavy duty vehicles.

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1. Rationale for improving the future position Rotterdam port

The port of Rotterdam is the largest port in Europe, where also many oil-related industries are located. The port together with the HIC (Harbour Industry Cluster) is now faced with a lot of challenges. Apart from pollution of the industry, a number of developments is greatly affecting the competitiveness of the port of Rotterdam. These include increasing congestion in the HIC (Harbour Industry Cluster) Rotterdam, growing pollution, and changing logistics flows. Furthermore, there is increasing competition from other Western European ports, particularly in the area of container handling. Based on said developments and expected economic growth the Port Vision 2030 was published in 2010. In this vision four scenarios were used to estimate the throughput for 2030. From low growth (+ 10% in 2030) to high growth (+ 100% in

2030). In addition to the expected economic growth and growing logistic flows, it has also been taken into account that container ships became ever larger and could no longer reach land-based ports due to the greater depth. Based on a medium growth scenario Rotterdam has invested in a new deep sea ports area in the sea: Maasvlakte 1 and 2. Especially Maasvlakte 2 is able to handle de largest containers vessels. Until recently, ships of 14,000TEU (Twenty-foot Equivalent Unit) belonged to the largest ships. More vessels with a capacity of 18,000 TEU are now operational. TEU is used to describe the capacity of container ships and container terminals. In 2017, it is expected that 36 new, ULCCs (Ultra Large Container Carriers with 20,000+ TEU) will come into service over the next few years. (Port of Rotterdam, 2015).
Such large vessels can only call at a limited number of ports in Europe. The containers from these vessels will continue their journey to the hinterland and other smaller ports in Europe. The containers for the smaller ports in Europe are transhipped to smaller short sea vessels, also called feeders. These feeders are handled in the Botlek, Eem- and Waalhaven ports, which serve more and more as short sea ports. In Figure 1 you can see the location of the deep sea ports and terminals at the coast as well as the location of the more inland located short sea ports. With the continuing changing role of the Port of Rotterdam as a transition hub, it is very likely that the number of movements of containers from the deep sea terminals to the short sea terminals and vice versa will increase significantly.

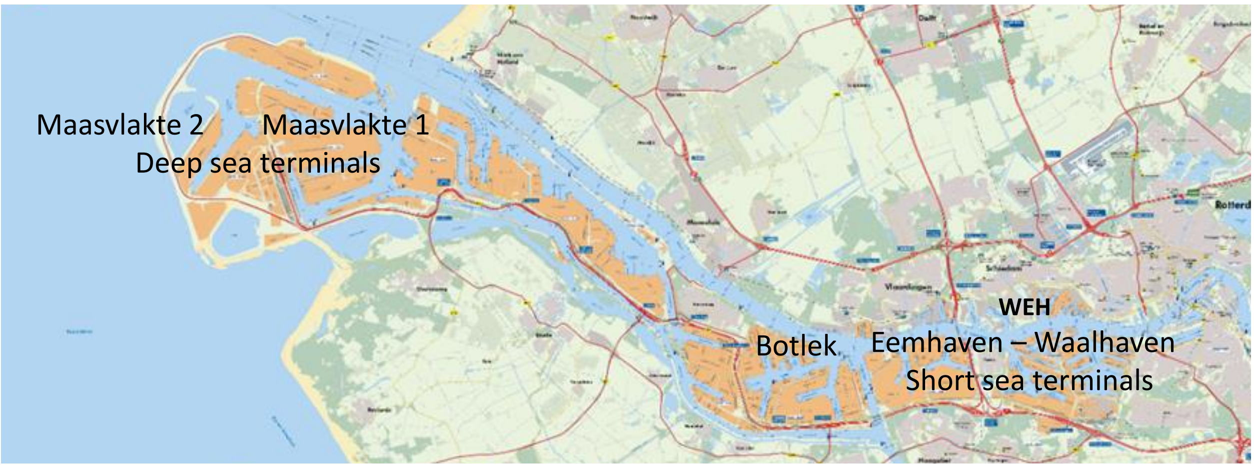


Figure 1 Overview of HIC with deep sea and short sea terminals

Many factors influence the productivity and efficiency of inter-terminal transportation as well as its economic and environmental implications. In the last two decades, these aspects have led to a growing interest in research, in particular concerning decision analytics and innovative information technology aiming to better understand, improve, and operate inter-terminal transportation.
A significant part of the ITT (inter-terminal transportation) is related to the transport of empty containers. Reduction of empty trucking requires either collaboration and vehicle sharing among competing terminals or a dedicated third-party service that coordinates ITT demands of the different terminals and service areas. As related empty flow and vehicle routing problems have been considered for several decades (see, e.g., Dejax and Crainic 1987; Golden et al., 2008; Cebon, 2016), they have also argued that high capacity vehicles give the best results for fuel reduction consumption. From 2011 to 2014 several studies on autonomous transport of containers in the port of Rotterdam were done by TU Delft. These studies have resulted in simulation and cost calculations for the CER (Negenborn et al., 2014).

For the competitive position of the port of Rotterdam it is of the utmost importance, that the clearance between the terminals and DC’s (Distribution Centres) is handled in the same efficient way as at the deep sea terminals. Areas to tackle include reducing the driving time, preventing waiting time, speeding up the docking operations and more accurate delivery to the distribution centres. In order to deal with these challenges a new transport system is considered to meet both the logistical and environmental requirements for the container flows in the HIC and to and from the hinterland.

This leads to the following research question:

"*How could the establishment of an independent autonomous transport system between terminals and major distribution centres be a sustainable answer to the future container flows*?"

Objective
The aim of the study, as described in INTRALOG project (Schrijer, 2014), is to examine, on the basis of the PPP values (People, Planet, Profit), how autonomous and sustainable transport system can be used for the transport and handling of containers in logistics operations at the distribution centre and inter-terminal traffic in the port.

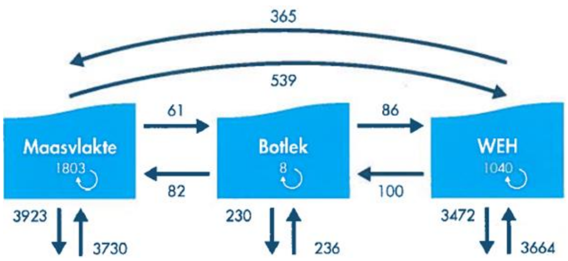
In section 2 this article discusses the analysis of the inter-terminal traffic. Section 3 provides an overview of the most important innovations that are vital in applying the Intralog project. Section 4 provides a quantitative analysis of the costs and logistics performance due to different vehicle configurations. Section 5 presents the main conclusions on this part of the Intralog project.

2. Analysis of the inter-terminal traffic

This section will first analyse the current transport movements (Section 2.1). In section 2.2 further infrastructure developments in the port area will be discussed.

2.1. Container flows within the HIC

The Port Authority owns the land on which competing terminals and transport companies operate. It receives limited information on what is really happening in terms of traffic data related to container flows. To capture live data, in the month of December 2011 students of the Rotterdam University investigated the container flows in the Harbour Industry Cluster (HIC) (Moving @ Rotterdam, 2012). At selected terminals and distribution centres along the A15 the licence plates of trucks with containers were recorded. On this basis, it has been estimated that approximately 40% of the containers remain within the HIC, a distance of about 30 km. The actual numbers measured on this route proved to be significantly higher than previously assumed.
An analysis of the Verdoorn & Roo (2014) shows that between the Maasvlakte and Botlek plus Waal- and Eemhaven area (WEH) 19,340 container journeys were carried out on an average workday. Figure 2 shows a subdivision of the different container trips. 7.625 Trips depart to a destination outside the HIC and 7.630 arrived from the hinterland. 4.064 Journeys were completed within the HIC.



	Total
Port / HIC internal	4064
Port out	7625
Port in	7630
Grand total	**19340**

Figure 2: Number of containers loaded and unloaded trips per day (Verdoorn and de Roo, 2014)

The number of empty trips were 5.921 per day. The degree of loading of the trucks is about 70%. The transport movements to and from the port are predominantly loaded with 79%.Transport between the container terminals in the port of Rotterdam is mainly done by trucks. Of the total container freight traffic (over 19.000 trips per day) 21% (4.084 runs) does not leave the HIC, see Figure 3). Approximately 70% of these internal movements (2.850 trips) remain within the same area of the port, 30% (1.234 trips) was a displacement between the entities themselves. Of these journeys 4,084, a whopping 72% (2.925), is unloaded. It is absolutely striking that the empty transport movements mainly consist of short journeys within the port. It seems that transport companies with containers from the hinterland deliver their containers to one final destination, and, then retrieve a container from another port location, presumably an empty depot.

	Total
Port / HIC internal	2850
Between areas	1234
Grand total	**4084**

Figure 3: Docklands internal movements (Verdoorn & de Roo, 2014))

2.2. New infrastructure for inter-terminal transport

Accommodating the future growth of the port and the desire of the deep sea terminals, the construction of the Container Exchange Route (CER) on Maasvlakte ports 1 and 2 will be put into operation in 2019. The main goal is to facilitate the internal transport between the terminals on the Maasvlakte port 1 and 2 in a quick and safe way. The CER is a track of 14 kilometres long. It will be autonomous ready and will facilitate zero emission transport. Apart from the deep sea terminals it also connects a barge terminal, a rail terminal, customs and phytosanitary services. At the start of the CER in 2019 an estimated 500.000 containers per year will be transported. The Port Authority assumes a growth to ultimately 1.200.000 containers per year by 2030. (Havenbedrijf Rotterdam, 2016).

When designing the CER it was decided to lay out the CER as a separate, closed track in order to simplify the step towards autonomous transport in future. However, due to demands of the labour union the transport will be manned for the first five years. After five years this requirement will expire and opens the way for autonomous transportation.

By prohibiting other traffic on the track, the autonomous transport process can be implemented much more quickly and easily, because the security risks and requirements are not as high as on a public road with unpredictable behaviour of manned vehicles. The only place where the CER path will intersect with other transport, is at the level of a railroad crossing. At present, no rules have been determined for priority on such an intersection and is still subject of discussion with the rail operator.

2.3. Sustainability

A zero-emission vehicle refers to a vehicle that emits no tailpipe pollutants from the on-board source of power (California Air Resources Board, 2017). We need to distinguish between greenhouse gases, such as CO_2, and NO_2. CO_2 is a greenhouse gas but not toxic. NO_2 is a harmful substance typically consisting of small soot particles. In order to keep track of the emission the Port of Rotterdam started in 2007 the Rotterdam Climate Initiative with the following objectives:

- 50% reduction in CO_2 emissions by 2025 as compared to 1990;
- 100% climate proof by 2025.

Today the focus has shifted to reduction of NO_x. (RCI, 2013).

3. Innovative developments related to Intralog

In section 3.1 innovation developments regarding autonomous driving will be explained. Section 3.2 deals specifically with guided vehicles. Section 3.3 provides an overview of status quo of terminals with autonomous guided vehicles. Section 3.4 deals with the adoption of autonomous vehicles. The sections 3.5 to 3.7 discusses new developments in energy technology. Section 3.8 deals with the impact of new technology on the labour market.

3.1 Overall picture on autonomous driving

It is expected that a number of current traffic problems can be solved with smarter autonomous vehicles. Under the definition of 'independent drive' there are different levels of autonomous driving. In January 2014 SAE International has created a standard definition to clarify what actually is an autonomous vehicle. SAE International (2014) has conceived six levels of autonomous driving, from zero to five. For autonomous driving at higher levels several steps in the field of legislation, cooperation between relevant stakeholders and the digital respectively the physical infrastructure are required. For example, the digital infrastructure should contain specific modules of ICT systems for traffic information and traffic management. For the CER it is foreseen that level 4 or 5 is achievable. Level 4 provides fully automatic driving or automatically under limited routes or conditions. At level 5 no limitation or human interaction is applicable to the vehicle. The vehicle will completely autonomously drive on the public road.

3.2 Legislation

An important condition for the feasibility of autonomous driving are the laws and regulations. Currently, autonomous transport is not allowed on public roads. There have already been several pilots, but the current rules date from 1968 (BWBV0003507, 2016). Currently the Government is working on adoption of the regulations. On 14 April 2016, the Declaration of Amsterdam has been agreed. It stipulates a number of agreements, including the cooperation on a European network for the operation of autonomous driving. These amendments should be implemented in 2019.

3.3 Truck platooning

Another interesting innovation for the transport sector is truck platooning. Today lorries are connected to a central server of the manufacturer and / or the owner through 3 or 4G. The trucks have transport management systems on board and are usually equipped with GPS, so that the GPS coordinates are available. In truck platooning a number of trucks, which are equipped with the driving assistance systems, form a small pack, whereby the trucks are digitally linked. The front truck drives actively and the drivers of the followers are sleeping or doing administrative work. At present, only vehicles within the same brand can be linked. So, to pair a Volvo with, for example, a Scania or Mercedes truck is not yet possible. To gain advantages it is therefore essential that multiple brands can drive in one platoon. Recently European projects have been started for the realization of a multi-brand standard. Such a standard is expected after 2020 (Janssen et al.,2016).

Large-scale, cross-border tests with platoons under real conditions were already executed on highways in 2016. These tests will be followed by tests on national highways and then further on the European ITS corridors, initially on the TEN-T network (Trans-European Transport Network) and can be extended to other main roads.

For the formation of platoons, a role is foreseen for Platooning Service Providers (PSPs). A PSP can be considered as a control tower or orchestrator that acts as an intermediary between various transport companies in order to establish the platoons. PSPs establish quality schemes with ‘trusted partners’. The PSPs also arrange administrative duties from the platooning activities, insurances, and make sure that benefits of platooning are distributed fairly among the platooning partners (Janssen et al., TNO 2016).

Another opportunity is to drive a platoon of three trucks by two drivers. New technology will make this achievable and consequently result in attractive business cases because of reduction in driver cost. In 2016 a number of calculations have been made by TNO for three logistics companies namely Peter Appel Transport, Logistics Winter and ECT. Yearly cost reductions varied between € 1.300 and € 13.200 per truck based on two drivers in a platoon of three lorries.

Apart from the longer operation time and reduction on driver cost, fuel cost can be saved. Scania refers to 12 percent based on an intermediate space of 10 metres between the trucks. We believe platooning is especially promising for the longer distances to the hinterland or a number of routes on the logistics corridors. For short journeys in the HIC with a wide variety of destinations, the savings potential of platooning does not outweigh against the costs of coordination by PSPs, waiting time for each other and the cost for the construction of infrastructure.

3.4 Roll-out of SAE level 3 vehicles from 2020

In an exploration of the implications of self-propelled vehicles on the design of roads in 2030 it is expected that SAE Level 3 passenger and cargo vehicles will have a penetration of 5 to 15% (in a scenario with a passive state). With an active government penetration rates of 15 to even 35% are possible. Incidentally, it is not expected that the deployment of automatic vehicles will go entirely in accordance with the SAE-levels. Most likely several market players will focus on different types of vehicles, thereby creating a new mix of vehicles on the road. In this context, it will not only mean a mix both manned and unmanned vehicles but also different automation levels (Morsink et al., 2017). The availability of only fully automated vehicles is expected by many experts in 2075 or perhaps even never (Shladover, 2015). The INTRALOG project is based on the highest levels of autonomous driving: SAE level 4 or 5, high or full automation.

3.5 Autonomous driving on the deep sea terminals

AGVs (Automatic Guided Vehicles) drive already on the terminals of ECT and APM 2 in the port of Rotterdam. These AGVs drive on a closed area, so that unexpected events cannot occur. The AGVs at the APM Terminal 2 are so called Lift AGVs, which are able to lift the containers from racks at the deep-water cranes next to the deep sea vessel. After lifting they can deliver the container to the stack (see Figure 4). This SAE Level 4 AGV cannot drive on public roads, because they do not have a license plate and are "blind". Monitoring and control of the vehicle is managed centrally. The positioning is done through transponders in the terminal surface. The accuracy of the positioning amounts to +/- 25 mm. The AGVs have an electric powertrain with batteries. The replacement process of the battery is fully automatic and is done in approximately five minutes in a special battery exchange station. The AGVs are in constant contact with each other and the main station. Because of all the steel objects (containers, cranes, vehicles) present at the terminals, the chances on temporary loss of the Wi-Fi communication is considerably. Therefore, on the terminals a wireless Wi-Fi network with additional amenities is used. If an AGV has no direct connection with the fixed Wi-Fi network, then it searches for a second AGV which is in communication with the network. This is done through a so-called mesh repeater (Techgenix, 2017), a transmitting and receiving unit that repeats a message until it arrives at the destination. By using this network, the AGVs are able to support themselves.

Figure 4: Zero emission lift AGV on APM2 terminal (Source: APM)

Initially the project Intralog is assumed to be based on the AGVs. The latter is particularly motivated by the fact that the first opportunity for fully autonomous transport outside the terminals is provided for the transport of containers on the CER. (Havenbedrijf, 2016) However, a survey among stakeholders revealed that major differences in the desired solutions exist. Most terminals on the Maasvlakte 2 have a strong preference for AGVs, because it fits with their handling equipment and processes. The other, less automated terminals have just a preference for a more traditional and less automated handling with trucks or Multi trailer Systems (MTS) (See Figure 5). Another involved party, as the FNV (Union of Labour), of course defends the employment situation. The FNV expressed the view that the carriage at the CER is port work and thus should be done by dock workers. To avoid a strike, the Port Authority herewith agreed that the employment of transport on the CER is guaranteed to 2020. Thus, the possibility to organize transport via unmanned AGVs is frozen until at least 2020.

Figure 5: MTS Multi Trailer System

3.6 Battery technology

In recent years, enormous investments have been made in the production of batteries. This has a significant impact on the price development of batteries. Nykvist & Nilsson (2015) have drawn up a comparison of the various studies on the development of the battery charge. Figure 6 shows that the cost in the US gradually drop to around US $ 230 per kWh in 2017-2018. This is significantly lower than elsewhere in peer-reviewed scientific literature, and is on par with the most optimistic future estimate among analysts outside academia (McKinsey, 2012), who declared in 2012 that the US $ 200 per kWh can be achieved by 2020, and $ 160 per kWh by 2025. This would require the aforementioned US $ 230 per kWh, the cost a third must descend to reach the US $ 150 per kWh. Only at that level battery-driven vehicles will become competitive with internal combustion engine vehicles (Gaines & Cuenca, 2000). If costs fall to US $ 150 per kWh, the use of electric vehicles is likely to go beyond niche applications, and so leading to large-scale advantages and a potential paradigm shift in automotive technology.

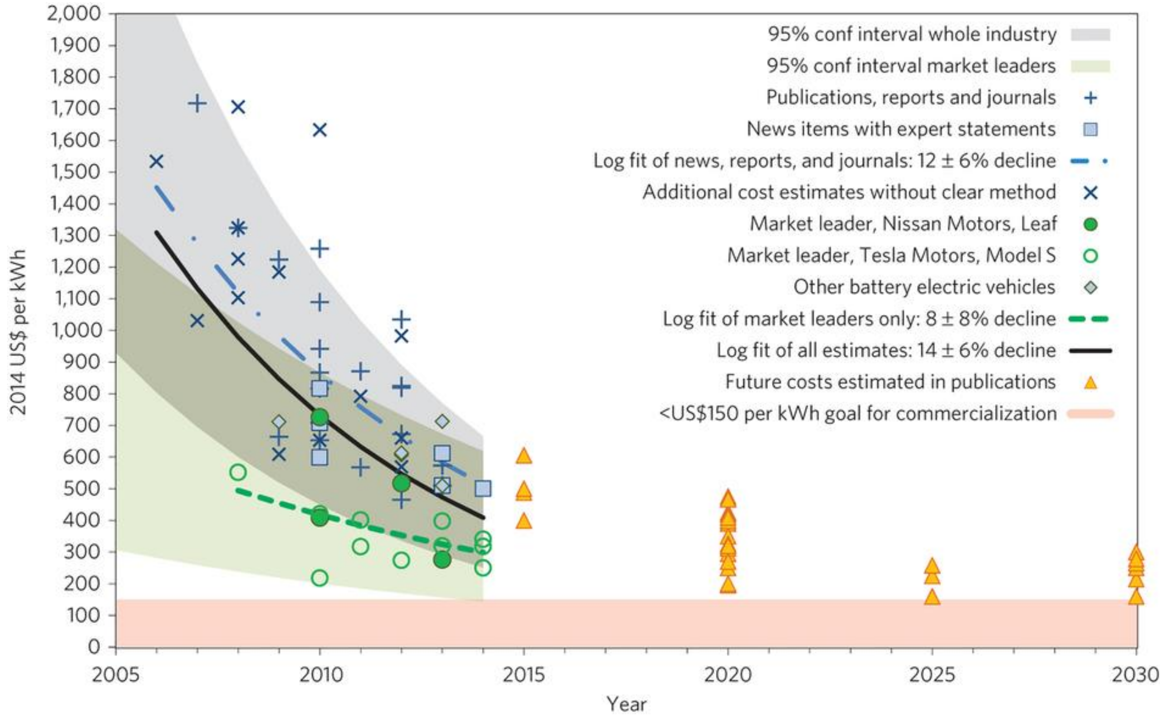


Figure 6: Estimation of price developments for batteries (Nykvist & Nilsson, 2015)

At the 28th International Electric Vehicle Symposium and Exhibition in Korea Tien Q. Duong was one of the keynote speakers. Tien is a Senior Technical Advisor and Manager of the Batteries for Advanced Transportation Technologies Program. During his lecture, he mentioned the following objectives to be realistic:

- In 2022 US $ 125 per kWh lithium-based;
- In 2025 US $ 100 per kWh based on lithium metal.

This cost development shows the positive side of the battery technology. On the other hand, in comparison with diesel or gas, this technology has several important drawbacks that hinder rapid market adoption:

- Charging times of batteries are too long. By comparison, in the same time batteries recharge: 50-600kW against 6.800-16.000kW in H_2 fuel or diesel;
- Batteries are heavy and reduce the payload of lorries. Batteries weigh 12.0 kg per km vs. 0,4 kg for diesel;
- Cold weather conditions have a major negative impact on the performance of batteries.

For short distances, one could think of changing batteries or to charge at stops on fixed routes during unloading. Induction charging in the road surface is ideal but the infrastructure investments are very high.

3.7 e-Highway

In order to achieve zero emission energy solutions through pantographs like trolleybuses are also an option. Siemens' e-Highway system combines the efficiency of the railroad with the flexibility of trucks in an innovative solution that is efficient, economical and environmentally friendly. In Germany, Siemens plans to introduce e-Highways for the main routes. The cost per kilometre for this system is only € 0,19. Batteries score € 0,20 per km, but has the disadvantage of loss on payload. H_2 is an environmental friendly alternative but costs € 0,55 per km, due to low WTW (Well to Wheel) efficiencies. Power-to-Gas (P2G, PtG or windgas) comes to € 0,77 per km, mainly due to a WTW efficiency of 20%. H_2 and Power to Gas are easier to store than electricity (See Figure 7) (Akkerman, 2016).

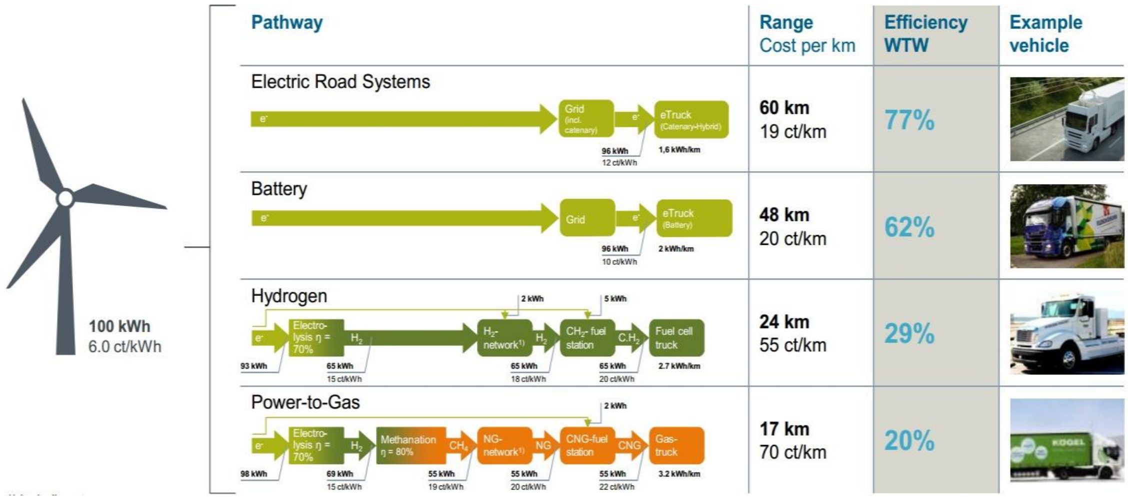


Figure 7: Cost comparison e-Highway - German Min. of Environment

Unfortunately, the ability to carry out the CER as e-Highway is not possible, because the containers in this system cannot be lifted off the vehicles in case of emergencies.

3.8 Consequences of innovation for the labour market / PEOPLE

The human aspect is an important factor in the current situation and in the near future. Automation will replace more routine or repetitive tasks, allowing employees to focus more on tasks that utilize creativity and emotion. Critical factors include the speed with which automation technologies are developed, adopted, and adapted, as well as the speed with which organization leaders grapple with the tricky business of redefining processes and roles. The degree to which executives embrace these priorities will influence not only the pace of change within their companies, but also to what extent those organizations sharpen or lose their competitive edge. (Chui et al., 2015). Until now a driver is always required for transport on the public road by law. At sea terminals with the arrival of the AGMTTs / AGTs, drivers will no longer be necessary, because the transport will be fully autonomously. This has obviously consequences for employment. There will be a need of fewer drivers in the future. The automation of the car dock will have some impact on employment among drivers.

At the same time, there will also be more demand for ICT professionals, for developing and maintaining the software and digital infrastructure. Affordable, suitable IT people are hard to get now. In theory, it could be that if 10 autonomous trucks are used, 10 drivers are needed less. Perhaps an ICT Staff member is required. Also for the planner in transport their job is already partly taken over by software. If autonomous driving continues the need for planners will decline further.

The aging of drivers in the labour market continues and there is a limited inflow. This will make the problem of less employment less visible. The need for ICT staff is already high and it is still difficult to fill these vacancies.

For the labour market, there will be large differences in each situation

- CER: up to 2020 via MTS driver, about 70 jobs;
- DC's impact of autonomous transport is confined to auto docking after 2020
- Only after 2025 starting with level 5 on public roads.

4. Quantitative analysis of autonomous inter-terminal transport container

As explained earlier, for accommodating the future growth to and from the deep sea terminals, the Container Exchange Route (CER) is built. In this section, the logistics performance for different vehicle configurations on the CER will be discussed. In Section 4.1, the results of the calculations of the TU Delft are presented. Subsequently, Section 4.2 provides an overview of custom simulations that are carried out by TBA, Delft. TBA is a company specialized in simulation software for container flows.

4.1 Detailed simulations TU Delft

Based on the various scenarios from the Port Vision 2030 TU Delft has performed detailed simulations on Lift AGVs, MTS and terminal tractors (TT) with two barges. These simulations are based on individual assignments and decentralized control, whereby the vehicle itself has the necessary intelligence to arrange transport more or less independently. In the meantime, the scenarios of Port Vision 2030 for the total port have been revised downwards by the Port Authority. The low growth scenario is now based. Therefore, we limit Negenborn's results to the current low growth scenario. In Table 1 the results of these simulations are shown.

Table 1: Logistics services for different vehicle configurations (Negenborn et al 2014)

Scenario	Configuration / number of vehicles	Non-Performance %	Average time in hours that the container arrives too late
Low growth	24 Lift AGVs 32 AGVs 9 MTS + 42 trailers 17 TTs + 2 barges	2,5 21,7 19,3 98,7	0,60 3,83 3,69 353,85

Interestingly, the overall non-performance scores relatively high. Lift AGVs score best with 2,5%. With higher volumes out of the medium and high growth scenario, non-performance for AGVs was 11,2 and 18,3% respectively. (Negenborn et al 2014). This is not acceptable for stakeholders.

4.2 Low growth scenario - Simulations by TBA

For the CER it is now assumed that 500.000 TEUs per year with an initial number of 250.000 TEUs are realistic. The reduction in these numbers in comparison with Negenborn is based on new insights. The number of containers for the rail terminal via the CER will be much lower. At the request of the Port Authority TBA created a simulation in 2016 based on the reduced numbers and manned MTSs, having in mind a future promotion to a structure with autonomous vehicles. The simulation is based on an average speed of 22 to 24 km per hour, the speed limit on the CER is 32km per hour. In the simulation TBA has also taken into account the crane moves. In addition, a number of essential differences from the study at TU Delft were applied:

- There is a central control;
- The commands for the transport of containers often consist of a plurality of containers (often> 10 TEUs);
- There are three service levels. Standard, Premium, Hot Box. Reefer containers and containers for customs fall under the category Hotbox. These hot boxes are transported by terminal tractors.

This model prompts limiting empty driving and more containers are ordered in one go. For example, containers from and to empty container depots are entered in greater numbers and are not entered individually. This is also true for flows to the rail and to a lesser extent between the terminals. By differentiation in urgency and the entry of larger numbers per order, efficient grouping of containers for the same destination is easier. In the simulation of TBA with 500.000 TEUs per annum 5 MTSs and 3 TTs are needed. See Table 2.

Table 2: service Products CER (TBA, 2016)

Scenario	Configuration / number of vehicles	*Service level*	*Time of delivery*	*Non-Performance*
500.000 TEU per annum	5 MTSs and 3 TTs	Standard	< 48 hours	5%
		Premium	<16 hours	2%
		Hot Box	<4 hours	1%

The occupancy rate at 500.000 TEUs per year is already over the 9 TEU per MTS. At 500.000 TEU, this is 9,7 and at the 1.000.000 TEUs even at 9,8 per MTS with a maximum capacity of 10 TEUs. Based on this high capacity utilization is already reached the break-even level at 400.000 to 500.000 TEU per year. The simulation is also carried out with combinations of MTSs and more individual vehicles. MTSs and a few terminal tractors give the best return. Depending on the necessary investments in the exchange places at the deep sea terminals, it could be that the port authority and stakeholders will decide for a scenario with adapted AGVs rather than MTSs.

When comparing the simulation results of TU Delft with the model as used by TBA, it can be concluded that the TBA-model gives a higher efficiency and a much better overall non-performance. In the model of TBA MTSs score better than the AGVs in the TU Delft study. This is mainly due to the introduction of different service levels and higher volumes per order, as applied by TBA. Besides, empty driving with a central control tower will be significantly lower than if the transport is performed by multiple parties. Given the importance and the need for an efficient solution, it is likely that the Port Authority will facilitate a central planning system. It seems therefore very unlikely that the CER transport will be performed by several carriers.

5. Conclusion

Based on the developments that have been mapped in this survey, it can be concluded that by the deployment of an independent transport system based on adapted AGVs, considerable cost savings and acceleration of the transit of container flows on the basis of the PPP criteria is possible in the port of Rotterdam.

Profit
A positive business case is essential. By deploying autonomous container transport over inter-terminal distances, a considerable reduction of the cost can be achieved. It also provides increasing capacity utilization and reduction in empty trips. Sharing of capacity will also contribute significantly to reducing the cost. An additional advantage is that the congestion of the road network is greatly reduced.

Planet
Zero-Emissions and noise reduction are increasingly important in today's society. Clean energy is becoming cheaper and more and more solutions are available for the distribution of clean energy: charging stations, battery exchange stations, hydrogen stations, pantographs (e-Highways). The adjusted AGVs can be a good answer for this.

People
Although autonomous driving will lead to a significant reduction in employment especially amongst drivers, it will not form an obstacle for the introduction. Aging among the driver population softens the impact. However, the demand for IT staff will increase further, but it will not in any way compensate for the loss in employment amongst drivers.

Phased introduction
In the container transport there are big differences in terms of distance, closed track or open road, energy source, energy distribution and on organizational level. Based on these criteria, four different situations can be distinguished: CER, Internet terminals and DCs in HIC (intermodal) inland terminals in the Netherlands and the long-distance transport. The feasibility of an automated system in time might look like this:

Table 3: Phased introduction of AGTs

Situation	Trip distance (km)	Road /Area	Speed	SAE level	Period
1. CER	6-14	Closed route	20-30km/u	4	Till 2020 by MTS with driver, from 2020 autonomous
2. Inter-terminal & DC’s in HIC	30-40	Public road	80km/u	5	From 2025
3. Inter-terminals & DC’s in the Netherlands	40-120	Public road	80km/u	5	From 2030
4. Hinterland	>150	Public road	80km/u	5	From 2035

Towards a System Change
In developing autonomous driving, the involvement of many stakeholders is required to successfully implement such an innovation. These include the Port Authority terminal operators, local and central government, transport, energy suppliers, vendors, transportation resources and ICT service providers. There is still a long way to go before the necessary obstacles will be overcome and cooperation between sometimes competing parties is not obvious (Hekkert & Ossebaard, 2010). The economic stakes are, however, large enough to facilitate future container flows with new technologies. Meanwhile, adequate initiatives with business and government are already available to make this innovation really a success.

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