C

Appendix C

Implementation of the Hive-Minded AGV in the Port of Rotterdam

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Abstract

As a part of the MAGPIE project, Port of Rotterdam is eager to improve inter terminal container transit to be more efficient and sustainable. After the design of the Amphibious Automatic Guided Vehicle (AAGV), options were explored to integrate the concept with concepts developed by other teams of the course "Integrated Design Project for Multi-Machine Systems". To improve on inter terminal transit, the Floating Terminal and D.O.P.E. Barge were chosen to integrate with. For the Floating Terminal, a location was chosen and a process was developed to be more efficient in movement of volumes of around 100 TEU from the deep sea terminals to the terminals more inland, like Eem- and Waalhaven. For D.O.P.E. Barge, a continuous bus-inspired route was developed featuring on-water container transfer using the D.O.P.E. on-board cranes to realize a robust, reliable and fast system to distribute containers between terminals throughout the entire port. For verification purposes, calculations on interaction between the concepts have been executed and time saving estimations of the ideas have been made.

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1 Introduction

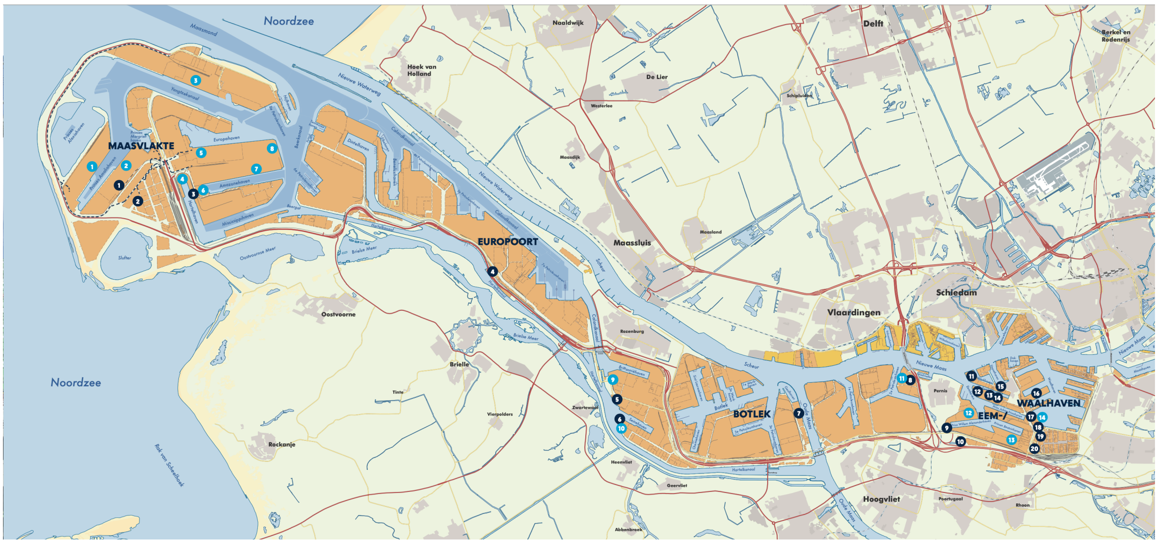

Figure 1: Map of the port of Rotterdam

The port of Rotterdam has seen unprecedented growth in the post Covid Era. In the pre- Covid era the port of Rotterdam saw an influx of 7.7 million TEU while an outgoing metric of 7.1 million TEU. On an average 2017-2019 saw a handling of 15 million TEU. In the post Covid boom, this figure is expected to reach 20 million TEU by 2025 and possibly earlier with Europe becoming a major trans-shipment hub. This is from the projected data of the 5 deep-sea terminals, 3 shortsea terminals present more inland and the empty depots at Port of Rotterdam. To summarise the container terminals at Rotterdam, the major set of deep sea terminals can be seen at the first point of entry into the Netherlands near the Hoek Van Holland. The report will discuss the major access points for the following terminals, those which saw the highest container handling activity.

- Rotterdam World Gateway (flanked by Princess Amaliahaven and Alexiahaven)
- APM Maasvlakte and Hutchinson ECT Delta (building 24 and 34)- Amazonehaven and Europahaven, Princess Magriet Haven
- Euromax Hutchinson (Yangtzekanaal)

With the rising demand for container transport, this calls for introduction of automation and smart planning of trans shipments to make the port capable of handling 25 million TEU with minor modifications. Another unified goal is to keep a check on harmful gas emissions. This is possible on the active level by eliminating or reducing dependence on petroleum and switching to renewable sources or electric. On a passive level we must ensure that rare earth elements are not chosen and to procure any minerals and metals through sustainable means. The demand also calls for efficient planning of day-to-day port operations for trans shipment. This rearrangement and reconfiguration are mainly with respect to how inland vessels transport containers. In 2019 alone, the total number of inland vessels recorded were 92,552 and 28,170 sea going vessels carrying multiple thousands of TEU. With minor modifications, Port of Rotterdam would be able to attend to the same demand with less inland vessels, thereby decongesting many short sea terminals. This is possible by having intermediaries in between which can act as a distribution centre to other terminals and also possibly a carrier of containers with additional capabilities. The two main problems to be solved are:

- Medium Scale transfer of containers (Up to 150 TEU)

1. At the moment this is done by barges which can carry 120 - 150 TEU. The main issue here is the effectiveness of loading and unloading and the time lost in that process since external equipment is still used to complete this process. The ill effect of this can be seen in short sea terminals and tight areas of the port which require versatility. In such a scenario, a barge with autonomous loading and unloading capacities would be beneficial. Furthermore, such a system will assist in transferring containers to AAGVs on water. A robust, continuous and reliable system of inter terminal transit of volumes of containers of about 120 - 150 TEU has to be developed.

- Small Scale transfer of containers (up to 20 TEU)

    1. One is the sheer distance and time that is consumed during inter terminal transfer. Transfer through water hence becomes more feasible as it cuts down the distance by 75% in some cases. Some terminal transfers by land can go up to 40 km, while transfer through water would only take 10 km.
    2. If the current system is analysed, it is evident that only 2 TEU at a time can be transferred by land in one go. This combined with the long distance compounds the existing time management issues. The potential that can be seen here with the HIVE minded AGV system is that 18 TEU could be transferred at once all be it at low speed. The estimate that can be made is that small scale transfer of containers can be now reduced by at least 4 times in terms of time and distance.

2 Recap of design

In an earlier report, an Amphibious Automatic Guided Vehicle (AAGV) was designed. The design of this AAGV was based on existing normal AGVs in terms of dimensions, power drives and battery features. Additionally, this AAGV has the ability to transfer from land to water, and vice versa, autonomously by various conceptual transfer systems, float steadily in calm port waters, sail itself and navigate and interconnect with other AAGVs to form a platoon and operate in a HIVE-minded fashion to smoothen port movement. In the design, close attention was paid to interaction with existing port equipment and machinery to be compatible in the port without the need of expensive investments. The only investments necessary will be a system for the battery replacement system and the water-land transfer systems. The final design of the AAGV portrayed in water mode and land mode can be seen in Figure 2. An illustration of the AAGV design in a 9x9 grid formation for HIVE minded control is portrayed in Figure 3.

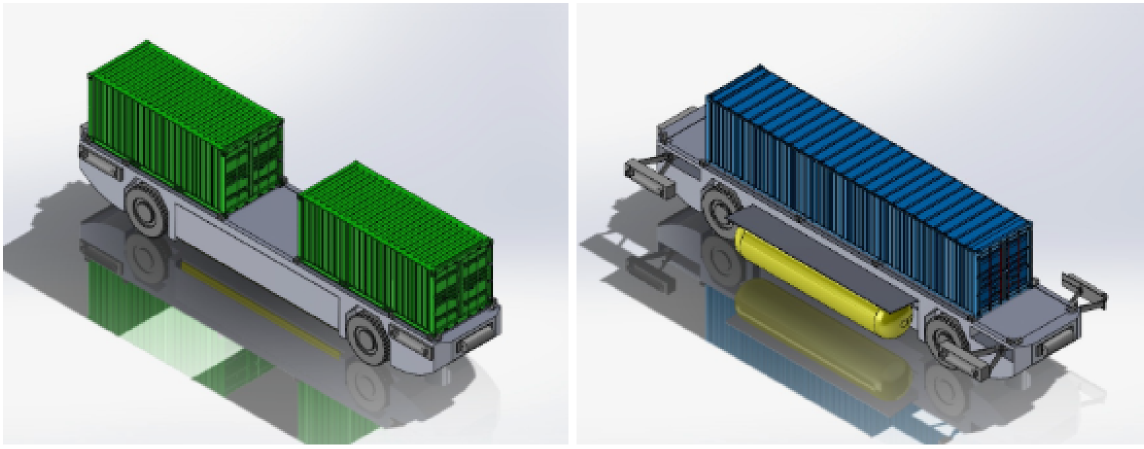

Figure 2: Final design AAGV in land mode (left) and water mode (right)

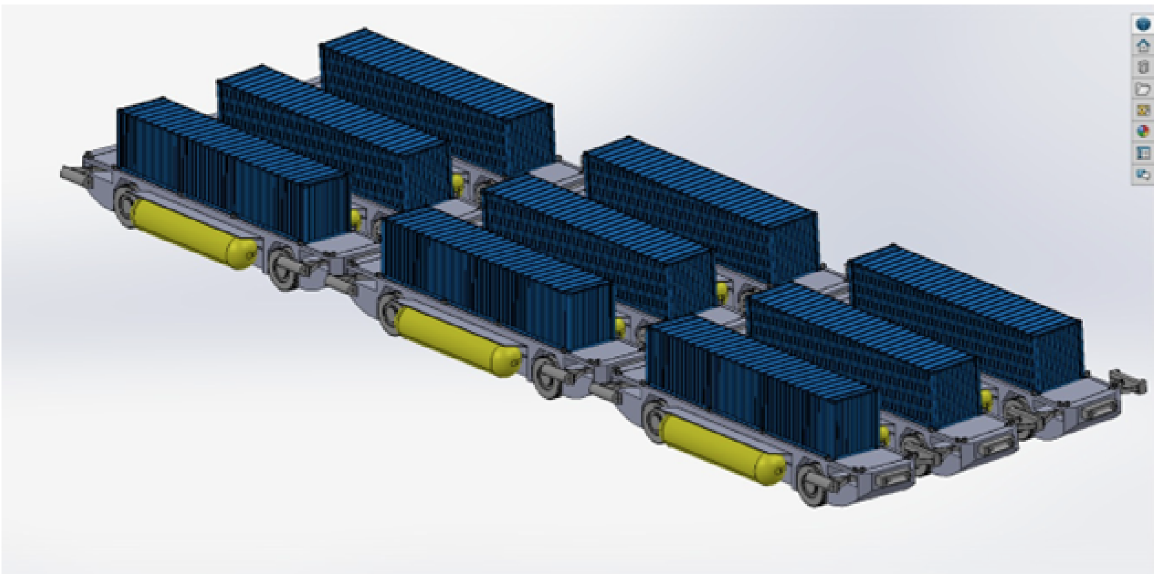

Figure 3: Final design AAGV in HIVE minded grid mode

3 Integration

After assessing several different designs of port equipment, choices were made on integrating the AAGV design with other port equipment designs to improve inter-terminal transit of containers for mid-range.

The chosen designs to integrate the AAGV with are:

- Floating Terminal (group 1)
- D.O.P.E. Barge (group 2)

The integration with both concepts will have different purposes in inter terminal transit. Both shall be discussed in detail.

3.1 Transfer systems for deep sea terminals

For the AAGVs to work, transfer systems from land to water and vice versa are needed. The in-depth design of these systems is out of the scope of this project. However, concepts are developed and location propositions at the current port are made.

The first area for the determination for the transfer systems is at the deep-sea terminals on the Maasvlakte. A satellite image can be found in Figure 4.

Figure 4: Satellite photo of deep-sea terminals Maasvlakte

Based on the local terrain and available space, 3 different types of transfer systems have been settled on:

- Passive ramp
- Active ramp
- Jack-up bays

The passive ramp system will be the cheapest to construct but requires most space. It will consist of two long parallel concrete lanes which are placed in a maximum angle of 2.5 degrees with respect to the water. The AAGV can simply drive into the lane and approach the water using its own motors until it hits water. When water is hit, the inflatable side pods will inflate and the AAGV proceeds until it is fully afloat. From there the jet propulsion will take over and the AAGV is in water mode. When approaching from the water, the other lane is used. In a similar fashion, the AAGV approaches the lane, but from the water. When the wheels hit the ramp lane, the side pods will slowly deflate. The AAGV will pull itself out of the water using its own motor drives. Once the AAGV is completely out of the water and the side pods are folded in, the AAGV is in land mode and can proceed to the terminal. A visualization of the passive ramp concept can be seen in Figure 5.

Figure 5: Visualization of passive ramp system with random amphibious vehicle

The active ramp works similar to the passive ramp. The difference is that the maximum inclination angle is increased to 5 degrees. In some spots an active ramp was chosen as there would not be enough space to implement a passive ramp with an inclination angle of max 2.5 degrees. Since such an inclination angle of 5 degrees is assumed to be too power consuming on power of the AAGV itself, a towing system seen in roller coasters is used. The concrete lane will have a chain system with hook points working in the middle where the AAGVs can hook onto. When, from water, the AAGV has approached far enough, the AAGV hooks onto the chain automatically and is pulled out by the chain. Transfer from land to water works similarly. A visualization of the concept can be seen in Figure 6

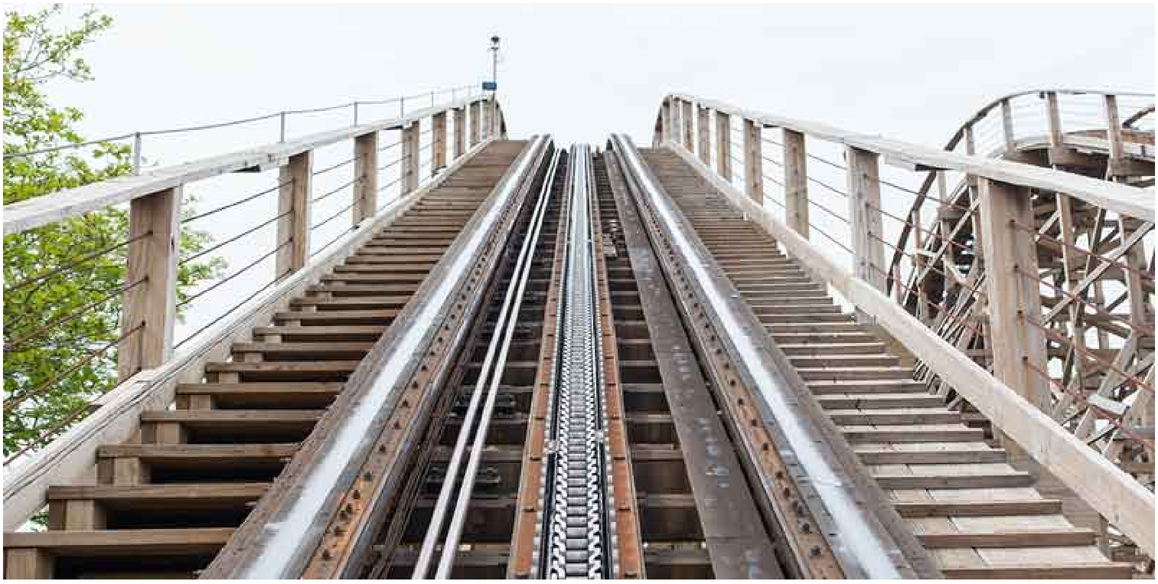

Figure 6: Visualization of active ramp system

Lastly, the jack-up bays. The ECT Delta terminal houses the most containers in the entire port and almost every spot is used for either container storage, crane placement or ship docking. Therefore, a passive or active ramp would disrupt existing infrastructure too much. Therefore jack-up bays are planned. Jack-up bays are essentially cut-outs in the quay with dimensions of 20 x 10 metres. In these bays, a platform is present in the dimensions of the cut-out. This platform is free to move up and down by a jack-up system. A visualization of the inspiration can be found in Figure 7.

Figure 7: Visualization of jack-up bay inspired by boat lifts used for pleasure craft

The AAGV transfer from water to land using a jack-up bay happens as follows:

1. The bay platform is positioned under water.
2. The AAGV approaches the bay using its own jet propulsion system.
3. When the AAGV is located inside the bay (still afloat), the platform starts rising.
4. As soon as wheels of the AAGV make contact with the platform, the side pods start deflating.
5. When the platform is completely level with the quay, the AAGV drives off using its own motor drives.
6. The bay can now service an AAGV from land to water in a similar fashion.

The disadvantage of this system is that it is not continuous. The throughput will very likely be a lot slower than that of both ramp types. However, the lack of space at certain terminals forced such a solution.

3.2 Floating terminal

The Floating Terminal is a large floating platoon with dimensions of roughly 120 x 65 metres which houses its own gantry cranes. This Floating Terminal is anchored at a tactical location in the port, floating passively while being connected by a waterproof cable for electricity supply. The initial idea for the terminal was that the terminal acts using a "ship & collect" system, where containers from large seagoing container vessels are loaded onto automated barges, these barges are unloaded on the Floating Terminal where the container can be temporarily stored (max 200 TEU) to, consecutively, be loaded onto a hinterland barge for transport to for instance Waalhaven. The final design of the Floating Terminal is depicted in Figure 8.

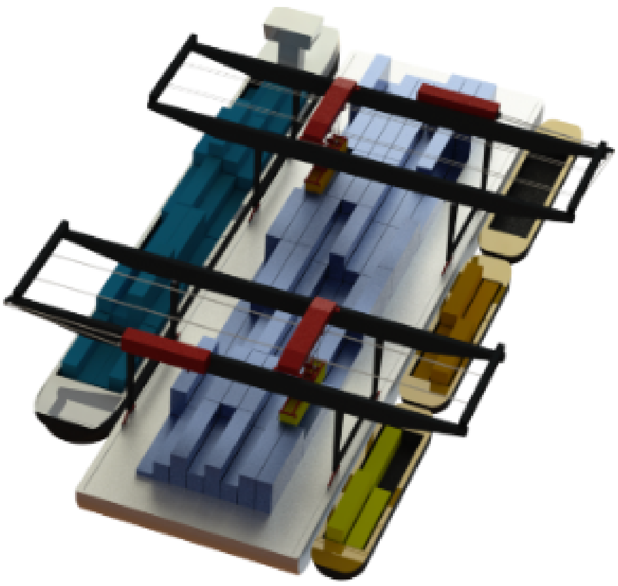

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Figure 8: Floating terminal

With the conventional process, containers will need to be loaded from a large container vessel onto a regular AGV, be driven to another crane, be transferred to an autonomous barge and then go to the Floating Terminal. When integrating the Amphibious Automated Guided Vehicle, the transfer from a normal AGV and onto an automated barge can be mitigated. The AAGVs will have the ability to directly dock at the Floating Terminal using the built in electromagnetic/mechanical locking system while in a max 3x3 grid format.

The process looks as follows:

1. A large vessel docks at a deep sea terminal.
2. Containers in need of transit to the same hinterland terminal are determined.
3. These containers are loaded directly onto an AAGV.
4. The AAGVs travel to the nearest land/water transfer point.
5. The AAGVs form a platoon by interconnecting and travel to the floating terminal.
6. The AAGVs dock at the floating terminal in grid format using the integrated locking system.
7. The containers are unloaded from the AAGVs and onto the hinterland barge.
8. The barge sets off to the hinterland terminal.
9. All containers are unloaded at the hinterland terminal.

For optimal use of the Floating Terminal, a tactical spot is needed which is central to all deep-sea terminals at the Maasvlakte. The chosen spot is marked in light blue in Figure 9. This area is chosen since this is the most spacious spot which is most central. The Floating Terminal in Figure 9 is depicted about 1.5 times larger than it would be to scale. Even with this factor of 1.5, the terminal would not be an obstruction for the largest vessels to manoeuvre. Many vessels, including one among the largest, can be seen at the terminals for comparison. For use of the Floating Terminal, the following land/water transfer system locations have been chosen (Figure 9).

Figure 9: Floating Terminal placement and AAGV transfer points (magnification factor of 1.5)

How the Floating Terminal interacts with the AAGVs can be seen in Figure 10, Figure 11, Figure 12, Figure 13 and Figure 14.

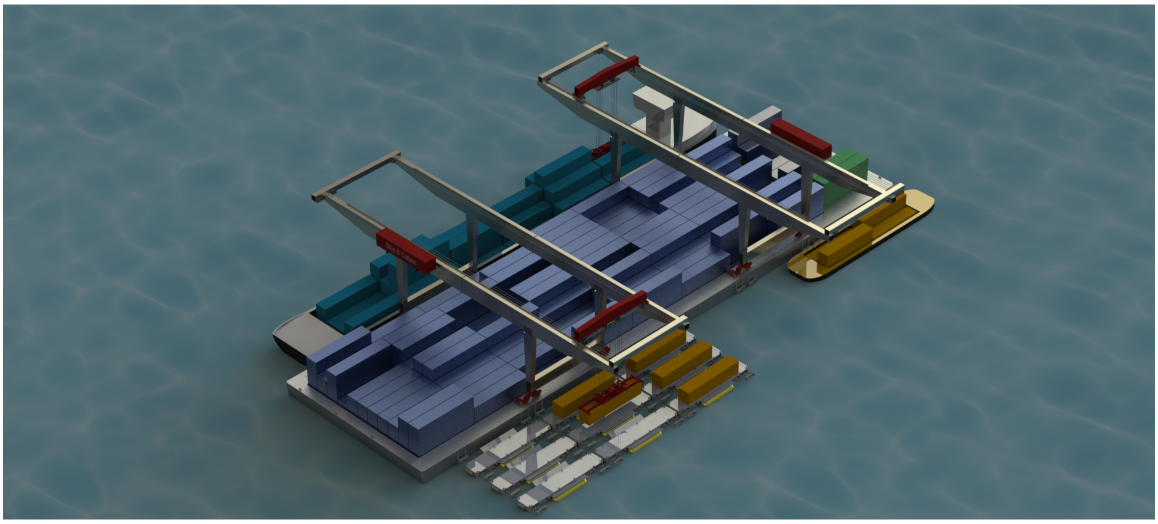

Figure 10: Overview of grid of AAGVs docked at Floating Terminal

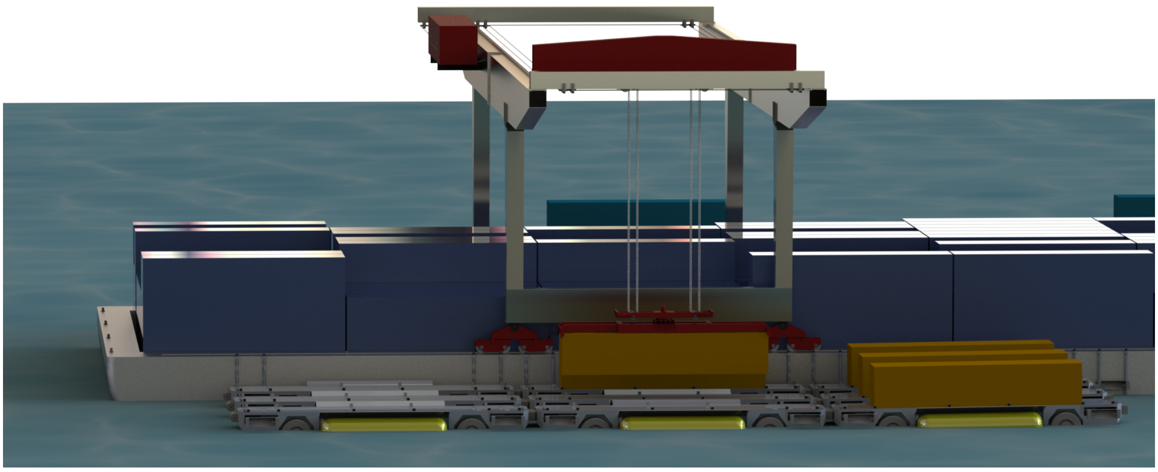

Figure 11: Visualisation of unloading of AAGVs in grid format to Floating Terminal

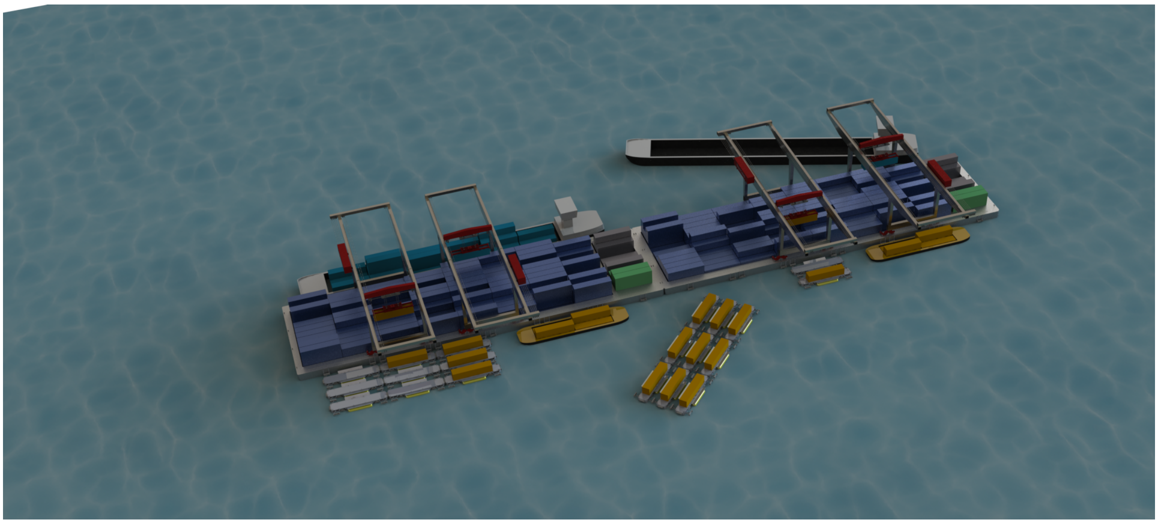

Figure 12: Visualisation of modularity of concept, 2 Floating Terminals and multiple configurations of AAGVs

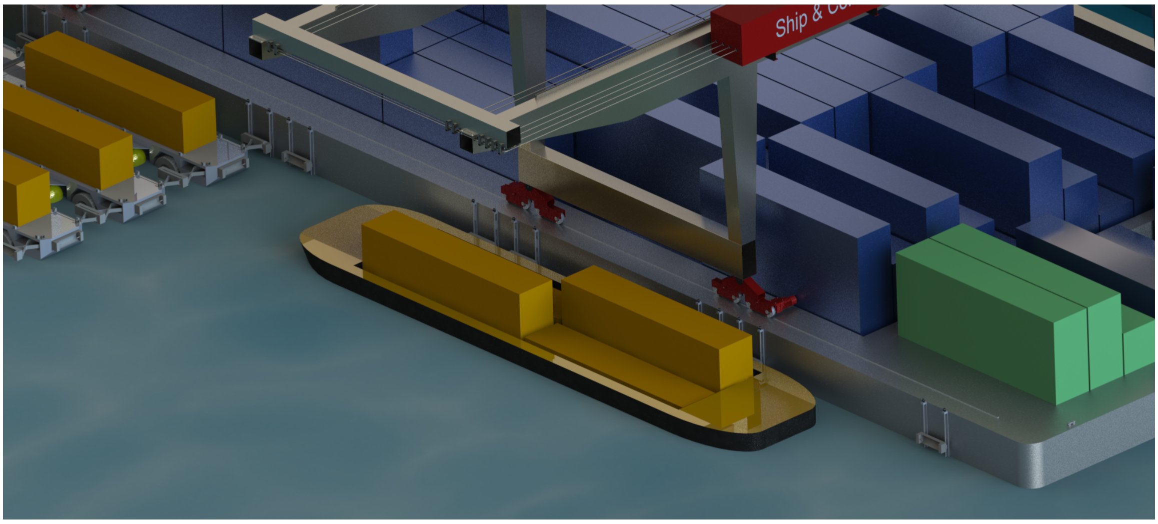

Figure 13: Visualisation of flexibility of Floating Terminal

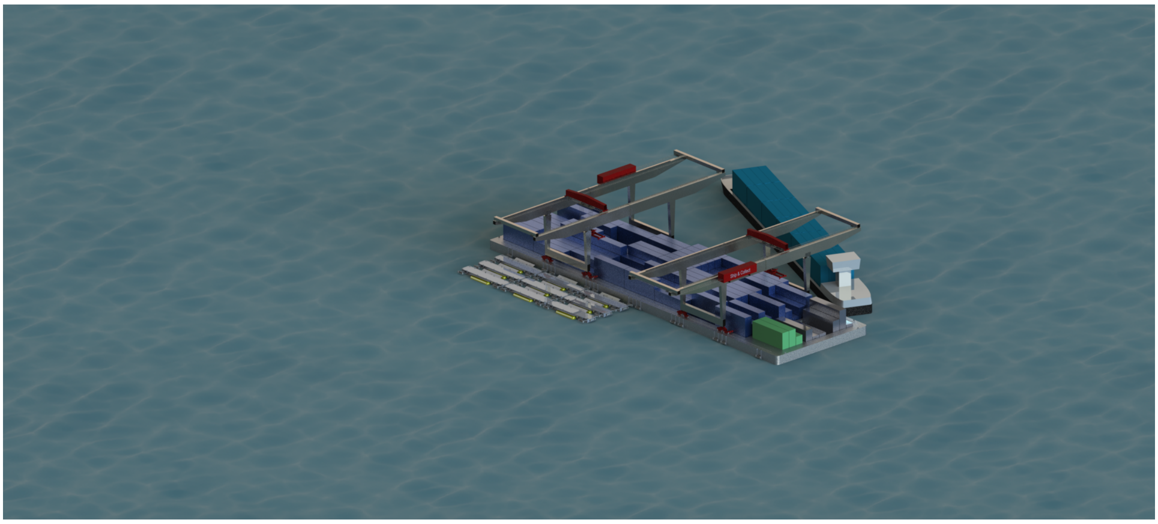

Figure 14: Departure of inland barge from Floating Terminal after unloading from 3x3 grid format AAGV

After all containers are unloaded from the AAGVs and loaded on the inland barge, the barge sets off to the inland terminal at, for instance, Waalhaven. A visualisation of the distance is displayed in Figure 15.

Figure 15: Example route of inland barge after being loaded at Floating Terminal

3.2.1 In depth AAGV transfer systems location descriptions

In this section, the exact specifications of all the transfer locations will be explained.

Location 1

Starting with the first transfer system at the RWG terminal at the Princess Amaliahaven. The chosen transfer system is the passive ramp. In the satellite photo in Figure 16 it can be observed that a lot of excess space is present at the north of the terminal. The proposed ramp lanes are indicated in red in Figure 16. From Google Maps, the distance of these lines over the map is 322 metres. This length represents a projection of the actual length and thus is equal to the cathetus of a right triangle. The estimated height of the quay wall with respect to the water is 11 metres. This will result in an inclination angle of around 2 degrees.

Figure 16: AAGV water/land transfer location 1 at Princess Amaliahaven

Location 2
The second transfer system is located at the APM terminal at the Princess Margriethaven. Again, a passive ramp system is used here. This is chosen since unused space was found. It is, however, unclear whether this area is available for the Port of Rotterdam to use. Since there are no existing structures, this is assumed to be a possible transfer location. A relatively small dock is present at the designated area right now so that would need to be sacrificed. The location is very suited for a passive ramp as there is enough space and the elevation is minimal. The ramp location proposition is 236 metres long as the crow flies and the elevation is estimated on 2.8 metres. This results in an inclination angle of 0.7 degrees and will thus account for an energy efficient water-land transfer without the need for expensive new machinery like an active ramp or a jack-up bay.

Figure 17: AAGV water/land transfer location 2 at Princess Margriethaven

Location 3
Location 3 is located at the Euromax terminal at the Yangtzekanaal. This location is the only location where an active ramp is used. The reasoning for this is that a passive ramp would simply require too much space, space that is not present. The indicated location for the active ramp is 120 metres long. The estimated quay height is set at 10 metres. This results in an inclination angle of 5 degrees, just below the set maximum.

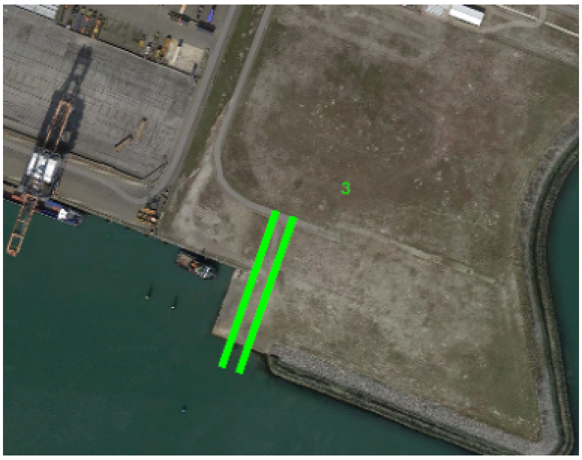

Figure 18: AAGV water/land transfer location 3 at Euromax terminal

Location 4
This location is the first of the jack-up bay transfer systems. It is located at the right tip of the Europahaven. At this spot, only a road is present now. This road could be rerouted. The size of the indicated jack-up bays is to scale. The actual size of the bays is 20 x 10 metres. The vertical elevation from water to quay is on average about 6 metres.

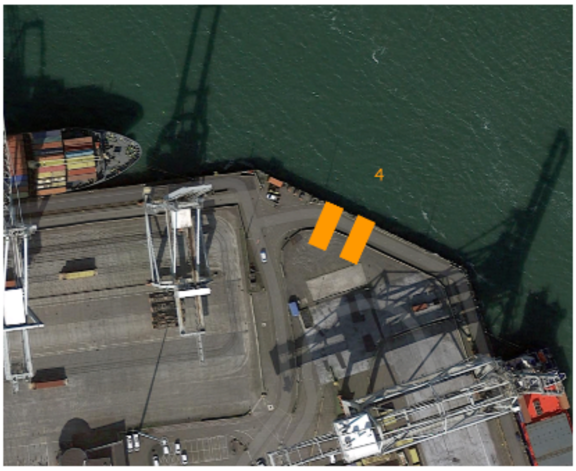

Figure 19: AAGV water/land transfer location 4 at Europahaven

Location 5
Location 5 is a jack-up bay similar to location 4 and is placed at the right end of the Amazonehaven. Here too, a road is present on the planned spot. Here too, there is more than enough space to reroute this road. The dimension of each bay is again 20 x 10 metres. The vertical elevation from water to quay is on average about 6 metres.

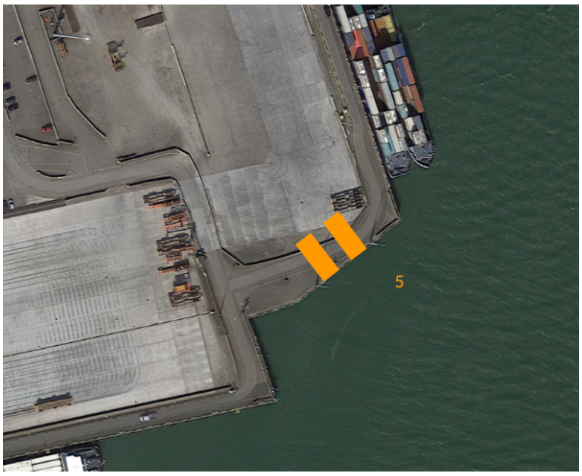

Figure 20: AAGV water/land transfer location 5 at Amazonehaven

3.2.2 Control System

Establishing a Control System Central Architecture is very essential for the automation of the Integration of Floating Terminal with the Amphibious AGV. The Smart Cranes on the floating terminal feed the information regarding destination onto the AGV. We need to establish an intelligent communication system between the Barge Floating Terminal, AGV and the machine handling the container post the AGV reaching its destination.

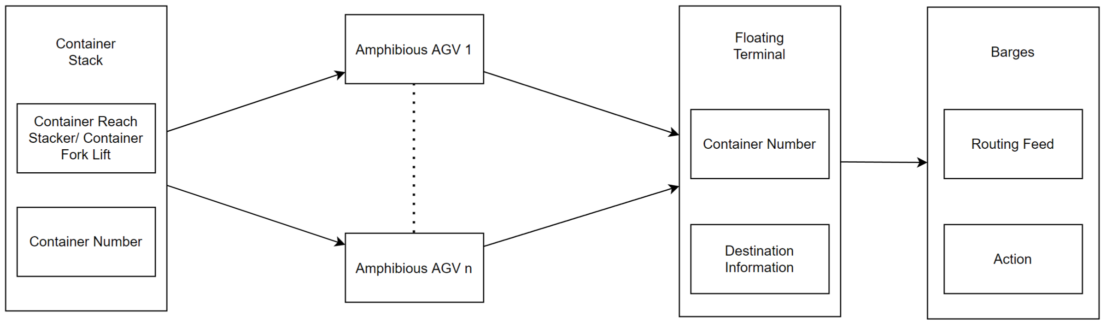

Figure 21: Control System between Floating terminal and Amphibious AGVs

For a safe Collaboration with the floating terminal, we have introduced a locking system between the Amphibious AGV and the Floating Terminal.

3.3 D.O.P.E.

The Drop or Pick Barge (D.O.P.E.) is a concept where a 120 TEU capacity barge has autonomous loading/unloading capacity thereby making it very versatile. D.O.P.E. also has the flexibility to access tight spaces. The current transfer of medium scale container operations involves barges that carry 120 - 150 TEU. One of the main problems faced in the port of Rotterdam is the amount of time lost in loading and unloading the containers. Also, the current barges can only dock at specific points in the port of Rotterdam specifically having low lying facilities. For example, barges cannot dock near Princess Amaliahaven, Alexiahaven and RWG due to excessive quay height. The only access point among the deep-sea terminals is located at Princess Margriethaven. This limits the scope of medium range transfer from deep sea to shortsea/inland terminals, since the unloading points are less present. Similarly, when we take this concept to the inland terminals such as Eemshaven, Waalhaven and Botlek the shallow waters mean concepts such as floating terminals are not very feasible. Also having STS cranes and big unloading equipment are not viable. In order to facilitate shortsea terminal transport, the use of AAGVs and D.O.P.E will be instrumental in the trans-shipment process. In a slight contrast to the floating terminal, the D.O.P.E. barge will act like a bus where passengers are the containers and just like how passengers are dropped off at every station, the containers too will be dropped off either at smaller depots or it can also be transferred to an Amphibious AGV which can then head to respective terminals and drop-off points. In essence, this will connect the incoming consignments from the deep-sea terminal to the inland and short sea terminals. Furthermore, the D.O.P.E. can help with trans-shipment. This would cover the medium scale and short scale requirements of the container transport.

The process flow will see the D.O.P.E access Botlek, Oude Maas (Eemshaven) and Nieuwe Maas (Waalhaven) in the Inland and short sea terminals. This will massively help in de-congesting the otherwise cluttered Waalhaven region. Also, this eliminates any external loading and unloading equipment hindering the quay side. These are key regions as an incoming AGV from the deep sea can use the unloading D.O.P.E. mechanism to transport container to the smaller terminals while the outgoing AGV will be loaded with containers to the deep sea terminals. The D.O.P.E. will also have a presence in the Deep-sea as well at the floating terminal and near the ECT Delta. The process flow will also see a maximum wait time of only 15 minutes at each drop off location. With the total distance and wait time, we can estimate 32 D.O.P.E. across the flow of cargo from the farthest point at Waalhaven to Euromax Via Eeemshaven, Botlek, entry point to deep-sea terminal and Euromax Terminal. The D.O.P.E can handle 120 TEU at one go and in ideal scenarios, if we see a transfer of 18 TEU to the D.O.P.E at each of the 5 points, this would mean 90 TEUs in one go for 32 DOPES implying nearly 3000 TEU transferred in 8 hrs for a continuous process. Furthermore, calculations will be justified in the validations section.

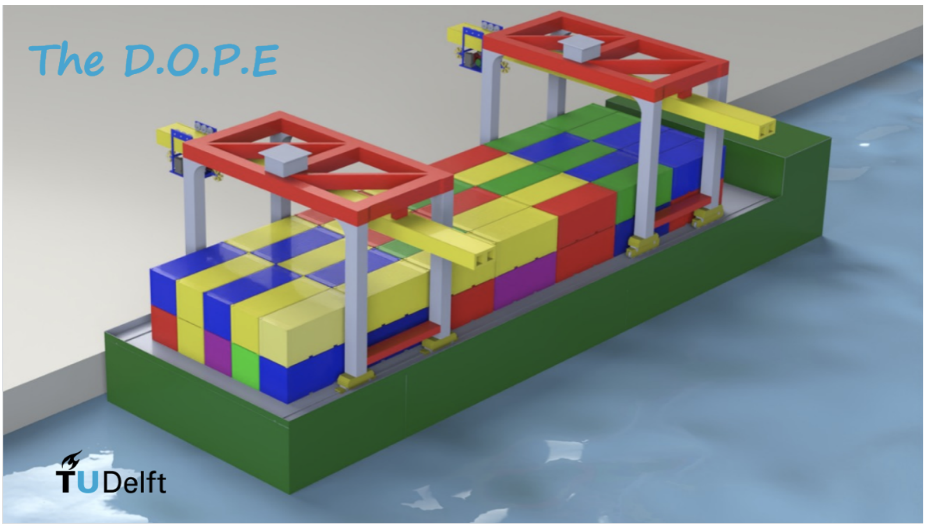

Figure 22: D.O.P.E. design

The 32 D.O.P.E. Barges will travel in a bus like routing schedule. The route with the drop-off locations is depicted in Figure 23.

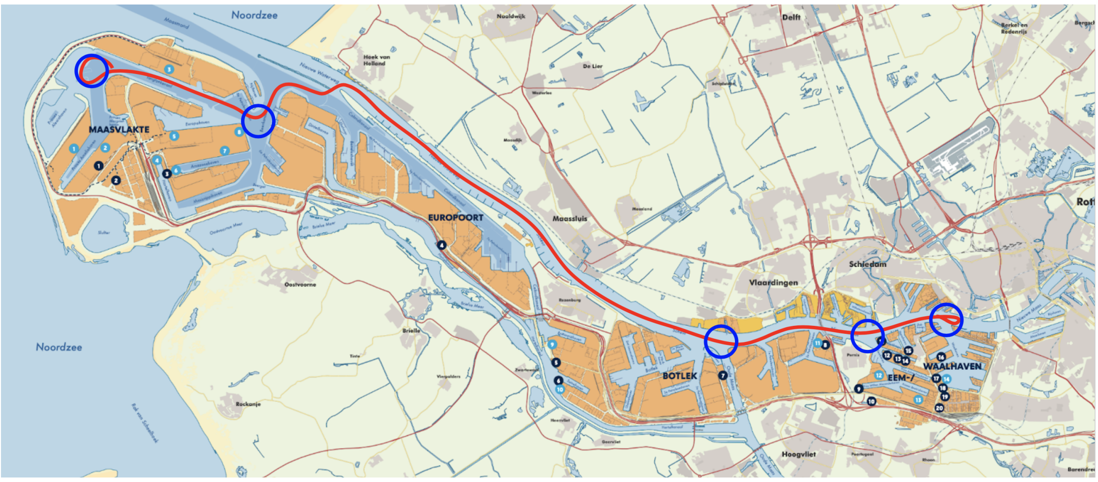

Figure 23: D.O.P.E. route

At every indicated drop-off location, the D.O.P.E. Barge will stop and float passively for 20 minutes to load and unload containers from AAGVs. In Figure 24 it can be observed how the AAGVs can dock onto the D.O.P.E. to stay steady. In Figure 24, the D.O.P.E. is also docked at the quay. This however is not necessary in the process.

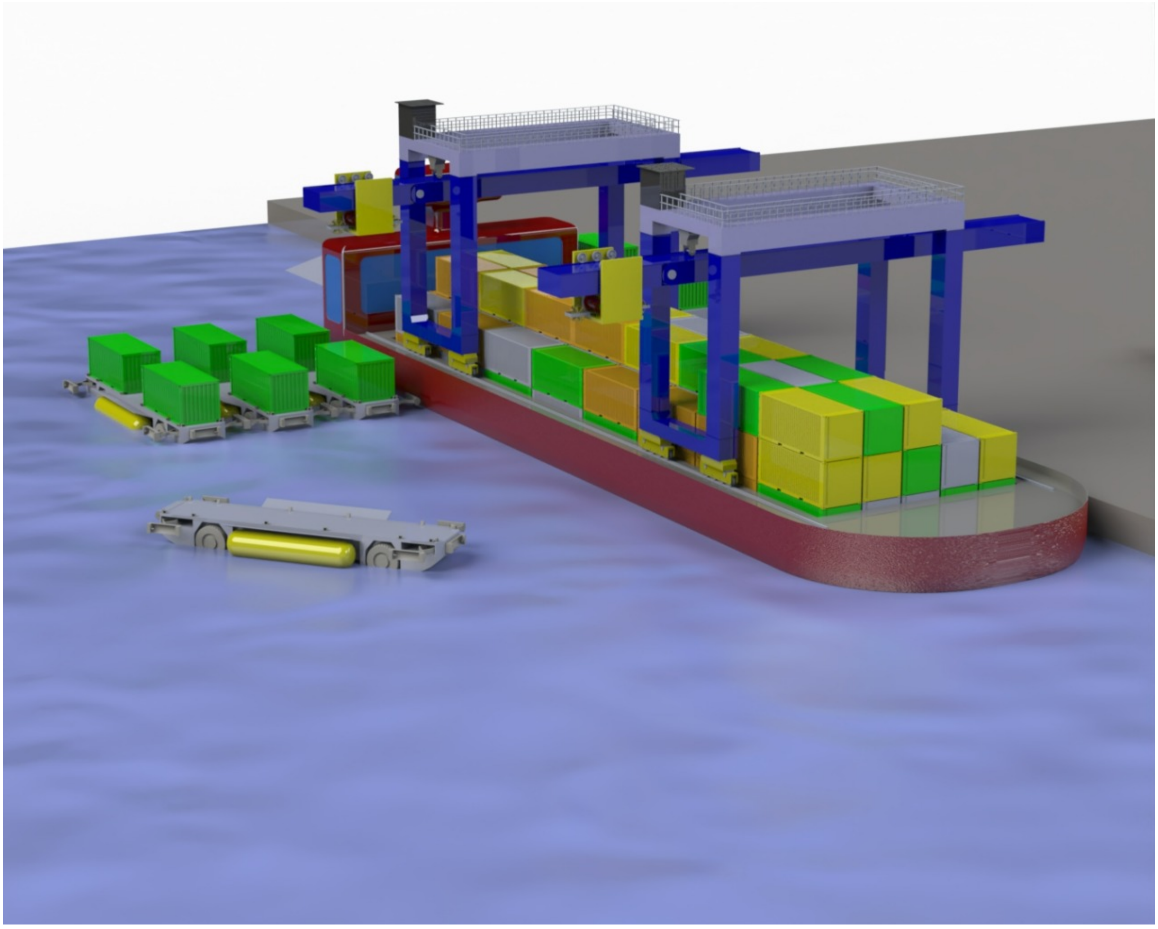

Figure 24: Visualisation of on-water container transfer AAGV to D.O.P.E.

3.3.1 In depth AAGV transfer systems location descriptions for D.O.P.E.

For the implementation of the D.O.P.E. barge, mostly the same water transfer systems as for the Floating Terminal will be used. However, the D.O.P.E. also has multiple drop-off locations deeper in the port. The drop-off locations of the D.O.P.E. are depicted in blue in Figure 25 and Figure 26.

Figure 25: DOPE drop-off locations and AAGV transfer systems Maasvlakte

Figure 26: DOPE drop-off locations and AAGV transfer systems inland terminals

The blue circles depict the locations where the D.O.P.E. will float idle, where AAGVs will dock next to the D.O.P.E. and containers are transferred from D.O.P.E. to AAGV.

3.3.2 In depth location descriptions for D.O.P.E. Barge

In this section, the remaining locations used for the D.O.P.E. system will be explained in depth.

Location 6

Location 6 uses a passive ramp system. From the satellite image in Figure 27, it is clear that this shoreline is already positioned in a shallow inclination angle. Also, a structure already is positioned into the water. This gives the convenient option to place the passive ramps out into the water. The length of the proposed ramp lanes is 50 metres from Google Maps. The estimated shore height is maximum 2 metres. This results in an inclination angle of 2.5 degrees, which is within the maximum inclination angle for a passive ramp.

Figure 27: AAGV water/land transfer location 6 at Oude Maas terminal

Location 7
In this location at the Eemhaven, no perfect spot was found. However, since this is one of the largest container terminals on the inland port section of Rotterdam a transfer spot was needed. Because of the lack of space, a jack-up bay is chosen. This area is rather narrow, contains some trailers and has some sort of service shack obstructing the bays, but this is the most central spot in the terminal that does not obstruct docking space, cranes and container storage. Therefore, this is the best location to propose. Again, the bays have dimensions 20 x 10 metres. The vertical elevation from water to quay is on average about 4 metres.

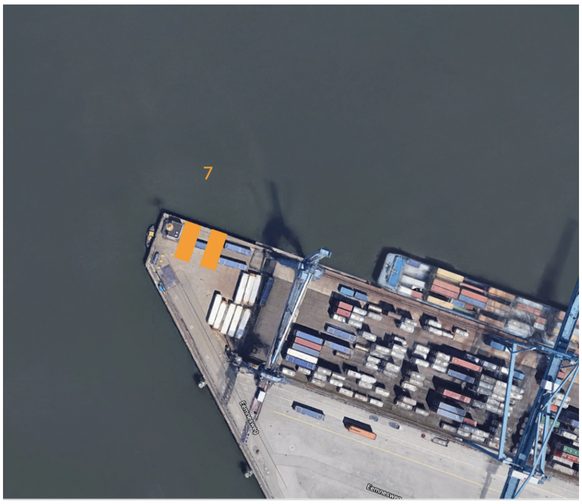

Figure 28: AAGV water/land transfer location 7 at Eemhaven terminal

Location 8
The last location is in a less advanced container terminal at the Waalhaven. However, this was the only option in Waalhaven for a land/water transfer system. Assuming that this container terminal will advance over the coming years, this could potentially become an important piece of infrastructure in the Port of Rotterdam. The dimensions of the jack-up bays are unchanged. The vertical elevation is on average about 6 meters.

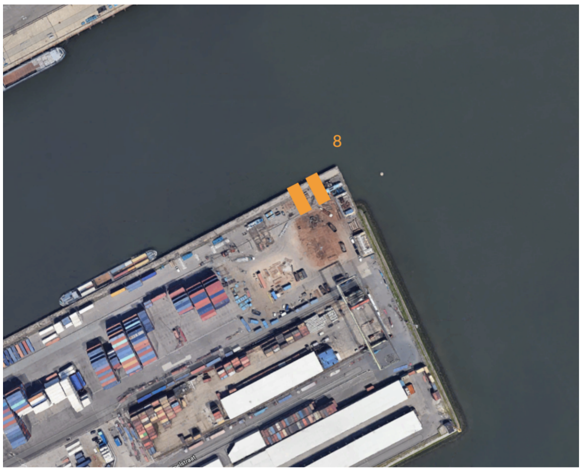

Figure 29: AAGV water/land transfer location 8 at Waalhaven

3.3.3 Control System

Establishing a Control System Central Architecture is very essential for the automation of the Integration of DOPE with the Amphibious AGVs. Assuming that the DOPE has a smart container, identification and placement system based on it's destination. This information is fed onto the AGV, so that it get's the information regarding the destination(coordinates). We expect a communication system to be established between DOPE, AGV and the Container reach stacker/Container Fork Lift.

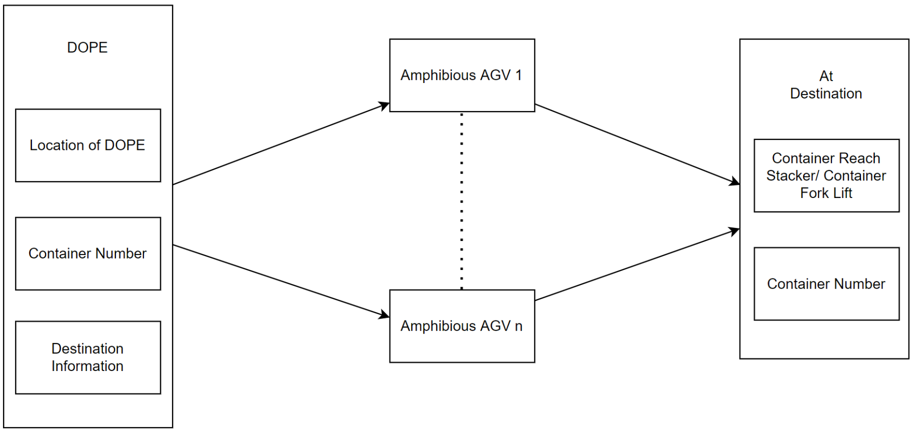

Figure 30: Control System between DOPE and Amphibious AGVs

3.4 The Smart System on a Whole

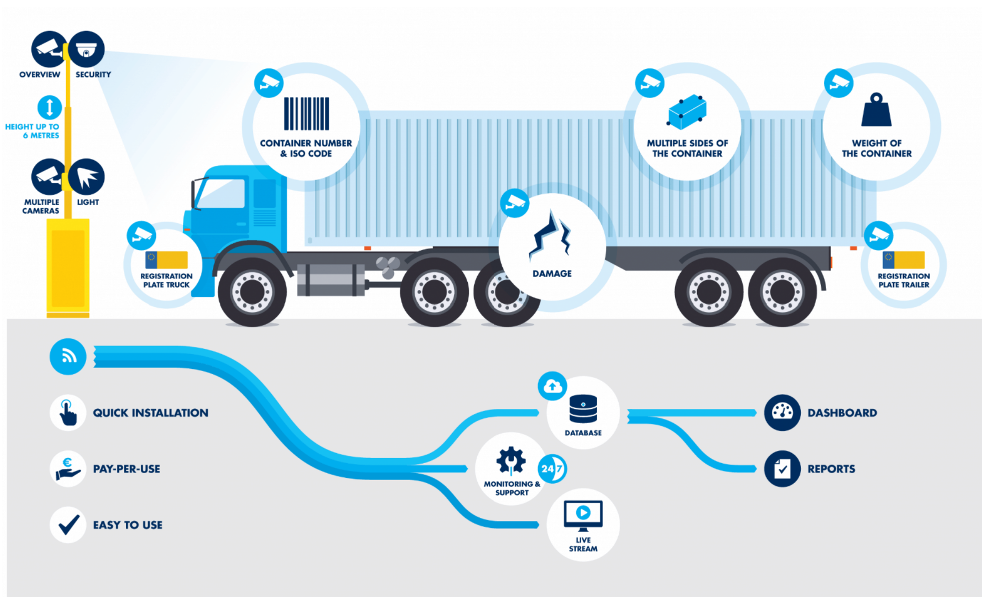

Figure 31: The Smart Scanning Infrastructure at the Port of Rotterdam

Integrating this existing infrastructre of a Mobile OCR for the seamless functioning of the Amphibious AGV.

3.5 Overall Integration

To end, an overview of the total integration of the chosen concepts is depicted in Figure 32.

Figure 32: Overview of implementation in the Port of Rotterdam

4 Validation

With the conceptual design done and the integration concepts clear, some aspects of the overall design need verification. In this section verification on AAGV interaction with each other and with other equipment will be assessed, the expected improvements of the new concepts will be estimated, and cost estimation will be made to see if the ideas are somewhat feasible.

4.1 Physical interaction verification

To start with the interactions the AAGVs will experience with each other and with other equipment during planned operation. When locked on the water, the AAGVs can experience some reaction moments and/or forces as a result of wind. Since the AAGVs will only operate within the port itself and inland terminals, waves are assumed to be negligible in these calculations. However, wind can have an effect on the AAGVs so calculations will be made to check if the arms of the locking system will be able to withstand these reaction forces.

The situations in which reaction forces occur are:

- When a strong wind blows the AAGV into the floating terminal while docking
- When the locking systems are extending, the moment induced by the weight of the electro-magnets

4.1.1 Situation 1

This situation will occur when either a single AAGV or a platoon of AAGVs tries to dock and a sudden wind pushes the vehicles into the floating terminal, such that the propulsion system and the control system do not have time to correct. A ballpark calculation will be made to check if the arms will yield and/or buckle.

Assumptions made here are that the speed at which the vehicle(s) will hit the floating terminal quay will be no more than 1 m/s. This is assumable because when the AGV is far enough away from the quay and a gust of wind is introduced, the control system will have time to correct the motion. Only when the AGV is already very close to the quay so that the control system can not correct in time, will there not be enough distance to match the actual speed of the wind. Therefore, a fraction of the wind speed at the Maasvlakte is considered. The maximum wind speed is 17 knots, which is 8,75 m/s. A ballpark estimation of the speed the AGV will reach when subjected to this wind speed for a very short amount of time is 1 m/s.

For this calculation, the stopping time of the AGV when it hits the quay is needed. Assuming the scissor beams have some flex, a stopping time of 0.5 seconds is estimated.

The impulse formulae are used:

$p = m * v$ and $\delta p = F * \delta t$

For a safe design, the maximum load of the AGV with cargo is assumed, meaning two fully loaded 1 TEU containers. To keep to the concept, a maximum of 3 AAGVs will be connected side-by-side while docking at the Floating Terminal. This means that the mass in the impulse calculation should include the mass of 3 AAGVs. Together with the earlier estimated load of the AGV, m is determined.

$m = 225.000$ kg
$v = 0.5$ m/s
$t = 0.5$ s

$F_t = \frac{mv}{\delta t} = \frac{225.000*0.5}{0.5} = 225.000$ N

This force will be distributed among two scissor mechanisms so the force on 1 arm will be:

$F = 112.500$ N

Since a scissor mechanism is used, the force will be again distributed among two members, and is decomposed into a force parallel and perpendicular to the direction of the resultantant force. The situation is depicted in Figure 33. Since only a ballpark estimation is made here, the angle the arms make with the horizontal is assumed to be 45 degrees.

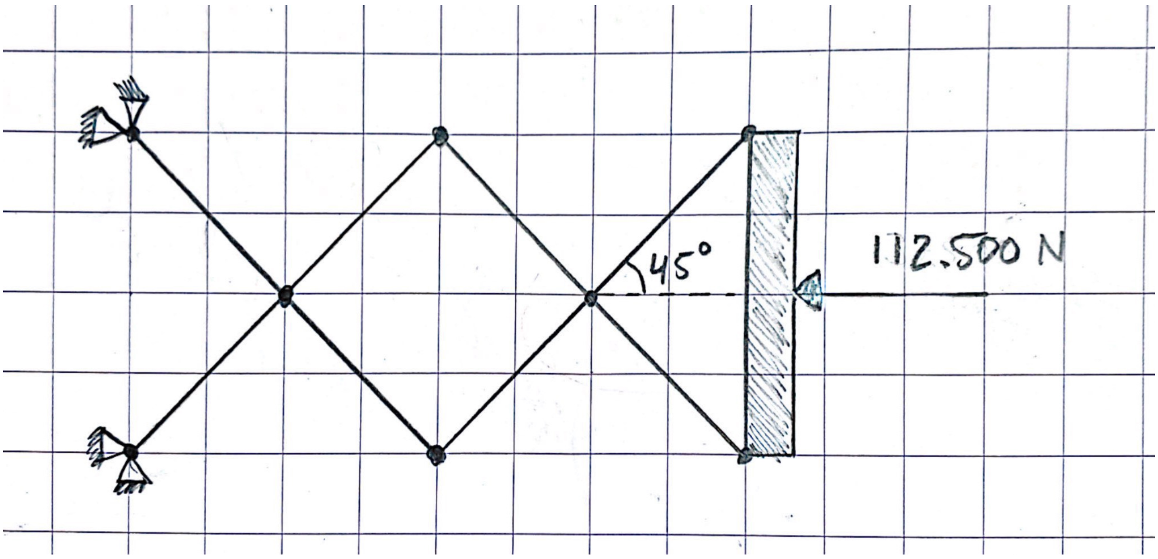

Figure 33: Schematic of force acting on AAGV scissor mechanism situation 1

Force in 1 arm due to symmetry:

$F_a = \frac{F}{2}\sqrt{2}$

Yield check
First, a check is done to verify whether the arm will yield as a result of a bump into the Floating Terminal. The dimensions of the cross sections of the arm are 0.2 x 0.05 meters. This results in a stress in the arms:

$\sigma = \frac{F}{A} = \frac{79550}{0.2*0.05} = 7.96$ MPa

The yield stress of steel is assumed:

$\sigma_y = 350$ MPa

Since $\sigma < \sigma_y$ the arms will not yield.

Buckling check
To check for buckling, beam buckling of a pinned-pinned beam can be assumed. First, the Euler critical buckling force is calculated, then this value is compared to the maximum induced force in the beam. To be safe, buckling over the weakest axis is examined. If the beam passes this check, the design is considered buckle safe.

Critical force:

$P_c = \frac{n^2 * \pi^2}{L^2} EI$

$n = 1$ (first order buckle)
$L = 0.698$ m
$E = 200$ GPa
$I = 0.00000208\ m^4$

$P_c = 8.44 * 10^3$ kN

$F_a < P_c$ so buckle safe

4.1.2 Situation 2

The locking system of the AGV is a mechanical attachment secured by electromagnets. This system will experience a self weight due to the attachments and magnets in the vertical direction. The effect on the system will be seen in terms of extension and compression on alternate locking systems. A point to be noted here is that the waves can be neglected so thereby little to no vertical movement on water. The lateral and side movements also have less fluctuations since wave speeds in ports are extremely low. The moment caused here will occur due to the weights of the electromagnet itself in the direction of the forward movement of the AGV.

First the weight of the electromagnet shall be estimated. Due to the complex formfactor of the connectors, the magnets are assumed to be rectangular in the calculation. From the dimensions of the Q3 report, the dimensions are estimated to be 1.7 x 0.475 x 0.245 meters. This results in a volume of 0.198 m^3. Electromagnets are mainly made from copper. When the complete volume is assumed to have the density of copper, an upper bound for the weight can be set. The density of copper is $8.96 * 10^3 kg/m3$.

The mass of a single connector is therefore estimated as:

$m = \rho * V = 8960 * 0.198 = 1.77 * 10^3$ kg

Since the scissor mechanism contains two beams and the structure is symmetric, the model can be simplified to a simple clamped beam with point load with half the mass on its end. The force at the end is $1.77 * 10^3 * 0.5 * 9.81 = 8.69$ kN.

The situation is depicted in Figure 34.
Using the bending moment formula:

$\sigma = \frac{-M * y}{I}$

$M = F * L = 8694.7 * 1.27 = 11.0$ kNm
$y = 0.5h = 0.1$ m
$I = 0,0000333\ m^4$

$\sigma = \frac{-M * h}{2I} = 33.2$ MPa

As seen before the yielding stress is $\sigma_y = 350$ MPa

Since $\sigma < \sigma_y$ the beam can hold the locking mechanism.

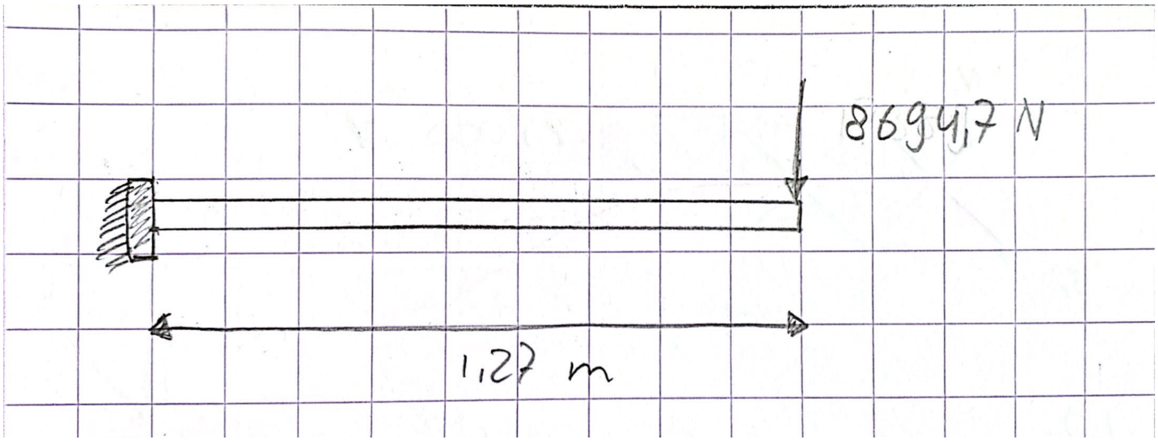

Figure 34: Schematic of simplified situation weight of electromagnet

4.2 Time saving estimation of integration concept

In this section, the developed concepts of the integration of the AAGVs with the Floating Terminal and with the D.O.P.E. barge will be validated on estimated time savings in certain situations. The main goal of the concept was to improve inter terminal transit of containers on mid-range within the Port of Rotterdam. For the verification, estimations and comparisons have been made for 2 main situations. Concerning the Floating Terminal, the situation that 100 TEU from a large vessel at the Euromax terminal have to be transported to the same terminal at Waalhaven. Here, the total time it will take to complete this is estimated for solemn use of trucks, use of train network and the use of the AAGVs and the Floating Terminal. For the D.O.P.E., the situation that 10 TEU from the terminal at Oude Maas, 10 TEU from the therminal at Eemhaven and that 10 TEU from Waalhaven all have to be transported to the Euromax terminal. Here, estimations on handling by train and by D.O.P.E. and AAGV are compared. To state: these are rough ballpark estimations. The numbers presented in this section are not factual, but based on common knowledge, Google Maps distance measure function and general equipment specifications.

4.2.1 Handling time estimations for Floating Terminal

To repeat, the situation considered for the use of the combination of the Floating Terminal and the AAGVs, is the need for 100 TEU in 50 units from a large oceangoing vessel to be transported from Euromax terminal at the Maasvlakte to Waalhaven. The modes of transport considered here are movement by truck train and by barge which departs at the Floating Terminal.

Truck
To start, it is assumed that the availability of trucks is not an issue. The limiting factor in the flow of containers is the rate at which the vessel is unloaded. This unload speed is assumed to be 25 moves per hour. This comes down to 144 seconds to unload a single container.

The number of cranes operating simultaneously is generally 4 to 6. Therefore, in this section the average is taken to be 5. As 50 units shall be unloaded, each crane has to unload 10 units and so after 10 crane cycles all containers will be at the quay.

Total unload time vessel:
$t_1 = 10\, cycles * 144\, seconds = 1440\, seconds$

At Euromax terminal, a large amount of gantry cranes is present to transfer containers from AGVs to trucks, so it is assumed that no waiting time is induced here. Therefore, the cycles in which the

STS cranes unload the containers is leasing for this transfer to truck. The gantry cranes have to travel about 260 meters. The speed of a gantry crane is estimated on 2.25 m/s [2].

Gantry crane cycle time:
$t_2 = 2 * 260/2.25 = 232\, seconds$

Assuming there will be enough gantry cranes to transfer containers to trucks, one gantry crane cycle time is added. The total time to unload the vessel to the last container being placed on a truck result in the following.

Total time until last unit is placed on truck:
$t_3 = 1440 + 232 = 1672\, seconds$

The last truck drive is the leading time. The truck has to drive 50 kilometers at an average speed of 70 km/h. The time it takes for a truck to arrive at Waalhaven is: $(50 * 3600)/70 = 2571\, seconds$.

The total time it takes to unload 100 TEU in 50 units from a large vessel at Euromax terminal and to transport Waalhaven by truck is comes down to:

Total transport time:
$t_T = 1672 + 2571 = 4243\, seconds\ (1\ hour\ and\ 11\ minutes)$

Train
To move the same number of units between the same terminals by train the following estimation is made. The information regarding inter terminal container transit by train is found at the website of Rotterdam Rail Service [4]. 1 train moves a maximum of about 50 units. Unloading and loading a full train takes about 7 hours. On average, 2 train rides are realised each day. The distance to be covered from Euromax terminal to Waalhaven is 50 kilometers. The average speed of the train is 50 km/h resulting in a travel time of 1 hour. As 1 train can be used for the entire shipment, the travel by train can be estimated by adding the total load and unload time, the train travel time and the total unload time from the vessel. The vessel unload time is the same as in before: 1440 seconds, or 0.4 hours. This results in the following total time.

$Total\ time\ by\ train = 1 + 7 + 0.4 = 8.4\, hours$

Floating Terminal
Now, an estimation will be made on how fast the same situation can be handled by using the earlier described AAGVs and the Floating Terminal. A similar method as for the truck movement will be used. The unloading of the vessel is the same and happens in 10 cycles with a total time of 1440 seconds. The average distance from the vessel to the AAGV transfer system is 1700 meters. The speed of the AAGV on land is 15 km/h (4.17 m/s). Driving time on quay: $1700/4.17 = 408\, seconds$. The unload time of the vessel is still 1440 seconds.

Time before last AAGV arrives at ramp:
$t_1 = 1440 + 408 = 1848\, seconds$

The ramp throughput time is 90 seconds. Only the last 5 units arriving at the ramp will queue up and add time to the process since the first waves can start transferring while other containers are still being unloaded from the vessel or are driving over the quay.

Time from start unload vessel to last AAGV in watermode:
$Queuing\ time\ at\ ramp = 5 * 90 = 450\, seconds$
$t_2 = 1848 + 450\, seconds = 2298\, seconds$

The distance for the AAGVs to travel over water from the Euromax terminal transfer system to the proposed Floating Terminal location is about 4000 meters. The average speed over water is legally limited to 13 km/h (3.61 m/s). The travel time over water is $4000/3.61 = 1108\, seconds$.

Time from start unload vessel to last AAGV arriving at Floating Terminal:
$t_3 = 2298 + 1108 = 3406\, seconds$

The cycle time of the cranes on the Floating Terminal is 120 seconds. Only 1 crane is able to handle the incoming pack of AAGVs. Only the last cycle of AAGVs coming in adds time to the process. The last cycle contains 5 AAGVs to handle. The time added is $120 * 5 = 600\, seconds$.

Total time from vessel unload to barge loaded:
$t_4 = 3406 + 600 = 4006\, seconds$

The distance over water the barge has to travel is 40 kilometers. The speed of the barge is about 20 km/h. This results in a travel time of the barge of 2 hours (7200 seconds).

Total time from vessel unload to arrival in Waalhaven:
$t_5 = 7200 + 4006 = 11206\, seconds\, (3\, hours\, and\, 7\, minutes)$

Unloading speed of the barge at Waalhaven is 144 seconds per unit. 2 cranes can operate the barge so a total of 25 cycles per crane will handle the 50 units. Total unload time will be $144 * 25 = 3600\, seconds$.

Total time from start vessel unload to unloaded at Waalhaven:
$t_T = 11206 + 3600 = 14806\, seconds\, (4 hours\, 7\, minutes)$

Results
The estimations of the container transit time of 100 TEU from the Euromax terminal to the Waalhaven terminal can be found in Table 1. Transportation by truck wins in terms of time, but is the contrary to sustainable.

Mode of transport	**Total transit time**
Truck	1 hour and 11 minutes
Train	8 hours and 24 minutes
Floating Terminal and AAGV	4 hours and 7 minutes

Table 1: Results time saving estimations Floating Terminal

4.2.2 Handling time estimations for D.O.P.E. Barge

To repeat, in this section the situation that 30 TEU from 3 different terminals deeper in the Port of Rotterdam will have to be transported to the Euromax terminal for ocean transport. 10 TEU comes from terminal at Oude Maas, 10 TEU from the terminal at Eemhaven and 10 TEU from Waalhaven. For this, the D.O.P.E. Barge (DB) will be used and a bus schedule fashion.

First, the amount of D.O.P.E. Barges in operation should be determined. The round-trip time of a single DB without stopping at drop-off locations is 368 minutes. There are 5 drop-off locations, and the DB has the capacity to load/unload a unit in 120 seconds. It is assumed that at each drop-off, 10 units shall have the option to be loaded/unloaded. Therefore, the pause time of each DB barge at each drop-off location is $10 * 120 = 1200\, seconds\, (20\, minutes)$. The total time for a round trip of one DB will therefore be 468 minutes.

To make operation efficient, an AAGV should have a maximum waiting time of 15 minutes at a drop-off location. This means that $468/15 = 32$ D.O.P.E. Barges will be running simultaneously. Assuming that the DB will first arrive at the drop-off location at Waalhaven, then proceed to Eemhaven and will then arrive at the drop-off at Oude Maas, only the AAGV water/land transfer time at Waalhaven will have to be taken into account, since the other AAGVs can transfer while the DB is on its way to these drop-offs.

For 10 TEU, 5 AAGVs will be used and so 5 AAGVS will need to be transferred to water using a jack-up bay. Jack-up system cycle time is 40 seconds. Total water enter time for AAGVs is $40 * 5 = 200\, seconds$. For the AAGVs to move to the closest drop-off location is assumed to be 600 seconds. Assuming the AAGVs just missed the DB, they will have to wait the maximum of 20 minutes. The time it will take the DB to reach the drop-off location at Euromax terminal consists of travel time and the waiting times at the intermediate drop-off locations: $184 + 4 * 20 = 264\, minutes$ $(15840\, seconds)$. The time the AAGVs take to move from the drop-off location to the active ramp system at the Euromax terminal is 600 seconds. The total transfer time is $90 * 15 = 1350\, seconds$.

$Total\ time = 200 + 600 + 900 + 15840 + 600 + 1350 = 19490\, seconds\ (5\, hours\ and\ 25\, minutes)$

The estimated value for this situation will be very robust since the process happens continuously. The competing mode of transport for this would be train. As explained in subsubsection 4.2.1, transport by train can experience loading and unloading times of 7 hours and waiting times of up to 10 hours since only 2 trains ride each day. Looking at the schedules of the trains, most trains are fully loaded before departing so shorter transit times by trains will be very unlikely. This shows that transit by DB is faster and more robust as these travel times are guaranteed at any point during the day.

Results
The estimations of the container transit time of 30 TEU from the Oude Maas terminal, Eemhaven terminal and Waahaven terminal to Euromax terminal can be found in Table 2.

Mode of transport	Total transit time
D.O.P.E. system	5 hours and 25 minutes
Train	4 hours to half a day

Table 2: Time saving D.O.P.E.

5 Conclusion

The Amphibious AGV system (AAGV) concept was designed and developed as part the Integration Project has multiple advantages over the current system utilising a mix of trucks, normal AGVs and barges. It has the advantage of being efficient and providing a much cleaner alternative to the present system.

The AAGV uses only electric motors and pumps for moving around the region. It is powered by batteries which do not produce any emissions and can be replaced with ease. It is efficient, quiet and implements clean technology. This reduces air pollution and noise pollution in and around the region of the port. This concept will introduce improvements in an acceptable way and keeps in spirit of the MAGPIE initiative.

The usage of the AAGV removes the need of barges and cranes for transferring containers to the barges for inter-terminal transfer, since the amphibious capabilities of the AAGV combined with the HIVE formation feature allows the transport of the same containers directly from a stack at one terminal to the other stack or ship at the other terminal seamlessly. In the same sense, the AAGV removes the need of the old diesel-hybrid AGVs too, because it does their job in a much cleaner way since the AAGVs featured in this report are powered only by batteries. The AAGV can also replace the truck in a country like The Netherlands since most areas are well connected by canals to accommodate water borne AAGVs, whether in formation or even individual. The HIVE Formation concept allows multiple AAGVs to join together on the water and be powered through it with reduced power consumption due to the fact that the control mechanism will utilize the propulsion power of only those AAGVs which are absolutely necessary thereby saving on overall power of the system and reducing downtime since the AAGVs with conserved power will not need to have their batteries exchanged at the Battery exchange facility. The Batteries themselves are replaceable from the top of the AAGV, and therefore do not need to be plugged in to recharge guaranteeing low down-times.

Considering the integration with the other possible proposals on the table, the AAGV is well poised in concept and design to seamlessly integrate, interact and work in tandem with whatever they might be. The AAGVs are equipped with locking mechanisms to work in a HIVE-minded formation, which can also be used by all the other proposals to lock the AAGVs to themselves for easier transfer of containers between them. They also come equipped with GPS navigation systems integrated with sensors to prevent collisions on the water as well as on land. They can also be integrated with the Radar system of the Port of Rotterdam as well as the Cloud network to log pickup and drop-off of containers at different points, to which the other projects can also be integrated.

Integration with Group 1 (The Floating Terminal concept) has been achieved by the usage of the locking system by them to allowing the AAGV to float alongside and lock onto the terminal to prevent relative movement between the two while transfer of containers is being carried out. The Floating terminal shall also provide via the cloud network, information about the container load and its destination to the AAGV so that it can successfully deliver a container to its intended location using an inland barge.

Integration with Group 2 (The Crane Equipped Barge concept called D.O.P.E.) has been achieved similarly by provisions of the locking systems on the barge as well as networking via the cloud to provide information of the container and its destination to the AAGV. Multiple D.O.P.E. Barges will be deployed and act in a bus route inspired way, picking-up and dropping-off containers from and to AAGVs on water, at designated drop-off points. Due to the drop off at different locations, the AAGV shall also be provided with the location of the barge in the port area through the cloud netwrok.

Given the fact that the AAGV is completely clean and near silent, it is believed that the effect on flora and fauna in and around the port region shall be reduced to a large extent as well as effect on society by the removal of pollution. As the AAGV will also be able to travel on inland waterways, it will also make the inland waterways cleaner and quieter thereby reducing the impact on communities along the waterways too.

The financial impact of the proposal is enormous given the fact that all the AGVs along with a sizeable number of trucks and barges can themselves be replaced with just the AAGVs doing the job of all of them in one go. The trucks and barges can then be used elsewhere in the country or in the case of Barges and AGVs, exported to ports in developing countries. The fact that the AAGVs can be joined together in various different types of formations makes it much more convenient for them to replace the barges.

The only downside that might be associated with the usage of the AAGVs would be the drastic reduction in employees since human operators needed to operate the vehicles that are being replaced will not be needed. However considering the fact that the benefits outweigh the cons, including the fact that the AAGVs will be in use for more than a decade to come thereby with a relatively quick breakthrough with operating costs in contrast to profits made, its easy to understand why the AAGV concept is the future of modern container port handling operations.

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