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AUTOFLEX

[D3.2] Transport System

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EXECUTIVE SUMMARY

This report constitutes the AUTOFLEX project deliverable that is based on the tasks 3.4 and 3.5, as outlined in section 0and 1.3 . The objective of task 3.4 is to identify the locations with high potential of being used as terminal points in a transport system network serviced by small (CEMT II) uncrewed autonomous ships. Furthermore, to use Operational Research optimisation methods developed for strategic decision support, to propose the AUTOFLEX network architecture and sailing schedules. The architecture consists of the locations where temporary port terminal (TPTs) and stow and charge hubs (S&Cs) should be placed, and the routes that each vessel should operate on. Task 3.4 is to propose a set of transport system architecture configurations and evaluate them in a logistics analysis simulation tool. The outcome will be typical voyages (routes, carried cargo between locations, sailing speed).

The objective of task 3.5 is to evaluate the performance of the typical voyages from task 3.4 to estimate cost and emissions. This is based on simulating the voyages based on an energy model of the AUTOFLEX Oscar 2.0 operating on the routes of the typical voyages.

A critical design input to task 3.4 is the transport demand within the use cases. The deliverable contains a proposed method for estimating transport volumes between concrete areas such as cities, based on NUTS 3 level data. The method also includes modal shift potential estimation, and allocation of regional demand to geographic locations. A synthetic NUTS 3 level dataset is used to estimate freight volumes eligible for transfer from road to IWT, using the AUTOFLEX transport system.

An optimisation problem for designing the AUTOFLEX transport system network, number of ships, routes and schedules is formed and solved. The result is a proposed redesigned transport system for shifting road freight to IWT. The network architecture for an increasing fleet size, from ten to thirty in increments of five, is designer and proposed. Transport system nodes are at this stage placed in cities/urban areas without detailed evaluation of concrete locations.

The report then moves on to propose concrete locations for the network nodes, either as Temporary Port Terminals (TPTs) or Stow and Charge hubs (S&Cs). This is done by expanding the analysis within AUTOFLEX deliverable D3.1 [1], which investigated most of the potential TPT and S&C locations, but with a perspective of developing the concepts rather than choosing location. Then, proposed realisations per TPT and S&C is proposed. This is based on the concept proposals for TPT and S&C in AUTOFLEX D3.1 [1]. As such, the analysis departs from the work therein.

Finaly, the proposed network is configured in the SIMPACT simulator, an agent- based logistics simulator with increased modelling accuracy (see Chapter 4 for more information), to evaluate and adjust the proposed network architecture and schedules. Multiple simulations were run during the process of adjusting schedules. In each simulation run, ten routes are simulated as a network. After adjusting the routes and schedules, typical voyages were derived and used to estimate transport cost for one short and one long route, each in two scenarios. The results that the uncrewed autonomous Oscar 2.0 significantly increase the amount of transported container per year and reduced transport cost per container, compared to bot a diesel and electric powered conventionally crewed container version of the Oscar

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Teubert. The results will be the basis for the further work in AUTOFLEX work package 5, where impacts of deploying the AUTOFLEX transport system will be studied.

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LIST OF ABBREVIATIONS

Abbreviation	Description
AAB	AUTOFLEX Advisory Board
API	Application Programming Interface
CA	Consortium Agreement
CAPEX	Capital Expenditure
CEMT	Conférence européenne des ministres des Transports
CEMT class	A classification system for inland waterways defining the maximum dimensions permitted for ships sailing on the waterway[1]
EuRIS	European River Information System is a platform providing waterway, infrastructure, and vessel information in real time and which supports voyage planning and routing: https://www.eurisportal.eu/pages/whatisEuRIS
GA	Grant Agreement
IWT	Inland Waterway Transport
MSC	Modal Shift Cluster
MSP	Modal Shift Potential
NUTS	Nomenclature of Territorial Units for Statistics
OD	Origin Destination (of cargo)
OPEX	Operational Expenditure
ROC	Remote Operating Centre
SOTA	State-of-the-art
TCO	Total Cost of Ownership
TEU	Twenty-foot Equivalent Unit (container capacity unit)
S&C	Stow & CHagre Hub
TPT	Temporary Port Terminal
VOYEX	Voyage Expenditure
ZES	Zero Emission Services[2]

[1] https://en.wikipedia.org/wiki/Classification_of_European_Inland_Waterways
[2] https://zeroemissionservices.nl/en/homepage/

1 INTRODUCTION

Introduction to the deliverable

1.1 PURPOSE OF THE DOCUMENT

This deliverable relates to tasks 3.4 and 3.5 as outlined in the AUTOFLEX Grant Agreement (GA) and repeated in sections 0 and 1.3 herein. As with any research, it is hard to predict how the course of the work will develop, as is the case for the AUTOFLEX project where the initial work leading to deliverable D3.1 [1] has proven to provide a very good basis for tasks 3.4 and 3.5, which was not foreseen in the GA. Namely, the geographical analysis within has narrowed down the area for which the AUTOFLEX transport system should target, and mapped concrete locations that will be further investigated as candidates for establishing the concepts given in [1]. As such, the deliverable D3.1 [1] contains the initial phase of tasks 3.4 and 3.5. Nevertheless, deliverable D3.2 contains the main part of the tasks and combined the deliverables D3.1 [1] and D3.2 documents that tasks 3.1 to 3.5 have been completed as foreseen in the GA.

This deliverable starts by developing an optimisation model to be used to propose the AUTOFLEX transport system architecture (section 2.2). Then it presents data sources and develops transport volume scenarios in section 2.3 . Resulting transport system architecture is given in section 2.5 where the network candidates consist of nodes representing origin-destination (OD) pairs. The nodes are at this point areas on the size of cities. The next step is to pinpoint the exact locations of the temporary port terminals (TPTs) and stow and charge hubs (S&Cs) of the transport system within each area (chapter 3). Deliverable D3.1 [1] provided several candidate TPT locations per area and did a qualitative preliminary analysis of each specific location within the areas. Section 3.3 expands on D3.1 [1] and applies a method that quantifies the suitability of each location through a rating system. Based on this and the cargo volume, one or more concrete locations are chosen as TPT locations within each area. Each chosen location is then evaluated in terms of how a TPT could be realised using the building blocks proposed in D3.1 [1] (section 3.4). Deliverable D3.1 [1] went some steps further for the S&C analysis and did a rating of each potential concrete S&C location. And since the locations were chosen in the transport system architecture proposal of chapter 2 , section 3.5 discusses the S&C locations briefly and focuses on the realisation per location. An evaluation of the AUTOFLEX transport system network(s) is presented in chapter 4 including comparison to a conventionally crewed electric and diesel powered container version of Oscar Teubert. The results clearly show that Oscar 2.0 operating in the AUTOFLEX transport system reduces cost per transported container and increases the number of containers moved per year by a significant margin in all comparisons to the baseline cases. This work will the basis for the impact analysis of work package 5.

1.2 AUTOFLEX TASK 3.4 GA DEFINITION

Task description from the Grant Agreement of the AUTOFLEX project:

This task will use the transport system components developed in Task 3.1-3.3, the vessel concepts from Task 4.2, as well as the quantified design parameters of the use cases from WP2 (transport demand, available resources and infrastructure, performance requirements, etc.), to re-design the use case transport system architectures. The placement of Stow&Charge hubs will be studied and optimised with respect to cargo flow and energy requirements for the inland vessels and trucks operating in the network. The number (and sizes) of vessels and trucks will be optimised with respect to overall transport cost, logistical KPIs, and environmental impact. Method: An optimisation algorithm for creating candidate network configurations will be developed. This algorithm will produce a set of potential transport system architecture configurations which are analysed in the SO tool module for logistical analysis. The SO tool is based on discrete event simulation, which allows multiple simulations of logistical operations over a time span of years. A clustering algorithm identifies the set of typical voyages for each vessel (route, shipments, ports of call, etc.), and this set of typical voyages can be used as the operational profile for the vessel design including battery package sizing, as well as input for estimating emissions and cost (which will be done in task 3.5).

1.3 AUTOFLEX TASK 3.5 GA DEFINITION

Task description from the Grant Agreement of the AUTOFLEX project:

This task will evaluate and validate performance of the AUTOFLEX transport system. Based on the developed new transport system (including vessel concepts, transport system components and architecture), logistical simulations will be run to estimate the performance in terms of logistical KPIs. The results will include operational profiles for inland vessels, as well as the estimated transport work. Which will be used to quantify logistical, environmental, and cost KPIs. The task will be aligned with Tasks 3.1-3.4 and WP4, by providing feedback on performance that will be used to adjust the concept designs. Multiple iterations of concept development and performance validation will be executed to optimise the design and performance of the transport system and its subcomponents, where the initial iteration will be with the transport system as it is today (with today's technology) to provide a baseline. Method: Based on the typical voyages generated by Task 3.4, simulations of the typical voyages will be run in the SO tool module for cost and emission analysis to estimate the consumed energy per voyage, transportation costs and emissions. The energy estimation is based on speed-power models from T4.3, while cost estimation is based on models for investment and operational costs from WP4 and WP5.

1.4 THE AUTOFLEX VESSEL – OSCAR 2.0

The AUTOFLEX transport system proposed within this deliverable is based on the Oscar 2.0 vessel. Oscar 2.0 was designed by the project work package 4, and more information can be found within the D4.x deliverables available at the project website. Key facts are also available in [1].

2 THE TRANSPORT SYSTEM ARCHITECTURE

2.1 INTRODUCTION

The purpose of this work is to develop a decision-support tool that helps identify the most promising strategic configurations of the AUTOFLEX transport system. These high-level decisions, such as where to locate key infrastructure and how many vessels to deploy, form the foundation for later assessments of system feasibility, performance, and cost-effectiveness.

To support these decisions, we have developed a mathematical representation of the transport system design problem using methods from discrete optimization (whole number or binary values, e.g. what locations to call to, how many calls to make). The model takes as input the best available estimates of technical characteristics such as sailing distances, energy consumption, vessel capacities, and operational constraints. An integer programming solver is then used to find the mathematically optimal system configurations that offer the best performance under the assumed conditions. The output is a set of candidate transport networks that appear most advantageous according to the model's objective.

Because this is a matter of long-term, strategic planning, the scope of the model is deliberately focused on components that define the backbone of the transport system. These include the number and placement of Stow&Charge hubs, temporary port terminals, and the fleet size. Other AUTOFLEX components, such as Remote Operations Centres (ROCs) and Mobile Distribution Centres (MDCs), are intentionally excluded. ROCs primarily provide operational oversight and do not influence the physical structure of the network, while MDCs support last-mile distribution and their placements and utilization involve short-term, tactical decisions that do not affect the system's core capacity.

In addition to identifying promising infrastructure layouts, the model also produces illustrative sailing plans, including routing, cargo flows, and battery-swap strategies. These should not be interpreted as optimized operational schedules, but rather as examples that are used to ensure functionality and estimate the capacities of the proposed network. The resulting model considers not only the placement of transport infrastructure and fleet size, but also the interaction between transport demand, vessel utilization, and energy supply. This reflects the AUTOFLEX objective of designing an integrated transport system where logistics performance and energy availability are jointly optimized.

2.2 OPTIMIZATION MODEL

The optimization model simultaneously addresses several interconnected dimensions. The most fundamental decisions are the placement of Temporary Port Terminals (TPTs) and Stow&Charge hubs (S&Cs), but fleet sizing and utilization and assignment of transport flows to network routes are also considered. Energy feasibility, represented through energy consumption, battery capacities and battery swap strategies are integrated into the model as constraints. The model does not explicitly optimize for these decisions to be made as cost efficiently as possible but ensures that the solutions produced are feasible also from this perspective.

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The transport network is modelled as a mathematical graph of nodes connected by arcs, where nodes represent terminals and hubs, and arcs are the possible sailing legs which could be used to move between nodes.

2.2.1. SETS

$\mathcal{V}$ Set of vessels, indexed by v

$\mathcal{H}$ Set of candidate locations for Stow&Charge hubs, indexed by h

$\mathcal{P}$ Set of candidate locations for temporary port terminals, indexed by p

$\mathcal{L}$ Locations, union of $\mathcal{H}$ and $\mathcal{P}$

$\mathcal{K}$ Set of demands, indexed by $k = (o, d)$

$\mathcal{S}$ Sequence of positions in vessel routes, indexed by s

2.2.2. PARAMETERS

N_H Number of Stow&Charge hubs to be opened

N_P Number of temporary port terminals to be opened

N_V Number of vessels to be deployed

Q Capacity of a vessel (TEUs)

BC Battery capacity (kWh)

C_{ij} Distance between locations i and j (kilometers)

T_{ij} Duration of leg (i, j): travel plus loading/unloading time (hours), with $T_{ii} = 0$

TB Battery swapping time (hours)

$S^{\max}$ Maximum number of visits on a vessel's route

$T^{\max}$ Length of the planning period (hours), i.e. the maximum duration of any single route

$n^{\max}$ Maximum number of route cycles a vessel may complete per planning period

EC_{ij} Energy consumption between locations i and j (kWh)

D_k Estimated volume of demand k

W_k Impact weight of demand k

2.2.3. DECISION VARIABLES

y_h Binary variable indicating if a Stow&Charge hub is deployed at location h

z_p Binary variable indicating if a temporary port terminal is deployed at location p

x_{vis} Binary variable indicating that vessel v visits location i at position s in sequence

w_{vijs} Binary variable indicating that vessel v sails from location i to location j between position s and $s + 1$ in sequence

t_{vs} Time when vessel v arrives at position s in its sequence (hours)

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e_{vs} Cumulative energy consumed by vessel v since last battery swap when vessel leaves location at position s (kWh)

b_{vis} Binary variable indicating if vessel v swaps battery at location i at position s in sequence

f_{ijk} Flow of cargo k on arc (i,j) (TEUs)

g_k Amount of demand k served

n_v Number of route cycles vessel v completes per planning period (continuous)

2.2.4. OBJECTIVE FUNCTION

The objective function (1) maximizes the total amount of transport work shifted from road to inland waterways, expressed in TEU-kilometres and weighted by impact. This formulation captures both the volume of transported goods and the distance over which road transport is replaced, thereby prioritizing solutions that deliver the highest overall system impact rather than simply maximizing handled volume.

$$\max Z = \sum_{k=(o,d)\in\mathcal{K}} C_{od} \cdot W_k \cdot g_k \qquad (1)$$

2.2.5. CONSTRAINTS

$$\sum_{h\in\mathcal{H}} y_h = N_H \qquad (2)$$

$$\sum_{p\in\mathcal{P}} z_p = N_P \qquad (3)$$

$$x_{vhs} \leq y_h \qquad \forall v\in\mathcal{V},\ h\in\mathcal{H},\ s\in\mathcal{S} \qquad (4)$$

$$x_{vps} \leq z_p \qquad \forall v\in\mathcal{V},\ p\in\mathcal{P},\ s\in\mathcal{S} \qquad (5)$$

$$\sum_{i\in\mathcal{L}} x_{vis} \leq 1 \qquad \forall v\in\mathcal{V},\ s\in\mathcal{S} \qquad (6)$$

$$\sum_{i,j\in\mathcal{L}} w_{vijs} = 1 \qquad \forall v\in\mathcal{V},\ s\in\mathcal{S}\backslash\{\mathcal{S}^{\max}\} \qquad (7)$$

$$w_{vijs} \leq x_{vis} \qquad \forall v\in\mathcal{V},\ i,j\in\mathcal{L},\ s\in\mathcal{S} \qquad (8)$$

$$w_{vijs} \leq x_{vj,s+1} \qquad \forall v\in\mathcal{V},\ i,j\in\mathcal{L},\ s\in\mathcal{S}\backslash\{\mathcal{S}^{\max}\} \qquad (9)$$

$$w_{vij,\mathcal{S}^{\max}} \leq x_{vj0} \qquad \forall v\in\mathcal{V},\ i,j\in\mathcal{L} \qquad (10)$$

$$w_{vijs} \geq x_{vis} + x_{vj,s+1} - 1 \qquad \forall v\in\mathcal{V},\ i,j\in\mathcal{L},\ s\in\mathcal{S}\backslash\{\mathcal{S}^{\max}\} \qquad (11)$$

$$w_{vij,\mathcal{S}^{\max}} \geq x_{vi,\mathcal{S}^{\max}} + x_{vj0} - 1 \qquad \forall v\in\mathcal{V},\ i,j\in\mathcal{L} \qquad (12)$$

$$x_{vi0} = x_{vi,\mathcal{S}_{\max}} \qquad \forall v\in\mathcal{V},\ i\in\mathcal{L} \qquad (13)$$

$$t_{vs+1} \geq t_{vs} + \sum_{i,j\in\mathcal{L}} T_{ij}\, w_{vijs} + TB\sum_{h\in\mathcal{H}} b_{vhs} \qquad \forall v\in\mathcal{V},\ s\in\mathcal{S}\backslash\{\mathcal{S}^{\max}\} \qquad (14)$$

$$t_{v,\mathcal{S}^{\max}} \leq T^{\max} \qquad \forall v\in\mathcal{V} \qquad (15)$$

$$t_{v0} = 0 \qquad \forall v\in\mathcal{V} \qquad (16)$$

$$e_{v0} = e_{v,\mathcal{S}^{\max}} \qquad \forall v\in\mathcal{V} \qquad (17)$$

$$e_{vs+1} \geq e_{vs} + \sum_{i,j\in\mathcal{L}} E\,C_{ij}\, w_{vijs} - BC\sum_{h\in\mathcal{H}} b_{vhs} \qquad \forall v\in\mathcal{V},\ s\in\mathcal{S}\backslash\{\mathcal{S}^{\max}\} \qquad (18)$$

$$e_{vs} \leq BC \qquad \forall v\in\mathcal{V},\ s\in\mathcal{S} \qquad (19)$$

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$$
\begin{aligned}
b_{vhs} &\leq x_{vhs} && \forall v \in \mathcal{V},\ h \in \mathcal{H},\ s \in \mathcal{S} && (20)\\
n_v\Big(\sum_{i,j\in\mathcal{L}} \sum_{s\in\mathcal{S}} T_{ij}\, w_{vijs} + TB \sum_{h\in\mathcal{H}} \sum_{s\in\mathcal{S}} b_{vhs}\Big) &\leq T^{\max} && \forall v \in \mathcal{V} && (21)\\
\sum_{j\in\mathcal{L}} f_{ojk} - \sum_{i\in\mathcal{L}} f_{iok} &= g_k && \forall k = (o,d) \in \mathcal{K} && (22)\\
\sum_{i\in\mathcal{L}} f_{idk} - \sum_{j\in\mathcal{L}} f_{djk} &= g_k && \forall k = (o,d) \in \mathcal{K} && (23)\\
\sum_{i\in\mathcal{L}} f_{ilk} &= \sum_{j\in\mathcal{L}} f_{ljk} && \forall k = (o,d) \in \mathcal{K},\ l \in \mathcal{L}\setminus\{o,d\} && (24)\\
g_k &\leq D_k && \forall k \in \mathcal{K} && (25)\\
g_k &\geq 0 && \forall k \in \mathcal{K} && (26)\\
f_{ijk} &\leq \min(D_k, Q) \sum_{v\in\mathcal{V}} n_v \sum_{s\in\mathcal{S}} w_{vijs} && \forall i,j \in \mathcal{L},\ k \in \mathcal{K} && (27)\\
\sum_{k\in\mathcal{K}} f_{ijk} &\leq Q \sum_{v\in\mathcal{V}} n_v \sum_{s\in\mathcal{S}} w_{vijs} && \forall i,j \in \mathcal{L} && (28)\\
\sum_{i\in\mathcal{L}} \sum_{s\in\mathcal{S}} x_{vis} &\geq \sum_{i\in\mathcal{L}} \sum_{s\in\mathcal{S}} x_{v+1,i,s} && \forall v \in \{1,2,\dots,N_V - 1\} && (29)\\
y_h &\in \{0,1\} && \forall h \in \mathcal{H} && (30)\\
z_p &\in \{0,1\} && \forall p \in \mathcal{P} && (31)\\
x_{vis} &\in \{0,1\} && \forall v \in \mathcal{V},\ i \in \mathcal{L},\ s \in \mathcal{S} && (32)\\
w_{vijs} &\in \{0,1\} && \forall v \in \mathcal{V},\ i,j \in \mathcal{L},\ s \in \mathcal{S} && (33)\\
b_{vhs} &\in \{0,1\} && \forall v \in \mathcal{V},\ h \in \mathcal{H},\ s \in \mathcal{S} && (34)\\
f_{ijk} &\geq 0 && \forall i,j \in \mathcal{L},\ k \in \mathcal{K} && (35)\\
g_k &\geq 0 && \forall k \in \mathcal{K} && (36)\\
t_{vs} &\geq 0 && \forall v \in \mathcal{V},\ s \in \mathcal{S} && (37)\\
e_{vs} &\geq 0 && \forall v \in \mathcal{V},\ s \in \mathcal{S} && (38)\\
n_v &\geq 0 && \forall v \in \mathcal{V} && (39)
\end{aligned}
$$

Constraints (2) and (3) ensure that exactly NH (Stow&Charge Hubs) and NP (Temporary Port Terminal) are opened, respectively. Constraints (4) and (5) enforce that vessels cannot use locations where the corresponding facility have not been established. Constraints (6) and (7) are logical constraints stating that vessels must be at exactly one place and use exactly one arc in the network at each point in their route sequence. Constraints (8) – (12) connect the sailing arcs variables with the vessel visit variables. Constraints (13) enforce that each vessel's route is a closed loop. Constraints (14) – (16) manage the timing of vessel arrivals, ensuring proper timing and limits on maximum cycle time. Constraints (17) ensures that the battery state is preserved across multiple repetitions of the cyclic routes. Constraints (18) track cumulative energy consumption, accounting for energy used on arcs and resets when batteries are swapped. Constraints (19) ensures that cumulative energy consumption does not exceed battery capacity, forcing battery swaps when needed, while constraints (20) ensure that battery swaps can only happen when the vessel visits a S&C hub. Constraints (21) keep

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the total duration of all cycles completed by a vessel below the maximum duration of the planning period. Constraints (22) – (24) enforce the conservation of flow throughout the graph, so that no flow leaves or enters the network save for at origins and demands. Constraints (25) and (26) ensure that the amount of demand served does not exceed the estimated demand and is non-negative. Constraints (27) link the flow variables to the routing decisions, ensuring that flow can only occur on arcs that are serviced by vessels. Constraints (28) ensure that the total flow on any arc does not exceed the capacity of the vessels servicing that arc. Constraints (29) are symmetry-breaking constraints, requiring that vessels are ordered based on the number of locations they visit. Constraints (30) – (39) define the domains of all decision variables, i.e. all possible values they can take.

To keep the model more compact, some constraints here use non-linear terms where two variables are multiplied together. Since we want to use linear solvers, these constraints are reformulated to equivalent, linear constraints in the actual implementation.

2.2.6. FACILITY LOCATIONS

Potential locations for Stow&Charge- hubs and temporary port terminals were selected based on the analysis in D 3.1[1], and used as origin/destination (OD) pairs in the optimization model. The selection criterion for including an OD pair was that the estimated demand was at least 5 TEUs per week, that the OD pair does not have an existing transport service by waterways, and that the route involved CEMT IV[3] or smaller waterways. First, an AUTOFLEX service would only be attractive if there is sufficient demand to have high utilization of the transport capacity, and volumes of less than 5 TEUs per week would add complexity without any real impact on the end result. As the AUTOFLEX vessel has a capacity of 24 TEU, the required demand is significantly smaller than for traditional ships. Second, if there are existing waterway services between the OD pair, the modal shift potential is less than for OD pairs without waterway services. And finally, if the waterway is large, a transport service with a CEMT V or larger vessel would be preferrable to the CEMT II AUTOFLEX vessel due to efficiency and cost. Furthermore, the aim of the AUTOFLEX vessel is to reactivate the smaller waterways, further justifying our focus on these.

For the purposes of the model proposed in Section 2.2 the accuracy of the placement of each location does not need to be perfect, but in no case are these more than one hundred meters away from the locations identified as promising candidates, which are the following 10 locations: Breda, Delft, Den Haag, Eindhoven, Haarlem, Katwijk, Leiden, Moerdijk, Roosendaal and Utrecht. The four candidate locations for Stow&Charge hubs were Alphen aan den Rijn, Amsterdam, Rotterdam and ‘s-Hertogenbosch.

2.2.7. SAILING TIMES AND OTHER DURATIONS

Distances and sailing times between all locations were estimated using EuRIS’s route calculation API. This also provides number of locks and bridges that must be traversed. However, the optimisation model does not simulate each voyage with actual loading condition. Which means it cannot be determined what bridges need to be opened or not. Delays due to bridge opening are therefore not accounted for in the optimisation model but will be included in the simulations in chapter 4 . Estimated time lost from delays due traversing locks was set to 15 minutes per lock, which is on the lower end of the waiting times

[3] https://en.wikipedia.org/wiki/Classification_of_European_Inland_Waterways

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observed in an analysis done on a capacity analysis on larger canals in Flemish and Dutch regions[2].

Vessels are assumed to operate with a maximum sailing speed of 7 km/h for all sailing legs. This equals the speed limit on narrower (CEMT II) canals and was chosen because our aim is to emphasize underutilized waterways rather than to compete on the larger canals.

Time spent at each terminal stop depends on several operational and logistical factors, including mooring and unmooring operations, cargo handling, berth availability, and possible delays. Because this model does not explicitly track the number of containers loaded or unloaded at each stop, we represent port time using a fixed value per terminal visit. In small inland waterway operations, the number of containers handled per call is typically modest and relatively stable, meaning that a fixed handling time has limited influence on the strategic planning outcomes. We assume that the average terminal call will handle 10 containers loaded and unloaded, which according to a previous study using similar reach stackers as intended in the AUTOFLEX case [3] will take approximately one hour.

Specific timing of actions is not considered in this model, and thus infrastructure opening hours are not included. Facilities are assumed to be open when the vessel arrives.

2.2.8. VESSEL DATA

Vessel data were based on results from work package 4, including vessel dimensions, estimated energy use and battery capacities.

2.3 TRANSPORT VOLUME SCENARIOS

Transport data is available based on geographical areas, or regions, called Nomenclature of territorial units for statistics (NUTS) regions[4]. There are three levels of NUTS regions where NUTS 1 are major socio-economic regions, and NUTS 3 are small regions. Transport data on NUTS level 3 are hence the most fine-grained data available. In the Netherlands, which is the focus of our investigations, there are 40 NUTS 3 regions. Open datasets on NUTS level 3 are hard to come by, however, Fraunhofer ISI shared their Synthetic European road freight transport flow data [5] from the ETISplus project, with the AUTOFLEX project. This data set is the basis of work.

2.3.1. DATA SOURCE

To evaluate the expected throughput of the transport network, an estimated demand between each pair of candidate terminals had to be calculated. To do this, data from ETISplus 2010 was used, which provides annual freight volumes between European regions on NUTS3 level. Since the goal is to replace road transport, we used data from the table on road transport in the harmonized dataset.

The data set does not fit directly into our model for a number of reasons. We are dealing with terminal candidates, not regions, and not all cargo volumes in the ETISplus dataset are relevant for our study. The following transformation was applied to adapt the ETISplus data set to our case, where D_{ij} represents estimated demand between nodes i and j, and V_{rsc} is the input from the ETISplus dataset, the historical transport volumes between regions r and s of cargo category c.

$$D_{ij} = \sum_{r\in R}\sum_{s\in R}\sum_{c\in C} V_{rsc} \cdot \alpha_{rs} \cdot w_{ri}{}^{OUT} \cdot w_{sj}{}^{IN} \cdot \beta_c \cdot \gamma_{ij} \cdot \rho \cdot \tau$$

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R is the set of all regions, and C is the set of all cargo categories. The various parameters are explained in the following subsections.

2.3.2. INCLUDED REGIONS

From the full ETISplus dataset, we include only freight between NUTS 3 regions that are deemed relevant. Eleven regions contain one or more candidate hub or terminal locations: NL310 Utrecht, NL324 Haarlem agglomeration, NL329 Greater Amsterdam, NL332 The Hague, NL333 Delft and Westland, NL337 Leiden and Bollenstreek, NL33B East South Holland, NL33C Rijnmond, NL411 West North Brabant, NL413 North-East North Brabant, and NL414 South-East North Brabant. A further six regions are adjacent to regions containing candidate terminals, and freight to and from these can plausibly be consolidated at a nearby terminal: NL323 IJmond, NL325 Zaanstreek, NL328 Alkmaar and surroundings, NL327 Het Gooi and Vechtstreek, NL33A South South Holland, and NL412 Mid North Brabant. Flows with an origin or destination outside these 17 regions are excluded, since they would require extensive road pre- and end-haulage which makes them unlikely candidates for shifting to the AUTOFLEX network.

2.3.3. CONTAINERIZATION RATES

Since we only want to include cargoes which are suitable for containerized freight, we filter the data based on the freight categories they are assigned in the ETISplus dataset. We thus exclude cargo which are typically handled in bulk (e.g., coal, ores, liquids, etc.) as well as categories where one unit will typically not fit or is otherwise unsuitable for container transport (e.g., heavy machinery, cars, etc.). There is not always a clear binary yes/no answer to the question of whether a goods category is suited for containerization or not. Thus, we have applied a categorization where we divide the different cargo types into High, Medium, Low or None as a measure of their suitability for containerization. The assignment of categories is found in Table 1. In the input for the optimization model, these categories translate into 100 %, 50 %, 25 % and 0 % of the historic volumes being used in the prediction of future transport demands. These numbers are reflected in the demand calculation formula as β_C.

Goods category	**Degree of containerization**
GT01 - Agriculture & forestry	Medium
GT02 - Coal & petroleum (crude)	None
GT03 - Metal ores & mining	None
GT04 - Food products	High
GT05 - Textiles & leather	High
GT06 - Wood & paper products	Medium
GT07 - Refined petroleum	None
GT08 - Chemicals & plastics	Medium
GT09 - Non-metallic minerals	Low
GT10 - Metals & fabricated metal	Low
GT11 - Machinery & equipment	High
GT12 - Transport equipment	Medium

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GT13 - Furniture & manufactured goods	High
GT14 - Waste & secondary materials	Medium
GT15 - Mail & parcels	High
GT16 - Empty containers & pallets	High
GT17 - Household removals & baggage	None
GT18 - Grouped goods	High
GT19 - Unidentifiable goods	Medium
GT20 - Other goods n.e.c.	Medium

Table 1: Containerization rates for all goods categories

2.3.4. REGIONAL MODAL SHIFT POTENTIAL FACTOR

Not all historic transport volumes are likely to be candidates for being shifted from road transport to the AUTOFLEX transport network, whether or not a feasible waterborne route exists. We therefore apply a regional modal shift potential factor, denoted α_{rs}, representing the proportion of the existing road-based freight flow between regions r and s that can realistically be transferred to the AUTOFLEX network.

The modal shift potential plays a crucial role in ensuring that the generated demand matrix reflects realistic system adoption rather than theoretical maximum capacity. By scaling down the historical road transport volumes, the model avoids overestimating the achievable impact of the proposed transport network. At the same time, the parameter can be varied across scenarios to explore how different assumptions regarding market uptake and policy support influence the resulting network design.

Providing realistic estimates for modal shift potential for each pair of regions individually is beyond the scope of this model development. To choose a realistic value for α_{rs}, we draw on Jonkeren et al. [6], who quantify the modal shift potential (MSP) of road freight on four international freight corridors in North-western Europe, defined as the share of road-transported weight that could be carried at a minimum of 10 % lower private cost by rail or inland waterways. They report MSPs between 35 % and 55 % depending on market segment and year, and for the container segment an MSP of 36 % for 2018, which they consider representative for the coming years. We adopt α_{rs} = 0.36 as our baseline and use this for all combinations of regions.

2.3.5. ALLOCATION OF REGIONAL DEMAND TO TERMINAL LOCATIONS

Another important step is the allocation of each region's transport volumes to specific candidate terminals. This is achieved through the introduction of weighting factors ${w_{ri}}^{OUT}$ and ${w_{sj}}^{IN}$, which represent the share of the transport demand originating from region r that is assigned to terminal i, and the share of the demand destined for region s that is assigned to terminal j, respectively. These weights serve as a disaggregation mechanism, transforming region-level flows into a consistent set of origin–destination pairs between candidate terminals. In some cases, there are multiple candidate terminals within the same region, whereas other places a single candidate terminal could possibly handle demand from several nearby regions. Terminals located centrally in the region and/or closer to major logistics hubs or industrial clusters are assumed to capture a larger share of the regional demand, while more peripheral terminals are assigned lower weights. These weights were assigned based on the approximate population in each terminal's catchment area and its centrality within the region, so that terminals serving larger and more central population bases receive proportionally higher shares of the regional volumes.

2.3.6. AUTOFLEX COMPETITIVENESS FACTOR

Many of the origin/destination pairs will already have good coverage by inland waterways, such as the ones located near the major CEMT V canals. The volumes transported there are not the main target of the proposed new transport network, since we consider it unlikely that the AUTOFLEX concept will be competitive in these areas against larger, established transporters who have the benefits of economies of scale and existing infrastructure. To eliminate such volumes from our model's set of demands, we apply a binary filter γ_{ij} which states whether the demand between terminals i and j should be included in the model input.

2.3.7. UNIT CONVERSION FACTOR

Since the background data are measured by weight, we had to convert this to container equivalents. Global Logistics Emissions Council Framework [7] suggest that an average of 10 tons per TEU can be assumed in calculations of the transport activity. We therefore apply a conversion factor ρ = 10 tons per TEU in our volume calculations.

Weight per container will naturally vary for different cargo types, however, this is not accounted for in the optimisation model.

2.3.8. TEMPORAL SCALING FACTOR

In order to account for the fact that the available demand data are from 2010, we apply a temporal scaling factor τ. Numbers from Statistics Netherlands (CBS)[8] indicate an increase in road freight transport from 690 million tonnes in 2013 to 746 million tonnes in 2024, an average annual growth of approximately 0.71 %. Extrapolating this trend across the full 2010–2026 period yields a cumulative growth of roughly 12 % This reflects a modest but steady expansion of Dutch road freight demand in tonnes over the period, and we therefore use $\tau = 1.12$ in order to account for the changes since the historic transport volumes data were collected.

2.3.9. FINAL VOLUMES

Finally, we filter out volumes which add up to less than 5 containers per week, since such low volumes will not have any real impact on the overall network design and would just add noise to the model input. We end up with the following 96 volumes which serve as input to our optimization model, given her organised in tables per location with connections and in and outbound TEU per year. Notice that this way of presenting the estimated volumes repeats some connections. A listing with single entry per connection is found in appendix 5.1 .

Table 2: Estimated yearly demand Alphen aan den Rijn

Connected location	Outbound TEU	Inbound TEU
Amsterdam	5 318	2 646
Delft	1 119	1 017
Den Haag	9 045	3 078
Haarlem	4 248	1 756

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Katwijk	976	1 364
Leiden	2 278	3 184
Total	22 985	13 046

Table 3: Estimated yearly demand Amsterdam

Connected location	Outbound TEU	Inbound TEU
Alphen aan den Rijn	2 646	5 318
Delft	2 397	2 439
Den Haag	3 035	1 987
Katwijk	2 654	2 724
Leiden	6 192	6 356
Total	16 925	18 825

Table 4: Estimated yearly demand Breda

Connected location	Outbound TEU	Inbound TEU
Delft	756	1 028
Den Haag	3 358	1 839
Eindhoven	13 598	18 863
Katwijk	1 078	0
Leiden	2 516	943
Moerdijk	0	11 216
Roosendaal	48 538	0
's-Hertogenbosch	63 683	70 125
Total	133 527	104 014

Table 5: Estimated yearly demand Delft

Connected location	Outbound TEU	Inbound TEU
Alphen aan den Rijn	1 017	1 119
Amsterdam	2 439	2 397
Breda	1 028	756
Den Haag	1 908	4 682
Eindhoven	0	1 337
Haarlem	930	1 369
Katwijk	654	572
Leiden	1 527	1 334
Roosendaal	885	703
Rotterdam	24 286	28 155
Total	34 674	42 423

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Table 6: Estimated yearly demand Den Haag

Connected location	Outbound TEU	Inbound TEU
Alphen aan den Rijn	3 078	9 045
Amsterdam	1 987	3 035
Breda	1 839	3 358
Delft	4 682	1 908
Eindhoven	632	644
Haarlem	2 286	4 699
Katwijk	3 131	3 644
Leiden	7 306	8 504
Roosendaal	1 347	2 075
Rotterdam	27 790	32 544
's-Hertogenbosch	2 815	6 434
Utrecht	8 012	6 569
Total	64 905	82 460

Table 7: Estimated yearly demand Eindhoven

Connected location	Outbound TEU	Inbound TEU
Breda	18 863	13 598
Delft	1 337	0
Den Haag	644	632
Katwijk	0	640
Leiden	0	1 494
Moerdijk	2 016	1 202
Roosendaal	9 071	5 408
Rotterdam	21 683	14 267
's-Hertogenbosch	60 879	82 574
Utrecht	11 843	9 974
Total	126 336	129 788

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Table 8: Estimated yearly demand Haarlem

Connected location	Outbound TEU	Inbound TEU
Alphen aan den Rijn	1 756	4 248
Delft	1 369	930
Den Haag	4 699	2 286
Katwijk	3 068	2 140
Leiden	7 159	4 994
Total	18 052	14 598

Table 9: Estimated yearly demand Katwijk

Connected location	Outbound TEU	Inbound TEU
Alphen aan den Rijn	1 364	976
Amsterdam	2 724	2 654
Breda	0	1 078
Delft	572	654
Den Haag	3 644	3 131
Eindhoven	640	0
Haarlem	2 140	3 068
Roosendaal	0	995
Rotterdam	9 169	5 625
Total	20 254	18 182

Table 10: Estimated yearly demand Leiden

Connected location	Outbound TEU	Inbound TEU
Alphen aan den Rijn	3 184	2 278
Amsterdam	6 356	6 192
Breda	943	2 516
Delft	1 334	1 527
Den Haag	8 504	7 306
Eindhoven	1 494	0
Haarlem	4 994	7 159
Roosendaal	820	2 322
Rotterdam	21 394	13 124
's-Hertogenbosch	1 140	1 001
Utrecht	2 569	0
Total	52 731	43 427

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Table 11: Estimated yearly demand Moerdijk

Connected location	Outbound TEU	Inbound TEU
Breda	11 216	0
Eindhoven	1 202	2 016
Roosendaal	9 169	9 169
Total	21 587	11 185

Table 12: Estimated yearly demand Roosendal

Connected location	Outbound TEU	Inbound TEU
Breda	0	48 538
Delft	703	885
Den Haag	2 075	1 347
Eindhoven	5 408	9 071
Katwijk	995	0
Leiden	2 322	820
Moerdijk	9 169	9 169
's-Hertogenbosch	17 912	22 528
Total	38 585	92 358

Table 13: Estimated yearly demand Rotterdam

Connected location	Outbound TEU	Inbound TEU
Delft	28 155	24 286
Den Haag	32 544	27 790
Eindhoven	14 267	21 683
Katwijk	5 625	9 169
Leiden	13 124	21 394
Total	93 715	104 322

Table 14: Estimated yearly demand s'-Hertogenbosch

Connected location	Outbound TEU	Inbound TEU
Breda	70 125	63 683
Den Haag	6 434	2 815
Eindhoven	82 574	60 879
Leiden	1 001	1 140
Roosendaal	22 528	17 912
Total	182 662	146 428

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Table 15: Estimated yearly demand Utrecht

Connected location	Outbound TEU	Inbound TEU
Den Haag	6 569	8 012
Eindhoven	9 974	11 843
Leiden	0	2 569
Total	16 543	22 424

2.4 TEST CONFIGURATIONS

The model was implemented in Java 21 using Google OR-Tools, with SCIP as the underlying mixed integer program solver. The tests were performed on a computer with an Intel Ultra 7 265U, 2100 Mhz processor with 12 cores and 32 GB RAM. Each test was run until proven optimality, or until the maximum time of 10,800 seconds was reached.

2.5 RESULTS

The model was tested on the scenario described in section 2.3 . The central parameter studied was that of fleet size to analyse the effect of adding extra transport capacity to the network.

2.5.1. SUMMARIZED RESULTS

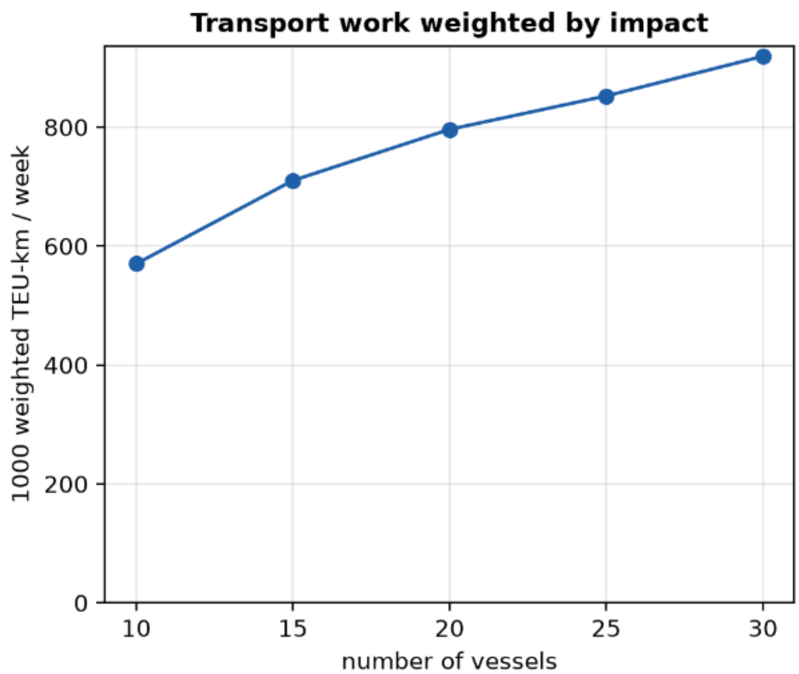

Figure 1: Objective function for various fleet sizes

Figure 1 shows how the objective function of transport work weighted by impact is handled by the AUTOFLEX network. As is to be expected, there is a somewhat diminishing return as more and more vessels are added. Note that even if the change in slope might not seem very large, we can tell that the first 10 vessels added to the network are able to deliver nearly

600,000 impact-weighted TEU-kms per week, while the next 10 (the increase in objective function moving from 10 to 20 vessels) constitute a little more than 200,000. This indicates that the most impactful cargoes are dealt with by the first vessels, and the value added per vessel decreases rapidly at the beginning.

The total demand served is shown in Figure 2. This shows a slight increase in served demand per vessel between 20 and 25 vessels, even if the contribution to the objective function per vessel is decreasing in the same interval. This is explained by the fact that the more demands with the highest impact weights have already been handled, and so the extra work performed by each added vessel has less of an impact on the objective function value.

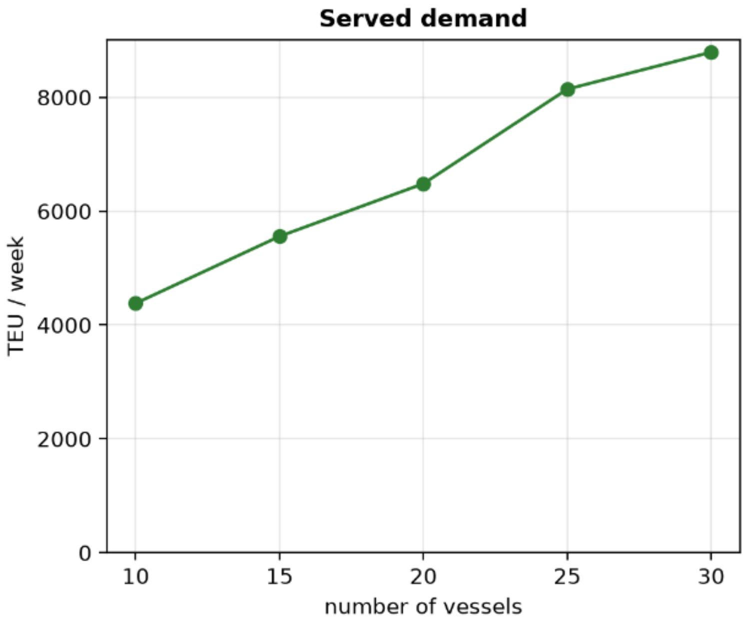

Figure 2: Demand served for various fleet sizes

2.5.2. SOLUTION COMPARISON

This section presents the results of solving the optimisation problem for an increasing fleet size. For each fleet size the impact on served transport demand is discussed and how that correlates to the objectives that were sought through the formulated optimisation problem.

10 vessels

Figure 3: Fleet of 10 vessels, transport intensity

For the case with 10 vessels, we note that most of the demand served is in a compact cluster of short, dense corridors in the southwestern Randstad, between Rotterdam and Delft, Den Haag and Leiden. A single vessel is assigned to a route between Rotterdam and Utrecht, and there are also routes visiting Amsterdam, Katwijk and Alphen aan den Rijn.

15 vessels

Figure 4: Fleet of 15 vessels, transport intensity

The 15 vessels case network layout is very similar to that of 10 vessels and can be described as “more of the same”. Some of the extra capacity is used on transport reaching Amsterdam and Alphen aan den Rijn, the area northwest of Rotterdam increases the most.

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20 vessels

Figure 5: Fleet of 20 vessels, transport intensity

With 20 available vessels, we see for the first time that some of the demand to Breda, 's-Hertogenbosch and Eindhoven is handled. This indicates that most of the demands in the Haarlem/Den Haag/Rotterdam corridor has already been handled at this point.

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25 vessels

Figure 6: Fleet of 25 vessels, transport intensity

The extra vessels in the 25 vessels seem to be almost exclusively assigned to the demand between Breda and 's-Hertogenbosch, this is likely the most beneficial not already dealt with on lower fleet sizes. We also see the first use of the links between Amsterdam and Utrecht and between Alphen aan den Rijn and Utrecht.

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30 vessels

Figure 7: Fleet of 30 vessels, transport intensity

With 30 vessels, it seems like we have reached the point where all beneficial demands are being dealt with.

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2.5.3. RESULTS DISCUSSION AND CONCLUSION

Given that this model is intended as a strategic decision-support tool and does not represent all operational constraints in detail, the transport volumes reported here should be interpreted as upper-bound estimates prior to operational validation. Nevertheless, the results establish a baseline for the simulation study presented in Chapter 4, where the operational feasibility of the proposed network configurations is assessed in greater detail.

The results indicate that with a limited number of vessels available, the model will prioritize servicing the area between Rotterdam and Den Haag/Leiden. This is consistent with expectations given that these are high-impact areas. With increasing capacity, the network expands into long-haul corridors to Noord-Brabant exactly when the high-impact demand is saturated. The expansion is routed through the hub at 's-Hertogenbosch, whose battery-swapping capability makes the long legs feasible and the terminals that remain unused at Moerdijk and Roosendaal are precisely those whose demand relations offer the least weighted transport work. The corridor structure does not radically change with fleet size; larger fleets extend and thicken the network rather than rearranging it. This indicates that the solutions capture a consistent and robust underlying structure. We conclude that the model does a good job of creating a representative transport network for a given fleet size: the resulting flow maps in Figure 3 to Figure 7 can be read as recommendations of where a fleet of a given size should operate, and the diminishing marginal returns visible in Figure 1 provide a basis for dimensioning the fleet itself. With improved accuracy in the input data, this model could give valuable insight for a decision maker looking to establish a similar transport network and provide guidance as to which locations to target and approximately how much capacity should be invested in to maximize potential outputs.

2.6 KNOWN SHORTCOMINGS AND SIMPLIFICATIONS

The model presented in this chapter is intended to support strategic decisions on infrastructure placement and fleet dimensioning, and its level of detail is chosen accordingly. A number of simplifications follow from this scope, and the results should be interpreted with these in mind.

2.6.1. AGGREGATED TREATMENT OF TIME

The model tracks time only along each vessel's route cycle; cargo itself is not followed through time. Demand is considered served as long as sufficient vessel capacity is provided on the arcs it traverses during the planning period, without regard to when within the period that capacity is available. Consequently, lead times and delivery deadlines are not represented. Transhipments between vessels are effectively free and instantaneous: the model imposes no transfer time, handling capacity, or storage constraints at hubs and terminals. In practice, multi-leg shipments would incur waiting time and handling effort at each transfer point, so the throughput of routings that rely on transhipment will probably be overly optimistic.

2.6.2. SIMPLIFIED OPERATIONS

Several operational quantities are represented by fixed averages. Port times are constant per port call regardless of the number of containers actually handled, and lock passages are approximated by a fixed time rather than actual lock operations and queueing. Delays caused by bridge openings are not represented in the optimization model at all, since the model does not determine which bridges must be opened; these effects are instead covered by the simulations in chapter 4. Sailing speed is held constant at on all legs, which deliberately understates feasible speeds on larger waterways. Infrastructure is assumed to be available around the clock, with no opening hours, berth capacity limits, or congestion. Similarly, battery swaps are assumed to always be possible at a hub, implicitly assuming that a charged battery is available whenever a vessel arrives.

2.6.3. ECONOMIC SCOPE

The model maximizes impact-weighted transport work and does not consider costs. The numbers of hubs, terminals and vessels are inputs rather than outcomes of economic trade-offs, and the model does not distinguish between solutions of different cost as long as they achieve the same modal shift impact. Cost-effectiveness must therefore be assessed separately, using the candidate configurations produced here as a starting point.

2.6.4. CONCLUDING REMARKS

None of these simplifications affects the model's core purpose: identifying which locations and corridors a network of a given size should concentrate on. They do, however, mean that the reported throughput figures are best regarded as upper bounds on what the corresponding physical system could achieve, and that detailed operational planning such as scheduling, transhipment coordination, and battery logistics remain to be addressed with more fine-grained models.

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3 THE CONCRETE LOCATIONS OF NETWORK NODES

3.1 INTRODUCTION

In chapter 2, the analysis concluded on a network between cities and larger areas. To develop the AUTOFLEX transport system, and to do the impact quantification in WP5, it is necessary to identify concrete locations for the TPTs and derive proposals for concrete realisations. For some cities the potential transport demand might require more than one TPT, and it is possible that a given city does not offer any feasible location for establishing a TPT.

This chapter investigates each identified city to narrow down to concrete locations for TPTs and proposes TPT realisations based on building blocks from D3.1 [1].

The analysis method is presented in section 3.2 . The investigations leading to concrete TPT location proposals is given in section 3.3 and it should be noted that in some cases, more than on location is eligible. The proposed locations are theoretical as it is beyond the scope of this work to contact the local stakeholders and discuss the possibility of establishing a TPT. Instead, we assume that this is solvable through a negotiation and contract process. Fortunately, most investigated areas have more than one feasible TPT location such that an actual realisation initiative would have multiple options in case the preferred location cannot be used for reasons such as failure to reach agreements. As elaborated in D3.1 [1], we try to account for this uncertainty by including permits and contracts as a rating category. Section 3.4 presents the proposed realisation for each TPT, creating the foundation for later cost and performance studies. Finally, section 3.5 discusses the location of the Stow&Charge hubs.

3.2 METHOD FOR EVALUATION TPT LOCATIONS

Based on the transport demand for each Model Shift Cluster (MSC) city or region, the general area where a transshipment site is needed is identified. An area in this context refers to the numbered areas identified in the introduction of each "city-analysis" in D3.1 [1]. If that area does not have container transshipment services in place, it is scrutinized for identification of a suitable TPT location. This will be based on D3.1 and the discussion of locations therein, with supplementing analysis where D3.1 might not cover the area, lacks information, or additional locations are found. Then, the TPT applicability indicator (I_A) from D3.1 [1] is used to score the reduced set of location candidates to choose the most suitable location:

$$I_A = \frac{1}{N} \sum R_i$$

Where N is the number of evaluated criteria, and R_i is the score of criteria number i. This score is used to compare locations within the same area. If scores are identical or close to identical, an evaluation of cost and impact on businesses on the location is used to make the decision.

The evaluation of each criterion is sometimes complicated due to lack of available information. In such cases a judgment is made based on discussing the information that is available and relative evaluation against the other candidates. Uncertainty might also lead to reduced scores. There are also cases where it is hard to determine the score of a criterion (e.g. both +2 and +1 could be argued). In such cases the analysis tries to balance such uncertainty out by looking to evaluation of other criterion for the same location. If more than one criterion are on the tipping point, one is given the lower option and the other the higher option to balance out.

Once a location is chosen, the TPT concept to be applied at the location is derived based on the TPT building blocks defined in D3.1. This includes a discussion on what changes and the investments that are required.

S&C locations are chosen based on the rating given in[1], and on providing sufficient coverage to navigate the routes connecting network nodes.

3.3 IDENTIFYING THE TPT AREAS

This section will choose the locations where the AUTOFLEX transport system will deploy a TPT concept to enable cargo transshipment. While it could be feasible to establish a TPT within each area investigated in [1], this would imply a quite significant investment. Furthermore, it would reduce the volume moved through each TPT. Hence, for the purpose of this report, we assume that a limited number of TPTs are needed to cover one city or region. Depending on the size of the city and freight demand, one or more TPTs are assumed to provide sufficient coverage and short last mile connection.

3.3.1. MSC CLUSTER 1: HAARLEM

Haarlem is close to Amsterdam and as such it could serve as an inland port connecting the AUTOFLEX transport system to the deep sea terminals of Amsterdam.

The Haarlem area is split into two sub-areas in [1], even though both are part of an almost continuous industrial area adjacent to the waterway. The estimated road freight with transfer potential to IWT is high at approximately 250-300 TEU in- and outbound weekly (see section 2.3.9). This motivates for establishing a TPT with high capacity, or possibly two, within the areas studied in [1]. Since this area stretches along the canal from south to north, we will compare potential TPT locations in the northern part (area 1) and southern part (area 2) separately.

3.3.1.1. *Northern industrial area of Haarlem (area 1)*

The northernmost part of the industrial area contains three locations identified in [1] as candidates for establishment of TPTs.

- Location 1: Brownfield under development, former Prins Staal. While the site was discussed as a potential TPT location in [1], the ongoing development at the site warranted further investigations. Unfortunately, it turns out that the site has been bought by property developers and that the plans are to build a business centre building. This means the brownfield will not be available as a TPT, and the remaining area is uncertain. For this reason, the site is not investigated further.
- Location 2: Smaller Brownfield south of the old Prins Staal. This smaller brownfield appears unchanged since 2012. Images from 2007 reveals that it was part of a bulk terminal that received cargo vessels. The bulk terminal has been demolished and repurposed, except for this remaining brownfield. No plans for the brownfield have been found through our investigation.
- Location 3: Identified as sewing machine factory or distribution centre in [1]. While our investigation has not definitely proven it, it appears from streetview that it is a sewing machine factory with a significant inventory of sewing machines that appears ready for shipping.

Starting with location 2 the brownfield appears to be a good TPT candidate with ample space for storage, cargo handling, and transhipment to trucks for hinterland. Quay length is approximately 57m and width 45-65m. It was previously part of a bulk terminal with confirmed port calls. The only challenge is that it has been left unused since at least 2012 with last confirmed active use in 2007 (no available imagery between these years). This means that growth has been left free for more than 14 years and that upgrades will be needed. How much work and cost this will require is highly uncertain. The final score is 2.5, which is a rather high score as the analysis in subsequent section will show.

Moving to location 3, it is likely a sewing machine factory that could be an anchor customer. The quay appears in good condition, is paved, and of sufficient size for free movement during cargo handling, some storage, and more than long enough for the AUTOFLEX vessel. Length is 78 m and width 15 m. The only challenge is that a circular hinterland connection might require some minor modification of the ground to somewhat widen the paved area at the northern corner of the building. Furthermore, that imagery does not confirm vessels moored at the site, indicating that bollards and fenders might need upgrades. The total rating is 2.63, which is close to that of location 2 but slightly higher. This is due to the better quay surface condition and gated access, both conditions lowering the bar for opening a TPT. The sewing machine factory is chosen as the potential TPT location for northern Haarlem industrial area.

Criteria	**Brownfield (location #2)**	**Sewing machine factory (location #3)**
Google earth link	Brownfield	Factory
R1 – Quay surface *(Physical usability of working platform; whether paved, structurally sound, free of vegetation and debris)*	+2 Old imagery shows that the site was part of a bulk terminal and that vessels have moored here. Ground is not paved but historically supported high loads. It is overgrown and needs clearing of brush and rubble, probably some levelling.	+3 Appears intact, minor growth of grass at the quay front, area appears paved and cars can be observed in imagery. Minor groundwork, if any, needed.
R2 – Quay clearance *(Unobstructed lifting and movement envelope for container handling between vessel and quay)*	+3 Space is more than sufficient, but minor work needed to clear light fencing and some rubble	+3 No observed obstructions and space should be more than sufficient to provide a movement envelope for container handling
R3 – Quay access *(Continuous and workable route between transhipment point and storage or handover area)*	+3 Site offers room for temporary storage, no hindrances between quay front and the area	+3 Site offers room for temporary storage, no hindrances between quay front and the area
R4 – Ship-terminal interface *(Ability of vessel to safely moor and be attended along the quay)*	+2 Last observed moored vessel is 2005. Since 2012 the site appears unused and left to growth and vegetation. Work will be needed to provide a good ship-terminal interface but should not be that extensive.	+2 The quay appears to be in good condition; however, no vessel can be observed at the site in the available imagery. This means that it could be necessary to install bollards and fenders.
R5 – Terminal-hinterland interface *(Ability of trucks and*	+3 While some groundwork is needed to clear growth etc. This was deducted in previous	+2 The quay width is 15m while a semi-truck need at least 25m width to make a U-turn. Site is

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road vehicles to reach, circulate and depart from handover area)	criteria evaluation. Apart from that, the site has ample space for creating a circulation pattern and connection to road	connected to road and is paved from road all the way to the quay front. There could be an option to create a circulation pattern from the road to the quay and around the building. This likely requires some brush clearing and paving to ensure wide enough passage and could limit storage space. The alternative is to back the truck into the quay area, which is less efficient.
R6 – Public interface *(Management of interactions between TPT operations and public roads, paths and spaces)*	+2 Existing lightweight fencing might be sufficient, but a gate and access road is missing	+3 fenced off and gated
R7 – Legal/contractual *(Lawful basis and stakeholder permissions for TPT operations at the site)*	+2 Unknown ownership implies some work to identify owner and negotiate a deal. Regulation should be feasible considering historic use as bulk terminal.	+2 While the factory is a potential anchor customer and a single point contract is feasible; regulation plans are more uncertain since no usage for ship calls have been identified.
R9 – Transport demand *(Credible and sufficient customer base for modal shift to IWT)*	+3 While the site does not have a clear anchor customer, the general area has high demand and across the road a storage site is located where imagery shows Temporary container storage in 2023.	+3 Potential anchor customer and generally high demand area
I_A	2.5	2.63

3.3.1.2. *Southern industrial area of Haarlem (area 2)*

The southernmost part of the industrial area contains three locations identified in D3.1 [1] as candidates for establishment of TPTs.

- Location 1: Concrete manufacturer with adjacent brownfield. While the concrete manufacturer is discussed in D3.1, it is concluded that the adjacent brownfield is the preferred option as the concrete manufacturer quay is blocked off by bulk compartments. The brownfield will be investigated further as location 1.
- Location 2: Waste and recycling centre with long quay and potential for local storage if some changes to the site layout is done
- Location 3: Waste and recycling centre, seemingly steel recycling. While the area has a long and workable quay, it has some properties that leads us to rule it out as a TPT candidate. First, the area has very little free space, and what free space is there is needed for vehicles to have access to various parts of the recycling centre. This means that storage at site would not be possible without significant impact on existing business and operations. Second, browsing the available imagery in google earth

(2005-2025), it seems that the quay is always occupied by vessels delivering or loading cargo.

Starting with location 1 the brownfield appears to be a good TPT candidate with ample space for storage, cargo handling, and transhipment to trucks for hinterland. Quay length is approximately 62m and width 50m. It was previously part of a bulk terminal with confirmed port calls. The only potential challenges are that it appears to be unused since 2022-2023, showing signs of beginning growth, and that ownership is unclear which might complicate contractual agreement. The final score is 2.75, which is a very high score.

Moving on to location 2, waste recycling centre, it offers a long quay with 150m accessible quay front. The area is large but actively used in daily business operations. Challenges mainly relate to available space for several TPT functions. For a sufficient movement envelope during vessel loading/offloading, for storage of containers, and for a circulation path for trucks delivering or picking up containers. It could be possible to re-arrange the layout of the site, but operational impacts are likely, which may hinder a possible cooperation and contractual agreement. The final score is 2.4.

The best suited location for a TPT in the southern part of the Haarlem industrial area is the Brownfield. It is therefore chosen as the potential TPT location in southern Haarlem.

Criteria	**Brownfield (location #1)**	**Waste recycling centre (location #2)**
Google earth link	Brownfield	Waste recycling
R1 – Quay surface *(Physical usability of working platform; whether paved, structurally sound, free of vegetation and debris)*	+2 Trucks observed on the area as late as 2021. Area is paved, or bricked, but there is growth that needs to be cleared. A structure/ramp, probably used during bulk off-loading by trucks, occupies a smaller part of the area.	+2 Paved, observed vehicles and containers on site. Structurally sound but appears to have little available space without re-arranging layout. Which would impact current business.
R2 – Quay clearance *(Unobstructed lifting and movement envelope for container handling between vessel and quay)*	+3 Area has 62m long quay front and is 50m wide. The only structure is the centrally placed ramp, and some minor debris. There is good space for accessing the entire cargo hold of the AUTOFLEX vessel.	+2 Area has an approximately 150m long quay. Parts of it is blocked by container like objects, and the remaining part is narrow due to wate containers. Some re-arrangement of layout would be needed to ensure a good movement envelope
R3 – Quay access *(Continuous and workable route between transhipment point and storage or handover area)*	+3 Area has 62m long quay front and is 50m wide. The only structure is the centrally placed ramp, and some minor debris. There is good space for a workable route between transhipment point and	+2 Somewhat uncertain. The best candidate for storage seems to be the parking lot. Which then would require some rearrangement of layout. Some objects would have to be moved to allow workable route

	storage, which would be within the area.	between transhipment and storage.
R4 – Ship-terminal interface *(Ability of vessel to safely moor and be attended along the quay)*	+3 Last observation of moored vessel is 2018, imagery does not indicate damages since then.	+3 last observation of moored vessel is 2007. However, the site appears to be well kept and actively used continuously since then.
R5 – Terminal-hinterland interface *(Ability of trucks and road vehicles to reach, circulate and depart from handover area)*	+3 Area has 62m long quay front and is 50m wide. The only structure is the centrally placed ramp, and some minor debris. There is good space for a circular route on site, which is also visible in historic google earth images	+2 Should be possible to create a circulation path. But this needs to be considered as part of re-arranging layout.
R6 – Public interface *(Management of interactions between TPT operations and public roads, paths and spaces)*	+3 Gated access	+3 Gated access
R7 – Legal/contractual *(Lawful basis and stakeholder permissions for TPT operations at the site)*	+2 Appears to be unused, but previously part of the bulk terminal. This indicates that regulations plans should be ok (no development plans found). Unknown ownership makes it hard to evaluate feasibility of contract, but a one-party contract is likely.	+2 Is used for cargo related industry so regulation should be ok. However, the contractual agreement could be hard to achieve unless an integration with minimal operational impact could be found. This requires a good understanding of the business at site.
R9 – Transport demand *(Credible and sufficient customer base for modal shift to IWT)*	+3 general demand in area is high, but all cargo would be to hinterland customers requiring short truck haulage	+3 general demand in area is high, but most cargo would be to hinterland customers requiring short truck haulage.
I_A	2.75	2.4

3.3.1.3. *Conclusion*

Both the southern and northern areas have viable TPT locations. For a smaller capacity network, as a starting point, the sewing machine factory is chosen due to holding a potential anchor customer. Expansion can then include the brownfield in the southern industrial area.

3.3.2. MSC CLUSTER 2: LEIDEN (INCLUDING KATWIJK)

Leiden, being a large city with a high transport demand, and considerable customer clusters also in the outskirts, it is deemed necessary to establish at least two TPTs. This is both due to the cargo volumes, and to ensure that last mile distances for truck transport are minimized. For good geographical coverage, one TPT should be located to the West-Northwest of Leiden (katwijk), and one to East-Southeast. This means that a TPT should be placed at either location 1: *Leiden Heen Industrial Park* or 2: *Rijn canal Northwest of city centre*, and that a TPT should be placed in either location 4: *The waterway intersection between Oude Rijn & Rijn-Shiekanaal* or 5: *Leiden Zoeterwoude-Rijndijk*.

3.3.2.1. *North-west of city centre – Katwijk aan Zee*

To the northwest of Leiden, three potential areas for TPT deployment were identified in D3.1 [1]:

- **Area 1,** Heen Industrial Park, is situated along the Maandagse Wetering canal and the Oude Rijn in the town of Katwijk aan Zee, just northwest of the Leiden municipal boundary. It is a dedicated industrial park hosting a cluster of businesses directly at or near the waterfront, including building materials suppliers, sand and soil traders, and a cement contractor.
- **Area 2**, the Rijn Canal Northwest of city centre, lies further southeast along the Rijn canal and consists of a more mixed-use stretch of smaller businesses, contractors, and repair shops, with some waterfront access but more fragmented industrial activity compared to area 1.
- **Area 3,** the Rijn Canal West of city centre, is a smaller area split between a group of garages and car dealerships on one end and a boat and barge rental company on the other. While the boat and barge rental site has mooring facilities and some storage capacity, the waterfront is crowded, the transhipment area near the water is very limited, and there is no industrial customer base that could generate meaningful containerised freight volumes. Additionally, location 3 is right between location 1/2 and 4/5, so to get a good spread of goods, location 3 will not be considered moving forward.

Both locations at Heen Industrial Park and Rijn Canal Northwest have potential customer clusters to the north, west, south and southwest, and either could in principle host a TPT. Heen Industrial Park is preferred, however, as the higher density of waterfront-adjacent industrial customers and the more established quay infrastructure make it a more robust and self-contained foundation for a TPT.

Within Heen Industrial Park, a location at Joh Guyt by the Maandagse Weteringt canal is selected as the preferred site for a TPT. The site has a recently upgraded hard surface capable of handling heavy vehicles, demonstrated mooring capability confirmed by satellite imagery from 2019 and 2021 showing barges moored at the site, with the infrastructure suggesting it was designed to accommodate two barges simultaneously. The existing bulk operations are compatible with container handling under a shared use arrangement. The main challenges are the quay length of approximately 30-50 metres relative to the 55-metre AUTOFLEX vessel — which may require either repositioning of bulk compartments or a waterside mooring extension — and limited operational space requiring careful truck scheduling to avoid congestion.

The detailed analysis of Heen Industrial Park is included in Table 16 including all areas from deliverable 3.1 [1] with direct waterfront access and no immediate showstopper preventing further investigation. From the scores, **Joh Guyt (at the Maandagse Wetering canal) had the highest score, followed by Heidelberg Materials in second place.** The main difference between the two is the utilisation of the quay at Heidelberg Materials, where existing storage compartments and bulk crane directly occupy the quay, making a container-based TPT costly to implement. The two other locations being analysed (Joh Guyt at Oude Rijn and BMN) scored equally lowest, both constrained by vegetation and limited accessible quay area.

Three other locations identified in D3.1 [1] (Van Kempen Houthandel, Argos Jonker Katwijk and shipyard) were not taken forward to detailed assessment. Van Kempen Houthandel and Argos Jonker Katwijk were excluded as the waterway interfaces at both sites are currently blocked by piles and pilings, making vessel calls unfeasible without significant clearance works; additionally, the gas station site offers only 25 metres of quay length which is insufficient for the 55-metre AUTOFLEX vessel. The shipyard was excluded as the unpredictable and sporadic nature of ship maintenance operations is fundamentally incompatible with the reliable and timely logistics requirements of a TPT. As none of these three sites present a credible path to TPT deployment without resolving fundamental access or operational constraints, a full assessment was not warranted at this stage.

Table 16: TPT placement Analysis Katwijk

Criteria	**Joh Guyt (area 1 by Noordwijkervaart)**	**Joh Guyt (area 1 by Uitwateringskanaal)**	**Heidelberg Materials (area 1)**	**BMN (area 1)**
Google earth link	Joh Guyt	Joh Guyt	Heidelberg	BMN
R1 – Quay surface *(Physical usability of working platform; whether paved, structurally sound, free of vegetation and debris)*	+3 Recently upgraded hard surface designed for heavy cargo transhipment and large open waterfront area.	+1 Overgrown vegetation near waterfront and potentially compromised underground necessitate further investigation; only small accessible area where quay is not overgrown confirmed. Pavement condition is uncertain.	**+3** The concrete paved surface with a heavy truck operating on it confirms the surface is structurally sound and capable of handling heavy machinery	+1 Pavement with significant overgrown vegetation running along waterfront, which prevents immediate access. Pavement condition is uncertain.
R2 – Quay clearance *(Unobstructed lifting and movement envelope for container handling between vessel and quay)*	+3 Large open waterfront area at entrance to site; no obstructions to lifting container.	+2 No fixed overhead obstructions mentioned; floating platform suggested as primary handling approach due to limited accessible area rather than due to fixed obstructions	+2 Mostly open quay with no overhead obstructions and heavy vehicle operating freely at quay edge; however, storage compartments present on the quay itself which may obstruct parts of the working face and require relocation before full container handling	+2 Direct access to a lot of waterfront space. No big obstacles for lifting operations, except vegetation.

			envelope is available	
R3 – Quay access *(Continuous and workable route between transhipment point and storage or handover area)*	+2 Open quay area; coordination with Joh Guyt operations needed; truck arrival planning required to avoid congestion	+2 Small stretch of road leading to quay confirmed; careful truck arrival planning needed to avoid obstruction and congestion; route exists but requires active management	+1 Storage compartments on quay block continuous movement; reach stacker path to waterfront not available without significant investment	+2 Road connections both to north and south of premises confirmed through satellite images.
R4 – Ship-terminal interface *(Ability of vessel to safely moor and be attended along the quay)*	+3 Satellite imagery identified barges moored at location, in addition recently upgraded infrastructure.	+1 General space quite limited restricting vessel attendance; no mooring infrastructure confirmed; floating solution suggested in D3.1 [1] as primary approach.	+2 Active bulk transhipment confirmed; vessels observed at site historically.	+1 There is a large waterfront present along site; however dense vegetation running between site and water prevents immediate vessel access; substantial vegetation removal and verification of mooring infrastructure required before safe vessel call possible
R5 – Terminal-hinterland interface *(Ability of trucks and road vehicles to reach, circulate and depart from handover area)*	+2 Site geometry is tight, and transhipment area will become congested after a few TEUs.	+1 General space quite limited, which restricts use of transhipment equipment.	+2 Open yard which is already used by trucks for moving cement, but not the biggest area.	+1 There is road access present along landside of waterfront; however dense vegetation blocking quay access means trucks cannot currently approach the transhipment point without

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				substantial clearance work first
R6 – Public interface *(Management of interactions between TPT operations and public roads, paths and spaces)*	+2 Its fenced off but some of the open waterfront quay area is not fenced off.	+2 Access to quay mostly fenced off but gate is missing.	+2 No public road or pedestrian path running directly alongside the quay or operational area; but not entirely fenced in.	+3 Relatively well fenced off and effectively no public interface at all for the quay.
R7 – Legal/contractual *(Lawful basis and stakeholder permissions for TPT operations at the site)*	**+2**: Permissions not yet secured but can reasonably be obtained through simple contractual agreement with a single known operator.	**+2**: Permissions not yet secured but can reasonably be obtained through simple contractual agreement with a single known operator.	**+2**: Permissions not yet secured but can reasonably be obtained through simple contractual agreement with a single known operator.	+1 Ownership of extended waterfront storage areas uncertain;
R9 – Transport demand *(Credible and sufficient customer base for modal shift to IWT)*	+2 Site is not potential anchor customer, but greater area has high demand	+2 Site is not potential anchor customer, but greater area has high demand	+2 Site is not potential anchor customer, but greater area has high demand	+2 Site is not potential anchor customer, but greater area has high demand
I_A	2.4	1.6	2	1.6

3.3.2.2. *Leiden Zoeterwoude-Rijndijk*

At Leiden, two potential areas were considered: Location #4 and #5.

- Area 4, located at the intersection between the Oude Rijn and Rijn-Schiekanaal to the east of Leiden, contains two subareas identified in [1]: the De Waard district to the north and the Zijlkwartier district to the south. The De Waard district was assessed but not taken forward, as [1] explicitly concludes that the businesses in the area are either too specialised or too small to be interested in waterborne transport solutions. The Zijlkwartier district, however, contains an array of industrial points of interest. In addition, there is confirmed recent cargo transfer activity, therefore this subarea is taken forward for detailed assessment.
- Within area 5, which is to the east-southeast of Leiden, an industrial area is located (see Leiden area 5: Zoeterwoude-Rijndijk on the Oude Rijn in [1]). The most prominent production site in the area is the Heineken brewery, which represents both an

importer and exporter of goods. In addition, there are several businesses, distribution centres and shops adjacent to the brewery. This location is therefore likely to depend on quite significant transport and is a good candidate for establishing a TPT or connecting to a nearby TPT.

At the Zijlkwartier district (area 4) there was assessed only one quay in deliverable 3.1 [1]: **the Zijlkwartier Quay.** The quay has confirmed recent cargo transfer activity demonstrating basic vessel access and operational feasibility. The quay has no fixed overhead obstructions providing a clear lifting envelope, and PostNL cargo services directly across the road as a potential anchor customer with an unused storage area available for TPT storage. However, the site faces significant challenges regarding traffic management and space, as a public road runs directly alongside the quay cutting off the industrial area from the waterfront, creating operational complexity for both vessel access and truck movements. The quay is also narrow at approximately 6.72 metres, limiting simultaneous equipment operations. In addition, the public ownership of the quay introduces multi-party legal complexity requiring municipal permissions before freight operations can be established, alongside a separate agreement with PostNL for storage access. The Zijlkwartier Quay is therefore selected not as a particularly strong standalone candidate, but as the most viable near-term option in the area given the limitations of all other sites assessed. The scores of Zijlkwartier Quay, is provided in the Table 17 below.

Within Zoeterwoude-Rijndijk (area 5), four potential locations were identified. Out of these 4, 3 were excluded from further analysis, due to:

- A cement contractor was immediately excluded as large cement storage units and limited quay space make container operations impractical without directly disrupting ongoing dry bulk activities.
- The Heineken/Rijneke Logistics terminal, while well located, has an overhead cargo pipe running from the terminal into the Heineken brewery creating an unresolvable obstruction within the container handling arc — reach stackers cannot lift and move cargo efficiently without risk of collision with the pipe (R2: -∞). A shopping centre waterfront was also excluded due to unrestricted public access making it unfit from a security and safety perspective (R6: -∞).
- An brownfield adjacent to the Heineken complex in location 5 (Figure 5-32 in D3.1 [1]), which have previously been used for storage of various construction material (Brownfield on Google earth 2023). As the brownfield is largely undeveloped with significant vegetation along the waterfront and no confirmed quay infrastructure but has significant long-term potential due to location and size.

Comparing the Brownfield adjacent to the Heineken complex and public **Zijlkwartier Quay**, the public The Heineken Brownfield achieves a slightly higher overall applicability score, reflecting strong hinterland conditions and a favourable public interface. However, the absence of quay infrastructure represents a fundamental constraint for near-term implementation. Consequently, while the Brownfield site demonstrates strong long-term potential, the Zijlkwartier Quay is considered the more viable short-term TPT location due to its existing waterway interface.

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Table 17: TPT placement analysis Leiden

Criteria	Zijlkwartier Quay (area 4)	Brownfield (area 5)
Link google earth	Zijkwartier public quay	Brownfield
R1 – Quay surface *(Physical usability of working platform; whether paved, structurally sound, free of vegetation and debris)*	+3 Quay has been used for cargo transfer in recent years, confirming basic usability.	+1 Site is not developed, so no confirmed hard surface and uncertain conditions. Surface would require major preparations.
R2 – Quay clearance *(Unobstructed lifting and movement envelope for container handling between vessel and quay)*	+2 Open quay with no overhead obstructions or fixed structures blocking the container lifting arc. However, the adjacent public road limits the effective lifting envelope.	+2 There is overgrown vegetation which would need to be removed, meaning quay clearance is largely acceptable, but would require minor interventions.
R3 – Quay access *(Continuous and workable route between transhipment point and storage or handover area)*	+1 Public road runs directly alongside the quay cutting off the industrial area from immediate waterway access, where PostNL is seen as a possible storage point. Establishing a continuous route between transhipment point and storage requires managing the road interface and formal traffic management arrangement	+2 Access is currently blocked by significant vegetation along the waterfront. Access can be established through vegetation removal and road development. Existing gate structures provide a starting point but require upgrades.
R4 – Ship-terminal interface *(Ability of vessel to safely moor and be attended along the quay)*	+3 Quay used for cargo transfer in recent years confirming vessel access feasible; lightweight fencing still present	+1 No quay infrastructure exists at the site. A quay would require substantial investment, and its feasibility is currently uncertain.
R5 – Terminal-hinterland interface *(Ability of trucks and road vehicles to reach, circulate and depart from handover area)*	+1 Public road along the waterfront separates the industrial area from the quay. This creates operational complexity for truck movements. The quay width is approximately 7 metres, leaving limited manoeuvring space.	+3 The site has previously been used by heavy trucks and provides sufficient space for manoeuvring; minor upgrades such as fencing improvements are required for controlled operations.
R6 – Public interface *(Management of interactions between TPT operations and public roads, paths and spaces)*	+2 Lightweight fencing from previous cargo operations remains in place. The public road still creates interaction challenges and additional measures are required to ensure safe and efficient truck movement.	+3 The waterfront at this site is separate from public, so no additional measures should be needed.
R7 – Legal/contractual *(Lawful basis and stakeholder permissions for TPT operations at the site)*	+2 Quay appears to be public infrastructure meaning municipal permissions are likely required before freight operations can be established. However, previous cargo operations indicate feasibility. A separate agreement with PostNL is also needed	+1 Quay construction requires permits. Site ownership is unclear, but permissions are expected to be achievable through standard processes and contractual agreements.

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	for storage access across the road, making multi-party coordination necessary before a TPT can be legally established	
R9 – Transport demand *(Credible and sufficient customer base for modal shift to IWT)*	+2 Several industrial points of interest identified in the area including a shopping mall, furniture retailers and PostNL cargo services.	+2 Cluster of several smaller companies in addition to the large and stable Heineken brewery.
I_A	2	1.9

3.3.3. DEN HAAG

Den Haag has a high transport demand (see section 2.3.9) and could benefit from a large TPT or several smaller TPTs. From D3.1 [1] four potential areas for TPT deployment were identified:

- Area 1, Laakhaven, is an inner-city harbour area in the process of being redeveloped into a mixed residential and commercial district. The redevelopment includes new buildings being erected along the waterfront, meaning future transshipment activities would be spatially, operationally and socially challenged within the envisioned urban blueprint. This results in the long-term availability criterion (R8) being evaluated to -∞, and the location is excluded from further analysis.
- Area 2, the Binckhorst District, is an industrial waterfront area in Den Haag. The district contains several physically promising sites. However, the municipality of Den Haag has a firm planning policy[4] to convert the waterfront into publicly accessible space, making long-term TPT deployment uncertain across the entire district. Due to the promising unused quay potential, the area is nevertheless analysed in this section.
- Area 3, the Westvlietweg Industrial Estate, hosts approximately 335 companies and accommodates a diverse range of businesses. However, the channel is shallow and there is currently no quay in the area, with a public road, bicycle lane and pedestrian path running directly between the waterfront and the industrial area, and various parts of the waterfront overgrown with greenery. A TPT concept deployed here would therefore be challenging, and as other areas were deemed more fitting, a detailed analysis has not been performed for this area.
- Area 4, Haven van Rijswijk, lies in the municipality of Rijswijk between Den Haag and Delft. The location contains various smaller enterprises, in addition to some larger organisations such as the European Patent Office (EPO), a DHL distribution centre and the research institute TNO. This area is therefore analysed as an alternative to the Binckhorst District.

Within Den Haag, Bouwmaat XL at the Binckhorsthaven is selected as the preferred site for a TPT, having the highest score across the assessed locations in both the Binckhorst District (Table 18) and Haven van Rijswijk (Table 19). The site has a confirmed hard quay surface of around 70 metres, previously actively used for mooring vessels. The entire area is fenced off,

[4] https://denhaag.raadsinformatie.nl/document/7832625/1#search=%22RIS303175%22

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a single known operator makes the contractual path clear, and the possibility of using the premises for transshipment outside opening hours provides a workable operating model, with Bouwmaat XL itself as a direct building materials anchor customer.

The Bouwmaat XL location benefits from nearby industry, however the planning uncertainty affecting the entire Binckhorst District remains a significant risk. Should an agreement not be negotiable with the municipality (drawing on the environmental merits of the TPT concept), the brownfield/former bulk terminal at Haven van Rijswijk is recommended as the second priority TPT location. The brownfield achieved the highest score in Haven van Rijswijk (Table Y). It has a history as an active bulk terminal until 2015 (to our knowledge), which suggests it could be relatively easily redeveloped into a container terminal, and the nearby DHL distribution centre could provide a credible anchor customer. However, as the brownfield is an undeveloped site, the Bouwmaat XL site remains the recommended primary location.

The detailed analysis of the Binckhorst District is included in Table X, covering all sites from [1] with direct waterfront access and no immediate showstopper preventing further investigation. Sites which had showstopper elements were:

- Dyckerhoff Basal was excluded as the cement contractor uses most of the waterfront for storage, served by a rail-mounted gantry crane. The crane could potentially be used outside normal operating hours.
- The BAM road construction site is confirmed through a municipality of Den Haag agreement to be redeveloped into at least 400 homes, resulting in R8: -∞.
- The southern basin has too narrow waterfront space, and a long boat pier with leisure crafts extending into the basin makes vessel manoeuvring very difficult.
- The central pier businesses (Titaan, Caballero Fabriek and the Loetje restaurant) consist largely of social spaces by the waterfront, including bars, creative spaces and a restaurant, which are not logistics customers.

Table 18: TPT placement analysis den Haag area 2

Criteria	NV HMS	Bouwmaat XL (green area # 1)	Info Centre + Storage slot (red area #2+#3)	Renewi (green area # 2)	LABgrond (Figure 5.42)	Bike Depot + Storage (figure 5-43)
Link Google earth	NV HMS	Bouwmaat XL	Info center + Storage	Renewi	LABgrond	Bike depot + storage area
R1 – Quay surface *(Physical usability of working platform; whether paved, structurally sound, free of vegetation and debris)*	+1 Quay present with containers stored on site confirmed but no evidence of active quay use for vessel operations. Surface	+3 Quay front appears to be intact. The quay where found to have been actively used 2007 on Google earth.	+3 Quay front appears to be intact. The quay where found to have been actively used 2014 on Google earth, of a smaller vessel.	+2 Quay front appears to be intact . Historically the BAM group have moored halfway on the Renwi area	+2 3,000m² paved area which seems to be intact and used in 2023, but some vegetation since then on	+3 Pavement quay which are currently being used by smaller vessels.

	condition and load-bearing capacity require physical inspection before operations can commence				the quay front.	
R2 – Quay clearance *(Unobstructed lifting envelope; no overhead pipes, bins or structural protrusions)*	+1 Satellite imagery shows materials and waste stored directly on and near the quay edge potentially obstructing the container lifting arc.	+3 No overhead pipes, canopies or fixed structures blocking container lifting arc.	+2 No overhead obstructions, but some fixed structures in front of waterfront which might need to be removed	+2 No overhead obstructions, but some fixed structures in front of waterfront which might need to be removed	+3 No overhead obstruction	+3 No overhead obstructions mentioned
R3 – Quay access *(Continuous workable route between transhipment point and storage or handover area)*	+1 Quay is part of a busy waste management operation meaning significant changes would be needed to establish a workable route between transhipment point and storage area without disrupting existing operations	+2 Quay area not that big, but parking area identified as possible storage, with okay route in-between.	+1 Narrow road at area #3 potentially too narrow for larger trucks; #2 requires reorganisation before clear access. Would most likely need to remove wall between areas.	+1 Small quay area, so storage must be arranged elsewhere.	+3 Abandoned brownfield with no fixed obstructions or existing operations blocking the route between transhipment point and storage area; open site allows for free movement between basin and both the paved and	+2 Combined transhipment and remote storage model; terminal tractor needed between the two areas

					brownfield areas	
R4 – Ship-terminal interface *(Vessel can safely moor and be attended along the quay)*	+1 140m waterfront confirmed but no proper quay structure visible in satellite imagery and no active vessel calls confirmed.	+3 70m quay, with previous vessels moored at location.	+2 Merging area #2 +# would lead to quay around 50m +40m; both. Smaller vessels have been moored.	+2 30m quay; Bigger vessels have previously been using some moring condionts there.	+2 80m basin confirmed, but quay seems to not be actively used in a couple of years.	+2 70m quay confirmed, but currently used for smaller vessels, so changes might be needed to facilitating mooring of bigger vessel
R5 – Terminal-hinterland interface *(Trucks can reach, circulate and depart from handover area)*	+2 Satellite imagery confirms large yard area with room for truck manoeuvring and circulation alongside existing waste management operations though some coordination with existing activities would be needed	+2 Large parking area provides manoeuvring space; geometry tight but manageable through minor adjustments	+1 Good room on #2 for trucks, but changes would be needed to reach storage on area #3	+1 Limited space for truck manoeuvring and circulation from quay to storage. Storage would be somewhere else, not decided.	+3 Paved area of approximately 30m wide and 75m long provides ample space for truck manoeuvring and circulation; basic TPT operations can be conducted on paved area without needing to clear the brownfield	+2 Road access confirmed to both transhipment and storage areas but small road at storage area limits truck manoeuvring space and simultaneous vehicle movements
R6 – Public interface *(Management of interactions with public roads, bike lanes and pedestrian routes)*	+2 Active waste management facility likely has existing access control in place, but TPT operations	+3 Fully fenced; option to fence off storage area from parking area already indicated	+3 Both sites fenced with gate, with no direct access to public interface.	+3 Enclosed area from public, so would be easily enough to fence of from public.	+2 Paved area fenced off providing good access control during normal operation	+2 Both areas fenced off per [1] but small public area in between the two sites requires

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	would need to be regulated and coordinated alongside existing waste management activities	by ground markings			s; however periodic public events at (parts of) the site require active management and temporary suspension of TPT operations	active management
R7 – Legal/contractual *(Lawful basis and stakeholder permissions for TPT operations)*	+2 Active operator; single known party; permissions for freight activities likely in place; shared use agreement needed	+2 Active operator; single known party, possible off-hours shared use.	+1 #3 appears to be municipal/public building; #2 ownership unknown; multi-party coordination required before legal basis can be established	+2 Active operator; single known party; waste management operations.	+1 LABgrond currently being set up as event space, which might make it hard to set up contract as a TPT.	+1 Bike depot and storage area assumed to have different owners requiring multi-party agreement.
R9 – Transport demand *(Credible and sufficient customer base for modal shift to IWT)*	+2 NV HMS waste management as direct anchor customer; broader Binckhorst industrial cluster including rail terminal as supplementary demand	+2 Bouwmaat XL building materials as direct anchor customer; however broader Binckhorst cluster demand uncertain given proximity of railway approximately which may already serve some potential	+1 No dominant anchor customer identified. Binckhorst cluster demand uncertain given proximity of railway approximately which may already serve some potential IWT customers	+2 Renewi waste management as direct anchor for importing waste and exporting recycled products. Binckhorst cluster demand uncertain given proximity of railway approximately which may already serve some potential IWT customer	+1 Event-based use only planned; no regular commercial freight anchor confirmed. Binckhorst cluster demand uncertain given proximity of railway approximately which may already	+1 No dominant anchor customer identified; demand dependent on consolidation across multiple smaller Binckhorst actors

		IWT customers			serve some potential IWT customer	
I_A	1.50	2.50	1.63	1.75	2.13	2.00

Table 19: TPT placement analysis Den Haag area 4

Criteria	Governmental Building (red, figure 5-48)	Brownfield/Former Bulk Terminal (yellow)	Multi-business Pier (green)
Link google earth	Governmental Building	Brownfield	Multi-business pier
R1 – Quay surface *(Physical usability of working platform; whether paved, structurally sound, free of vegetation and debris)*	+1 Vegetation along both vest and north side. North side of the quay have previously been pavemented (back in 2005). Both north and south requires substantial clearing before operations can commence.	+1 Previously active bulk terminal until 2015 and today utilised by smaller vessels. However, quays is not in working condition and would need work as quay has not been maintained. +1 Previously active bulk terminal until 2015 confirming quay infrastructure exists. Quay surface does not seem to be well maintained since abandonment in 2022 and would need work before larger vessel operations can commence. (Some smaller vessels currently using it, but without cargo handling)	+2 Recently erected buildings (2018) with paved quay present. Currently only smaller vessels moored there.
R2 – Quay clearance *(Unobstructed lifting envelope; no overhead pipes, bins or structural protrusions)*	+2 No fixed overhead obstructions mentioned; however, pine trees along waterfront need clearing before full lifting envelope is available	+3 No overhead obstructions mentioned; open site with no fixed structures blocking container lifting arc	+2 No overhead obstructions mentioned; wider sections of 13m provide adequate lifting envelope; narrower 5m sections more constrained
R3 – Quay access *(Continuous workable route between transhipment point and storage or handover area)*	+1 Area has unknown traffic patterns from existing governmental activities; no confirmed storage area available; residential neighbours	+3 Open undeveloped site with no fixed obstructions blocking route between quay and storage area; ample space for free movement	+2 Car and van access points for businesses require coordination. Storage would most likely be in adjacent storage area and

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	to north introduce time management constraints that further complicate establishing a workable route between transhipment point and storage		brownfield available for remote storage with terminal tractor model
R4 – Ship-terminal interface *(Vessel can safely moor and be attended along the quay)*	+1 Two possible quays: West side its an 80m quay sufficient for AUTOFLEX vessel, vessels moored at other side there back in 2011. North side can merge two quays of 60m in total, but no previously confirmed moorings.	+2 Around 50m quay described, in addition to an underdeveloped land right in front of it which might be able to further develop. So just sufficient space for AUTOFLEX vessel. Historical bulk terminal use confirms quay infrastructure present back in 2011 on Google earth.	+2 190m total quay with wider 13m sections suitable for operations, but will most likely needs some minor interventions to attend bigger vessel
R5 – Terminal-hinterland interface *(Trucks can reach, circulate and depart from handover area)*	+3 Large open yard area with ample space for truck manoeuvring and circulation with no obvious geometric constraints	+3 2,000m² plot area provides ample space for truck manoeuvring and circulation.	+1 Quay alternates between narrow 5m and wider 13m sections limiting truck manoeuvring; access points shared with existing business car and van entrances creating geometric constraints for truck circulation
R6 – Public interface *(Management of interactions with public roads, bike lanes and pedestrian routes)*	+2 Site fenced; access can be controlled, but residential neighbours to north may limit night operations due to noise and light pollution	+3 Fencing and gate already present, quay no direct access to public interfaces.	+2 Site not fenced, and easily accessible from public. However, fencing can be installed but might be higher cost.
R7 – Legal/contractual *(Lawful basis and stakeholder permissions for TPT operations)*	+1 Single known party but, governmental stature may impede initiating TPT activities; permissions likely more complex than a standard commercial operator	+1 Ownership unclear; site abandoned since 2022 with no known current operator; ownership clarification needed before any agreement can be established	+1 Multiple companies in individual modules; multi-party coordination needed.
R9 – Transport demand *(Credible and sufficient customer base for modal shift to IWT)*	+1 Governmental department as occupant is not a typical freight customer; no dominant anchor customer identified at this specific	+2 No direct anchor customer at the brownfield itself; however DHL distribution centre explicitly identified as	+2 Multiple smaller companies on site with no confirmed anchor customer; DHL nearby identified as potential

	site; broader Haven van Rijkswijk cluster including EPO, TNO and DHL nearby provides some supplementary demand potential	potential anchor in D3.1 [1] and broader Haven van Rijkswijk logistics cluster including EPO and TNO provides credible supplementary demand	anchor; broader cluster including EPO and TNO provides supplementary demand potential
I_A	1.5	2.25	1.63

3.3.4. DELFT

Delft is another high demand area (see section 2.3.9) where more than one TPT might be desirable. From D3.1 [1], two potential areas for TPT deployment were identified (notice that Den Haag and Delft is combined in [1] such that the first area within Delft was numbered "Area 5"):

- Area 5, Gist- en Spiritusfabriek te Delft, is home to the DSM-Firmenich complex and its associated Biotech Campus Delft, consisting of startups, researchers and established companies focused on food innovation, biotech research and diet transformation. Given that the campus is fundamentally a research and innovation hub rather than a production or distribution facility, the freight volumes generated are unlikely to be sufficient to justify a dedicated TPT. Furthermore, the chemical plant's safety-critical and commercially sensitive nature means access would be extremely restrictive for third parties, ruling out broader modal shift potential, and rail transport is already present as an existing modal shift alternative. Area 5 is therefore not taken forward to detailed assessment.
- Area 6, the Delftse Schie, hosts a range of industrial actors, some with direct waterfront access and some without. Six sites were carried forward for scoring.

Within the Delftse Schie, the western waterfront digger site is selected as the preferred site for a TPT. Although [1] notes that it is not intuitively an obvious TPT location, the site already demonstrates live transhipment between inland vessels and trucks on an open quay using mobile handling equipment, with satellite imagery showing multiple trailers loading in parallel and departing onto the adjacent public road. Its limitations — a tight working strip shared between handling and circulation, and a multi-party setting among several adjacent companies — are operational rather than structural, and the site shows that a compact, low-footprint TPT is workable with minimal fixed infrastructure. It is also surrounded by credible demand, with Prysmian, a container provider, a truck transport company and various home and furniture suppliers nearby.

The detailed analysis of the potential TPT placements at Delftse Schie (area 6) is included in Table 20. In addition to the western waterfront digger site, the BMN Delft site also stood out. BMN Delft is an established 220m bulk terminal with confirmed vessel operations, fenced controlled access and convenient road access, and benefits from BMN's multi-site presence across Delft and Leiden opening potential inter-site flows. However, its container-handling capability is fundamentally blocked in its current configuration: a series of fixed bulk storage compartments sits 5–6m from the waterfront and the existing cranes cannot reach containers past them into the hinterland (R2 and R3 both scored +1). Converting the site to container handling could require major physical modification, e.g. redesigning or removing sizeable

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bulk installations. Consequently, while BMN Delft achieves a comparable overall applicability score, the western waterfront digger site is considered the more viable near-term TPT location, as it avoids the major physical reconstruction that container handling at BMN would demand and builds on transhipment activity already taking place at the site.

Consequently, while BMN Delft achieves a comparable overall applicability score, the western waterfront digger site is considered the more viable near-term TPT location, as it avoids the major physical reconstruction that container handling at BMN would demand and builds on transhipment activity already taking place at the site. BMN Delft is retained as a strong longer-term candidate should investment in container-capable infrastructure be justified.

Table 20: TPT placement analysis Delft

Criteria	Western Waterfront Digger Site	Octatube Brownfield	Tree Composites	BMN Delft	Avalex	KPS Delft
Google earth link	Link	Link	Link	Link	Link	Link
R1 – Quay surface *(Physical usability of working platform; whether paved, structurally sound, free of vegetation and debris)*	+3 9m quay actively bears parked trucks and a semi-permanently located digger.	+2 Hard quay walls confirmed on both the canal frontage and the basin frontage, with a ~2,000m² paved area along the basin. The basin face is the preferred working frontage.	+2 Hard quayside, with some vegetation closest to the water.	+3 Active bulk terminal with confirmed inland vessel operations confirming quay surface in continuous use	+3 Actively engaged in shipping containers over waterways confirming quay surface in working condition	+2 Hard and somewhat well-maintained quay wall of almost 100m.
R2 – Quay clearance *(Unobstructed lifting envelope; no overhead pipes, bins or structural protrusions)*	+2 No overhead obstructions, but vehicles and a permanently stationed digger occupy the narrow 9m working strip at certain points of the quay. Might need	+2 No overhead obstructions, or other usage of area.	+2 No fixed overhead obstructions, but the lot is currently filled with stored caravans up to the quay edge, occupying the working envelope. These would	+1 Fixed bulk storage compartments sit 5–6m from the waterfront in the working envelope, and the cranes cannot reach containers past them.	+2 Already exist a cargo crane. No obstructions if this is being utilised. No fixed overhead obstructions blocking lifting arc on quay side but public road limits	+2 Large open storage area with no overhead obstructions. Might need to relocate some of the already existing storage to fit TPT-container.

	intervention.		require clearing — a minor intervention — before the lifting area is free.	Freeing the envelope would require redesigning or removing these sizeable installations	operational envelope	
R3 – Quay access *(Continuous workable route between transhipment point and storage or handover area)*	+2 Quayside is narrow and right by a road, so do not offer a lot of storage possibilities. Currently, trucks seem to drive directly onto public road, but might need some traffic management within the site.	+2 Storage is possible either at the paved area close to the basin or the brownfield itself, suggesting a workable on-site route. However [1] does not confirm a designated storage area, so the route cannot be fully confirmed	+2 The 75m quayside and the 4,500m² area sit on the same contiguous site, giving a workable route between transhipment and storage. The lot is currently occupied by caravans, which would need clearing both to open the route and to free the storage area.	+1 Bulk compartments most likely separate the storage area from the quay, meaning changes to the current internal infrastructure would be required to establish a workable route	+2 Small unidentifiable storage area in vicinity. Road interface requires management to establish continuous route.	+2 Large open storage area currently used for garden items. Reorganisation needed to fit transport route.
R4 – Ship-terminal interface *(Vessel can safely moor and be attended along the quay)*	+3 The quay is already actively being used by larger vessels (58m and 63m).	+2 Basin already hosting various inland vessels. Might need small interventions for the bigger Autoflex vessel.	+2 75m hard quay, but no confirmed vessels found mooring quay and vegetation close to the channel.	+3 Active bulk terminal with confirmed inland vessel operations.	+3 Actively used for shipping with 20" container units.	+2 Hard quay wall, but no confirmed mooring.
R5 – Terminal-hinterland	+3 Site geometry is tight as the	+1 Satellite measurement	+2 The 4,500m² site offers	+3 Area already used for	+1 Would need to utilize	+2 Location used for storage of

interface *(Trucks can reach, circulate and depart from handover area)*	handover and circulation share the same ~9m strip, however satellite images show that location is already being utilised by trucks to access trucks. Placing TPT on other side of the road together with industry would increase space as well	indicates the working strip is ~20m at its widest and ~9m at its narrowest. The narrow geometry constrains truck manoeuvring and circulation and would require work before trucks can reliably reach, circulate and depart	generous space for truck manoeuvring in principle, but it is currently occupied by stored caravans which reduce the available space until cleared.	bulk storage transported through trucks.	same space as the company with mounted crane, without needing to build bigger public road.	garden items, so would need to do changes in order for truck manoeuvring.
R6 – Public interface *(Management of interactions with public roads, bike lanes and pedestrian routes)*	+2 A public road and adjacent bike/pedestrian strip run directly alongside the working quay, so a public interface exists but can be managed through standard management measures	+2 The canal-facing quay is used by the neighbouring residential area for swimming. The basin-facing quay is open in nature but more manageable with regard to public access, making it the preferred working frontage	+3 Entire area fenced off with gate controlling.	+3 Fully fenced with functional separation and controlled access. Might need to setup temporal segregation of bulk and container operations.	+2 Fence erected on public road on each side of crane. Proven solution restricting access during operations. Public road still present.	+2 Garden-centre customers present during opening hours, but off-hours operation avoids direct public contact.

R7 – Legal/contractual *(Lawful basis and stakeholder permissions for TPT operations)*	+1 Its several functionalities among the quay, e.g. bulk storage and parking slots. Establishing a TPT would require multi-party coordination across these separate actors before a workable arrangement could be secured	+2 Octatube identified as the single owner. Quay is being used by smaller vessels, so need to check out agreements on that part.	+1 Tree Composites may not be interested in transhipment. Third-party lease arrangement needed adding contractual complexity.	+1 Active freight site with existing permissions. Single known operator. Container use would require new agreement, however establishing a TPT here would likely not be possible without operational impact for BMN	+2 Active operator already engaged in waterborne container transport. Single known party.	+2 Active operator. Single known party.
R9 – Transport demand *(Credible and sufficient customer base for modal shift to IWT)*	+2 Industry area close by, were e.g. Prysmian, NFK cable factory, furniture stores and home supply stores are potential transport customer.	+1 No confirmed anchor customer on the Octatube side of the canal. The brownfield itself is unused, and the nearest neighbour is Hordijk EPS across the basin, whose access [1] flags as poor. The larger actors such as Prysmian sit across the canal, but close bridge.	+1 Tree Composites not interested in transhipment per [1]. No dominant anchor customer identified. Demand only from neighbouring industry area.	+2 BMN's bulk core business gives weak incentive, but its broader non-bulk product range and on-site forklifts open a credible interest in smaller containerised volumes. BMN appears at multiple sites in this analysis (Delft and Leiden), enabling potential inter-site AUTOFLEX transports	+2 Active container shipping over the waterway already confirmed, with Avalex as direct anchor.	+2 KPS Delft garden centre as potential customer but off-hours operating model limits volumes. No dominant anchor beyond KPS themselves
I_A	2.25	1.75	1.88	2.25	2.13	2.00

3.3.5. ROOSENDAAL

Roosendaal has a larger industrial connected to a CEMT IV waterway. This includes several logistics companies and warehouses, and a truck transport company that currently stores shipping containers at their site. The huge, estimated demand (see section 2.3.9) motivates at least on TPT in Breda, even if just some parts of the volume is shifted from road. The main challenge is that there are only two locations with quays, whereas most of the waterfront is not developed into workable quays. Both these sites are engaged in bulk transport, and it is only one of them that could accept the AUTOFLEX vessel and offer access to the entire cargo hold. The analysis will investigate the following locations:

- Breure Grondwerken has an active quay that can accept the ATUOFLEX vessel and offer access to the entire cargo hold. However, quay space is limited, and usage will be shared with Breure Grondwerken.
- On the opposite side of the canal, we find Roosendaalse Asfalt Centre, which has two quays, both short and offering access to only parts of the AUTOFLEX vessel hold. No storage at quay is feasible, but the next plot is a logistics company already storing containers. Quay usage would be shared with Roosendaalse Asfalt Centre.
- The third, feasible option, would be establishing a temporary quay at one of the sites that currently has no quay. From these sites, DHL is most promising due to the largest available space adjacent to the water, and the fact that this space has a traffic pattern for trucks already.

The Roosendaalse Asfalt Centre is a good candidate for a TPT, though it has limitations in terms of efficiency as the quay does not support access to more than about 50% of the AUTOFLEX vessel cargo hold. That is assuming that the quay could be modified to remove the concrete structure blocking parts of the quay front. The quay could be extended by a temporary floating or jack-up quay, or permanently, mitigating this issue. However, the site is not a potential anchor customer, and with the limited available space, a TPT here would depend on storage at the adjacent transport company. As the other potential TPT sites have less restrictions, the Roosendaalse Asfalt Centre is not prioritised as a TPT location.

The Breure Grondwerken and DHL received the same rating. While Breure Grondwerken has a quay which is actively used for transhipment of bulk, the DHL site does not have a proper quay front at all, and a temporary quay would be needed. However, DHL is a potential anchor customer, their site has good space for temporary storage of both own cargo and cargo destined to hinterland customers, and good connection to hinterland. In contrast, Breure Grondwerken is not a likely anchor customer, has a good hinterland connection, but establishing a TPT would require re-arranging the terminal layout. Both sites are good TPT candidates, and despite the additional cost of a temporary quay, the DHL potential as anchor customer is evaluated as the tipping point. The DHL site is therefore chosen as the TPT location for Roosendal.

Table 21: TPT placement analysis Roosendal

Criteria	**Breure Grondwerken**	**Roosendaalse Asfalt Centre (largest quay)**	**DHL**
Link google earth	Breure Grondwerken	Roosendaalse Asfalt Centre	DHL

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R1 – Quay surface *(Physical usability of working platform; whether paved, structurally sound, free of vegetation and debris)*	+3 Surface is intact and in use	+3 Surface is intact and in use	+1 No quay, need temporary quay or new quay to be constructed.
R2 – Quay clearance *(Unobstructed lifting and movement envelope for container handling between vessel and quay)*	+2 No overhead structures, but bulk compartments made by concrete limits movement envelope and intermediate quay storage.	+1 No overhead structure, but the quay is too short to grant access to the entire hold. Furthermore, there is some structure, likely a barrier to prevent trucks from falling into the canal during loading bulk from ships, that further limits the available movement envelope	+3 Quay front missing, but the "would be" quay area has not obstructions. Some coordination with truck traffic at the distribution centre is expected.
R3 – Quay access *(Continuous and workable route between transhipment point and storage or handover area)*	+3 Continuous and workable route between transhipment point and storage, assuming some of the area can be converted to storage	+2 A continuous and workable route to storage can be facilitated, however, it would be rather long as the feasible storage is the adjacent lot where containers are stored already	+3 Continuous and workable route between the would be transhipment point and storage. Lack of quay not included here as it is accounted for in previous rating criteria
R4 – Ship-terminal interface *(Ability of vessel to safely moor and be attended along the quay)*	+3 Vessels call her for bulk transhipment, and the quay length supports access to the full AUTOFLEX vessel cargo hold	+2 Vessels call her for bulk transhipment, but the quay length only supports direct access to about half the AUTOFLEX vessel cargo hold	+1 Currently there is no ship-terminal interface. But the site is well suited for installing a temporary floating or jack-up quay as there is space in the canal and the waterfront.
R5 – Terminal-hinterland interface *(Ability of trucks and road vehicles to reach, circulate and depart from handover area)*	+2 The area is well suited for circular truck traffic, tracks from bulk carrying trucks can be observed in satellite imagery, however on-site storage might be challenging and would require coordination with existing operations.	+3 Assuming the adjacent container storage is used as intermediate storage.	+3 The site is a distribution centre with established circulation pattern for trucks.
R6 – Public interface *(Management of interactions between TPT*	+3 Fenced off and gated.	+3 Fenced off and gated.	+3 Fenced off and gated.

operations and public roads, paths and spaces)			
R7 – Legal/contractual *(Lawful basis and stakeholder permissions for TPT operations at the site)*	+2 Site is an active bulk terminal so regulation plan should be in place. However, it would probably be challenging to reach an agreement with Breure Grondwerken as they are not likely a customer of the transport service	+1 Site is active in bulk transhipment so regulation plan should be ok. However, would need contract with both Roosendaalse Asfalt Centre and the adjacent transport company. While the latter might be interested in the AUTOFLEX transport service, they might also view it as competition. Furthermore, the Roosendaalse Asfalt centre would have to adapt their site by making layout changes.	+3 The site is a potential anchor customer, and the general area is industrial and transport related. Permits and contracts should be obtainable.
R9 – Transport demand *(Credible and sufficient customer base for modal shift to IWT)*	+2 The general area has high demand, but the site is not likely a customer	+2 The general area has high demand, but the site is not likely a customer	+3 The site is a potential anchor customer, and the general area has high demand.
I_A	2.5	2.13	2.5

3.3.6. BREDA

The analysis in [1] investigated three subareas of Breda, all of which are arguable part of a larger industrial area. The estimated cargo volume going into Breda by road is huge (see section 2.3.9). Although it is not realistic to assume that all of this could be shifted to the waterways, there could be enough demand for two TPTs in Breda. We will therefore investigate if we can place two TPTs that together serves the larger industrial area. Combined geographical coverage will therefore also be given significant weight, especially if two or more locations are scored relatively similarly. It should be noted that a potentially major customer cluster is located to the west of Breda centrum. This cluster holds three large distribution centres, two IKEA storages and an IKEA retail store.

3.3.6.1. North part of MSC Breda

The MSC identified in Breda is located north of the city centre. As the MSC is large, it is divided into three areas of interest in [1]. Number 1 to 3 from north to south.

Starting with the northern part (area 1), there are 4 locations investigated in [1]:

- Location 1: Tiferto Breda Terminal, wholesaler of fertiliser in 600-1000kg bags. Actively uses the quay for importing bulk, presumably for the fertiliser production.

- Location 2: Locomotion watersport. Hypothetically eligible as TPT, but the core business relies on using the small quay area. Hard to imaging integrating a TPT with the current business. **Not analysed further.**
- Location 3: Van Iersel Geveltechniek (a window supplier). Has a quay and a parking lot that could be converted to storage.
- Location 4: Sando Puinrecycling. Quay and large bulk storage area. Near Micheline tire distribution centre and MSB container rental service provider.

The evaluated sites in northern Breda come out at a quite similar score, see Table 22. All three are feasible sites for establishing a TPT. To compare them further, we consider the investment need and business impact for the local residents. Firstly, Tiferto Breda Terminal would be a very good candidate for a TPT sharing infrastructure with Tiferto, however, for efficient operations the existing quay is not sufficient. One would need to extend the quay, either permanently or temporary. Which represents a significant cost. In comparison, investment needs at the other two sites are low. For these, the bigger issue is the potential impact on existing business. For Sando, the impact is related to the area being used by their equipment, and to mobility within their premisses (coordination between operations will be needed). For Van Iersel the main impact is reduced space for parking. If we then consider that Sando had a slightly lower score than the others, and that a TPT at their premisses would have very low quay storage capacity, it seems that Van Iersel is the best option and is therefore chosen as the TPT location for northern Breda.

Table 22: TPT placement analysis northern Breda

Criteria	Tiferto Breda Terminal (Subarea 1)	Van Iersel Geveltechniek (Subarea 3)	Sando Puinrecycling (Subarea 4)
Link google earth	Tiferto Breda Terminal	Van Iersel Geveltechniek	Sando Puinrecycling
R1 – Quay surface *(Physical usability of working platform; whether paved, structurally sound, free of vegetation and debris)*	+2 The quay is in use, however, it is small and occupied by the bulk silo. Quay extension is likely needed, or only a few containers could be transhipped without having to move the AUTOFLEX vessel.	+2 Satellite imagery indicates that the quay is paved, with some possible patching needs. Also, some growth needs to be removed and fencing separating quay from parking area must be removed. Some groundwork is thus expected. Latest observed usage for port-calls is 2016.	+3 In use today by heavy machinery
R2 – Quay clearance *(Unobstructed lifting and movement envelope for container handling between vessel and quay)*	+1 Restricted by the bulk silo and conveyor, only a small part can be used for transhipment lifting operations.	+2 No obstructions for lifting, but the quay is small, 7m wide, and for this site to function well it would have to include at least parts of the parking lot. Some groundwork expected to ensure minor	+1 There is a lot of Sando equipment currently blocking container transhipment

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		storage and movement envelope.	
R3 – Quay access *(Continuous and workable route between transhipment point and storage or handover area)*	+2 Good access to quay by road but requires alignment with onsite operations as the site "big-bag" storage area would have to be used as storage.	+3 Assuming car park is converted to storage, and fencing modified to clear the path to the quay, the quay access will be good. As the modifications needed caused reduced score in previous categories, and are minor, no subtraction in this category.	+1 Space is tight between the quay and concrete structures where bulk is stored (approx. 7m). Furthermore, this space (the quay) is occupied by Sando equipment
R4 – Ship-terminal interface *(Ability of vessel to safely moor and be attended along the quay)*	+2 Vessels moor here, but access would only be to parts of the hold. The vessel would need to reposition to deliver or load full capacity.	+2 last observed moored vessel is 2016. Imagery indicates some ware; hence some modification might be required. Furthermore, it cannot be confirmed that bollards are still intact from satellite images.	+3 Last observed ship moored in google earth is 2021. However, the site is clearly still active for the same purpose (bulk), and the newest images show no sign of deterioration of the quay infrastructure.
R5 – Terminal-hinterland interface *(Ability of trucks and road vehicles to reach, circulate and depart from handover area)*	+2 The quay is connected to road through the site storage area. Circular pattern established. But coordination with site activities is a must.	+2 The quay is connected to road through the parking lot, which would have to be converted to storage. Space is limited and a high traffic flow is not feasible. This is thus a slightly limiting factor for throughput but not preventing the site from being used as TPT.	+2 The area is well suited for circular truck traffic, however, currently there is equipment blocking what would be the most efficient circulation path. In general, the area seems to have high activity and limited space for storage.
R6 – Public interface *(Management of interactions between TPT operations and public roads, paths and spaces)*	+3 Gated access, entire area fenced off	+3 Gated access, entire area fenced off	+3 Gated access, entire area fenced off
R7 – Legal/contractual *(Lawful basis and stakeholder permissions for TPT operations at the site)*	+3 area is used for cargo transhipment, so regulation should be fine. Contract and agreement with site owner is required. The legal/contractual part is not the limiting factor	+1 unknown, but historic images indicate that area regulation might allow transhipment. Quay ownership is also uncertain as it is separated from the	+2 Area is in use for cargo, though it is bulk, and ships call to the quay for transhipment. Hence, regulation should be fine. Stakeholder permission, i.e. a deal with Sando, might be dificult as

	per say, it is the willingness of the site owner to participate in a TPT constellation that would have to be secured.	window manufacturer site. Might need contracts with two parties.	careful planning would be needed to avoid any impact on their operations.
R9 – Transport demand *(Credible and sufficient customer base for modal shift to IWT)*	+3 Location is good in terms of the MSC and the overall transport demand. Also, the site owner could be a significant customer, though probably not an anchor customer.	+3 Location is good in terms of the MSC and the overall transport demand. Site owner potential significant customer but not anchor customer.	+2 Location is good in terms of the MSC and the overall transport demand. Site owner potential demand is low, if not non-existing, as they deal in bulk materials.
I_A	2.25	2.25	2.13

3.3.6.1. Haven De Krouwelaar and Belcrumhaven port

These areas have multiple very promising sites for TPT applications. Considering that they are so close to each other, separated by a road that connects to major distribution centres, the geographical coverage is quite similar if a TPT is placed in Haven de Krouwelaar or Belcrumhaven. For this reason, they will be evaluated together.

- Haven de Krouwelaar (area 2): Karlshoven pier, a public pier; Brand Masters distribution centre; Dycore, a cement contractor; Mebin, a cement supplier; DB Schenker distribution
- Belcrumhaven port (area 3): a largely decommissioned harbour area with a brownfield (subarea 1) and a public quay with shops, restaurants and a crane service provider (subarea 2). With the large brownfield available in this area, we rule out subarea 2 as it has little space on quay meaning operations would have to be aligned with traffic, storage would have to be remote, it holds restaurants implying pedestrians will be in the area and that regulations plans are likely not allowing transhipment. On the contrary, the brownfield is currently not used and offers space suitable for a small permanent container terminal.

There are several good candidate locations for establishing a TPT in Haven de Krouwelaar and Belcrumhaven, see Table 23 and Table 24. What appeared to be the perfect example of an abandoned and nearly ready to use infrastructure, Belcrumhaven brownfield, turned out to be under development for housing and hence ruled out as a TPT location. Mebin is strategically located in terms of several larger potential customers, has a working quay and good hinterland connection, but received the second lowest score as it is hard to envision how a TPT operation could be established here without severe impact on the Mebin daily operations. Furthermore, transhipment operations cannot be undertaken without changes to the bulk terminal layout, which would impact Mebin business. Mebin is therefore ruled out as the location for a TPT.

Slightly better suited locations are DB Schenker and Brand Masters distribution centres, both receiving a score of 2.25, Brand Master would be a perfect location had it not been for the lack of a workable quay. The small quay that is there would have to be extended and reinforced, and a short road would be needed to connect it to the main area. The alternative is to install a temporary floating or jack-up quay, with structure/ramp to connect to the main area. While this implies rather high costs, it could be feasible considering Brand Masters potentially being an anchor customer. DB Schenker has a similar problem as it lacks a proper quay front and there is a sloping bank between the large, intact and in use, would be terminal area. Once more it would depend on either building a quay front, or a temporary quay to be placed at the waterfront. These two sites were ruled out mainly due to high cost associated with solving the lack of a workable quay/quay front.

The two most promising sites are Karlshoven pier and Dycore terminal. The Karlshoven pier is another prime example of abandoned infrastructure that can be re-invoked. It is currently used for “parking” vessels, but not for transhipment. Its surface is intact, and there is some space for intermediate storage. However, the main storage would have to be at the customers or a nearby business willing to rent areas for container storage. Another minor issue is the public interface. There is no fencing in place, implying traffic management is needed during lifting. Also, space for circular traffic is limited, which again implies traffic management during transfer to hinterland/truck transport. Nevertheless, the site should be possible to use as a TPT. Dycore comes out as the winner. The site is an active bulk terminal with sufficient space for allowing the AUTOFLEX vessel to call for cargo transport. Alignment between AUTOFLEX vessel operations and site operations will be needed, however, this is deemed feasible to solve. The main drawback of the site is that the quay space is limited, implying no storage directly near the quay front. However, this is compensated by the fact that the area is large and that the distance between transhipment and storage would be relatively short. Dycore is assumed the location of the TPT in this area of Breda. If a project seeking to implement the AUTOFLEX system fails to reach an agreement with Dycore, Karlshoven pier would be the second best option.

Table 23: TPT placement analysis southern Breda part 1

Criteria	Karlshoven pier (Area 2)	Brand Masters distribution (Area 2)	Dycore (Area 2)
Link google earth	Karlshoven pier	Brand Masters	Dycore
R1 – Quay surface *(Physical usability of working platform; whether paved, structurally sound, free of vegetation and debris)*	+3 Paved, in use, cars park there today and trailers are observed in streetview on the pier/Quay	+1 There isn’t a meaningful quay here, instead the site is dominated by overgrown banks. The small quay that is here, is 20m long and 5m wide, shows clear signs of wear (cracks), and isn’t connected to the site by a road. To establish a TPT the site requires construction of quay, extension and upgrades to the existing quay combined with demolition of a concrete structure and construction of a short road, or a floating or jackup quay for	+3 Already active transhipment, concrete modules stored on site, no growth

		temporary deployment. This means significant investment is needed.	
R2 – Quay clearance *(Unobstructed lifting and movement envelope for container handling between vessel and quay)*	+3 (maybe 2) One side is empty; the other has cars parked which would have to be moved.	+1 No overhead hindrances, but in addition to reconstructing, constructing or establishing a temporary quay, the bank needs significant work to enable access to the quay.	+2 While the site is actively used for transhipment, there is littler rom for movement for a reach stacker as is, nor is it likely to install a permanent crane as it would potentially conflict with existing operations. Re-structuring some of the storage might open a section of the quay currently not used for transhipment. However, this part might need upgrades to provide a good interface for mooring.
R3 – Quay access *(Continuous and workable route between transhipment point and storage or handover area)*	+3 There is space for on-quay storage, however it is limited. Off-site storage would probably be needed, potentially at cost of efficiency.	+3 As the lack of a workable quay was accounted for in the previous and next category, it is not included here. Storage will be on site, and once a quay is in place, connection to storage will be good	+2 The existing quay has no space for storage, but the area in general has good storage space. If the existing quay is to be used, a reach stacker would need to move between the quay and storage during loading through a workable route, but at the cost of efficiency
R4 – Ship-terminal interface *(Ability of vessel to safely moor and be attended along the quay)*	+3 Vessels moor here today, can hold two AUTOFLEX vessels simultaneously while the whole length of the vessels would be accessible	+1 Requires reconstruction of a quay to allow a vessel to moor	+3 Vessel moor here. But if the unused section of the quay was to be used, some upgrades are likely needed, which would reduce score to +2
R5 – Terminal-hinterland interface *(Ability of trucks and road vehicles to reach, circulate and depart from handover area)*	+1 (or 2) Trucks cannot turn on the quay, ruling out a circular traffic pattern. Adjacent road is also small. Hinterland connection would therefore be a bit cumbersome and require traffic management such that trucks can back into the quay from the road, or the trucks would have to be loaded/unloaded	+3 As the lack of a workable quay was accounted for in the previous categories, it is not included here. Once a quay is in place, the site already has a circulation pattern for trucks and good connection to hinterland	+3 Trucks already operate in circular pattern on site and have good hinterland connection

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	while parked on the road.		
R6 – Public interface *(Management of interactions between TPT operations and public roads, paths and spaces)*	+2 The area is not fenced; there is a road directly parallel to the ends of quay(es). However, similar sites have been observed in operation for bulk transhipment	+3 completely fenced off and traffic regulated through gate.	+3 area is fenced off and gated
R7 – Legal/contractual *(Lawful basis and stakeholder permissions for TPT operations at the site)*	+2 Unknown ownership, likely public. No cargo operations are observed, but vessels are moored here and trailers are observed parked here. In sum, it is assumed feasible to obtain legal and contractual permission but that it will require some work.	+3 The site is a good anchor customer candidate. The entire area is industrial with no public interface. Regulation plans are likely industrial use already.	+3 Already transhipping cargo over the quay, regulation should be in order. One party contract needed.
R9 – Transport demand *(Credible and sufficient customer base for modal shift to IWT)*	+3 Although customers will require hinterland transport, the location is central with good road connection to several major distribution centres.	+3 Great general demand in the area and good hinterland connection, and the site is a likely anchor customer.	+3 Great general demand in the area, potential anchor customer Brand Masters is adjacent to the site, Dycore might be a customer, and hinterland connection is good
I_A	2.5	2.25	2.75

Table 24: TPT placement analysis southern Breda part 2

Criteria	**Mebin (Area 2)**	**DB Schenker distribution (Area 2)**	**Brownfield (Area 3)**
Link google earth	Mebin	DB Schenker	Brownfield
R1 – Quay surface *(Physical usability of working platform; whether paved, structurally sound, free of vegetation and debris)*	+3 In use for cargo transhipment, no vegetation	+1 The main sections of the quay and area is paved and even holds some waste containers. However, the space between the water and the main area is a sloping bank with some growth. Either the quay needs to be extended, or a fixed crane that can reach the vessel needs to be installed.	+2 Some vegetation and some minor debris must be cleared, possibly some groundwork to level and strengthen the ground, but the quay surface appears solid. Historic images show previous buildings and what appears to be containers or heavy equipment.

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R2 – Quay clearance *(Unobstructed lifting and movement envelope for container handling between vessel and quay)*	+1 Existing bulk crane limits container lifting envelope, very short space between quay edge and concrete compartments for bulk	+3 Significant parts are unobstructed, apart from cars parking here. However, it appears that parking space is redundant. It could be argued that the bank prevents access, but a fixed crane would solve this.	+3 Nothing is obstructing lifting and movement envelope is cleared.
R3 – Quay access *(Continuous and workable route between transhipment point and storage or handover area)*	+1 Not accessible as is. Could possibly be solved be upgraded crane that can lift both containers and bulk, and reach beyond the bulk storage compartments, or by removing a section of the bulk storage to create a road – but this would have major impact on Mebin business	+3 As the need to extend quay or install fixed crane to get access to the vessel hold was accounted for in previous criteria, it is not deducted here. The storage would be on quay or directly adjacent but still on the same site, so a workable route between transhipment point and storage is in place.	+3 The quay is a large open space allowing on-site storage and free movement
R4 – Ship-terminal interface *(Ability of vessel to safely moor and be attended along the quay)*	+1 Vessels moor, but quay space makes access to cargo hold very limited and cumbersome	+1 Currently there is a bank between the quay/terminal area and the water. Work is needed to establish a ship-terminal interface	+2 The quay appears sound, but no usage can be identified over the last 20 years. There is a sign indicating that mooring is not allowed at the moment. Likely that some works for fenders and bollards is needed. But the quay wall appears in good condition with no visible damage.
R5 – Terminal-hinterland interface *(Ability of trucks and road vehicles to reach, circulate and depart from handover area)*	+3 Circular pattern for trucks with hinterland connection in place	+2 the area is large, however, unless most of the parking is relocated, the moveability will be somewhat restricted. With good traffic management circular path for trucks should be possible.	+2 Great space for circular truck traffic pattern, connection to a rather small public road. As it is a brown field, some groundwork might be needed to level and strengthen the ground into a workable road on site.
R6 – Public interface *(Management of interactions between TPT operations and*	+3 fenced off and gated	+3 Fenced off and gated	

public roads, paths and spaces)			
R7 – Legal/contractual *(Lawful basis and stakeholder permissions for TPT operations at the site)*	+1 Although the legal permission might be in place as the site is engaged in transhipment already, it is unlikely that a contract with Mebin can be achieved as impact on their business would be significant	+2 Although transhipment is not observed, the area is a distribution centre, which makes legal permission feasible, and the site a potential anchor customer. Some contractual and permission work is expected. Somewhat reduced score as waterborne transhipment appears not to be ongoing.	$-\infty$ While the site appears abandoned and looks to be the perfect location for a TPT, it turns out that it is being redeveloped into housing. An image of the planned new housing is found here. The site is thus judged to be unsuitable for a TPT.
R9 – Transport demand *(Credible and sufficient customer base for modal shift to IWT)*	+3 Although there is no anchor customer on site, it is adjacent to potential anchor customer and has great hinterland connection	+3 The site is a potential anchor customer and is located centrally for hinterland customers.	+3 Although customers will require hinterland transport, the location is central with good road connection to several major distribution centres.
I_A	2	2.25	$-\infty$

3.3.7. EINDHOVEN

The analysis in [1] investigated four subareas of Eindhoven, where Area 3 was rejected as not relevant for establishing a TPT, and area 1 was believed to be most promising. However, the cargo volume going in and out of Eindhoven by road corresponds to more than 2000 TEU in each direction per week (see section 2.3.9). Although it is not realistic to assume that all of this could be shifted to the waterways, there could be enough demand for two TPTs in Eindhoven. We will therefore investigate if we can find one area outside Eindhoven, and one withing the centre, that could be used to establish a TPT. As the analysis in [1] showed that large potential customers are located north of the city centre, in and around the investigated areas 1 and 2, we will locate one TPT here. TPT candidates within areas 1 and 2 will therefore be compared. Area 3 was rejected in [1], hence, we will investigate area 4 for potential deployment of a second TPT.

3.3.7.1. Ekkersrijt and Best industrial park (North Eindhoven – Area 1 and 2)

As discussed above, the Ekkersrijt area (Area #1) and Best industrial park area (Area #2) will be investigated to determine where a TPT should be located to serve the Northern parts of Eindhoven.

- Area 1 Ekkersrijt is located north of Eindhoven, on the right side of A50 and the south side of the canal. It contains two subareas, the quay adjacent to Rhenus distribution centre, and the quay adjacent to Ubiquity distribution centre. Arguably, this is one continuous quay split in two for the properties where Rhenus and Ubiquity are located. Nevertheless, the analysis will treat the two quay sections individually.

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- Area 2 Best industrial park is also located north of Eindhoven, to the west of Ekkersrijt at the intersection of the canal and the A2 road. The area holds several businesses, mostly B2C, and has a promising looking quay.

The scoring indicates that Ubiquity is best suited, but the difference between the sites is small (Table 25). It should also be noted that some categories are hard to determine accurately due to scarcity of information. For instance, quay surface is one of the categories where the Ubiquity site scores better than the other two options. The reason is mainly due to the google earth images showing trucks parked at the Ubiquity quay, confirming it is in good condition, while similar evidence is not found for the other two sites. If it turned out that Best industry park has a quay surface scoring +3, then it would be a draw with Ubiquity. While Best industry park is a good candidate, in fact it is a perfect example of the type of site that inspired the TPT, a draw with Ubiquity would still leave Ubiquity as the winner. The reason is the two large distribution centres, Ubiquity and Rhenus, being adjacent to the quay. It can be expected that a significant share of the estimated demand for Eindhoven is related to these two distribution centres, hence, a TPT here would offer no need for road transport for first and last mile for this share. Furthermore, there are several businesses adjacent to Rhenus and Ubiquity, two additional distribution centres 1km west of Rhenus, and 8km to the centre of Best industry park. Cargo destined to these locations can also be moved through a TPT located at the Ubiquity quay as it only requires a short first/last mile transport. In conclusion, even with the small differences in score between the sites, the Ubiquity quay is evaluated as the best location and chosen as the TPT for northern Eindhoven.

Table 25: TPT placement analysis Eindhoven area 1 and 2

Criteria	**Rhenus Distribution Centre (Area 1)**	**Ubiquity Distribution (Area 1)**	**Best industrial park (Area 2)**
Link google earth	Rhenus	Ubiquity	Best industrial park
R1 – Quay surface *(Physical usability of working platform; whether paved, structurally sound, free of vegetation and debris)*	+2 The quay section protruding into the canal, the part with best space for cargo and equipment, is heavily overgrown and has been for decades [1]. The other parts of the quay are narrower, with less available space for cargo and movements, but is observed to be used for cargo transfer in 2005. However, it is also overgrown and requires brush clearing and tree felling, indicating that minor structural work is required.	+3 Quay has bollards, historic images show leisure crafts moored. A section of about 100 meters of quay front is free of vegetation, covered in coble stone with some minor signs of growth. Streetview shows that trucks park here, indicating structure is sound and that no intervention is needed.	+2 Cover appears to be cobblestone. There is growth, which can be observed 20 years back, though it is not heavily overgrown. It has been used as a car park for this period, and surface seems to be in relatively good condition. But there is no clear evidence that no reinforcement at all is needed. Streetview indicates that there are no structures or debris/objects that needs to be moved, apart from the low barrier between carpark and quay front..
R2 – Quay clearance *(Unobstructed lifting and*	+2 Open quay with no overhead obstructions or fixed structures blocking the container	+2 Open quay with no overhead obstructions or fixed structures blocking the container lifting arc. However,	+2 No obstructions observed except that the location is used as car

movement envelope for container handling between vessel and quay)	lifting arc. The adjacent road is not public. Seems to be some fencing between the quay and the road, which would have to be removed.	the adjacent road will have to be used during lifting operations, i.e. traffic management is needed. Even though the traffic seems to be very limited.	park. This parking would have to relocate.
R3 – Quay access *(Continuous and workable route between transhipment point and storage or handover area)*	+2 Good access to quay by road but requires clearing fence or structure separating quay and road. Appears that one way traffic is most likely. Storage would be the same as for Ubiquity site.	+2 Good access to quay by road, but the road is parallel to quay, and space is quite narrow. Will need some traffic management. Which should have low impact as the area is industrial and seems to have little traffic. Storage space is extremely limited, but the quay is adjacent to two large distribution centres. Storage would be at the distribution centres, and access between quay and these are good.	+3 No obstructions between loading point and temporary storage, however, the TPT would rely on extended storage at nearby businesses. The road parallel to the Quay creates a need for temporary traffic management.
R4 – Ship-terminal interface *(Ability of vessel to safely moor and be attended along the quay)*	+1 No moored vessel is observed in historic images, and growth is substantial. Imagery does not reveal bollards. It is possible that substantial upgrades are needed, but this cannot be concluded.	+2 Although google earth and streetview images show bollards and historic use by leisure crafts, it cannot be concluded if some low cost intervention might be needed (fenders, debris removal in the water, or possible reinforcements of quay front)	+1 Most likely need new bollards and removal of blockages/barriers between parking space and quay front.
R5 – Terminal-hinterland interface *(Ability of trucks and road vehicles to reach, circulate and depart from handover area)*	+2 The quay is next to a road, but fence or structure would have to be removed. One way traffic is likely, but good traffic flow should be possible to achieve with some interventions.	+2 The site is being used for truck parking and has a road parallel to the quay. Hence, trucks can move to and from the quay. It is a bit narrow and would require one-way circular traffic flows. Since some other traffic uses the road, some traffic management is expected. Also, quay	+2 The site is parallel to public road. Access is not an issue, but one-way traffic will be required as temporary storage of containers would significantly reduce the available space. This also means that space restrictions may have some impact on efficiency of loading/offloading (also reach stacker movements

		storage space is limited, implying that cargo may somewhat restrict movements.	will be restricted to narrow spaces).
R6 – Public interface *(Management of interactions between TPT operations and public roads, paths and spaces)*	+2 Only public interface is the possible pedestrians walking through the area. However, the area is industrial, though not fenced off making it possible to walk through.	+2 No fencing, but the area is industrial and fencing is probably not needed. Traffic management is expected, but impact on public mobility is foreseen to be low.	+2 Fencing in place, it does not hold ISPS standards, and the gate is not guarded and seems to be manual. Some upgrades/re-arrangement of fencing and gates will be needed to create a path for trucks. Fencing is likely needed since the quay has direct interface to public road and users. But as observed in some locations, it is possible to use such quays without fencing.
R7 – Legal/contractual *(Lawful basis and stakeholder permissions for TPT operations at the site)*	+2 Area is industrial; however, it is not known if regulation plans allow cargo transhipment. Even so, it is not a public area, which would have been harder to convert. Ownership is unknown; hence permission is expected to require some work.	+2 Area is industrial; however, it is not known if regulation plans allow cargo transhipment. Even so, it is not a public area, which would have been harder to convert. Ownership is unknown; hence permission is expected to require some work.	+2 Areas is used as parking, seems to be owned by a business. No known urban development plans, should be feasible to obtain permit.
R9 – Transport demand *(Credible and sufficient customer base for modal shift to IWT)*	+3 Two large distribution centres are directly adjacent to the quay. In addition, the greater area holds several industrial sites, t least two other distribution centres, and the overall demand estimation for Eindhoven is high.	+3 Two large distribution centres are directly adjacent to the quay. In addition, the greater area holds several industrial sites, t least two other distribution centres, and the overall demand estimation for Eindhoven is high.	+3 High transport demand for Eindhoven in general, and the location is adjacent to an industrial cluster. It is also 8km from the distribution centres of Rhenus and Ubiquity but will have to use the main road a short distance to connect. While demand is good, and isolated justify a +3 rating, its location is not as good as the two alternatives where cargo could be delivered to anchor customers without trucking. Could therefore also be judged as +2
I_A	2	2.25	2.13 (or 2 if relative location is considered)

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3.3.7.2. Eindhoven Centre (Area 4)

As the current road freight volumes deemed to be eligible for waterborne transport creates a high potential demand for IWT in Eindhoven, a second TPT is needed. This second TPT should be placed as near the city centre as possible (Area 4) to reduces road freight in the most densely populated areas, and to create good geographical coverage of Eindhoven considering that other TPT was placed in Ekkersrijk.

- Area 4 is adjacent to the city centre to the west. It includes two locations that were identified in [1] as potential TPT locations. Bot locations are close to the A2 motorway (regarded as the busiest in the Netherlands). Location 1 is adjacent to MIREC recycling and holds an approximately 450m long and 17m wide quay that appears to be unused. Location 2 is an active bulk handling quay shared by three to four companies.

Both locations come out with a similar score (Table 26). Location 1 has the potential drawback of needed some re-enforcements as it has not been observed in active use for some years, while the integration at Location 2 might limit capacity through reduced operational hours. Location 2 also depends on the local businesses being willing to do some changes, relocate some light equipment/structure, and tight coordination with existing operations. The further analysis will assume location 1 due to being likely to operate for longer hours, but the locations are adjacent so if one turns out not to be possible to use for a TPT the other would be a good option.

Table 26: TPT placement analysis Eindhoven area 4

Criteria	Abandoned quay near MIREC (Location 1)	Shared bulk quay (Location 2)
Link google earth	Location 1	Location 2
R1 – Quay surface *(Physical usability of working platform; whether paved, structurally sound, free of vegetation and debris)*	+2 Covered in grass, but historic imagery shows it being used temporarily as general cargo transhipment quay in 2013. Closer inspection is required to determine actual state as there is a risk that more substantial work is required than just clearing grass/vegetation. To be noted, visible tracks indicate that trucks drive over the grass at times.	+3 In use for bulk transhipment today
R2 – Quay clearance *(Unobstructed lifting and movement envelope for container handling between vessel and quay)*	+3 No observed obstructions, the would be available space if surface is cleared is big enough for free movement and some storage.	+2 No observed obstructions, however, space might be somewhat limited depending on storage configuration and how much other traffic one would expect at the site. Some containers, which appears to be for waste, will need to be moved. Might cause some interference with existing operations, and cooperation is needed.

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R3 – Quay access *(Continuous and workable route between transhipment point and storage or handover area)*	+3 Adjacent to road (appears to be private/industrial, probably part of IMEC site). Some trailers are parked at this road without blocking it. Continuous and workable route between transhipment point and storage/handover area appears to be present already. Especially since the dimensions of the quay makes temporary storage on the quay feasible.	+2 (or +3, depending on option for storage). The area in front of HKS Metlas could be used as storage, however, that blocks or restricts traffic through the gate to the right. Alternatively, the access road in the centre of the area could be used to access the temporary storage, which would make hinterland connection a bit more complicated but storage-ship operations more efficient. Storage is also feasible within ABZ area, though that might make the driving distance for a reach stacker between storage and quay a bit longer.
R4 – Ship-terminal interface *(Ability of vessel to safely moor and be attended along the quay)*	+2 As discussed, historic google earth imagery shows previous usage for transhipment, confirming the ship-terminal interface in 2013. No changes to the location since then can be observed, apart from growth of grass. However, closer inspection is needed to determine if some upgrades are needed or if the interface is still intact.	+3 vessels moor here today
R5 – Terminal-hinterland interface *(Ability of trucks and road vehicles to reach, circulate and depart from handover area)*	+3 Adjacent to road (appears to be private/industrial, probably part of IMEC site). Some trailers are parked at this road without blocking it. Continuous and workable route between both transhipment point and temporary storage, and hinterland connection by road appears to be present already. While general hinterland connection appears good, IMEC is a likely anchor customer, and minor alterations would be needed to create a direct path from quay to their premisses.	+2 Access through the gate to the right and then the truck would have to turn at the open space seen through the link above. This might interfere with existing operations, and if the quay is to be used for temporary storage, traffic management would be needed as it could be dificult to have enough space for two-way traffic. Alternating one-way traffic through the gate might be needed. Alternatively, the access road in the centre of the area combined with the road passing through the gate could be used for a one-way traffic flow. This option depends on even more interference and alignment with current site operations. And both options reduce storage space adjacent to HKS Metals. Evaluated as +2 since handover area will likely need coordination with existing operations

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R6 – Public interface *(Management of interactions between TPT operations and public roads, paths and spaces)*	+2 The would be terminal area is not currently fenced off. However, it resides within an industrial area, and it appears that public interaction is limited. Although, Streetview imagery confirms that it is possible to drive through the area at present, indicating that traffic management or some barriers could be needed.	+2 The area is fenced off from one side, but open from the other. Google streetview confirms that cars can drive into the area. Considering that bulk operations are currently happening at the site, some management should be in place already. However, container operations might require detected traffic management.
R7 – Legal/contractual *(Lawful basis and stakeholder permissions for TPT operations at the site)*	+2 Area ownership is unknown, as such it might need significant work to gain permits. On the other hand, it is being used for parking trucks that are likely related to IMEC business. It is also in an industrial zone making permits feasible.	+3 Single party agreement needed, but since area is in use for cargo transhipment, regulations plans should not be a problem
R9 – Transport demand *(Credible and sufficient customer base for modal shift to IWT)*	+3 As previously discussed, general demand for transport to Eindhoven, which could be shifted to IWT, is large. The cite is adjacent to a large recycling facility who appears to do a lot of waste container transport. An anchor customer is hence feasible. Furthermore, the location is central in an MSC with several other potential transport customers that could be served by a short road connection.	+3 While one large anchor customer might be missing, the location is central with a lot of businesses that are potential customers. And with the high overall demand at Eindhoven, the evaluation is that transport demand is high.
I_A	2.5	2.5 (or 2.63)

3.4 THE TPT LOCATIONS AND CONCRETE REALISATION

This section analyses the locations, including some rejected ones, and evaluates their applicability and how concretely the TPT realization would be (what TPT building blocks would be used). Cost estimates for TPTs are given in section 4.4.5.

3.4.1. METHOD

The possible realisations of the TPT are presented as building blocks in [1]. In this section, the analysis in section 3.3 leading to deciding on locations is also used as basis for a qualitative assessment of which building block option is best suited for each TPT. For each TPT location, a discussion of each building block will conclude on chosen option. For some building blocks, e.g. storage, more than one option might be applicable.

Once the realisation is decided, an evaluation of CAPEX and OPEX is done. At this point in time, it is not possible to do an exact evaluation. Instead, we will assess if the given TPT can be considered to fall into categories low, medium or high CAPEX and OPEX, respectively. The following defines each category:

3.4.2. HAARLEM – NORTH

A. Cargo Handling

The recommended configuration is **A2 — Mobile, ashore.** The quay has room for movements, and the agility of a reach stacker is preferable as it can handle transhipment for both vessel-quay, and storage-truck movements.

B. Cargo Storage

The recommended configuration is **B1** on-quay and potentially **B3** remote using nearby businesses. The quay area does support some short-term storage, but the capacity is limited. Hence, it could be that high activity will require expanding storage to a remote site.

C. Site utilities

The base configuration is **C3 — Permanent utilities**, as the site is an active factory.

D. Waterway interface

The recommended configuration is **D2 — Shoreside enablement.** Quay length is sufficient, it appears in good condition, vessels can moor along the quay and there will be access to the entire cargo hold.

E. Hinterland interface

The recommended configuration is **E2 — Direct delivery** and **E1 Last mile delivery.** Storage at site is limited, which means cargo needs to move efficiently through the TPT here. This works better for last mile delivery than for self-service pickups. As the site is a manufacturer, some direct delivery and shipping is also expected.

F. Public interface

The area is fenced off and gated, restricted access already in place **F3.**

G. Temporal availability

The recommended configuration is **G1 continuous availability** as it should be possible to operate the TPT without considerable impacts on daily business. The quay is on the backside of the building and appears to be unused.

H. Operation model

The recommended configuration is **H1 Independent** and **H2 Integrated.** This is because it can function both as a service for hinterland customers, and for direct delivery and shipment for the factory.

3.4.3. HAARLEM – SOUTH

A. Cargo Handling

The recommended configuration is **A2 — Mobile, ashore.** The quay has room for movements, and the agility of a reach stacker is preferable as it can handle transhipment for both vessel-quay, and storage-truck movements.

B. Cargo Storage

The recommended configuration is **B1 on-quay** as the site should have sufficient space for storage.

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C. Site utilities

The recommended configuration is **C2 — Temporary utilities**, as the site is a brownfield which does not have utilities in place, but which would benefit from long operational hours due to high demand in the area. If successful, it can be upgraded to **C3 — Permanent utilities**

D. Waterway interface

The recommended configuration is **D2 — Shoreside enablement.** Quay length is sufficient, it appears in good condition, though some work will be needed to make it ready, vessels can moor along the quay and there will be access to the entire cargo hold.

E. Hinterland interface

The recommended configuration is **E1 Last mile delivery.** The site is a brownfield with implying some last mile transport will be needed.

F. Public interface

The area is fenced off, but only by light fencing. It does not have a gate. Initially **F2 limited access** might be sufficient.

G. Temporal availability

The recommended configuration is **G1 continuous availability** as it should be possible to operate the TPT at all hours. The site is industrial with no direct integration to other businesses.

H. Operation model

The recommended configuration is **H1 Independent.** This is because it would most likely not be dedicated to an anchor customer but rather offer transport services to companies in the greater area.

3.4.4. LEIDEN – ZIJLKWARTIER QUAY

A. Cargo Handling

The recommended configuration is **A4 — Mobile, afloat**, supported directly by [1] which documents that historical cargo transfer at this quay used barge-mounted handling equipment. An afloat solution is preferable because it addresses the two main constraints at the site: the narrow 6.72-metre quay leaves little room for equipment to operate ashore, and the public road running directly alongside limits the shoreside operational envelope. Keeping the handling equipment on the water minimises the shoreside footprint and reduces reliance on the constrained quay.

A2 — Mobile, ashore (a reach stacker operating on the quay) is a theoretical alternative that would avoid the complexity of a floating platform, but the narrow quay and adjacent public road would leave an ashore reach stacker obstructing truck movements or encroaching on the road. A2 is therefore retained only as a fallback should an afloat solution prove unviable.

B. Cargo Storage

The recommended configuration is **B3 — Remote storage**, using the unused storage area on the north side of the PostNL distribution centre across the road as the primary storage location. This is the natural fit given the two main constraints at the site: [1] explicitly notes that storage space is limited at the quay, and the narrow 6.72-metre quay leaves virtually no room for on-quay container buffering without obstructing the transhipment operations themselves. D3.1 [1] also explicitly identifies an empty storage zone further down the quay as a potential remote storage option, further supporting this configuration.

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C. Site utilities

The base configuration is **C1 — Absent utilities**, as [1] explicitly identifies the Zijlkwartier district as an example of this configuration. This means TPT operations would rely entirely on ambient conditions, functioning only during daylight hours with no permanent power supply on site. Given the open and public nature of the quay this is the most straightforward starting point requiring no infrastructure investment.

C2 — Temporary utilities represent a natural upgrade path, where mobile lighting and portable power supply — such as containerised batteries or ZES packs delivered with the incoming vessel — would extend operational hours beyond daylight. This would be particularly relevant if PostNL's logistics needs require operations outside standard daylight hours.

D. Waterway interface

The recommended configuration is **D3 — Waterside enablement**, consistent with the A4 cargo handling recommendation. A floating mooring structure such as a spud barge or modular pontoon provides the vessel with a stable mooring face on the water side, decoupling TPT feasibility from the narrow and constrained shoreside geometry. D3.1 [1] explicitly notes that D3 can be combined with water-based cargo handling to create an almost entirely water-based TPT constellation with minimal shoreside footprint — which directly addresses the key constraints at Zijlkwartier of the narrow 6.72-metre quay and the adjacent public road.

Should the A2 fallback be adopted instead, **D2 — Shoreside enablement** would be the more appropriate waterway interface configuration, providing secure parallel mooring through bollards and fendering to support safe reach stacker operations alongside the vessel.

E. Hinterland interface

The recommended configuration is **E2 — Direct delivery**, with PostNL cargo services across the road as the primary anchor customer. Since the recommended storage configuration (B3) uses the unused storage area on the north side of the PostNL distribution centre, cargo is effectively delivered directly into the PostNL premises once it reaches the storage area. Given PostNL's existing last-mile distribution operations, onward delivery to the broader cluster of smaller actors within the Zijlkwartier district could potentially be handled by PostNL as part of their existing logistics services.

F. PUBLIC INTERFACE

The recommended configuration is **F2 — Limited access**. D3.1 [1] documents that during previous cargo transfer operations at this quay, a minor mobile concrete barrier was erected to prevent accidental intrusion by third parties — demonstrating that limited access control is both feasible and has been practiced at this specific site. The existing lightweight fencing still present at the quay provides a starting point, though additional fencing would be needed to manage truck movements between the quay and the PostNL storage area across the public road.

G. TEMPORAL AVAILABILITY

The recommended configuration is **G2 — Constrained availability**. While the quay itself is publicly accessible at all times, practical TPT operations are constrained by two factors. First, the public road running alongside the quay creates safety concerns that limit when truck movements between the quay and the PostNL storage area can safely take place. Second, access to the PostNL storage area is dependent on PostNL's operating hours, meaning TPT operations would need to be coordinated within their working schedule.

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H. Operating model

The recommended configuration is **H2 — Integrated TPT**, with PostNL cargo services as the proposed anchor partner. While [1] identifies PostNL only as a potential customer, this deliverable recommends pursuing a deeper integration where PostNL acts as both the primary customer and the storage host — consistent with the B3 and E2 recommendations above. This would create a coherent and predictable operational model embedded within PostNL's existing supply chain. This integration is however contingent on stakeholder engagement with PostNL to confirm their interest in such an arrangement.

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3.4.5. KATWIJK – JOH GUYT # 5

A. Cargo Handling

Recommended configuration is **A2 — Mobile, ashore**. D3.1 [1] explicitly notes that *"heavy vehicles such as reach stackers etc. could begin operations here with relative ease"* given the recently upgraded hard surface designed for heavy cargo transhipment. The existing Joh Guyt operations use a wheeled digger with a semi-fixed platform to unload bulk vessels — demonstrating that vehicle-based cargo handling from vessel to quay is already proven at this specific location. A reach stacker follows the same operational principle but adapted for containers rather than bulk materials, making A2 a natural and low-investment fit for the TPT at this site.

B. Cargo Storage

Recommended configuration is **B1 on-quay.** The quay area of approximately 30-50 metres provides limited space for on-quay container storage (B1) alongside active transhipment operations, or one could also change some of the parking spots to storage. If that is not possible, a remote storage arrangement (B3) could be identified within the Heen Industrial Park would be a key requirement before the TPT can be fully activated.

C. Site utilities

Recommended configuration is **C3 — Permanent:** D3.1 [1] explicitly identifies all bulk terminals as examples of C3 permanent utilities. Joh Guyt #5 is an active bulk transhipment site with ongoing sand and soil operations, meaning industrial-grade utilities including power and lighting are already present and can be integrated into TPT operations without additional utility investment.

D. Waterway interface

Recommended configuration is **D2 — Shoreside enablement.** D3.1 [1] documents a recently upgraded infrastructure designed specifically for vessel calls, and satellite imagery confirms barges moored at the site — both pointing to existing shoreside mooring capability consistent with D2. D3 — Waterside enablement via a spud barge or modular pontoon — is retained as a fallback given the quay length of 30-50 metres relative to the 55-metre AUTOFLEX vessel; if the vessel cannot be fully accommodated within the available shoreside length, a floating mooring extension would resolve this constraint.

E. Hinterland interface

Recommended configuration is **E2/E1 — Direct and last-mile.** Joh Guyt themselves represent a direct delivery opportunity (E2) as the anchor customer, with cargo moving seamlessly between the vessel and their existing sand and soil operations under the integrated shared use arrangement. The surrounding cluster of building materials suppliers and contractors in the Heen Industrial Park would require truck-based last-mile delivery (E1) given they are not directly integrated with the quay.

F. Public Interface

Recommended configuration is **F2 — Limited access**. D3.1 [1] explicitly cites the quay area at Joh Guyt in Industrieterrein 't Heen as an example of F2 limited access. While the Joh Guyt premises itself is fenced off, the open waterfront quay identified for TPT deployment is not fenced. D3.1 notes that access has been limited to some extent by the nature of the ongoing bulk operations and suggests that coordinated restriction efforts via traffic wardens or temporal fencing could enforce the required level of access control for TPT operations.

G. Temporal Availability

Recommended configuration is **G2 — Constrained:** D3.1 [1] explicitly states that coordination with the Joh Guyt facility must be ensured to safeguard quay availability for both existing bulk operations and TPT operations. The ongoing sand and soil transhipment activities using the digger-based handling equipment will occupy the quay during Joh Guyt's working hours, meaning TPT operations are naturally constrained to windows when the bulk operations are not active — most likely outside normal working hours or during periods of lower bulk activity.

H. Operating model

Recommended configuration is **H3 — Ecosystem.** While Joh Guyt would host the TPT under a formal shared use agreement, the primary cargo base would come from the broader cluster of building materials suppliers, contractors and industrial actors in the Heen Industrial Park rather than from Joh Guyt's own bulk operations. This makes H3 — Ecosystem TPT the more appropriate configuration, where the TPT serves multiple actors within the surrounding industrial area while being physically hosted within Joh Guyt's premises. A formal agreement with Joh Guyt as host operator would still be required, but the TPT's commercial viability depends on attracting cargo from the wider ecosystem rather than from a single integrated anchor tenant.

3.4.6. DEN HAAG – BOUWMAAT XL

A. Cargo Handling

D3.1 [1] does not mention specific cargo handling equipment at Bouwmaat XL. However, the site has a 700m² quay area with 10m width — sufficient for a reach stacker to operate. D3.1 [1] explicitly suggests the site could be used for TPT purposes outside opening hours, implying mobile equipment brought in as needed. This points to **A2 — Mobile, ashore**.

B. Cargo Storage

D3.1 describes 700m² quay area for transhipment, 1,250m² outdoor storage area, 3,500m² parking space as potential additional storage, and a brownfield adjacent that could be developed. This gives multiple storage options — **B1** on-quay and potentially **B3** remote using the parking area or brownfield. It also gives the site a potential to grow if a TPT here proves successful and attracts more cargo.

C. Site Utilities

Active building materials supplier with confirmed operations — D3.1 identifies all bulk terminals as C3. Bouwmaat XL is an active commercial site, so **C3 permanent utilities** are confirmed.

D. Waterway interface

The recommended configuration is **D2 — Shoreside enablement**: Google Earth confirmed previous vessel mooring at the 70m quay.

E. Hinterland interface

Bouwmaat XL as direct anchor customer **E2 – Direct delivery**; broader Binckhorst cluster requiring last-mile **E1 Last-mile delivery**.

F. Public Interface

Recommended configuration is **F2 — Limited access.** D3.1 explicitly confirms the entire area is fenced off, providing a good foundation for access control. However, D3.1 also notes the option to further fence off the storage area from the parking lot — with ground markings suggesting this was previously in place — indicating that additional internal fencing is needed before full operational separation between the TPT zone and the parking area can be achieved.

G. Temporal availability

Recommended configuration is **G2 — Constrained:** D3.1 explicitly suggests the site could be used for TPT purposes outside opening hours, noting that an appropriate access control procedure between the parking area and storage area would be needed for inside opening hours use. TPT operations are therefore naturally constrained to coordination with Bouwmaat XL's business hours, making G2 the appropriate configuration.

H. Operating model

Recommended configuration is **H2 - integrated:** Bouwmaat XL acts as both the primary anchor customer and the host of the TPT infrastructure under a formal shared use agreement. D3.1 explicitly suggests the site could generate additional revenue for Bouwmaat XL by allowing their premises to be used for transshipment purposes, confirming that an integrated model where Bouwmaat XL is central to the TPT operation is the intended arrangement.

3.4.7. DELFT – WESTERN WATERFRONT DIGGER SITE

A. Cargo handling

Recommended configuration is **A2: Mobile ashore** handling equipment of this type already operates on the quay, and the frontage is very long — measured at approximately 700m from satellite imagery — even though the strip is only around 9m deep. A2 is therefore considered the primary configuration and the minimal-change, near-term option consistent with selecting this site for ease of transition. The only real constraint is the shallow 9m depth, which limits cross-strip staging at any given point — so A4, mounting handling equipment afloat, is retained as an option at specific points where strip depth rather than length is the binding issue, rather than as a throughput upgrade. One caveat: the equipment currently on the quay is bulk-handling plant, so a container-capable reach stacker would still need to be brought in even under A2.

B. Cargo storage

Recommended configuration is **B3 — Remote storage:** The quay is shallow at around 9m, which limits stacking and prolonged storage directly on the waterfront, so the storage solution must sit largely off the strip. Remote storage (B3) is the near-term, minimal-change primary — utilising storage options in the close industry area, such as the former NKF cable factory or the neighbouring truck transport. Where such remote space cannot be secured, or where it is preferable to keep storage off the strip entirely, floating storage (B2) is the natural water-based alternative: containers buffered on a moored barge or pontoon, consistent with the afloat handling (A4) and waterside mooring (D3) options and with the site's broadly water-based character.

C. Site utilities

Recommended configuration is **C3 permanent:** The quay hosts an active bulk operation and several established companies along its frontage, so industrial-grade power and lighting can reasonably be expected to already serve the waterfront and be available to a TPT without new installation, leading to the C3 option for site utilities with permanent configurations. This should be confirmed for the specific stretch of open quay where the TPT would operate, as the existing supply may serve the adjacent businesses rather than the open strip itself.

D. Waterway interface

Recommended configuration is **D2 shoreside enablement:** The long quay frontage allows a vessel to moor parallel against the wall and be attended directly from the shore, which matches the transhipment already taking place at the site and suits the A2 ashore handling, leading to D2 shoreside enablement as the primary configuration. Where handling is instead placed afloat (the A4 option), D3 waterside enablement becomes the natural pairing — a semi-permanently moored platform with no onboard propulsion, relying on a push boat, which lowers CAPEX and reduces exposure to equipment tampering and forms an almost entirely water-based constellation with minimal shoreside footprint.

E. Hinterland interface

Recommended configuration is **E1 Last-mile delivery:** The surrounding actors — Prysmian, the home suppliers and furniture stores — are separate from the quay rather than embedded with it, so cargo would leave the terminal by truck for onward delivery, leading to E1 last-mile delivery as the configuration. The elevated bulk-storage structure already observed at the site, which lets a truck drive underneath with an empty trailer and be filled directly, points to an efficient drive-through handover worth adapting for containers to streamline this last-mile transfer.

F. Public interface

The recommended configuration is **F2 Limited access:** A public road and an adjacent bike and pedestrian strip run directly alongside the quay, so although the current bulk operation runs with little access restriction, a container TPT would need active control to keep people clear of suspended loads — leading to F2 limited access as the configuration. The cross-canal Avalex precedent, where fencing was erected on the public road on each side of the crane to restrict access to relevant people only, provides a proven template to apply here.

G. Temporal availability

Recommended configuration is **G2 constrained availability:** The quay is shared among several active companies and an ongoing bulk operation along its frontage, so TPT windows would have to be coordinated around existing use rather than treated as continuously available, leading to G2 constrained availability as the configuration.

H. Operating model

Recommended configuration is **H1 independent:** No single actor hosts or operates the quay, and while the site sits among potential customers — Prysmian, the container provider, the truck transport company and various home and furniture suppliers — no collaboration or shared arrangement with these actors is confirmed. The TPT is therefore best framed as an independent operation running on the open quay, leading to H1 as the configuration, with the surrounding cluster representing potential demand rather than committed partners.

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3.4.8. ROOSENDAAL – DHL

A. Cargo handling

The site is a distribution centre that can be an anchor customer. In addition, some cargo would go to hinterland as the site has space for some temporary storage. This implies some internal movements, loading/offloading ships and trucks. This points to **A4 — Mobile, afloat**.

B. Vargo storage

As mentioned under point A, the site is a potential anchor customer and has space for some temporary storage of cargo bound to/from hinterland. This motivates – **B1** on-quay.

C. Site utilities

Active distribution centre at site with established utilities. Power grid should be available, hence **C3 permanent** is chosen.

D. Waterway interface

Google Earth shoved that there is no quay front at site, but that there is space for a temporary floating or jack-up quay needed → **D3 waterside enablement**

E. Hinterland interface

Site is potential anchor customer, but the area also holds several other potential customers → **E1 Last-mile delivery and E2 Direct delivery**

F. Public interface

Recommended configuration is **F3 Restricted access** – Restricted access already in place.

G. Temporal availability

Recommended configuration is **G1 — Continuous** the site is an active distribution centre, so coordination with daily operations is needed. However, the TPT could become an integrated part of the daily operations, including expanded services to hinterland.

H. Operating model

Recommended configuration is **H2 - integrated:** The operations would most likely be integrated to DHL operations. Both as a waterborne alternative for their existing cargo flows, and for potentially additional hinterland services.

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3.4.9. BREDA NORTH – VAN IERSEL

A. Cargo handling

The site has potential for short-term storage, some of which would not be directly at the quay. Space is limited, and trucks for last mile will have limited space for movement. The agility of a reach stacker seems preferable in this situation. The alternative would be a fixed crane that loads directly to truck, which would increase coordination complexity and probably prolong the port calls. This points to **A2 — Mobile, ashore**.

B. Cargo storage

Storage is somewhat limited. But some capacity should be possible to establish at site, potentially including some of the space on the opposite side of the building to the parling lot. This motivates — **B1 on-quay.**

C. Site utilities

Active company at site with established utilities. Power grid should be available → **C3**.

D. Waterway infrastructure

Google Earth confirmed previous vessel mooring in 2016. But some upgrades might be needed → **D2 — Shoreside enablement**.

E. Hinterland interface

Main customers are within the northern Breda area requiring last-mile (**E1 Last-mile delivery**).

F. Public interface

Recommended configuration is **F3 restricted access** — Restricted access already in place.

G. Temporal availability

Recommended configuration is **G1 — Continuous** Operations should be possible without interfering with the business daily activities. There is no apparent usage of the quay, but parking lot would have to be partially converted to storage.

H. Operating model

Recommended configuration is **H1 - independent:** With the main customers being in the surrounding area, the TPT would be an independent terminal offering transhipment to customers in the general area.

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3.4.10. BREDA – DYCORE

A. Cargo handling

There is little space at the quay front, but enough to service the vessel and move cargo from the quay to storage a bit back from the quay front. The agility of a reach stacker seems preferable in this situation, which points to **A2 — Mobile, ashore**.

B. Cargo storage

The area is large and seems to have significant spare capacity. Some replanning of the site layout would be needed to accommodate both container storage and Dycore concrete structures storage, but this should be possible to solve — **B1** on-quay

C. Site utilities

Active bulk terminal and concrete module factory with confirmed operations → **C3**.

D. Waterway interface

Google Earth confirmed vessel mooring in 2205 → **D2 — Shoreside enablement**.

E. Hinterland interface

Nearby distribution centre anchor customers motivate **E2 Direct delivery**; broader Breda area requiring **E1 Last-mile delivery**.

F. Public interface

The area is fenced off and gated, restricted access already in place **F3 Restricted access**

G. Temporal availability

Recommended configuration is **G1 — Continuous** Operations should be possible without interfering with the Dycore daily activities if operations are aligned, however, it is also possible that there could be some periods, e.g. during bulk vessel calls, that TPT operations would have to be put on pause **G2 – Constrained** is hence also feasible.

H. Operating model

Recommended configuration is **H2 - integrated:** The operations would have to be integrated with Dycore operations to ensure that no impact occurs. This includes operational planning, area planning, and possibly shared use of resources such as workers that could operate both TPT reach stacker and similar mobile equipment used to move the Dycore concrete structures.

3.4.11. EINDHOVEN – EKKERSRIJT (UBIQUITY)

A. Cargo handling

D3.1 does not mention specific cargo handling equipment at Ekkersrijt. However, the site has limited quay width, hence limited storage. There could be space for a reach stacker, but cargo needs to move swiftly from the quay to storage at the adjacent distribution centres, or to hinterland by truck. The agility of a reach stacker seems preferable in this situation. The alternative would be a fixed crane that loads directly to truck or terminal tractor that moves containers to the distribution centres. This points to **A2 — Mobile, ashore**.

B. Cargo storage

Storage is somewhat limited. The quay length is a hundred meters but can be extended by several hundred meters by clearing brush. But only 6.2 meters wide. Adjecent quay, connected to Rhenus, is 10 meters wide, with a section that is 25 meters wide. This gives multiple storage options (if upgrades are included) — **B1** on-quay and **B4** ecosystem storage using the distribution centres.

C. Site utilities

Active distribution centres with confirmed operations → **C3 Permanent**.

D. Waterway interface

Google Earth confirmed previous vessel mooring and bollards are visible → **D2 — Shoreside enablement**.

E. Hinterland interface

Distribution centres anchor customers motivate **E2 Direct delivery**; broader Ekkersijt area requiring last mile motivates **E1 Last Mile delivery**.

F. Public interface

Recommended configuration is **F1 — Open access** as there is nothing restricting pedestrians from walking through the site, not cars passing the quay. However, it is an industry site making it less attractive, and satellite imagery indicates little traffic as no cars are observed on the road.

G. Temporal availability

Recommended configuration is **G1 — Continuous** Operations should be possible without interfering with the distribution centre daily activities. There is no apparent usage of the quay and road, apart from occasional parked trucks.

H. Operating model

Recommended configuration is **H2 - integrated:** With the distribution centres as anchor customers, most cargo would be moved to and from these. While usage of infrastructure, apart from the quay, is not foreseen, it could be possible that the distribution centre employs the reach stacker operator and handles traffic management.

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3.4.12. EINDHOVEN - CENTRE

A. Cargo handling

D3.1 does mention the possibility to use the bulk crane/digger at the bulk terminal if outfitted with a spreader. This, and other issues, would require tight cooperation and coordination with site activities. The other option in the centre, the quey near MIREC, was therefore chosen. There is no existing equipment at this site, hence, a reach stacker is evaluated as suitable. It would handle transhipment between ship and quay and loading trucks. It can also deliver cargo to MIREC directly. **A2 — Mobile, ashore**.

B. Cargo storage

Potential space for storage on quay should be sufficient. But some cargo can be delivered directly to potential customer IMEC. Hence — **B1** on-quay and **B4** ecosystem storage using the IMEC current waste container storage area for their cargo.

C. Site utilities

IMEC with confirmed operations present, needs some work, but full utilities should be possible → **C3 Permanent**.

D. Waterway interface

Google Earth confirmed previous vessel mooring but bollard status and quey integrity cannot be confirmed. Some work might be needed but should not prevent full enablement from shore side → **D2 — Shoreside enablement**.

E. Hinterland interface

IMEC anchor customer motivates **E2 Direct delivery**; broader area requiring last-mile **E1 Last Mile**.

F. Public interface

Recommended configuration is **F2 Limited access** — access is not restricted as streetview shows that it is possible to access the area by car. At the same time, gates can be identified, but they do not completely fence of the greater industrial area. The area is industrial and trucks moves there regularly. It is expected that public traffic is limited. Some access limitation is there, and some additional might be required.

G. Temporal availability

Recommended configuration is **G1 — Continuous** Operations should be possible without interfering with the IMEC daily activities. There is no apparent usage of the quay and road, apart from occasional parked trucks. It is also possible to access the quay without passing through the IMEC operational area, by a road between IMEC and the bulk quay area.

H. Operating model

Recommended configuration is **H2 - integrated:** With the IMEC as anchor customers, much cargo would be moved to and from their storage area. While usage of IMEC infrastructure, apart from the quay, is not foreseen, it could be possible that IMEC employs the reach stacker operator and handles traffic management. **H1 – independent** for the greater area, the TPT could function independently from IMEC.

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3.5 THE S&C LOCATINS

While stow and charge hub (S&C) locations for the AUTOFLEX transport system were not chosen in [1], the candidate locations were analysed and rated according to how well suited they were. In this section we discuss and chose the locations included in the AUTOFLEX network which also should serve as S&C locations. In addition, the section includes a short discussion of Utrecht and Moerdijk

3.5.1. AMSTERDAM

For Amsterdam the proposed S&C location was Holland Cargo Terminal, receiving a full score. This location will be used as S&C in the further transport system analysis. This is a big terminal receiving deep sea vessels, making it potentially hard to be allowed to call with a small vessel. However, inland vessels are observed transferring cargo here. If the terminal is to be used, ZES charging would have to be established but local zero emission energy production is already in place.

3.5.2. ROTTERDAM

There are several potential sites for an S&C in Rotterdam, some of which were investigate in [1]. The main challenge in Rotterdam is arguably to find a terminal that would accept small vessels such as the AUTOFLEX vessel, given that multiple IWT ship operators[5] complain about prolonged waiting times in the Port of Rotterdam (and the Port of Antwerp) due to prioritisation of larger vessels. However, we assume that it is possible to include one terminal in Rotterdam as an S&C node of the AUTOFLEX network. Exact location will not influence the simulation results in chapter 4 much as the potential terminals are within the same geographical area. Another aspect is that the area has generally good grid connection, with local production of zero emission energy. Hence, it is assumed that if there is no observed production at site, green energy is available through the grid. For the further analysis we therefore chose one of the terminals that are observed to accept inland ships, namely the Hanseatic GlotGlobal terminal in Waalhaven. It should be noted that ZES announced that ZES pack charging and swapping will become available in Rotterdam, which supports our assumption that Rotterdam can function as an S&C hub.

3.5.3. HERTOGENBOSCH

Hertogenbosch received the highest S&C hub suitability rating in [1]. It was also used as an S&C hub in the network derived in section 2.5 for high transport capacity scenarios. In fact, Hertogenbosch already offers ZES pack charging and swapping. As such, Hertogenbosch is chosen as an S&C hub to support growth.

3.5.4. ALPHEN AAN DEN RIJN

As ZES already offers charging and swapping of ZES packs in the CCT terminal in Alpherium, this location is effectively functioning as an S&C hub. Since it is also a central node of the network derived in section 2.5 it is chosen as an S&C hub.

3.5.5. UTRECHT

The analysis in section 2.5 resulted in a network that includes one connection to Utrecht, except in the high demand case where three connections were found. Utrecht was also

[5] Ship operators have been interviewed by the project as part of the work package 5.

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investigated in [1] and scored well, although it did not receive a full score. It has an existing container terminal, some local zero emission energy production, and would only need installation of ZES charging. However, since the AUTOFLEX network proposed in section 2.5 have few routes to Utrecht, even in the high capacity scenario, and since any vessel calling to Utrecht does so from Either Amsterdam, Alphen aan den Rijn or Rotterdam, all of which are chosen as S&C hubs, there is no need to establish Utrecht as an S&C hub for the AUTOFLEX network.

3.5.6. MOERDIJK

Moerdijk was investigate in [1] as a stow and charge candidate and received the maximum rating. Moerdijk has a port and container terminal already, as well as solar and wind energy production. As such it is well suited as a stow and charge hub, with relatively low foreseen investment needs (ZES charging needed). In fact,, ZES announced that Moerdijk will become a terminal for charging and swapping ZES packs. The results in section 2.5 indicates that Moerdijk is not a central node for the AUTOFLEX transport system. However, this highly depends on the feasibility of calling to Rotterdam. Moerdijk already functions as an inland port connection to Rotterdam with regular services. In a scenario where the AUTOFLEX vessel cannot call to Rotterdam, Moerdijk could be the connection point.

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4 PERFORMANCE EVALUATION

This chapter presents the performance evaluation of the candidate networks that were derived in chapter 2 . In section 2.5 the results of solving the network design problem for respectively 10, 15, 20, 25 and 30 ships were presented. The optimisation problem was solved with a simplified model of energy estimation, time to pass bridges and locks, cargo flows and terminal operations. The results of solving the optimisation problem therefore represent theoretical maximums in terms of roundtrips and transported containers. In this chapter we will run simulation in the tool SIMPACT [9] to further investigate the proposed routes and schedules in simulations with increased model fidelity, including concrete TPT and S&C locations. Some adaptations to routes and schedules will be made and in such cases the changes will be discussed. The simulation results will provide more insight into performance in terms of how many times a route can be completed within a week, how much cargo can be moved on each route, estimated lead times and energy usage. Furthermore, an evaluation of transport cost will show differences between a short and a long route, and how cost differs if only one route is realised or a network of ten routes is realised.

Section 4.4 contains both the logistical analysis leading to typical voyage definitions of task 3.4, and the logistical and cost performance evaluation of task 3.5.

4.1 WHY THE PERFORMANCE EVLUATION IS NEEDED

The reason why we need to investigate the performance of the proposed network from section 2 in more detail is that the optimisation model used in section 2 was made for providing strategical decision-making support. The scope of the optimisation model is to identify what locations, routes, and schedules holds the highest potential to replace as much as possible road transport with high external cost impact. This provides insight into what routes should be prioritised initially, and how the network should be expanded as vessels are added to the fleet.

However, solving optimisation problems with high model fidelity is computationally costly. The more complicated the model is, the longer time it takes to solve the optimisation problem and the higher the requirements to the computer hardware becomes. As such, some important simplifications were made to make it possible to efficiently run multiple scenarios and solve the optimisation problem to gain insight into what routes and schedules should be investigated further. The result is a reduced set of scenarios which makes it feasible to evaluate them in simulations with higher model fidelity, and hence, improved accuracy. Section 4.2 discusses how SIMPACT improves accuracy relative to the optimisation model.

4.2 ACCURACY IMPROVEMENTS IN SIMPACT VERSUS THE OPTIMISATION MODEL

The following will elaborate on the modelling simplifications of the optimisation model discussed in section 2.6 , and how SIMPACT improves accuracy by higher model fidelity.

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4.2.1. VOYAGE DURATION IMPACT BY LOCKS AND BRIDGES

While the optimisation model in chapter 2 accounted for delays due to passing locks, it could not capture delays introduced by waiting for bridges to open as the dynamic ship height was not modelled.

SIMPACT has an API to EuRIS[6] for retrieving routes and information about bridges and locks on the routes. This is used to determine if delays due to opening bridges or passing locks occurs. For bridge passing, the ship hight is calculated based on the ship model, the carried cargo, and the draft for the given loading condition, see [10] section 3.2 therein. In SIMPACT, the hight above water of the vessel is calculated based on the ship model and the loading condition. As SIMPACT also retrieves information about bridges from EuRIS, this makes it possible to detect if a bridge needs to be opened or not. Hence, this is one of the accuracy improvements achieved by using SIMPACT to evaluate the optimisation model results.

In the SIMPACT simulations, an average delay of 15 minutes is assumed for passing a lock and 5 minutes for bridges. The latter assumption is made due to some moveable bridges being part of lock complexes and being operated as part of the lock procedure, and some bridges being very close to each other such that the opening of one implies the opening of another. For a specific bridge the waiting time can hence be longer, while for others shorter. This assumption is made because the EuRIS API does not distinguish between a bridge part of a lock complex and a standalone bridge, nor does it provide typical waiting times for specific bridges.

4.2.2. CARGO FLOW AND HANDLING IMPACT ON PORT CALL DURATION AND LEAD TIME

Another simplification made in the optimisation model is that it did not simulate the actual cargo flow. This means that it did not capture cargo lead times, nor how cargo handling influences the duration of port calls. SIMPACT on the other hand models each cargo unit and tracks it throughout the simulation. This means that the simulation includes the loading of the cargo unit onto vessels, the transport of the cargo unit by the vessel, and the unloading of the cargo unit. This includes transhipments where a cargo unit is moved across more than one route and vessel to reach its destination. E.g., a container originating in Amsterdam with destination Katwijk is transported from Amsterdam to Alphen aan den Rijn by Vessel 6, then from Alphen aan den Rijn to Katwijk by Vessel 8. SIMPACT accounts for each loading and unloading activity, sailing time, and dwell time at terminals.

An important consequence of this is that SIMPACT calculates the port call duration dynamically based on the number of loaded and unloaded containers, the differences in lifts per hour that each location is capable of, and the approach/mooring and depart time. This is a significant improvement over the optimization model from chapter 2 where all port call times were assumed identical.

4.2.3. ENERGY CONSUMPTION AND BATTERY SWAPS

The final significant simplification made in the optimization model is the energy modelling. The optimisation model includes energy consumption by the vessel from the battery container as a fixed kWh per nautical mile. Which is a significant simplification.

SIMPACT on the other hand does not make this simplification and has two levels of simulation fidelity in terms of energy estimation. The first model fidelity level is for the logistical simulations where energy consumption is modelled through a speed-power curve,

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[6] EuRIS

which is based on scale model tests of the Oscar 2.0 design. In addition, SIMPACT includes auxiliary loads, additional energy spent during approach and departing ports, and for position keeping while waiting for a bridge or lock. This means that energy estimation accuracy is increased, such that the need for swapping battery container is more accurate.

Regarding battery swaps, the optimisation model assumes that there is always an available battery when it needs to be swapped. SIMPACT on the other hand models and simulates each individual battery, its location and state of charge. This means that situations where a vessel needs to wait for battery charging is captured. Furthermore, the time required to swap a battery is simulated by the handling time specific to the individual location.

The second simulation fidelity level of SIMPACT is higher accuracy simulations of specific voyages. These simulations are used when the logistical simulations are completed and the different loading conditions for each segment of a voyage has been derived. These simulations are used for cost and emission evaluations for operating on specific routes. In this case the energy estimate is based on a hydrodynamic model that accounts for draft, speed, weather, and canal dimensions relative to ship dimension. In addition, auxiliary consumption, station keeping, and acceleration and deceleration consumption. This significantly improves the energy estimation relative to the optimisation model and provides basis for energy cost estimation, and for confirming that the battery range is sufficient for operating on a given route.

4.3 METHOD

The routes and schedules, as well as estimated transport volumes, from section 2.5 are used to configure simulations in SIMPACT. SIMPACT is an agent-based simulator for both logistic simulations, and ship concept performance evaluations. The method behind SIMPACT is described in [11], [12], and upgrades as part of AUTOFLEX in [10].

The method based on SIMPACT which was employed in the context of task 3.4 and 3.5 is illustrated in Figure 8. First the SIMPACT simulator for logistical analysis was configured with the locations for TPTs and S&Cs, vessels and the routes they were to operate on in the network, the transport demand per location, and the sailing schedule per vessel and route. Then, a logistical simulation was run and the results were analysed to identify if any vessels could not keep their schedules, if any demand could not be served or if there were bottlenecks, and if the placement of S&Cs combined with number of ZES battery containers in the system was sufficient. Based on identified challenges the route and schedules were adjusted and simulations repeated. An important part of this was to determine which locations served as transhipment terminals to connect routes, and to adjust some of the served transport demand. This iterated until all vessels kept their schedules, the configured transport demand was served, and the ZES battery container and charging station capacity was balanced (not too high but sufficient to avoid delaying voyages).

The next step of the method was to configure cost parameters and then run the typical voyages in the energy estimation simulator. The outcome was used to estimate transport cost for each evaluated voyage.

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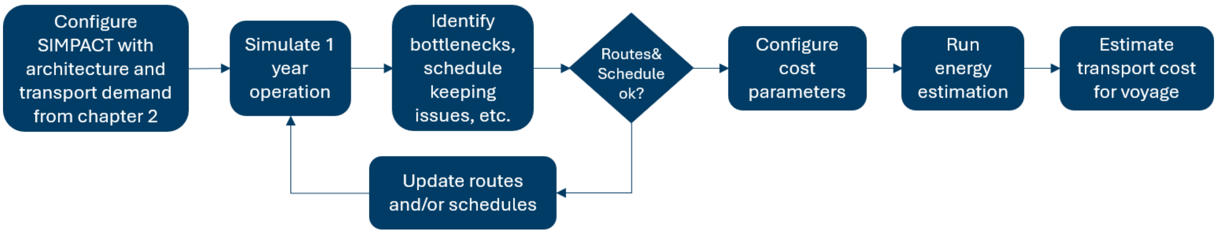

Figure 8: The performance evaluation method

The simulations in SIMPACT are configured as follows:

- Routes: Routes are based on the optimisation problem in section 2.5 , and are configured as roundtrips starting and ending in the same location. Routes are made up of waypoints, which are generated through the EuRIS API.
- Schedules per vessel are configured by connecting vessel and route and specifying how many roundtrips per week the vessel should complete the route. Simulations will show if the configured number of roundtrips are achievable, and if not, the schedule is adapted such that it is feasible.
- Transport demand: Origins and destinations are the geographical locations where cargo enters and exists the AUTOFLEX transport system. Each location which is an origin of cargo (see Table 27) is modelled through a process that adds new containers to the storage inventory of that location. The configuration of this model is based on specifying transport orders. Each order has a destination, the number of containers (specified by type, e.g. 40ft ISO), weight of each container, and how often the same order is repeated. By configuring multiple orders, it is possible to model the desired transport demand for each origin location. Note that if an order contains more containers than a vessel can load during a specific port call, the vessel will load as many containers as it can while the remaining containers will be loaded during a subsequent port call.
- Lead time: During simulations, each container is timestamped when it is added to the storage. Each container is then tracked throughout the simulation by its position (either at a geographic location or onboard a specific vessel). When it arrives to its destination, it is timestamped when it is discharged from the vessel. In this way, the lead time for each container can be tracked.
- Vessels: Vessels are modelled with their cargo capacity, dimensions, and speed-power curve or hydrodynamic model for energy estimation. The speed-power curve is used during the logistical simulations to capture ZES battery container swapping and charging, while the hydrodynamic model is used in the simulations leading to cost estimations. In both cases, consumption of energy from the battery containers considers loss between draining the battery and putting out the calculated power at the propeller. In the latter case, the draft and resulting hight above water is dynamically updated based on loading condition. The hight above water also considers the position of the cargo hold relative to the bottom of the vessel and the height of the cargo. Vessel configuration and energy models are based on the Oscar 2.0, for details see section 1.4 .
- TPTs and S&Cs: TPTs are modelled as cargo origin and destination locations (see transport demand above). S&Cs are modelled as origin/destination locations that in addition can replace the vessel battery containers and recharge them. Both TPT and S&C models also include the cargo handling equipment that they have, such that cargo

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handling rate in lifts per hour can be configured uniquely per location. Finally, both TPTs and S&Cs have an inventory of cargo which is updated through the process that adds containers to create the transport demand, and through vessels that discharge or load containers. Tracking the inventory enables identification of bottlenecks and evaluation of the location (TPT or S&C) storage capacity.

- Battery containers: Battery containers are modelled by their kWh capacity, their charging efficiency, and discharging efficiency. Furthermore, their state of charge and position (on a vessel or a S&C) are tracked throughout the simulation. For this simulation, one battery container is initially configured on each vessel, three at Rotterdam, and two each at Alphen aan den Rijn and Amsterdam.
- Simulation duration is set to one year; however, seasonal variations are not considered. This means that transport demand is assumed constant throughout the year.
- Cost parameters are described in more detail in section 4.4.4

While several iterations of simulations and design adjustments were conducted, the following sections will report on the results.

4.4 EVALUATION OF NETWORKS: THE AUTOFLEX TRANSPORT SYSTEM

The candidate networks from section 2.5 that we evaluated were the networks resulting from optimising a fleet of 10 ships. As the discussion in section 2.5.3 showed that this captures the backbone of the ATUOFLEX network and that it is only in growth scenarios that additional locations should be included. This is because modal shift from road to inland waterways will have the highest impact in this area. The details for routes and the achieved transported volumes from the optimisation problem are given in appendix 5.1 . The following sections will first give the routes and schedules per vessel configured in SIMPACT, and then the simulated transport demand per location. Finally, section 4.4.3 presents logistics simulation results and battery capacity evaluation, and section 4.4.4 presents a cost evaluation of two routes, while section 4.4.6 discusses results and concludes the performance evaluation.

4.4.1. ROUTES PER VESSEL

The routes obtained from the optimisation problem were mostly used unchanged in the SIMPACT simulations, except for some modifications to the routes of Vessel 5, 7 and 9. In contrast, the sailing schedule had to be modified for several vessels. The modifications to routes and schedules had to be done due to accuracy improvements achieved by SIMPACT simulations, as discussed in section 4.2 . For instance, the Delft – Den Haag – Rotterdam – Delft route was scheduled for 10 roundtrips per week in the optimisation problem result, while SIMPACT simulations found that only 7 roundtrips per week are feasible. Some of the longer routes, such as Den Haag -Alphen aan den Rijn – Amsterdam – Den Haag was less impacted by the modelling assumptions such that the schedule from the optimisation problem not only proved feasible, but also that a slightly higher roundtrip frequency could be scheduled.

Through the iterative process of simulating the logistical operations and adjusting routes, schedules and transport demand, the final routes and schedules were determined. The following listing presents the vessels with the final routes and schedules that were simulated in SIMPACT and which the results were derived from. Deviations from the optimisation problem results are highlighted.

Vessel 1:

- Route: Katwijk – Den Haag – Rotterdam – Den Haag – Katwijk
- Schedule: 6.3 roundtrips per week

Vessel 2:

- Route: Alphen aan den Rijn – Den Haag – Leiden – Alphen aan den Rijn
- Schedule: 7.56 roundtrips per week

Vessel 3:

- Route: Den Haag – Rotterdam – Den Haag
- Schedule: 12.2 roundtrips per week
- **Updated** schedule: 9 roundtrips per week

Vessel 4:

- Route: Rotterdam – Den Haag – Leiden – Rotterdam
- Schedule: 6.73 roundtrips per week
- **Updated** schedule: 6 roundtrips per week

Vessel 5:

- Route: Delft – Den Haag – Rotterdam – Delft
- **Updated** Route: Delft - Den Haag – Rotterdam – Den Haag - Delft
- Schedule: 10 roundtrips per week
- **Updated** schedule: 7 roundtrips per week

Vessel 6:

- Route: Den Haag – Amsterdam – Alphen aan den Rijn – Leiden – Den Haag
- Schedule: 4.45 roundtrips per week

Vessel 7:

- Route: Rotterdam – Utrecht – Den Haag – Rotterdam
- **Updated** route: Den Haag – Rotterdam – Utrecht – Rotterdam – Den Haag
- Schedule: 4.51 roundtrips per week
- **Updated** Schedule: 4.25

Vessel 8:

- Route: Haarlem – Leiden – Katwijk – Alphen aan den Rijn – Haarlem
- **Updated** Route: Haarlem – Katwijk – Leiden – Alphen aan den Rijn – Katwijk – Leiden – Haarlem
- Schedule: 6.51 roundtrips per week
- **Updated** schedule: 5.5 roundtrips per week

Vessel 9

- Route: Den Haag – Alphen aan den Rijn – Amsterdam – Den Haag
- Schedule: 4.64 roundtrips per week
- **Updated** schedule: 5 roundtrips per week

Vessel 10

- Route: Rotterdam – Delft – Rotterdam
- Schedule: 16.78 roundtrips per week

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- **Updated** schedule: 12 roundtrips per week

4.4.2. TRANSPORT DEMAND

The estimated demand in section 2.5 is given in TEU. In the simulations used for the performance evaluation, we assume that containers are 40ft and 22 ton.

By operating on the routes and schedules resulting from the optimisation problem in section 2.5 , the estimated weekly cargo volumes in Table 27 column "TEU Estimated" were served (rounded to whole TEU). Through the iterative SIMPACT simulation and design update process we arrived at the final served volumes as given in column "TEU sim". The differences between the estimated served volumes of section 2.5 and the final served volumes archived through the SIMPACT simulations are the results of the changes in schedules and routes, as discussed in 4.4.1 and the iterative evaluations and design updates.

Table 27: Estimated weekly TEU by optimisation vs TEU per week achieved in simulation

Origin	Destination	TEU Estimated	TEU sim
Amsterdam	Alphen aan den Rijn	51	56
Amsterdam	Delft	46	4
Amsterdam	Katwijk	51	28
Amsterdam	Leiden	12	14
Amsterdam	Den Haag	58	56
Alphen aan den Rijn	Amsterdam	81	84
Alphen aan den Rijn	Delft	9	14
Alphen aan den Rijn	Katwijk	19	14
Alphen aan den Rijn	Leiden	32	42
Alphen aan den Rijn	Den Haag	173	154
Delft	Amsterdam	47	56
Delft	Alphen aan den Rijn	20	14
Delft	Haarlem	18	0
Delft	Katwijk	13	14
Delft	Leiden	29	28
Delft	Rotterdam	467	280
Delft	Den Haag	37	28
Haarlem	Katwijk	59	56
Haarlem	Leiden	97	70
Katwijk	Amsterdam	52	14
Katwijk	Alphen aan den Rijn	26	28
Katwijk	Delft	11	14
Katwijk	Rotterdam	85	84
Leiden	Alphen aan den Rijn	61	70
Leiden	Delft	26	0
Leiden	Haarlem	94	56
Leiden	Rotterdam	162	140
Leiden	Den Haag	114	98
Rotterdam	Delft	449	280

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Rotterdam	Katwijk	48	42
Rotterdam	Leiden	125	112
Rotterdam	Den Haag	626	504
Utrecht	Den Haag	108	98
Den Haag	Amsterdam	38	42
Den Haag	Alphen aan den Rijn	59	56
Den Haag	Delft	90	98
Den Haag	Haarlem	44	42
Den Haag	Katwijk	60	56
Den Haag	Leiden	141	140
Den Haag	Rotterdam	534	448
Den Haag	Utrecht	109	98
Total	-	4381	3523

4.4.3. RESULTS

The logistical performance per vessel will be discussed in this section. The focus will be on the capacity utilisation and lead time from origin to destination. In addition, a summary of transport system performance will be discussed in terms of combined lead times and total potential replaced road transport. Finally, the battery capacity will be evaluated.

First, after updating routes, schedules, and cargo volumes as discussed in the previous two sections, all 10 vessels were able to stay on schedule (see Figure 9). While most vessels have on average one to five hours to spare between roundtrips, vessels 3, 5 and 10 have minutes. This means that the results we present in the following are the best case scenario results where no disturbances occur. Furthermore, for the fleet, the simulated schedules would depend on continuous operation from an ROC.

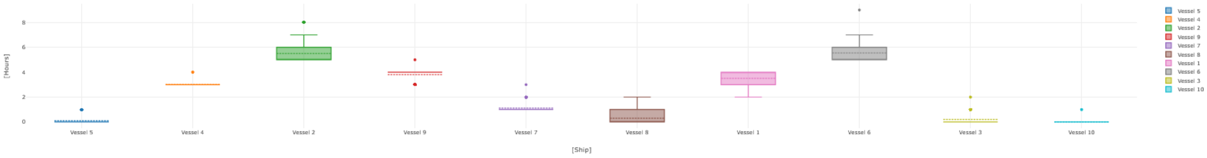

Figure 9: Available time between voyages per ship

4.4.3.1. *Vessel 1*

Starting with Vessel 1 we can see from the results that there is some spare capacity between Katwijk and Den Haag, while it is almost fully loaded between Den Haag and Rotterdam (Table 28). With an average of 6.3 roundtrips per week, the vessel moves 379 TEU, or 189 - 40ft containers per week, corresponding to approximately 7 million ton-kilometre (tkm) per year.

Table 28: Vessel 1 cargo capacity utilisation

Statistical value	Katwijk -> Den Haag	Den Haag -> Rotterdam	Rotterdam -> Den Haag	Den Haag -> Katwijk
Mean	65	93	93	75
Median	58	83	100	67

Q1	58	83	83	67
Q3	58	92	100	75

4.4.3.2. *Vessel 2*

Vessel 2 has significant spare capacity between Leiden and Alphen aan den Rijn, with an average utilisation of 39 percent, however, the longer connections are almost fully exploited (see Table 29). With an average of 7.56 roundtrips per week, the vessel moves 406 TEU or 203 – 40ft container per week, corresponding to approximately 5.8 million tkm per year.

Table 29: Vessel 2 cargo capacity utilisation

Statistical value	Alphen aan den Rijn -> Den Haag	Den Haag -> Leiden	Leiden -> Alphen aan den Rijn
Mean	93	93	39
Median	100	100	42
Q1	100	100	42
Q3	100	100	42

4.4.3.3. *Vessel 3*

Vessel 3 has almost no spare capacity at an average utilisation of 97 % with 100% utilisation for at least 75% of the trips (Q3), see Table 30. With an average of 9 roundtrips per week, it moves 420 TEU, or 210 – 40ft containers weekly. This corresponds to approximately 6.6 million tkm per year.

Table 30: Vessel 3 cargo capacity utilisation

Statistical value	Den Haag - Rotterdam	Rotterdam - Den Haag
Mean	97	97
Median	100	100
Q1	100	100
Q3	100	100

4.4.3.4. *Vessel 4*

Vessel 4 has some spare capacity between den Haag and Leiden, but has generally high capacity utilisation (Table 31). With an average of 6 roundtrips per week, it moves 280 TEU or 140 – 40ft containers. With most of the cargo being moved between Leiden and Rotterdam, the yearly transport work is approximately 7.3 million tkm.

Table 31: Vessel 4 cargo capacity utilisation

Statistical value	Rotterdam -> Den Haag	Den Haag -> Leiden	Leiden -> Rotterdam
Mean	97	78	97
Median	100	83	100
Q1	100	67	100
Q3	100	83	100

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4.4.3.5. *Vessel 5*

Vessel 5 has some spare capacity between Delft and Den Haag, but a high average capacity utilisation (Table 32). With an average of 7 roundtrips per week, it moves 592 TEU or 296 – 40ft containers weekly. This corresponds to approximately 6.8 million tkm per year. Perhaps a bit surprising considering it moves about twice the number of containers compared to Vessel 4, but the reason is the shorter distance between locations.

Table 32: Vessel 5 cargo capacity utilisation

Statistical value	Delft -> Den Haag	Den Haag -> Rotterdam	Rotterdam -> Den Haag	Den Haag -> Delft
Mean	83	100	100	94
Median	83	100	100	92
Q1	83	100	100	92
Q3	83	100	100	100

4.4.3.6. *Vessel 6*

Vessel 6 has high capacity utilisation except between Alphen aan den Rijn and Leiden (Table 33). Low utilisation between Leiden and Alphen aan den Rijn was also observed for Vessel 2. With an average of 4.45 roundtrips per week, it moves 336 or 163 – 40ft containers weekly. This corresponds to approximately 7.7 million tkm yearly. Again, the longer distance between some of the Vessel 6 locations explains the high tkm estimate.

Table 33: Vessel 6 cargo capacity utilisation

Statistical value	Den Haag -> Amsterdam	Amsterdam -> Alphen aan den Rijn	Alphen aan den Rijn -> Leiden	Leiden -> Den Haag
Mean	91	91	42	92
Median	100	100	52	100
Q1	75	75	58	75
Q3	100	100	42	100

4.4.3.7. *Vessel 7*

Vessel 7 has high capacity utilisation with almost no spare capacity (Table 34). At an average of 4.25 roundtrips per week, it moves 196 TEU, or 98 – 40ft containers weekly. It should be noted that it makes port calls to Rotterdam for battery package replacements only. As SIMPACT does not support dynamic routes (i.e., you always repeat the same port calls when operating on a route), the simulations include several port calls to Rotterdam where battery packs are not replaced. This causes the results to be somewhat conservative, and it could be possible to operate with a somewhat higher frequency. Nevertheless, the estimated transport work performed by Vessel 7 is approximately 11 million tkm, owing to the route having the longest sailing distance between locations. However, it should be noted that this route is the only route where the truck driving distance is considerably shorter than the sailing distance.

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Table 34: Vessel 7 cargo capacity utilisation

Statistical value	Den Haag -> Rotterdam	Rotterdam -> Utrecht	Utrecht -> Rotterdam	Rotterdam -> Den Haag
Mean	96	96	96	96
Median	100	100	100	100
Q1	92	92	92	92

4.4.3.8. *Vessel 8*

Vessel 8 operates on the route with most connections, and between both Leiden and Alphen aan den Rijn and Katwijk and Leiden, there is considerable spare capacity (Table 35). These connections are important to deliver cargo from other locations. With an average of 5.5 weekly roundtrips, the vessel moves 308 TEU or 154 – 40ft containers per week. This amounts to an estimated 7.5 million tkm per year.

Table 35: Vessel 8 cargo capacity utilisation

Statistical value	Haarlem -> Katwijk	Katwijk -> Leiden	Leiden -> Alphen aan den Rijn	Alphen aan den Rijn -> Katwijk	Katwijk -> Leiden	Leiden -> Haarlem
Mean	95	84	32	63	32	74
Median	100	92	25	67	25	83
Q1	100	83	25	50	25	58
Q3	100	92	50	75	50	83

4.4.3.9. *Vessel 9*

Vessel 9 has significant spare capacity, especially between Amsterdam and Den Haag (Table 36). This spare capacity could be used for the unserved cargo volume from Amasterdam to Delft, if capacity between Den Haag and Delft is increased, or if trucks transport the cargo from Den Haag to Delft. However, the latter solution is undesirable from the modal shift perspective. The vessel completes 5 roundtrips per week and moves 270 TEU or 135 – 40ft containers. This corresponds to approximately 7 million tkm, owing to the long distance from Amsterdam.

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Table 36: Vessel 9 cargo capacity utilisation

Statistical value	Den Haag -> Alphen aan den Rijn	Alphen aan den Rijn -> Amsterdam	Amsterdam - > Den Haag
Mean	93	81	50
Median	100	75	50
Q1	100	67	33
Q3	100	100	67

4.4.3.10. *Vessel 10*

The final route we investigated was that of Vessel 10. It is a direct short connection between Rotterdam and Delft, moving cargo to and from the seaport. The capacity is almost fully utilised (Table 37), and the vessel completes 12 roundtrips per week, moving an average of 560 TEU or 280 – 40ft containers. This corresponds to approximately 5.8 million tkm. While this number is low compared to some of the other routes moving less containers, the vessel operates along one of the busiest roads making modal shift here highly attractive.

Table 37: Vessel 10 cargo capacity utilisation

Statistical value	Rotterdam -> Delft	Delft -> Rotterdam
Mean	97	97
Median	100	100
Q1	100	100
Q3	100	100

4.4.3.11. *Summarized transport work*

If we summarize the transport work performed by the network, we find that this corresponds to approximately 97 thousand trucks, and 73 million tonkilometres yearly, see Table 38. Where the estimated number of trucks assumes two TEU per truck. However, since some of the cargo targeted by the AUTOFLEX transport system is moved on trucks and smaller transport vehicles carrying significantly less cargo than the equivalent of two TEU, the number of replaced goods vehicles could be even larger.

Another thing to note is that these numbers are for the distances between origins and destinations as defined in the AUTOFLEX transport system. While some of these locations are the true origin and destination, others are consolidation or distribution points which require some truck transport connections to the true origin and destination. As an example, a TPT may be located in an industry cluster or a more urban area. Some truck transport will then be needed to reach the customers that are not directly located on the quay. But this transport will be within the industrial or urban area as the network design is based on the customer cluster analysis of [1] such that long first/last mile transport is not needed. Another example where first/last mile transport is not needed, from the perspective of Randstad, is Rotterdam where cargo coming in or going out is mostly related to the deep-sea ships such that movements are between the S&C and deep-sea terminal. All these movements, within ports, industrial or urban areas, will be over short distances and possible to do with electric vehicles.

The final point to notice is that the 10 vessel network was estimated in section 2.5 to be able to capture 27% (4381 TEU) of the total convertible cargo (16220 TEU – see appendix 5.2),

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whereas in this section where we performed the logistical simulations, we were only able to move 3523 TEU. This means that there is still room for increasing the capacity of the network and replacing more truck transport.

Table 38: Summarized yearly transport work for 10 vessel AUTOFLEX network

Vessel	Trucks replaced weekly [#]	Trucks replaced yearly [#]	Transport work yearly [tkm]
Vessel 1	189	9828	7081000
Vessel 2	203	10556	5785000
Vessel 3	210	10920	6576000
Vessel 4	140	7280	7302000
Vessel 5	296	15392	6830000
Vessel 6	163	8476	7671000
Vessel 7	98	5096	11089000
Vessel 8	154	8008	7500000
Vessel 9	135	7020	7084000
Vessel 10	280	14560	5824000
Total	1868	97136	72742000

4.4.3.12. *Lead times*

While the modal shift from road to water is desirable, a commonly encountered challenge is the differences in lead times. A lot of the cargo we target in this investigation is related to seaports. Truck traffic in and out of seaports causes congestion, is slow (though arguably faster than inland shipping), and highly desirable to reduce. We therefore also investigated the maximum lead times between the different locations. This investigation was done through the SIMPACT simulations where each container is time stamped when it is added to the inventory of its origin location. This corresponds to the point in time when it is delivered to an S&C after having been moved from a deep-sea terminal, or when it is delivered to a TPT by truck after being hauled from a nearby factory. From this point, each container is tracked through the simulation, while it is waiting for transport and while it is on board a vessel, until it is delivered to its destination location. SIMPACT then aggregates the lead time estimate of each container and creates statistics for lead times between each origin destination pair.

For each location, we checked which connection that SIMPACT had estimated the highest maximum lead time. We also investigated the minimum lead time on the same connection. These are given in Table 39 in days. It should be noted that for all these connections the average lead time is approximately in the middle between the minimum and maximum lead time. The exceptions are Haarlem – Katwijk with an average of around 1.5 days, and Den Haag – Haarlem with an average of around 3 days.

Table 39: Connections with highest lead times

Origin	Destination with max lead time	Max lead time	Min lead time
Alphen aan den Rijn	Amsterdan	2.2	0.5

Utrecht	Den Haag	3.2	0.8
Leiden	Den Haag	2.5	0.4
Haarlem	Katwijk	2.2	0.4
Den Haag	Haarlem	4.2	1.2
Delft	Amsterdam	2.7	0.7
Katwijk	Amsterdam	3.3	1
Rotterdam	Leiden	2.3	0.6
Amsterdam	Katwijk	3.5	1

4.4.3.13. *Battery capacity*

The ZES battery container capacity of the system was evaluated by assuming that each vessel needed one ZES battery container onboard, and that each S&C location needed at least one spare ZES battery container for swapping. As part of the iterative simulation and design adjustment process, the number of batteries in the system were also adjusted. This was done by observing the status of the ZES battery container inventory of each S&C hub. If the combination of the number of charged ZES battery containers and number of ZES battery containers being charged revealed that vessel had to wait for charging before they could load charged ZES battery container, the capacity was adjusted.

The final simulations show that the battery capacity (one container onboard each ship, three in Rotterdam, two in Alphen aan den Rijn and Amsterdam) is sufficient. This can be seen by inspecting the number of charged and charging containers in stock at the S&C hubs. Starting with Rotterdam in Figure 10, we see that the number of charged containers never drops below one, but that this rarely happens (two charged containers are available most of the time) indicating capacity for additional routes to be connected. Moving to Alphen an den Rijn in Figure 11 and Amsterdam in Figure 12, it can be observed that available charged ZES containers varies but never drops below one.

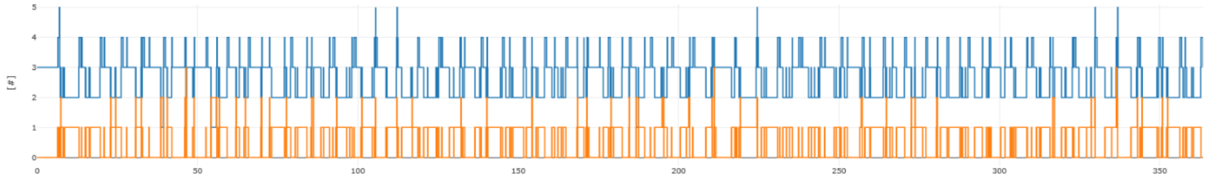

Figure 10: Charged (blue) and charging (orange) ZES packs at Rotterdam

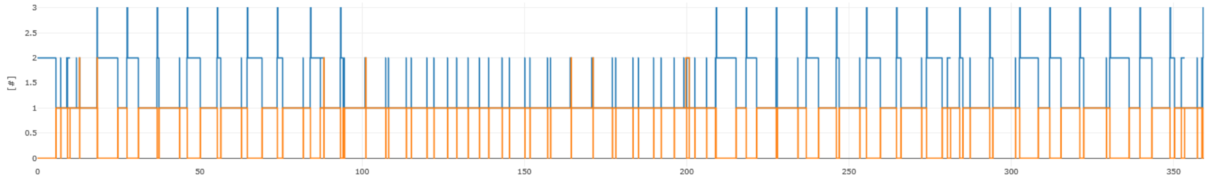

Figure 11: Charged (blue) and charging (orange) ZES packs at Alphen aan den Rijn

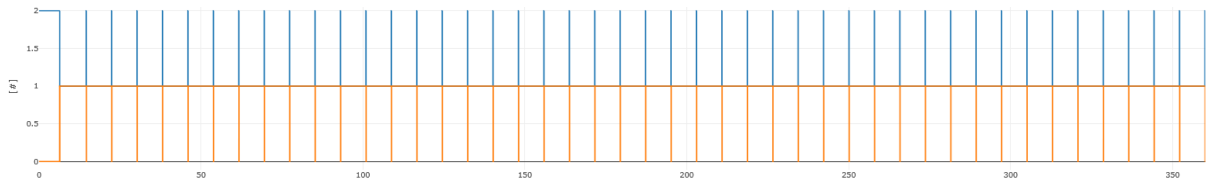

Figure 12: Charged (blue) and charging (orange) ZES packs at Amsterdam

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4.4.4. COST ITEMS

To establish the proposed AUTOFLEX transport system there are both operational and investment costs that must be considered. Here we do not consider who needs to bear the cost but rather focus on identifying the cost items that should be considered. Business model is investigated within work package 5, as will the impact of deploying the AUTOFELX transport system.

The required investment cost items to realise the proposed AUTOFLEX transport system are:

- 10 Oscar 2.0 vessels
  - The ship/hull, with propulsion, power system, etc.
  - The autonomous ship technology package (sensors/situational awareness, autonomous navigation system)
  - Automated mooring
- 17 ZES packs
- 3 ZES Megawatt Charging Systems
- 5 Electric reach stackers (one at each included TPT)
- 5 permit/contract agreements for establishing TPTs
- ROC with capacity for 10 vessels, i.e. at least 4 workstations assuming one operator can handle at least three vessels and reserving some spare capacity for situation handling.
- None of the chosen TPT locations used for the entry-level 10 vessel network requires quay upgrades

However, the question to be answered by the business model task of work package 5 is if the ZES packs and chargers are to be considered pay-per-use services, or dedicated investment costs. The same question needs to be answered for the ROC.

In terms of operational cost items, the following should be included:

- ROC as a service, or the cost of crewing the ROC, building costs, etc.
- Connectivity costs
- Energy as a service (ZES pack rental), unless procured.
- Reach stacker operators for five TPTs (implies several employees in shifts, some TPTs more than one operator at all times to account for traffic management and facilitating breaks)
- Administrative costs, including employees for planning vessel schedules, cargo movements, maintenance and service, consumables and insurance.
- Service and maintenance personnel that enters the vessels at S&Cs or TPTs
- Utilities at TPTs
- TPT area rental costs
- Dry docking and special surveys/service upgrades and period maintenance

In addition, cost incurred because of completing a voyage should be included:

- Energy (electricity)
- Port charges and canal dues
- Cargo handling costs at S&Cs

4.4.5. COST ESTIMATES

To give an indication of the cost performance of the AUTOFLEX transport system, we include two example evaluations, the short and high volume route between Delft and Rotterdam of

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Vessel 10, and the longer medium volume route between Den Haag, Alphen aan den Rijn and Amsterdam, of Vessel 9. These two routes also represent one route with no spare capacity, and one with some spare capacity.

The following cost item estimates were used (these will be updated in the impact evaluation of work package 5 as at time of writing there are some remaining uncertainties).

4.4.5.1. *CAPEX*

The investment cost includes the new build cost, the technologies for uncrewed autonomous ships, the ZES packs, the ZES charging stations including installation and grid connection cost, a reach stacker at each TPT, and the cost of obtaining permits for establishing a TPT:

- New build (without autonomous technology and ZES packs): The new build cost estimate is based on Hekkenberg [13] who provides a regression formula for estimating building cost of inland ships. Using the regression formula for the Oscar 2.0 resulted in 1.735 million Euro and adjusted for inflation 2.4 million Euro. This is excluding the ZES battery container and the cost of technologies needed for an uncrewed autonomous ship, i.e., key enabling technologies.
- Key enabling technology: The cost of key enabling technologies (autonomous navigation, sensors, connection to ROC, and autonomous mooring arms) is estimated to 1.05 million Euro by Tangstad [14], which is 1.1 million Euro when adjusted for inflation to 2026[7].
- Reach Stacker: We chose to use the publicly available price of an electric non-autonomous reach stacker, as this is what AUTOFLEX assumes, as the reach stacker price estimate. The price is listed as 1.14 million Euro[8] (converted from 1.3 million USD in July 2026).
- ZES pack: The ZES pack procurement cost is estimated to 800-1000k Euro. This number should not be considered the official cost of a ZES pack but their best estimate at time of writing. To ensure conservatism, we use 1 million Euro as the price estimate for one 2.6MWh ZES pack. For one vessel we need two ZES packs, one at the S&C terminal and one onboard the vessel, resulting in a 2 million Euro total for ZES packs.
- Charging station hardware: ZES charging station hardware costs are similarly estimated to 700-900k Euro by ZES. To stay conservative, we choose 900k Euro as our estimate.
- Charging station installation and grid connection: We also need to account for installation and grid connection costs. As ZES cannot provide this, we refer to a study on charging infrastructure cost for trucks published in 2026 [15], which estimates the installation cost as up to 114k Euro/MW, and grid connection as 90k Euro per 1 MW charger (assuming 150 Euro/kw and 60% simultaneity in power demand). Assuming 2MW charging, the installation and grid connection totals at 408k Euro. Once again, this should not be considered an official ZES estimate.
- TPT permits, contracts and planning: With TPTs being a novel concept, there are limited sources for this estimate. To account for uncertainty, we aim for conservatism and estimate personnel cost corresponding to one year of engineering hours. The engineer salary is assumed to be the median salary for engineers in the Netherlands[9], which is 84k Euro per year, and the personnel cost is calculated by adding 30% to

[7] https://www.in2013dollars.com/europe/inflation/2023?amount=1050000
[8] https://terminalift.com/product/tl-electric-reach-stacker/
[9] Salary & Compensation Calculator | Compensation Hub - SalaryExpert

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account for the additional costs of employing an engineer. This amounts to 55k Euro. The fees paid to the municipality are also uncertain, though investigating the permit fees for Delft municipality we find that each application related to environmental permits cost 3700 Euro to 2450 Euro, where the latter is in the case of more than five activities. Not knowing what permits or how many would be needed to establish a TPT, we estimate 40k Euro to account for uncertainty. This makes the total estimated cost related to permits, planning and contracts 150k Euro. However, to account for possible minor modifications (e.g. fencing) and the high uncertainty, we double the estimate and use 300k Euro.

The included investments used for one vessel operating on one route are listed in Table 40.

Table 40: Estimated CAPEX

Cost item	Unit cost [million Euro]	Units needed	Total [million Euro]
Newbuild	2.4	1	2.4
Autonomy package	1.1	1	1.1
ZES packs	1	2	2
Reach stacker	1.14	1	1.14
Charging station	0.9	1	0.9
Charging station installatoin and grid connection	0.41	1	0.41
TPT permits, planning and contracts	0.3	1	0.3
Total	-	-	8.25

Note that in this example we include two ZES packs and one charger investments when calculating the transport cost for one route, but if all ten routes were included, the investment cost would be shared between the routes. For the ten routes evaluated in section 4.4 we used three charges and 17 ZES packs. The investment cost per vessel in a ten vessel network would hence be 1.7 ZES packs and 0.3 chargers with installation. This reduces the CAPEX per vessel by approximately 1.2 million Euro in the ten vessel scenario. We will include an estimate of this impact in our transport cost evaluation.

When we convert the investment to a yearly cost, we assume an interest rate of 5% and a depreciation period of 20 years.

4.4.5.2. *OPEX*

The total operational costs of the AUTOFLEX transport system include remote operation centre (ROC), other operational costs of vessels such as maintenance, periodic maintenance and service, administrative costs, consumables and insurance. Furthermore, TPT operational costs related to personnel and utilities (including power for reach stackers), and TPT Quay lease.

- ROC cost: We assume ROC as a service and use the estimate by Tangstad [14], converted to 2026 Euro this is 140 kEuro per year per vessel.

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- Other operational costs: Other operational costs including maintenance personnel, are estimated as a lump sum as 300 kEuro in [14], which would be 316 k 2026 Euro. However, considering that the Oscar 2.0 is not a shortsea vessel and is significantly smaller (24 TEU vs 60-110TEU), the assumed other operational cost is reduced to 200k Euro. This covers connectivity, maintenance and service, administrative costs, consumables and insurance.
- TPT operational cost: The operational cost of a TPT is yet to be estimated in detail, however, in [12] a concept similar to the TPT was investigated. The case study therein investigated the relocation of the container terminal in Bergen to Ågotness and replacing it with a small interface for transhipment to trucks. This small terminal in Bergen is basically a TPT. As such, we use the estimated cost of operating the TPT from [12], which is 155k Euro (converted from 150 k Euro in 2024).
- TPT quay lease: In addition to the estimated cost of operating the TPT we need to add the cost of leasing a quay. While quay lease prices are not readily available online, we base our estimate on the listed prices for leasing industrial units in Delft[10] . These industrial units include buildings and land area for storage. As the TPT depends on leasing the quay area, not a building, we used 100 Euro per square meter per year, which is lower than the high end prices, but higher than the lowest prices. Since we need about 55 meter length and space for storage and moving a reach stacker or for trucks picking up containers, we assume that 500 square meters are needed. This adds up to 50k Euro per year.

The summarized operational cost estimates are given in Table 41.

Table 41: Estimated OPEX

Cost item	Unit cost [thousand Euro]	Units needed	Total [thousand Euro]
ROC	140	1	140
Other ship OPEX	200	1	200
TPT operations	155	1	155
TPT quay lease	50	1	50
Total	-	yearly	545

4.4.5.3. *VOYEX*

Voyage related costs are electricity to power the vessels, port fees and dues, and cargo handling costs. These cost items depend on the SIMPACT simulations and estimated quantities consumed energy and number of cargo handlings. Except for the port fees and dues which are estimated as a yearly cost based on assumed continuous operation for a year:

- Energy cost: The energy, or electricity cost, is set to 0.7 Euro per kwh based on available data on electric car charging costs in the Netherlands[11]
- Port costs: The port dues and fees are assumed 77 kEuro per year based on the NSP calculator[12] where we entered the data for Oscar 2.0, used an ESI score of 100, assumed

[10] https://www.fundainbusiness.nl/en/bedrijfshal/delft/
[11] https://tapelectric.app/blog/cost-to-charge-an-electric-car-netherlands/
[12] https://www.northseaport.com/en/calculator

number of port calls per year, and assuming the uncrewed electric ship is exempted from the waste fee.
- Cargo handling: While we have not been able to find the handling rates for the chosen terminal for the Rotterdam S&C hub, we have found barge handling rates for the PortShuttle CTT terminal, located in the outskirts of Waalhaven towards west. The rate for this terminal is listed as 38 Euro per move.

The energy cost is estimated by using a hydrodynamic model of the Oscar 2.0 operating on the routes at an average speed of 7kmh. The average speed is set to the most observed speed limit in the area. In addition, the following consumptions are included: 10kW of constant auxiliary load, 10% increase in power consumption during docking/undocking, and 2 kW plus the auxiliary load during position keeping at zero speed while waiting for bridges or locks to open. Average cargo weight of 40 foot containers is set to 22 ton, and since vessel 9 was found to be more or less fully loaded in section 4.4.3.9, twelve forty foot containers (24 TEU) are assumed to be loaded and discharged for each port call. The carried weight impacts the draft, and hence the energy consumption. This is accounted for in the model. The voyage cost item unit costs are listed in Table 42

Table 42: VOYEX unit cost items

Cost item	Unit cost
Energy cost	0.7 [Euro/kwh]
Port costs	77 [k Euro/year]
Cargo handling	38 [Euro/move]

4.4.5.4. *Results Vessel 10*

Running the Vessel 10 with the above cost parameters in SIMPACT, moving the cargo estimated in section 4.4.3.10, which was 280 40ft containers weekly, or 14560 containers yearly, requires approximately 606 roundtrips. This results in a total yearly cost of 1.92 million Euro, which, when divided by the number of transported containers (14,560), equates to 132 Euro per container.

4.4.5.5. *Results Vessel 10 in the ten vessel network scenario*

If we consider the case where the investment costs for the ZES packs and chargers are shared between the vessels of the network investigated in section 4.4 , the yearly cost reduces to 1.82 million Euro, corresponding to 125 Euro per container.

4.4.5.6. *Results Vessel 9*

To compare with a significantly longer route, we repeated the SIMPACT simulation for Vessel 9. The total yearly cost came out at 1.75 million Eurom, which is lower than for the shorter route. This is due to less cargo being moved, resulting in less cargo handling cost in the S&C terminals where 38 Euro per container move is assumed. Operational and investment costs are identical, while energy costs differ by a few thousand euro only. Which is not surprising since the shorter route is sailed more frequently than the longer route. In section 4.2.3.9, the estimated yearly volume was 7,020 40ft containers. This means that the per container transport cost is approximately 249 Euro, if we do not differentiate between the different OD pairs on the route.

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4.4.5.7. *Results Vessel 9 in the ten vessel network scenario*

Finally, if we consider the case where all ten routes are operational such that the ZES pack and charging investment per vessel is reduced, the yearly cost for operating vessel 9 reduces to 1.65 million Euro, which is 235 Euro per transported 40ft container.

4.4.5.8. *Results baseline conventional CEMT II*

To serve as a reference, we evaluated the case of a conventional container version of the Oscar 2.0. The AUTOFLEX project evaluated the design changes for optimising the CEMT II design Oscar Taubert for container freight in [16]. This showed that a conventional vessel with crew accommodation could carry as many containers as the Oscar 2.0. However, when the CEMT II designs are optimised for electric propulsion power by ZES packs, it is only the uncrewed Oscar 2.0 that can accommodate this without reduced carrying capacity. An electric conventionally crewed CEMT II vessel would thus have 4 TEU reduced carrying capacity, unless approval for stacking cargo containers in the same bay could be achieved.

The baseline cases are therefore a conventionally crewed diesel powered vessel, and a conventionally crewed electric vessel.

For both baseline cases the operational cost impacts relative to the Oscar 2.0 are as follows:

- ROC cost of 140k Euro is removed
- Crew cost is added: To stay conservative, we estimate a crew of two even though some vessels employ apprentices and then have a crew of three. Wages are taken from [17] adjusted by 30% to account for overhead costs of employment, and for inflation. This results in 159k Euro total for crewing
- Other operational costs are reduced to 150k Euro to account for reduced costs related to maintenance (no need for “boarding” maintenance crews)

For both baseline cases the investment cost impact is:

- No cost related to key enabling technologies (1.1 million Euro is removed)

For the conventional diesel powered version, the additional investment cost impacts are:

- No cost related to ZES packs and charging (3.31 million Euro is removed)

The final major difference for the baseline cases is that small conventional inland vessels do not operate 24/7. And vessels smaller than 70 meters typically operate in A1 operational regimes, implying 14 hours a day Monday to Friday. In fact, there are also other holidays where the vessels are not operational, but we do not account for these to ensure a conservative bassline estimate. Which in this perspective would be making assumptions leading to lower-end cost estimates. The impact of this is that the baseline vessels are operational 3640 hours out of the 8760 hours in a year, which is 41.5%.

Baseline Vessel 10 route

The results are that the conventional diesel powered baseline operating on the Vessel 10 route moves 7440 containers at a cost of 1.12 million Euro per year, which corresponds to 151 Euro per container, and that the electric conventional vessel moves 6460 containers at a cost of 1.4 million Euro per year. Which corresponds to 217 Euro per container. If we are very conservative and assume that it is possible to create an electric vessel with 24 TEU capacity, the result is 7392 TEU per year at a cost of 1.44 million Euro, and 195 Euro per container.

Baseline Vessel 9 route

If we consider the Vessel 9 route operated by the conventional diesel powered vessel, the annual containers transported are 2862 at a cost of 990k Euro, leading to 346 Euro per container. For the electric conventional version, the cost increases to 1.31 million Euro per year, but as the Vessel 9 capacity is not fully exploited the battery container does not reduce the number of transported containers per voyage, resulting in 2862 containers transported annually at a cost of 458 Euro per container.

4.4.6. DISCUSSION AND CONCLUSION

When we compare the results of the optimisation problem and the simulations in SIMPACT we can clearly see the impact of bridges on the overall transportation times. While several moveable bridges have high enough clearance when closed, many must be opened. Since one of the main drivers for the modal shift from road to waterways is to relieve traffic congestion, it is undesirable if bridges must be opened more frequently due to new waterborne transport. While the waterborne transport would relieve roads by replacing trucks, opening bridges would counteract this somewhat by causing temporary stops in traffic. This is a major challenge for the viability of cargo transport on the CEMT II waterways of Randstad. This conundrum should be discussed further in the policy recommendations deliverable of work package 5. How can we realise the modal shift without negative impacts on road traffic?

Another important take-away from the results is that a fleet of 10 AUTOFLEX vessels has the potential to move a significant cargo volume from road to the inland canal network. Our simulations estimate that such a fleet could move as much as 97 thousand truck trips, or 73 million tkm, yearly. Saving significant societal costs, both because the transport system is zero-emission, and because waterborne transport has lower external costs in important categories such as accidents and congestion. Furthermore, there is still room for growth and shifting even more truck transport from roads to waterways.

Investigating the cost performance by using Vessel 10, the shortest route, as an example, we found that transport would come at 132 Euro per container if only the vessel 10 route is considered, and 125 Euro per container if ZES pack and charging investments are shared by the vessels operating in the 10 vessel network. Investigating Vessel 9, one of the longest routes, we found that the cost per transported 40ft container is about 249 Euro in the single route evaluation, and 235 Euro per container if ZES pack and charging investments are shared by the vessels operating in the 10 vessel network. An important thing to note is that some of the cost item estimates have high uncertainty, which will be addressed in the work package 5 impact assessment task. Comparing to the baseline case for Vessel 10, we find that a conventional diesel powered Oscar Teubert optimized for container transport can transport approximately half of the containers as the autonomous Oscar 2.0 can transport during a year, and that the transport cost is 19 (14%) to 26 (20%) Euro higher (depending on ZES pack and charging assumptions for Oscar 2.0). Comparing to an electric version of the Oscar Teubert, moved containers and cost per year increases such that transport by the electric conventional version results in a 48 to 56% higher cost per container, depending on Zes pack and charging assumption for Oscar 2.0. Moving to Vessel 9, the cost increase per container for the conventional diesel powered Oscar Teubert relative to Oscar 2.0 is 39-47%, while the electric conventionally crewed version results in a per container cost increase of 84-95% relative to Oscar 2.0.

The performance evaluation results show that the AUTOFLEX Oscar 2.0 increases cost and logistical competitiveness compared to conventional CEMT II vessels. In short, the Oscar 2.0 can complete more transport work per year at a lower cost per container. Both when comparing to a diesel powered and electric conventionally crewed baseline vessel. Noting that assumptions in the baseline case chose options bringing costs down to create a "hard to beat"

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baseline, and assumptions in the Vessel 9 and 10 cases chose options bringing costs up to avoid overly optimistic estimates, the cost saving potential of the AUTOFLEX transport system is reinforced.

An important observation to note is that the cost savings are directly related to capacity. Annual costs, including annualised capital costs, are higher for operating the autonomous vessels, but the cost savings appears by being able to move a significant higher amount of containers per year. Furthermore,

During our investigations we have frequently encountered blockages on some of the canals of the proposed network when doing routing in EuRIS[13]. While most destinations do have alternative routes, these blockages would cause disruptions by reducing how many roundtrips that are feasible to complete within a week. As such, the results should be considered maximum potentials.

In the next project phase, work package 5 will investigate the transport network performance further and estimate cost and competitiveness towards road transport. Some of the routes from chapter 2 are quite overlapping, and as found in section 4.4.3, some of the connections have significant spare capacity. The further work should hence investigate if some re-routing could improve overall capacity utilization.

As part of the investigations in work package 5 it should be considered if Vessel 7 should be applied to another route since the alternative road route is significantly shorter than the current Vessel 7 route. This means that although the estimated transport work of this route is high, the road alternative would result in a lower tkm total, potentially making the impact higher if the vessel is moved to another route, such as Breda – Hertogenbosch.

[13] EuRIS

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5 REFERENCES

[1] K. Kloch, 'D3.1- TRANSPORT CONCEPTS', Mar. 2026. [Online]. Available: www.autoflex-vessel.eu
[2] Bückmann, Ewout, Harmsen, Jorrit, Sendar, Tessa, Goffin, Dries, and Scheltjens, Tom, 'Capaciteitsanalyse binnenvaart Scheldegebied. Eindrapportage', Ecorys/Resource Analysis/Vlaams Nederlandse Schelde Commissie (VNSC), Rotterdam, 2009.
[3] E. J. Tangstad *et al.*, 'Evaluation of an autonomous, short sea shipping feeder-loop service through advanced simulations', *J. Phys.: Conf. Ser.*, vol. 2618, no. 1, p. 012018, Oct. 2023, doi: 10.1088/1742-6596/2618/1/012018.
[4] Eurostat, 'Overview - NUTS - Nomenclature of territorial units for statistics - Eurostat'. Accessed: Mar. 24, 2026. [Online]. Available: https://ec.europa.eu/eurostat/web/nuts
[5] D. Speth, V. Sauter, P. Plötz, and T. Signer, 'Synthetic European road freight transport flow data', *Data in Brief*, vol. 40, p. 107786, Feb. 2022, doi: 10.1016/j.dib.2021.107786.
[6] O. Jonkeren, K. Friso, and L. Hek, 'Changes in external costs and infrastructure costs due to modal shift in freight transport in North-western Europe', *J. shipp. trd.*, vol. 8, no. 1, p. 24, Aug. 2023, doi: 10.1186/s41072-023-00154-9.
[7] Global Logistics Emissions Council, 'Framework for Logistics Emissions Accounding and Reporting; v3.0 edition, revised and updated', Smart Freight Centre, Amsterdam, 2023. [Online]. Available: https://smart-freight-centre-media.s3.amazonaws.com/documents/GLEC_FRAMEWORK_v3_UPDATED_25_10_23.pdf
[8] Statistics Netherlands (CBS), 'Goods transport; modes and flows of transport to and from the Netherlands'. CBS (Centraal Bureau voor de Statistiek) / StatLine, Feb. 16, 2026. Accessed: Jul. 16, 2026. [Online]. Available: https://opendata.cbs.nl/#/CBS/en/dataset/83101ENG/table
[9] H. Nordahl, E. J. Tangstad, O. E. Mørkrid, and L. A. L. Wennersberg, *SIMPACT - SIMulation based ship concept imPACT evaluation tool*. SINTEF Ocean AS, 2023. Accessed: Jun. 07, 2023. [Online]. Available: https://sintef.brage.unit.no/sintef-xmlui/handle/11250/3070283
[10] C. Alias *et al.*, 'AUTOFLEX Deliverable [D2.1] DESIGN BASIS: DESIGN PARAMETERS, BOUNDARY CONDITIONS, MODEL FOR LOGISTICS ANALYSIS DEFINED', D2.1, 2024. [Online]. Available: https://autoflex-vessel.eu/wp-content/uploads/2025/01/AUTOFLEX_D2.1_Design-Basis.pdf
[11] E. J. Tangstad *et al.*, *SIMPACT - SIMulation based ship concept imPACT evaluation tool*. SINTEF Ocean AS, 2023. Accessed: Aug. 06, 2024. [Online]. Available: https://sintef.brage.unit.no/sintef-xmlui/handle/11250/3070283
[12] H. Nordahl, E. J. Tangstad, P. Specht, V. C. Podimatas, J. S. Dæhlen, and L. A. L. Wennersberg, 'A novel method for evaluating ship concept performance in transport systems', in *Journal of Physics: Conference Series*, Trondheim, 2024. doi: 10.1088/1742-6596/2867/1/012015.
[13] R. Hekkenberg, 'Inland Ships for Efficient Transport Chains', 2013.
[14] E. J. Tangstad *et al.*, 'Evaluation of an autonomous, short sea shipping feeder-loop service through advanced simulations', in *Journal of Physics: Conference Series*, Rotterdam, 2023. doi: 10.1088/1742-6596/2618/1/012018.

[15] P. Plötz, A. Sgaramella, S. Link, D. Speth, and T. Gnann, 'Future Demand and Costs of Megawatt Charging for Battery Electric Trucks', *World Electric Vehicle Journal*, vol. 17, no. 8, p. 386, Aug. 2026, doi: 10.3390/wevj17080386.
[16] I. Bačkalov *et al.*, 'Impact of automation and zero-emission propulsion on design of small inland cargo vessels', *Journal of Physics: Conference Series*, vol. 2867, no. 1, p. 012018, Oct. 2024, doi: 10.1088/1742-6596/2867/1/012018.
[17] A. Colling, 'Waterborne platooning: A viability study of the vessel train concept', 2021. doi: 10.4233/uuid:8e7b13cb-6c1c-43e8-bcfc-22e588c862b6.

A. APPENDIX

5.1 ESTIMATED DEMAND BY SIZE

Table 43: Estimated demands in TEUs per year

Origin	Destination	Demand TEUs per year
s'-Hertogenbosch	Eindhoven	74316
s'-Hertogenbosch	Breda	63113
Breda	s'-Hertogenbosch	57314
Eindhoven	s'-Hertogenbosch	54791
Breda	Roosendaal	43684
Rotterdam	Den Haag	29290
Rotterdam	Delft	25339
Den Haag	Rotterdam	25011
Delft	Rotterdam	21858
s'-Hertogenbosch	Roosendaal	20275
Eindhoven	Rotterdam	19515
Leiden	Rotterdam	19254
Eindhoven	Breda	16977
Roosendaal	s'-Hertogenbosch	16121
Rotterdam	Eindhoven	12840
Breda	Eindhoven	12239
Rotterdam	Leiden	11812
Eindhoven	Utrecht	10659
Moerdijk	Breda	10095
Utrecht	Eindhoven	8976
Roosendaal	Moerdijk	8252
Moerdijk	Roosendaal	8252
Katwijk	Rotterdam	8252
Eindhoven	Roosendaal	8164
Alphen aan den Rijn	Den Haag	8140
Leiden	Den Haag	7654
Den Haag	Utrecht	7211
Den Haag	Leiden	6576
Haarlem	Leiden	6443
Utrecht	Den Haag	5912
s'-Hertogenbosch	Den Haag	5791
Leiden	Amsterdam	5721
Amsterdam	Leiden	5573
Rotterdam	Katwijk	5062
Roosendaal	Eindhoven	4867
Alphen aan den Rijn	Amsterdam	4787
Leiden	Haarlem	4494

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Haarlem	Den Haag	4229
Den Haag	Delft	4213
Alphen aan den Rijn	Haarlem	3824
Katwijk	Den Haag	3280
Breda	Den Haag	3022
Leiden	Alphen aan den Rijn	2866
Den Haag	Katwijk	2818
Den Haag	Alphen aan den Rijn	2770
Haarlem	Katwijk	2761
Amsterdam	Den Haag	2732
Den Haag	s'-Hertogenbosch	2533
Katwijk	Amsterdam	2452
Amsterdam	Katwijk	2389
Amsterdam	Alphen aan den Rijn	2382
Leiden	Utrecht	2312
Breda	Leiden	2265
Delft	Amsterdam	2195
Amsterdam	Delft	2158
Roosendaal	Leiden	2090
Den Haag	Haarlem	2057
Alphen aan den Rijn	Leiden	2050
Katwijk	Haarlem	1926
Roosendaal	Den Haag	1868
Eindhoven	Moerdijk	1814
Den Haag	Amsterdam	1788
Delft	Den Haag	1717
Den Haag	Breda	1655
Haarlem	Alphen aan den Rijn	1581
Delft	Leiden	1375
Leiden	Eindhoven	1345
Haarlem	Delft	1232
Katwijk	Alphen aan den Rijn	1228
Den Haag	Roosendaal	1213
Eindhoven	Delft	1203
Leiden	Delft	1200
Moerdijk	Eindhoven	1082
Leiden	s'-Hertogenbosch	1026
Alphen aan den Rijn	Delft	1007
Breda	Katwijk	971
Delft	Breda	925
Delft	Alphen aan den Rijn	915
s'-Hertogenbosch	Leiden	901
Roosendaal	Katwijk	896
Alphen aan den Rijn	Katwijk	879
Leiden	Breda	849
Delft	Haarlem	837

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Delft	Roosendaal	796
Leiden	Roosendaal	738
Breda	Delft	680
Roosendaal	Delft	633
Delft	Katwijk	589
Eindhoven	Den Haag	580
Katwijk	Eindhoven	576
Den Haag	Eindhoven	569
Katwijk	Delft	514
Katwijk	s'-Hertogenbosch	440
s'-Hertogenbosch	Katwijk	386
Katwijk	Roosendaal	316
Den Haag	Moerdijk	269

5.2 FLEET OF 10 VESSELS

```
VESSEL ROUTES FROM OPTIMISATION
--------------------------------------------------------------------------

Vessel 1:   (6.30 cycles/period)
  Pos | Location                | Time (h) | Energy (kWh) | Battery Swap
  ----|-----------------------|----------|--------------|-------------
    0 | Katwijk                 |     0.00 |        40.00 | No
    1 | Den Haag                |     6.38 |        79.42 | No
    2 | Rotterdam               |    13.20 |       130.60 | YES
    3 | Den Haag                |    20.28 |         0.58 | No
    4 | Katwijk                 |    26.66 |        40.00 | No

Vessel 2:   (7.56 cycles/period)
  Pos | Location                | Time (h) | Energy (kWh) | Battery Swap
  ----|-----------------------|----------|--------------|-------------
    0 | Alphen aan den Rijn     |     0.00 |        82.00 | YES
    1 | Den Haag                |     8.19 |         0.86 | No
    2 | Delft                   |    11.07 |        16.13 | No
    3 | Leiden                  |    18.88 |        60.98 | No
    4 | Alphen aan den Rijn     |    22.21 |        82.00 | No

Vessel 3:   (6.10 cycles/period)
  Pos | Location                | Time (h) | Energy (kWh) | Battery Swap
  ----|-----------------------|----------|--------------|-------------
    0 | Den Haag                |     0.00 |       103.00 | No
    1 | Rotterdam               |     6.83 |       154.18 | YES
    2 | Den Haag                |    13.90 |         0.64 | No
    3 | Rotterdam               |    20.73 |        51.82 | No
    4 | Den Haag                |    27.55 |       103.00 | No
```


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Vessel 4: (6.73 cycles/period)

Pos	Location	Time (h)	Energy (kWh)	Battery Swap
0	Rotterdam	0.00	164.00	YES
1	Rotterdam	0.25	0.16	No
2	Den Haag	7.08	51.34	No
3	Leiden	13.19	83.25	No
4	Rotterdam	24.95	164.00	No

Vessel 5: (10.00 cycles/period)

Pos	Location	Time (h)	Energy (kWh)	Battery Swap
0	Delft	0.00	0.00	No
1	Den Haag	2.88	15.27	No
2	Rotterdam	9.70	66.45	YES
3	Delft	14.90	0.00	No
4	Delft	14.90	0.00	No

Vessel 6: (4.45 cycles/period)

Pos	Location	Time (h)	Energy (kWh)	Battery Swap
0	Den Haag	0.00	32.00	No
1	Amsterdam	16.66	158.99	YES
2	Alphen aan den Rijn	28.04	6.76	YES
3	Leiden	31.63	0.09	No
4	Den Haag	37.74	32.00	No

Vessel 7: (4.51 cycles/period)

Pos	Location	Time (h)	Energy (kWh)	Battery Swap
0	Rotterdam	0.00	0.00	YES
1	Utrecht	13.24	41.45	No
2	Den Haag	30.18	188.82	No
3	Rotterdam	37.01	240.00	YES
4	Rotterdam	37.26	0.00	No

Vessel 8: (6.51 cycles/period)

Pos	Location	Time (h)	Energy (kWh)	Battery Swap
0	Haarlem	0.00	0.00	No
1	Leiden	7.04	55.14	No
2	Katwijk	11.01	79.88	No
3	Alphen aan den Rijn	16.79	123.39	YES
4	Haarlem	25.80	0.00	No

Vessel 9: (4.64 cycles/period)

Pos	Location	Time (h)	Energy (kWh)	Battery Swap
0	Den Haag	0.00	102.00	No
1	Den Haag	0.00	102.00	No

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```
    2 | Alphen aan den Rijn    |     7.94 |         152.67 | YES
    3 | Amsterdam              |    19.32 |          87.77 | YES
    4 | Den Haag               |    36.23 |         102.00 | No

Vessel 10:   (8.39 cycles/period)
  Pos | Location               | Time (h) | Energy (kWh) | Battery Swap
  ----|------------------------|----------|--------------|-------------
    0 | Rotterdam              |     0.00 |          36.00 | No
    1 | Delft                  |     4.95 |          71.91 | No
    2 | Rotterdam              |     9.89 |         107.81 | YES
    3 | Delft                  |    15.09 |           0.09 | No
    4 | Rotterdam              |    20.04 |          36.00 | No

DEMAND SATISFACTION (TEU per week) FROM OPTIMISATION
----------------------------------------------------------------------------
-----

Demand ID | Origin -> Destination     | Served (TEU) | Total (TEU) |
Satisfaction
----------|--------------------------|--------------|-------------|--------
-----
D1        | Amsterdam  -> Alphen aa… |        51.00 |       51.00 | 100.0%
D2        | Amsterdam  -> Delft      |        46.00 |       46.00 | 100.0%
D3        | Amsterdam  -> Katwijk    |        51.00 |       51.00 | 100.0%
D4        | Amsterdam  -> Leiden     |        12.11 |      119.00 |  10.2%
D5        | Amsterdam  -> Den Haag   |        58.00 |       58.00 | 100.0%
D6        | Alphen aa… -> Amsterdam  |        81.11 |      102.00 |  79.5%
D7        | Alphen aa… -> Delft      |         8.53 |       22.00 |  38.8%
D8        | Alphen aa… -> Haarlem    |         0.00 |       82.00 |   0.0%
D9        | Alphen aa… -> Katwijk    |        19.00 |       19.00 | 100.0%
D10       | Alphen aa… -> Leiden     |        32.00 |       44.00 |  72.7%
D11       | Alphen aa… -> Den Haag   |       173.00 |      174.00 |  99.4%
D12       | Breda      -> Delft      |         0.00 |       15.00 |   0.0%
D13       | Breda      -> 's-Hertog… |         0.00 |     1225.00 |   0.0%
D14       | Breda      -> Katwijk    |         0.00 |       21.00 |   0.0%
D15       | Breda      -> Leiden     |         0.00 |       48.00 |   0.0%
D16       | Breda      -> Roosendaal |         0.00 |      933.00 |   0.0%
D17       | Breda      -> Eindhoven  |         0.00 |      262.00 |   0.0%
D18       | Breda      -> Den Haag   |         0.00 |       65.00 |   0.0%
D19       | Delft      -> Amsterdam  |        47.00 |       47.00 | 100.0%
D20       | Delft      -> Alphen aa… |        20.00 |       20.00 | 100.0%
D21       | Delft      -> Breda      |         0.00 |       20.00 |   0.0%
D22       | Delft      -> Haarlem    |        18.00 |       18.00 | 100.0%
D24       | Delft      -> Katwijk    |        13.00 |       13.00 | 100.0%
D25       | Delft      -> Leiden     |        29.00 |       29.00 | 100.0%
D26       | Delft      -> Roosendaal |         0.00 |       17.00 |   0.0%
D27       | Delft      -> Rotterdam  |       467.00 |      467.00 | 100.0%
D29       | Delft      -> Den Haag   |        37.00 |       37.00 | 100.0%
D31       | Haarlem    -> Alphen aa… |         0.00 |       34.00 |   0.0%
D32       | Haarlem    -> Delft      |         0.00 |       26.00 |   0.0%
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D33	Haarlem -> Katwijk	59.00	59.00	100.0%
D34	Haarlem -> Leiden	97.28	138.00	70.5%
D35	Haarlem -> Den Haag	0.00	90.00	0.0%
D36	's-Hertog… -> Breda	0.00	1349.00	0.0%
D38	's-Hertog… -> Leiden	0.00	19.00	0.0%
D39	's-Hertog… -> Roosendaal	0.00	433.00	0.0%
D40	's-Hertog… -> Eindhoven	0.00	1588.00	0.0%
D41	's-Hertog… -> Den Haag	0.00	124.00	0.0%
D42	Katwijk -> Amsterdam	52.00	52.00	100.0%
D43	Katwijk -> Alphen aa…	26.00	26.00	100.0%
D44	Katwijk -> Delft	11.00	11.00	100.0%
D45	Katwijk -> Haarlem	0.00	41.00	0.0%
D48	Katwijk -> Rotterdam	85.42	176.00	48.5%
D49	Katwijk -> Eindhoven	0.00	12.00	0.0%
D50	Katwijk -> Den Haag	0.00	70.00	0.0%
D52	Leiden -> Amsterdam	0.00	122.00	0.0%
D53	Leiden -> Alphen aa…	61.00	61.00	100.0%
D54	Leiden -> Breda	0.00	18.00	0.0%
D55	Leiden -> Delft	26.00	26.00	100.0%
D56	Leiden -> Haarlem	94.28	96.00	98.2%
D57	Leiden -> 's-Hertog…	0.00	22.00	0.0%
D58	Leiden -> Roosendaal	0.00	16.00	0.0%
D59	Leiden -> Rotterdam	161.63	411.00	39.3%
D60	Leiden -> Eindhoven	0.00	29.00	0.0%
D61	Leiden -> Utrecht	0.00	49.00	0.0%
D62	Leiden -> Den Haag	113.82	164.00	69.4%
D64	Roosendaal -> Delft	0.00	14.00	0.0%
D65	Roosendaal -> 's-Hertog…	0.00	344.00	0.0%
D66	Roosendaal -> Katwijk	0.00	19.00	0.0%
D67	Roosendaal -> Leiden	0.00	45.00	0.0%
D68	Roosendaal -> Eindhoven	0.00	104.00	0.0%
D69	Roosendaal -> Den Haag	0.00	40.00	0.0%
D70	Roosendaal -> Moerdijk	0.00	176.00	0.0%
D71	Rotterdam -> Delft	449.47	541.00	83.1%
D72	Rotterdam -> Katwijk	47.86	108.00	44.3%
D73	Rotterdam -> Leiden	124.72	252.00	49.5%
D74	Rotterdam -> Eindhoven	0.00	274.00	0.0%
D75	Rotterdam -> Den Haag	626.00	626.00	100.0%
D76	Eindhoven -> Breda	0.00	363.00	0.0%
D77	Eindhoven -> Delft	0.00	26.00	0.0%
D78	Eindhoven -> 's-Hertog…	0.00	1171.00	0.0%
D81	Eindhoven -> Roosendaal	0.00	174.00	0.0%
D82	Eindhoven -> Rotterdam	0.00	417.00	0.0%
D83	Eindhoven -> Utrecht	0.00	228.00	0.0%
D84	Eindhoven -> Den Haag	0.00	12.00	0.0%
D85	Eindhoven -> Moerdijk	0.00	39.00	0.0%
D86	Utrecht -> Eindhoven	0.00	192.00	0.0%
D87	Utrecht -> Den Haag	108.22	126.00	85.9%
D88	Den Haag -> Amsterdam	38.00	38.00	100.0%
D89	Den Haag -> Alphen aa…	59.00	59.00	100.0%

D90	Den Haag -> Breda	0.00	35.00	0.0%
D91	Den Haag -> Delft	90.00	90.00	100.0%
D92	Den Haag -> Haarlem	44.00	44.00	100.0%
D93	Den Haag -> 's-Hertog…	0.00	54.00	0.0%
D94	Den Haag -> Katwijk	60.00	60.00	100.0%
D95	Den Haag -> Leiden	141.00	141.00	100.0%
D96	Den Haag -> Roosendaal	0.00	26.00	0.0%
D97	Den Haag -> Rotterdam	534.00	534.00	100.0%
D98	Den Haag -> Eindhoven	0.00	12.00	0.0%
D99	Den Haag -> Utrecht	108.22	154.00	70.3%
D101	Moerdijk -> Breda	0.00	216.00	0.0%
D104	Moerdijk -> Roosendaal	0.00	176.00	0.0%
D105	Moerdijk -> Eindhoven	0.00	23.00	0.0%
TOTAL		4380.67	16220.00	27.0%