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Towards a Greener Europe: Analysis of the SeaBubble waterline in Rotterdam

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Abstract

The current work focuses on the performance analysis of a novel vehicles that use the principle of hydro foiling and re-chargeable batteries. These vehicles will emit zero pollution. They will be used for partially replace the operation of Ferries in the waterline of Rotterdam in The Netherlands, bringing as a benefit, a more efficient transport which is greener and cheaper to the government. The authors have done a study based on simulation for analysing the future performance of the waterlines in Rotterdam. The results reveal that the impact will be positively high in all aspects; it will reduce the pollution drastically, it will allow an on-demand service, better service for the passengers and the operational costs will be reduced.

Keywords: simulation; future; transport; ports; on-demand

1. Introduction

Due to the importance of developing novel modes of transport that result more efficient, less pollutant and more sustainable, the company SeaBubbles (SeaBubbles, 2020) has developed different sizes of vehicles that can be used in the waterways of the globe taking advantage of their characteristics which are fast, small, environmental-friendly, silent among others.

The transport of people in the waterways of Rotterdam has been traditionally done using fast boats or big vessels (Ferries) that use a typical engine with propellers that have almost not changed since their invention in 1827 (Smith, 1905) almost 200 years ago. The disadvantage of using such a propeller-engine is that its dimension is proportional to the size of the vessel to propel and that most of them are fossil fuel-based which emits CO2, particles, and other pollutants (FAO, 2020).

The region of Rotterdam is a territory that in contrast with other regions of many countries, a waterway network connects most of the land locations. For that reason, the transport of people between the different locations is composed by road network, rail network and for some locations via water transport as it can be seen in figure 1. In that region, currently the transport of people is done using public water vehicles (Ferries) that follow a scheduled operation like any public Bus network does in any city. The current system in operation, is the one presented in Figure 1.

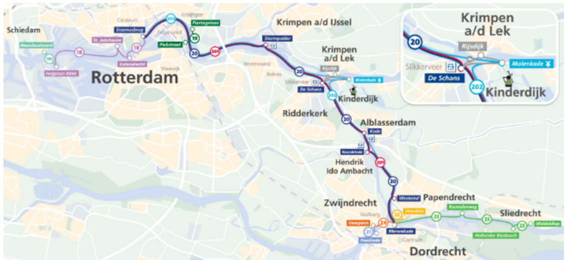

Figure 1. The water transport in Rotterdam

The different lines can be seen with different colours. The longest one is Line 20 that goes from Rotterdam to Dordrecht which corresponds to approximately 20 kms. As mentioned, the operation uses Ferries like the one presented in Figure 2. Which operate on-schedule basis and they do not match properly the demand, as it is a common practice for the design of these routes to make all the requirement design based on the peak demand concept which assumes the worst-case situation.

Figure 2. The current ferry operation

This concept makes that the operational costs are high, and the old vessels emit diverse pollutants like noise, CO2, NOX, and other ones. Furthermore, the operation is not efficient as during low season the demand is low, but the vessels are kept the same size.

The SeaBubble concept is a vehicle based on hydrofoil system that uses the hydrodynamic of a water wing to elevate the vehicle and reduce the drag, consumption, noise, and travels at high speed. The company SeaBubbles has designed different sizes of vehicles based on this principle that can be used for different purposes and that can carry different number of passengers at high speed with minimum drag and using eco-friendly electrical engines; besides that, due to the size of the vehicles it seems to fit perfectly for an on-demand operation. Figure 3 illustrates the SeaBubble.

Figure 3. Illustration of a SeaBubble

These vehicles have been successfully tested in different locations in Europe and the globe (SeaBubbles, 2020); however, their use as commercial transport is the next step in the implementation roadmap.

The current article presents a simulation-based analysis for the operation of the vehicle instead of the use of Ferries in some lines of the current network. This study allows to understand and gives light on the potential benefits that will bring the use of a SeaBubble fleet. The methodology followed is presented in the following section.

2. State of the Art

There have been different techniques and methodologies for studying infrastructures like the one presented in the current work. Only in recent studies the use of simulation has been used as the key technique for analysing the systems. For instance, in the work of Wolbertus et al (2021) the authors use an agent-based approach for modelling of charging infrastructures in urban areas. Other studies like the ones from Voegl et al. (2019) use a similar approach for evaluating some effects like environmental or economic ones for transport infrastructures. The simulation methodology is used for making a deep understanding the balance between economic or environmental benefits. Other studies focus on the analysis of infrastructures like Ports, such as the review made by Olba et al. (2018), the authors present a review on the simulation models for risk and capacity assessment on Ports. The study presented by Mujica et al. (2019) uses for the first time multi-model simulation for the analysis of the supply chain in Ivory Coast, and a similar approach has been developed in the current work. To the best of the authors knowledge a simulation approach like the one presented here has not been used before combining network analysis, stochastic and on-demand analysis for large waterways infrastructures and from diverse angles like productivity, environmental and economical ones.

3. Methodology and description

The methodology followed in the analysis is the one developed by Mujica et al. (2018) for developing a multi-level simulation model considering different levels of aggregation. This methodology allows to efficiently simulate the operation of the system and it also considers the variability inherent to the operation in which other techniques fall short to address all the aspects of a dynamic system such as the one in place in Rotterdam.

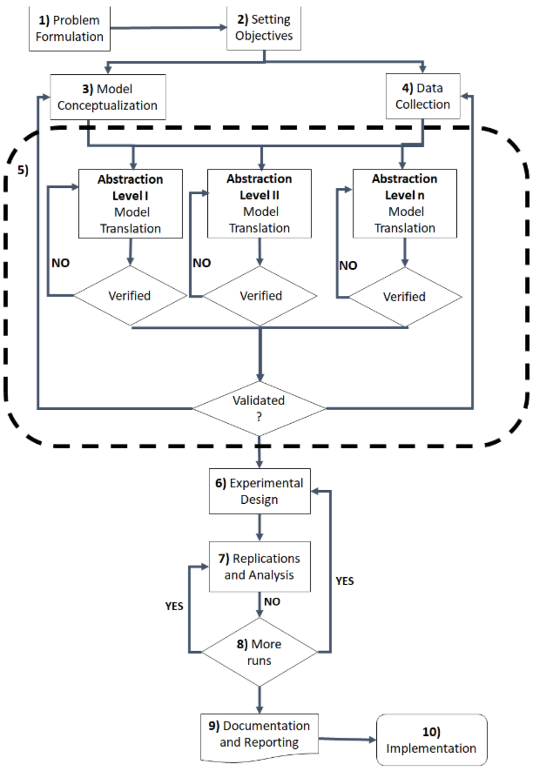

Figure 4. Multi-level simulation approach

The methodology allows to build a detailed model by combining different modelling levels altogether which in turn are verified and validated. When the model is finished, the resulting one can be used for performing the experimental analysis to extract information about the system under study. Then for the case under study a GIS layer and a network layer are used as it is illustrated in Figure 5.

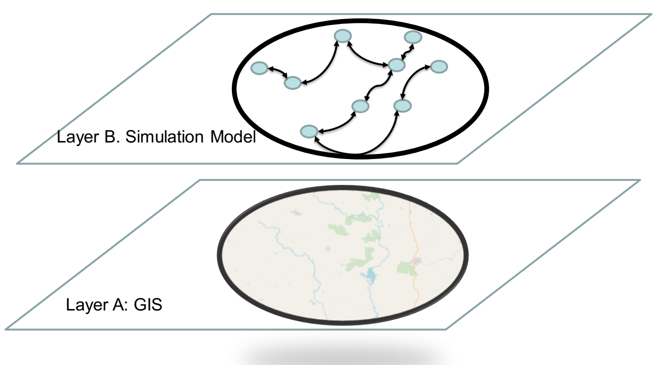

Figure 5. Layers of the Computer Model

The study developed, is based on the information provided by the companies Waterbus and SeaBubble which considers real data and information from the passengers that use the current facilities.

Passenger Movements

The company has provided information of the amount of people that take a ride for the lines 20, 21, 22, 23 and 24 of the Waterbus lines for three weeks of the most representative months of the year.

The data presents the information of the origin and destination of passengers using the OV-chip card (OV-Chipkaart 2020).

The data we used for the simulation is actual data that contains information like:

- line of operation
- date, time of check-in the vehicle
- time of checkout
- initial destination and end destination.

The data provided does not present information of the NON OV-chip card users; however, a correction factor has been applied for considering the total amount of people that use the service.

Fleet

The current fleet has been provided and the different lines considered (Lines 20,21,22,23 and 24) have the following fleet:

- Line 20: 2 boats type RR150 with a capacity of 130 pax, and 2 boats type RR200 with a capacity of 200 pax during all the seasons during the weekdays.
- Lines 21, 23 and 24: 2 boats type RR150 with a capacity of 130 pax during all the seasons and the weekdays.
- Line 22: 1 boat with a capacity of 200 pax, during all the seasons and weekdays.

The lines follow the public schedule (Waterbus 2020) using the fleet considered. The operation of the vessels is approximately 14 hrs/day.

All the current vessels emit CO2 and particles. The amount of these particles and CO2 depends on the type and conditions of the engine. The exact amount of CO2 emissions/vessel has not been provided and it is not available in public pages, for that reason an assumption to estimate the amount of CO2 was considered in the simulation model.

4. Conceptual design and boundaries

The study is limited to the lines 20, 21, 22 23 and 24 of the operation. The Geographical Information System (GIS) considered for the computer model was taken from OpenStreetMaps (2020) considering only the geographical locations of the stations within the boundaries.

Table 1. Assumptions

Concept	Value	Comments
	Current OPS – Base Case	
Current OPS, L20	Speed: 37 km/hr, Capacity: 130 Pax (2X), 150 Pax(2X)	Constant, matching the actual frequency

Current OPS, L21	Speed: 37 km/hr, Capacity: 130 Pax (1X)	Constant, matching the actual frequency
Current OPS, L22	Speed: 12 km/hr, Capacity: 200 Pax (1X)	Constant, matching the actual frequency
Current OPS, L23 & L24	Speed: 37 km/hr, Capacity: 130 Pax (1X)	Constant, matching the actual frequency
Vessels Dwell time @ stations	2 minutes	
Demand	The model considered High, Low demand of Weekdays (5 days) and Weekends (2 days) of 2 periods of day: morning/afternoon	The frequency of arrivals was split in morning and afternoon.
Demand Profile	Poisson process	Exponential distribution during the day with a variable mean value depending on the peak times.
Operational Time	14 hrs	These are the operation times
Routing Type	Fixed Route-Scheduled	Using public information
Costs	Confidential	Provided by Waterbus and SeaBubbles
	ON – DEMAND OPS	
L20	Speed: 37 km/hr, Capacity: 130 Pax (2X), 150 Pax(2X)	No change compared to Base-case
Line On-Demand	L21, L22, L23, L24 merged	A new line operating on an on-demand basis
Line On-Demand Policy	Pax share a ride when they have the same destination	No public information is available
SeaBubble Fast Taxi	Speed: 46 Km/hr, Capacity: 4 Pax	Provided by SeaBubble
SeaBubble JET	Speed: 56 km/hr, Capacity: 12 Pax	Provided by SeaBubble
SeaBubble Dwell Time @ Stations	2 minutes	Considered for boarding of Pax
Demand Data	High demand 2 periods of day: morning/afternoon	
Demand Profile	Poisson process	Following a variable exponential distribution during the day
Operational Time of the Model	14 hrs	
Routing Type	ON-DEMAND Except Line 20	Line 20 keeps on a schedule basis
Costs	Confidential	Provided by Waterbus and SeaBubbles

It is important to highlight that the model design is based on numerous assumptions and subjected to some uncertainties. At this stage in the study the optimum fleet was not investigated, in the study we considered a scenario of a mixed fleet which performed well and adapted its operation to the demand of the day.

4.1. Computer Model

The computer model was created using a two-layer approach (Mujica et al 2018) in which one is a GIS map, and the second layer is a Network layer composed of capacitated nodes and weighted edges.

Layer A corresponds to the GIS region that is considered, it includes the locations of the different stations and the distances between stations, by using the GIS all the distances are scaled. With the use of this layer, the model represents accurately the physical location of stations and distances between them which will enable to efficiently calculate the performance of the operation. Layer B represents the conceptual model translated into the logic of the simulation software which is placed over the GIS layer for efficient scaling of the elements. The model was coded using a general-purpose simulator. Figure 6 depicts on the left-hand side the 2D view of the network over the GIS layer while the right-hand side figure shows a view of the SeaBubble model transporting a passenger.

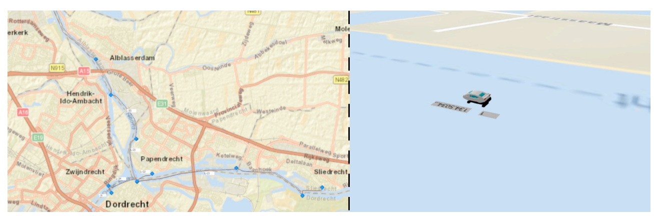

Figure 6. Computer model

Layer B is overlapped over the GIS map to match the longitudes of the edges with the distances of the paths of the real system and the nodes (i.e., stations of Waterbus) with the locations of the stations. Layer B also considers other characteristics of the elements under study like capacity, speeds, schedules among others.

4.2. Transport Network

The transport network is modelled by a set of capacitated nodes and weighted edges, where the weight of the edges represents the distances between destinations. The nodes represent the stations where the people get in and out of the vessels. The entities that flow in the system are those that represent vessels (Boats and SeaBubbles) and passengers. The vessels traverse the network and they pickup and delivery passengers throughout the different stations in the system always respecting the restrictions for instance, passengers that use line 20 will not use the on-demand line and vice-versa.

4.3. Demand

As the demand does not follow a uniform distribution of arrivals and departures of passengers throughout the day, after analysing the provided data, the frequency of arrivals of the day for each station was split in two periods of 7hr each: [morning, afternoon]

The arrivals and departures data were modelled using a Poisson process with different mean of Arrivals/hr. Table 2 presents the Exponential distributions used for the different lines and demands considered.

Table 2. Modelled Distributions

	High Season		Low Season		Weekends	
Line Number	Poisson Arrivals/ Hr: Morning	Poisson Arrivals /hr: Afternoon	Poisson Arrivals/ Hr: Morning	Poisson Arrivals /hr: Afternoon	Poisson Arrivals/ Hr: Morning	Poisson Arrivals /hr: Afternoon
Line 20 Merwekade	41.8	65.8	22.2	52.8	6.4	20.7
Line 20 Ppd Westeind	10	3.8	3	2.8	2.2	1.2
Line 20 Hia Noordeinde	19.5	7.7	5.6	3.6	4	2.1
Line 20 Abs Kade	33.2	14.3	16.6	10.4	6.5	2.7
Line 20 Rdk De Schans	25.5	18.8	20	12.6	5.4	7
Line 20 KIJ Stormpolder	40.7	25.3	19	9	9.1	3.5
Line 20 Rt Erasmusbrug	49	72.8	30.2	58	11	23.8
Line 21 Zwijndrecht, Veerplein	20	13.7	22.5	15.8	15.9	10.8
Line 21 Dordrecht, Hooikade	8.1	22.1	9.2	30.8	8.4	21.2
Line 22 Dordrecht, Merwekade	24.1	43.2	11.2	29.7	13.4	33.7
Line 22 Papendrecht, Veerdam	33	30.2	24.4	19.1	22.08	27.79
Line 23 Dordrecht, Merwekade	9.5	5.7	6	2	5.9	3.3
Line 23 Papendrecht, Rosmolenweg	0.28	1.4	0.42	0	0	0.4
Line 23 Dordrecht, Hollandse Biesbosch	1.2	6.4	1.5	4.4	0.5	3.7
Line 23 Sliedrecht, Middeldiep	6.7	4.2	3.5	3	3.1	2.4
Line 24 Dordrecht, Merwekade	1.2	3.2	0.57	1.7	0.8	1.1
Line 24 Zwijndrecht, Veerplein	4.1	2.2	3	2	1.9	1

Validation of Data

The current operation has been considered as the Base-Case scenario for comparison and then different scenarios considered different fleets of SeaBubbles; this has been done for the three demand levels considered. The conceptual model was translated into a General-purpose software and the base case was positively validated using a t-test for mean comparison (Salkind 2018) of the average demand values of the system.

4.4. New operations: On-demand Network

A new network model was developed where the Line 20 was left without modifications as it is the one that has more stable demand; and the lines 21, 22, 23 and 24 have been merged into one On-demand line that uses only SeaBubbles. Then, a new network is created with the docks of the former lines 21, 22, 23 and 24, and within this network, the passengers will use only SeaBubbles in different modalities. Figure 7 shows the on-demand line.

Figure 7. On-demand Network

The On-demand network follows a First-Called-First-Served policy for the operation. This policy assumes that the passengers from the former Lines 21, 22, 23 and 24 that are travelling to the different destinations of the network make a request of transport from within the network. Once the SeaBubble accepts the request, it travels to the location of the passenger. In the model, during the time between the request-acceptance and pickup operation, other passengers from the same location can appear and if they have the same destination as the original passenger, they will share a ride if the Bubble has enough capacity. If it does not have enough capacity, then the passenger that did not fit, will request another SeaBubble. When implemented, we expect that the occupation will be better than the one from the model, as (using an App) passenger can be influenced to arrive earlier or later to share the ride. This situation will be investigated at a later stage.

5. Experimental Design and Analysis

The model developed was used for evaluating different scenarios to understand the potential of the operation with this new concept. The following indicators were considered for the study: Load Factors, CO2, ride duration and operational costs. The following scenarios were considered for the experimental design.

Base Case

The base case corresponds to the current situation considering the fleet mentioned in Table 1. We have run an experiment of one week with 20 replications of the model and we obtained the initial values of the PI under study.

Scenario B1

This scenario assumes that lines 21 – 24 disappear and they are used on an on-demand basis with a new fleet. We used a mixed fleet of 18 SeaBubbles (6 Bubble Jets and 12 Bubble Fast Taxi). The reasoning behind the selection of this initial fleet was based on the economic factor which plays an important role in the selection of any fleet.

Scenario B2

In the scenario B2 we changed the Bubble Jets, which are more expensive, for Bubble Fast Taxis whose costs are smaller than the ones from the BubbleJets.

Scenario B3- Scenario B5

On scenarios B3 to scenario B5 we evaluated the dependencies of the PI with the number of available SeaBubble Fast Taxis by increasing the Fast Taxis to 24, 28 and 30 respectively. We identified a lineal dependency on the load factor with the amount of SeaBubbles.

Scenario A: Efficient Fleet

There are several options that need to be considered to get a close-to-optimal fleet of the on-demand operation. One of the most important is the optimal mix of the different SeaBubbles used, since they differ in speed, size, and cost. We developed Scenario A which uses a mix where the Bubble Jet (which is the most expensive one) is bigger in quantity than the Bubble Fast Taxi which has been used in the previous scenarios. In addition, we varied the number of SeaBubbles used in the morning to adapt their operation to the demand which is lower in the morning than in the afternoon. For the case of high season, the fleet in the morning was reduced by two vehicles:

Morning (23% fleet reduction): RR150 (2X), RR200 (2X), SeaBubble Fast Taxi (1X), SeaBubble Jet (4x)

Afternoon: RR150 (2X), RR200 (2X), SeaBubble Fast Taxi (2X), SeaBubble Jet (5x)

5.1. Results

The following graphs illustrate the results achieved with the different scenarios.

Ride Duration

Figure 8 presents the difference on average ride duration, as is can be seen, the Fleet A which is the one that aims at improving the system achieves the lowest ride duration in this case the rides are around 6 minutes. The results are similar with the Low Season, that is why we only present the ones from High Season.

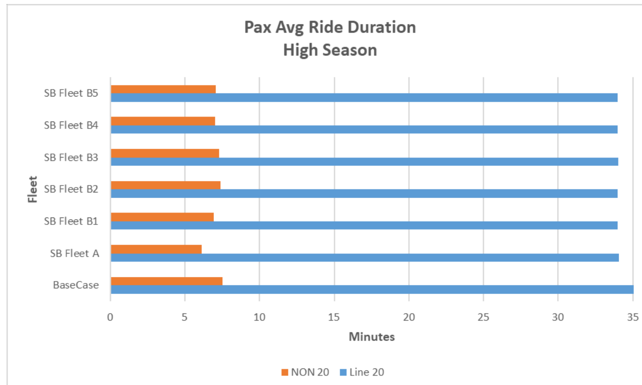

Figure 8. Average Ride Duration High season

Emissions

Another remarkable improvement of the use of the fleet is the emissions reduction, in the base case the lines that were replaced were emitting approx. 8.4 TONS/week of CO2 during high season and 3.3 ton/week during low season. Once they are replaced with the SeaBubbles that are electric, the emissions of those lines disappear as it can be seen in Figure 9 and Figure 10. In the scenarios, the number of emissions is coming only from Line 20 which still pollutes.

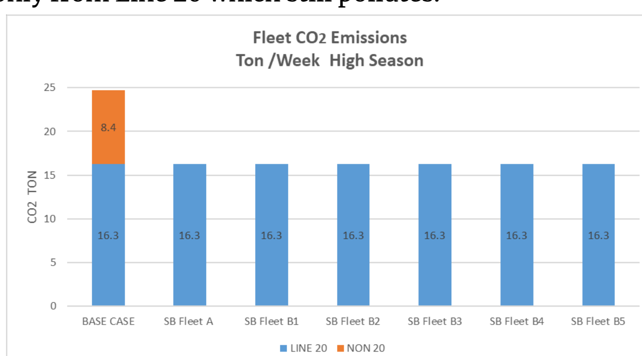

Figure 9. Emissions for the scenarios during high season

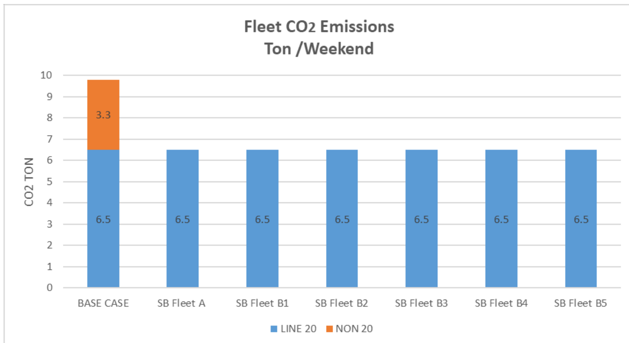

Figure 10. Emissions during weekend

Utilization

Regarding the efficient use of the fleet, the Load Factors are an important indicator, as the ride cost is shared between the passengers that use the vehicle. In this case it is striking that for the Base case, during the high, low and weekend seasons, the load factors of the lines L21 to L24 are very low with less than 10% of the use of the capacity (See Figures 11, 12 and Figure 13) which makes it a very costly operation. This situation is caused by the combination of low demand during the day and big capacity of the vehicles. In the new scenarios, the fleet adapts better to the demand as clearly the utilization increases drastically. In the B scenarios, the load factors are increased to 30 to 50%, while in the case of the most efficient mix (Fleet A), the load factors are always around 90% which make a very efficient ride (low cost).

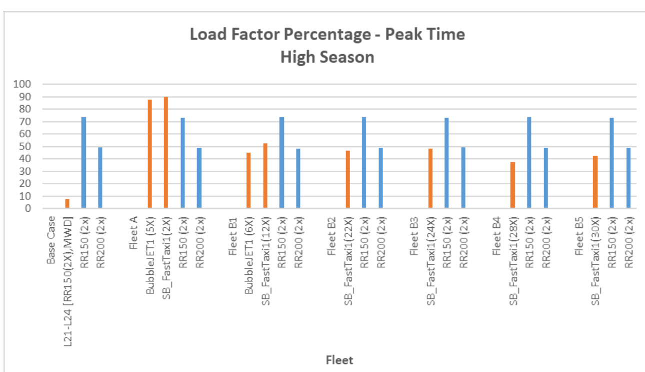

Figure 11. Load factors during high season

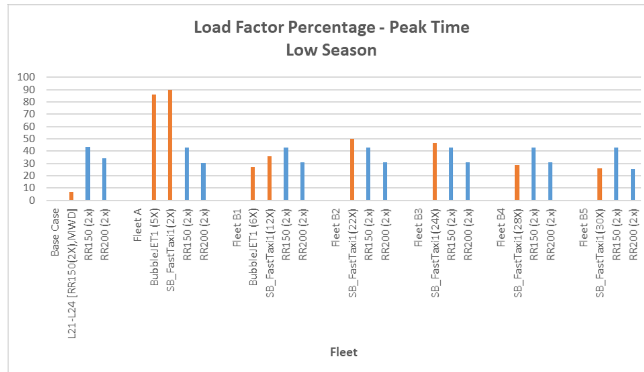

Figure 12. Load factors for Low Season

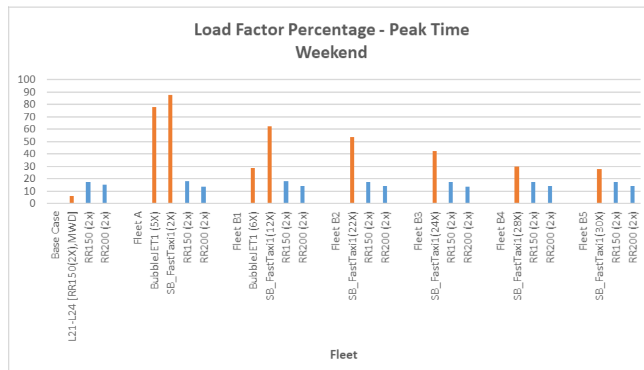

Figure 13. Load factors of weekend season

Costs

Regarding the costs, as it can be expected, the higher the load factor, the better variable costs as the ride is more efficient. Figure 11 illustrates this. Also, there is a direct correlation between the number of vehicles and the costs, that is the reason Fleet B5 has the highest costs. Furthermore, it can be noted that Fleet A has the lowest related costs compared to the base case and the other scenarios. This can be further investigated to identify where the optimal fleet might lie in the real operation.

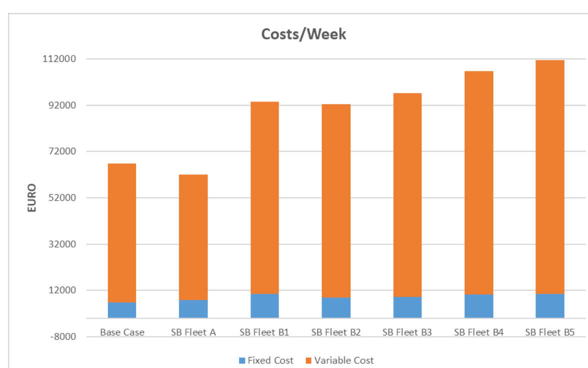

Figure 14. Operational Costs

6. Conclusions and further work

The article presents the results of the operational study performed for analysing the potential and impact of the introduction of SeaBubbles as an eco-friendly alternative for the current operation of Waterbus in the waterline network of Rotterdam. A methodology was applied simulating the operation of some lines considering the waterway transport network, current fleet, schedule, and demand. The study is a proof-of-concept of the operational capacity of the SeaBubbles

The results considered three performance indicators and one economic indicator: ride duration, emissions, capacity efficiency and operational cost. For the performance indicators analysed, the SeaBubbles outperformed the current operation.

Regarding the average ride per passenger, SeaBubbles provided a faster service than the current one, especially when the Bubble Jets are used.

On the environmental dimension, SeaBubbles eliminated the emissions once the operation is substituted with the on-demand network (saving approximately 12 TON of CO2 every week).

For the efficiency of the operation, the use of the on-demand network with SeaBubbles provided a more efficient utilization since the load factors were higher than the current operation making the rides/passenger less costly.

Regarding the cost of operation, the SeaBubbles present similar fixed costs and in the scenario with a flexible use of the SeaBubbles from mornings to afternoons, the simulations revealed that it is possible to achieve a cheaper operation.

All in all, the results obtained suggest that with the use of SeaBubbles, it would be possible to reduce the costs of operation by 9% under certain conditions, eliminate the pollution when substituted the old fleet with SeaBubbles, increase the utilization from 7% to 80% and make the rides faster with the use of the Bubblejets.

The study only considered the fixed and variable costs of operation; however, in a cost/benefit analysis, other costs that make the use of SeaBubbles more attractive should be considered:

- lower docking costs
- required docking space for the SeaBubbles
- 24/7 service time of SeaBubbles
- Possibility of autonomous driving
- Higher passenger revenue for low demands
- Possibility of picking up passengers during the ride
- Multiple new locations among the networks

These are planned for a further phase of the study.

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