Memo

To

to whom it may concern

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Subject

Case study on the application of hubs and spokes in inland water transport.

1 Introduction

The hubs-and-spokes model is a system used in transportation and logistics to manage the distribution of goods. This model centralizes operations around a main hub, which serves as the primary point for receiving, sorting, and redistributing goods to various destinations, known as spokes. From these spokes the goods are then transported to their final destination.

An example of a hubs-and-spokes model can be seen in the Dutch supermarket chain Jumbo. Jumbo has multiple distribution centers spread across the Netherlands. These centers serve as the hubs in the model. The different suppliers transport their goods to these distribution centers, where they are sorted and stored. The sorted goods are then distributed across different supermarkets, which serve as the spokes. From these spokes, the customers can get their groceries and are the final destination of the chain.

The main advantage of the hubs-and-spokes model over its counterpart, the point-to-point model where every node is connected to every other node, is that it greatly reduces the number of connections you need to make for larger networks. Assuming we have n nodes, which need to be connected, then in the point-to-point model we have $\frac{n(n-1)}{2}$ connections. If we would convert one of the nodes to a hub instead, and thus apply the hubs-and-spokes method, we would only need $n-1$ connections, which is considerably smaller for higher number of nodes. Figure 1 shows this for six nodes. To ensure that each node has a path to each other node, a total of 15 connections are needed for the point-to-point network, opposed to only five for the hubs-and-spokes network. Another advantage of the hubs-and-spokes method is that the more complex logistic operations can be centralized at the big hubs, allowing for simpler spokes to operate.

Voorliggende rapportage is een product van het project TRANS2 (“TRANSitie naar een klimaatbestendig en duurzaam Rotterdams achterlandTRANSport”), een project met 15 partners onder coördinatie van Deltares. TRANS2 gaat primair over klimaatadaptatie: hoe kan de binnenvaart zich aanpassen aan, meer grip krijgen op een veranderend klimaat? Project TRANS2 is mede gefinancierd door TKI Deltatechnologie uit de PPS-innovatie programmasubsidie van het Ministerie van Economische Zaken.

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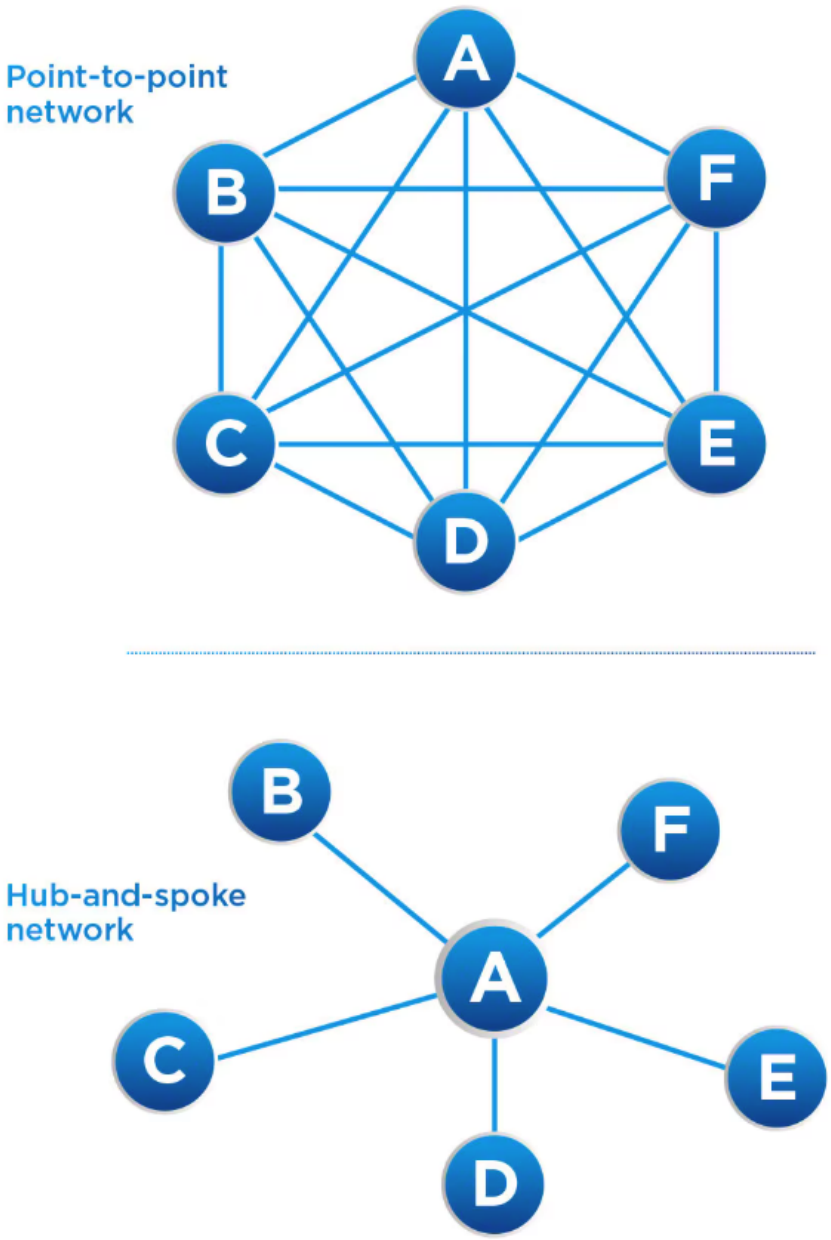

Figure 1: *Connections needed in point-to-point compared to hubs-and-spokes if all nodes need to have a route to each other node. Figure taken from (1)*

These are some clear advantages of the hubs-and-spokes concept, however inland water transport offers some different challenges. Firstly, due to nature of river navigation there is a limited amount of routes a ship can take to get from A to B. Therefore, it is not as clear cut if centralized hub offers noticeable benefits. Moreover, since the hubs-and-spokes model has never been used for inland water transport, there current infrastructure is not suitable to accommodate this, so large investments would be required to establish such a network. Lastly, a general disadvantage of a hubs-and-spokes network, is that there is a large dependency on the hubs. Disruptions to the hubs, due to for example the weather or technical

issues, can interrupt the whole network. Still, we believe it is worth to investigate the possibility of the implementation of hubs into the network. Especially for periods of low water level during a drought. The low water level can introduce a bottleneck into the system, preventing the use of larger barges past this bottleneck. In the current situation, this would automatically reduce the size of the barge for the whole route or reduce the load of these barges to be able to pass the bottleneck. By implementing a hub before these bottlenecks, large vessels would still be able to sail to these hubs, from where smaller barges transport the goods past the bottleneck to the destination further on the route.

To assess the possibility of the use of a hubs-and-spokes network in inland water transport, we did a small case study. In this case study we mainly looked at time efficiency.

2 Case study

For the case study we chose to look at the route from Rotterdam (NL) to Duisburg (DE) via Nijmegen (NL). Here we used Nijmegen as a hub, meaning that ships will transport their goods from Rotterdam to Nijmegen and then different ships transport the dropped of goods from Nijmegen to Duisburg. We compared this scenario to the 'direct line' scenario, where the ships transport the goods from Rotterdam immediately to Duisburg, after which they return to Rotterdam to pick up the next goods (Figure 2). Since we are mostly interested in the effects of the hubs and spokes method when the water level is low, we looked at the period of 29 August 2022 to 10 October 2022, which is when there was a big drought. In this period a total of 23334 containers were transported from Rotterdam to Duisburg. To keep the case study for this proof of concept simple, we only considered one ship per route. This means that for the hubs and spokes scenarios there is a ship that sails between Rotterdam and Nijmegen and a ship that sails between Nijmegen and Duisburg. For the scenario with the direct line from Rotterdam to Duisburg, we only have one ship. We made the following assumptions for the ships: each ship moves with a constant velocity of $4\mathrm{m/s}$. The transfer rates of the containers from the terminal to the ship and from the ship to the terminal is $20\mathrm{s/container}$ and we assume a constant capacity of 200 containers per ship. The simulations were done using the Python package Simpy, for the environment, and the Python package OpenTNSim, for vessel movement (2), (3).

In the second part of the case study, we considered different capacities of the ships between Rotterdam and Nijmegen compared to the ships between Nijmegen and Duisburg. In the case of a drought, the water level can decrease causing a bottleneck shortly after Nijmegen. As a result, the ships cannot be fully loaded when passing this bottleneck. To simulate this, we assumed that the capacity due to low water level decreases to 100 containers per ship to pass the bottleneck. This means that in the direct-line scenario from Rotterdam to Duisburg the ship now only has a capacity of 100 containers for the entire route. In the hubs-and-spokes scenario however, this is only true for the ship between Nijmegen and Duisburg. The water level between Rotterdam and Nijmegen rarely plays a role in the maximum capacity. Therefore, we assume that the ship sailing between Rotterdam and Nijmegen still has a capacity of 200 containers.

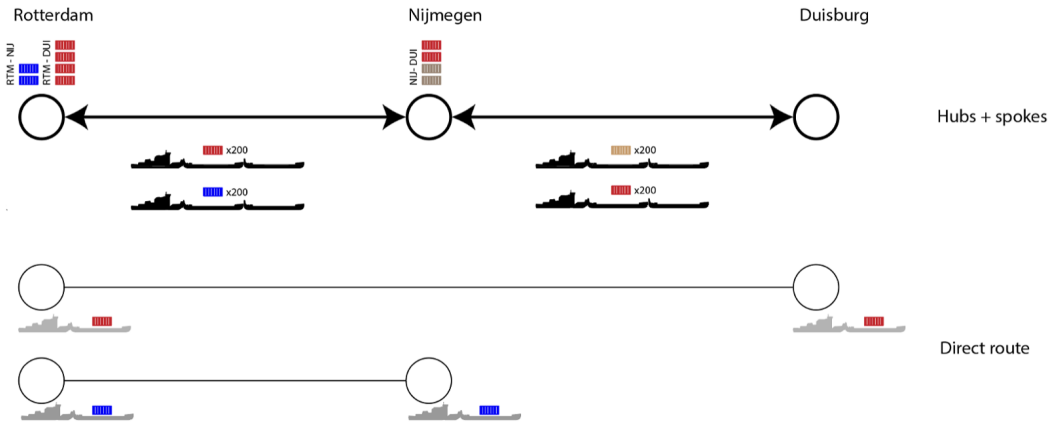

Figure 2: *A schematic overview of the two different scenarios compared in the two case studies.*

3 Results

The results of the simulations show that the ships in the hubs and spokes scenario took about 4 months fewer to transport all the containers from Rotterdam to Duisburg. Figure 3 shows the activities over time for all three ships (RTM-NIJ, NIJ-DUI with a hub and RTM-DUI without a hub). Here an activity is defined as a full cycle for the ship, so loading the cargo, moving to the destination, unloading the cargo and then moving back to the source location to pick up more cargo. The figure makes clear that the ships in the hubs scenario have a shorter cycle compared to the ship in the scenario without a hub, resulting in a steeper line.

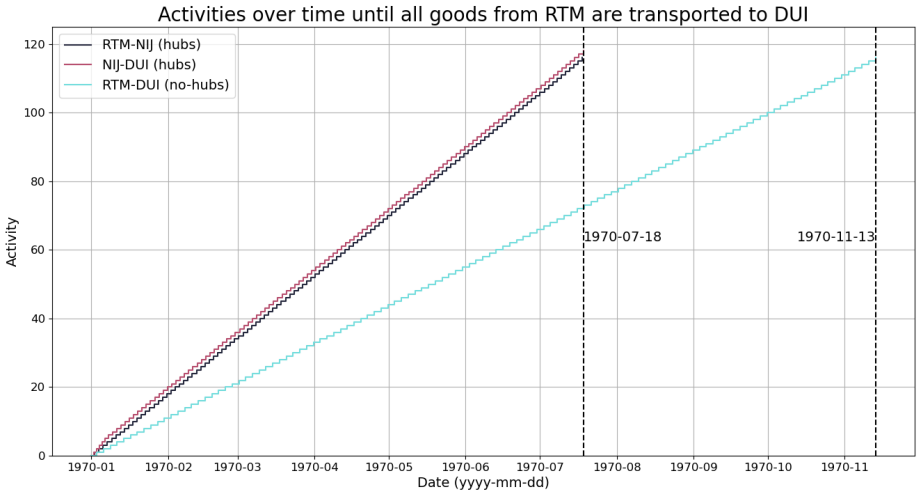

Figure 3: *The activities of the individual ships in the hubs-and-spokes method and the direct line method until all goods at Rotterdam are transported to Duisburg.*

If we zoom in to the first 15 activities in Figure 4, the dynamic between the ships in the hubs scenario becomes more clear. The figure shows 'move full' and 'move empty' for each trip, indicating when the ship is transporting goods and when the ship is sailing back to the source location to pick up more goods respectively. We see that the route NIJ-DUI takes longer compared to the route, resulting in some waiting time at Nijmegen where the ship to Duisburg

needs to wait for the containers from Rotterdam to arrive. Despite this, the hubs scenario is still marginally faster due to the overlap in 'move full' and 'move empty'. During the time the NIJ-DUI ship is empty moving back to Nijmegen, the RTM-NIJ ship is transporting its goods to Nijmegen and vice versa. It is important to note that, while the hubs scenario is faster, it does require more transfers of the containers from and onto the ship, hence it comes with higher costs. Furthermore, an extra ship is required to be able to carry it out.

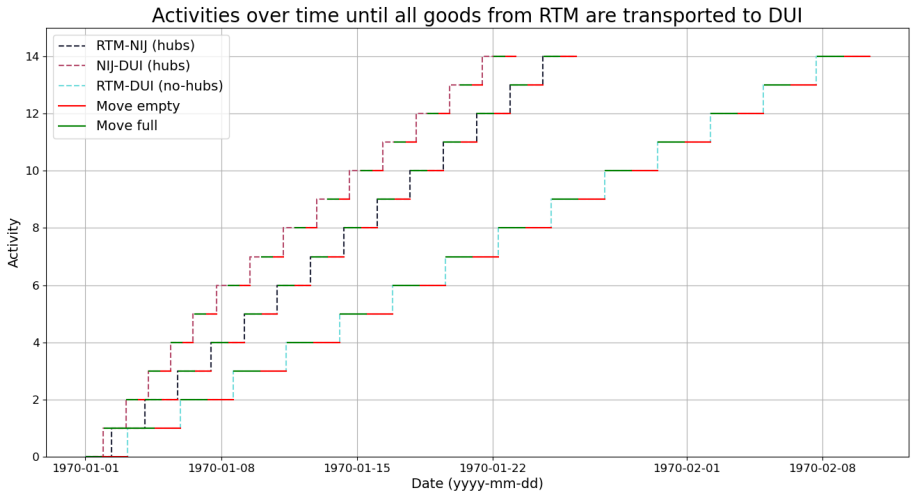

Figure 4: *The first 15 activities of the individual ships in the hubs-and-spokes method and the direct line method. The movements with cargo and without cargo are indicated by the green and red lines respectively.*

In Figure 5 we show the results of the second simulation where the ships sailing between Nijmegen and Duisburg have a lower capacity. Here an even bigger difference in total time is present, with the direct-line method taking a year longer to transport all goods, taking more than twice as much time than the hubs-and-spokes method. We also note that the NIJ-DUI ship for the hubs-and-spokes method has a steeper line than the ship RTM-DUI. This is due to the lower capacity of NIJ-DUI, resulting in a lower transfer time at the ports.

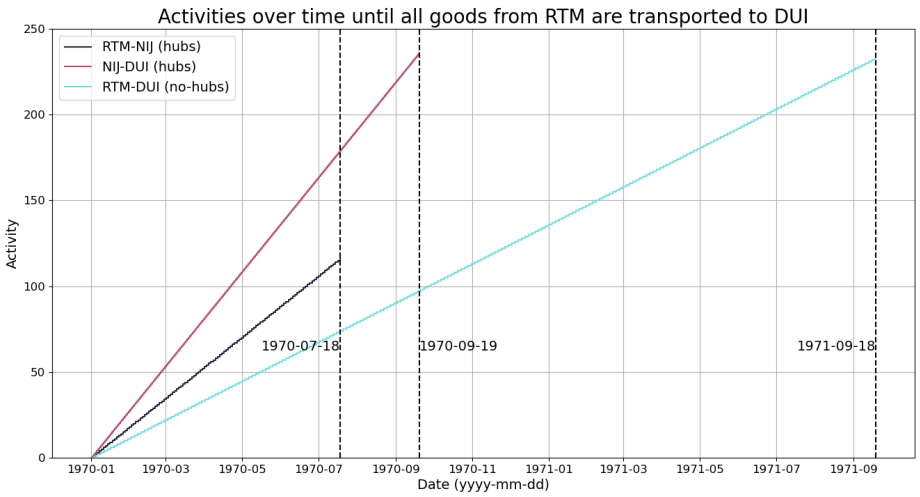

Figure 5: *The activities of the individual ships in the second case study of the hubs-and-spokes method and the direct line method until all goods at Rotterdam are transported to Duisburg. The ship RTM-NIJ has a capacity of 200 containers and the ships NIJ-DUI and RTM-DUI have a capacity of 100 containers.*

4 Conclusions

From the case studies we can conclude that the hubs-and-spokes model is more efficient in time compared to the direct line between Rotterdam, Nijmegen and Duisburg. This despite the extra time needed for transferring the goods from and onto the ship at the ports. And while the hubs-and-spokes method proved to be more efficient in time, it does bring extra costs with it for these extra transfers that are needed. We would like to stress that two different ships were used in the hubs-and-spokes method while we only used one ship in the direct line method. For the first case study we considered the same capacity for the whole route, which resulted in the direct-line method taking roughly 1.5 times as long as the hubs-and-spokes method. When considering a halved capacity between Nijmegen and Duisburg, the difference was bigger, with the direct-line taking more than 2.3 times as long. Therefore, even if a second ship would be added to the direct-line method, the hubs-and-spokes method would still be faster.

To get a more complete overview of and answer to the question, we would need to do a more thorough analysis. For one, the difference in fleet composition needs to be analyzed in more detail. The introduction of a hub allows for a different fleet composition, but this was not researched in this case study. Furthermore, a more thorough research on the comparison between the emissions for the two methods needs to be carried out in addition to a variable draught. For this case study, we did consider a dry period, but this was only used to gather the total amount of transported goods during this period. In a more in-depth analysis, we can look at an actual change in waterlevel and its actual impact on the different methods.

References

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