

TRAVISIONS

TRA VISIONS 2020

Final Project Template – This template is to be used for submitting the final version of the project. The final deliverable should be submitted by the 31st of October 2019

Idea Number:

C2020 - 47

PILLAR / TRANSPORT MODE				
ROAD ☐	RAIL ☐	WATERBORNE ☒	AIRBORNE ☐	CROSS MODAL ☐
Project Related to:	☐ RA1: Climate Change, Mitigation and Resilience ☐ RA2: Digitalisation, Digital Safety and Security ☐ RA3: Automation and Robotisation ☐ RA4: Electrification, Energy and Power Alternatives ☐ RA5: User-focused Mobility services, Servitisation ☐ RA6: Social Change and Quality of Life ☒ RA7: Technology and Engineering ☐ RA8: Planning, Modelling and System Design ☐ RA9: Policy and Regulation, Market Efficiency, Competitiveness ☐ RA10: Transport Safety and Security ☐ RA11: Investments, Finance and Public-Private Partnerships ☐ RA12: Innovation and Human Capital			

Project Title:

A new solution for turning an inland ship on a narrow waterway

1 Introduction

The shipping industry is the driving factor for the globalisation of the market economy. Large ports not only contribute significantly to the gross domestic product (GDP) of a country, they are also responsible for direct and indirect job creation. In Belgium ports accounted for 7.8% of the GDP and attracted 4.6 billion of direct investments in 2016 (Flows, 2019).

The surrounding infrastructure and logistics chain is vital for the long-term growth of a port. Inland shipping forms an important mode of transport, especially considering the traffic congestion on the (ring)roads of many large cities. For the port of Antwerp 38% of the cargo is transported using the inland waterway network (Port of Antwerp, 2017), which partly explains the good growth numbers of the port. A well-developed waterway network, with sufficient capacity, is key in this case.

As the hinterland consists of various countries, a coordinated European effort is needed. CESNI¹ played a big role in this matter by launching the ESTRIN document (CESNI, 2017), which lays down technical requirements for inland ships. Many waterways in Europe are upgraded to allow more traffic / larger ships to travel on the network (IMDC, 2019). In most cases, bottlenecks are present, which are hard to overcome due to space restrictions.

The example in this project concerns the optimisation of a turning basin for inland ships in a narrow waterway, where the river current is the driving force to turn the ship. In order to turn the ship efficiently, a dolphin – mooring line pivot system (denoted as 'line-pivot'), could provide a solution here (Mansuy et al., 2019), reducing the need for additional manoeuvring space. In the current project, the pivot point is optimised and formed by a fixed magnetic / vacuum connection (denoted as 'pad-pivot'). The concept and design of this system is elaborated on in this proposal.

In a first part, the problem statement is provided, based on the research that was carried out (Mansuy et al., 2019). In a next section, the pad-pivot concept is explained, after which the existing magnetic / vacuum technology is reviewed. Hereafter, all the forces which are part of the problem are discussed, showing how an existing ship manoeuvring simulator model can be updated to model the pad-pivot system. Future work includes performing dynamic manoeuvring simulations, including the pad-pivot structure, and using the results to come up with a detailed design for the pad-pivot.

¹ CESNI (Comité Européen pour l'Élaboration de Standards dans le Domaine de Navigation Intérieure

2 Problem statement

The current research follows up on the simulation study performed for the Quai des Trois Fontaines, a berthing area in Chooz, France (Mansuy et al., 2019). The area under investigation is a 95 m wide river section, shown in Figure 1. The turning manoeuvre for ships of 80, 85 and 90 m length was investigated by means of manoeuvring simulations (Figure 2). In this turning manoeuvre, the main river current is used to turn the ship. Some ships have a bow thruster, which makes it easier to control the manoeuvre and to perform it faster.

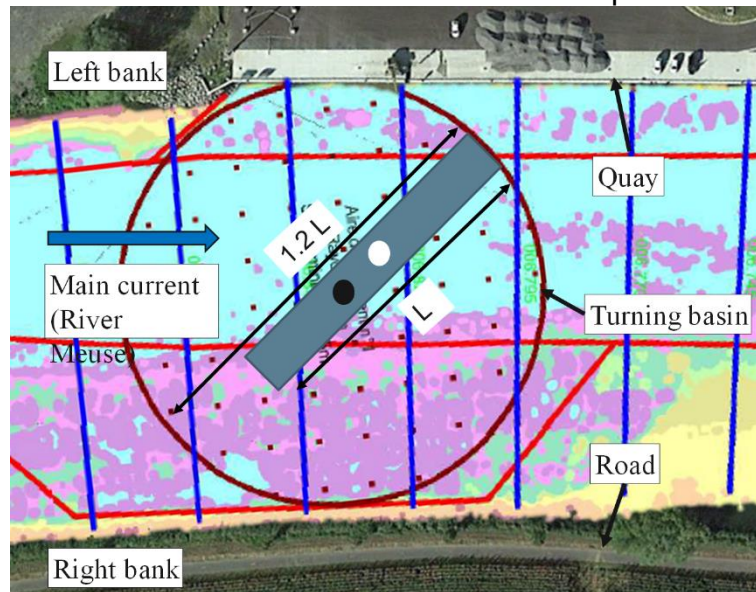


Figure 1 : turning basin geometry near the Quai des Trois Fontaines in Chooz (France), from (Mansuy et al., 2019)



Figure 2 : view from the ship simulator bridge, from (Mansuy et al., 2019)

According to the PIANC WG141 design guidelines for inland waterway dimensions (PIANC, 2019), a width of $1.5 L$ (with L the ship length) is required to safely perform a turning manoeuvre. In the existing section, the 80 m ship only has a width of $1.2 L$ available, hence the need for manoeuvring simulations to validate this specific design. The simulations showed that for the 80 m ship, the turning manoeuvre could be carried out, using all of the available $1.2 L$ wide section (see Figure 4). Consequently, the simulations revealed that for 85 m and 90 m ships, a local widening of the channel over a considerable distance would be necessary.



Figure 3 : swept path of an 85 m ship generated with the real time simulator, from(Mansuy et al., 2019)

Additional simulations have been performed using a fixed pivot point to which the ship is attached using a mooring line (line-pivot). This yields more control and a smaller turning circle. The implementation of the line-pivot however comes with many practical difficulties. By using a mooring line, the turning circle radius is always enlarged by the presence of the line itself. This line also stretches under tension, which influences the behaviour of the ship. The quality and capacity of the line is uncertain as well, which means that the line could break while performing the turning manoeuvre.

Another important drawback of this system is that the skipper needs to manually attach a mooring line to the pivot, which is always a dangerous and rather time consuming operation. In harsh weather conditions (wind, rain) and in the presence of current, which make it difficult to hold position, this quickly becomes a critical operation. Finally, the pivot connection with mooring lines requires an action by the main propeller to keep the lines tight. With the fixed connection, this propeller action is not needed anymore, resulting in a safer manoeuvre with less emissions and less forces on the pivot.

3 Pad-pivot concept

A fixed connection between pivot and ship would overcome the issues listed above and allow to safely perform turning manoeuvres with large inland ships in restricted sections. The pad-pivot concept is introduced here, comparing the needed manoeuvring space without pivot and the two pivot types.

3.1 *Pad concept*

The connection is be made with a vacuum suction pad or a magnetic pad. In section 4, the pad concept is explored in further detail, focusing on existing vacuum and magnetic technologies. This connection needs to deliver a normal reaction force, acting along the ship's longitudinal direction and a tangential force. As explained above, no main propeller action is required to turn the ship, which means that the normal forces remains limited. There is thus expected that the pad requirements are within existing design applications. A full dynamic calculation (future work) will still be required to confirm this.

3.2 *Pivot concept*

The pad forces are subsequently transferred to the pivot, which needs to allow rotation of the pad and anchor the system in the ground. In the basic concept, the pivot itself is designed as a passive structure, i.e. no torque is delivered to aid the turning manoeuvre. In an active system, on the other hand, the pivot could provide at least part of the torque required to perform the swinging manoeuvre. However, as the lever arm would be very small (section 5.1), an active system would be costly and large, and would require lots of maintenance.

3.3 *Needed manoeuvring space*

The main objective of the pivot design is to minimize the needed manoeuvring space. This mainly concerns the width of the section, but also the control over the longitudinal position of the ship. In section 2 it was already stated that PIANC recommends 1.5 L as section diameter. The manoeuvring simulations revealed a required width of 1.2 L. By introducing the pivot, the required section width is decreased. Another benefit is that due to the position control ensured by the pivot, the length of the section is also reduced, which is otherwise significant due to the presence of the current.

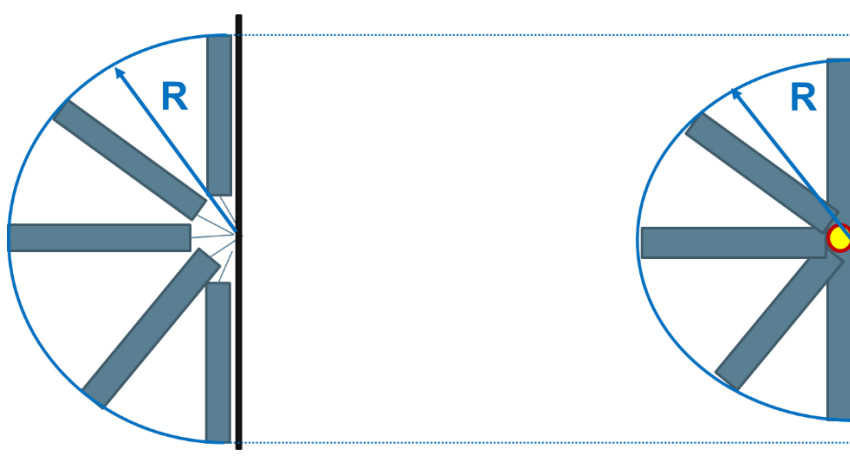


Figure 4 : comparison of the required manoeuvring space for line-pivot (left) and pad-pivot (right).

Figure 4 sketches the radii of the turning circle when the pivot system is applied. In case of the line pivot system, the radius equals the sum of the ship length and the line length. This length is a function of the load in the line, as it will stretch during the manoeuvre. When the pad-pivot system is used, the radius only comprises the length of the ship and the radius of the pivot, which is limited. In this case the design radius is known in advance with a high degree of accuracy, contrary to what happens when using the line-pivot or when performing the turning manoeuvre without any pivot.

4 Pad connection design

The connection between the ship's stern and the pivot point is ensured using vacuum or magnetic units. These technologies have already been applied in practice for mooring a ship against quay walls during loading/unloading (Figure 5 and Figure 6) and to hold the ship in position in locks. They are thus proven technology, already tested in harsh sea environments.

Well-known companies active in this field are Cavotec (Cavotec, 2017) and Trelleborg (Trelleborg, 2019) for vacuum mooring and Mampaey (Mampaey, 2018) when it comes to magnetic mooring. These units are designed to both deliver the needed reaction force, and to provide active/passive damping using cylinders and/or springs.



Figure 5 : application MoorMaster for mooring of ships (from Cavotec website)



Figure 6 : application magnetic mooring for mooring of ships (from Mampaey website)

The holding forces depend on the dimensions of the unit, and more specifically of the pad. In the vacuum application, the maximum suction pressure is always equal to ambient (air) pressure, making it easy to calculate the needed surface for a given force. (Cavotec, 2017) depicts a holding force of 200 kN tons per pad. (Trelleborg, 2019) delivers pads with rated force of 20 tons. (Mampaey, 2018) mentions a holding force of 320 kN in sway and 130 kN in surge. The results of the manoeuvring simulation model will be used to optimise the pad dimensions and design for this specific case.

5 Force models – manoeuvring simulator update

In the previous sections the reader might have been getting the impression that the problem is quite straightforward. It indeed uses proven technologies. An accurate estimation of the forces acting on the pad and on the pivot system, however, requires a sound expertise on the dynamic modelling of ship manoeuvres in confined waters. By performing these manoeuvring simulations, limitations in the use of the current-driven turning area can also be exposed, for example in unfavourable wind conditions.

This section starts off with a discussion of the forces on the system and two approaches to make a pivot design, static and dynamic. Based on these results, the suction pad can be designed. As the update of the manoeuvring model to include the pad-pivot is still ongoing, a qualitative assessment of the pivot reaction in function of the forces is given.

5.1 Static and dynamic model

The turning ship – pivot equilibrium can be solved for all (time) steps during the turning manoeuvre. This section describes a static method at first. This static method allows to assess whether the turning moment present for all angles is positive, meaning that the ship can certainly perform the full turning manoeuvre.

A static analysis can provide a useful preliminary insight on the problem. However, a static analysis will not allow to calculate the speed of the rotation (yaw rate), which is a critical parameter since the manoeuvre needs to be executed within a certain timeframe, not to hinder other traffic. The dynamic model provides an answer to this question. The force components part of the dynamic model are shown in Figure 7. The static model looks similar, albeit without the hydrodynamic forces due to ship velocity and acceleration.

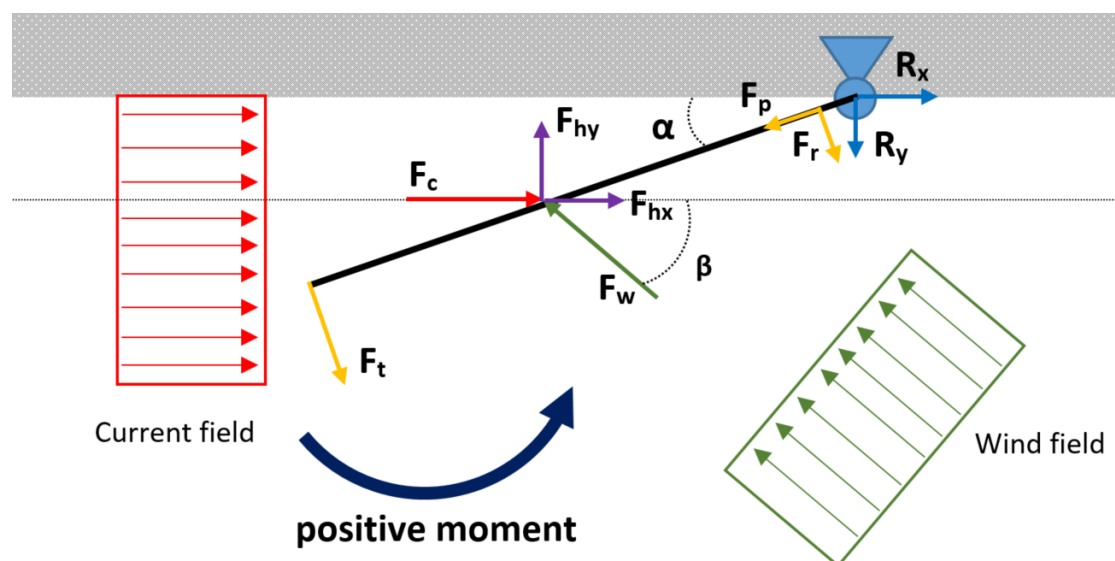


Figure 7 : summary of the forces present on the ship : dynamic model

Static approach

A simplified static force model is denoted by the following forces (see Figure 7)

- A current field, assumed to be uniform, is present. The ship's starting position is always chosen in order for the current to deliver a moment which turns the ship. The resulting current force is denoted F_c . Current effects are modelled through a conventional approach based on angle dependent current coefficients and hull wetted areas (OCIMF, 2018)
- The wind force (F_w) is variable in direction, as wind can come from all incoming directions, some more frequent and with higher wind speeds compared to others. In order to design the system, the most unfavourable combination of wind direction and speed needs to be assessed, counteracting the current moment, making it harder for the ship to turn. Wind effects are modelled through a conventional approach based on angle dependent wind coefficients and wind exposed areas (OCIMF, 2018).
- Many inland ships have a bow thruster (F_t). This force has a large lever arm with respect to the pivot point, and thus greatly aids in the turning manoeuvre of the ship.
- Despite being inefficient, a ship could still use propeller (F_p) and rudder (F_r) to assist in turning the ship. The very small lever arm around the pivot however minimises this contribution. It would also cause additional forces on the pad, making these larger and more costly.

R_x and R_y are the required pad reaction forces. As the basic system shown in Figure 7 considers a passive pivot (no torque delivered by pivot), there is by default no static moment equilibrium. A resulting positive moment (sign convention Figure 7) means that the ship will want to accelerate and turn. A negative moment would result in an acceleration in the other direction, meaning that the ship stops turning. The static analysis thus indicates if under the assumed forces, the ship will perform the turning manoeuvre, without knowing how long this will take. In order to answer this question, a dynamic model needs to be used.

The attentive reader will remark that in the initial position, there is no current moment which will induce turning of the ship. However, even a small perturbation of the initial equilibrium in order to detach the bow from the bank will create an initial moment which would start to turn the ship. This is achieved easily by literally pushing the ship bow off the quay wall using a stick, a technique which is often used by inland skippers in locks / berths.

Dynamic approach

The dynamic approach builds on an existing 3DOF mathematical manoeuvring model developed at Flanders Hydraulics Research (FHR) (Elout, 2012). This model describes the inertial and hydrodynamic forces acting on the hull. Differently from the static case, the current effects are modelled by the speed-through-water approximation, which is commonly implemented in ship manoeuvring simulators (Donatini et al., 2019). According to this approach, the current induced forces are not calculated directly, but a relative speed-through-

water is computed first and then used to replace the speed over ground as an input to the hull hydrodynamic forces estimation performed by the manoeuvring model.

As this manoeuvring model is already state-of-the-art, the only step required is to add the pivot forces to the manoeuvring model, forcing it to turn around the pivot point. This last step requires writing a “pivot” plugin for the existing simulator code (Figure 8). In this way, the required pad reaction to keep the aft in place can be calculated. The pivot reactions are then added to the other forces in order to solve the equations of motion for the ship attached to the pivot.

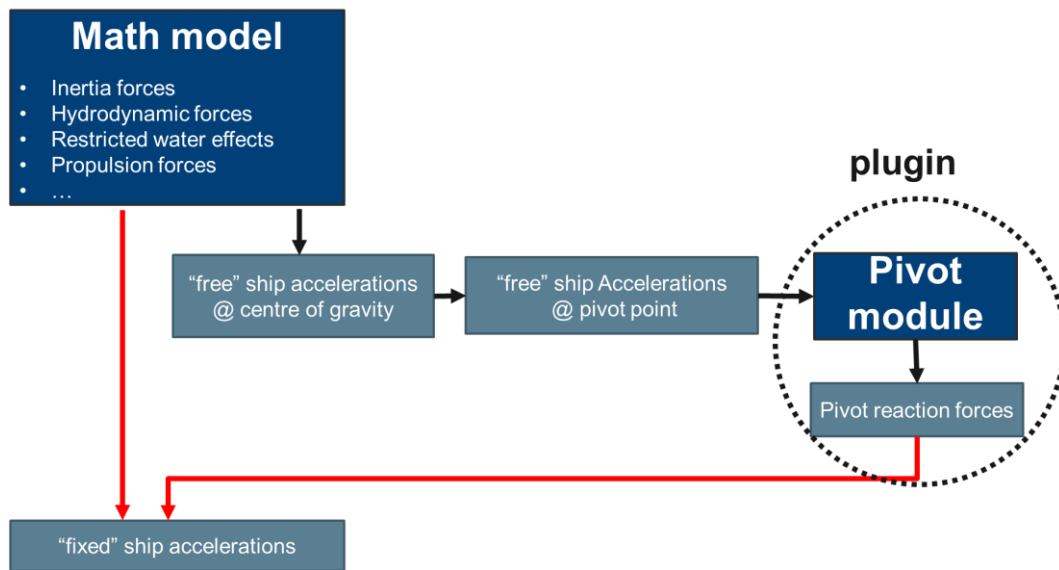


Figure 8 : schematical representation FHR manoeuvring model, with pivot plugin.

The dynamic simulations not only provide more accurate pad-pivot reaction forces compared to the static model, it also delivers velocities and accelerations as output. The resulting time window needed to perform the turning manoeuvre needs to be assessed and compared with the maximum allowable time for this manoeuvre.

5.2 Pad design

The reaction forces R_x and R_y , resulting from the dynamic model, are subsequently used to design the pad. This is done by rewriting the forces R_x and R_y as L (normal force) and T (transversal force) (Figure 9), by simply applying a 2D rotation to the forces, based on the angle α . The pad can cope with both force directions.

For a suction pad, the normal reaction force (L) is limited by the vacuum capacity (V). The transversal force is transferred by friction in the pad (Figure 9). The available friction reaction force however is affected by the normal force (L), as follows, where the sign of L can be positive and negative.

$$T = (V - L) \cdot \mu$$

From this equation, it follows that the needed vacuum capacity (V) can be expressed a function of L and T as:

$$V = \frac{T}{\mu} + L$$

This required capacity V is calculated for all time steps and cases (combination of wind, current and bow thruster), finally leading to the minimum pad dimensions for the case at hand. A similar exercise can be made for the design of the magnetic pad.

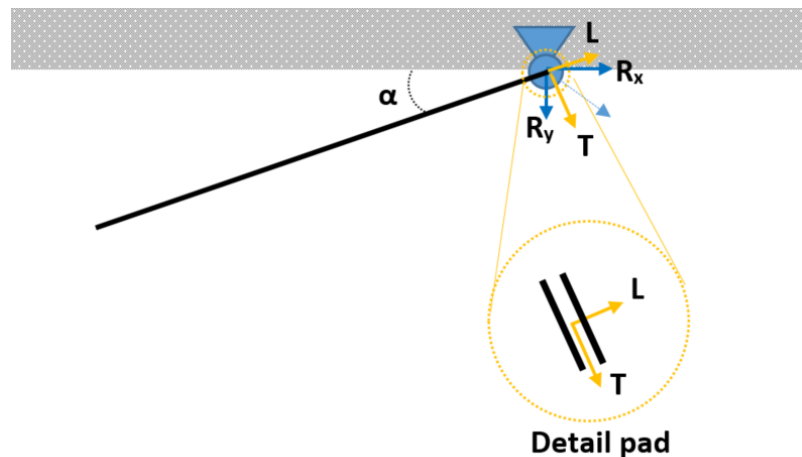


Figure 9 : design of the suction pad, based on normal force (L) and transversal force (T)

5.3 Qualitative assessment pivot system

Based on the description of the forces above, the application and limitation of the pivot system is briefly discussed in this section. A more detailed assessment of the forces is subject of future work.

- In case of low wind speeds, or wind direction similar to current direction, the ship will always perform the turning manoeuvre. The presence of a bow thruster would add to the rate of turn, completing the manoeuvre faster and thus safer.
- Larger wind speeds, from less favourable directions, could make the manoeuvre harder to perform. The presence of a bow thruster solves this issue, by counteracting the moment due to wind.
- In case of unfavourable wind and absence of a bow thruster, there will be a wind speed above which the manoeuvre cannot be completed (within the allocated time window). In this case, there are still two possible measures, albeit with limited efficiency. The ship could use its own rudder and propeller to assist in the turning manoeuvre and/or the pivot could be designed as an active rotation point (see section 3.2). Both however deliver forces close to the pivot point, limiting the efficiency. It would be more appropriate here to define a maximum wind speed (in function of direction) at which the turning manoeuvre can no longer be executed safely. The ship then needs to wait or look for a better location to turn along the river.

6 Conclusion and future research

A pad-pivot turning system for inland ships in narrow waterways was presented, based on simulations performed for a berthing area in Chooz, France. The pivot system in general (pad-pivot and line-pivot) reduces the required manoeuvring space (width of the basin). The pad-pivot system counteracts many of the disadvantages linked to the line-pivot. It consists of a vacuum or magnetic fixed connection with the aft of the ship. These technologies exist for similar applications, where a connection with a ship hull is made.

Static and dynamic models are here identified. The static model is suited to explore the possibility of making the turn in the section, under all possible force combinations. A dynamic model is needed however to get more accurate results for the reaction forces delivered by the pivot and the time needed to perform the turn. Based on the required reaction forces, the needed pad surface can be designed.

The future work involves finishing and implementing the pivot plugin for the existing dynamic manoeuvring model at FHR. Using this model, a number of case studies will be simulated. These will give the minimum pad dimensions, as well as possible restrictions for current and wind, up to which the turning manoeuvre can be performed safely. This model can be used for fast-time simulations, as well as full bridge real-time simulations.

7 References

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