MODERN RIVER TRANSPORT ON THE CONGO RIVER

As autonomous driving of road vehicles becomes a reality, will river transport always remain in the era of navigational beacons?

Satellite-guided riverboat navigation uses signals from space-based systems to determine a vessel's position, velocity, and time anywhere in the world. This system inherently does not require local physical beacons for primary positioning.

This proposed mode of transport must notably ensure the rail connection between Kisangani and Kinshasa in order to ensure the export of 50Mt/year of iron ore from the Banalia deposit.

INTRODUCTION

Characteristics of the Congo River

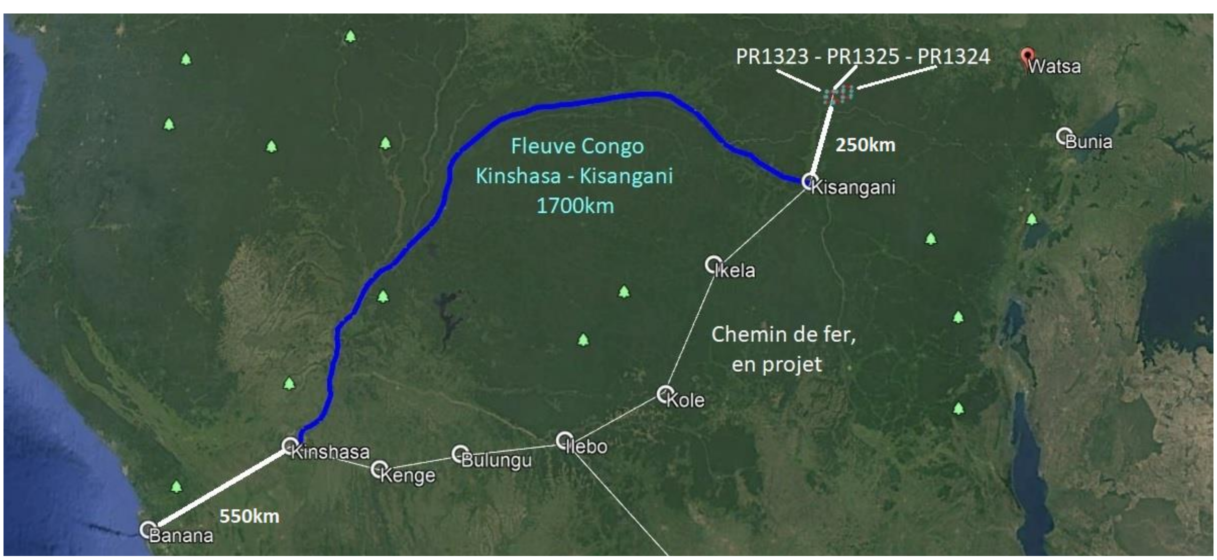
- Very wide
- Very large curves
- Not yet marked
- No lock
- Shifting sandbanks
- Shallow depth
- Average current between Kisangani and Kinshasa 4km/h

Characteristics of traditional river transport

- Economical
- Known to be slow
- breakage of transport load

Characteristic of iron ore transportation from Banalia deposit

- By rail from the mine to the river in Kisangani (250km)
- By river from Kisangani to Kinshasa (1700km)
- By rail from Kinshasa to the port of Banana (550km)



THE MIFOR RAIL PROJECT VS THAURFIN LTD RIVER PROJECT

In general, river transport is the most economical way to transport raw materials.

🚢 River Transport
• Lowest cost per ton-kilometer
• Very efficient for large quantities (coal, grain, ores, oil)
• Low energy consumption → economic and environmental advantage
• Ideal for long distances with available waterways
👉 Example: transporting coal on the Rhine is often cheaper than by train.

🚆 Rail Transport
• Faster and more flexible than river transport
• Intermediate cost (cheaper than road, but often more expensive than river transport)
• Accessible even without a river → more extensive network
• Less dependent on natural conditions (water level, frost, etc.)

⚖️ Conclusion
• Cheapest: river transport
• Most versatile and fastest: rail transport

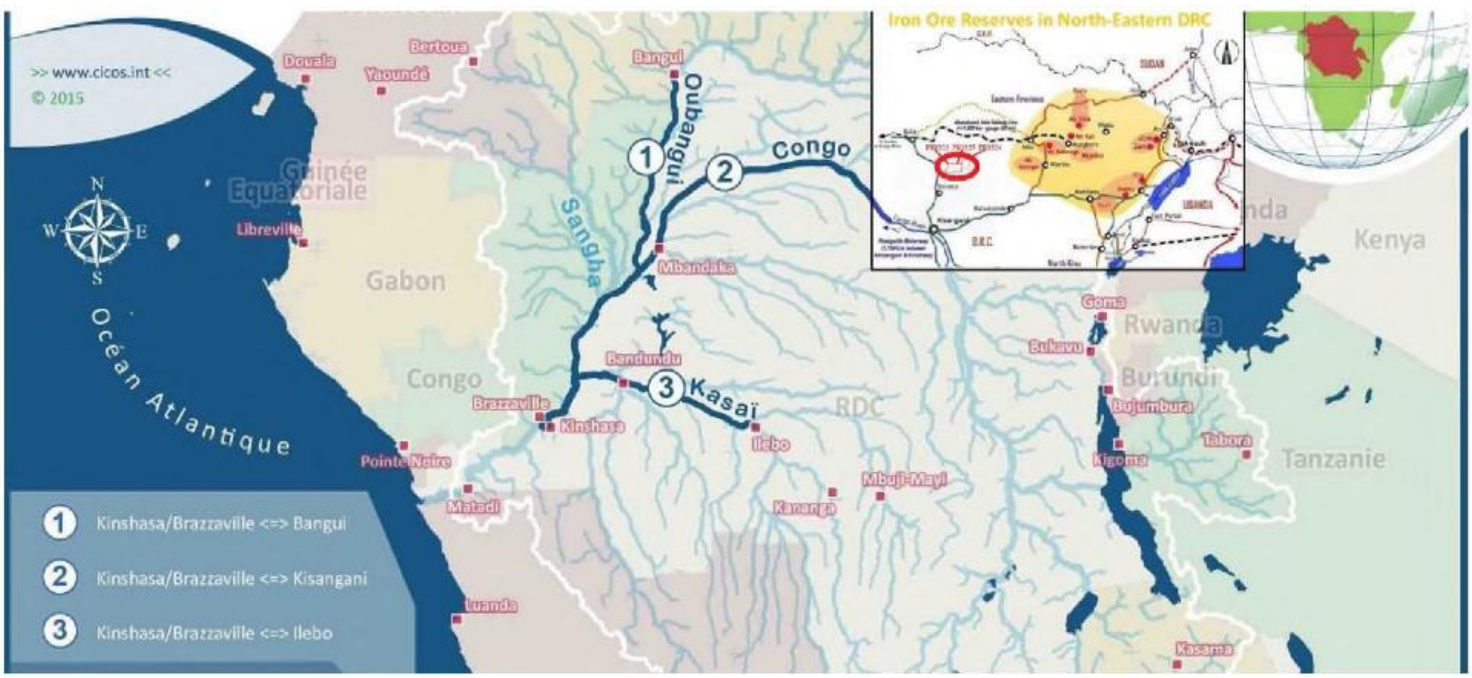
✅ Therefore:
• If you have a navigable river + large volumes + no urgency → river transport
• If you want more speed or no access to water → rail

📊 Key Takeaways
👉 River transport is generally 30 to 50% cheaper than rail
👉 It becomes unbeatable when:
• volumes are very large
• the distance is long
• there is a direct waterway
👉 Rail becomes attractive if:
• there is no river
• speed is required
• logistics are more complex

🧠 Simple Conclusion
• 🥇 Cheaper → River transport
• ⚖️ Cost/Speed Compromise → Rail

The iron resources of the former Orientale Province are estimated at 20bt. The Banalia deposit is closest to the Congo River which facilitates export to the next deep water port of Banana. Here is the map of iron deposits in Eastern Congo .
Taking into account the prospecting already carried out, the iron ore reserves are greater than 1bt@65%Fe which will allow its export equipment to be amortized over more than 20 years for an annual export of 50Mt. https://thaurfin.com/Iron-deposit.pdf

by superimposing these deposits on the map of the main rivers :



(intuitive) NOTIONS OF HYDRODYNAMICS GENERAL INFORMATION

Moving a boat requires energy which depends on 3 factors;

- The form drag
- Friction drag
- Wave or gravity drag on the water surface

The form drag

According to Archimedes, the weight of the boat is the weight of the displaced volume of water, which is why we do not speak of the weight of a ship but of its displacement. When this boat moves, this volume of water must be displaced, which requires energy that depends on :

- The displaced volume of water
- The shape of the hull
- The frontal surface area
- The speed

The formula for form drag is $TF = \frac{1}{2} Cx\ \rho\ S\ V^2$. The coefficient which depends on the shape is Cx, ρ : is the density of the fluid, S : is the frontal surface V^2 : the square of the speed.

Wave or gravity drag on the water surface

A moving boat creates a wave system.
The pressure at the bow exerts a dual action. As mentioned, it displaces the water upstream to allow the boat to take its place. However, a large part of this water is also lifted above the free surface by the bow to fall on either side of the boat. The potential energy gained during the uplift is transformed into kinetic energy during its fall, which extends below the equilibrium surface of the water. This displaced water oscillates away from the boat which creates waves around the boat. This gravitational drag transfers some of the boat's consumed energy to the waves. Gravity drag depends on the Froude number which is inversely proportional to the boat's immersed length. The bow wave and the stern wave are predominant. The distance between two crests (the wavelength) depends on the speed of the wave. As the boat's speed increases, the bow wave lengthens and deepens. The boat's speed when the wave's length equals its length is called the critical speed. If L is the wavelength in metres, the critical speed Vc = 2.39 * (square root of L).

Friction drag

This friction of the water on the hull of the ship depends on these factors

- The submerged surface
- The submerged surface condition
- The speed

As with form drag, friction drag increases with the square of the speed. The surface condition and the flow (Reynolds) are represented by the parameter CF. The formula for friction drag is $TS = \frac{1}{2} CF\ \rho\ S\ V^2$, where S is the wetted surface area and V^2 is the square of the speed.

Effect of speed of movement

If the speed increases, the immobilized equipment decreases proportionally (less investment) but the energy cost increases according to its square (cost $/ton increases)

RIVER TRANSPORT IS VERY ECONOMICAL

The iron ore that supplies the Austrian steel industry is transported by river up the Danube over a distance equivalent to that between Kisangani and Kinshasa.

The volume of goods transported on the entire navigable Danube between Kelheim (Germany) and the Black Sea (via the Danube-Black Sea Canal and the Sulina Canal) fluctuates between 36 and 40 million tons per year, cf https://inland-navigation-market.org/chapitre/2-freight-transport-on-inland-waterways-2/

On the Danube, approximately two-thirds of the transport involves iron ore and steel products, cf https://www.ccr-zkr.org/files/documents/om/om13_fr.pdf

SOLUTION RECOMMENDED BY THAURFIN LTD

Relating to the river speed of movement

Since the market value of iron ore per ton is low, transportation costs must be minimized. Because the iron ore export project is long-term, the extended amortization period encourages increased investment (minus the speed of transport) to reduce energy costs.

Regarding the costs of loading ore onto barges

The transshipment of goods in river transport is a major drawback that impacts its cost.

Given the characteristics of the Congo River (no locks, wide river, large curves), Thaurfin Ltd. proposes transporting a loaded railcar on a convoy of barges coupled together, each carrying a railway wagon.

The relative position of two successive barges is controlled by electric actuators so that each barge in the convoy follows a path determined by satellite.

Each barge is propelled by two electric propeller pumps installed on either side. The positioning and power of these propeller pumps are controlled by software that dictates movement along a path determined by satellite.

Advantages

- Only the convoy's travel route needs to be dredged to ensure the required draft.
- The ore loaded at the mine is unloaded at the deep-water port.
- The loading/unloading operation is very quick.
- The infrastructure at the departure and arrival ports is minimal.
- With the barges positioned close together, the wetted surface is continuous, resulting in minimal friction drag.

DESIGN

- **Draft**

According this publication, https://thaurfin.com/Tec.Sc.(NS)-T.XVI,8-LEDERER-1969-1970.pdf

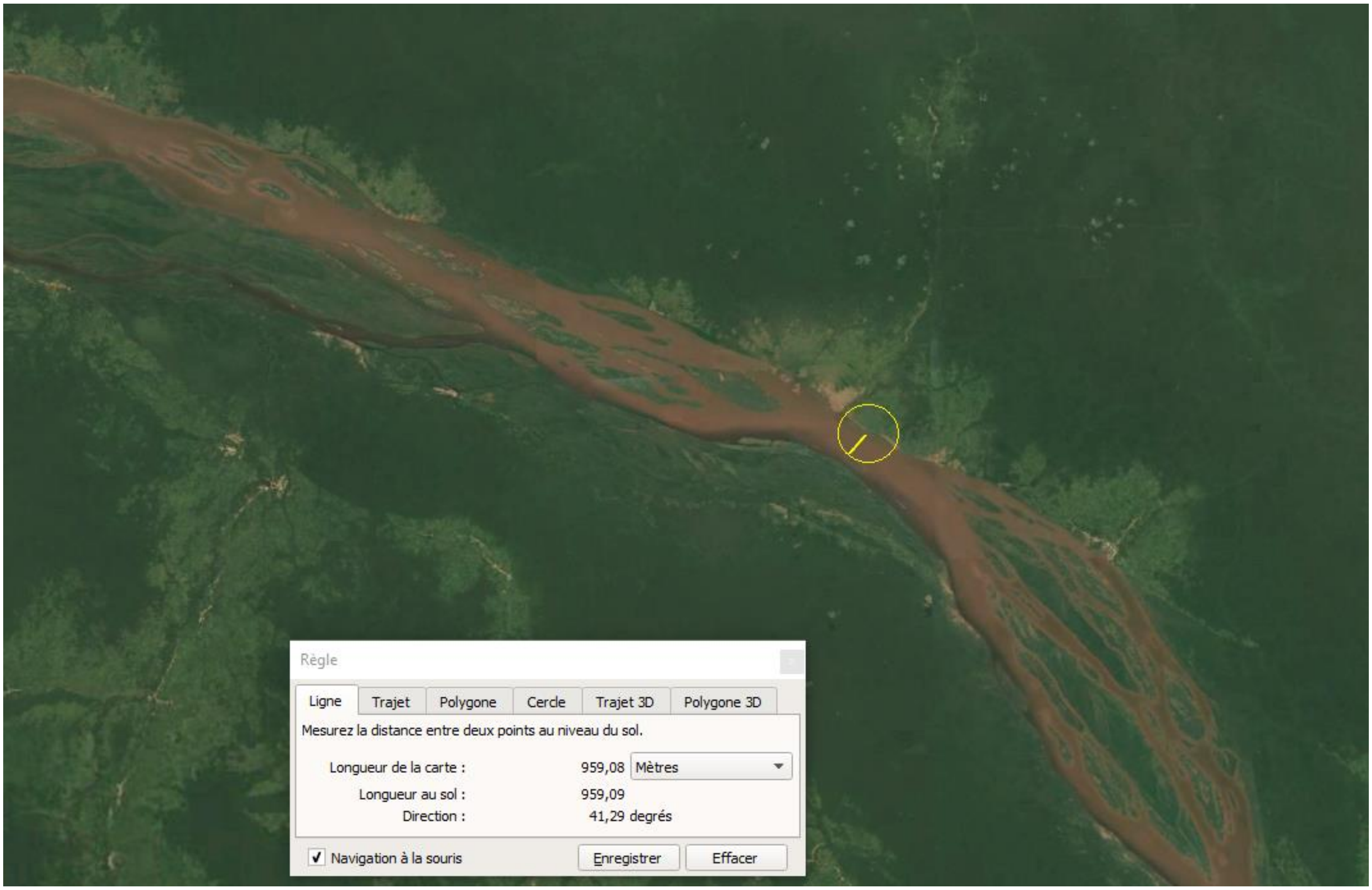
> Les zones donnant lieu à difficultés sont dispersées, mais ne représentent qu'un faible pourcentage de la longueur de ces rivières. Ainsi sur le Congo le tirant d'eau, aux basses eaux, est réduit à 1,50 m; mais les longueurs cumulées qui empèchent la navigation au tirant d'eau à 1,80 m ne représentent que 1 % des 1 700 km qui séparent Kinshasa de Kisangani.

*The areas causing difficulties are scattered, but represent only a small percentage of the length of these rivers. Thus, on the Congo, the draft at low water is reduced to 1.50 m**; but the cumulative lengths that prevent navigation at a draft of 1.80 m represent only 1% of the 1,700 km that separate Kinshasa from Kisangani.***

As only the convoy's travel route needs to be dredged to ensure the required draft.
A draft of 1.5m can be ensured since the well-defined channel can be dredged regularly

- **<u>The curvature of the convoy</u>**

The wide curves of the river (>1km) allow for a minimal curvature of the convoy.



- **<u>Railway wagons</u>**

The dimensions of railway wagons determine the dimensions of barges.

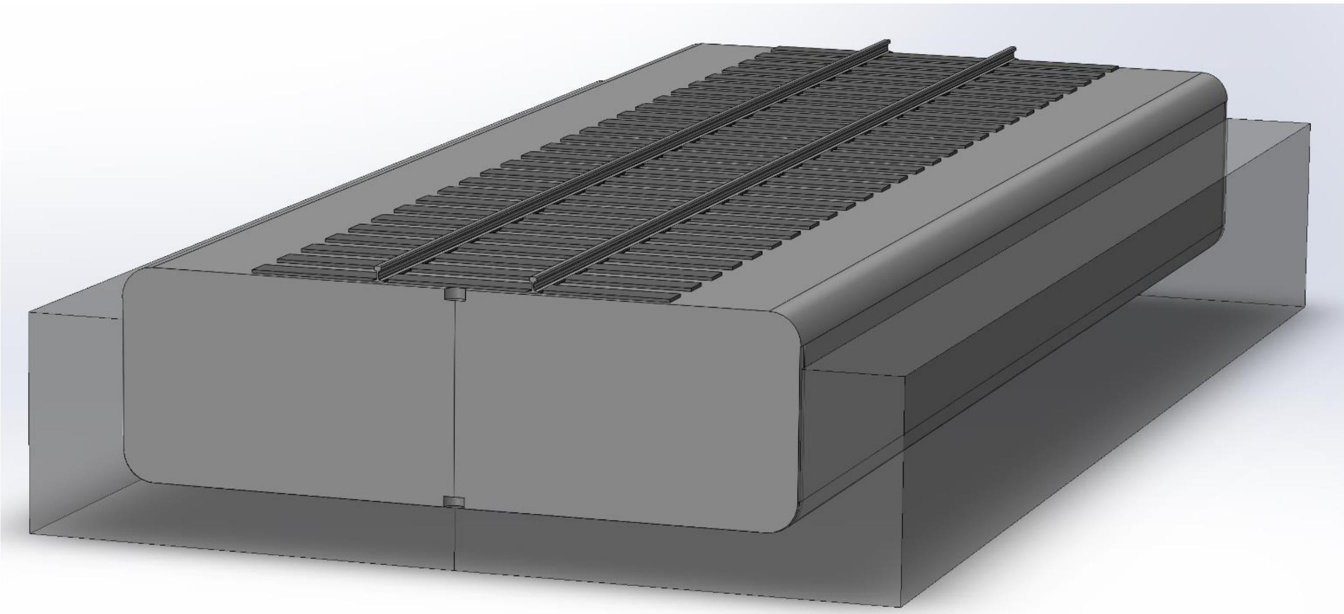
Lenght : 15,5m
Loading weight : 90t
Empty weight : 30t

- **Dimensions of a barge**

Lenght : 15,5m

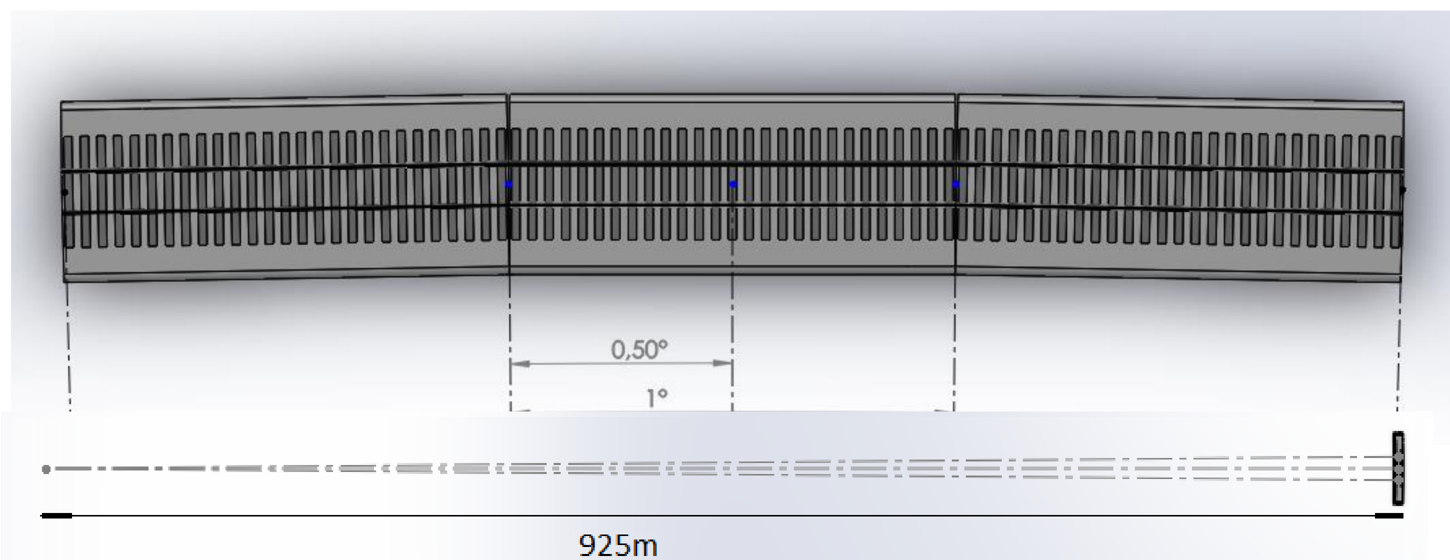
- **Design**

To ensure maximum safety, we are considering unsinkable barges made of polyester laminate filled with polyurethane foam. This rigid foam also provides maximum barge rigidity.

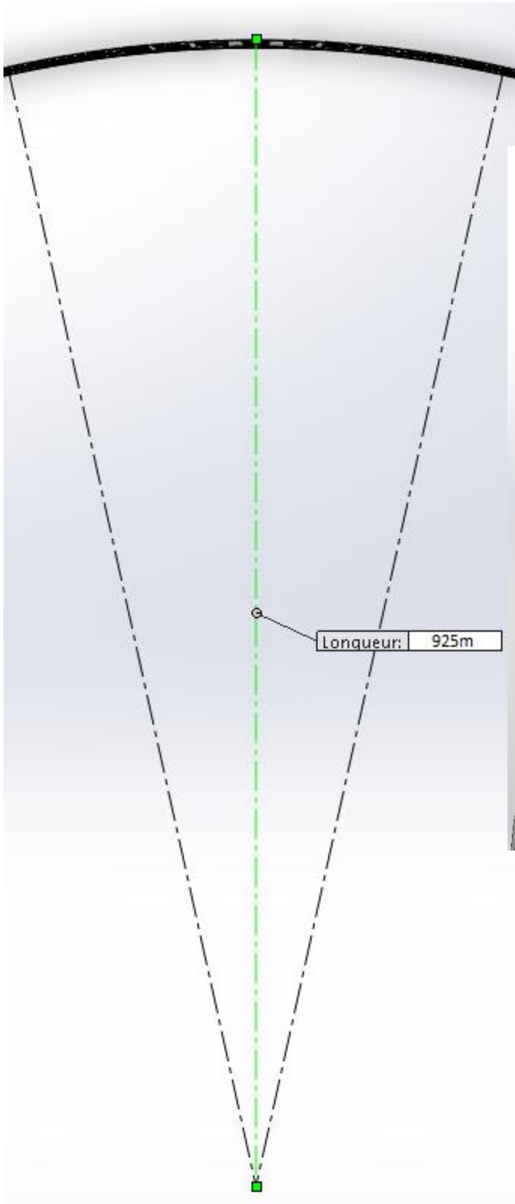


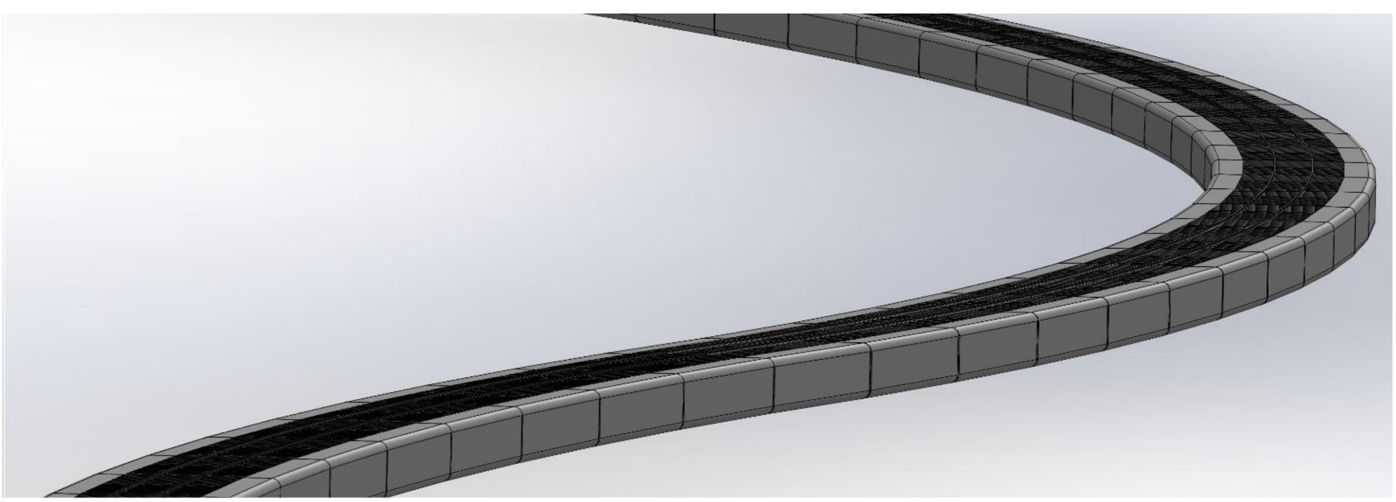
- **Hitch and design of the barge**

The coupling of two barges should allow the relative rotation enabling the convoy to follow a route with curves of a maximum radius of 1000m.

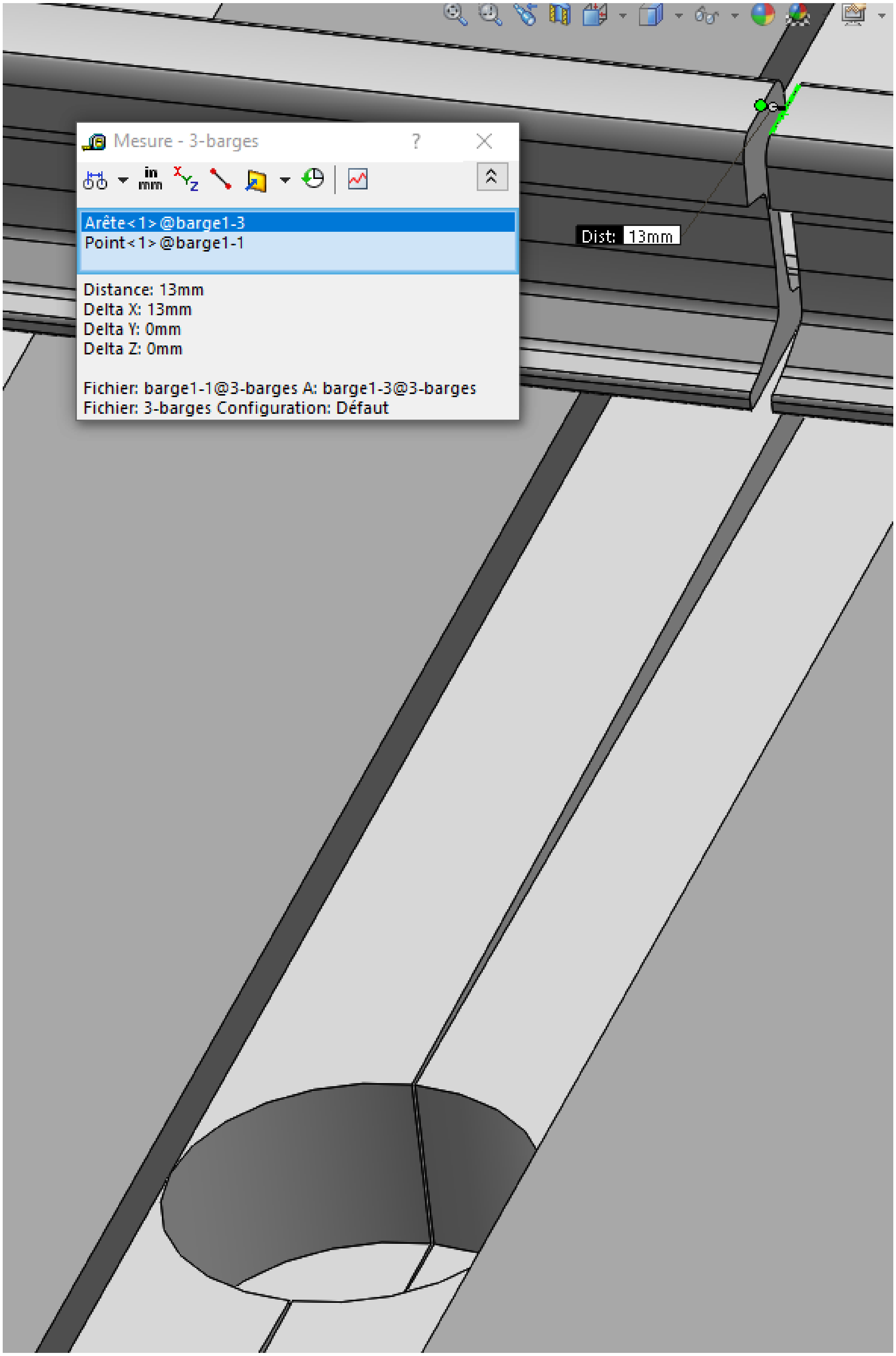


A spacing of 1° between two barges allows a convoy rotation of a radius of 922m for a barge of 16.1m in length.

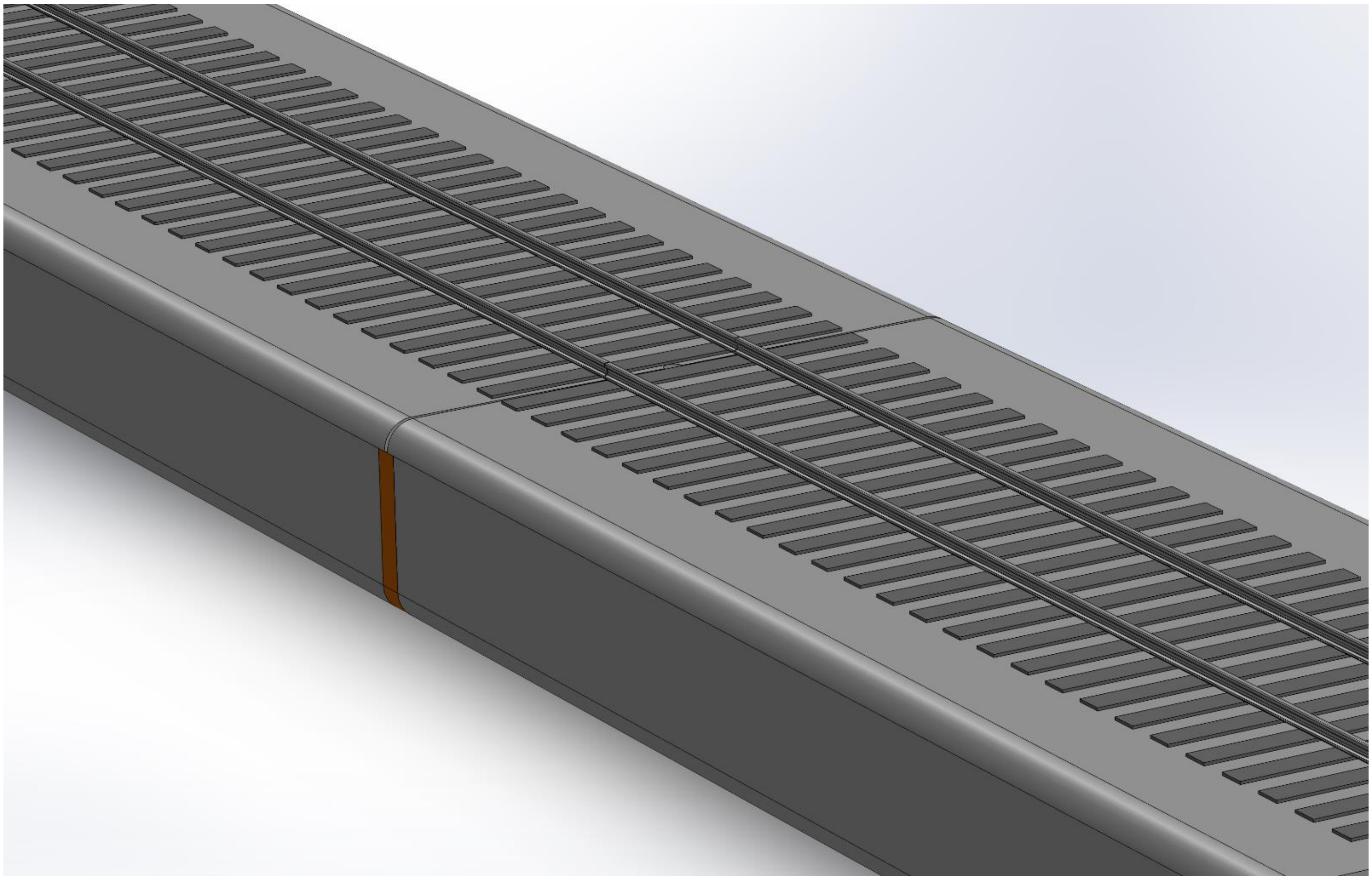




In straight position, i.e. in the position of loading and unloading wagons, the rail gauge is only 13mm.

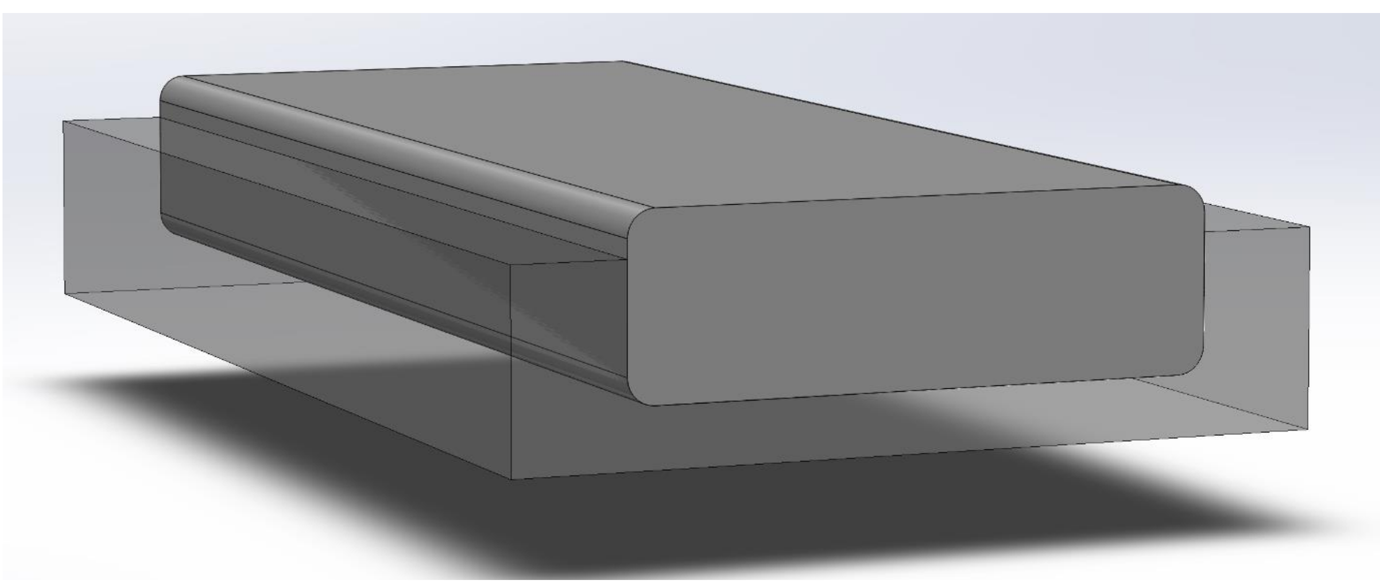

Mesure - 3-barges
Arête<1>@barge1-3
Point<1>@barge1-1
Distance: 13mm
Delta X: 13mm
Delta Y: 0mm
Delta Z: 0mm
Fichier: barge1-1@3-barges A: barge1-3@3-barges
Fichier: 3-barges Configuration: Défaut
Dist: 13mm

The wetted surface should have minimal roughness and be as continuous as possible. Therefore, the inter-barge space is closed by a strip of stretchable elastomer fixed to each of the barges.



- **Reduction of specific wetted surface area.**

Increasing the draft of the barges decreases the specific surface area (m^2/t). The draft was selected at 1.6m in this example; it will be optimized once the river dredging study is completed, as the convoy's narrow width is favorable for consistent dredging to ensure a specific draft.



THE QUESTIONS TO BE RESOLVED

- **The effects of confinement (see literature in appendix)**

- **Load stability on barges**

  Because the center of gravity of a loaded barge is located above the center of hydraulic thrust, the convoy is unstable.Its stability is ensured by lateral floats that support the propeller pumps. The orientation of these propeller pumps is controlled on three axes by the onboard software. These floats do not touch the water because their horizontal position is ensured by the propeller pumps located on each side of each barge. These floats are only used for safety or when the barges are stationary.
  The barge convoy is symmetrical, allowing it to move in both directions; the software orients the engines accordingly.
  The vertical orientation of the engines ensures perfect horizontality of the barges and therefore perfect stability.

- **Longitudinal rigidity of the convoy during loading and unloading operations**

  The draft of the barges decreases from 1.6 m under load to 0.35 m during the unloading of the railcars. This loading/unloading operation induces bending stresses in the barge convoy, which must be distributed over a sufficient length to allow the railcars to move and maintain a minimum spacing between barges. Therefore, the longitudinal rigidity of the convoy must be optimal to ensure the success of this loading operation.

- **River equipment to ensure the transport of 50 million tons of ore per year**

  Port facilities and their location must be studied in order to integrate them into the future rail network.

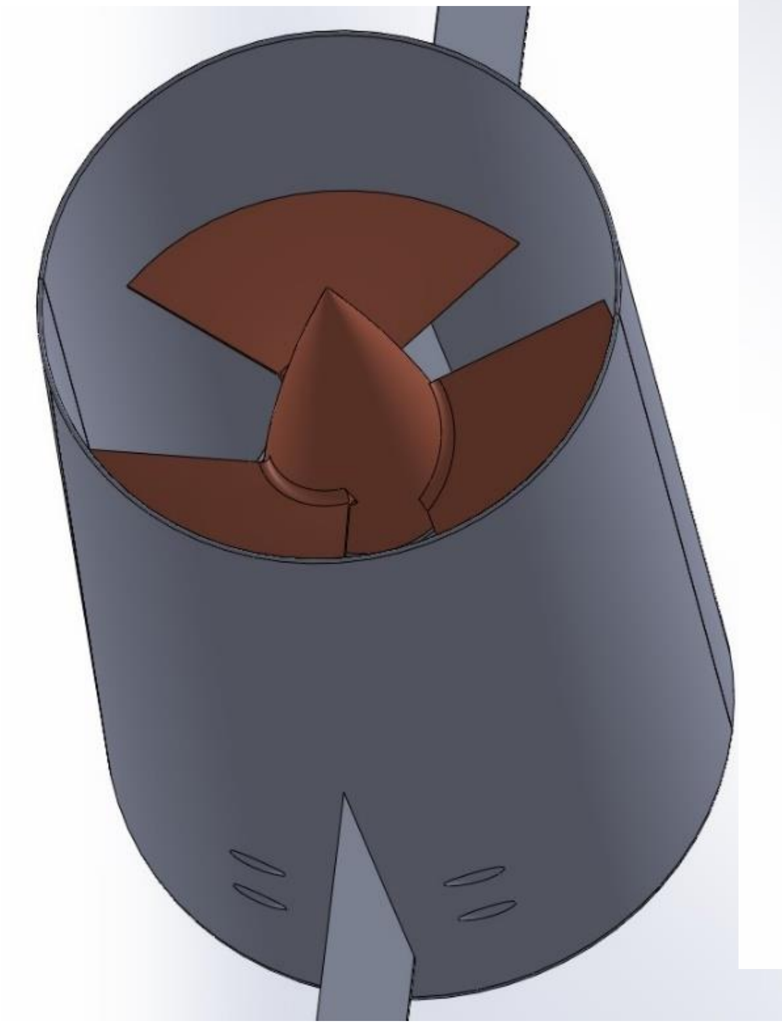
  The train is loaded at the mine and travels to the river port.
  This train is powered by electric locomotives, which are themselves powered by generators mounted on wagons. These generators are fueled by tank cars that complete the train.

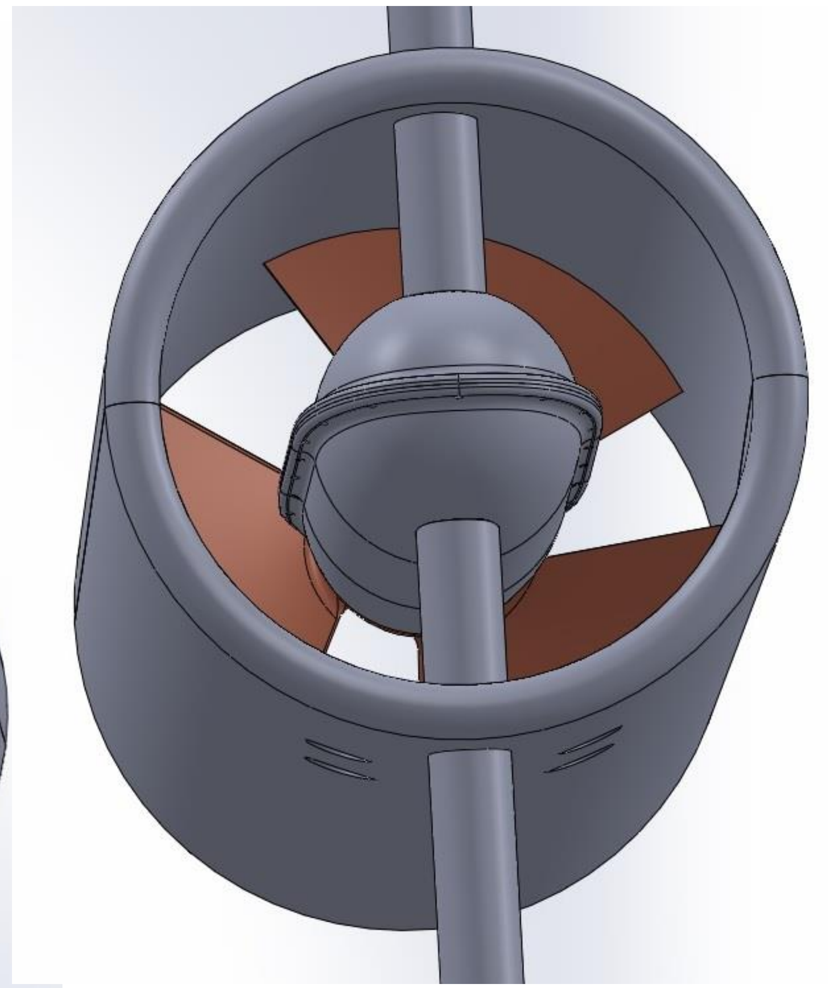
  At the port, the train is uncoupled, and the locomotives are then coupled to to to another train of empty ore wagons and the full fuel wagon and returning to the mine.

  The wagon train is loaded with ore, and some of the fuel is unloaded at the mine. Another train of full ore wagons is coupled to the locomotives returning to the river port.
  This loaded wagon train returns to the port with the generators and tank cars. The train is then loaded onto the barges.
  The generators are connected to the barges' electrical system, which has been temporarily powered by backup batteries.
  Upon arrival at the port of Kinshasa, after the generators are disconnected, the train is unloaded and coupled to the locomotives, which are then connected to the generators.
  The train convoy travels to the deep-water port of Banana to be unloaded. The tank cars are then loaded with fuel for the round trip to supply the mine.
  The convoy of empty and full tank cars returns to the mine.

- **The side-mounted propeller pumps will be built locally.**

  Propeller pump will be installed on both sides of the convoy on each barge
  These propeller pumps will be orientable in 3 axes, which allows them to ensure both directions of movement, and above all to be able to guide each barge in the channel defined by satellite. In this way, the constraints between barges will be minimal. As for the vertical orientation, it ensures perfect horizontality of the convoy.





The motor is placed in the axis of the propeller. It will rotate at high rotation speed to reduce the torque and therefore obtain a minimum diameter of the motor. The rotation speed will be reduced with a planetary gearbox. Numerical simulation studies which will determine the optimal diameter of the propeller and its rotation speed.

The MC MOTOR running at 20kRPM seems to be a good fit. The switching of this brushless motor is done by a controller which will itself be controlled by the on-board software.

A high-speed motor offers a minimal diameter allowing it to be installed in the propeller shaft via a reduction gear.

ON-BOARD SOFTWARE FOR NAVIGATION AND IN KINSHASA FOR CORDINATION

The position of each barge in the convoy must follow a defined route, guided by satellite.

The outward and return journeys will be defined to only accept curves with a radius of more than 3000m.

The propulsion of the convoy is distributed evenly along the convoy and on either side.
The propeller pumps are adjustable along the 3 axes controlled by the on-board software, as is the power transmitted to the propellers.
These orientation and power settings are optimized by the on-board software so that the constraints between barges are minimal and the perfect horizontality of the convoy is ensured.

This on-board software communicates constantly with the central software which manages the traffic of all convoys in order to ensure the efficiency of loading and unloading operations.

LOCAL CONSTRUCTION OF RIVER EQUIPMENT

Thaurfin Ltd advocates for the local manufacture of barges, their engines and ore wagons.
An industrial zone should be located upstream from Kinshasa, where these river and rail transport activities would be concentrated.
The river port for railway convoys would also be located there, with a railway junction to Banana and Ilebo (see https://thaurfin.com/multimodal.jpg) and future developments.

PRELIMINARY CONCLUSIONS

The orders of magnitude need to be assessed to determine the feasibility of this river transport solution.

Logistics is a determining factor in the development of iron ore, which is priced at around $100/ton. We are only considering the energy cost of river transport.

Given the length of the barge convoy and its small frontal area, it is reasonable to disregard wave drag.As for friction drag, the study will focus on minimizing it. This value is between 0.0015 and 0.005.

The space between barges will be closed by an elastic band to maintain the continuity of the flow.

This coefficient is a parameter in the transport cost assessment and has been set at 0.002.
The convoy's speed relative to the water is another parameter, set at 6 m/s in this example. The tank cars will be placed at regular intervals within the ore train to maintain the required draft.

They will provide power for a round trip from the port of Banana (where they will be filled) to the mine. The generator cars will be installed at the front and rear of the train. They will provide power to the locomotives on the rail journeys and to the propeller pumps on each barge.

Convoys of 200 90-ton wagons, similar to the ore train in Mauritania, is considered.We observe that, with a coefficient of 0.0015, the energy cost of transport per ton transported is less than $4.50.

Energy costs are significant because the investment will be amortized over more than 20 years to exploit the deposit of more than 1 barrel at 65% iron. The logistical costs between the mine and the river, and between Kinshasa and the port of Banana, must be added to limit the energy cost to less than $5/t.

In the future, the diesel purchased at Banana will be replaced by hydrogen produced by the 2000MW dam upstream of Kisangani, which will be financed by iron ore exports.

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BVI

PS Between the mine and the river, 250km of railway must be built, this line will participate in the future railway from Kisangani to Mombasa
The distance by river from Kisangani to Kinshasa is 1700km, this is the longest section. It is then appropriate to imagine economical and secure river transport
The distance between Kinshasa and the deep-water port of Banana under construction is 550km, this railway is also of national utility

The cost of the single-track railway between Mombasa and Nairobi with a length of 450 km was \$4.7b, or nearly \$10M/km. The feasibility study supporting the project, financed by China, had stated that the railway would be profitable if it transported 22 million tons of freight annually, or 20 trains per day, every day. This is more than double the current operational capacity of the track, according to a study by the Kenya Institute for Public Policy Research and Analysis.

The proposed river transport ensures the transport of 50Mt per year. Its cost is about \$2 billion, or much less than 100km of single-track railway line since we are in the equatorial forest.
This cost of river equipment is then of the order of 5% of the cost of a single-track railway between Kisangani & Kinshasa which does not ensure the transport of 50Mt/year.

To bring the river transport projects to fruition, the Heads of State of the four riparian countries (Republic of Cameroon, Republic of Congo, Central African Republic and Democratic Republic of Congo) signed on November 6, 1999 the Agreement establishing a Uniform River Regime and creating the International Commission of the Congo-Oubangui-Sangha Basin (CICOS),
Cf https://www.cicos.int/ & https://www.cicos.int/2014/03/

Literature

B01 Slides Smart Rivers 2019 Workshop WG141 Vessel-waterway interaction PJPompee
B02 Introduction à la navigation en milieu confine (Driving dynamics of inland vessels)
B03 Exemple estimation (BAW)
B04 Exemple estimations (Schijf)
B05 Smart Rivers 2015 180_paper_Pompee
B06 CR 2011 11 30 Visite DST Duisbourg
B07 Smart River 2019 Paper Th Guesnet DST Duisbourg
B08 Smart Rivers 2019 Slides Th Guesnet DST Duisbourg (improved 9-14-19-20)
B09 Bateaux Rhenans - 2003
B10 HERMIONE montage pompe helice 2011
B11 Phénomènes hydrauliques liés au mouvement des péniches dans les voies navigables
B12 Modelisation_du_comportement_hydrodynamique_des_ba
B13 novimar
B14 Points de fonctionnement moteur sur cubique d helice
B15 POMPE HELICE HERMIONE chronique3groupes__copie__094587300_1505_05112013
B16 180_paper_Pompee_FRA
B17 ABB - Azipod Selection Guide
B18 Consommation-de-carburant-essai-de-synthèse
B19 danub2016
B20 Elements-sur-la-Pompe-Hélice
B21 inland-waterway-transport-China
B22 investir-dans-le-transport-et-infrastructures-ANAPI-RDC-2016
B23 roadmap-RD-et-innovation-ds-la-flotte-francaise-2016
B24 Traffic-Fluvial-Marchandise-UE-2021