Paper 119 - Benchmarking of Optimal Barge Train for Navigation on the Waterways linking Ecuador with Peru and Brazil

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ABSTRACT: As a result of the "Treaty of Commerce and Navigation" signed by Ecuador and Peru in 1998, Ecuador may use the rivers that - from the Peru border - allows the directly linkage with the Amazon River. The paper explains the reasons for navigation restrictions at the main waterways, focused on the possibilities for transboundary commercial transport by barge trains, and the construction and operation of transference facilities (in order to optimize barge capacities accordingly to the different characteristics of each river stretch).

1 INTRODUCTION

Actually, there is only one river being used by Ecuador for commercial navigation of barge trains, the Napo River (Figure 1).

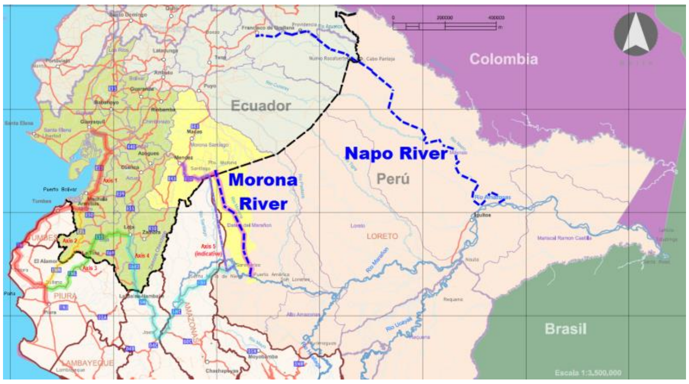

Figure 1: Waterways that links Ecuador and Peru
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The commercial navigation that uses Napo River begins at Providencia (Ecuador), where a port is being constructed. The Ecuadorian stretch of the river presents strong limitations for navigation with 4 feet draughts (or more), in low water periods. Offices for border control are located at Nuevo Rocafuerte (Ecuador) and Cabo Pantoja (Peru).

At this point, there is the confluence with Aguarico River, so the discharge of Napo river increases and the navigation conditions at the Peruvian stretch of the river become better.

The optimal barge trains for each stretch of this river was analyzed and defined in 2010; the analysis include a proposal of a transference station in order to improve transport capacity. It can be located near the international border at Cabo Pantoja (Peru).

The Napo River falls into the Amazon River, 70 km downstream of Iquitos. From this point, the river has small limitations for the navigation of barge trains, upstream to Iquitos, or downstream to Santa Rosa (Peru), Leticia (Colombia) and Tabatinga (Brazil) in the triple Border Area (and beyond to Manaos).

Other relevant Ecuadorian rivers linking with the Amazon River, are Tigre, Pastaza, Morona and Santiago. All of them are tributaries to Marañon River (the Amazon River borns in the confluence of Marañon and Ucayali rivers).

The Tigre and Pastaza rivers have not been studied systematically until now, because they are small and not well linked to the road system of Ecuador. They falls in the stretch of Marañon River downstream the confluence of Huallaga River, where is possible the navigation of barge trains with 6 feet or more (during drought) and more than 50 m length (each barge), in a 2 x 2 array.

The Morona River was recently being studied (2014), in order to improve the navigation of barges with 4 feet of more during drought. It is a very meandering river so navigation is limited to barges with no more than 37 m length, in the upper reach near Puerto Morona (Ecuador). Currently, there is not systematic navigation between Ecuador and Peru using the Morona River, due to the absence of custom and migration controls at the border. If authorities wants to allow the commercial use of such river, they must implement those controls.

It was analyzed the possibility to build and operate a transference station near the end of the Morona River (at Puerto América, Peru), from reduced length barges to the big ones used in the Marañon River, in a 2 x 1 array.

The Santiago River is linked with Ecuador near the binational Vial Axis No. 5, and falls into the Marañon River 7 km upstream of a critical point for navigation of barge trains named "Pongo de Manseriche". This is a relevant problem to use the Santiago River as an alternative for navigation.

The Peruvian commercial waterway begins about 50 km downstream of this critical point, at the population of Saramiriza. This place will be linked with Ecuador by the binational Vial Axis No. 4. Saramiriza is about 70 km upstream the confluence of Morona River into Marañon River.

There are several critical points for navigation in this stretch, that would be dredged as part of de Concession of the Amazonian Waterways. Downstream this confluence, there are not problems to navigate with the same barges that are used in the Peruvian Amazon Waterways.

The current fleet sailing on the Peruvian commercial river system and the Ecuadorian Napo river is composed by a diverse set of vessels with particular characteristics:

a) river boats and river sliders,

b) motor self-propelled barges (a naval construction for cargo transport know as "motochata"),

c) motor self-propelled ships (a naval construction for both cargo and passenger transport know as "motonave"),

d) deck barges and

e) fluvial pushers.

The following analysis is mainly focused on the navigation of barge trains ("pushing trains"), complemented by motor barges and motor ships.

2 NAVIGATION CONDITIONS IN THE NAPO RIVER

2.1 *Ecuadorian Stretch*

In the Ecuadorian stretch of the Napo River, to define the location of the critical stretches, the water levels were considered with a permanence of 95% (11.5 months / year, on average terms) and, due to the existence of hard bottom material, a minimum security over depth of 2.0 feet (0.60 m) was adopted. Additionally, it was considered an extra margin due to the unpredictability of the river levels because, when passing flood waves, they may rise more than 2.0 m, descending at a rate higher than 1.0 m / day and normally not exceed 60 cm / day.

Under the above conditions, the minimum depth needed was 4 feet of navigable draft + 2 feet minimum margin + 2 feet for water level variability = 8 feet deep (2.4 m).

In this section is not feasible to navigate a barge train configuration 2 x 2 (4 barges), except for 2 or 3 months a year, at the time of flood. Considering the condition of a self-propelled barge or tug plus a barge for a "permanence" of 95% of the time (11.5 months / year) and the security margin recommended, it should be dredged more than seventy (70) critical stretches (known locally as "Malos Pasos") involving more than 40 km of river (only in the section downstream of Providence).

Consequently the length to be dredged is more than fifteen (15) times the length to be dredged at the Peruvian section; Moreover, cutting depths are considerably higher (because the river at low water, has minimal natural depths of only 0.20 to 0.40 m in the critical stretches).

The magnitude order of the annual dredging volume is more than 15,000,000 m^3, considering both dredging and maintenance opening, which would require to have a very large fleet of dredgers operating at least 6 months / year with a cost certainly higher than US $ 70 million / year.

At the sector located downstream of the Providence port, without performing dredging, but based on bathymetric information regarding channel position, knowing the hydrometric levels and navigating by means of electronic positioning systems (GPS), navigation could be made:

a) with drafts of up to 4 feet for about 5 or 6 months / year,

b) with drafts equal to or greater than 2.5 feet (depending on the hydrometric level) for about 9.5 months / year (on average),

c) with drafts of up to 2.0 feet during dry season months (December to mid-February). With minimum levels it is not feasible an efficient commercial navigation.

In the river stretch between Francisco de Orellana and Providence navigation conditions are less favorable, consequently the entry port to Napo river was considered to be downstream of such section.

Consequently, dredging of the critical stretches in the Ecuadorian section of the Napo River is technically, economically and environmentally unfeasible.

For this stretch it has been identified an initial stage (called "Phase 0") in which a "push train" formed by a tugboat and a barge with maximum draft of 4.0 feet (1.2 m), would navigate cyclically between Providence and an international border transfer port, located near Cabo Pantoja (in an approximate length of 150 km), carrying both local and international freight.

This maximum draft could be used for about 5-6 months / year and should be reduced, in the dry season, to a minimum of 2.0 feet, making them difficult to navigate efficiently for one or two months a year or so, as the minimum values of depths in the critical stretches fall in the range of 0.20 to 0.40 m. It is considered that the typical navigation will be performed with 2.5 feet of water (0.76 m) for about 9 months / years, although the depth could be increased seasonally. The estimated load capacity is 170 ton to 2.0 feet (in dry season), 230 ton to 2.5 feet (typical), 295 ton to 3.0 feet and 420 ton to 4.0 feet (in flood season).

. The main dimensions of the equipment considered adequate for the characteristics of this stretch are as follows:

- Tug: Length = 15 m, Beam = 6.5 m, Moulded depth= 1.2 m, Draft = 0.9 m, Power = 2 x150 HP.
- Barge: Length = 35.5 m, Beam = 11.5 m Maximum draft = 1.2 m.

Given the similar magnitude between the navigation time and the one for loading and unloading cargo, a reasonable improvement could be achieved by extending the floating park to a tugboat and three barges, which would avoid the tug to stay inactive at terminals and being traveling meanwhile barges are being loading / unloading at each end of the route

This operating condition has been termed as "Phase 1". Navigation with more than one barge is not considered possible; therefore, any increase in the supply of transport that may arise in the medium or long term should be realized by:

a) increasing the number of "push train" (each being composed of a tugboat and three barges, two charging in the ports and one navigating) or,
b) enabling night navigation (when the authorities consider that to be sure).

3 While this system has been designed for operation by government agencies, it is possible to create a similar system from the private sector.

3.1 *Peruvian Stretch*

In the Peruvian stretch of the Napo River it exists - in almost all cases - a navigable channel with depth, dimensions and curvature sufficient to allow - in almost the entire stretch – barge traffic with 4 feet draft (1.20 m), with a permanence of 95% (11.5 months / year, on average).

In the few places where this is not possible ("critical stretches"), and even without performing dredging, it is possible to navigate with 4 feet draft for about 10.5 months / year. To do his, the pilots must know where the channel is located inside the river cross section. Also, they must have information about the hydrometric level that the river will take while the navigate through any critical stretch (to calculate more accurately the possibility of passing through the sector without beaching the barge or ship). Using electronic positioning systems (GPS), such navigation could be done without interventions in the river.

In this stretch there are less than 10 critical stretches that should be dredged to achieve navigation with 4 feet of water (1.20 m) 95% of the time (11.5 months / year).

The total dredging length would be of about 2.4 km and the annual maintenance volume would be around 500,000 m^3. Due to the low depths available on the critical stretches and the low thickness to be dredged, it is not feasible to obtain - with one or two dredgers - the production needed to complete the task prior to - or during - the ebb period. Therefore the operation becomes technically very complex (needing a fleet of dredgers operating in a very short time) and economically inconvenient (overcoming 2,000,000 US$ / year and only to win an extra month navigation).

Accordingly is no justified to invest in dredging to navigate - only – an additional month. Indeed, it would be more efficient to reduce the draft of navigation - during one of the months of the dry season - in order to compensate the low river levels (although some efficiency is lost in terms of cargo and increases - temporarily - the cost per ton of freight).

Consequently, the dredging in the Peruvian stretch of the Napo River is not technically or economically desirable.

For the Peruvian stretch of the Napo River natural navigation conditions allowed from the start ("Phase 0") the use of a barge train composed by a tug (fluvial pusher) and two barges with 5.0 feet of maximum draft (1.50 m). This train will be able to navigate - cyclically - between the transfer point at the international border and the port of Iquitos (in an approximate distance of 640 km), carrying both local and international freight. It is considered that the typical navigation will be performed with 4.0 feet depth for 10.5 months / year, being possible to navigate with a minimum depth of 2.5 to 3.0 feet at low water. The load capacities for each barge were estimated in 500 ton to 4.0 feet draft, 580 ton to 4.5 feet and 655 ton to 5.0 feet, which could lead the convoy to carry 1,000, 1,160 and 1,310 ton (depending on the draft).

The main dimensions of the equipment considered adequate for the characteristics of this stretch are as follows:

- Tug: Length = 26 m, Beam = 10.8 m, Moulded depth= 1.8 m, Draft = 1.2 m, Power = 2 x 250 HP.
- Barge: Length = 44.5 m, Beam = 11.5 m Maximum draft = 1.5 m.

Eventually, the so-called "Phase 0" could begin with a single tug and barge which, although it is less efficient and more expensive in terms of cost per transported ton, represents an usual navigation practice at the Peruvian Amazon. The second barge would be incorporated where the smooth operation of the navigation system and the demand for transportation will be enough to fulfill the supply of such barge.

The transport capacity at the Peruvian stretch of the Napo River is higher than the capacity of the Ecuadorian section. So that, even if all the cargo carried in the Ecuadorian stretch is transferred to the barge trains corresponding to the Peruvian section (extreme hypothesis), the latter would have remaining capacity to transport also the cargo from riverine communities of the Peruvian stretch.

It was analyzed also the possibility that the cycles were done between the border transfer point and the town of Mazan (rather than extending to the port of Iquitos). Considering that the construction of a paved road between Iquitos and Mazan is likely in the medium term, the alternative becomes feasible (with the consequent reduction of navigation length) being of maximum interest in order to increase the capacity of river transport.

Such an option would reduce the travel length of just 470 km so that, in the condition known as "Phase 1", and identical barge train of a "Phase 0", the carrying capacity would grow by 25%.

In the case of a sustained growth in the demand for transport (long-term), navigation conditions at the Peruvian stretch of the Napo River would allow the operation of pushing trains formed by a tug and up to four barges.

Such a condition would mean a reduction in transport costs and constitute the hypothesis for further development of navigation (in terms of the size of the "push train"). Any major increase in transport cargo should be addressed by multiplying the floating park (number of "push train") or enabling night navigation, which allows almost to double the capacity of the system and reduce tariffs to the load on a 45% average.

2 NAVIGATION CONDITIONS IN THE MORONA RIVER

The Morona River has 450 km from Puerto Morona (a site in Ecuador where there are not cargo facilities) to the Marañon river. Near the river mouth is located the town of "Puerto America" in Peru. Despite the name, there is no "port" at this location. Only about 10 km of the river length are in the Ecuadorian sector. This river has near 400 significant curves with bend radius predominantly between 240 and 360 m; moreover, the curves with larger radii, exceeding 1,200 m, not even reach 20% of river curves (Figure 2).

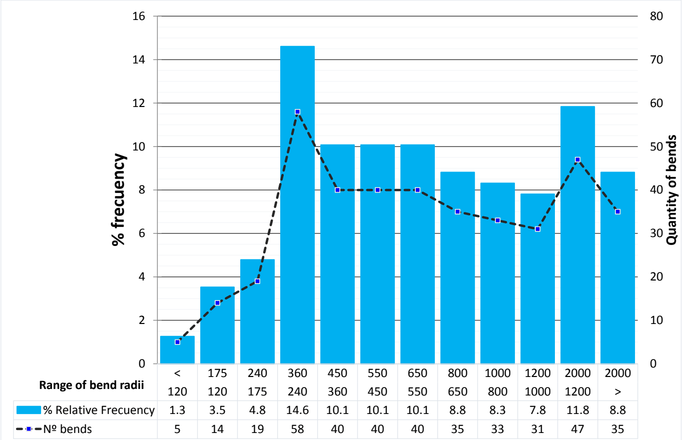

Figure 2: Meander radius distribution of bends in the Morona River

The most critical curve - with a curvature radius of 74 m - is the one at progressive km 442, near the border between Ecuador and Peru, in a site called "Remolinos" (Figure 3).

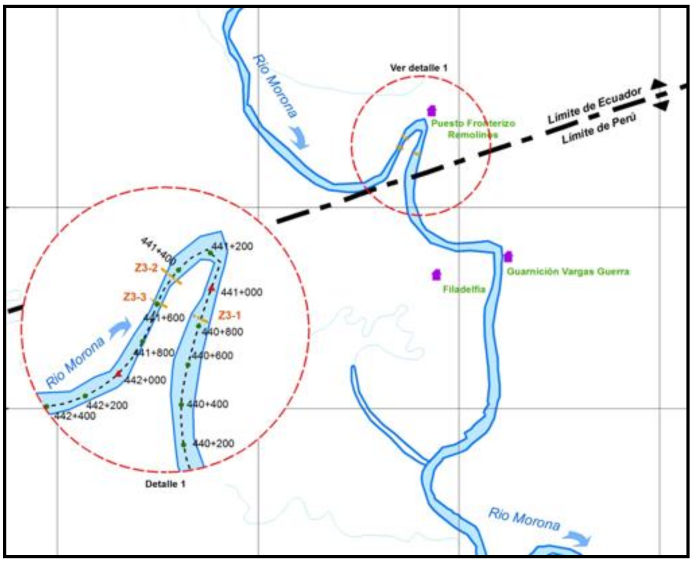

Figure 3: Critical meander radius at "Remolinos"

The other critical sectors - with smaller radii of curvature at 140 m - occur upstream of "Sargento Puño", a facility of PETROPERU (at 385 km from the mouth).

In cases where the radius of curvature is too small for the passage of a convoy of two barges, the viable option (already used by ships in the service of

Talisman Energy and PETROPERU) is to disarm the train. So, each barge can cross the stretch, and the train can be then reassembled; this option is effective, provided that the quantity of disarms in the river is not too high, because the lost time would be excessive.

In sharp bends, even for a train with a single barge, the options are:

a) low speed navigation with extreme care;

b) use of smaller barges (compared to those currently being used at the main rivers of the Peruvian Amazon Waterway: Marañon, Huallaga, Ucayali, Amazonas);

c) performing correction works in the margins of the meanders (involving significant environmental impacts).

Option b) was adopted in in order to allow safely navigation with minimal investment.

According to the limitations generated by meanders in the upper part of the river (100 km in length), a barge train with smaller size to those normally used in the Peruvian Amazon Waterway was adopted.

The dimensions of the barge should be equal to 37.0 m of length, 11.5 m beam and 2.20 m depth, with a freeboard of 0.37 m (Figure 4). Taking into account that this river has hard bottoms in some places, it should be constructed in marine steel with double bottom (to ensure greater tightness) and continuous deck (for the purposes of general cargo). With these features, load capacity - to drafts of 3.0, 4.0, 4.5, 5.0 and 6.0 feet - would be respectively about 245, 368, 430, 492 and 615 tons.

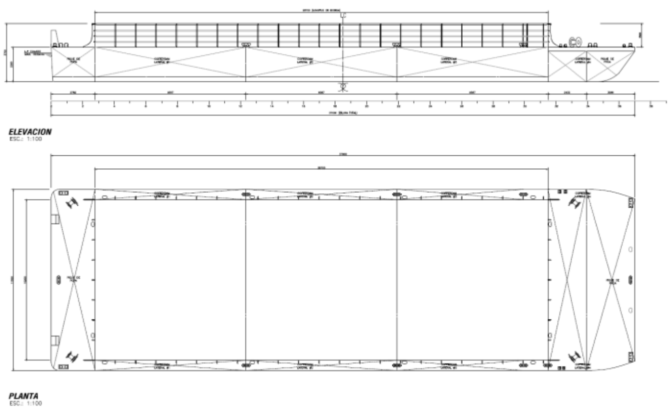

Figure 4: Dimensions of reduced barge for Morona River

The dimensions of the pusher tug should be equal to 18.0 m long, 6.50 m wide and 1.80 m in depth (Figure 5), Power = 2 x 200 HP. It should have low draft, conventional double propeller shaft and adequate power to push up to two barges, accommodate 4-6 crewmembers and the fuel needed to achieve a range of more than 1,200 km from Puerto Morona to Iquitos (without the need to refuel).

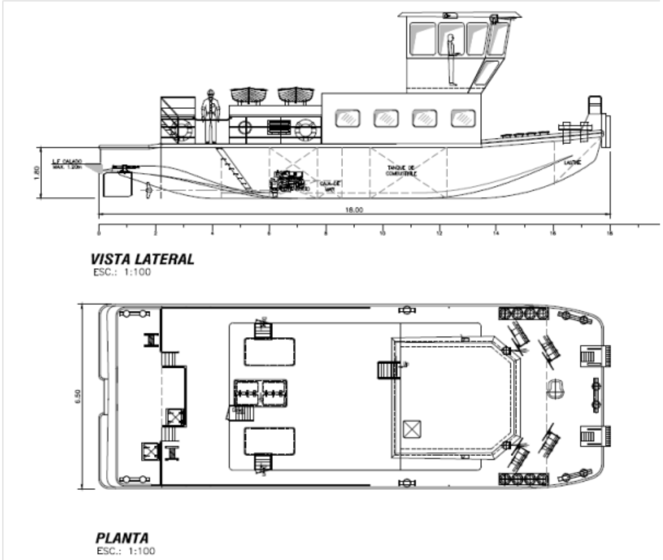

Figure 5: Dimensions of reduced pusher tug for Morona River

The overall length of the barge train would be equal to 55 m, which would allow the navigation with a margin of two (2) lengths in turns with a minimum bend radius of 110 m.

Thus, using this train of reduced dimensions, the Morona River, upstream of Puerto Alegria (progressive km 350), would be navigable - without dredging - for (approximately):

- 64% of the time (just over 7 months a year) with 4.0 ft (1.22 m) or more in draft.
- 75% of the time (9 months a year) with 3.0 ft (0.91 m) or more in draft.

Best navigability conditions (reaching 90% of the time with 4 feet - 1.22 m - draft) necessarily imply performing dredging, which was analyzed by quantifying the corresponding volumes for capital and maintenance dredging.

Particularly, in order to quantify the sediment volumes for maintenance dredging (and their associated costs) some critical sections of the Morona River were studied with a hydro - sedimentological modeling; the obtained results were extrapolated to other similar areas.

The capital dredging volume was about 100.000 m^3, and the estimated maintenance dredging was in the order of 35.000 m^3 / year.

The total minimum cost for capital dredging was estimated as US $ 650,000 meanwhile maintenance dredging was estimated as US $ 360,000 / year.

The dredging needs are related with the reference water level for navigation. Currently available information is scarce and the water level statistics are not very reliable

So that, to evaluate the need of dredging in order to increase the time period of operation with 4 feet of draft, is necessary to have an extended hydrological statistics, using additional stations to be installed in the river. Based on the development of the freight demand, it is recommended in case of having a dredger in the region with low cost of mobilization, to perform an initial limited dredging, to improve the situation of most critical stretches, and analyze their progress with detailed periodic surveys to determine in practice the typical rates of sedimentation in this river.

It is recommended to build a pier in the header of the navigable stretch (Puerto Morona).

When traffic grows enough and if the overall feasibility of the operations is confirmed, it will be convenient to build a transfer pier in Puerto America. This in order to further reduce the costs of transportation to Iquitos (Peru) and / or Manaus (Brazil), by consolidating loads from Puerto Morona and loading it into trains with larger barges, more efficient and lower cost per ton transported. For example, the typical barge for the Marañon and Amazonas River, has 50 m length, 12 m beam, and navigates with drafts of 6 feet to 9 feet. The cargo capacity is 750 ton for 6 feet and 1,250 ton for 9 feet.

At the Marañon river, the train would be able to navigate as a 2 x 1 array (with a minimum capacity of 1,500 ton), and in the Amazonas river it would be able to navigate without problems in a 2 x 2 array (with maximum capacity of 5,000 ton).

4 CONCLUSIONS

The navigation in the Napo and Morona River is restricted by is restricted by hydrological and morphological issues.

The main restrictions arises mainly from the instability of water levels, the small depths in low water periods, the changes in the channel axis (Napo River), and the low radii of curvature in bends (Morona River).

The limitations affect the length of each barge, the maximum draft for navigation, and the quantity of barges in the train.

So that, the barge trains that can navigate in each river, have less cargo capacity that the ones that navigate in the Peruvian Amazonian Waterways.

To address this problem and improve the capacity of the system, it is proposed to build piers for cargo transfer at the following locations:

a) Near Cabo Pantoja (international border in the Napo River),
b) Mazán (town in the Peruvian Stretch of Napo River that would be linked by road with Iquitos, saving time of travel)
c) Puerto Morona (Ecuadorian extreme of the navigable Morona river)
d) Puerto América (near the mouth of Morona River)

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