

ANALYSES OF NAVIGABILITY OF THE RIVERS AT AMAZON REGION UNDER CARGO TRANSPORTATION APPROACH

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Abstract

Nowadays several researches have been developed about the Amazon region; however, those researches have not been able to exhaust all the knowledge reached about such region, namely, as its total natural available resources as its real potential of development are still unknown. Among the natural available resources existing at Amazon region detach the great rivers, which could be taken advantage in order to displace products and people among the “*big blanks*” existing in the region. However, to use those rivers as waterways it is necessary to provide appropriate conditions of navigability, such as: minimum depth of water, width and alignment of river, locking time, current velocity, the terminal facilities and others. This way, the objective of this study is to analysis the main rivers placed at Amazon region concerning their use as waterways in order to carry the main products existing in the region, considering among other factors the variables: minimum depth of water, width and alignment, and the rivers' specification.

Keywords: Inland water transport, waterway transport network, and river navigation.

1. INTRODUCTION

The Brazil, country with large territorial dimension, possesses one of the biggest hydro potential around the world. The wide Brazilian hydro graphic network is constituted of many rivers in their natural state. Such rivers have been used from the beginning of the colonisation of the country as ways of transport for the penetration of the continent and as the links to integrate many different centres of colonisation spread in the distant regions¹.

However, so far most of these rivers are kept in their natural state, and constitute in majority of parts the unique ways of transport. This situation can be observed especially at Amazon region, where the great distances and the adverse natural conditions are considered as obstacles to use other modes of transport, which the cost of implantation and maintenance are considered higher. In that context the Amazon region has the possibility to use the available great rivers in order to displace products and people among the “*big blanks*” existing in the region, constituting thus in a great waterway transport network². However, in order to use the rivers and lakes as waterways, it is necessary to provide the appropriate conditions; namely, the rivers must hold some conditions of navigability, especially for the carry of cargo. In that case, there are the criteria: minimum depth of water, width and alignment of river, locking time, current velocity, the terminal facilities and others^{3, 4}. Such criteria, however, are not considered strict, being thus variable depending of approach to be done.

As the depth of the water, width and alignment are variables intricately linked with rivers; they will be taken into the consideration to analyse the conditions of navigability of the rivers at Amazon region in order to identify the potential ones appropriate to the transport of cargo.

Therefore, the principal goal of this study is to analyse the main rivers placed at Amazon region. Concerning their use as waterway in order to carry goods of the region, considering among other factors the variables related to the navigability of rivers and the rivers’ specifications. In order to reach the proposed objective, the main factors considering the development of the research will be briefly described. The theoretical assumptions about Inland Water Transport, theories about river navigation and requirements of navigable rivers are included. Moreover, the case study for the identification of the main navigable rivers at Amazon region is also presented.

2. INLAND WATER TRANSPORT (IWT)

Inland water is defined as being a kind of transport that can be carried out by rivers, lakes, bays or estuaries placed inside of the continent⁵. In the rivers the navigation may be developed in natural conditions with few improvements along their stream, or by artificial channels building. This feature determines the difference existing between IWT and other types of water transport such as coastal and ocean transport.

2.1. Main Features of the Inland Water Transport

A clue to the inherent importance of IWT agency lies in the paradox that a river is at the same time both a transporting agency and the material being transported⁶. In fact, it is possible to say that it is the basic characteristic found in the IWT, however some other characteristics are considered important, such as:

- When potentially navigable, the river requires low investment to improve its natural condition and to turn in a good waterway⁷.
- By the great lengths that constitute the way, the costs to maintain its conditions of navigability decrease as the increase of traffic flow⁷.
- Steel and iron, oil, sand and gravel, grain, automobiles and others bulk products may usually be shipped more cheaply by water than by other means^{3, 6, 7, 8, 9}.
- Low power plant of vessel and barges for each ton carried when displacing in waterway with appropriated technique characteristics^{7, 8}.
- The advantage lies in handling a large volume of bulk cargo over long hauls⁸.

The characteristics presented previously show that IWT holds distinct features in comparison mainly with other modes of transport. In fact, what may be observed is that the main factors that make it different from other modes are directly regarded with its elements, primarily the way and vehicles. The first one, which has already been defined in some cases, needs only little interventions to improve its potential. The second element, which is defined in accordance with the characteristics of the first, namely, the morphologic characteristics of the river and the types of commodities and its amount will be the elements that will define the types of vehicles to be used.

2.2. Elements of the Inland Water Transport

As all transport system, the IWT is also constituted by some basic elements and the level of interrelation among all of them will determine the level of the reached result. Considering the transport of cargo, there are some elements that constitute the IWT: vehicles, terminals and ways.

2.2.1. Vehicles: vessels

The waterway vehicles are composed of a technology totally different from the others, because in this case the vessels displace by a fluid way, the water¹⁰. Basically there are three types of waterway vehicles classified in accordance with the type of object to be carry, namely, vessel for people, vessel for cargo and finally the mix vessel, this one carries both people and cargo. This study will be focused only on the vessels for cargo.

Since in general the depth of an inland water channel is not great, most freight is carried on unmanned shallow-draft barges moved in-group by towing vessels (Figure 1). In addition there are two main types of towing systems^{9, 10}. *Towboats*, which are designed to push barges ahead of them; and *Tug*, generally pull the barges on a hawser. Basically, the type of water determines which method is used. On most inland waterways that are relatively calm and protected by surrounding landmasses, the towboat is used for push-towing operations. On the other hand, on waterways where wind, wave, and tidal actions would break up a tow of vessels lashed rigidly together, the pull-towing method is used instead⁹. Regarding barges, these may vary in size and shape depending on the kind of cargo they are meant to carry or their mode of use. Barges designed for single tow with a rake at both ends would create a great of drag and therefore loss of efficiency when towed in multiple units. In addition, the typical measurements of a convoy system of towboat and barges (Figure 1) are:

- Total length of the convoy (*CT*), that is the length between the edges of the vessels;
- Length between perpendiculars of the convoy (*CPP*);
- Breadth (*B*), maximum width of the convoy;

- Draft of the convoy (CL), the maximum height of the immersed part of the vessel in the water; free rim (BL);
- Small height (P), and;
- Height of the super-structure (S).

¹⁰ However the relevant measurements for the geometric project of the infrastructure of the waterways are: total length (CT), breadth (B) and finally the draft (CL). While the total length and breadth are fixed values, the draft varies with the load of the vessel. The main measurements of the towboats and barges used in the waterways placed in Brazil are summarised in Tables 1 and 2.

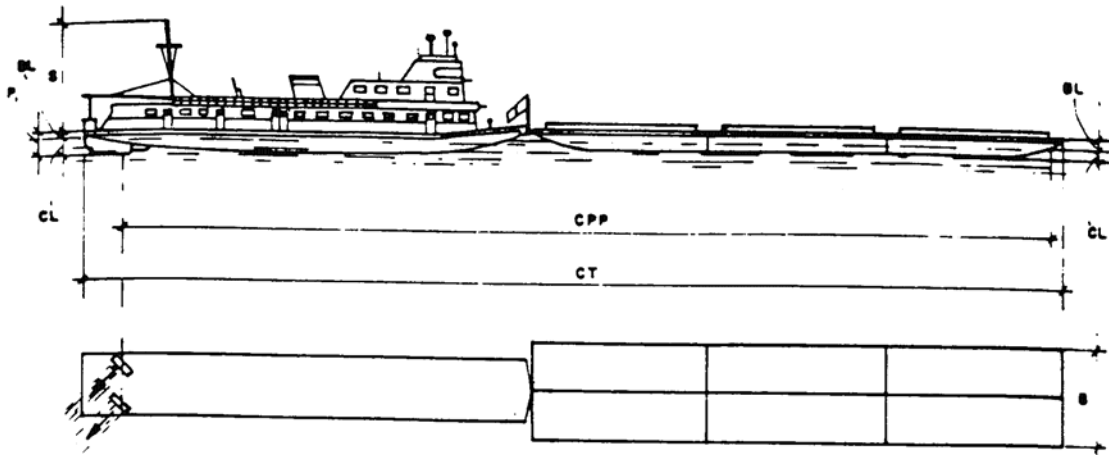


Figure 1: Towing system of towboat and barges and its typical measurements.

Table 1: Main measurements of the barges used in Brazil.

Length (m)	Breadth (m)	Draft (m)	Capacity (t)
40 ⁽¹⁾	10	1.00	253.75
40 ⁽¹⁾	10	1.50	423.75
50 ⁽²⁾	8	1.50	525.00
60 ⁽³⁾	8	1.80	650.00
40 ⁽⁴⁾	10	2.00	570.00
40 ⁽⁵⁾	11	2.50	723.30
60 ⁽⁶⁾	8	2.50	900.00
60 ⁽⁵⁾	11	2.50	1245.00

Source: (1), (4) and (5)¹¹. (2), (3) and (6)¹².

Table 2: Main measurements of the towboat used in Brazil.

Length (m)	Breadth (m)	Draft (m)
18 ⁽¹⁾	8	1.00
20 ⁽²⁾	5	1.50
20 ⁽³⁾	8	1.50
20 ⁽⁴⁾	6	1.80

Source: (1)¹¹. (2), (3) and (4)¹².

2.2.2. Terminals

An inland water port is an intermodal transport centre in which transport by waterway may be the mode, and which produces the greatest community economic impact. Moreover, the facilities within an inland water port, which are located on the waterfront for the purpose of loading and unloading barges, are the terminals. ⁶ The chief requirements of a port are obvious ones:

- Vessels must be able to reach the port, so the passage must have sufficient depth and width and must be suitably marked to aid navigation.
- Vessels regarding harbour must be able to anchor while waiting for a berth to discharge or take on cargo, fuel and supplies.
- Finally, the port must possess suitable wharves, backed by appropriate facilities for handling and storing the components passing through the port and for servicing the ships.

In fact, it is not possible to specify rigid minimum requirements for port facilities. In general, each port must be built to the needs of its commerce.

2.2.3. Ways: rivers

The way in the IWT is easily identified as the rivers, which have already been formed; however in many cases, rivers in their natural state are not ideal passageways or waterways. Rapids and sandbars offer formidable barriers that could be passed with the utmost labour. Isolated rocks, fallen trees, and other obstructions may be considered as hazard as well. ⁷ The river to be considered as waterway in order to serve to the traffic of vessels has to hold appropriated features to the navigation, such as: depth of river and current velocity, minimum width and favourable alignment of the river. Such conditions are considered as requirements of navigable rivers and the principal ones will be described in detail next.

3. RIVER NAVIGATION: REQUIREMENTS OF NAVIGABLE RIVERS

The simple fact of existence of rivers it does not mean that there is navigation, e. g., it is common for rivers in their natural state to hold barriers to the traffic of vessels and this way they need some intervention to achieve the navigability. In some cases the navigability can be reached just by regulating the flow in storage reservoirs, dredging, banks stabilization or snag removal. On the other hand, some rivers in their natural situation provide appropriated conditions for displacement of vessels, in those cases it is necessary to analyse what type of vessel may be used and the amount of the cargo to be carried. Thus, there are no criteria of navigability and in the final analysis, economic criteria control ³. Therefore, there are the physical factors with an influence of the costs of waterborne transport: depth of water, width and alignment of river, locking time, current velocity and the terminal facilities ^{3, 4}. All of them are defined in accordance with the vessel pattern to be used. Such criteria are considered in the classic requirements of navigable rivers.

3.1. Depth of River

^{3, 4} The depth of the water in the river must be sufficient to a safe displacement of determined vessel, the barges cannot be loaded further so that their draft exceeds this minimum depth (hp_{min}).

¹¹ The hp_{min} is the minimum distance that has to be reached between the draft of the vessel and the bottom of the river. The hp_{min} has to be equal to the depth of the rivers minus the

draft of the vessel and minus the “squat” – slight depression in the surface of water that happens by the moving of vessel. The equation (1) expresses the definition of hp_{min}

$$hp_{min} = h - CL - Sq \quad \text{Equation (1)}$$

Where hp_{min} : minimum distance between the draft of the vessel and the bottom of the river (m).

- h : Depth of the river (m).
- CL : Draft of the vessel (m).
- Sq : Squat (m).

¹³ In addition, based on experimental data, an empiric formulation to solve the problem about the forecast of the “squat” is defined as

$$Sq = \frac{h}{CL \cdot 0.298 \cdot \left[\frac{V}{(g \cdot h)^{1/2}} \right]^{2.289} \cdot \left(\frac{h}{CL} \right)^{-2.972} \cdot kb} \quad \text{Equation (2)}$$

$$kb = \frac{3.1}{\left(\frac{W_o}{B} \right)^{1/2}} \text{ When } \frac{W_o}{B} < 9.91, \text{ and } kb = 1 \text{ when } \frac{W_o}{B} \geq 9.91$$

- Where h : depth of the river (m).
- CL : Draft of the vessel (m).
- V : Speed of the vessel (m/s).
- g : Acceleration of the gravity, $9.81m/s^2$.
- W_o : Width of the river (m).
- B : Breadth of the vessel (m).

However¹¹ hp_{min} must be greater than or equal to C_{min} ($hp_{min} \geq C_{min}$), where C_{min} is the minimum distance between the draft of the vessel and the bottom of the river for vessel displacing in cruise speed. The Table 3 shows the values of C_{min} , in accordance with “*Associação Brasileira de Normas Técnicas*” for rivers with different types of bottom.

Table 3: Values of C_{min} .

Type of bottom	C_{min} (m)
Oozy	0.30
Sandy	0.50
Rocky	1.00

Source: ABNT.

¹⁴ Another formulation about the hp_{min} has been proposed in Brazil, where it has been defined as a minimum height of the water, which allows the traffic of the vessels at a low speed in the critical part of the route, during the season that the minor level of the water took place. Thus, specifically for the rivers of the Amazon basin with sandy bottom, it has

been defined $hp_{min} = 0.50m$ ¹⁴. The Figure 2 shows the scheme of minimum depth (hp_{min}) of the rivers at Amazon Region for the displacement of vessel.

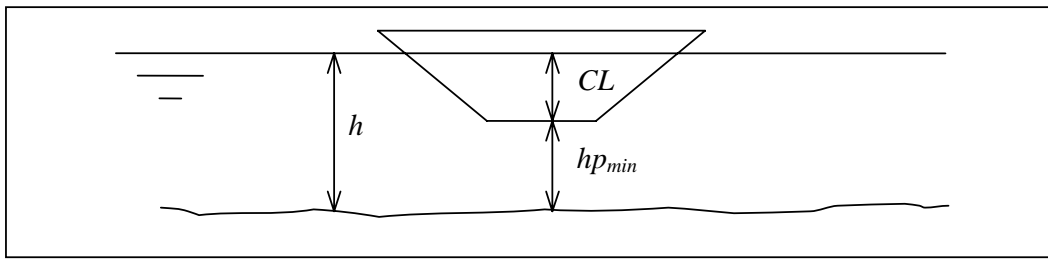


Figure 2: Scheme of minimum depth (hp_{min}) of the river for the displacement of vessel.

3.2. Width, Alignment and Current Velocity

The number of barges in a tow and the transit time depends of the alignment, width, and current velocity³. The width of a channel required for navigation, although a matter of less importance than the depth, yet requires consideration⁴. It is difficult to manoeuvre a long tow of heavily loaded barges in a channel not wider than the tow itself.³ A minimum width of 91.44m is the goal of present navigable channel of the Mississippi River, on the other hand, for a cargo of 1500 tons register, this would require a channel about 70m wide⁴.

A highly irregular alignment also increases the “circuits”, or length in excess of airline distance, which the barge tow must travel. The speed of most barge tows in still water is around 6mph or 9ft/sec. Current velocities on the order of 3ft/sec or 4ft/sec represent a substantial reduction in the speed for tows bound upstream or more specifically in the ton-miles moved per horsepower-hour³.

3.3. Terminal Facilities

Since charges for tugs and barges continue while the tow is at a terminal, facilities that permit rapid cargo transfer effectively reduce lost time and decrease cost. Terminal facilities thus are an important factor in the economics of navigation projects⁴.

In fact, it should be noted the difficulty in estimate the exactly criteria to determine the navigability of rivers in general, perhaps this happens in reason of the absence of great studies and researches about such matter. However for consider that the depth, width, and alignment are directly intrinsic with the characteristics of rivers in their natural state, these variables have been taken into the consideration to analyse the main rivers existing at Amazon region in terms of the conditions of navigability for the transport of cargo.

4. CASE STUDY: AMAZON REGION

Nowadays several researches have been developed about the Amazon, however they have not been able to exhaust all the knowledge reached about such region, i. e., as its total natural available resources as its real potential of development are still unknown; on that score one brief description concerning the characteristics of the Amazon region becomes appropriated, in that case under transport approach translated in terms of hydrograph.

4.1. Brazilian Amazon Region: hydrograph

In this study, an approach to the Brazilian Amazon region is constituted by hydrographical basins of Amazonas River, Tocantins River and the part of the South Atlantic basin. The

Brazilian Amazon region covers about 4,850,000km²; equivalent to 57% of the territory of Brazil and almost nine times the territory of France, such region includes the totality of North region, the most part of the Centre-Western region and part of Northeast region in the Maranhão State^{5,7}.

¹⁵ From the hydrographical point of view, the Brazilian Amazon Region is constituted basically by basin of the Amazonas River which represent one fifth (1/5) of all fresh water of the world. The rivers are supported by the periods of rain and they are considered basically to be the unique ways of transport of the local inhabitants. There are more than 20,000km of fluvial rivers linking distant communities in that region. ¹⁵ In the context described previously the Amazonas River is detached, mainly by being the second most extensive river in the world (total length about 6,515km of which 3,600km are in Brazil), and the first in volume of water, 100,000m³.

Even though the Amazonas Basin plays an important role in the displacement of people and goods, another hydrographical basin placed in such region is considered important as well. In appropriated conditions of navigability, the rivers of the Tocantins Basin could provide an excellent ways of transport, linking the Amazon Region with the centre of Brazil, constituting a wide and useful waterway transport network. Both, the Amazonas and Tocantins basin are constituted by many rivers, the principal ones and which have been analysed in this study were:

- **Amazon Basin:** *Amazonas, Solimões, Javari, Juruá, Tarauacá, Embira, Parú, Jarí, Guamá, Capim, Purús, Acre, Madeira, Mamoré, Guaporé, Tapajós, Xingú, Içá, Japurá, Nhamundá, Negro, Branco, Trombetas and Uatumã.*
- **Tocantins Basin:** *Tocantins, Araguaia and Mortes.*

The Figure 3 shows the Amazon region and the main rivers of the Amazonas and Tocantins basins.



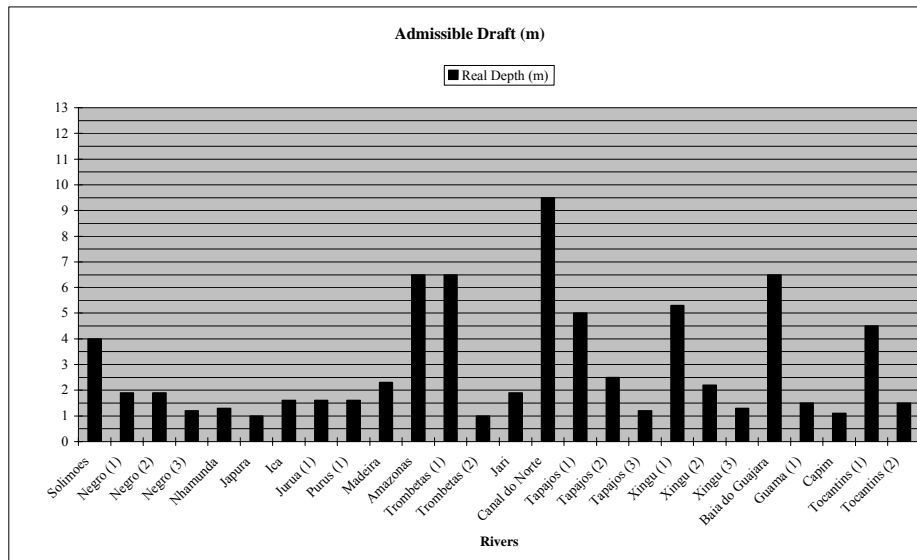
Figure 3: Amazon Region and the main hydrograph basins.

4.2.1. Analysis of the depths of the rivers

The analysis has been done as regards to the depths of the rivers constituting the Amazonas and Tocantins basins, in order to determine the admissible drafts of the vessel that can navigate. Thus, using the Equation (1), considering $hp_{min} = 0.50m$ (bottom of the rivers is sandy) and for the low speed of the vessels ($S \cong 0$)¹⁴, there is the following sentence

$$CL = h - 0.50 \quad \text{Equation (3)}$$

Thus, using the depths of the rivers in the Equation 3 it was possible to determine the admissible drafts of the vessel as shows the Graphic 1.



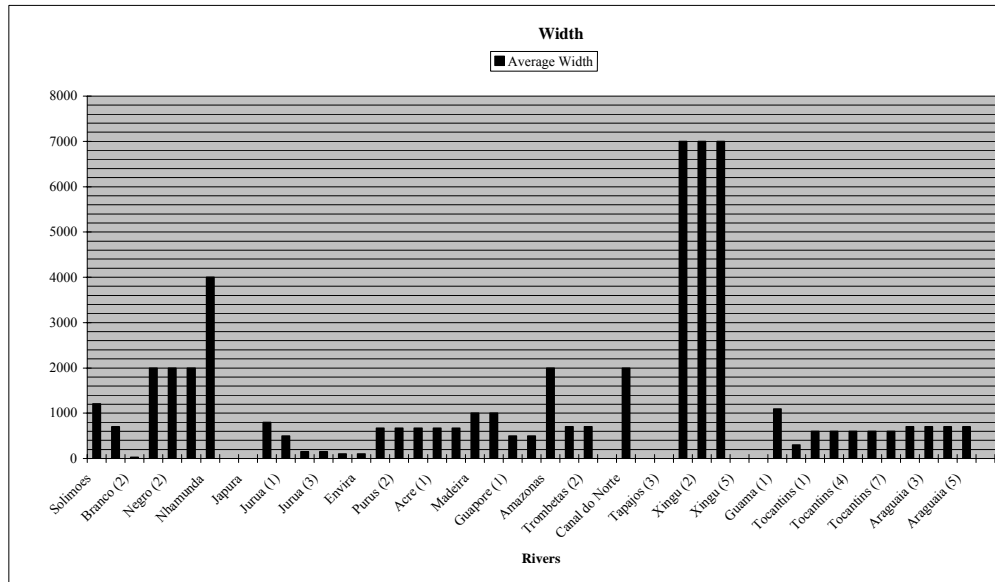
Graphic 1: Admissible drafts for the rivers at Amazon Region (Source: ^{1, 7, 16, 17, 18}).

It has been determined the maximum value of 1.00m for drafts of the vessel which are the maximum drafts utilized by the barges and towboats in the rivers of Brazil (Table 1), differently of the pattern of the *Mississippi River*³, which it has a defined channel. Thus, analysing the Graphic 1 may observe that the drafts of vessels for some reaches are more than 1.00m, such as: *Solimões* (4.00m), reach (1) of *Tocantins* (4.50m), reach (1) of *Tapajós* (5.00m), reach (1) of *Xingú* (5.30m), *Amazonas* (6.50m) and reach (1) of the *Trombetas River* (6.50m), with great admissible drafts of the vessels. The Table 4 shows the navigable rivers and some reaches of the Amazon Region in accordance with the admissible drafts.

4.2.2. Analysis of the average widths of the rivers

As regard to the average width, the minimum identified measurement was of 500m, exception of reach (1) of the *Juruá River* with 150m, and *Capim River* with 300m. Thus, the traffic of some vessels, especially in *Juruá River* may suffer some interruptions, depending on the total length (*CT*) of the convoy. However, these rivers still have a good width to build channel when they are compared with the minimum width of 91.44m ($\cong 300ft$) found in the *Mississippi River*. Hence, under the width approach the main rivers at Amazon region analysed in this study do not present problem, i. e., that requirement

does not produce restrictions for the navigability. The Graphic 2 shows the variation of the average width of main rivers at Amazon Region. The most part of the *Xingú River* (reaches 1, 2 and 3) is detached with average width of 7,000m, and some rivers with average width of about 1,000m.



Graphic 2: Average width of the main rivers at Amazon Region (Source: ^{1, 7, 16, 17, 18}).

4.2.3. Analysis of the alignments of the rivers

The analysis of the rivers as regard to the alignment has been possible basically by identification of the rivers that have many accentuated curves along their ways. The literary information from some authors about the conditions of the rivers concerning their alignment has been used instead of the data that could express exactly that requirement, such as the variable radius of curvature. However the absence of such data may be understood as the region is developing.^{2, 7} This way, the rivers that have accentuated curves and that need to be analysed in details under the alignment approach are: *Japurá*, *Juruá*, *Purús* and *Içá*.

4.2.4. Rivers potentially navigable

By the analysis of the three variables (depth, width and alignment), in this study has been possible to identify the rivers or part of them localized in Brazilian Amazon region that are potentially navigable and have appropriate condition to allocate the traffic of some kind of the vessels (in accordance with the Tables 1 and 2), considering the natural state of such rivers. Thus, the rivers or reaches are: *Içá*, *Solimões*, *Purús*, *Juruá*, *Japurá*, *Negro*, *Madeira*, *Nhamundá*, *Trombetas*, *Tapajós*, *Amazonas*, *Jarí*, *Xingú*, *Guamá e Capim*. The Figure 4 and the Table 4 summarise the spatial localization of the rivers potentially navigable at Amazon region considering their real situation and natural state, and the main characteristics under the depth, width, and alignment approaches.

Identified the navigable rivers at Amazon region, the follow up of this study could be the development of a waterway transport network using such rivers as the links of the network, reaching the great distances existing in the region. However, for such proposal it becomes

necessary to achieve analyses of cost of transport in those links (rivers) in order that main produced goods at Amazon region might have optimised displacement.

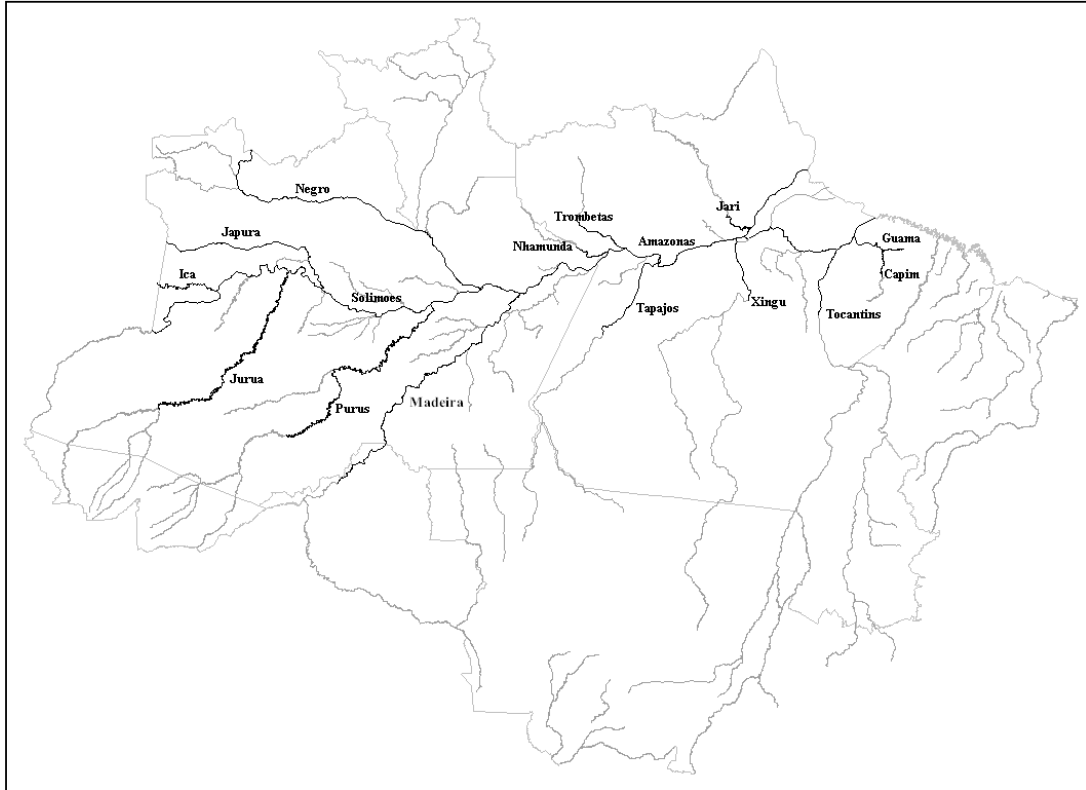


Figure 4: Rivers and reaches potentially navigable at Brazilian Amazon Region.

5. CONCLUSIONS

The studies developed in the field of the Inland Water Transport still are considered of small relevance due to little importance that the sector accords to the problem. However, increasingly there is the necessity to develop studies, projects and researches alternatives, which may reduce the cost in transport, especially toward the use and maintenance of ways to displace cargo. Noting the small quantity of research studies concern Inland Water Transport, and the great potential of using waterway mode for the development of the hinterland of some regions placed in Brazil, specially the Amazon region, which holds a great hydro graphic constituted by extensive rivers in natural state, a research has been developed. In this case, considering the way element as being one of the most important actor in the development of the Inland Water Transport system, whose the characteristic about navigability is considered as determinative factor to use it as waterway on the waterborne transport. However, for a river to be navigable is necessary to attendance some requirements. This was opted in working with three variables that intervene directly in the physic characteristics of the rivers and that has power to determine their potentiality as navigable, namely, the minimum depth of water, width and alignment.

Table 4: Main characteristics of the rivers and reaches potentially navigable at Brazilian Amazon Region.

Reaches	Length (km)	Average Width (m)	Admissible Draft - CL (m)	Alignment
Solimões	1,620	1,210	4.00	Regular
Negro (1 and 2)	801	2,000	1.90	Regular
Negro (3)	270	2,000	1.90	Regular
Nhamundá	155	4,000	1.30	Regular
Japurá	721	(*)	1.00	Winding
Içá	358	800	1.60	Very winding
Juruá (1)	1,650	500	1.60	Very winding
Purus (1)	1,688	670	1.60	Very winding
Madeira	1,100	1,000	2.30	Regular
Amazonas	1,488	2,000	6.50	Regular
Trombetas (1)	120	700	6.50	Regular
Trombetas (2)	140	700	1.00	Regular
Jarí	110	(*)	1.90	Regular
Tapajós (1)	170	18,000	5.00	Regular
Tapajós (2)	110	(*)	2.50	Regular
Tapajós (3)	47	(*)	1.20	Regular
Xingú (1)	58	7,000	5.30	Regular
Xingú (2)	115	7,000	2.20	Regular
Xingú (3)	63	7,000	1.30	Regular
Guamá (1)	160	1,100	1.50	Regular
Capim	120	300	1.10	Regular
Tocantins (1)	60	600	4.50	Regular
Tocantins (2)	190	600	1.50	Regular

(*) – Data no available.

Thus, through the analysis made, this paper attempted to identify the main rivers and reaches potentially navigable at Brazilian Amazon region, considering among others factors the minimum depth of water, width and alignment, besides the rivers specificities. Finally, in the near future such navigable rivers can be used as safety waterways for the transport of cargo. Furthermore, the improvement of reaches under the navigability approach would act as element in the increase of ways of transport improving the accessibility of the several distant points placed in the region. Beyond the development of a waterway transport network using such rivers as the links of the network would be a follow up of this study.

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