# 11º Seminário Internacional De Transporte E Desenvolvimento Hidroviário Interior

Brasília/BR, 22 até 24 de outubro de 2019


# A Latin American Inland Waterways Classification Assessment Method as a Strategy for Regional Economic Growth


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**Abstract**

*A strong logistics chain has proven to be a key factor and a priority goal in any modern economy as it provides efficient ways to connect internally in terms of both production and people. However, inland waterways in South American countries are weak and poorly developed. A solid connectivity strategy, aiming at improving productivity and reliability, must be designed and implemented for the entire region. This involves the development of a standardization process that can be based on European, North American and specific local references. This paper intends to provide guidelines originating from a case study, which could be applicable for further studies. As a result, this paper suggests the improvement of a waterway known as "Paraguay-Paraná," set for convoy use according to the river capacity based on specific calculations including breadth, length, and draught as well as curvature radius. The standardization process will take place in different phases within a specific timeline, and the expected outcome entails a logistics chain capable of boosting the region´s economy in terms of increasing its load movement capacity, as well as contributing to the development of its own internal waterways classification methodology at the local level.*


## 1. Introduction

Countries in Latin America and the Caribbean (LAC) have made great efforts to overcome domestic trade limitations in the region over the past decades. Multilateral, regional and unilateral exchange releases represent a reduction in trade tariffs resulting in an increase in imports on average. These reductions have resulted in lower tariffs, multilateral negotiations and participation in trade agreements or simply "Free Trade Agreements" (FTAs) between nations. (KOTSCHWAR, 2012).

LAC countries are rich in natural resources and renewable energy sources, providing an ideal environment for projects that can boost their economies, (MOSTACEDO, 2018). New transport policies in the context of cargo movement and people in general need to consider the impact on the environment and the damage that each mode of transport causes. In this regard, several studies have shown that movement by waterways generates the least impact by better and more efficiently using infrastructure. (RADMILOVI, 2007).

Although geographically privileged, with an extensive and dense river network, Latin America inland waterways (IW) continue to be underused for cargo and people transport. There is a lack of infrastructure and investment in naval works to enable sustainable logistics and integral mobility in the region. It can be said then that multimodal transport is not developed with regards to Inland Waterways, which makes the insertion of river transport in the multimodal logistics system a complex task, (ECLAC, 2018). Therefore, a statistical information-processing tool should be sought to establish project trends. It is necessary to standardize all information. The data considered should be filtered by recurrence rate (number of days under normal conditions and flow susceptibility), routes that do not meet the classification criteria, and the methods and technologies for updating the exchange routes in question and safety posts. Navigable streams will be set according to each route. (ECLAC, 2018).

There are several known standardizations that are part of the current transportation system. For example, the European classification of inland waterways, the American standardizations by the Mississippi River, and the regional/local standardizations such as those in Brazil, Colombia and Ecuador. These make up a part of the analysis that, together with the information from each country, will form the basis of the regional waterway standardization method.

In this context, the research will seek to evaluate the main physical characteristics of rivers and vessels, for the classification of a regional standard waterway through specific analysis of the Paraguay-Paraná-Uruguay waterway or “Paraná Waterway”. Thus, creating a method for a convoy determination or arrangement set, according to the river capacity based on specific calculations including breadth, length, and draught as well as curvature radius as a replicable method strategy for economic development in Latin America.

The identification and analysis of physical and logistic variables applied to a basin allows for the methodological assessment of the standardization of waterways in Latin America, which, when applied, has the potential to optimize cargo displacement between countries.

## 2. Objectives

### 2.1. General objective

To analyze, according to the standards referenced in this research, four physical characteristics of rivers and vessels to generate the regional standard classification of a waterway through specific analysis of the Paraguay-Paraná or “Paraná Waterway”.

### 2.2. Specific objective

- Evaluate the methodology of standard classification of inland waterways in Latin America based on the European, North American, Asian, and specific regional models.
- A qualitative analysis of the subtypes of inland waterway vessels with reference to the largest available fleets in the studied region; based on standard operating and technical parameters.
- To identify the logistic variables, services and infrastructure available, according to the proposed waterway, as an evaluation criterion in the subdivision of sections.
- To develop the proposed methodological guide for waterway standardization for Latin America according to the results of this research.

## 3. Navigable Channel Design

The general concept of inland waterway design currently represents part of good waterway construction practice. However, this does not mean that for special cases a one-of-a-kind design is required. The key factors of interconnected design are alignment, width and depth, (PIANC 1997).

Waterway design considers straight canals connected by unclosed open bends as well as navigation at different speeds according to the widths and depths of the sections.

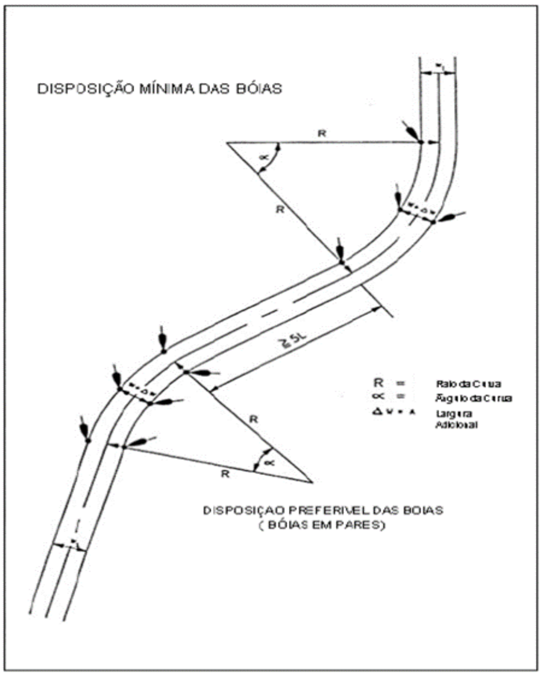


Figure 1 – Curved sections (PIANC, 1995)

In addition, the angle of curvature when the boat navigates unaided by any of the tugboats, and calculating the turning of the train, becomes the account for safe navigation. This is from 2 to 3 deep water lengths up to 5 or more windless deep water lengths, at a depth / draft ratio of 1.10 m.

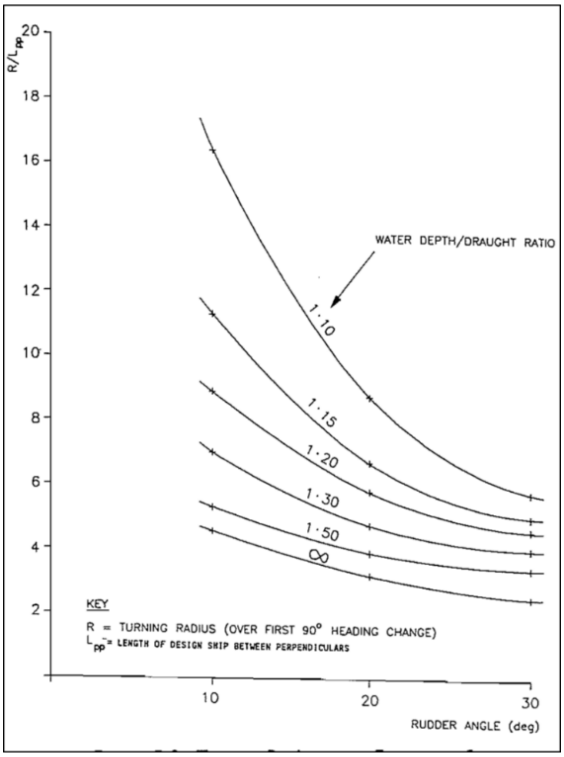


Figure 2 – Minimum bending radius as a function of rudder angle and depth / draft ratio (PIANC, 1995)

The World Association for Waterborne Transport Infrastructure (PIANC) points out that long, slender vessels (L / B> 6.5) are more directionally stable than short and wide vessels (L / B <6). As shown in Figure 2, the last vessel would be able to maneuver around sharp turns more easily.

## 3.1. Relationship between depth and speed

The hydrodynamic resistance to displace a boat to shallow waters is related to the ratio of speed to depth, defined by the Froude number (Fnh):

$$F_{nh} = \frac{V}{\sqrt{gh}} \qquad (1)$$

Where:
V is the velocity in the water in m/s,
h is the undisturbed water depth in m,
g is the acceleration of gravity (9.81 $m/s^2$)

When Fnh approaches or equals one (1), the movement / displacement resistance is higher, and most ships / pushers do not have enough engine power to control the displacement.
In fact, ships could not reach values of 0.6 or 0.7. Therefore, there is an effective speed barrier to consider. However, for the design it is recommended to choose the speed, to find the minimum depth required in the navigation channel (opposite case).

From here, the different convoy speeds can be obtained, knowing that the depth of the channel obtained from the nautical charts along the river is less than 1.4 times the draft of the larger vessel (CAPRACE et al., 2013) compared to the above formula.

## 3.2. Additional Widths for Straight Channel Sections

According to (PIANC 1997 and 2014), the additional widths are set in relation to the convoy speed, so the variables can be chosen depending on the "low", "moderate" or "high" speed category for the chosen segment.

Depending on the waterway characteristics, the additional width factor recommended by the PIANC is in following table:

| Width for bank clearance ($W_{BR}$ and/or $W_{BG}$) | Vessel Speed | Outer channel (open water) | Inner channel (protected water) |
|---|---|---|---|
| Gentle underwater channel slope (1:10 or less steep) | fast<br>moderate<br>slow | 0.2 *B*<br>0.1 *B*<br>0.0 *B* | 0.2 *B*<br>0.1 *B*<br>0.0 *B* |
| Sloping channel edges and shoals | fast<br>moderate<br>slow | 0.7 *B*<br>0.5 *B*<br>0.3 *B* | 0.7 *B*<br>0.5 *B*<br>0.3 *B* |
| Steep and hard embankments, structures | fast<br>moderate<br>slow | 1.3 *B*<br>1.0 *B*<br>0.5 *B* | 1.3 *B*<br>1.0 *B*<br>0.5 *B* |
| Note: $W_{BR}$ and $W_{BG}$ are widths on 'red' and 'green' sides of channel | | | |

Table 1 – Additional Widths (Wi) for Straight Channel Sections (PIANC, 2014)

## 3.3. Existing Main Standards – Reference

**European Standard**

The European network is divided into four smaller systems connected as described below:

- Northwest Navigable System: Mainly formed by the Rhine, Elba, Odra, Vistula rivers and other rivers and canals.
- South-West Navigable System: Rhone, Seine, Saone, Marna and other rivers and canals.
- Danube Navigable System: Includes Channels and tributaries.
- East Navigable System: formed by the Volga, Dnepr, Dniester, Don Rivers, lakes, canals and other rivers.

The European classification standardized navigable networks in Europe based on the size of the artworks on the waterways; therefore, the size for each is limited by the structures that over time have been enlarged or reconstructed.

The following chart shows classification by classes:

Chart 2 – European Waterways Classification Standard

| Classification | Tonnage (t) | Length (m) | Breadth (m) | Draught (m) | Air Draft (m) | Notes |
|---|---|---|---|---|---|---|
| RA | | 5.5 | 2.00 | 0.50 | 2.00 | "Open boat" |
| RB | | 9.5 | 3.00 | 1.00 | 3.25 | Cabin cruiser |
| RC | | 15.0 | 4.00 | 1.50 | 4.00 | "Motor yacht" |
| RD | | 15.0 | 4.00 | 2.10 | 30.00 | "Sailing boat" |
| I | 250–400 | 38.5 | 5.05 | 1.80–2.20 | 3.70 | "Péniche" |
| II | 400–650 | 50.0–55.0 | 6.60 | 2.50 | 3.70–4.70 | Euro-barge |
| III | 650–1,000 | 67.0–80.0 | 8.20 | 2.50 | 4.70 | "Gustav Koenigs" |
| IV | 1,000–1,500 | 80.0–85.0 | 9.50 | 2.50 | 4.50; 6.70 | "Johann Welker" |
| Va | 1,500–3,000 | 95.0–110.0 | 11.40 | 2.50–4.50 | 4.95; 6.70; 8.80 | "Large Rhine" |
| Vb | 3,200–6,000 | 172.0–185.0 | 11.40 | 2.50–4.50 | 4.95; 6.70; 8.80 | 1×2 convoy |
| VIa | 3,200–6,000 | 95.0–110.0 | 22.80 | 2.50–4.50 | 6.70; 8.80 | 2×1 convoy |
| VIb | 6,400–12,000 | 185.0–195.0 | 22.80 | 2.50–4.50 | 6.70; 8.80 | 2×2 convoy |
| VIc | 9,600–18,000 | 270–280 | 22.80 | 2.50–4.50 | 8.80 | 2×3 convoy |
| | 9,600–18,000 | 195–200 | 33.00–34.20 | 2.50–4.50 | 8.80 | 3×2 convoy |
| VII | 14,500–27,000 | 285 | 33.00–34.20 | 2.50–4.50 | 8.80 | 3×3 convoy |

Class 0 comprises of small boats, ranging from laser to tourism boats. The transport capacity is very variable, but always below 300 tons.
Class I for the depth of 1.80 m and Spits, for the depth of 2.20 m, which carry 350 to 400 tons.
Class II has a larger size of up to 600 tons with a draft of 2.50 m.
Class III has larger dimensions carrying 1,000 tons.
Class IV, vessels carry 1,250 tons with a draft of 2.50 m.
Class IV A, a variation of Class IV for oil and gas tankers, requiring depths of 3.00 m and locks of 110.00 m, carrying up to 1,800 tons.
Class V (or Va), allow tonnage of 1,600 tons for 2.70 m draft, and up to 3,000 tons for 3.50 m draft. This class also encompasses the single barge with pusher.
Class VI (or Vb) includes convoys of 2, 4 or 6 barges. The tonnage carried varies from 4,600, 10,000 to 18,000 tons. Depending on the width of the Class VI locks (12.00 or 24.00 m); the convoys regroups to transpose them.

**North American Standard**

The US Inland Waterway Infrastructure is managed by the Army Corps of Engineers (USACE) and funded by its budget.

Waterways were developed and integrated into a world-class transportation system that has been instrumental in the economic development of this country. Today, there are more than 17,700 kilometers of commercially important navigation channels in the 48 states of the USA. Therefore, inland waterways are a national security asset. So much so that the Jones Act of 1920 required water-based domestic trade to be carried on US-built vessels under the rules and laws of the state and property of US citizens. This law covers more than 42,000 commercial vessels, 124,000 jobs and $15 billion in economic activity annually.

**Chinese Standard**

In addition to the 24,000 km of commercially significant network, China has an additional 37,000 km of Class VI-VII waterways capable of carrying barges of up to 100 tons; known as the residual network.
Classification is based on judgment of class engineering and traffic level; however, as the result is indicative, it is defined in seven standardized classes as follows:

Chart 3 – Chinese Waterways Classification Standard

| Canal Class | I | II | III | IV | V | VI |
|---|---|---|---|---|---|---|
| Vessel tons (t) | 3000 | 2000 | 1000 | 500 | 300 | 100 |
| Canal depth (m) | 3.5 – 4.0 | 2.6 – 3.0 | 2.0 – 2.4 | 1.6 – 1.9 | 1.3 – 1.6 | 1.0 – 1.2 |

## 3.4. Comparison of Chinese, American and European Navigation Standards.

A critical issue when comparing the three systems is the navigation patterns of the waterways. A useful reference in assessing waterway standard is the ability of a waterway to provide draft and configuration that will allow it to handle at least one 1000 T barge. There are savings based on vessel sizes, with generally lower costs versus traffic costs for larger vessels. The difference in costs and traffic per ton displaced over 1000 tons is relatively small. (PRŠIĆ; CAREVIĆ; BRČIĆ, 2011)

## 3.5. Local Standards

**Brazil Standard**

Brazil classifies waterways according to ANA (National Water Agency) in the following classes:

- CLASS A: Channels and rivers more than 2.10 meters deep over 90% of the days of the year. Its use is disciplined and maintained by the government, having been sized, prepared and maintained to receive the traffic of a " vessel type".

- CLASS B: Channels and rivers more than 1.30 to 2.10 meters deep over 90% of the days of the year. Commonly navigated rivers have a minimum presence of the Government without a defined classification.

- CLASS C: River without any transportation and government support infrastructure, used by small vessels at their own risk.

Chart 4: Brazilian Waterways Classification

| Class | Features | Depth (% of time) 75% | 25% |
|---|---|---|---|
| I | "Special": Rivers with access to maritime navigation | - | - |
| II | Rivers with high navigation potential | > 2.5 | 2.0 – 1.5 |
| III | Rivers of average nav potential. | > 2.0 | 1.5 – 1.2 |
| IV | Rivers with lower nav potential | > 1.5 | 1.2 – 0.8 |
| V | "Special": Rivers with remotely possible navigation or interrupted | - | - |

Source: National Inland Waterway Plan

## 4. Methodology and Analysis

The data for this research was collected from international organizations, state control agencies, digital tools and reports as well as the codes and regulations of countries with commonly used waterways. This is in addition to the guidelines of the World Association for Waterway Transport Infrastructure (PIANC Working Group 09, 26) and both, abroad and regional classifications. Therefore, the methodology will use a selection of readings, both selective and analytical.

The selective part seeks data: fleet, waterway, statistical and stoichiometric referents to approve the standardization guidelines. However, possible inconsistencies or scattered data will be organized to project trends. Thus, recurrence index (normal conditions and flow susceptibility), security and control posts, and other categories for non-standard roads and regional multimodal connection should be considered.

Analytically, the research will compare the European, US, and regional standards, with the recommendations presented by the ECLAC Expert Report (2018).

In this context, the case study selected was the Paraguay-Paraná Waterway for the evaluation of the regional standard method.

## 4.1. Case of Study Definition - Characterization of the waterway

**Localization of Paraguay - Paraná Waterway**

The Paraguay-Paraná Waterway is one of the main river arteries in South America, and one of the most extensive and important axes of political, social and economic integration in the region.

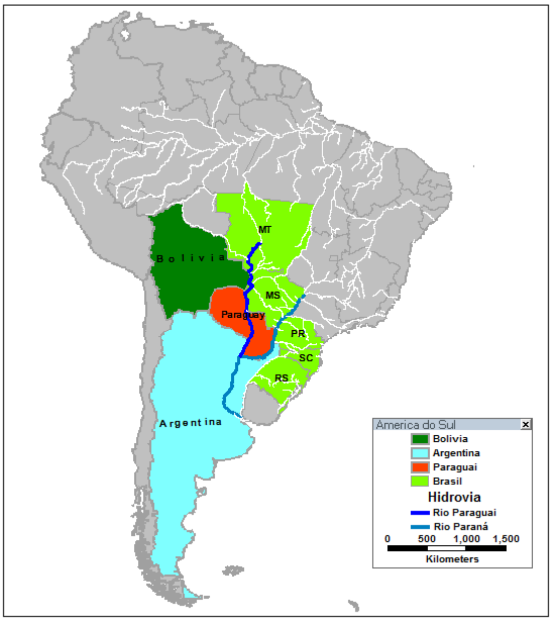


Figure 3 – Waterway Paraguay-Paraná (own source)

It begins in the Brazilian municipality of Cáceres, in the state of Mato Grosso, and extends to the port city of Nueva Palmira in Uruguay. It covers five countries - Argentina, Bolivia, Brazil, Paraguay and Uruguay - with a navigable length of approximately 4,122 km. (2018). Argentina contains 30% of the extension entirely in its territory, Brazil at 22%, 14% in Paraguayan territory and, additionally, under shared jurisdiction between the countries, an approximate extension of 34%.

**Analysis of the physical characteristics of the waterway**

The bathymetric analysis of the Paraguay-Paraná waterway from north to south is as follows:

The Nautical Charts of the Paraguay River, from 3442 at Carne Seca Port in Cáceres, Brazil, to 3300 at Asunción Port, Paraguay, were taken from the websites of the Brazilian Navy. However, cards 3380 and 3318 were not available, so the necessary data was assumed by mediating the others under and above them. This portion is very winding, short and sharp curved, 25 cards with narrow portions identified.

For the remaining portion of the Paraguay River, it was necessary for this study to take pictures of the bathymetry in the similar format of Nautical Chart from the online software “Navionics” in real time. Thus, it took place in digital format from the Port of Asunción, Paraguay at km 364 to km 13 in “Passo da Patria”, in the union of the Paraguay River with the Paraná River. These charts were digitized on the standard scale of the first ones, so the measurements match each other. The portion of the river has greater width and less winding. Wide curves.

Finally, in the Argentinean part corresponding to the Paraná River, it was documented with nautical charts from “Passo da Patria”, to AR530040 in the port of Conchillas on the river De La Plata. All except blade H-1034 were found on the Argentine Naval Hydrographic Service website. This river portion is: medium and mouth of the basin, wide and fast stretch.

## 4.2. Determination of the waterway vessel

The formation of the convoys in this study is in agreement with the sections and the restrictions of each one. Thus, the arrangement will depend on the stretch according to the parameters of width, depth, length and turning radius. Therefore, we highlight those combinations that meet the maximum dimensions of the sections: 1x1, 2x1, 2x2, 2x3, 2x4, 3x3 to 5x5.
The methodology allows for the optimization of the use of currently available train and vessel configurations and defines the new convoy arrangement prototype according to the maximum measurements for each leg. Note that for some sections with smaller depths, convoys will have the restriction on freight thus limiting the draft.

## 4.3. Sections Division criteria

The definition of each section or portion in a waterway goes according to the physical and bathymetric characteristics of the basins, so the Paraguay-Paraná waterway has sections with various types of restrictions (high, medium and low). In terms of constant flow, it is important to know the restrictions for establishing frequencies, convoy configuration, time storage, and free zones, among other related services.

Each nautical chart is evaluated bathymetrically, so the formulas described in chapter 3, together with the PIANC recommendations and the additional dimension tables, form the criteria necessary in the methodology to establish the subdivision by sections in a waterway.

**Additional Widths**

The chosen values evaluate, according to the behavior of the Paraguay and Paraná rivers over time, the waterway in general. In fact, there is historical data that allow us to make assumptions based on technical criteria.

Chart 5. Additional Widths

| ADDITIONAL LENGTHS MINIMUM SPEED RATIO (XB) | | | OTHER ADDITIONAL LENGTHS | | | |
|---|---|---|---|---|---|---|
| Convoy Speed | Wind Speed | Traverse Speed Longitudinal Current | Navigation Aids | Bottom type | Waterway Depth | Cargo Hazard |
| 0 | 0,5 | 0,4/0,2 | 0,2 | 0,2 | 0/0,2/0,4 | 0 |

**Convoy´s Maximum Width**

The maximum width of the convoy is calculated by measuring the minimum width of the navigable channel of each nautical chart divided by the total measurement of the additional widths plus one overall width.

Therefore, it is feasible to derive the maximum number of vessels per nautical chart channel according to the standard width size of the chosen vessels (10.67m and 11.40m).

**Maximum draft**

Vessels must travel at an approximate fixed speed. Therefore, the maximum permitted speeds are calculated with formula (1) in section 3.1. The maximum Froude number (Fnh) is assumed to be 0.7 in the opposite calculation process on each of the nautical charts. Thus, the convoy draft / depth ratio according to the PIANC criteria for the 30° rudder is 1.40. In relation to the depth of the channel for each nautical card, it results in the maximum draft data of the convoy for each of them.

**Turning radius**

Taking the standard measurements of the vessels chosen for this paper, the length is used in conjunction with the recommended PIANC guideline for turning radius in restricted areas or waterways. The factor from 2 to 2.5 was used in accordance with the relation depth/draft ratio of 1.40 (maximum draft criterion).

Therefore, in the selection of sections, the turning radius compared with the smaller scale of the nautical cards, results in a binary matrix to establish which vessels with known turning radius pass through the winding of the Paraguay-Paraná waterway. However, in the subdivision it was possible to identify several portions of the river that need waterway improvement works or simply configure a different arrangement, depending on waterway restrictions.

## 4.4. River Subdivision – Waterway Sections

The subdivided sections are a result of the application of the methodology. Three sections has been identified and recommended by the procedure developed.

**Section 1.** From Carne Seca Port, Cáceres, to Corumbá Port in Brazil, the channel has a minimum width of 30m, but an average of 95.5m. Highly winding, draft and width restrictions on convoys. According to bathymetric charts, it maintains the same level in the navigable channel 90% of the time per year. However, 70% of the time the average depth drops to 1.80m, imposing the load restriction on convoys. 30% of the time the depth is 1,50m, especially by the sand banks near the cities like Cáceres. In this section, 67 “bad passes” were identified as narrow meanders that have less than minimum depths and radius. Most were between the nautical chart from Castelo-Mutuca (3423) to Argolão-Carandá Grande (3397), where almost all the works signaled within the referenced are dredging and course corrections.

The average speed calculated for this stretch was low, 6 to 7 knots. Speed was taken for the (PIANC 2014) tables for additional widths. The width data input was calculated by obtaining the number of barges or by the maximum width per channel; up to 3 flats of 11m may pass through the section but for convoy operation the restriction will be 2 flat boats (column) to allow overtaking if necessary.

The calculated maximum length of 162m allows the turning radius of the convoy to be safe and to be considered with low / medium maneuverability and not poor; Therefore, the factor of 2.5 times the projected length was used. The projected convoys are 2x1, 2x2 and 2x3 for this section.

**Section 2.** Channel of moderate sinuosity starts at the Port of Corumbá in Brazil to the confluence with the Paraná River in La Patria Pass. It presents a draft of 3.0m 80% of the time; and a minimum average of 2.71m the rest of the year.

The channel has a minimum width of 75m but there is a point in the port Sastre (nautical chart 3334) which is 50m wide; however, it does not represent any complication to the convoys designed in this section. Therefore, 6 flats of 11m were considered for convoy operation, but the restriction will be 4 flats to allow overtaking of other convoys.

The allowed navigation speed is 7 knots and the turning radius factor applied in this section is 2.5C (lengths). The maximum calculated length is 220m. Therefore, the convoy´s configurations are 4x2, 4x3, 4x4 and 4x5.

**Section 3.** From the confluence with the Paraná River in the La Patria Pass to La Plata River in Argentina/Uruguay. The relatively narrowly restricted stretch maintains an average minimum depth level of 2.45m 90% of the time.

Therefore, the convoys that travel are of the order of 5X5 and larger. However, the calculation of the number of openings allowed, according to the waterway width, is an average of 20 (width between 10 and 12m). The immediate constraint would be the capacity of the pusher or tug.
Depending on the convoy configuration, there are parts of the track that need a change of configuration to ensure the pass. For example, under the bridges.

These previous sections are defined as highly winding and restrictive, narrow with moderate winding and low restraint (sections 1 to 3 respectively); Along the river, the following ports / associated cities can be found:

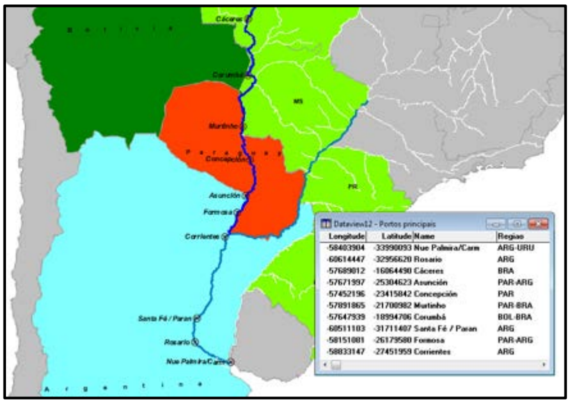


Figure 4 – Waterway Ports and Facilities (IIRSA, 2007)

## 4.5. Types of Cargo - Waterway

According with the ports previously mentioned on the waterway, the general statistics of the commercial flow of cargo and barges from 2016 and 2017 were evaluated. According to the CIH (Paraguay-Parana Waterway Intergovernmental Committee) the flow of cargo in the upper and lower Paraguay was:

Chart 6. Cargo Types (CIH, 2017)

AMOUNT COMMERCIAL FLOW

| Commodities | 2016 (Ton) | % | 2017 (Ton) | % |
|---|---|---|---|---|
| General Cargo | 998.664,00 | 21,25 | 893.702,00 | 20,38 |
| Fuel | 2.937.350,07 | 62,49 | 2.286.097,60 | 52,12 |
| Other | 764.377,59 | 16,26 | 1.206.423,68 | 27,50 |
| Total | 4.700.391,66 | 100 | 4.386.223,28 | 100 |

FLUXO COMERCIAL JUSANTE

| Commodities | 2016 (Ton) | % | 2017 (Ton) | % |
|---|---|---|---|---|
| Soybeans/Derivatives | 9.668.812,00 | 64,25 | 8.951.395,00 | 67,23 |
| Iron Mineral | 3.829.229,60 | 25,45 | 2.743.241,00 | 20,60 |
| Other | 1.550.881,14 | 10,31 | 1.620.189,00 | 12,17 |
| Total | 15.048.922,74 | 100 | 13.314.825,00 | 100 |

Note that the trend of cargo transportation is negative, both for the entry and exit of goods. However, the demand continues to increase for the people next to the river. The need for exporting products from the producing areas continues to be by highways and other more expensive transport modes. In addition, solid bulk cargoes consolidate as the main regional export commodities, and liquid bulk cargoes are those demanded as imports.

**<u>Cost per ton transported</u>**

The planning and logistics company S.A (EPL) of Brazil, has a cost simulator available on its website, which provides tool per ton moved, according to the mode of transport and the type of cargo, and including the type of restriction in the case of waterways. Therefore, it was possible to simulate the costs for each section according to the available variables.

Chart 7. Cargo Types (EPL, 2019)

Waterway Average cost

| Cargo Type | Restriction | Cost per ton per km Section 1 (USD) |
|---|---|---|
| Bulk Agricultural Solid | | 2,03 |
| Non-Agricultural Solid Bulk | | 1,91 |
| Liquid Bulk | High | 2,84 |
| General Cargo | | 4,57 |
| Container Cargo | | 4,52 |

| Restriction | Cost per ton per km section 2 (USD) | Restriction | Cost per ton per km section 3 (USD) |
|---|---|---|---|
| | 1,47 | | 1,05 |
| | 1,42 | | 1,01 |
| Medium | 2,45 | Low | 2,44 |
| | 3,74 | | 3,74 |

| 3,69 | 3,69 |
|---|---|

The costs per kilometer and per ton in low and medium restriction sections 2 and 3 are very similar. However, in the highly restricted section 1, they are almost 50% higher, which means that costs per ton will decrease if the distances traveled are longer. In other words, the cost will be even more favorable depending on the distance traveled.

## 5. Result – Methodological Guide for Classification of Inland Waterways

The result of the study presents a methodological guide as a technical document, describing the standard set of rules for optimizing the use by the classification of inland waterways in the region.

### 5.1. Step 1. To parameterize the waterway

The improvements that optimization allows in the macro context must be evaluated. Therefore, it is important to consider the pre-viability of the proposed waterway, and aspects such as economic indicators, cargo transportation, production, ports, associated services, people and zone of influence. Rivers should be selected from the study zone mark at the beginning and end of the waterway (usually from the mouth to the upstream). It is important to know if the investment in bathymetric studies will be of high benefit for the region.

### 5.2. Step 2. Data Input

Once the waterway has been chosen, physical and bathymetric data collection is necessary. There are several sources of information regarding bathymetric charts; some of them are paid for and some are available on the navy websites of the country where the study river is located. Certain physical measurements, photo-type satellite tools can also be used with good approximation.

This provides information on width, length, depth, turning radius, slope, or level changes for both the river and navigable channel. If bathymetric charts come from different sources, the shape and scale are certainly not similar. Therefore, it is convenient to digitize each of them in sequence on the same scale. In a way, the software allows you to scale and recognize narrow zones, bad steps or improvements along the way. This database is the core of the methodology.

However, if some charts or portions of the river are not available, important data can be assumed or estimated based on those next to them. Depending on the study resources and the importance within the application zone, a complete bathymetric study is economically viable.

### 5.3. Step 3. Complementary Information

The following information to complement the general database is macroeconomic, regarding the determination of its impact or influence zones, production centers, demanded products, inter modal transport, associated services, public and private ports, imports and exports. It is established according to the research scope.

It is important to make a first selection of ports and services along the study waterway, because it will divide the waterway into standard sections to optimize transport times, vessel types and pushers, and costs in the logistics chain.

The choice will depend on the ease of data collection; therefore, if there is no reliable information along the waterway, it is better to propose new services and infrastructure to complement the study and to determine the budget of each case.

### 5.4. Step 4. Variables Evaluation

This will identify the vessels or convoys that travel along the waterway or divided in sections. The process is to take the convoy measurements, width, length, draft, block coefficient, and load capacity (previously determined from vessels or standard convoys) to calculate maximum values within the navigable channel (step 2). Then, the maximum length and width approximations are converted into the appropriate measurements for each nautical chart, turning it into the “ideal” arrangement.

The formulas, charts and figures in section 3 were used to determine maximum measurements. For example, the maximum allowable speed per section required for the application of the charts in the additional widths was determined with formula 1 by the Froude factor (Fnh). Knowing if the speed is low, moderate or high, the application of PIANC´s references results in additional measures to increase the maximum width per nautical chart. A calculation example would be:

Fnh = 0,7; g = 9,8 m/s2; h = 2,1 m V =?

Applying formula 1; V = 3.18 m/s or 6.17 knots; corresponding to a slow speed.

In the case of the Paraguay-Paraná waterway, the speed data was assumed, since no public study was found. However, if there is no information for the study, the historical references can be evaluated, or a complete study can be performed.
The additional widths of the PIANC charts are approximations according to the loads carried, services and infrastructure based on the research information from step 3. The extra widths by navigational aids factor, bottom type, waterway depth and hazardous cargo are set according to the circumstances of the waterway.

Then the maximum width calculated by each nautical card is divided by the width of the boat or convoy resulting in the number of barges allowed to pass per each river portion. This data is another variable in determining the standard sections. It is the maximum width of the channel and, therefore, the number of bays allowed.

The maximum draft of the vessel or convoy will be calculated from the Froude factor; knowing that the maximum value would be 0.7 then the factor in the depth/draft relation (W/B) would be 1.40 recommended in the paper CAPRACE, 2013. For each nautical chart, the convoy´s draft is calculated by dividing the minimum depth in the channel for the recommended factor of 1.40.

The turning radius taken from the digitization of the nautical charts is compared to the one calculated for the simulated convoy arrangements. The smallest turning radius is compared to each desired configuration in a matrix of two variables: positive or negative. The positive response assures the pass of the vessel or convoy and the negative response limits the pass through the channel. In this way, we will know what kind of configuration can be projected, from 1x1 to 5x5 (columns x rows).

The division evaluates not only the dimensions but also the type of pusher, types of cargo or services required for each of them. This corresponds to another variable within the portion selection.

However, in some cases, some values or measures have been out of range. Isolated cases must consider a re-evaluation or facilities addition.

The values that generate a trend, an intermediate subdivision, arrangement configuration change or complementary improvements could be considered, such as dredging, correction of lines, channels, bridges, among others.

## 5.5. Step 5. Sections Division

Finally, the standard division into sections with the appropriate convoy arrangements for the studied waterway is presented. In order to properly subdivide the waterway into sections, it should not only evaluate the variables obtained from the physical measurements and calculated data, but also the associated services, nautical aids, borders, logistic facilities, multimodality of the nautical pad or portion of the river. The sections can be lengthened for better planning and project use.

An analysis in the matrix can mediate the sections where the arrangements change or generate trends. For instance, the average number of barges per chart changes, and in our case, varies from 2 to 6 on average for section 1 and from 6 to 20 for section 3. Here we evaluated widths, maximum mouth, recommended factors and charts.

The maneuverability factor of the convoy is calculated according to the calculated navigation speed being low, moderate or high. In our case, it changes from moderate to good.

The dual matrix, designed to evaluate two types of barges or more, changes its section when the response is positive or negative, depending on the type of arrangement used. Therefore, the union of the previous evaluations closes the criterion for choosing the sections. Then, it also determines the maximum length, width and depth for the projection of the most optimal vessels or convoys for each section, according to the facilities and associated services on the waterway and the facilities improvement of the route if necessary.

## 6. Result Analysis

### 6.1. Dimensions and Physical Variables

The dimensions are directly linked to the existing restrictions on the waterway, which includes locks, depth-limited stretches, sharp turns, narrow stretches, road conditions, associated services, stocking, transshipment, safety, product outlets, and climate change, among others. These are used to determine the largest possible dimensions of a convoy. It presents the methodology of maximum dimension of the convoy to travel unrestricted on that section of waterway. Therefore, in the logistics chain, the associated times and costs can be calculated.

For other critical passages (sharp turns, sandbanks, etc.), the model considers the risk and interference levels for determining the largest convoy formation. The methodology selects both length and width of the barge to optimize the use of space in the transport of goods.

The operating convoy draft for a river is chosen for two reasons: economical, to carry as many loads as possible in one trip, and by operational restrictions. It tends to use the largest convoy draft in a waterway. Consequently, the higher cost of investing in boring or heavy draft convoys may not be efficient and, on the contrary, make the transportation project unviable.

### 6.2. Convoys

This assessment or proposal developed through the systematic variation of convoy combinations ensures the operation of efficiently designed vessels for each section of a waterway, taking into regard physical, service, safety and interference aspects of the waterway.

Consequently, this study evaluates the standard classification methodology for waterways and proposes convoy configurations (ships, pushers and/or barges) specified for each section of the subdivided waterway. Dismemberment at critical points is specified as well.

The methodology allows for the study of the waterway, with the vessels present in the research area, and from there, understanding the maximum measures, width, length and draft to design efficient convoy arrangements for each selected section.

### 6.3. Speed and operating time

Operating speeds depend directly on the restrictions of each section, the convoy arrangements and the available engine power. Based on the proposed methodology, its use would reduce traffic times in the winding and optimize the services along the waterway obtaining lower cost per ton transported.
The proposal lists the maximum allowed speeds, on average per section. However, if critical speeds are slower than cruising speeds, the waterway may have unique restrictions based on the practitioner's experience.

This methodology does not define the power or capacity of the pushers or tugs of each train formation, because it was not the object of this research.

## 7. Conclusion

The proposed regional standardization methodology for inland navigation on the Paraguay-Parana-Uruguay waterway was the result of the evaluation of the four physical characteristics (length, width, depth and turning radius) in the optimization of the maximum measurements and convoy arrangements that run along the river, subdivided into sections.

The new methodology is based on a comparison of other international classifications tested and used by some developed countries. It is a tool to support the establishment of a regional database for the development of inland transport.

Based on European, North American, Chinese and specific regional models, the regional classification of waterways in terms of efficiency per ton transported allows intermodal transport connectivity. Applying this method can ensure a sustainable transport option that competes with the strongest markets globally.

The regional standard also allows establishing access to “exit channels” for region's security. In other words, if national security is at risk by moving all kinds of cargo, from people to weapons, this waterways are clear and ready knowing the particular constraints as well as the available supporting infrastructure.

Studies show that waterway transport uses fewer fuels, producing fewer emissions. It is safer compared to travel on railways or highways for the same distance and load. The proposal maximizes vessel or convoy measurements divided in specific sections. Ship owners and designers will be able to develop efficient vessels without overestimation or underestimation, so investments and return planning will be even more real.

## 8. Recommendations

Using this model for new classifications for other waterways in the region, we can achieve a unique methodology to facilitate the inter modality of cargo transport.

To minimize the problem of background shocks, convoy speed restrictions may be set. If, even with the reduction in speed, the level of risk of an accident is still high, it is feasible to include suggestions to change the draft in combination with the convoy's passing speed to meet safety requirements.

Vessel Traffic Service (VTS), piloting, towing, ice breaking and navigation information are part of the waterways standardization process. However, the budget for project implementation must guarantee aid for navigation. In the transportation logistics chain, additional services do support the operation and offer greater safety, maintenance, reasonableness, hope, and social and economic development for the directly or indirectly related population.

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