Paper 107 – Introducing Smart Navigation into the Amazonian Waterways

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ABSTRACT: Considering that essential conditions for safety navigation at the Peruvian Amazon region are the knowledge of the navigable channel location and the availability of water level information it is proposed to implement a "River Information System" (RIS) that – as WEB page format easily accessible to both the river mariners and the general public – will provide information about river channel axis and edge location (as *.gpx files), water level data at measurement stations and "depth correction abacuses" as well as the information produced by the Hydrography and Navigation Service of the Amazonian – SHNA (river charts, pilot books and notices to river mariners).

1 INTRODUCTION

The Republic of Peru has a total of 159 river basins of which 62 belong to the catchment area of the Pacific Ocean, 13 to Titicaca Lake and 84 to the Amazon River (Figure 1).

Figure 1: The Peruvian hydrographic network

Eleven rivers represent the main waterways of the Peruvian Amazon region with 7,131 km total length (Table 1). Six of them form the so–called "main commercial fluvial system" (4,081 km long): a) Marañón (Saramériza – Ucayali confluence), b) Amazonas (Ucayali confluence – Santa Rosa), c) Ucayali (Marañon confluence – Pucallpa – Atalaya), d) Urubamba (Atalaya – Las Malvinas / Camisea), e) Huallaga (Marañón confluence – Yurimaguas), and f) Napo (Cabo Pantoja – Amazonas confluence).

River	Stretch	Length (km)
Marañón	Saramiriza – Ucayali Confluence	621
Amazonas	Ucayali Confluence – Santa Rosa	598
Ucayali	Pucallpa – Marañón Confluence	1,248
	Atalaya – Pucallpa	517
Urubamba	Las Malvinas / Camisea – Atalaya	293
Huallaga	Yurimaguas – Marañón Confluence	220
Santiago	Yaupi river – Marañón Confluence	260
Morona	Filadelfia – Marañón Confluence	440
Pastaza	Bobonaza river – Marañón Confluence	420
Tigre	12 de Octubre – Marañón Confluence	550
Napo	Cabo Pantoja – Amazonas Confluence	584
Putumayo	confluence with Yaguas – Gueppi rivers	1,380
	Total Length (km)	***7,131***

Table 1: Main rivers of the Peruvian Amazon region

Due to the almost total lack of roads, the "main commercial fluvial system" represents the engine for economy development and for internal and external integration of the Peruvian Amazon region as well as the main means for mass communication.

In fact, the influence area of such river network comprises almost all the regions of Loreto and Ucayali and part of Cusco region including 10 provinces and 57 districts that generate and receive cargo flows; the area of this region amounts to approximately 415,000 km^2 (32.3 % of Peruvian territory) with a population of 1,640,735 inhabitants (2013 projection).

Consequently, any action aimed to improve navigation and river transport will generate significant impacts on the river and social integration of a vast region of Peru.

2 CURRENT CHARACTERISTICS OF INLAND NAVIGATION AT THE PERUVIAN AMAZON REGION

2.1 *The river fleet*

The current fleet sailing at the Peruvian Amazon region is composed by a diverse set of vessels with particular characteristics: a) river boats and river sliders, b) motor barges (a naval construction for cargo transport), c) motor ships (a naval construction for both cargo and passenger transport), and d) deck barges and fluvial pushers.

In order to obtain primary information regarding the number and characteristics of such vessels, during the studies conducted for the elaboration of the "Development Plan for the Peruvian Commercial Waterways" – the so called "Waterways Plan" – a "census" was made based – mainly – on the information regarding arrivals and departures at the three main Peruvian Amazon ports (Iquitos, Pucallpa and Yurimaguas) during the period 2010 – 2012.

According to such information a total amount of 1,361 vessels was obtained: a) 497 (36%) were motor boats and river sliders (86% of them had a gross tonnage lower than 10 GT, 3.00 to 28.00 m in length, 0.60 to 4.00 m wide and 0.40 to 1.80 m depth), b) 378 (28%) were motor barges and motor ships (70% had a gross tonnage between 100 and 1,000 GT with 19.50 to 74.11 m in length, 4.20 to 13.0 m wide and 1.20 to 3.40 m depth), c) 312 (23%) were deck barges (89% had a gross tonnage between 100 and 1,000 GT with 19.0 to 72.0 m in length, 5.44 to 14.00 m wide and 1.20 to 3.65 m depth) and d) 174 (13%) were fluvial pushers (94% had a gross tonnage between 20 and 500 GT with 10.97 and 38.00 m in length, 3.36 to 10.10 m wide and 1.00 to 5.20 m depth).

2.2 *The river infrastructure*

The main facilities of the Peruvian Amazonian region are located at the cities of Iquitos (440,000, inhabitants; 71 facilities: three of them classified as formal ones meanwhile the others are characterized by their infrastructure and equipment deficiencies), Pucallpa (220,000 inhabitants; 98 facilities that do not meet the minimum standards) and Yurimaguas (65,000 inhabitants; 12 facilities: two of them classified as formal ones meanwhile the others are characterized by their infrastructure and equipment deficiencies).

The rest of the commercially important river infrastructure corresponds to the towns of Saramiriza, San Lorenzo, San José de Saramuro, Nauta, Yanayacu, San Pablo, Pebas and Santa Rosa (on the Marañon and Amazon Rivers), Contamana and Requena (on the Ucayali River), Atalaya (on the Urubamba river), Lagunas (on the Huallaga river), and Cabo Pantoja and Mazán (on the Napo river).

The remaining towns and river communities are characterized by the complete lack of infrastructure so – for goods loading / unloading or for passengers boarding / unboarding – most of the vessels simply approach to the riverside.

Additionally, some river communities have small wood or concrete stairs (typically with erosion damage at the lower part) or simply stairs carved on the riverside.

Finally it must be noted that, currently, two new – well equipped – port terminals are being constructed at Pucallpa and Yurimaguas towns.

2.3 *The magnitude of river traffic*

According to recent studies (SERMAN & Asociados SA – CSI Ingenieros SA – ECSA Ingenieros SA. 2014a), during 2012 river traffic amounted to 3,545,000 tons and 500,000 passenger meanwhile projections to the year 2023 amounts to more than 5,000,000 tons and over 700,000 passengers.

Petroleum and derivatives, wood and wood products, beer and empty beer bottles account for 60% of the charges; the rest includes various products (food, cement, vehicles, machinery, steel / iron boards, beverages, pharmaceuticals and toiletries products, textiles, hardware, chemicals, electrical appliances and construction materials).

2.4 *Main problems related to inland navigation at the Amazon region*

The use of the Peruvian commercial river system is affected by the lack of infrastructure, by deficiencies on services and by time restrictions (navigation is – usually – possible only during daytime); in addition, there are important factors related to hydrological regimen:

- Seasonality (flood and drought) and variability of the flow regimen: One of the main consequences of the flow regimen seasonality are – obviously – the water level seasonal variations but also the sudden variations associated with extensive and prolonged rainfall events at the highlands of the watersheds (which may determine that, in a few hours, water level can rise – or reduce – more than 3.0 m).

- Presence of “palizadas” and “quirumas”: Adrift transportation of shrubs, branches, logs and trees that may form significant accumulations or floating islands (“palizadas”) or that may be driven into the river bed (“quirumas”) constitutes major obstacles or hazards to navigation. This is a common phenomenon in most of the rivers of the Amazon region – which is usually observed during flooding period – being a characteristic of the biological dynamics of the Amazon ecosystem where trees fall to the ground for various reasons (destruction of trunk, strangulation by other plant forms, loss of balance) and, during flooding time, float to the rivers where they are carried away by currents. Falling trees due to riverside erosion phenomena should be also considered.
- Riverside erosion and river channel migration: Riverside erosion represents a consequence of fluvial dynamics that occurs mainly during flood / drought transition when water level begins to fall and the saturated materials lose their sustentation and slide into the river due to gravitational action. Channel river migration represents the final product of such phenomenon.
- Sedimentation processes with formation of sandy banks and alluvial islands: The decrease of river speed in areas with low slope as well as the presence of natural or artificial obstacles determines deposition of the materials transported by the river and the simultaneous reduction of its depth and section. Moreover, river sinuosity generates flow acceleration and deceleration phenomena favoring sedimentation processes and – consequently – the formation of sandy banks and alluvial islands that represents real obstacles to navigation (particularly during dry season).
- Presence of meandering and braided channels: A characteristic feature of the Amazon region is the presence of meandering and braided channels. Meanders are curves – characteristics of floodplains or very low sloping rivers – that generates erosion (on the outer side of the arc) and sedimentation (on the inner side of the arc) meanwhile braided channels represent multiple ramifications of the river course separated by temporary or permanent sandbanks and islands that – during the dry season – restrict the navigation channel both in width and depth.

Due to the above reasons, rivers of the Peruvian Amazon region are characterized by the presence of "critical stretches” (“malos pasos") defined as those sections of the river where depths are less than the minimum depth required for the passage of a vessel (usually with 4.0 feet or 1.20 m draft plus an additional margin of 1.0 ft or 0.30 m).

To the previous elements it must be added the fact that navigation is basically of visual character (based on knowledge of the river and on crew experience). In fact, knowledge of the rivers is essential and irreplaceable, being an element always present in river navigation.

A common practice, consist of sending, ahead of the vessel, a canoe with the elements necessary to verify the deep and to signalize the deepest area. This makes possible to cross the "critical stretches” (“malos pasos") with minimal water margins.

Other common practices consist of: a) maneuvering ahead and back in order to “open” the channel; b) turn the boat (where possible) and to use the propeller in order to generate turbulence and remove the sediment that conforms the "critical stretch” (“mal paso"), and c) transfer part of the cargo to another vessel.

Moreover, it is not common to use the elements currently offered by technology such as echo sounders, radars and global positioning systems (GPS). Also, river navigation charts, notices to river mariners or simple sketches made by mariners themselves, are not used.

Finally it must be appointed that the Hydrography and Navigation Service of the Amazonian (SHNA), created in 1971, is the technical organism in charge of the development of river navigation charts and the installation and maintenance of limnimetric stations and river signaling. The latter includes electric lights, river signs (installed only on the Huallaga River) and placards identifying population centers.

2.5 *Some common practices applied for inland navigation at the Amazon Region*

At the Peruvian Amazon region, the crews know "by memory" the specific conditions of each river including navigation directions and shallow areas, navigation channel and “palizadas” locations as well as bed characteristics.

Such knowledge – which includes not only the restrictive elements to navigation but also insights regarding winds and currents behavior as well as vessels responses to maneuvers – is learned over time and continuous navigation; the latter element is essential (whatever the size of the vessel).

Thus, the river crew knows that: a) the deep channel can be localized by the presence of floating foliage carried by the current; b) a floating shrub may be the branch of a large semi – submerged tree floating adrift; c) the bonding of leaves, shrubs, branches, logs or trees may be an indication of suddenly flows ("repiques") associated with the beginning of the flood or with the occurrence of heavy rainfall episodes (extremely common in the region), and d) areas with particularly brackish waters means river bed instability, bank erosion or notable depths differences.

Beyond these practical skills, river navigation also requires the use of own methods, techniques, maneuvers and procedures.

Downstream navigation has greater absolute speed, greater kinetic energy and less maneuvering conditions meanwhile sailing against the current (upstream) the vessel has lower absolute speed, less kinetic energy and better maneuverability. This becomes a law for river navigation: "who sails with the current follows the middle of the river and who sails against the current follows the riverside".

Moreover, every river has easily navigable stretches interspersed with difficult ones; as a consequence there are several navigation rules:

- Along high riversides, depths are generally greater so it's preferable to navigate very near to them.
- During the dry season, the shallow and gently sloping emerging areas ("playas") are generally located at the inner side of the curves; accordingly, navigation in these areas should be avoided.
- Along the section between the extremes of a shallow and gently sloping emerging area ("playa"), the greatest depths are located on the opposite side to it.
- Along the long and straight sections located between two shallow and gently sloping emerging areas ("playas"), the greatest depths are located on the middle of the river.
- Along straight stretches the greatest depths are located at one of the riversides and near the end of the stretch it's necessary to cross to the other riverside.
- In areas where there are no current or where the current is opposite to general river flow direction ("remansos"), usually located on the inner side of sharp curves, the depths are lower and vessel government is very difficult.
- Sharp curves with strong currents ("vueltas cerradas") require very complex maneuvers involving navigating near the outer margin and crossing the river to continue the navigation at the opposite riverside.
- The curves that maintain their curvature in its entirety extension ("vueltas redondas") require maintaining navigation close to the outer edge of the curve without crossing the river.

3 SMART NAVIGATION PROPOSAL

The Inter--American Development Bank (IDB) has supported the General Directorate for Aquatic Transport (DGTA) of the Ministry of Transport and Communications (MTC) through non–reimbursable technical cooperations aimed to promote the development of river navigability as well as of the waterway system itself.

With such support and own resources, several studies have been developed. Thus, based on topographic and hydrographic surveys it has been possible to identify: a) on the Marañón and Amazonas rivers (Saramiriza – Santa Rosa) five (5) "critical stretches" (Instituto de Consultoría SA – SerConsult SA – Proyectos y Desarrollos SA, 2008), b) on the Ucayali river (Marañon confluence – Pucallpa) sixteen (16) "critical navigation areas" of which only four (4) were "critical stretches" (HyO Ingenieros SA – ECSA Ingenieros SA, 2005), c) on the Ucayali river (Pucallpa – Atalaya) eight (8) "critical stretches" (Dirección de Hidrografía y Navegación – DHN, 2008a), d) on the Urubamba River (Atalaya – Las Malvinas / Camisea) twenty–one (21) "critical stretches" (Dirección de Hidrografía y Navegación – DHN, 2008b), e) on the Huallaga River (Marañón confluence – Yurimaguas) seven (7) "critical stretches" (Instituto de Consultoría SA – Proyectos y Desarrollos SA, 2005), e) on the Napo River (Cabo Pantoja – Amazonas confluence) eighteen (18) "critical navigation areas" of which only seven (7) were "critical stretches" (SERMAN & Asociados SA – CSI Ingenieros SA, 2010) and f) on the Morona River (Filadelfia – Marañón confluence) fourteen (14) "critical stretches" (SERMAN & Asociados SA – CSI Ingenieros SA – ECSA Ingenieros SA, 2015).

Solving the navigation problems previously detailed through dredging usually involves small aperture volumes and relatively large maintenance volumes (up to 40–60% of the aperture volume, depending on hydro – sedimentological conditions and – possible – with important yearly variations).

Additionally, due to the probability of finding coarse sediments and even "hard materials", aperture dredging will involve the use of cutter suction dredges (CSDs) while maintenance dredging will involve the use of trailing suction hopper dredges (TSHDs). Both equipments have significant operational constraints associated with the average thickness of the material to be removed, the productivity to be achieved and the operational depth (all of them usually very low and affecting the cost of the works). Moreover, costs would be highly dependent on the availability of dredges at the Amazon region (since mobilization would be the largest component of the final cost).

Considering the above elements and based on their work experience at the Peruvian Amazon region (SERMAN & Asociados SA – CSI Ingenieros SA, 2010; ALATEC Ingenieros Consultores y Arquitectos SA – CSI Ingenieros SA – SERMAN & Asociados SA, 2013; SERMAN & Associates SA – CSI Ingenieros SA – ECSA Ingenieros SA, 2014), the authors believe that the essential condition for a safety navigation are the knowledge of the navigable channel location and the availability of water level information.

In fact, at the Amazon region there are many elements that during dry season become significant restrictions to navigation (seasonality and variability of the flow regimen, presence of "palizadas" and "quirumas", riverside erosion and river channel migration, sedimentation processes with formation of sandy banks and alluvial islands, presence of meandering and braided channels). Other important limitations must be also mentioned: a) navigation is basically of visual character (based on the knowledge of the river and on the crew experience), b) it is not common the use of the elements currently offered by technology (echo sounders, radars and global positioning systems – GPS), and c) river charts, notices to river mariners or simple sketches made by mariners themselves, are not used.

Currently, the Hydrography and Navigation Service of the Amazonian (SHNA) has the capability to perform nautical charts according to ISO 9000 – 2008 nevertheless river charts are based on a planning that involves the survey of the major rivers every three (3) years and of the remaining rivers every five (5) years.

Obviously, the high hydro – morphological and sedimentological variability of the Amazon rivers determines that – in order to maintain a constantly updated knowledge of the navigational channel location – a survey frequency as the aforementioned is undesirable. In fact, the optimal one would be on an annual basis (previous to the beginning of dry season).

Additionally, the magnitude of the effort for acquiring and processing the information as well as the time elapsed between the survey and the availability of the cartographic document must be considered; especially when data is necessary immediately to survey (the dry season).

Another key element to be considered is the global trend to replace traditional nautical charts in paper format with new formats ranging from "print to demand" through Acrobat Reader ® *.pdf format to full color digital geo – referenced images (raster format) and electronic navigational charts (vector data, ENC format) produced according to international standards and requiring special visualization programs (Electronic Chart Display Information System – ECDIS).

Obviously, at the Amazon region, the evolution from empirical navigation towards high–tech systems based on electronic navigational charts is not feasible in the short and – even – medium term.

Consequently, it is proposed – as a first step towards modernization of navigation – to provide – annually and prior to the dry season – the trace of the navigational channel (axis and edges) on a format compatible with the most commonly used satellite positioning systems (*.gpx files).

A system as the previously proposed, very easy to use, will provide information about navigable channel location (implying a qualitative leap over the current situation). Moreover, the system could include a virtual navigation aids system based, for instance, on margin signals ("actions to be taken").

In order to improve the previous system it should be conducted an annual bathymetric survey (prior to the beginning of the dry season) which shall cover the existing water surface with: a) 100 m spaced cross sections at the "critical stretches" ("malos pasos") and 200 m spaced cross sections at the rest of the river length, and b) a longitudinal profile according to river "thalweg". Measured depths should be referred to water surface and be reduced by water level variations, "transducer" immersion and hydraulic gradient; the final depth should be referred to a certain "navigational reference level".

Another aspect of particular interest, it would be to have information regarding river water level. In fact, from the knowledge of the river level upstream and downstream of a certain point it would be possible to know the depth on such point.

Currently the "Derrotero de los Ríos de la Amazonía Peruana" (SHNA, 2011) includes numerous tables providing information about the distances (mileage) along the Amazon rivers.

Such data may be used to produce "depth correction abacuses" which – based on distance tables and measured river levels – will allow to determine the depth to be expected at "critical stretches" ("malos pasos"): a valuable data not only for the mariners but also for ship owners who will be able to plan the maximum load to be transported in order to cross "critical stretches" ("malos pasos") without difficulties.

Once the mariners achieve the necessary training and practice, the use of the elements described above will be intuitive and simple. Additionally, in current state of technology, it will be possible to develop easy software to be used on notebooks, tablets and – even – smart phones.

The development and approval of the software performing such functions will be simple and an "official" version of the same one could be provided by the competent authorities.

All the above information (nautical charts on *.pdf or RNC format, river channel axis and edge as *.gpx files, water level at different measurement stations, depth correction abacuses, application software) as well as the information produced by Hydrography and Navigation Service of the Amazonian (river charts, pilot books, notices to river mariners and so on) supplemented with information produced by other government institutions could be part of a "River Information System" (RIS) that – as WEB page format – must be easily accessible to both the river mariners and the general public allowing, at the same time, to view and to download the information.

The availability of a "River Information System" (RIS) as the described above is one of the projects included on the "Development Plan for the Peruvian Commercial Waterways" proposed by SERMAN & Asociados SA – CSI Ingenieros SA – ECSA Ingenieros SA (2014a) as well as a service to be offered by the future concessionaire of the "Amazon Waterway" (a public – private partnership process promoted by the Ministry of Transport and Communications through the Agency for Promotion of Private Investment).

Finally, it must be noted that "River Information Systems" (RIS) as the previously proposed are commonly used at the region; the one available for Magdalena river represents one of the best examples.

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