Statistical analysis of accidents in the Tietê-Paraná Waterway in the period from 2003 to 2012.

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1. INTRODUCTION

The Tietê-Paraná waterway (TPW), compound by 2,400 kilometers of navigable waterways, has played an important role in the logistics system of agricultural productions distribution from the Middle West region of the country [1, 2]. The TPW presents a series of physical constraints (locks, bridges and artificial channels) that limit the vessel's dimensions (length, width, draft and air draft), imposing navigation requirements for self-propelled vessels. The convoys, because of the possibility of dismemberment, use compositions (most of Tiete-Double standard) compatible with the propulsive and government capacity, attending a viable economically operating condition. Navigation requirements are set forth in the Rules and Procedures of the Capitânia Fluvial do Tietê-Paraná (Tiete-Parana Waterway Captaincy). The TPW deserves attention taking into consideration that it will be used in the transportation of ethanol, with highly dangerous characteristics, which may pose a high social risk due to the existence of several municipalities located alongside the waterway. The ship-owners intends to operate twenty convoys, each composed of one pusher and four barges, which will result in a considerable increase volume of traffic on the waterway, and, consequently, congestion at points where the split-up of the convoy is necessary to enable the transposition, such as locks, bridges and canals.

An inland waterway transportation system is a complex system subject to the effects of multiple factors, and constituted of four main elements: human, vehicle, environment and management [3]. The study of influence of each factor in accidents, and the interaction of them, is extremely important to ensure the safety of navigation, the protection of persons on board and the preservation of water pollution. In this context, aiming to support a decision-making process, a risk analysis can be used not only to determine the risk associated with an inland waterway transport system, as well as, to identify the factors that contribute most significantly in the composition of this risk, and possible control actions during the project phase or in the system in operation [4].

Risk analysis can be qualitative or quantitative and comprises an integrated assessment of three elements: scenario, frequency and consequences. The qualitative analysis aims to study, in qualitative terms, all possible risk events related to the system, considering the probability of occurrences and its consequences. From this analysis, it is possible to establish priorities to perform a quantitative analysis [4].

In Brazil, the studies to examine the risk of accidents in Brazilian waterways have employed statistical surveys and exploratory and deterministic methods [5, 6]. However, the use of probabilistic methods proves to be more effective in complex systems, in view, that it allows to sort events in terms of frequency and consequence. It is the method used by the classification societies and recommended by the International Maritime Organization [7] with the use of a structured and systematic methodology called Formal Safety Assessment (FSA) [8]. Similarly, recent researches were developed on the Delaware River in the United States [9], and the Yangtze River in China [10].

According to Awal [11], a single factor does not caused accidents that is a result of a complex interaction between mechanical failure, human error and natural causes. The same author cites the factors behind the waterway accidents and some of its causes, summarized in Table 1.

Using similar reasoning, in the processes (IAFN – Administrative Investigation of Accidents and Facts of Navigation), which are initiated and led by a Captaincy or subordinate organization and tried by the Maritime Court (TM), are raised the factors that contributed to the occurrence of an accident or fact of navigation, which are classified into: human factor - relating to biological and psychological aspects; material factor – design, construction, installation, maintenance and availability of the vessel and its systems, including the structure, machinery and equipment; and operating factor – errors in actions or omissions, and violations of rules and procedures of the waterway labor, ship-owners or professionals involved.

Table 1 – Factors related to the waterway accidents.

Factor	Some causes
Factor related to the vessel design	Project and construction failure; mechanical failures; and insufficient or inadequate navigation instruments.
Factor related to the operating environment	Fog; excessive currents or swirls; and cyclone and storm.
Human factor	Overcrowding and cargo; incompetence of the captain, master and other professionals; and turmoil on embarking and disembarking of the passengers.
Factor related to the implementation and organization	Insufficient in the application and practice of the vessel safety standards; deficiency in the awareness programs; and deficiency of bad weather and contingency systems warnings.

Source: Adapted from Awal [11].

The frequencies, the causes, contributing factors and consequences associated to the accidents can be obtained from historical data, if available, or expert opinion, with the use of an appropriate methodology. Expert assessment is used in several areas, among which the risk assessment, and is typically used when data are scarce, difficult or expensive to obtain, and open to differing interpretations. The expression of opinion may be in quantitative ways, having a numerical value, or qualitative, having a textual description [12].

This research presents the accidents that occurred in the Tietê-Paraná Waterway (TPW) and its tributaries, whose data were collected from one hundred sixty-four IAFNs, concluded by the TM in period 2003 to 2012. Of these cases it was possible to estimate the frequency of each type of accident (annual and monthly), type of vessel involved, the causes and contributing factors (human, environmental and mechanical), climatic influence, traffic routes, higher period of incidence in the day, and the consequences to the people. In addition, it presents the test results of expert opinion in convoys driving on TPW, in order to know the most likely causes of the occurrence of a certain type of accident, type of consequence, contributing factor and type of human error.

2. OBJECTIVES

One of the objectives of this study was to quantify accidents and facts of navigation that occurred in the Tietê-Paraná waterway, in the period from 2003 to 2012, and to identify their causes and contributing factors, using official historical data. Another objective was to evaluate the opinion of experts as a source of data for the problem analysis, especially the methodology of obtaining these opinions, and the method used to analyze and classify the answers.

The overall objective of the research was to obtain information to support a doctoral thesis, under development by the first author within the Risk Assessment Laboratory (LabRisco) of the Department of Naval Architecture and Ocean Engineering at University of São Paulo (USP), whose goal is to analyze the influence of the human factor in the risk of convoys accidents in TPW, using Bayesian networks.

3. DESCRIPTION OF ACTIVITIES

3.1 Initial considerations

Since this is an exploratory study, in order to obtain initial information about the problem (accidents in TPW), two parallel activities were conducted, the first one focused on collecting and stratification historical data of accidents and facts of navigating on TPW, and the second one guided in obtaining and analyzing opinions of specialists on navigation, as detailed in the sequence.

3.2 Accidents data and facts of navigation in the Tietê-Paraná Waterway

The historical data of accidents and navigation facts were obtained from the trial judgments of the TM, available for public access on the internet. The annuals TM, of a period of ten years, starting in 2003 until the year 2012, were analyzed and stratified. Of these directories, were extracted the files relating to accidents and facts of navigation that occurred in the jurisdictions of the Tiete-Parana Waterway Captaincy (CFTP) and its subordinate military organization – Delegacia Fluvial of President Epitácio (DLPREP), totaling one hundred sixty-four processes.

3.3 Expert opinion

The generic profile of the experts who contributed to this work comes down to the waterway labor deck sector (convoy Pilot or Captain), with training and proven experience in the operation of typical TPW convoys, exercising the functions of driving or command (pilot, immediate or commander).

The used procedure to obtain the feedbacks from specialists was based on questionnaires focused on the following elements of interest: I) Personal data; II) Professional data; III) Data of vessels and convoy; IV) Route data; V) Operation data; VI) Accidents; VII) Factors influencing the performance, and; VIII) Situational attributes.

Personal data, professional data, data about the vessel (or convoy), the route and the operation (items I to V), were used to obtain a profile of the specialist and his routine work activities. About the route data, it was possible to express the opinion in a free text about the perception of the risks inherent in the workplace. For accidents (item VI), the goal was to identify the probable causes and probabilities of occurrence of a given type of accident, type of result, contributing factor and type of human error. Factors that influence performance (item VII) correspond to the aspects that, in some way, interfere with the possibility of an accident. These aspects correspond to the organizational, internal and environmental factors, and abilities. Organizational factors refer to aspects related exclusively to the ship-owner (influence of the company). Internal factors relate to the individual on the physical conditions, stress, mental and memory. Environmental factors correspond to the conditions of the workplace (vessel) and operation (route). Abilities are relate to individual characteristics that interfere with specific professional activity (pilotage or command). The situational attributes (item VIII) correspond to those aspects that can interfere in the case, the type and consequence of an accident [9]. The attributes considered were: Period - day and night; Status - navigation, waiting in buoy and sluice; Type of cargo - hazardous and non-hazardous; Section - the waterway region; Traffic - density in a distance of 10 km; Waiting buoys - congestion; and Season of the year. In the case of section, the waterway was divided into three regions, according to Table 2. Section I covers the lakes of all the Tiete River reservoirs in the navigable portion. The Section II includes access to the northern stretch of the TPW to its navigable extreme - São Simão/GO. The Section III corresponds to navigation on the southern section of the TPW to the Hydroelectric Power Plant (UHE) of Porto Primavera, which is the jurisdiction of the Delegacia Fluvial of President Epitacio, on the Paraná River. The division of the sections considered the routes used by convoys in longitudinal route.

Each attribute was associated with the possibility of failure of the propulsion systems, steering and electrical, and human error.

Table 2 – TPW's division into sections.

Section	Local
Section I	1-Barra Bonita; 2-Bariri; 3-Ibitinga; 4-Promissão; 5-Nova Avanhandava; e 6-Três Irmãos.
Section II	7-Canal Pereira Barreto; 8-Ilha Solteira; e 9-Rio Paranaíba.
Section III	10-Jupiá; e 11-Porto Primavera.

Two types of questionnaires were developed, being the second one (Q2) an evolution (reassessment) of the first (Q1), with similar questions that address all elements of interest described above. The main difference between the questionnaires is the format of the responses to the items related to accidents, factors that influence the performance and situational attributes. For these items, in Q1 it was used the method of classification according to the degree of importance, frequency or probability (ex.: 1 -most likely and 5 - least likely). In this case, the expert should write a number for the chosen option. In Q2 we used the method to point out the best option (ex.: choose MB option for very low probability or MA for very high probability). The results of Q1 led to the need for changes to the Q2 because most people did not answer all questions, confirming that open questions are inefficient for long questionnaires.

Two groups of experts answered a type of questionnaire, at different times, both in 2014. The first group (G1) consists of nineteen persons and the second (G2) of twelve persons.

The answers to the questionnaires were condensed and presented in the results section of this article, in tabular form, in which, from Table 5 through Table 17, except for Table 16 (environmental factors-Group 2), in the first and second columns are presented the results for G1 and G2, respectively, for a comparison of the results, as explained in the following:

1) The first column shows a numerical rating that indicates the order of the options most frequently cited by G1. However, it is important emphasize that the Q1 format allowed the indication of the same degree of importance to more than one item.

2) The second column shows the classification most often cited by G2 for each factor. Possible options for each category are described below:

(a) Accident causes (Table 5): N (no influence); P (little influence); M (moderate influence); or G (large influence);

(b) Accident types (Table 6); consequences (Table 7); contributing factors (Table 8); and type of human error (Table 9): Z (zero probability); MB (very low probability); B (low probability); M (moderate probability); A (high probability); and MA (very high probability);

(c) Organizational factors (Table 10); internal factors - stress (Table 11); mental (Table 12); memory (Table 13); physical (Table 14); and environmental factors (Table 15) - Group 2 (Table 16); and abilities (Table 17): N (no influence); P (little influence); M (moderate influence); and L (large influence); and;

(d) The relationship between the type of vessel and situational attributes - G2 (Table 18); and relationship between the situational attributes and failures in the cause, type and consequence of the accident (Table 19): N (no influence); P (little influence); M (moderate influence); and L (large influence).

The results obtained by the questionnaires to each of the elements of interest described above were classified, considering the quantitative criteria for ranking.

4. RESULTS

4.1 Accidents and facts of navigation in the Tietê-Paraná waterway (data)

The Figure 1 shows the annual distribution of the number of processes completed by TM from 2003 to 2012. In this period, 164 cases were analyzed, of which 72.6% are related to the jurisdiction of CFTP and the rest of DLPREP. Of all the cases, 39.6% resulted in a condemnation. The Rivers Tietê and Paraná respond respectively to 42.7% and 29.3% of all accidents and facts of navigation in the analyzed processes. From this point, it was omitted information that the results refer also to the facts of navigation, only for simplification effect.

The distribution of accidents per year of occurrence is shown in Figure 2, where it can be seen that, between the years 2001 and 2005, the number of accidents remained stable, in the period from 2006 to 2008, occurs an approximate increase of 100%, with decline in 2009 and again a significant increase in 2010 followed by further decline. This distribution comes down the influence of accidents involving convoys and recreational vessels. In the first case, in general, the frequency of accidents in convoys tracks the cargo volume transported annually. Already the frequency of recreation vessels use relates to factors not measured in this study, such as the number of registered vessels and navigation licenses granted annually.

On a monthly distribution of accidents, considering the entire period of years (Figure 3), there is a significant increase until the month of March, with sudden drop in the next month and a considerable decline until June, which records the least amount of accidents. Following, in July, there is new growth around 300%, with great recovery in the following month, but followed by an increase of large proportion and subsequent decline, and stabilization in the last two months. This distribution relates to the seasonality of cargo transported in HTP, except in the months of January, February, September and October, in which the influence of recreational vessels is more significant. In January and February, little or no cargo is carried while leisure activities are higher due to summer holidays. What causes the number of accidents in the months of September and October are the climatic conditions observed spring, mainly afternoon and evening - rain with strong winds at times - corresponding to 76.2% of accidents in the period and 64.3 % involving recreational craft more susceptible to adverse weather conditions because they are small.

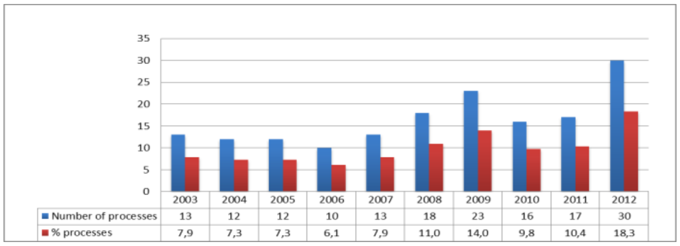

Figure 1 - Process concluded annually.

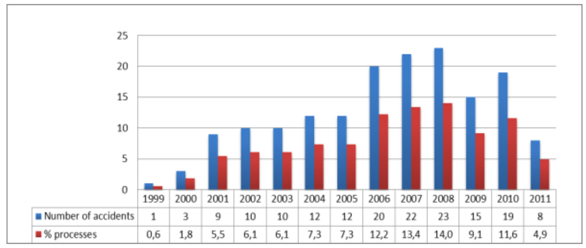

Figure 2 - Accidents each year.

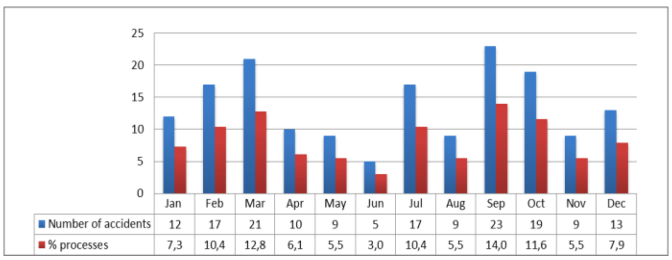

Figure 3 - Accidents in each month.

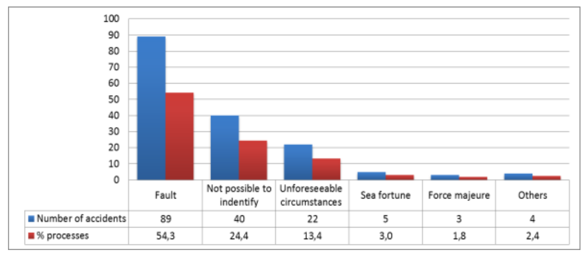

Figure 4 - Causes of accidents.

The types of accidents, according to its nature, that occurred in the analyzed period are presented in Table 3. The results were arranged in descending order of frequency occurrence, which show that the collision (33.5%) was the most frequent accident. The accidents that occurred only once were grouped as others, which comprise the following types: accident with crew; running over; breakdown in lock gates; death on board; drifting; stranding; and situation that endangered the safety of the vessel and the people.

Of the totality of the cases analyzed, it was found that most of the accidents involved vessels classified as sports and recreation (52.4%), followed by vessels classified as commercial (43.3%) and fishing (3.7%). In just one of the processes (0.6%) was detected an unrelated incident with a vessel - lock gates.

Classifying the sports and recreational vessels involved in accidents, it can be seen that the most frequent incidence (37.2%) involved the small vessels (boats), followed by motorboats (12.8%), jet skis (9.1%) and sailboats (1.8%), as shown in Table 4. In addition, from this figure, the convoys also draw attention because they correspond to the second most frequent accidents, with 23.8%. Also in Table 4, it were grouped as "others" the types of vessel (pusher, canoe, dinghy and floating) and one incident with the door of a sluice, as were cited in only one instance.

The decisions of the process show that 54.3% of the accidents were due to fault (recklessness, malpractice or negligence) of conductors or owners of vessels, as shown in Figure 4. Another result that stands out is that in 24.4 % of the cases it was not possible to identify the real cause of the accident. The other causes were characterized as unforeseeable circumstances (13.4%), sea fortune (3%), force majeure (1.8%) and others (2.4%). This last group includes the various causes of the previous ones and with only one occurrence - natural cause, misfortune of victim, excess flow downstream of the barrier and causes not characterized as an accident or fact of navigation.

In most cases it was possible to interpret the existence of a contributing factor to the occurrence of the accident cause. However, instead of seeking a framework in the types of factors used in inquiries (human, material and operational), it was established three other factors: human, environmental and mechanical. The reports of guilt were characterized as human factor. Situations caused by the environment (e.g. a submerged tree trunk), along with the adverse weather conditions, were considered as environmental factor. The cases where a mechanical failure contributed to the occurrence of an incident were characterized as mechanical factors. When the processes reported that the accident had not the cause determined accurately, as well as cases of unforeseeable circumstances and force majeure, were considered indeterminate. Thus, Figure 5 shows the results of contributing factors interpreted processes, where there is a clear preponderance of influence of the human factor (over 50%). Still on the contributing factors, a point that deserves mention is that the contribution of climatic conditions has been neglected in most of the analyzed cases (60.4%). In the other cases, the contribution of aspects related to climate in the cause of the accident was mentioned in most cases (28.7%).

Table 3 – Nature of accidents.

Id.	Type	Qty.	%
I	Collision with fixed object or person	55	33.5
II	Total or partial shipwreck	38	23.2
III	Fall into water	30	18.3
IV	Collision with other vessel	9	5.5
V	Capsizing	8	4.9
VI	Fire or explosion	7	4.3
VII	Damage	3	1.8
VIII	Car fall into water	3	1.8
IX	Heeling	2	1.2
X	Drowning	2	1.2
XI	Others	7	4.3

Table 4 - Types of vessels.

Types of vessels	Number of accidents	% processes
Boat	61	37,2
Convoy	39	23,8
Motor boat	21	12,8
Jet ski	15	9,1
Rail barge	11	6,7
Dredge	5	3,0
Passengers	6	3,7
Sailboat	3	1,8
Sand barge	2	1,2
Barge	3	1,8
Others	5	3,0

The influence of period of the day also was analyzed (Figure 6). In this case, a full day (24 hours) was divided into three periods for analysis: morning (6:00h to 12:00h); afternoon (12:00h to 18:00h); and night (18:00h to 6:00h). Contrary to expectations, in view of the restriction of visibility during the night, the results indicated a higher incidence of accidents during the day, in the afternoon (51.8%).

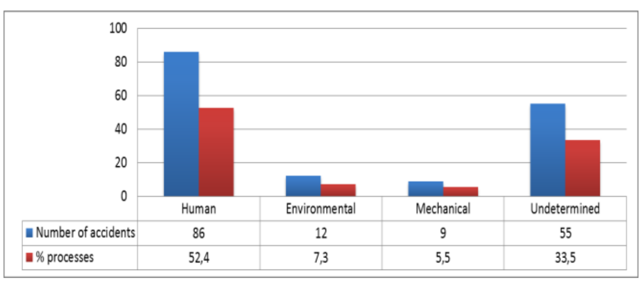

Figure 5 - Contributing factors.

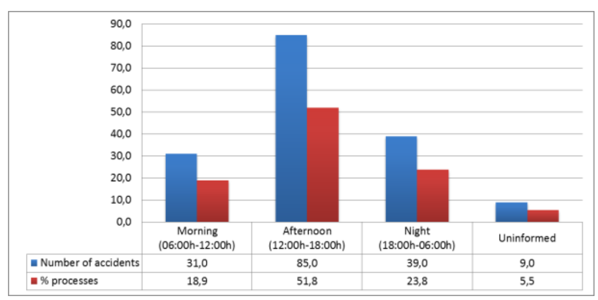

Figure 6 - day period.

Regarding the harm to people on files examined, 45.7% of the accidents resulted in fatalities, 10.4% injuries and 43.9% without damage.

4.2 Information obtained from expert opinions

4.2.1 Accidents

The G1 members pointed to human error as what most influences the occurrence of accidents (Table 5). The results of experts from G2 indicated option P, with 36% to human error, based on the criterion adopted. However, the results for the M and L options were 27% for each, totaling 54%, indicating that most people from G2 understands that there is at least an moderate influence. On the other hand, the possible causes of accidents related to electrical system failure and a failure to another system, for which the majority of the participants of G2 assigned a moderate influence, were classified in third and sixth (last) respectively by G1 members, which indicates difference of opinion between the two groups. The results of the other possible causes analyzed, with little influence, presented consistency in classification.

The occurrence of stranding was the type of accident listed by G1 as most probable (Table 6). The results for G2 group indicated the option B, with 36% for stranding, based on the established criteria. However, the results for the options M, A and MA were 9%, 27% and 18%, respectively, totaling 55%, indicating that the majority understands that there is a probability of at least moderate to stranding. In the event of open water - breaking the hull below the waterline - there is disagreement between the groups because the G2 understands to be the kind of accident with higher chances to occur among others. The results for the other types of accidents showed befitting values on the classification obtained by both expert groups.

The specialists of G1 indicated the injuries as the most likely effect (Table 7). Likewise, a moderate probability has been assigned to the same result, with a greater degree than the other - B and MB. Other results for the consequences are appropriate.

The data on the contributing factors obtained by the two groups were fully aligned, as shown in Table 8.

The results concerning the possibility of some kind of human error, in most cases, for the two groups were compatible. The only exception refers to transgression for which the groups are discordant, as shown in Table 9.

Much of the answers of both groups converge to the same risks and location, referring to the low water level, with the possibility of running aground and breaking the hull downstream of the Nova Avanhandava UHE. They were cited also the risks from the wind and the excess flow (dams), and others.

Table 5 - Accident Causes.

G1	G2	Influence:
1	P	Human error
2	P	Organizational factor (company)
3	M	Failure in the Electrical System
4	P	Failure in the Propulsion System
5	P	Failure in the Command System
6	M	Failure in other System

Table 6 – Accident Types.

G1	G2	Probability:
1	B	Stranding
2	B	Collision1(1)
3	MB	Collision2(2)
4	MB	Shipwreck
5	B	Malfunction or defect that endangers the vessel, persons or cargo
6	MB	Fire
7	M	Open water(3)
8	MB	To enter the vessel in port or else not programmed
9	MB	Explosion
10	MB	Intentional grounding
11	MB	Throw in the water intentionally goods or property

(1) Collision of vessels.
(2) Vessel collision with any object other than another vessel or even against person.
(3) Rupture of the hull below the waterline.

Table 7 - Consequences.

G1	G2	Probability:
1	M	Injuries
2	B	Property damage - vessels involved
3	MB	Death or permanent disability
4	B	Environmental damage
5	B	Property damage - civil works and other

Table 8 - Contributing Factors.

G1	G2	Probability:
1	MA	Human Factor
2	MA	Operating factor
3	MB	Factor materials

Table 9 - Human Error Types.

G1	G2	Probability:
1	A	Slip
2	Z	Transgression
3	B	Mistake
4	MB	Oversight

4.2.2 *Factors the influence performance*

With respect to the influence of organizational factors in performance, the results of expert groups related to workload and training programs were compatible, as shown in Table 10. In this table, based on the criterion adopted, it was assigned to G option to the factor related to the attitudes of supervisors (and others) because it is the option chosen by 36.4% of G2 members. However, considering the balance of the results, it could be assigned a moderating influence (M), considering that the P and M options have been chosen by 36.4% and 27.3% of participants from G2, respectively. For the others items, that alternate between M and P, a more comprehensive analysis will indicate the possibility of adaptation in sorted order and degree of influence assigned.

Internal factors were divided into stress, mental, memory and physical for better organization and to facilitate the analysis.

Regarding the factors related to stress (Table 11), the results from the G2 to the risk factor in the task execution were equal (33.3%) for P, M and G. The criterion used was to take the most important decision in the case of a draw, but would fit the possibility of another, such as M, if the criterion was the average. In the case of the factors characterized as monotonous work and a lack of warnings, also, has been adopted option among the most relevant answers, in view of the occurrence of a draw between P and M. To the relative speed factor of the task, the application of a weighted average of the results indicates that could be applied to a P-grading, rather than M. Since no internal factor stress-related was deemed influential in accident, it is assumed that stress is a parameter of minor significance compared to the others.

Table 10 - Organizational Factors.

G1	G2	Influence on performance:	G1	G2	Influence on performance:
1	G	Load (regime) Working	9	G	Supervisors attitudes, unions, regulatory agencies, etc.
2	G	Training programs	10	P	Coordination of Work
3	M	Quality of life	11	P	Performance Evaluation
4	P	Awards, recognition, benefits	12	M	Time
5	P	Staff turnover	13	P	Organizational culture
6	M	Physical Resources	14	P	Oral or written communication
7	M	Staff selection	15	M	Company's programs
8	P	Formalization	16	P	Organizational learning

Table 11 - Internal factors - stress.

G1	G2	Influence on performance:
1	P	Conflicts about the reasons for obtaining the best result
2	P	Long periods without action
3	P	Duration Stress
4	G	Risks in the Task Execution
5	M	Task speed
6	M	Monotonous work
7	M	Lack Notices
8	P	Treatment of the failure (loss of jobs)
9	P	Distraction

Table 12 - Internal factors - mental.

G1	G2	Influence on performance:
1	M	Personality and Intelligence
2	M	Emotional state
3	G	Identification with the team
4	G	Motivation and Attitude
5	G	Attitudes based on the influence of groups or others
6	M	Speed in the Task Accomplishment
7	P	Task criticality

In the case of mental factors shown in Table 12, also was verified a draw in the responses of the G2 members, for P options, M and G on the factor related to attitudes based on the influence of groups or others, for which it was adopted the gradation G, because it is the most relevant. For the others mental factors, the gradation adopted are consistent with the G2 opinions for each item. Thus, although there is divergence between the classification results for each group, it is assumed that, in general, mental aspects must be considered for moderate-to-high importance.

The comparative results of memory-related factors (Table 13) indicated divergence of opinions between the groups only in the present state of the practice (memory), considering that was classified by the G1 members as the second most important factor, while in the opinion of G2, corresponds to a factor of moderate influence. In overall appearance, the results showed that the memory has a remarkable effect (medium or large) in accidents.

The results relating to physical factors from both groups were converged (Table 14).

Table 13 - Internal factors - memory.

G1	G2	Influence on performance:
1	G	Experience and Training
2	M	Current state of Practice (Memories)
3	G	Ability
4	G	Knowledge of Standards
5	M	Motor control

Table 14 - Internal factors - physical.

G1	G2	Influence on performance:
1	G	Sleep Quality
2	G	Lack of Physical Exercises
3	M	Pain and Discomfort
4	M	Physical condition
5	P	Fatigue

The analyses from the influences of environmental factors are presented in two tables. Table 15 lists the factors considered by both groups, and Table 16, only the factors appreciated by the G2 experts as they have been incorporated with the revaluation of questionnaires.

Table 15 - Environmental factors.

G1	G2	Influence on performance:	G1	G2	Influence on performance:
1	M	Wind	7	-x-	Insufficient oxygen
2	G	Noise	8	P	Waves
3	G	Temperate	9	M	Cleanliness
4	G	Vibration	10	P	Humidity
5	G	Visibility	11	P	Flow
6	P	Storm	12	G	Luminosity

Table 16 - Environmental factors-Group 2

G2	Influence on performance:
G	Confinement
M	Cabins
P	Sanitary units (insufficient or inadequate)
P	Food supply (poor)
N	Leisure (absence)

Based on Table 15, the influence of the wind is indicated by G1 as the most important aspect, different from G2 that signaled a moderate influence on the same. Factors with P response to the G2 possibly pass for an M gradation with the adoption of a weighted average criterion, making consistent the classification given by G1, to the levels 6 to 11. Another factor of great difference of opinion was the influence of light, which was understood by the G2 as relevant (large influence), while the G1 considered other factors as priorities. Oxygen failure was only assessed by the G1. This environmental factor was dismissive of Q2, assuming the absence of ordinary labor activity on board in such a situation. An overview of the results of the influence of environmental factors in both groups indicates that they are relevant, for the most part.

Environmental factors in Table 16 were not part of Q1, applied to G1, and, were inserted in Q2 to incorporate the issues of habitability, comfort, food and leisure. The absence of leisure was named Z (no influence), considering that was the most preferred option, with 33.3%. However, the sum of M and G options corresponds to 50% of the choices, which shows that the majority believes that the absence of leisure has influence on performance. In the case of health and food conditions, who received the P gradation (little effect), it is considered that the perception of experts was based on a minimum necessary conditions, which are supplied by vessels on which perform their professional activities.

As for the influence of abilities in performance (Table 17), the empathy factor characterized as little influence (P) by G2 could pass for the last rating level, changing the criteria used. On the other hand, the opinions of the two groups diverge on the most relevant factors, regardless of the criteria adopted, where it was verified alternation between the adopted grading (M or L) in the classification order. However, the results demonstrate that abilities have a great importance in the performance of activities, or at least considerable.

Table 17 – Abilities

G1	G2	Influence on performance:
1	M	Leadership
2	G	Knowledge procedures
3	M	Team and communication
4	G	Planning
5	M	Calculation
6	G	Concentration
7	G	Creativity
8	G	Interpretation

G1	G2	Influence on performance:
9	G	Flexibility
10	G	Motor control
11	G	Physical Resistance
12	M	Long and short term memory
13	P	Empathy
14	G	Perception
15	M	Frequency and Repeatability

4.2.3 Situational attributes

The results for the situational attributes shown in the following refer to the opinions of the G2 specialists, due to few members of G1 responded, and also, incompletely, such that the data are insufficient to allow reliable analysis, which led to an adaptation of Q1, as mentioned in section 3.3.

The perception of influence (or relationship) of the type of vessel on the cause (CA), type (TA) and consequence (CO) of the accident is presented in Table 18. The results indicate that the convoys, used in the transport of hazardous or non-hazardous goods, have great connection (G) to the cause and the consequence of the accident. The same relationship was observed for the type of accident with hazardous cargo convoys. In the case of non-hazardous cargo convoys, the end result indicated a small ratio (P), but the difference for the second major result (great relationship) was only 8%, which represents the opinion of only one expert.

Table 18 - Relationship between the type of vessel and situational attributes - G2.

Type of vessel	CA	TA	CO
Convoy (non-hazardous goods)	G	P	G
Convoy (hazardous goods)	G	G	G
Sand dredger (convoy)	M	P	P
Sand dredger (self-propelled)	M	P	P

Type of vessel	CA	TA	CO
Ferry-boat	M	M	M
Passenger (and tourism)	P	M	M
Recreational	P	P	M

The identification of situational attributes is presented in Table 19, which were used to detect the influence (or relationship) of them in the cause, type and result of the accident resulting from human error (EH) and propulsion systems (PR), command (GO) and electric (EL). Condensed results are shown in Table 20.

Table 19 - Situational attributes.

N.	Situational Attribute (A)
1a	Period (day)
1b	Period (night)
2a	Status (navigating)
2b	Status (float)
2c	Status (at lock)
3a	Type of goods (hazardous)
3b	Type of goods (non-hazardous)
4a	Section I
4b	Section II
4c	Section III

N.	Situational Attribute (A)
5a	Number of vessels sailing in 10 km (up to 1)
5b	Number of vessels sailing at 10 km (2 to 3)
5c	Number of vessels sailing at 10 km (more than 3)
6a	Number of vessels on the waiting buoy (up to 1)
6b	Number of vessels on the waiting buoy (2 to 3)
6c	Number of vessels on the waiting buoy (more than 3)
7a	Season of the year (spring)
7b	Season of the year (summer)
7c	Season of the year (autumn)
7d	Season of the year (winter)

In Table 20, in the case of the relationship of situational attributes (A) to the causes of the accident (CA), it is clear that at moment it was indicated a major relationship of EH, PR, GO or EL to the attributes: period of the day; navigation or waiting in the buoy; transport of hazardous goods; section; and seasons. For the others it was evident a strong relationship (large or medium) in the navigation situations with greater intensity of traffic and congestion in the waiting buoys, being more evident to the EH. As for the relationship of the attributes identified with the type of accident (TA), the EH happens to be influenced by several attributes, among which, the period, the navigation, type of cargo and section. The results of the influence of the attributes in the consequences (CO) of the accident show that all attributes interfered in a moderate or large way to the EH, and the failures of the PR and GO systems.

Table 20 - Relationship between situational attributes and failures in the cause, type and result of the accident.

A	CA				TA				CO			
N.	EH	PR	GO	EL	EH	PR	GO	EL	EH	PR	GO	EL
1a	P	P	M	P	P	M	P	P	P	M	M	M
1b	M	M	M	M	G	G	M	M	G	M	M	M
2a	M	M	P	P	G	M	M	P	G	M	M	M
2b	P	M	M	M	M	M	M	M	P	M	M	M
2c	M	M	G	G	G	M	M	M	G	M	M	M
3a	P	M	M	P	G	M	G	M	G	M	M	M
3b	N	G	G	G	G	M	M	M	M	M	M	M
4a	P	P	M	M	M	M	M	M	G	M	M	M
4b	M	M	M	M	G	M	M	P	G	M	M	P
4c	M	P	P	M	M	M	M	M	M	M	M	M
5a	P	P	P	P	P	M	M	M	P	M	M	M
5b	M	M	M	M	M	M	M	M	M	M	M	P
5c	G	M	M	M	M	M	M	M	M	M	M	P
6a	G	G	G	M	M	M	M	P	M	M	M	P
6b	G	G	G	G	G	G	G	P	M	M	M	P
6c	G	G	G	G	G	G	G	G	G	G	G	G
7a	P	P	P	M	P	M	M	M	P	M	M	M
7b	P	P	P	M	P	M	M	M	M	M	M	M
7c	P	P	P	P	P	M	M	M	M	M	M	M
7d	P	M	M	M	M	M	M	M	G	M	M	M

5. CONCLUSION

From the analysis of historical data, collected from the accident and facts of navigation processes, concluded by the Maritime Court, from 2003 to 2012, it can be concluded that the number of accidents in the Tietê-Paraná Waterway is small, despite having a considerable growth in 2005, with an average of 16.5 accidents per year, but with a significant proportion of fatalities (45.7%). As data of interest for continued research, it was possible to prove the significant involvement by convoys (23.8%) in collision-type accidents (33.5%) in the Tiete River (42.7%), arising from fault (54, 3%), with considerable climatic influence (28.7%) and major contribution of the human factor (52.4%). Moreover, the results of the annual and monthly occurrence of accidents, as well as the observation of a higher incidence of accidents during the evening period, can feed future studies to better understanding of the variables involved.

The results of the experts in the drive convoys in the TPW demonstrated that stranding and collision are accidents most likely to occur, with the human error, the most important factor for their causes, and the injuries, the probable consequences, with considerable influence of the human factor and organizational factors, internal and environmental, and abilities. The analysis of the situational attributes was important because it could clarify which variables favor the occurrence of system failures or human error that interfere or have a relationship with the cause, type and consequence of the accident. In future work, we intend to re-evaluate the way in which the results of the questionnaires will be considered in order to circumvent the differences described in the results.

Finally, as mentioned in the objectives, the refined data obtained from the results of this work will be used to support the development of a model in the Bayesian networks, as well as feed a Table of Conditional Probabilities (TPC), required for measuring results the same network, which will be used to analyze the influence of the human factor in the risk of convoys accidents in TPW.

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