Conference Paper, Published Version

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Design Guidelines for Inland Waterways (PIANC-INCOM WG 141)

Paper 201 – Design Guidelines for Inland Waterways (PIANC-INCOM WG 141)

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ABSTRACT: The WG was founded in 2010 to analyse existing recommendations and collect data on best practice examples of existing waterway dimensions such as fairway width in canals and rivers, bridge openings, diameters of turning basins, the length and width of lock approaches, etc. for defining adequate inland waterway dimensions. Since simulation software for analysing ship behaviour is available and increasingly used for design purposes, the guidelines should provide planners not only with adequate values for these dimensions, e.g. for preliminary design purposes, but should also include process recommendations concerning the appropriate use especially of ship handling simulators. In the present paper the approach WG 141 will be presented. The paper starts with the common "Concept Design Method", based on experience, existing guidelines and additional information from research, e.g. for wind or curve increments. These are used, for instance, to define minimum fairway widths and depths in straight canals. In special design cases, like rivers with high flow velocities, the "Best Practice Approach" can be chosen which provides information and comments on existing waterway dimensions, thus helping users to choose the appropriate data for the case to be considered. Where experience is not available, a "Case by Case Design", using simulation software as in ship handling simulators, is recommended. In all design cases it is necessary to find an appropriate safety and ease of navigation standard. This standard depends on the ship type, ship speed and traffic density and special boundary conditions to be considered. WG 141 has proposed an approach to account for this essential aspect in inland waterway design. The paper shows selected results of the findings of WG 141 and the SMART Rivers workshop on "Inland Waterway Design".

1 INTRODUCTION

One of the motives for founding PIANC-INCOM WG 141 "Design Guidelines for Inland Waterways" was the lack of internationally accepted guidelines for inland waterway dimensions, in contrast to regulations for sea-going ships. So, there is a need for adequate new guidelines, especially on minimum horizontal dimensions of fairways, lock approaches or bridge openings, to support several new waterway improvement projects, e.g., in Europe, the construction of Seine-Nord Canal in France and Belgium and the improvement of several existing canals or dammed rivers in Germany, as well as the improvement of the Yangtze River in China.

Another reason to update existing knowledge of waterway design corresponds to the change in fleet, especially with an increasing part of longer, wider, deeper going and stronger powered vessels and because of this the dimensions of the design vessels. These new vessels are generally the reason why wider lock chambers, lock approaches and fairways are needed.

On the contrary, these new vessels are generally better equipped than traditional vessels, e.g. with two thrusters instead of one, with twin rudders instead of single ones or with bow thrusters and passive bow rudders in some cases. This development, combined with a general reduction of the number of ships sailing on our waterways, provides an opportunity to restrict the lateral dimensions of the navigation channels despite the larger widths of the vessels.

New and better information services are available on the basis e.g. of GPS, ECDIS and AIS. Additionally, ongoing improvements in updating bathymetry data, better forecasts of hydrological conditions and the numerical modelling of our rivers provide more detailed information about local velocities. This can lead to more and more vessels, steered by an autopilot in the future, helping to exploit existing or restricted waterways as much as possible.

In contrast to sea-going ships, the traffic with inland vessels is generally less dangerous, e.g. collisions with bank protections are more or less a normal situation when travelling in inland canals. One reason is that sea-going ships are less powered and worse steerable related to their dead weight and drive with comparatively high ship speeds, forcing the need of high safety standards. Thus, design standards for sea-going ships as those of PIANC MARCOM WG 49, are generally not applicable for inland waterways and are probably very much on the safe side.

Constraints for using our waterways due to environmental aspects, especially the Water Framework Directive in Europe, or climate change effects on free-flowing rivers might force planners and operators of waterways to narrow fairways or to increase their distance to ecologically sensitive areas. These constraints generally affect the safety of inland shipping.

In Belgium, to give a first example concerning these boundary conditions, several dammed-up rivers and existing canals shall be upgraded from CEMT (European Classification System of Waterways) Class II to IV or from IV to VI. Smaller vessels and especially older vessels have no bow thrusters. Nevertheless, they shall be able to sail even in very narrow sections where the Dutch Standards for Waterway Design are not applicable. Hence, there is a need for smaller standards for these special situations. Especially in one-way-traffic situations restrictions concerning the ease of navigation can be accepted.

Developing countries such as Egypt or Vietnam, to give a second example, face huge problems maintaining fairways, especially in case of a highly mobile river bed as in the Nile River. This situation may become worse if climate change continues. The required fairway dimensions therefore play an important role in balancing the safety of shipping and the economics of dredging fairways.

One of the challenges of the next decades, to provide a third example, is the improvement of the Middle Yangtze River in China. The most important problems are related to damages during high water stages and sediment transport processes, because the navigational channel is always changing. This fact is important especially for sea-going ships because of their large draughts. Additionally, bank erosion due to ship waves is an issue. Appropriate minimum fairway dimensions are important therefore, even in very large rivers as the Yangtze, e.g. to maximise fairway depth and the distance from fairway to riverbank. Furthermore, safety distances, e. g. to groynes, are of interest and should be a part of the new WG 141 guidelines.

All these aspects mean that there is the need to set standards for appropriate minimum waterway dimensions. These standards should be internationally accepted in order to avoid needless discussions e.g. with opponents to waterway improvements.

This is the main task of PIANC-INCOM WG 141. It started in 2010, has had 7 regular and 3 intermediate meetings up to now and is planning to finish the guidelines in 2014. The present paper provides some information about the progress of its work and the main decisions made. It also contains some information about the chosen three-step design: "Concept Design", "Best Practice" and "Case by Case Design", about how to choose adequate safety and ease of navigation standards ("s&e-standards") and define what are the boundary conditions under which ship handling simulators will be used.

2 WORKING GROUP PROGRESS

The kick-off meeting took place during the PIANC Congress in Liverpool in 2010 (see also Table 1, where some important information about the working group's progress is collected). The discussion about the terms of reference issued by INCOM in Liverpool and the next meeting in Karlsruhe, showed that the group probably cannot fulfil all of the requirements. We decided e.g. to restrict our work to freight vessels and technical aspects and to neglect recreational boating and environmental aspects in a first step.

The detailed review of existing guidelines concerning these topics which followed during the next two meetings in Brussels and Paris, showed some huge differences, e.g. concerning appropriate minimum waterway dimensions or length of lock approaches, between the lower limits set in German or French guidelines or between the upper limits of Russian or Chinese guidelines, for instance. Besides the guidelines, existing dimensions e.g. of fairway widths in rivers are totally different from country to country or river to river.

Thus, the group had to face these special boundary conditions, e.g. narrow canals, low ship speed, very well equipped vessels and optimally trained helmsmen delivering arguments to accept a reduced standard in some cases. On the other hand, large sea-going vessels, sailing with high speed on the large rivers of China, causing a substantially higher risk level, will force planners and operators of these waterways to demand for higher levels of s&e.

The group decided to explain the huge differences in its design recommendations and to collect arguments for choosing an appropriate design standard from case to case. This may help to align the different guidelines. The group began to identify appropriate minimum dimensions of canals during the next two meetings in Brussels and Bonn. The widths, depths in straight reaches and corresponding vertical and horizontal clearances of bridges, diameters of turning basins or the lengths and of berthing places were derived from existing guidelines and best practice examples.

The group members found out that it is possible to recommend specific numbers, e.g. the appropriate width in terms of ship's beam, corresponding to ease of navigation levels which are mostly dependent on traffic density or the consideration of extra effects as wind in inland or coastal areas. The working group called these recommendations "Concept Design Method", which may be used in standard cases with defined boundary conditions.

Only a few guidelines, e.g. from Russia or China, provide detailed information about appropriate waterway dimensions for rivers, e.g. the minimum width of lock approaches in rivers with significant flow velocities. Seeing that every river can be unique regarding its nautical boundary conditions, general recommendations may fail in special conditions. The group decided to recommend a detailed design in these cases during the meeting in Madrid.

This method is acceptable as the costs of a detailed nautical study are only a little fraction of the construction costs – and the study can reduce the latter significantly. The group therefore discussed the possibilities and restrictions of modern simulation software, especially ship handling simulators for these purposes – and what should be the necessary inputs and results of simulations.

Appropriate safety and ease of navigation standards are hard to define, and since safety and ease will change waterway dimensions significantly, the group decided to recommend, besides the "Concept Design" and "Case by Case Design", an approach based on best practice examples. Here the group collected and discussed numerous data during the meetings in Utrecht and Antwerp, e.g. existing fairway or lock approach dimensions, to define the corresponding boundary conditions and to give comments about practice experience. Thus, the user, taking the "Best Practice Approach", is able to compare his special boundary conditions with the existing examples and will be supported to find out appropriate dimensions for his special design cases. If there is a wide spread in existing data, he will find arguments to perform a detailed design study instead or additionally.

No.	Date, Location	Main topic	Main results
1	Liverpool	Subject and TOR, general approach	Start review existing guidelines
2	Karls-ruhe	Table of contents	Commercial vessels only
3	Brussels	Collection exis-ting guidelines	Definition design vessels
4	Paris	Review existing guidelines	Need to consider safety & ease
I1	Brussels	Workshop planning	Best practice in rivers instead of using guidelines
5	Bonn	Fairways in canals, rivers, bridge , turning basins	Dimensions for concept design method in terms of ship beam
I2	Madrid	Application of ship handling simulators	Need for case by case design, especially for locks
6	Utrecht	Fairway rivers, Turning Basins, berthing places	3-step design, best practice fairway rivers
7	Antwerp	Discussion on s&e, lock approaches	Lock approach dimensions, turning basins
I3	Maas-tricht	Workshop Smart Rivers	1st draft of the report

Table 1: Overview of meetings of WG 141 with main topics and decisions ("I"=interim)

Presently, and as shown during the workshop at the PIANC-SMART Rivers Conference in Maastricht, the group has begun to write the corresponding chapters. Nevertheless, the discussion especially on appropriate safety and ease of navigation standards is not finished yet, and also some numbers for the concept design are still under discussion. So, the following detailed information reflects the present status of discussion only.

3 SAFETY AND EASE OF NAVIGATION STANDARDS

As stated earlier, there are significant differences in recommended dimensions of waterways. This may be caused by the fact that every waterway system with its specific features, especially water depth and widths, flow velocities, average transport distance, economic conditions of inland waterway transport, cargo type and the tradition of shipping, has its unique fleet from which the accepted minimum dimensions of waterway infrastructure are derived. In addition, there are several objective criteria why waterways should be built to wider dimensions, e.g. if there is a great potential risk of loss of human life in case of damages. Otherwise standards can be reduced, e.g. if the usable or possible ship speed is poor as in narrow canals. Hence, scaling criteria for waterway dimensions depend on a large number of interacting parameters.

Some parameters are listed in Table 2. Those criteria (C^+), in favour of a higher standard, are collected in the second column of Table 2. The right column shows arguments for deciding that lower s&e-levels may be acceptable (criteria C^-). Obviously the appropriate standard should be higher where many C^+ criteria are fulfilled or if only a few appropriate C^- arguments can be found. A lower standard may be acceptable if many of the criteria in column 3 are met or if only a few of the criteria listed in column 2 are relevant.

The group agrees that two safety and ease of navigation levels as can be found in many guidelines are not sufficient. It intends to define three levels (according to Table 3). The group's discussion on a scoring system to select the appropriate s&e- levels based on the number of arguments is not finished.

The characterization of standards in Table 3 does not include generous standards as can be found e.g. in the Lower Rhine River for the majority of existing vessels. The WG 141 decided to define minimum standards only which apply to the largest permitted vessels under worst case conditions as high water. No standard below level C will be specified. These standards concern manoeuvring conditions such as entering a lock and therefore do not come into the scope of WG 141 guidelines.

criterion		a higher level should be chosen in case of (criteria C^+):	a lower level may be adequate in case of (criteria C^-):
1	ship load and acceptable speed	normal up to high ship speed is necessary, e.g. for safety reasons, deep draught vessels, dangerous goods	low ship speed is acceptable and not safety-relevant, empty or ballasted vessel, no dangerous goods
2	level of training, personnel skills and experience	poorly trained pilots, low knowledge of waterway features and infrastructure	optimally qualified and experienced helmsman
3	attention level, distraction and stress of the helmsman	long-time or boring journey, permanent manoeuvring conditions	short manoeuvre situation, e.g. during a meeting or by passing a bridge opening
4	danger level, possible damages	Buildings, quay walls, floating facilities, vessel berths in the vicinity of the navigational area, danger to life and limb	sloped banks, guiding walls, parallel dykes or short groynes besides the fairway
5	uncertainty of waterway conditions	turbulence, secondary currents, irregular banks, long groynes, rocky or stony river bed, wind, fog	regular shoreline, sloped sand or gravel banks, low wind speed or wind protections
6	traffic situation, ship-ship and ship-bank interaction	one-way traffic, many manoeuvres as overtaking	2 or more navigational lines, accepted interaction forces
7	vessel equipment and instrument-ation	main rudders only or weakly powered bow thrusters, sea-going ships, low engine power, no information systems	strongly powered bow thruster or passive bow rudder, high engine power, dual propellers, optimal information systems

Table 2: Design criteria to define adequate safety and ease of navigation standards

Since ship speed is one of the most important factors to ensure safety, the ranking in Table 4 may help to quantify possible restrictions to ship speed according to the chosen or existing s&e-standards. The table is based on measurements of speed in nearly unrestricted channels such as large rivers, speed limits in canals according to existing guidelines and local regulations, e.g. for very small and shallow canals and the Canal Grande in Venice (5 and 7 km/h), and typical speeds of ships approaching locks. The table may also be used as a second approach to define adequate ease of navigation levels.

ease level	designation	example from existing waterways
A	nearly unrestricted drive	Lower and Middle Rhine River for all permitted vessels
B	moderate to strongly restricted drive	largest permitted push tow units on the Mississippi River, Upper Rhine River, Neckar River, Dutch canals, normal profile, passing narrow bridges under good visibility conditions
C	strongly restricted drive on short distances	German canals or narrow profile of Dutch canals, narrow bridges under bad visibility conditions or strong currents, sailing at lock approaches

Table 3: Designation of ease of navigation standards with examples (still under discussion in WG 141)

Another essential criterion to be considered when choosing adequate standards is traffic density (see Table 5). This third criterion should be used to define appropriate standards, together with the scoring system based on Table 2 and the speed criterion applied in Table 4.

The thresholds to distinguish the different standards in Table 5 are mostly derived from Dutch standards, stating that e.g. the so-called "narrow profile" (ease of navigation level C) is adequate for traffic below 5000 craft per year.

design-nation of ship speed	approx. ship speed over ground	objective:	ease of naviga tion levels
no res-trictions	> 14 km/h	avoiding severe damage and danger to life and limb in case of accidents	A
adapted speed	ca. 9 – 10 km/h	reduced interaction forces in case of meetings	A, B
small canal speed	ca. 7 km/h	reduced wave heights, e.g. to avoid conflicts with pleasure boats	B
reduced speed	ca. 5 km/h	reduced bank forces	B, C
strongly reduced speed	ca. 3 km/h	no significant interaction forces	C
creep speed	< 2 km/h	no significant damage in case of accidents	C

Table 4: Assignment of ship speed to standards (still under discussion in WG 141)

vessels per year, commercial navigation	selection of waterway profile	possible selection of ease of navigation levels
> 30,000	further studies required (e.g. extra lanes to accommodate such high traffic)	A
15,000 – 30,000	normal profile for two-lane traffic	B
5,000 – 15,000	normal profile, narrow profile for short sections	B, C
< 5,000	narrow profile for two-lane traffic, single-lane profile in exceptional cases	C

Table 5: Assignment of traffic density to standards

4 THREE RECOMMENDED DESIGN METHODS

4.1 *General approach*

After an adequate s&e- standard is chosen, the first step in waterway design is to look at existing guidelines. If guidelines are available, e.g. on a national basis, the choice is specified. Nevertheless – and this is the main reason for setting up additional PIANC guidelines on an international basis –, some countries don't have their own regulations or the national recommendations do not give advice for all design cases to be considered, e.g. for inland vessels in case of the Canadian guidelines (sea-going vessels using inland waterways only) or free-flowing rivers in case of the Russian guidelines (generally dammed rivers considered only).We can find this in many regulations. Using the example of fairway design in canals and rivers, Table 6 gives an overview of design recommendations regarding the appropriate fairway width for selected international guidelines. Table 6 shows that there are only a few specifications available concerning appropriate fairway increments to account for cross-flow velocities, extra width in curves or wind effects in rivers with significant flow velocities.

country	canals and still waters				rivers with significant flow velocities				
	min. width incl. in-stabilities and safety distances to banks	extra width in curves	cross-flow increment	wind increments	min. width incl. in-stabilities and safety distances to banks	extra width in curves	cross-flow increment	wind increments	safety distances for groynes
China	x	x	x	x	x	x			
Nether-lands	x	x	x	x					
Russia	x	x	x	x	x	x	x	x	
Canada	x	x	x	x					
France	x	x			x	x			
Germany	x	x	x						

Table 6: Available design recommendations (x) in selected guidelines concerning different aspects of appropriate fairway width in canals and rivers

Besides, recommendations are generally only applicable to a small number of boundary conditions. This is the case in canals. But this is mostly not the case in rivers and in particular not in free-flowing alluvial rivers with their typical variety of depths, flow velocities and irregular shorelines. In these cases, the concept design method fails. So, existing guidelines, even if they may treat all the relevant design aspects, have to be used carefully to find appropriate waterway dimensions and to avoid overdesigning or designing below the standard.

Nevertheless, the following approach named "Concept Design Method" which uses existing guidelines or formulae given in relevant publications, e.g. for fairway increments, will be recommended by WG 141 generally, even if it is only a first step in the design process. This approach gives an idea of appropriate dimensions, their variety and thus their range of uncertainty, when values recommended by different guidelines are compared.

4.2 *Concept Design Method*

This design method can be demonstrated using the example of appropriate fairway width in canals for two-way traffic. What we found first is that all the values specified in existing guidelines are multiples of a ship's beam B, measured in the depth of a ship's draught. The design of approach channels for sea-going ships (PIANC 1997) uses the same principle, but accounts for some extra allowances for high draught (T) to water depth (h) ratios.

The beam B and draught T define the displacement of the ship and thus the ship-induced longitudinal currents, especially the return current, leading to the well-known water level drawdown and its effect on crosswise pressure forces on the ship's hull, and crosswise currents, especially on bow and stern, displacing the two ships sideways. Hence, the ship's breadth defines, together with ship speed, the ship-induced currents and corresponding forces, and consequently the appropriate extra width for navigation, e.g. the drift angle to counteract these forces.

As the water level depression and thus the forces are mostly scaled by the relation of ship speed v_S to critical speed v_{crit} and the water depth, the recommended multiples of B should be larger in case of higher allowed v_S/v_{crit} or smaller h, as is the case in Dutch guidelines compared to e.g. German guidelines. This explains in combination with the accepted safety and ease of navigation standard, the different design values in existing guidelines. WG 141 recommended from this minimum design width for deep draught vessels in straight river reaches of 3 B up to 4 B, which may be allocated to s&e- levels C and B. Level A will be not considered, because meetings of ships in canals are more or less a manoeuvring situation where a temporarily reduced ease of navigation standard may be acceptable, just as a high attention level of the helmsman.

The T/h-ratio is not considered in these values as in the case of sea-going ships. The reason is that inland vessels are generally more powered compared to the ship's displacement than sea-going ships. Inland vessels have more efficient rudders too, so that they are generally better able than sea-going ships to counteract bank and ship-ship-interaction forces even in case of low keel clearances.

Nevertheless, there may be other influences on adequate fairway dimensions which are not scaled by B, e.g. the “human factor”. But it can be assumed that their influence is small compared to the basic physical influences discussed above. But research on this subject is still ongoing.

In contrast to the small influence of T/h on the necessary width in straight reaches, T/h has a strong effect on the necessary widening of the canal Δb_K in curves. Taking the Dutch guidelines as an example (Rijkswaterstaat, 2011), the relative position of the tactical turning point c_F (distance from stern to bow, divided by ship’s length L), which corresponds to the coefficient c_K in the design formula for one ship $\Delta b_K = c_K L^2/R$ by $c_K = c_F^2/2$, is between 0.63 and 0.89, concerning a fully loaded and an empty CEMT class Vb vessel respectively, and 0.71 up to 1.0 for a loaded or empty vessel of classes I – Va. These values are equivalent to c_K = 0.2 – 0.4 for class Vb and 0.25 – 0.5 for classes I up to Va. So the recommended extra width doubles in case of an empty vessel compared to a fully loaded one. Comparable values of c_F between 0.9 for class Vb and 1.0 for class Va can be found in German guidelines (BMVBS, 2011), concerning the worst design case of empty vessels.

The main reason for reducing extra width in curves by increasing T/h is that the forces on the underwater body of the vessel due to drifting increase more with increasing T/h – because the water has to pass through the narrowing gap between the ship’s bottom and the canal bed –, than the centrifugal forces by increasing the ship’s mass at larger T/h. This may be somewhat confusing, because the radius of a turning circle increases generally from deep to shallow water (increasing T/h). But in case of the last-mentioned manoeuvre, the rudder angle is fixed. By contrast to the first-mentioned manoeuvre where the helmsman tries to follow a predefined track with constant R, the rudder angle will be adjusted as desired, leading to very much larger rudder angles in case of high T/h. Both effects are therefore correct: a smaller swept area width for larger T/h in case of a steady drive with a constant radius, and a larger turning circle in case of larger T/h by taking a constant rudder angle.

It should be mentioned additionally that measurements of swept area width show that even in canals with their generally small flow velocities v_{flow} (≤ 0.5 m/s according to Dutch and German guidelines), they can have a significant influence on c_F in case of small T/h and v_S (VBW, 2013). Hence, the appropriate ship speeds are a safety factor not only in rivers, e.g. to counteract cross flows like secondary currents in bends or to maintain sufficient rudder forces in case of unforeseen necessary manoeuvres, but also in canals. This has to be considered when choosing the design ship speed and corresponding safety and ease of navigation levels.

4.3 *Best Practice Approach*

As indicated in Table 6 only little design information is available regarding fairways in rivers. This holds also, and especially, true for lock approaches. If, for instance, a new lock is to be designed or an existing lock approach has to be adapted e.g. to larger vessels (as in parts of the German Neckar river, which will be upgraded from 105 m long vessels to accommodate vessels of up to 135 m length in future), existing guidelines provide only limited information on how e.g. the length (from mole tip to lock entrance) and the entrance width of the upper and lower harbors have to be enlarged to accommodate longer design ship with significant flow velocities. These enlargements are generally indicated, especially because of the wider swept area width of longer ships in the strong cross currents in front of harbours and the need of an adapted length with reduced flow velocities inside harbours. But these information gaps can be closed by looking at best practice examples of lock approaches in rivers. The task is to find out existing examples that are comparable to the unique design situation considered. WG 141 will provide users with appropriate data.

The problem is that conditions can differ considerably from case to case, especially concerning existing harbour lengths. Examples are the German rivers like the Main and the Neckar. Constructed harbour lengths are between 0.7 – 2.0·L (L = length of the design vessel) on the Neckar River, with an average of 1.5·L. The latter value is even shorter than the recommended minimum harbour length specified in German standards for lock approaches in *canals* – not in rivers with their higher flow velocities – of about 2·L (due to the requirement of two berthing ships behind each other).

The upper harbours on the Main River are generally longer, from 1.4 up to 4.2·L, with an average length of about 2.5·L. There hardly seem to be any compelling reasons why one specific lock harbour is so much longer than another one. But one of the main findings from this extremely wide spread of existing dimensions is that planners of lock approaches probably tried to make the harbour length as long as feasible, in order to optimize the s&e-standard – and accepted a lower standard if there was obviously no realistic chance to realize larger dimensions.

Another important finding is that even in cases of very short harbour lengths safe navigation seems still possible, but clearly the ease of navigation is reduced. Maybe this is a special characteristic of German rivers with their specific fleet, especially because of the very restrictive licensing of the vessels. For example, efficient active bow thrusters are specified for the largest vessels. This underlines the need for adequate safety and ease of navigation standards and the assignment of ease of navigation levels to best practice examples, especially in cases where the wording *best* in "best practice" may not be appropriate for all the examples.

4.4 *Case by Case Design*

The examples of existing harbour lengths demonstrate impressively the partly large range of uncertainty regarding appropriate waterway dimensions. Hence, when the spread of data from different guidelines or best practice examples seems too large, instead of specifying any additional values provided by WG 141, e.g. averages of multiples of L and B for harbour lengths and widths, appropriate process recommendations should be provided. These will help to support a detailed study for the design case under consideration, especially if the local boundary conditions are different from existing knowledge. The criteria for cases where a detailed study (left column) or ship simulation software (right column) seems to be adequate for performing the Case by Case Design are listed in Table 7.

Such process recommendations shall include:

- Examining whether a detailed design study or the use of simulation techniques are necessary (see Table 7),
- Choosing the investigation method (bridge simulator, where a human being steers the ship; fast-time simulation, using autopilots to steer the vessels; traffic simulations, taking simplified driving dynamics or scale model tests),
- Choosing, collecting and appropriately processing the required minimum bathymetric, flow, construction and calibration data, especially for the design vessels,
- Calibration of the flow models and the parameters of the design vessels, taking field data or/and scale model tests and comparing them with simulation results, if possible having similar conditions as the design case,
- Validation of the models by performing runs to compare them with measurements that are not used for calibration,
- Conducting simulations, especially with respect to human factor effects, which may require many simulation runs for one variant,
- Choosing and conducting adequate sensitivity analyses concerning critical design parameters,
- The proper statistical elaboration and interpretation of results, especially concerning human factor effects and
- The assessment of application limits and unavoidable uncertainties of used simulation technique.

need for performing a detailed study for design	**ship simulation techniques needed**
design problem is not within scope of existing guidelines or experience	vessel has special properties, e.g. type, propulsion, steering
difficult layout like sharp or sequential turns, narrow width, variable depths, junctions, lock approaches, bridges, turning areas, berths	large discrepancy between space available and navigation needs
environment plays an important role, e.g. intense or variable longitudinal or cross currents, visibility, turbulence, water level variations	significant construction cost savings seems possible through optimization of engineering works and designs
to define operational limits or to accept higher operational limits	when evaluating risk-based design and traffic management
doubts about using a lower standard	training of captains to fulfil standards
human factor effects have great impact on design	demonstrating the results and nautical aspects of design
accounting for high traffic density	considering special traffic or operations
to plan and check aids to navigation	to gain acceptance for navigational needs

Table 7: Criteria speaking for a detailed study (left column) and the use of ship simulation techniques (right column) in the design process

The last-mentioned process recommendation seems to be the most critical one. It is a fact that users of ship handling simulators tend to overrate the applicability of simulators just as clients of the navigational study tend to mix up real life and virtual reality in the simulator. Consequently the application limits of standard ship handling simulators must be considered (see Table 8). Generally speaking, the limits are presently reached in the case of ship-induced currents and when the water level drawdown interferes significantly with the water body and with other ships. Future developments which are under way at several developers of ship handling simulators may be able to overcome these application limits by simulating ship-induced currents and waves simultaneously with the ship motion.

Strong interaction forces (ship-bank and ship-ship) as in narrow canals.
Strong shallow water and canal effects, especially during overhauling
Strong bed roughness effects, e.g. on bow thruster performance or thrust
Irregular banks and long groynes
Strong water level longitudinal or crosswise slope
Drive inside lock chambers
Special problems, e.g. stones being sucked into propellers or ship-induced sediment transport processes like clouding, which are to be avoided in design case

Table 8: Present application limits of usual ship handling simulators

The application limits listed in Table 8 not mean that simulators totally fail in these cases, but simulation results should be interpreted carefully and used in a more or less comparative sense, as it is normal e.g. for hydraulic modelling. The reason is that even the best models will never be able to fit reality or nature completely, but model errors eliminate partly, if the *difference*, e.g. of the calculated swept area widths of two variants, is the aim of the study. The need of "comparative thinking" in using ship handling simulators is one reason why MARCOM WG 49 ("Vertical and Horizontal Dimensions of Fairways" concerning sea-going vessels) and INCOM WG 141 will provide process recommendations for the optimal use of ship simulation software for waterway design purposes.

5 CONCLUSIONS

The PIANC INCOM WG 141 on "Design Guidelines for Inland Waterways" has now been working on its tasks for 3 years. The corresponding workshop on the occasion of the SMART Rivers Conference leads to revisions or first drafts of several essential chapters of our future report, like those to existing guidelines, the three approaches in waterway design presented in this paper, and the safety and ease of navigation considerations. We are therefore optimistic that a first editorial meeting will take place soon.

Nevertheless, some topics are still under discussion, especially concerning the choice of adequate safety and ease of navigation standards, the reference of these standards to best practice examples or the application limits of ship handling simulators. Having said this, it is clear that simulators, even if they definitively are not reality, are an excellent tool to consider nautical aspects in waterway design, if they are used properly. WG 141 will provide some process recommendations to support this point.

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