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Application of Innovative Methods in Waterways Engineering

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ABSTRACT: The requirements regarding the navigational dynamic consultancy and support services pro-vided by the Federal Waterways Engineering and Research Institute (BAW) to the offices of the Federal Waterways and Shipping Administration (WSV) are steadily increasing both qualitatively and quantitatively. Against this background, the BAW took the decision some time ago to develop numerical models that are capable of describing the complex navigational dynamic processes. Models to improve conditions for shipping on the River Oder are discussed here as an example to demonstrate how hydraulic-morphological and navigational dynamic studies can be respectively integrated into physical and numerical models. The ship handling simulator purchased recently will enable the BAW to further deepen its navigational dynamic expertise.

Keywords: Navigability analyses, Hydraulic navigational dynamic model, Ship handling simulation, Fairway stabilization

1 INTRODUCTION

Inland navigation makes an important contribution to long-distance goods transport in Germany. In 2004, goods with a total tonnage of 235.9 million t were transported on the country's inland waterways. Solid bulk products (e.g. coal, stone and earth, ores and scrap metal) are the most popular cargo classification. Two thirds of all goods transported on Germany's rivers and canals come under this category, followed by liquid bulk cargo (e.g. petroleum products) and solid piece goods (e.g. iron and steel products). Only 6% of the total cargo load is comprised of containers, though this segment has experienced high growth rates in the last few years. The inland waterways are also excellently suited for special transports involving particularly heavy or bulky goods (BMVBS, 2009).

Long-distance goods transport in Germany is dominated by road haulage. In 2004, heavy goods traffic accounted for 72.2% of all long-distance transports as compared to 16.0% for rail and 11.7% for inland waterways.

According to forecasts, the volume of long-distance goods traffic in Germany is expected to rise sharply in future. Between 2004 and 2025, the overall traffic volume is predicted to increase by 48% to around three billion tons. Long-distance road transport will grow fastest at 55%, while the growth rate for rail and inland waterways will be 34% and 20% respectively. Freight services (product of freight transport volume and transport distance) will expand by as much as 74% to approximately 900 billion tkm during the same period, because not only the volume of traffic (+48%) but also the mean transport distance (+18%) will be significantly higher (Intraplan/BVU, 2007). The anticipated growth in goods traffic represents an enormous challenge for Germany's transport infrastructure and traffic planning.

With 7300 km of inland waterways and more private and public inland ports than any other country in Europe, Germany still has plenty of reserve capacity when it comes to inland navigation – and this capacity should be used more intensively in future. Its inland navigation is capable of handling the majority of dangerous goods transports absolutely safely as well as coping with an increasing share of intermodal transports, which can strengthen its position in the bulk transport segment and help win new custom in conventional markets. The focus must be gradually shifted towards the hinterland connections of the traditional sea ports via the inland waterways network. In particular, more container transports on inland vessels will noticeably ease the burden on road and rail as the two dominant modes of transport (BMVBS, 2009).

When all this is taken into account, the immense importance of the waterways – and the need to maintain the associated infrastructure while continuing to develop it to meet demand – is beyond dispute. The Federal Waterways and Shipping Administration, the public authority responsible for Germany's waterways, currently oversees some 290 weirs, 350 navigation locks, 500 culverts, 1600 bridges, 15 canal bridges, 8 barrages, 4 ship lifts and numerous other structures designed to support inland navigation. River control structures such as bank rip-rap and groynes are likewise an important part of the waterways infrastructure. This complex system needs to be kept in the best possible state of repair and modernised where appropriate, because a safe and efficient transport infrastructure is a crucial prerequisite for the desired deflection of trade to waterways.

The principal challenges confronting waterways engineers today – and specifically with regard to infrastructure construction, operation and maintenance – are as follows:

- Trend towards larger vessels in the shipbuilding sector (individual vessels, push-tow units),
- Optimisation of river training and sediment management,
- Unfavourable age pyramid of the waterways infrastructure with a high percentage of older structures,
- Need to take account of ecological requirements, e.g. as described in the European Framework Directive on Water, and
- Development of adaptation strategies to minimise the expected impact of climate change on shipping.

In its function as a provider of expert opinions and consulting services, the Federal Waterways Engineering and Research Institute (BAW) supports the German Federal Waterways and Shipping Administration (WSV) and the Federal Ministry of Transport, Building and Urban Development (BMVBS) in the waterways engineering field in connection with the construction, operation and maintenance of waterways. These responsibilities are the source of recurrent technical questions to which the current state of technology is unable to offer satisfactory solutions and on which research and development work therefore needs to be undertaken. The BAW's core tasks include conducting research and development projects designed to extend and continually improve the quality of the consulting services it provides as well as furnishing WSV offices and the BMVBS with modern, reliable and cost-effective methods and tools. The BAW's research and development activities cover the entire spectrum of waterways engineering, with its classical disciplines of structural engineering, geotechnical engineering and hydraulic engineering in inland and coastal areas.

Research and development are what drive innovative waterways engineering solutions. Taking the example of navigational dynamic studies of inland waterways, a small selection of the BAW's diverse innovations is described in the following. Navigational dynamic consultancy and support services are much more important than they were few years ago owing to the trend towards ever larger vessels and the increased traffic density on German waterways. At the same time, the safety and ease of navigation have to be ensured continually.

2 NAVIGATIONAL DYNAMIC STUDIES

The main focus of the BAW's consultancy and support services is on so-called navigability analyses, of which the following are just a few current examples:

- Navigability analysis of the River Neckar for very long (135 m), large motor vessels (the current maximum limit for navigation on the River Neckar by large motor vessels is 105 m),
- Navigational dynamic bottleneck analysis for the free-flowing stretch of the River Rhine between Iffezheim and Lobith on the border between Germany and the Netherlands,
- Determination of the maximum dimensions of push-tow units in the free flowing part of the Upper Rhine River, a navigationally demanding stretch,
- Navigational dynamic studies linked to the approval of push-tow units consisting of six barges on the Lower Rhine River up to high water mark 1, and
- Navigational dynamic studies to assess the option of widening the navigability window in the framework of KLIWAS, the research programme concerned with the impacts of climate change on waterways and navigation. (KLIWAS was initiated by the BMVBS in 2009, and the BAW is currently investigating waterways engineering aspects such as possible options for adapting to the changed run-off regime.)

Navigability analyses are generally carried out on the basis of the numerical models developed by the BAW over the last few years. An overview of the navigational dynamic models and their underlying theories can be found in (Heinzelmann et al., 2010).

2.1 *Hydraulic navigational dynamic models*

Hydraulic **n**avigational **d**ynamic (HND) models are obtained by combining hydrodynamic models and navigational dynamic models. They also integrate virtual navigation and the time referenced ship simulation. The four elements fit together like the pieces of a puzzle (Heinzelmann et al., 2009).

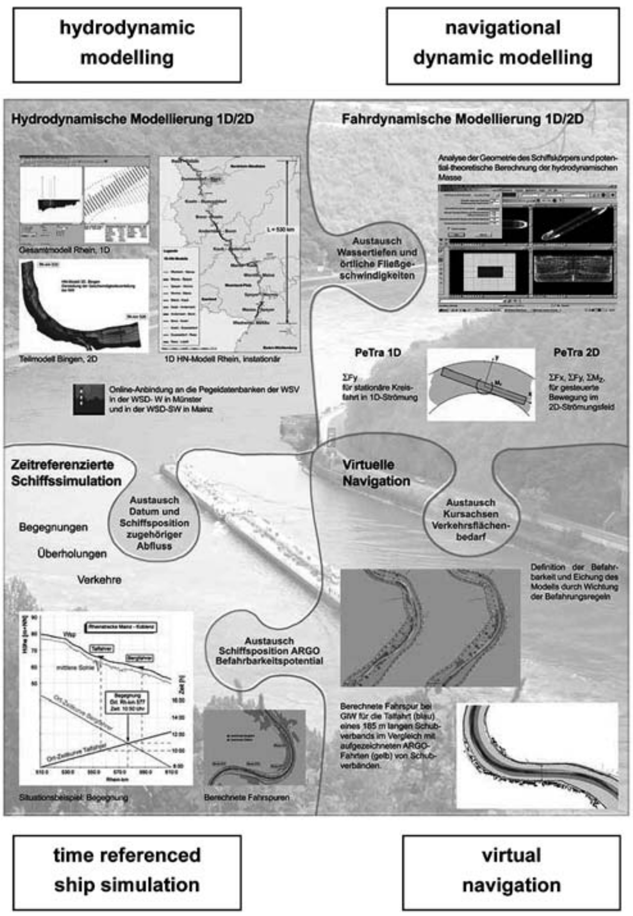

Figure 1: Hydraulic navigational dynamic models

The **hydrodynamic models** contribute water depths and flow velocities as input parameters for the navigational dynamic models. 1D HN models are generally used for this purpose. 2D models are preferred for water stretches with strong crosscurrents.

The navigational dynamic models supply the navigational track, in other words the traffic space needed by the ship to navigate, taking account of the ship type, vessel speed and local flow rates. Once again, either 1D or 2D models are used, depending on the specific boundary conditions.

The third piece in the HND model is the **virtual navigation**. Course axes are required to calculate the navigational track width from the navigational dynamic models. In wide waters such as the River Rhine, the position and form of the course axes selected by shipmasters are influenced by a large number of boundary conditions. Firstly, a sufficient water depth is vital. Secondly, it is important to consider aspects such as river police regulations, bridge clearance heights or the flow velocity and water depth distribution in the cross-section. The aim of the virtual navigation is to enable the actual activities of the shipmasters to be adapted as precisely as possible in the navigational dynamic model. In the first step of the virtual navigation, a navigability potential distribution is determined for each cross-section (usually every 100 m) based on the above-mentioned boundary conditions, together with a passage for the cross-section with the highest potential. In the second step, a course axis is constructed according to the order of the passages. In the third step, the navigational dynamic model yields the navigational track. All of these steps are automated. The results delivered by the model were verified by comparing the findings with field study measurements on the River Rhine in connection with the ARGO pilot project (WSD Südwest, 2003). The twelve vessels taking part in ARGO recorded all trips undertaken with a navigation system over a period of 15 months. More than 500 such trips were subsequently evaluated by the BAW. The water levels measured during the ships' passages were then simulated with the HN model. Providing the hydraulic conditions were known, it was possible to calculate, calibrate and verify the course axes with the help of the virtual navigation. The recorded trips correlated very closely with the navigational tracks calculated using the model.

In the analyses performed to date, all calculations for individual vessels refer to an uninterrupted trip, in other words the vessel speed was optimal and there was no interference from moving traffic. The location-time curve for each vessel can be determined and represented by introducing a time reference, for example departure time, arrival time, constant vessel speeds against water in defined sections, taking account of the transient results of the HN model. Encounters, overtaking manoeuvres and other traffic situations can be planned and evaluated in this way **(time referenced ship simulation)**.

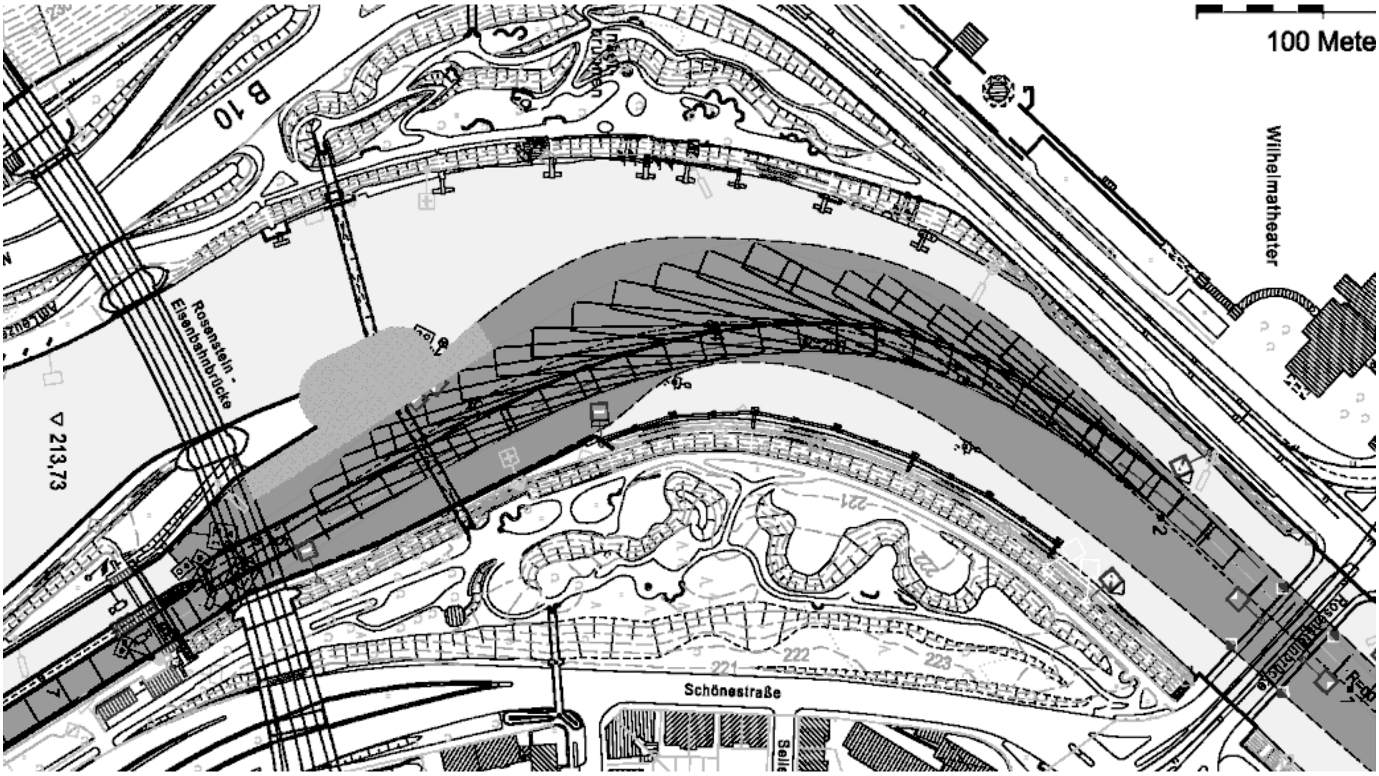

Figure 2: Navigational track in bends of single ship positions derived from the navigability analysis of the River Neckar for 135 m long motor vessels.

2.2 *Application of an HND model to the River Oder near Hohenwutzen*

In lowland rivers like the River Oder, significant quantities of sand and gravel are transported along the river bed. Particularly in straight river sections, this sediment is transported in the form of banks that alternate between the left and right sides of the river as they migrate downstream. The banks measured in the River Oder can be up to 800 m long and 1 to 2 m high; they advance at a rate of around 5 m a day. These large shapes are overlaid by smaller and faster moving dunes. The shape of the banks and dunes and the nature of the downstream movement vary according to the hydrological, hydraulic and morphological boundary conditions as well as the geometry of the river control structures such as bank rip-rap, groynes and longitudinal training walls.

The alternating banks in the River Oder constitute a considerable obstacle to shipping. They reduce the loading depth and impair the economic efficiency of the inland waterways transport. Regular soundings of the river bed are necessary to adapt the course of the fairway to the changed bed topography. The groynes along certain sections of the River Oder are either badly damaged or missing completely. Scouring in the vicinity of structures increases the cross-section of discharge and leads to the formation of shallow water zones. The Eberswalde Waterways and Shipping Office has charged the BAW with carrying out fairway stabilisation studies, with the aim of improving the conditions for shipping on the River Oder and reducing the high costs for maintenance.

The BAW's concept comprises hydraulic-morphological studies with physical and numerical models as well as navigational dynamic studies with the HND model. The physical models for the part of the River Oder near Hohenwutzen are briefly presented in the following together with selected outcomes of the HND model. Further details can be found in (Hentschel, 2007, Henning et al., 2007, Hentschel, 2009).

Figure 3 shows the physical model with the measurement bridge in the background. The model reach is 78 m long with a length scale of 1:100; the height scale was calculated as 1:40 based on the hydraulic and morphological requirements and a similarity analysis. Polystyrene pellets with a mean particle diameter of 2.1 mm and a density of 1.055 g/cm³ were used as sediment for the purposes of the model.

Figure 3: Physical model of the River Oder with the measurement bridge in the background.

Figure 4: Measurement grid projected onto the model bed.

The measurement bridge with its photogrammetric measurement system forms the heart of the instrumentation for the model of the River Oder. This system permits automated and highly precise measurements of the model bed without interrupting the experiment, i.e. the bed geometry is measured through the flowing water. The system's main components are a slide projector, which projects a grid onto the model bed, and three high-resolution video cameras that film this grid from three different angles. The position of each grid point can be determined in the three spatial coordinates using triangulation methods. The results are then read into a digital terrain model (Henning et al., 2009).

Sediment transport is a very random phenomenon, so that every experiment conducted with the model is different, even though the starting and boundary conditions remain unchanged. In order to obtain a statistically meaningful database, each test was performed at least five times under identical conditions, separately for the three stationary discharges MNQ (247 m³/s), MQ (525 m³/s) and 2MQ (1000 m³/s). The model variants studied were each based on modifications to the existing river training system. Digital terrain models are generated from the photogrammetric measurements of the bed geometries of the physicalmodel, as well as sections at intervals of 50 m for the analysis with the HND model (field study). Figure 5 shows selected results of these calculations as an example. The traffic lanes for five test runs in the baseline condition can be seen in the top part of the figure (reference condition). The navigability analysis was based on a vessel 82 m long and 11.40 m wide. The lanes indicate the course with the greatest navigability potential. The significant deviations between these lanes from one test run to another are clearly visible – a pointer to the marked instability of the water bed in the baseline condition.

In the bottom part of the figure (variant V2a), the traffic lanes for the five tests are much closer together. The following changes were made to the physical model in this variant compared to the baseline condition:

- Regulation lines harmonised,
- Slightly meandering pattern implemented for the regulation lines
- Damaged groynes repaired and missing groynes replaced, and
- Groyne heads flattened to an incline of 1 : 10.

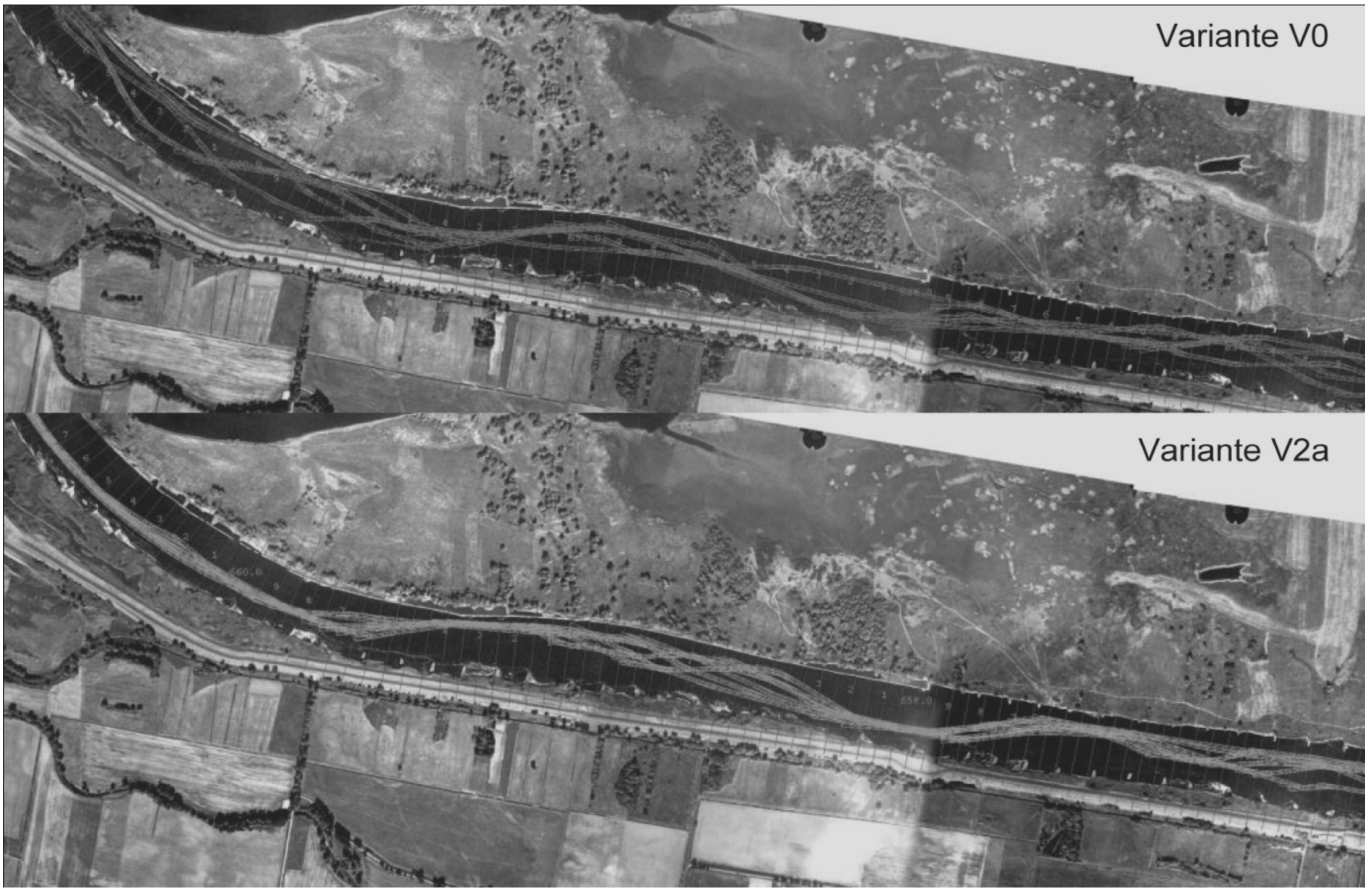

Figure 5: Results of the HND model for the baseline condition (variant V0) and after optimising the river control structures (variant V2a), for five test runs in each case.

The results of the HND model calculations reveal a clear stabilization of the water bed in variant V2a, coupled with an increase of 0.50 m in the fairway depth with MNQ that can be utilised for shipping. The use of a physical model with a movable bed enables potential fairway courses and their stability to be analysed, because in addition to the similarity of the mean parameters the model also exhibits bed geometry variations resembling those that actually occur in the field.

2.3 *Ship handling simulation at the BAW*

The BAW's navigational dynamic models were developed first and foremost to support waterways extension planning with CAD systems and allow shipping at normal speed to be analysed over long stretches in shallow water conditions. Amongst other things, bottleneck analyses can now be carried out at a reasonable cost for a variety of scenarios involving different ship types, water levels and bed topographies. On the other hand, these methods are only limitedly suitable for determining the traffic space required for manoeuvre situations or for navigation in shipping channels with a restricted width and depth. For this reason, the BAW also commissioned the development of a dynamic model that is suitable for navigation in shallow flowing water (Kolarov, 2006); a ship handling simulator was recently purchased and will be enhanced with the BAW's own models, in particular to take account of the shipping channel conditions on inland waterways, which tend to be very restricted. Simultaneous modelling of the ship-generated current and wave system, for instance, as well as ship handling and its interaction in the form of bank forces will probably be added at a later development stage. A simulator without a bridge, or with a bridge in the minimum configuration, is the only hardware that is normally necessary because the vessels are mostly controlled by autopilot. If a "human factor" is occasionally unavoidable, an otherwise identical simulator with a bridge can be obtained from an external operator.

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