TRAFFIC MANAGEMENT, RELIABILITY AND ECONOMIC TRANSPORT ON THE INLAND WATERWAY DANUBE

by

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ABSTRACT

The analysis on goods transport in the Danube together with cost factors and infrastructure reliability revealed the strengths, weaknesses, risks and opportunities of the Inland Waterway Danube. According to the results waterway transport will stay competitive or may even regain market shares if continuous reliable fairway conditions with an available water depth of at least 2.5 m can be provided even in low-water periods. Improving transport logistics e.g. with fixed contracts using mixed modes of transport and optimal loading depending on actual conditions are necessary as well. For managing a dynamic river as transport infrastructure in a cost-efficient and environmentally friendly way viadonau has teamed up with Vienna University of Technology and Hoffmann Consulting in order to develop a holistic Waterway Asset Management System (WAMS). In a first phase from 2012 to 2015 the principal methodological availability approach and a dredging management have been developed (WAMS 1.0). In the second phase from 2016 to 2018 additional functionalities for sediment, waterway structures, and traffic management have been implemented (WAMS 2.0). The development and implementation in a software tool has been work in progress providing constant feedback between theoretical considerations and practical results as new functionalities become available. Thus, the WAMS software tool is becoming the central database providing viadonau with the means to move from empiric reactive maintenance approaches towards quantitative asset management strategies with fast semi-automated processing capabilities and pro-active maintenance in a user-friendly environment. The focus of this paper is traffic management connecting the physical availability and its optimization with an analysis of actual traffic flows and utilization of the vessel fleet in real time. To achieve this goal anonymized transponder data leaving only vessel type, position and draught loaded are imported for calculating encounters, traffic distributions and fairway utilization. Based on these data it is possible to generate traffic heatmaps and assess critical encounters in narrow sections at low water periods as a basis for aligning the fairway path and defined levels of service. Furthermore, the WAMS is capable of monitoring the progress of pro-active dredging measures allowing a fast implementation and communication of results to the transport industry. With historic and actual data from riverbed surveys, water levels and traffic it is already possible to calculate the availability of any defined level of service for any transport route on the Danube in Austria in a matter of minutes. The possible loading of any vessel type can also be derived from calibration curves linking utilization and static draught with dynamic squat depending on vessel speed and necessary underkeel clearance. With the Ministers of Transport on all riparian countries of the Danube endorsing a common Fairway Rehabilitation and Maintenance Master Plan in 2014 (FAIRway) the EU - project WAMOS will lead to one common database on fairway conditions of the entire Danube. Combining these information with traffic analysis capabilities will allow both efficient investments in waterway availability as well as competitive pricing and transport planning on 2.400 river kilometer on the entire Danube until 2020.

KEYWORDS: Danube, inland waterway, availability, asset & traffic management, traffic distribution, fairway alignment

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1. INTRODUCTION

Transport infrastructures as important assets of national economies develop in very long cycles due to their service lives and costs whereas transport of goods (and passengers) are closely related to economic development (Hoffmann, M. 2017). Figure 1 provides an overview on the waterways in Central Europe with the Danube as a central transport axis. Figure 2 (top) shows the cross-sectional traffic volumes in the Danube corridor at the borders of Austria. To the west at Passau the total volume grew from 19.5 million tons in 1990 to 62.4 million tons in 2016 (+8.5% p.a.) and to the east at Hainburg from 12.9 to 44.2 million tons (9.3% p.a.) proving an increasing importance of international transport. During this period, there have been huge shifts in modal split from 13.2% down to 6.2% (Danube), 42.1% down to 27.9% (rail), and from 44.7% up to 65.9% (road) to the West. To the East these shifts have been even more significant from 48.9% down to 15.3% (Danube), from 38.6% down to 31.2% (rail), and from 12.4% up to 53.4% (road). In summary, transport volumes on rail and Danube have been stable or declining slightly with the majority of growth being allocated to roads. Fig. 2 (bottom) shows transit, import, export and domestic transport volumes in Austria with the main Ports being Linz and Vienna. Fig. 3 provides an overview on the entire goods transport shares on 2.400 km Danube in all riparian countries from Germany to the Black Sea. Long distance bulk good transport with the main commodities being ores & metal waste (26.7%), agricultural & forestry products (19.0%) and petroleum products (14.6%) are characteristic for the Danube. In contrast, passenger transport is still increasing setting a record high of 1.23 million in 2016 in Austria (cruise ships, and day-trip vessels) with good prospects for further growth.

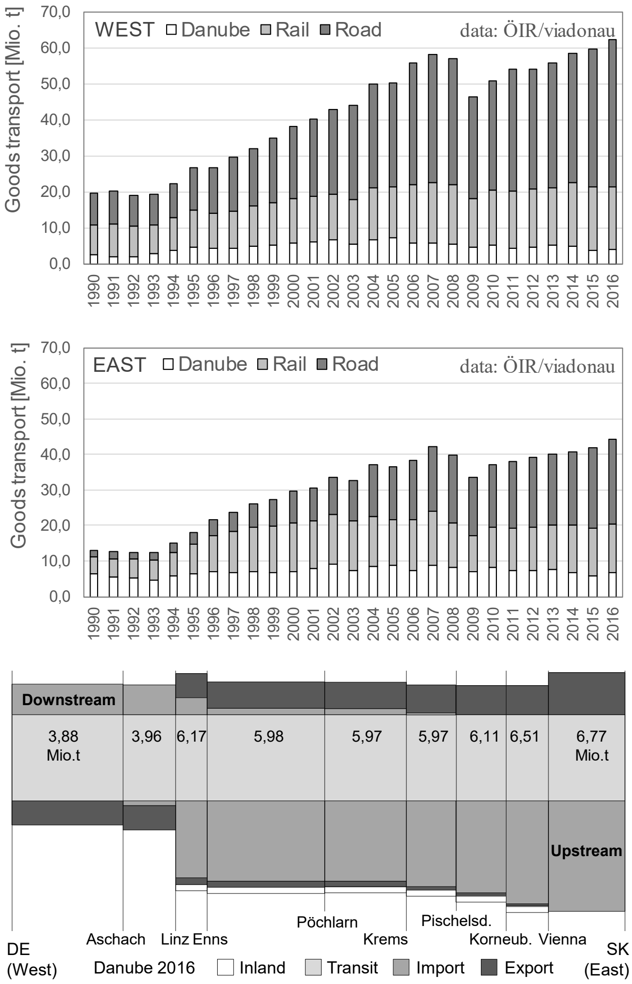


Figure 2: Traffic volume development in the Danube corridor in Austria from 1990 to 2016 and traffic flow analysis on the Danube in Austria 2016

Figure 1: Overview on Inland Waterways in Central Europe with the river Danube in Austria

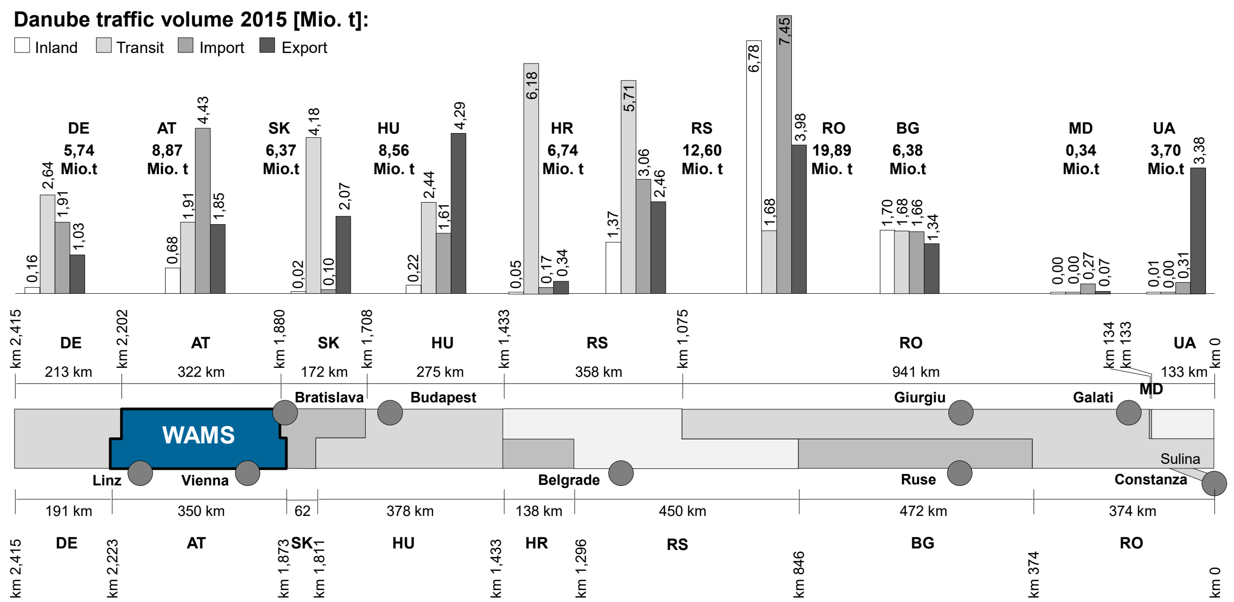


Figure 3: Overview total traffic volumes per country on the river Danube from Germany to Austria and the Black Sea in 2015 with Waterway Asset Management System WAMS in Austria

2. Waterway transport conditions in Austria

In general, the volume of regional transport markets decreases with increasing distance with the main decision factors in transport logistics of bulk goods being reliability and costs on the entire (multi-modal) transport chain (Hoffmann, M. et al. 2014). Fig. 4 shows the distance-related transport unit costs and modal dominance in the Danube corridor including pre- and end haulage in a catchment area of 50 km for road, rail and river Danube. In summary, transport on rail and inland waterways is economic on long transport distances at high loading factors due to large fixed and low variable cost components. Transport on waterways is especially sensitive as adverse weather conditions (ice, floods) may block vessels and low water depths are limiting utilization. With ongoing pressure on the transport market (e.g. overcapacities, low fuel prices) fairway depths between 2.0 to 2.4 m (average vessel utilization up to 50%) are insufficient as the resulting transport costs are far too high. However, if a high availability with reliable fairway depths above 2.5 m can be provided on entire transport routes waterway transport is becoming increasingly economic. Apart from transport cost analysis the proof may be found in the comparison of fairway availability and transport volumes in consecutive years. Due to an exceptionally warm and dry weather between July and December 2015 a water depth of 2.5 m east of Vienna was only available on 35% of this period with the total transport volume on the Danube in Austria dropping from 10.1 in 2014 to only 8.6 million tons in 2015. With better weather conditions and intense pro-active maintenance, the conditions on the Danube

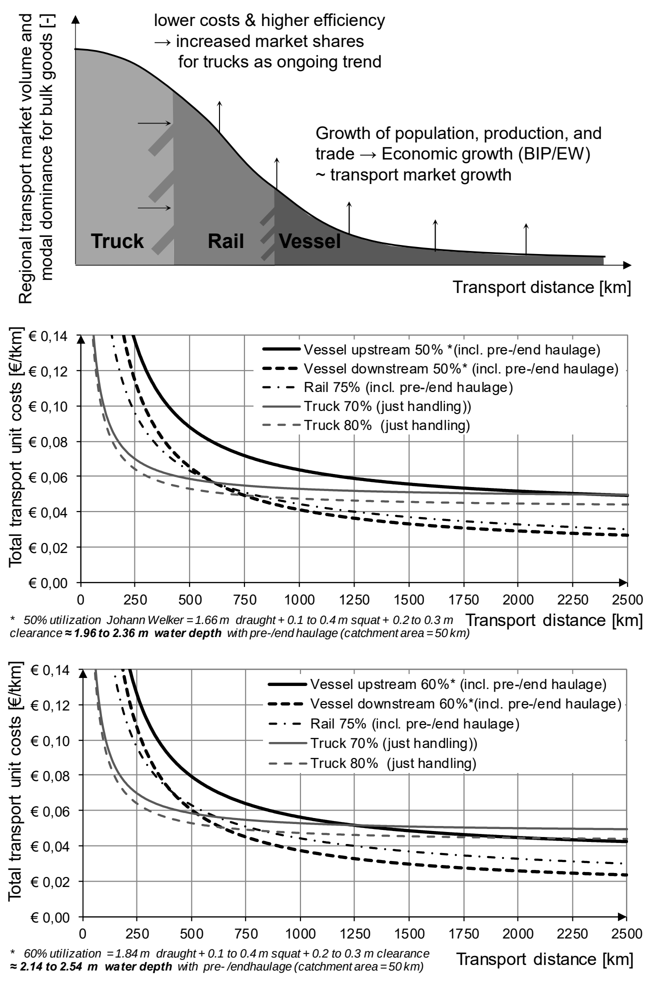


Figure 4: Distance related transport market (bulk goods) and transport unit costs of road, rail and waterway on the Danube Corridor 2016

have improved in 2016 (Fig. 5) with 89% availability downstream and 98% availability upstream. As a consequence, transport volumes on the Danube have recovered increasing to a total of 9.1 million tons at an average load factor of 61.7% (viadonau 2015/16).

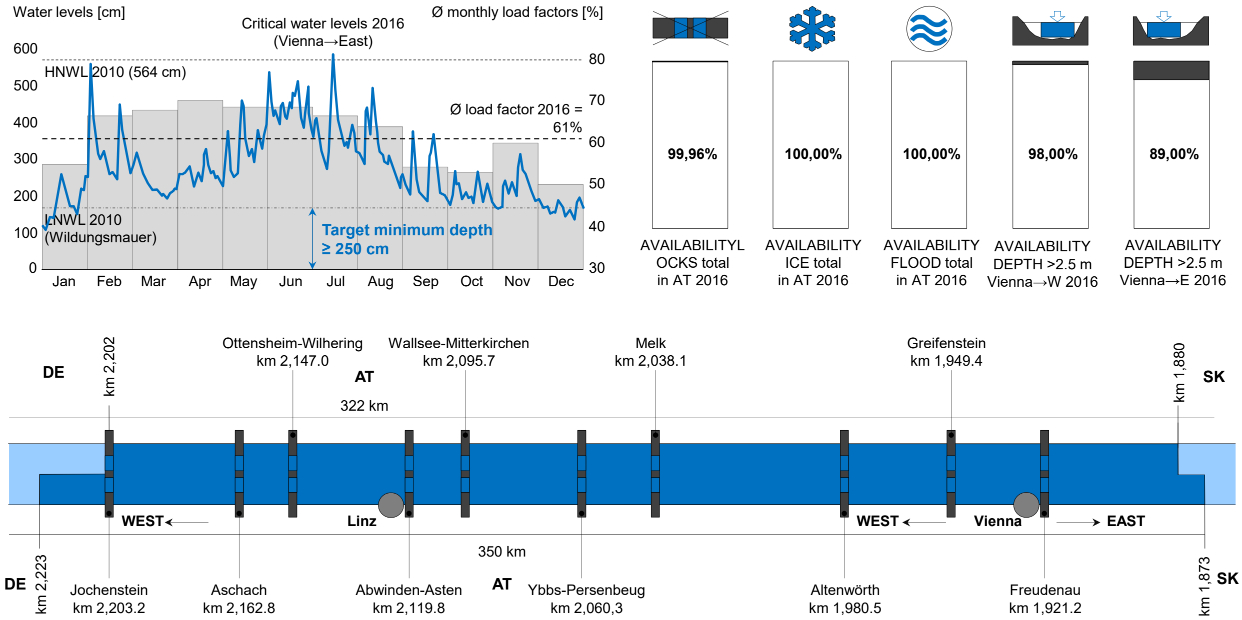


Figure 5: Key performance indicators waterway: Overview critical water levels, vessel load factors, locks and availability on the Danube in Austria 2016

3. Overview Waterway Asset Management System WAMS

Effective waterway management with sufficient fairway width and depth throughout the year is crucial for an economically successful development of waterway goods transport. Therefore, viadonau decided in 2012 to move from existing empiric reactive approaches towards an analytic proactive life cycle costing approach with the development of a waterway asset management system WAMS (Hoffmann, M. et. al. 2014a,b, Haselbauer, K. 2016). At the core of the developed approach is the total availability concept based on all possible available combinations of fairway width and depth in days per year with the levels of service accounting for typical encounter situations at a minimum fairway depth of 2.5 m (Fig. 6). The principal methodological approach and software WAMS 1.0 with Module 1: Database, core system and availability and Module 2: Dredging Management have been developed in cooperation with Vienna University of Technologies - Institute of Transportation from 2012 to 2015 with the software being operational since July 2015. In the second stage viadonau teamed up with the principal developers (Hoffmann, M. & Haberl, A.) in order to extend the system with Module 3: Sediment Management, Module 4: Structure Management and Module 5: Traffic Management (Fig. 7) from 2016 to 2018.

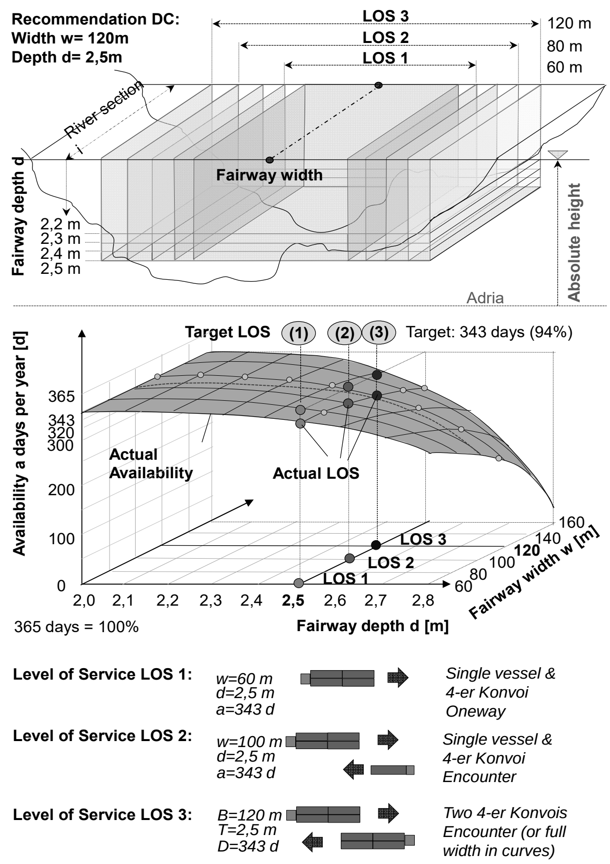


Figure 6: Fairway recommendations, total availability concept and levels of service (LOS) for a minimum fairway depth of 2.5 m

The focus of this paper is presenting an overview on principal considerations and methods together with developed functionalities and results from Module 5: Traffic Management in the WAMS software. The goal of Module 5 is to provide the waterway operator viadonau with all necessary information connecting the physical availability of the waterway as dynamic series system of fords, locks and civil structures with information from actual utilization of the vessel fleet in real time. In the following sections, the paper describes the anonymization of vessel trajectories as basis for generating comprehensive traffic analysis and fairway utilization information for any given set of conditions. Comparing cumulative vessel trajectories and traffic distribution for all types of encounters allows to optimize fairway alignment and pro-active maintenance measures for any given budget. Furthermore, these results will improve the capability of viadonau to provide shippers with actual and reliable information on fairway conditions as basis for optimizing transport logistics and competitive prices on the transport market.

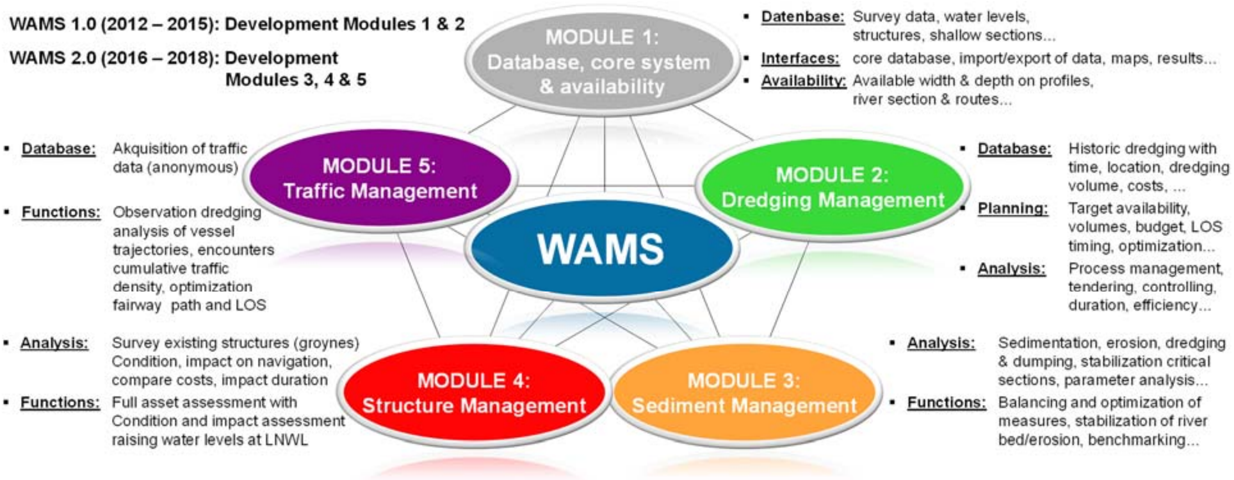


Figure 7: Overview developed modern modular Waterway Asset Management System WAMS of viadonau being operational since 2015

4. Traffic management and fairway alignment (Module 5)

4.1 Water depths, levels of service and fairway alignment

With Module 1: Database, core system and availability holding actual and historic information on riverbed surveys, water levels, structures, shallow sections and fairway alignments from almost a decade all kinds of analysis become feasible. As an example, Fig. 8 shows the calculation of total fairway availability as convex falling surface for increasing width and depth with the results for previously defined Levels of Service. From the perspective of economic waterway transport insufficient width translates into alternating one-way traffic at narrow sections with a few minutes waiting time in cases of encounters. In contrast, insufficient fairway depth at one single shallow section on an entire transport route will severely limit vessel utilization of the entire fleet with one-centimeter additional depth translating into a possible extra load of 7 to 20 tons depending on vessel or convoy type. With average travel times between one to three weeks on an average transport distance of 1.000 km neither waiting times at locks (on average 33 minutes) or rare

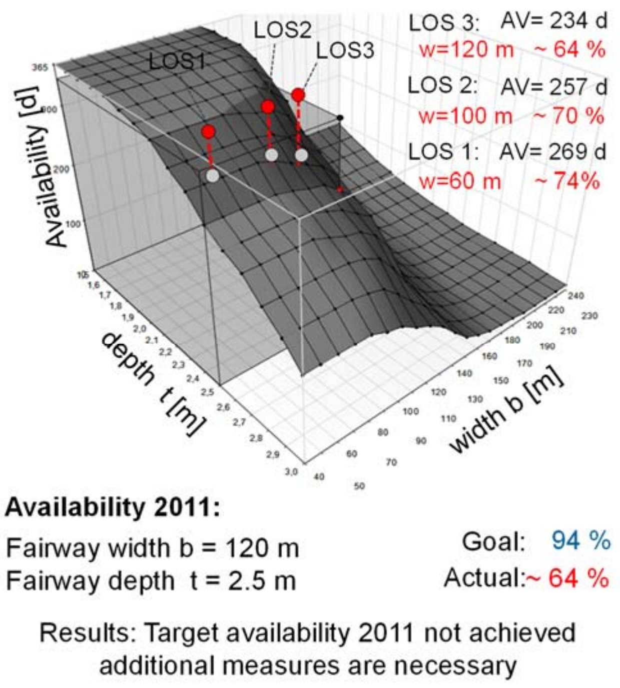


Figure 8: WAMS – Example calculation of total fairway availability of the River Danube with Levels of Service in 2011

cases of encounters in a few narrow sections really matter. However, conducting the same analysis on an inland waterway or a channel with high traffic density would yield different results and optimal strategies.

As a conclusion for the river Danube what really matters is providing a deep fairway channel with at least 60 m width and 2.5 m depth at all times on the entire transport route even at low water periods. The means of waterway authorities to achieve this goal are shifting of the fairway, dredging of shallow sections and the construction of structures (e.g. groynes, training walls). However, with a reactive approach to insufficient water levels possible realignments or emergency dredging would still lead to substantial losses of availability due to the time required for planning, tendering, implementation and communication of results. Employing pro-active strategies aiming at necessary measures prior to arriving at insufficient conditions lead to far better results. For implementing such pro-active strategies, the WAMS provides fast processing methods for an analysis of acquired data on all critical fords and water levels together with the capability for optimal fairway alignment (Fig. 9) and planning of dredging measures (Module 2). Conveying reliable availability information to skippers via signalization and different communication channels is equally important for success.

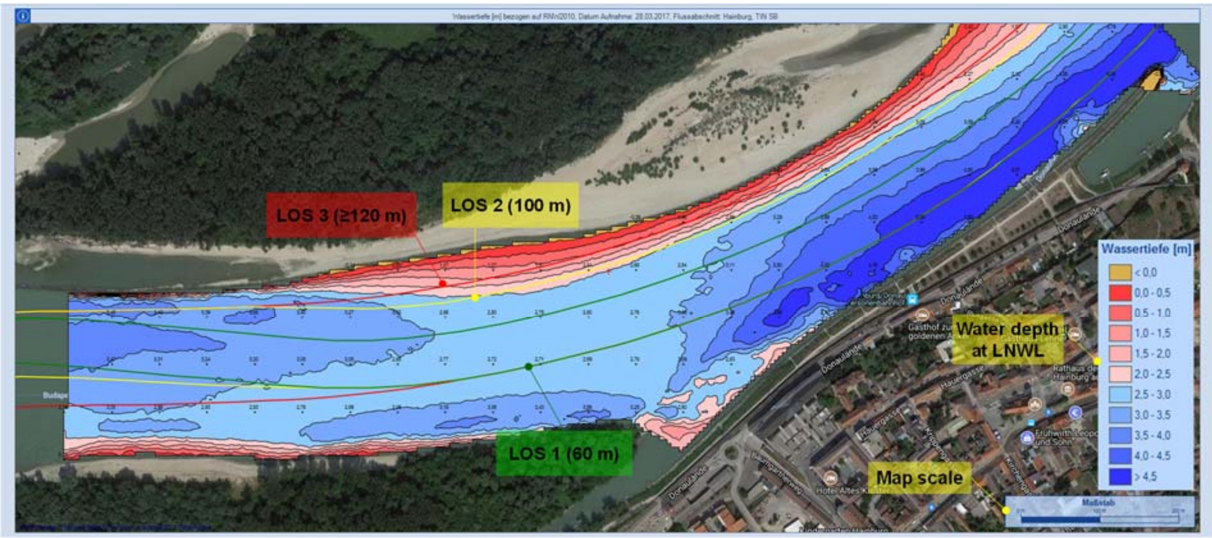


Figure 9: Automated analysis of water depths (LNWL 2010) based on multi-beam survey and water levels with fairway alignment and LOS 1, 2, 3 in 2017 (WAMS)

4.2 Vessel maneuvering, trajectories and encounters

In inland navigation, a transponder-based AIS (Automatic Identification System) is used for an automatic identification and tracking of vessels. This AIS transponder on vessels sends static (e.g. ship number, vessel type, number, name, call sign), dynamic (e.g. position, course, speed), and voyage related (e.g. draught loaded, destination) information to base stations on the shore. For reasons of privacy and data protection only the information on vessel type, position and draught loaded are kept in the WAMS for further analysis with all other data being discarded prior to importing. Furthermore, position data is thinned out reducing the size of the database and allowing for a fast processing.

Based on vessel types and recalculated heading information Module 5 of WAMS is capable of providing aggregated information on the number and types of vessels passing selected river sections in any given time-frame. Together with the distribution of vessel speed and loading depth this information enables a comparison of provided fairway availability and actual fairway utilization. For the analysis of vessel encounters it is necessary to project the position data and time stamp to a river kilometer with encounters due to passing or overtaking being located at the intersection of two-dimensional lines. Fig. 10 (top) provides an overview on all encounters for a selected river section and time frame with timing, location, direction, vessel speed and encounter type. By selecting a specific encounter, the trajectories of involved vessels are mapped, providing insight into maneuvers especially at low water periods (Fig. 10 bottom). At narrow sections, the aggregated information on encounters will allow an optimization of fairway alignment as well as an assessment of time losses and energy consumption due to waiting.

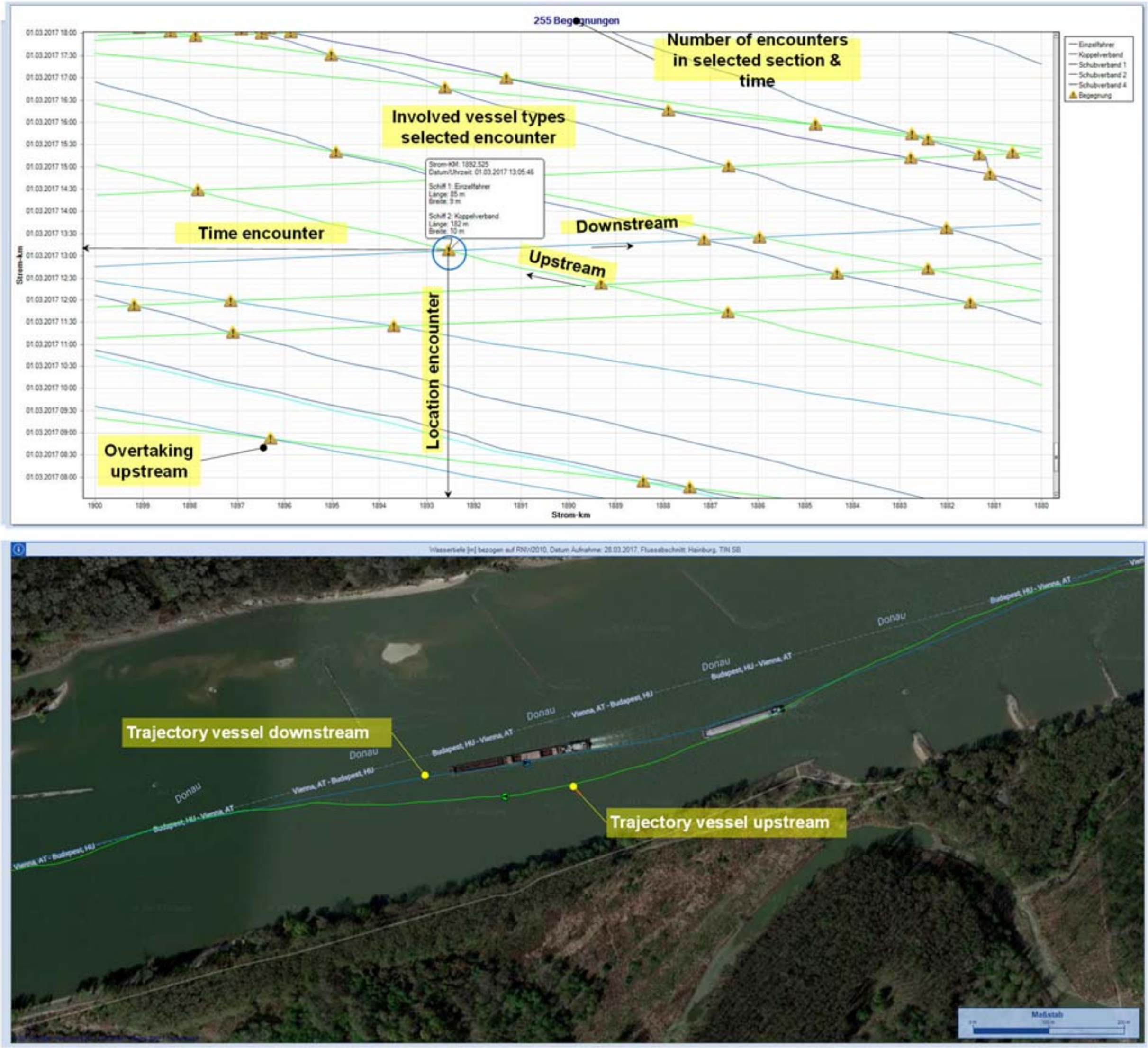


Figure 10: Automated traffic analysis and encounters in a river section (above) with vessel trajectories for a selected encounter (WAMS)

4.3 Traffic analysis, density and heatmaps

As interesting single vessel trajectories or encounters may be, they provide little information regarding optimal fairway alignment and optimization of fairway conditions for the entire vessel fleet. In this regard, the traffic distribution in comparison to fairway alignment, levels of service and actual water depths are what matters. For managing piers, ports and berths it may also be important to find out about their importance based on the number of arriving vessels and length of stay aside from their structural condition. These questions can be answered based on an algorithm using a defined grid with each square acting as a counting cell for vessel trajectories passing that square. For an analysis of piers, ports and berths this approach may be extended based on a predefined catchment area with an arrival counting if the length of stay from the transponder signal exceeds a certain threshold.

Fig. 11 (top) shows the results of this algorithm in the form of a color-coded traffic density heatmap in a given time frame and river section together with the calculated average fairway path and given level of confidence. The resulting heatmap may be used as an overlay for the map with water depths and fairway paths allowing for justified adaptions on a quantitative basis. Combining these results in cross sectional profiles also provides important insights as traffic distribution may be directly compared to water depths, fairway path and levels of service (Fig. 11 bottom). With skippers communicating accurate information on draught loaded it will also be possible to calculate underkeel clearance giving waterway authorities comprehensive information on actual utilization. A possible incentive for skippers conveying accurate data may be the possibility to use this info “a priori” in transport logistics and pricing and as feedback for loading efficiency on transport routes (Hoffmann M. et. al. 2016, 2018).

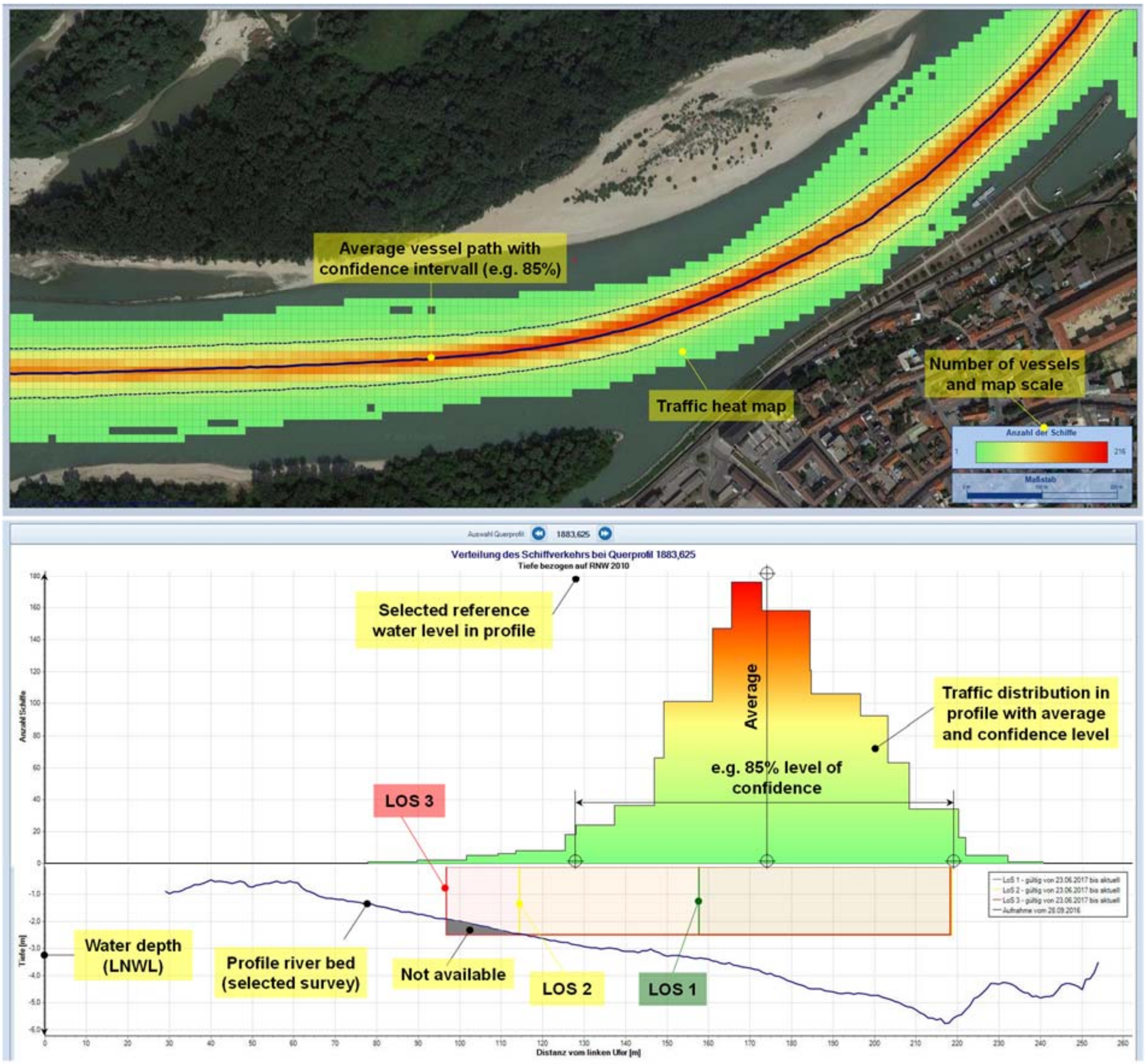


Figure 11: Automated traffic analysis in a river section (top) with heatmap and traffic distribution (bottom) in a selected river profile compared to water depths (WAMS)

4.4. Tracking of dredging vessels and achieved results

Monitoring the progress of fairway dredging as the most common maintenance measure on the upper Danube is of high importance for detecting any deviations during dredging as well as releasing updated plans and information on fairway availability. Starting with planning of dredging measures from Module 2: Dredging Management it is possible to track the entire dredging process including vessel trajectories between dredging and dumping sites. The transponder data in these cases is not part of the provided anonymous data for traffic analysis allowing specific tracking of the entire transport process including a playback of each transport run (Hoffmann M. et. al. 2016; 2018).

Fig. 12 shows detailed information on the selected dredging measure (e.g. river-km, time-frame, dredging volume, cost estimation, transport distance) together with an overview on vessel tracks on dredging and dumping sites as well as the entire route between. Riverbed surveys (multi-beam) shortly prior and after dredging ensure compliance with planned results being the basis for payments of dredging companies as well as releasing updated information on fairway availability to the shipping industry. The main advantage in this regard is streamlining the maintenance process towards a pro-active approach allowing fast reactions in cases of falling water levels and sedimentation in fords. Furthermore, acting on the base of pre-tendered framework contracts with dredging companies helps to avoid lengthy legal battles with unsuccessful bidders as well as negotiations under time pressure. With the WAMS being operational to some extent since July 2015 the first results of the implementation of these pro-active strategies are already visible leading to much higher efficiency of and accountability for investments together with an improved availability of the waterway Danube in Austria since 2016.

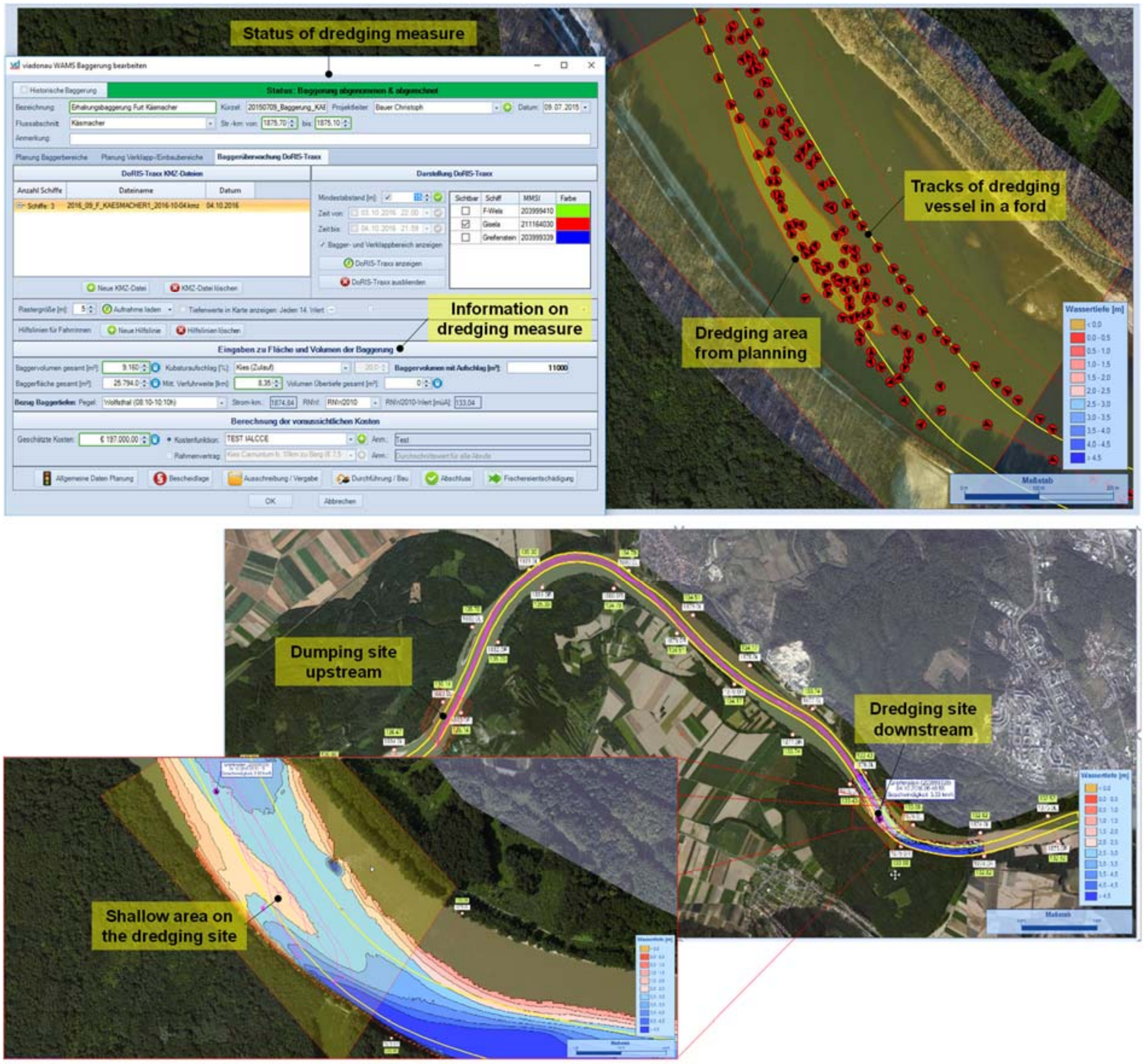
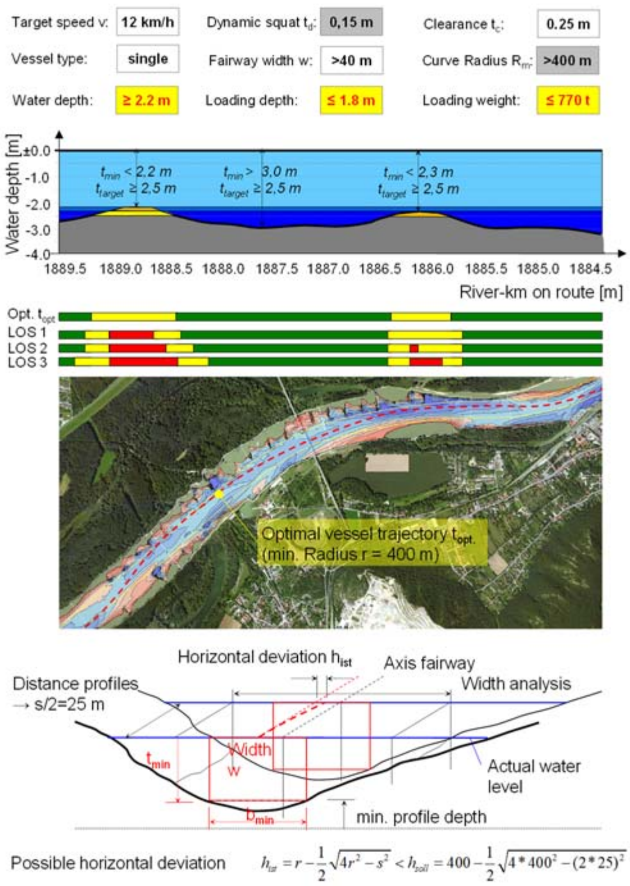


Figure 12: Automated analysis of dredging measure status with monitoring of dredging vessels and results based on transponder data and multi-beam surveys (WAMS)

4.5. Towards real-time availability and a waterway route planner

The availability of waterways is calculated as a serial system with the most critical ford regarding water depth at any time being the bottleneck for any given fairway width or level of service (LOS) on a transport route. The calculation of dive depths of vessels equals the sum of stationary draught loaded (speed v=0 km/h) and squat (v>0 km/h) with an additional clearance to avoid groundings for the necessary minimum water depth (viadonau 2013). The possible loading weight can be derived from calibration curves linking possible utilization and static draught loaded for different vessel types (Hoffmann M. et. al. 2014a,b). Combining this information, it is possible to estimate possible maximum vessel loading based on information of water depths or calculate an optimal trajectory from actual water levels, fixed points, minimum curve radii and tangent lines between cross-sectional profiles with specific search algorithms (Fig. 13). For the implementation the waterway route planner therefore has to incorporate current data from gauging stations and multi-beam surveys as well as the calibration curves for most common vessel types. Implementing data from a combination of echo-sounding and transponder information could add additional information regarding real-time assessment of current fairway availabilities.

Currently, it is already possible to calculate fairway availability based on existing fairway alignments or LOS, riverbed surveys and water levels for any given water depth on the entire Danube in Austria for the last 10 years until now. Fig. 14 shows such an automated WAMS - calculation for January 2016 with the critical fords at any given day resulting in a total availability for any selected condition. Together with the capabilities from Module 2: Dredging Management it is already possible to calculated dredging needs and costs on all critical sections for any given combination of fairway width and depth or available budget. The main challenge for extending already existing capabilities of the system towards a route and transport logistics planner for waterways would be reliable predictions of water levels and obtaining actual data from the entire Danube. In the past this was almost not possible as the survey standards have been very different. With the EU-project WAMOS the waterway authorities are currently working towards harmonizing information on water levels and riverbed survey in a common database. In the next years this database will be combined with actual depth information of echo sounders from the vessel fleet on the river Danube to provide the WAMS with route planning and transport logistics capabilities.



$$h_{ist} = r - \frac{1}{2}\sqrt{4r^2 - s^2} < h_{soll} = 400 - \frac{1}{2}\sqrt{4 * 400^2 - (2*25)^2}$$

Figure 13: Example for a simplified route planner with calculation of trajectory with max. water depth and possible loading of a vessel

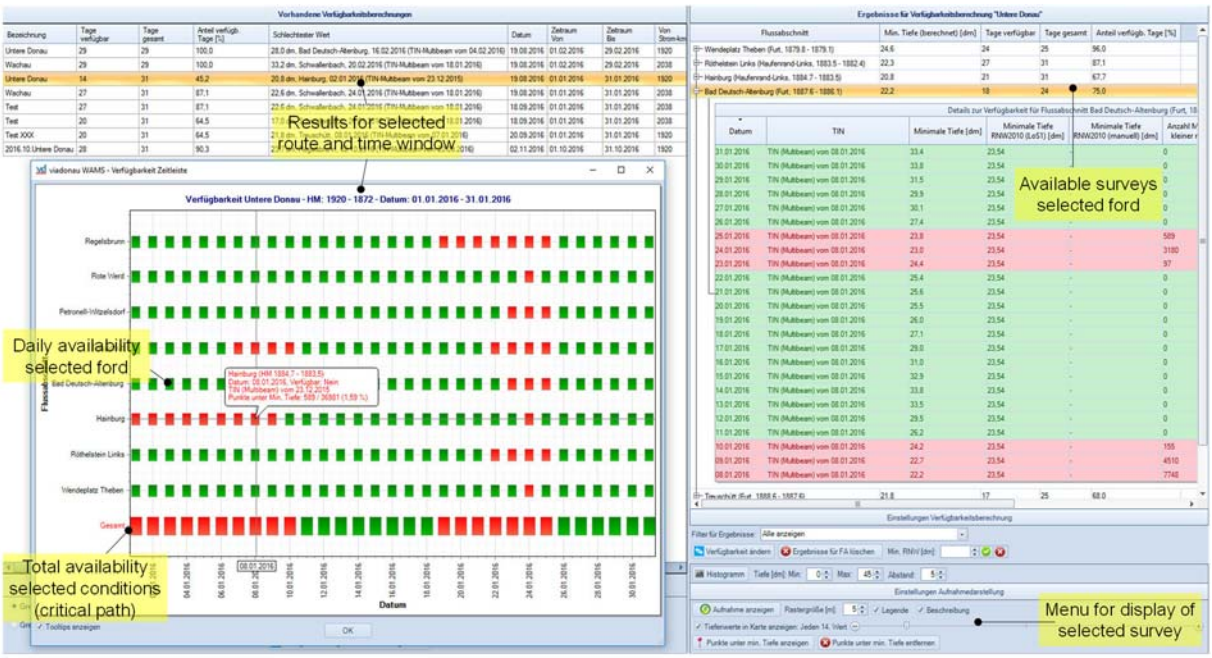


Figure 14: Automated analysis of available fairway width and depth with critical fords and total availability on a transport route (WAMS)

5. Conclusions and outlook

The analysis on goods transport in the Danube together with cost factors and infrastructure reliability clearly revealed why the majority of transport growth in the last two decades has been allocated to road transport with rail and waterway barely holding their ground. Enormous investments in road infrastructure, transport logistics and technology have led to substantial comparative improvements of road transport especially on short to medium transport distances. Existing bureaucratic hurdles, lack of investments, current low costs of fuel and external costs still not being internalized are also factors contributing to this development. Despite these developments waterway transport will stay competitive or may even regain market shares if continuous reliable fairway conditions with an available water depth of at least 2.5 m can be provided in low-water periods. Furthermore, improving transport logistics e.g. with fixed contracts using mixed modes of transport and optimal loading depending on actual conditions are necessary.

For managing a dynamic river as transport infrastructure in a cost-efficient and environmentally friendly way viadonau has teamed up with Vienna University of Technology and Hoffmann Consulting in order to develop a holistic Waterway Asset Management System (WAMS). In a first phase from 2012 to 2015 the principal methodological approaches for Modules 1: Database, core system and availability and Module 2: Dredging Management have been developed (WAMS 1.0). In the second phase from 2016 to 2018 Module 3: Sediment Management, Module 4: Structure Management and Module 5: Traffic Management are being implemented (WAMS 2.0). With the WAMS in operation since July 2015 the development is a work in progress providing constant feedback between theoretical considerations and practical results as new functionalities become available. In this regard, the WAMS is becoming an integrator of all kinds of data providing viadonau with the means to move from empiric reactive maintenance approaches towards quantitative asset management strategies with fast semi-automated processing capabilities and pro-active maintenance in a user-friendly environment.

Starting with an analysis of current developments in the transport market and the role of the waterway Danube this paper shows the principal approaches and functionalities of the WAMS with the main focus on methods and recently implemented functionalities in Module 5: Traffic management. The goal of this module is to provide viadonau with all necessary information connecting the physical availability and its optimization with an analysis of actual traffic flows and utilization of the vessel fleet in real time. To achieve this goal anonymized transponder data leaving only vessel type, position and draught loaded are imported for calculating encounters, traffic distributions and fairway utilization. Based on the implemented algorithms it is possible to generate traffic heatmaps and assess critical encounters in narrow sections at low water periods as a basis for aligning the fairway path and defined levels of service. Furthermore, the system is capable of monitoring the progress of pro-active dredging measures allowing a fast implementation and communication of results to the transport industry. With historic and actual data from riverbed surveys, water levels and traffic it is already possible to calculate the availability of any defined level of service for any transport route on the Danube in Austria in a matter of minutes. The possible loading of any vessel type can also be derived from calibration curves linking utilization and static draught with dynamic squat depending on vessel speed and necessary underkeel clearance.

The remaining challenges for optimizing vessel loading and route planning would be an implementation of prediction capabilities for water levels together with reliable information on fairway conditions on the entire Danube as average transport distances are rather long (1,000 km). With the Ministers of Transport on all riparian countries of the Danube endorsing a common Fairway Rehabilitation and Maintenance Master Plan in 2014 (FAIRway) the EU - project WAMOS will lead to one common database on fairway conditions of the entire Danube. Combining this information with actual water depths from echo sounders of the vessel fleet with already existing capabilities of the WAMS would improve both investment efficiency and enable modern transport logistics and route planning. For the years to come implementing these features in a user-friendly environment with automatic checking and updating will be one of the main upcoming challenges.

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