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The Maturity of Inland Waterway Transport Systems in Europe

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ABSTRACT: The development of inland navigation is an important component of sustainable transport in Europe. Its use contributes to reducing harmful emissions, improving transport safety, and increasing the economic efficiency of freight movement. However, the varying geographical, infrastructural, and institutional conditions make it difficult to assess navigation systems across countries in a consistent and comparable manner. This article aims to assess the maturity level of inland waterway transport systems in selected European countries using a five-level maturity model that considers factors related to fleet, infrastructure, and system operations. The study analyses systems operating in Central and Eastern Europe, as well as in Western Europe (primarily in the Rhine basin)—a total of 12 systems. The countries were grouped according to geographic location and the strategic role of inland navigation within national transport policies. The results reveal significant differences in maturity levels and, through benchmarking, identify development priorities for individual systems. The use of a coherent assessment model at the supranational level enables the identification of development gaps and investment priorities across different regions of Europe. This approach provides practical support for policy makers in the shaping of sustainable and integrated transport strategies across the continent.

1 INTRODUCTION

The evaluation and possibility of comparing systems is an element that enables their development. This also applies to transport systems. They are most often compared within the same branch (the same systems in different areas) or in some area (e.g., systems of different branches operating in the same country). In both of these situations, the comparison of systems is useful, but fraught with difficulties. One of the tools used to evaluate transport systems is the model that defines the maturity of systems or their components. The maturity of a transport system is an indicator reflecting the level of development and organization of the system in relation to its key components. Maturity models allow for the evaluation of the parameters studied at specific levels.

Each mode of transport is greatly influenced by the political situation of the area in which the system operates, but road or rail transport is mainly dependent on access to infrastructure, which is the result of investments made. Inland waterway transport is a system that is highly sensitive to geographical and climatic conditions (including the presence of rivers and the amount of rainfall), which is why comparing systems of this type of transport in different areas is more difficult than in the case of other modes.

The aim of this publication is to present the results of research determining the maturity of selected inland navigation systems in Europe, based on the author's maturity model. The presented results allow for the assessment of individual systems and also for the comparison of the systems studied with each other.

The structure of the article includes: i) a presentation of the inland navigation systems subject to analysis, ii) methodology - introduction of maturity models for the assessment of transport systems and presentation of the model used in the presented analysis, then iii) the results of the conducted analyses, a comparison of systems, and iv) conclusions resulting from the conducted research.

2 EUROPEAN INLAND NAVIGATION SYSTEMS

Inland navigation in Europe is an important part of the continental transport system, handling about 5% of total freight transport in the European Union [1]. The waterway network includes more than 40,000 km of navigable rivers, canals, and lakes. Western European countries such as Germany and the Netherlands account for more than 70% of the total transport performance in the EU [1], [2]. In 2023, the total transport performance of inland waterway navigation in the European Union was approximately 116.5 billion tonne kilometres, and the total weight of transported cargo reached 450 million tonnes [1]. The main shipping routes in Europe are the Rhine, the Danube, and the numerous canals connecting these rivers with other regions. The Rhine remains the most important waterway, connecting Switzerland with the North Sea and handling huge volumes of goods (143.11 million tonnes of goods in the first half of 2024) [1].

The dominant groups of cargo transported in inland navigation are metal ores, coal, refined petroleum products and chemicals, rubber and plastics, and agricultural products that together represent more than 65% of all transport [2]. Container transport also has a significant share of total inland transport in the EU, especially important in inland ports such as Duisburg or Rotterdam, which serve as multimodal logistics hubs [2]. The inland navigation fleet in Europe is diverse and is undergoing continuous modernisation, especially in the context of growing environmental requirements and energy efficiency. Modern traffic management systems, such as River Information Services (RIS), are being implemented, which increase the safety and efficiency of transport . Inland waterway transport remains one of the safest forms of transport, as confirmed by low accident rates [2].

European inland navigation handles a significant share of the total transport of goods on the continent, offering ecological and efficient logistics solutions. Its development is supported by investments in infrastructure and digital technologies, which allow integration with other modes of transport and strengthens the role of inland navigation in a sustainable European transport system.

2.1 *Inland navigation systems of selected countries*

The research presented in this publication focuses on inland waterway systems in selected Central and Western European countries: Poland, the Czech Republic, Romania, Hungary, France, Austria, Luxembourg, Switzerland, Belgium, Germany, the Netherlands, as well as the Rhine River. This selection includes countries representing a cross section of diverse governance models, infrastructure availability, and the role of inland navigation in national transport systems. The choice was also guided by the availability of reliable data and the previous research experience of the author in these regions.

The data presented in Table 1 indicate that well-developed waterway infrastructure and favourable hydrological conditions are key factors in determining the intensity of inland waterway freight transport. However, they are not sufficient on their own—logistical, organizational, and policy-related factors also play a critical role in determining the actual share of this mode within national transport systems.

Table 1. Inland waterway parameters and cargo transported in selected countries of the EU in 2023. Source: own work based on [2].

	Goods transport by inland waterways		National modal split	Length of inland waterways
	Thousand tonnes	Million tonnes-kilometre (TKM)	Percentage	km
European Union	468,849	116,405	5.0	
Austria	6,047	1,187	1.7	351
Belgium	159,990	6,952	10.7	2,043
Czechia	378	18	0.0	726
France	47,333	5,920	1.9	8,507
Germany	171,689	41,506	6.6	7,675
Hungary	5,200	1,316	3.2	1,575
Luxembourg	4,745	165	6.9	37
Netherlands	327,479	41,631	40.9	7,040
Poland	587	29	0.0	3,767
Romania	32,102	11,947	22.3	2,763
Switzerland	7,100	38	0.1	531

The largest volumes of freight transported through inland waterways were recorded in the Netherlands (327.5 million tonnes), Germany (171.7 million tonnes), and Belgium (160.0 million tonnes). These countries also possess some of the longest navigable inland waterway networks in the EU—7,040 km, 7,675 km and 2,043 km, respectively, indicating a strong correlation between the length of the waterway network and the intensity of inland waterway freight transport. In the Netherlands, inland water transport accounted for up to 40.9% of the national modal split, the highest figure in the EU. High shares were also recorded in Romania (22.3%), Belgium (10.7%), Luxembourg (6.9%), and Germany (6.6%). [2]

On the contrary, countries such as Poland, Czechia and France –despite having relatively extensive inland waterway infrastructure (3,767 km, 726 km and 8,507 km, respectively) –show very low freight volumes, ranging only several hundred thousand tonnes annually, and a marginal modal share of inland water transport. In both Poland and Czechia, this share was only 0.0%, and in France it reached just 1.9%. This may reflect a significant under-utilisation of the potential for inland navigation in these countries, possibly resulting from infrastructure limitations (for example, lack of continuous waterway routes that meet the required navigability parameters), organisational barriers, or insufficient integration with key industrial and logistics hubs. [2]

In terms of transport performance (measured in million tonne kilometres), which better reflects the scope and intensity of long-distance freight movement, the leading countries were Germany (41.5 billion

TKM), the Netherlands (41.6 billion TKM) and Romania (11.9 billion TKM).). It is worth noting that despite a comparatively lower volume of cargo, Romania achieved a relatively high transport performance, suggesting the significant use of inland waterways over long distances, mainly along the Danube River. Inland waterway freight transport among the selected European countries is characterized by significant variation in both the volume of goods transported and the sector's share in the overall modal split. Data from 2023 [2] indicate that countries with well-developed inland waterway infrastructure and supporting logistics networks achieve the highest volumes of freight transport and transport performance, which is reflected in their relatively high share of inland waterways in the national transport structure.

3 MATURITY MODELS AS A TRANSPORT SYSTEMS ASSESSMENT TOOL

Transport systems are essential for economic growth and social integration. They significantly influence quality of life by enabling the movement of goods and people, supporting industrial activity, and connecting regional and international markets. However, the structure of transport systems is complex, as it combines diverse technical, organizational, legal, and financial subsystems. These subsystems operate under different geographical, economic, and administrative conditions, making it challenging to create universal benchmarks for assessment. Traditional methods for evaluating transport systems often focus on isolated parameters, such as infrastructure condition, fleet size, or cost efficiency. While these metrics are important, they do not offer a comprehensive understanding of a transport system's overall development or readiness to respond to modern challenges such as digital transformation, environmental constraints, or integration with other modes. There is a growing need for tools that not only assess the current condition of transport systems, but also guide their development in a structured and consistent manner.

One promising approach that addresses this gap is the use of maturity models. Maturity models offer a multidimensional framework for assessment. They originated from the need to improve the quality and predictability of software development processes. The most influential concept, the Capability Maturity Model (CMM), was developed in the 1980s [3]. Its objective was to assess organisations' ability to manage projects effectively and mitigate operational risks, primarily in the IT sector. Since then, maturity models have been widely adapted to other fields, including healthcare, education, manufacturing, and, more recently, transport systems (e.g., [4], [5], [6], [7], [8]).

A maturity model is built around three fundamental components: (i) defined maturity levels, typically ranging from three to five, indicating a progression from initial or ad hoc stages to fully optimised and integrated processes; (ii) evaluation criteria, which outline the conditions that must be fulfilled at each level of maturity; (iii) development path, which illustrates how to move from a lower to a higher level by implementing specific actions. These models serve multiple purposes: to support benchmarking, identify gaps between current and desired state, guide strategic planning, and offer a tool for risk analysis. In the context of transport, they can be used to assess aspects such as safety, infrastructure coherence, operational efficiency, and regulatory alignment.

3.1 *Transport systems maturity model*

Despite mentioned examples, maturity models are rarely used to evaluate entire transport systems in a comprehensive manner. Most existing studies focus on isolated elements or single branches of transport, without considering the broader system interactions and the variety of stakeholders involved, e.g. [4], [5], [6], [7], [8]. To address this gap, the author has developed a Transport System Maturity Model (TSMM) aimed at assessing the maturity of transport systems as a whole [9].

The TSMM consists of three core domains:

– Fleet: which includes sub-parameters such as vehicle age, compliance with international standards (equipment), match to market demand (number and type), and human resources (crew number and competence).
– Infrastructure: subdivided into funding adequacy, linear infrastructure network coherence, point infrastructure intramodality potential, and the operation of administrative and safety services.
– Management System: with emphasis on legal and regulatory alignment, clarity and enforcement of procedures, and the efficiency of information exchange between system elements. [9]

Each sub-parameter is described across five maturity levels. For example, infrastructure funding ranges from insufficient even for maintenance (Level I) to comprehensive support for major investments (Level V). Similarly, legal regulations may range from non-alignment with supra-local law (Level I) to leading in setting regional standards (Level V). These clearly defined stages enable decision-makers to identify strengths, weaknesses, and areas for strategic intervention.

The strength of this model lies in its universality. While tailored to support comparisons within a single transport branch, it can be adapted to assess multiple modes (e.g. road, rail, inland waterways). Furthermore, it addresses both technical and organisational components, offering a more complete picture than traditional indicators. Importantly, the model also provides a roadmap for progress, identifying which actions are required to move to higher maturity levels and thereby enhance system effectiveness, sustainability, and integration.

The TSMM supports various applications: (i) benchmarking: comparing different systems or regions; (ii) strategic planning: identifying long-term improvement priorities; (iii) monitoring: allowing ongoing assessment and tracking of progress; (iv) policy support: informing infrastructure investment, regulation updates, or organizational reform.

3.2 *Inland navigation systems maturity model*

Building on the previously discussed transport system maturity model — designed as a universal framework applicable across various transport sectors — it was necessary to adapt the structure to the specific characteristics of individual transport branches. Recognizing the unique requirements of inland waterway transport, the author developed a dedicated Maturity Model for Inland Waterway Transport Systems, presented in publication [10]. The adapted model retains the original structure of key parameter groups (fleet, infrastructure, and operations) but incorporates refinements and subcategories tailored to the inland navigation context.

Fleet parameters are subdivided into four elements:

- Age: The vessel fleet is categorised based on the average age of units, reflecting ongoing modernisation and higher operational performance.
- Navigation equipment: The model recognises the progressive integration of navigational technology. This sub-parameter is specifically described due to its unique relevance to inland navigation and lower general familiarity compared to other transport sectors.
- Fleet number: This factor evaluates the alignment between the quantity and type of vessels and market demand. It reflects not only adequacy but also proportionality, assessing whether the fleet's capacity and composition meet current and anticipated transport needs.
- Crew: This criterion assesses both the availability and competence of fleet personnel. Progression across maturity levels reflects increasing sufficiency and professional qualification of crews, essential for safe and efficient inland navigation operations.

Infrastructure parameters cover four critical dimensions:

- Financing: This sub-parameter evaluates whether the funds allocated for infrastructure maintenance and development are sufficient. The highest maturity level implies support not only for current operations but also for large-scale investments and strategic growth.
- Linear infrastructure: The model assesses the coherence of the waterway network and its connectivity with other regional or international systems. It distinguishes between isolated segments and fully integrated, cross-border networks.
- Point infrastructure: The availability and efficiency of transhipment points are essential in inland navigation, where intermodal operations are frequent. Higher maturity levels indicate full intermodal compatibility and operational integration.
- Maintenance strategy: Introduced in this model as a distinct sub-parameter, the evolution of maintenance approaches is traced from reactive practices (responding post-failure) to proactive systems that emphasise predictive analytics and condition-based interventions. The inclusion of this dimension highlights the increasing importance of maintenance planning in infrastructure resilience.

System operations (originally labelled as the management system) are also assessed through four components:

- Safety and security services: Originally part of infrastructure, this factor is now recognised as operational. It tracks the development from inconsistent or limited administrative presence to fully functional and development-supportive safety and security systems.
- Regulations: This element evaluates the alignment between local and supra-local (e.g., international) legal frameworks. Maturity reflects the degree of legal responsiveness, ranging from delayed adaptation to proactive norm-setting.
- Procedures: This sub-parameter focuses on the operational clarity, enforceability, and simplicity of rules governing fleet operation and transportation processes. Higher levels indicate the implementation of efficient, standardised, and user-friendly procedures.
- Information flow: Effective communication and data exchange between system components is essential in modern transport systems. The model assesses the shift from poor or fragmented communication to fully integrated, digital, and real-time information systems. [10]

The model provides a structured, scalable, and replicable method for assessing and comparing inland waterway systems. It supports strategic planning by identifying development gaps, benchmarking system performance, and guiding investments and policy decisions. Its application in this publication — demonstrated through examples from selected European countries — aims to validate its effectiveness and illustrate its practical utility in the context of sustainable transport development.

The exact structure of the model, divided into maturity levels for individual criteria, is presented in Table 2.

Importantly, the model applies relative assessment principles — it does not impose fixed quantitative thresholds. For instance, in assessing fleet adequacy, the model considers whether the number and type of vessels are aligned with current and projected demand, rather than prescribing a specific numerical value. Similarly, linear infrastructure is evaluated based on network connectivity and interoperability, rather than on predefined route lengths or counts. For this reason, the use of the model requires expert knowledge.

Table 2. The maturity model for assessment of inland waterways transport systems. Source [10].

Parameters		Maturity Level I	II	III	IV	V
Fleet	Age	Most of the fleet is over 20 years old	Most of the fleet is over 15 to 20 years old	Most of the fleet is over 10 to 15 years old	Most of the fleet is over 5 to 10 years old	Most of the fleet is 5 years old or less
	Navigation equipment	No navigation equipment	Paper maps and GPS	Level II and radar, AIS, and ECDIS	Level III and ERI, autopilot, and steering assistance	Level IV and automatic steering, and collision prevention equipment
	Number	Fleet number and type significantly exceeds or falls below market needs	Fleet number or type meets market needs, but the other factor significantly exceeds or falls below market needs	Fleet number and type are slightly below or slightly above market needs	Fleet number or type meets market needs, but the other factor is slightly above or below market needs	Fleet number and type meet market needs in the long term
	Crew	Number and competency of fleet and process staff do not meet the demand	Number or competency of fleet and process staff does not meet demand	Number and competency of fleet and process staff are slightly below demand	Number or competency of fleet and process staff is slightly below demand	Number and competency of fleet and process staff meet the demand
Infrastructure	Financing	Funds allocated for infrastructure maintenance do not cover current needs	Funds allocated for infrastructure maintenance cover current needs	Funds allocated for infrastructure maintenance cover current needs and minor preventive measures	Funds allocated for infrastructure maintenance cover current needs and investments	Funds allocated for infrastructure maintenance cover current needs and large-scale investments
	Linear infrastructure	Linear infrastructure does not create a network	Linear infrastructure creates a network with certain limitations	Linear infrastructure creates a coherent network and connects to the network of another region	Linear infrastructure creates a coherent network and connects with networks of other regions	Linear infrastructure creates a coherent network and connects with all neighbouring networks
	Point infrastructure	Point infrastructure is insufficient and does not allow for inter-branch transshipment	Point infrastructure is insufficient but allows for some inter-branch transshipments	Point infrastructure is sufficient and allows for some inter-branch transshipments	Point infrastructure is sufficient and allows for inter-branch transshipment	Point infrastructure fully integrates available transport modes
	Maintenance	Reactive maintenance	Prevent maintenance	Condition-based maintenance	Predictive maintenance	Proactive maintenance
System operations	Operation of safety and security services	Administration and security services do not operate to the appropriate extent	Administration or security services do not operate to the appropriate extent	Administration and security services operate to the extent that allows maintaining the current status quo	Administration and security services operate to the extent that allows for the improvement of the current situation	Administration and security services ensure the development of the system
	Regulations	Local regulations do not correspond to supra-local regulations	Local regulations correspond to supra-local regulations to a minimum extent and are introduced with a delay	Local regulations are adapted to supra-local regulations with a slight delay	Local regulations are constantly being adapted to supra-local regulations	Local regulations set the directions for creating supra-local regulations
	Procedures	Regulations and procedures governing the fleet and transport process are unclear and unenforced	Regulations or procedures governing the fleet and transportation process are unclear and unenforced	Regulations and procedures governing the fleet and transportation process are complicated	Regulations and procedures governing the fleet and transportation process are clear	Regulations for governing the fleet and transportation process are clear and as simple as possible
	Information flow	Information flow between system elements is very difficult	Information flow between some system elements is hindered	Information flow between system elements is efficient	Most information flows between system elements occur online	Information flow between system elements occurs online

4 RESULTS -MATURITY OF INLAND NAVIGATION SYSTEMS IN EUROPE

Using the inland navigation maturity model, the inland navigation systems of 11 European countries and the Rhine were assessed. The assessment was carried out by the author based on her own knowledge and professional experience, without the participation of other independent experts. This decision was made consciously, due to the nature of the assessment model used and the specificity of the systems examined.

The inland navigation maturity model described in the previous part of the article is based on a set of criteria, some of which are objective and measurable (e.g. fleet age, level of navigation equipment, type of linear infrastructure), while others require interpretation and expert assessment (e.g. compliance of local regulations with supra-local ones, adequacy of the number of units to market needs, level of integration with other modes of transport). According to the literature on maturity models, especially those adapted for the needs of transport systems, factors requiring subjective assessment are an integral part of such tools and cannot be completely eliminated.

All assessed systems were analysed based on the same set of criteria and by the same person, which eliminates the risk of incomparability of results resulting from differences in the perception of the assessors. In comparative studies, such an approach is justified, as it allows for maintaining methodological consistency and a uniform point of reference. The results for all parameters are presented in Table 3 and on Figure 1.

Table 3. The maturity levels of selected European inland navigation systems. Source own work.

		Austria	Belgium	Czech	France	Germany	Hungary	Luxembour	Netherlands	Poland	Rhine	Romania	Switzerland
Fleet:	Age	3	4	1	3	4	2	3	5	1	4	1	3
	Navigation equipment	4	4	3	4	4	4	4	5	3	5	2	4
	Number	4	4	3	4	4	3	4	5	3	5	3	4
	Crew	3	4	2	3	4	2	5	5	2	4	2	5
Infrastructure:	Financing	3	3	2	3	4	1	3	5	2	4	1	3
	Linear infrastructure	3	4	2	3	4	3	3	5	2	5	3	3
	Point infrastructure	3	4	2	3	4	3	3	5	2	5	3	3
	Maintenance	3	4	2	3	4	3	3	5	2	5	3	3
System operations:	Operation of safety and security services	3	4	2	3	4	3	3	5	2	5	3	3
	Regulations	5	4	3	4	4	3	4	5	3	5	3	4
	Procedures	4	4	3	4	4	3	5	4	3	4	2	5
	Information flow	3	4	2	2	4	3	3	5	2	5	2	3

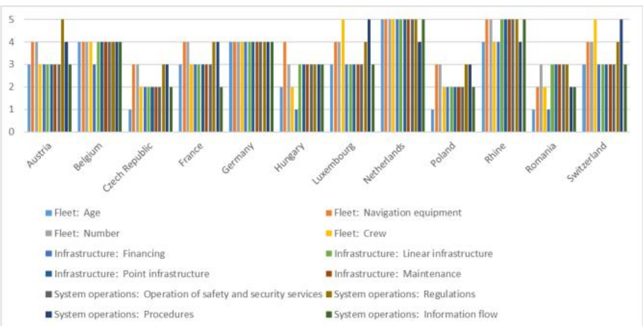

Figure 1. The maturity levels of selected European inland navigation systems. Source own work.

Austria presents a moderately developed inland navigation system, mainly concentrated on the Danube River. In terms of the fleet, the vessels reach level 3 in terms of age – most of them are between 10 and 15 years old. The navigation equipment was assessed at level 4, which indicates an advanced implementation of radar, AIS and electronic chart systems (ECDIS). The number and type of the fleet (level 4) are adequate to the market needs, although shipping in Austria is rather regional. The staff was assessed at level 3 – balanced, although with limited growth potential. The infrastructure along the Austrian section of the Danube is well maintained, although financing remains at an average level (3). The linear and point network, including ports and terminals, was assessed at level 3 – sufficient, but requiring better integration with other modes of transport. The infrastructure maintenance strategy is also level 3 – activities are systematic, but not fully predictive. The operational system is developed. The regulations are fully compliant with international standards (level 5), and the procedures and safety services reach levels 3–4. The flow of information is partially computerised (level 3), which allows for efficient, although not fully automated, management.

The inland navigation system in Belgium is characterised by a high degree of integration and modernisation, especially in the Flanders region, where water transport is an important element of freight logistics. The fleet is modern (level 4), well-equipped technologically (4), and the number and type of units are adapted to market needs (4). The crewing was assessed at level 4, which indicates a well-prepared, although not fully diversified, workforce. The infrastructure is one of the best developed in Europe – a dense network of canals, locks and ports allows for efficient movement of cargo. Linear, point infrastructure, and maintenance systems reach level 4. Financing is rated slightly lower (3), which may be due to differences in interregional management (Flanders-Wallonia), although access to EU funds significantly supports development. The operational system is mature: the operation of security services and the quality of regulations and procedures are rated at level 4. The flow of information also functions well (4), especially in the area of data exchange between the administration and the operator. Belgium stands out for its strong emphasis on digitalisation and interoperability within the TEN-T network.

The Czech Republic has a poorly developed inland navigation system, mainly limited to the lower reaches of the Elbe and a few short canal sections. In terms of the fleet, the situation is difficult - most units are over 20 years old (level 1), which significantly affects efficiency and safety. Navigation equipment is rated at level 3 - the presence of basic systems such as GPS or radar is standard, but more advanced technologies are rare. The fleet is insufficient in numbers (3), and the availability and competence of crews is limited (2). Infrastructure also remains underinvested. Funding (2) does not provide for large-scale investments, and the linear and point networks are fragmented (level 2). Infrastructure maintenance is also rated low, which translates into low availability and reliability of shipping routes. The operational system is characterized by low coherence. Safety services and regulations and procedures are rated at level 2-3. Information flow (2) is weak - lack of integrated traffic management systems and low digitalization result in limited efficiency. The Czech Republic has been declaring its desire to develop shipping for years, but the lack of strategic investments and modernization limits real progress.

The French inland navigation system, mainly managed by Voies Navigables de France (VNF), comprises one of the largest inland waterway networks in Europe (over 6,700 km). The fleet is at a moderate level of maturity: the age of the vessels is in the average range (level 3), the navigation equipment is at a high level (4) and the fleet structure is relatively adapted to needs (4). Staffing is average (3), reflecting the lack of intensive investment in professional development in the sector. The infrastructure in France is extensive but not fully modern. Financing is rated at level 3 – it allows the maintenance of the network but does not support extensive modernisation. Both the linear and point infrastructure are rated at level 3. The maintenance strategy is planned but not systematic (3). The operational system shows maturity in the regulatory and procedural areas (4), with well-established regulations and functioning services (3). The flow of information remains limited (2), with slow digitalisation and a dispersed management structure.

The inland navigation system in Germany is one of the most developed and integrated in Europe. It covers approx. 7,300 km of navigable waterways, with a strong emphasis on freight transport along the Rhine, Elbe or Dortmund-Ems Canal. The German fleet presents a high level of modernity: the units are relatively young (4), perfectly equipped with navigation systems (4), adequate in numbers (4) and the staff is highly qualified (4). The infrastructure is supported by strong, stable financing (4), enabling not only current maintenance, but also modernisation of waterways and hydrotechnical facilities. The linear and point infrastructure was assessed at level 4 – a dense network and good connections to land ports are the hallmarks of the system. The maintenance strategy also operates at a high level (4), with increasing use of predictive systems. The operating system is coherent and integrated. The safety services, legal framework and procedures reach level 4, ensuring operational stability. The flow of information is well developed (4), with extensive use of RIS systems, reporting platforms and electronic traffic management.

Hungary's inland navigation system is mainly based on the Danube, which is a key transport route for the country. However, its use does not reach the potential similar to Germany or Austria. The fleet is quite outdated - most units are over 15 years old (level 2). However, the navigation equipment is relatively advanced (4), which indicates partial technological modernization. The number of units and types of fleet partially correspond to market needs (3), but the competences of the crews are limited (2), which may be due to the lack of systemic support for training. The infrastructure is at a lower level of maturity. Financing was rated the lowest (1), which significantly limits the possibilities for modernization. The linear, point and maintenance infrastructure was rated at level 3 - basic functionality is provided, but without development reserve. The operational system reaches an average level: services, regulations and procedures are rated at level 3, which suggests compliance with international requirements, but without excessive flexibility. The flow of information is also at level 3 – reporting systems are in place, but their integration and availability are limited.

The inland navigation system in Luxembourg, despite the small size of the country, is functionally integrated with the Rhine system and the European network (TEN-T). The fleet achieves good parameters: the average age of the units (3) is not particularly low, but the navigation equipment is advanced (4), and the number and type of units are adapted to the needs (4). The highest ratings were given to the competence and availability of the crews (5), which reflects the high standard of service and operational efficiency. The country's infrastructure is of a supporting nature, not independent - it mainly serves a transit function. Financing and the infrastructure network were rated at level 3 - they ensure efficient operation, although without a large scale of investment. The maintenance strategy is planned and effective (3). The operational system achieves a high level. The operation of services, compliance with regulations and procedures operate at level 4-5, indicating adaptation to European standards. The flow of information within the system was rated at level 3 - the system operates efficiently, although it does not achieve full digital integration as in the Netherlands.

The Netherlands is the undisputed leader of European inland navigation. The system is highly developed, fully integrated with national and international logistics. The fleet presents the highest level in all categories: very young (5), fully equipped with advanced technologies (5), numerically and typically adapted to the market (5), and the staff is highly qualified (5). The infrastructure in the Netherlands is a model example of sustainable and modern management. Both the linear and point networks were rated at level 5. Financing is stable and high, which allows for the implementation of strategic and adaptive projects. The maintenance strategy is comprehensive and predictive (5), using monitoring systems and data analytics. The operational system is characterized by the highest level of integration. The services operate efficiently (5), and the procedures are standardized and transparent (4). The flow of information (5) is fully digital - the Netherlands was the first to implement advanced RIS systems, and cooperation between the administration and operators is an example of good practice at EU level.

The Polish inland navigation system has great potential, but remains one of the least developed in Europe. Despite the existence of several major navigable rivers (Oder, Vistula), their actual availability and technical quality are limited. The fleet is clearly outdated (1), equipped with basic technologies (3), and the number of units does not correspond to the real demand (3). Technical and operational staff remains unevenly available (2) (there are many specialists working outside Polish system). The infrastructure was assessed low: financing is limited and irregular (2), which translates into the fragmentation of the linear and point network (2). The maintenance strategy is planned, but not based on the analysis of the technical condition - level 2 reflects the lack of predictive implementation and low repair efficiency. The operational system is at a medium level of maturity. Regulations are partially compliant with EU standards (3), but require adaptation to practice. Management procedures were assessed at level 3 - they are present, but not always applied. The flow of information (2) remains limited, with a lack of digital solutions in key links of the system.

Romania has a large shipping potential linked to the Lower Danube and the port of Constanta, but the use of this infrastructure is still limited. The Romanian fleet is outdated – most of the vessels are over 20 years old (1), poorly equipped with navigation systems (2), the number of vessels and their types do not fully meet the needs (3). The operational staff was assessed at level 2 – staff shortages and staff turnover are problems. The infrastructure is functioning at a basic level. Financing was assessed very low (1), which affects limited development and modernisation. Despite the presence of a long section of the Danube, the linear and point network was assessed at level 3 – functionality is maintained, but integration with other modes of transport is lacking. The maintenance strategy is also basic (3). The operational system is characterised by medium maturity. The services and regulations operate at level 3 – in line with the European framework, but often ineffective in practice. The procedures are of low transparency (2), and the flow of information (2) takes place mainly in the traditional form, without wider digitalisation.

Switzerland, despite not having a wide inland navigation network, actively participates in traffic on the Rhine and plays an important logistical role through the port of Basel. The fleet is moderately modern (3), well-equipped (4), numerically adapted to needs (4), and the crews achieve a very high level of qualifications (5) – which is the result of the national transport quality policy. The infrastructure is functional and supported by systems integrated with the German and French water networks. Despite the lack of an extensive internal network, the point and linear infrastructure in the Basel area operates efficiently (3), financing and maintenance are stable (3). The operating system was rated high. The safety services and the regulatory framework operate effectively (3–4), the procedures are standardized and easy to use (5). The information flow is partially computerized (3), with access to systems shared with Rhine (e.g. RIS), although without full national digitalization.

The Rhine inland navigation system (covering several countries, including Germany, the Netherlands, France and Switzerland) is the most important water corridor in Europe and the main axis of the trans-European TEN-T network. The fleet operating on the Rhine is among the most modern (4), fully equipped with ECDIS, AIS, autopilot and collision devices (5), adequate to the needs (5) and operated by qualified crews (4). The infrastructure was assessed as the highest possible – the linear and point network is extensive, interoperable, and systematically developed (5), and maintenance is carried out in a predictive manner. Financing is stable and adapted to the needs of expansion and adaptation to climate change (4). The operational system is fully mature: services operate efficiently and coordinate across borders (5), regulations are unified within the AGN and CCNR conventions (5), procedures are harmonised (4). The information flow (5) is digital and real-time, supported by RIS systems and common reporting platforms, providing a reference point for the entire EU.

5 CONCLUSIONS

The evaluation of 12 inland navigation systems in Europe showed significant differences in their level of development, organisation and the degree of utilisation of the potential of inland waterway transport. By analysing three main areas, fleet, infrastructure, and operational system, it is possible to distinguish both leaders and countries requiring intensive modernisation.

The Netherlands received the highest scores in all areas analysed. Its fleet is modern, technologically advanced, and numerically adapted to market needs. The water infrastructure is the best developed in Europe – interoperable, well-financed and perfectly maintained. The operational system in the Netherlands achieves full digitalisation, efficiency of services, and transparency of procedures. The Netherlands can serve as a model for a comprehensive approach to inland navigation. The Rhine system, considered as a cross-border whole, also presents a high level of maturity. It benefits from strong international structures (CCNR) and excellent hydrotechnical infrastructure. Both the fleet and the water traffic management system are highly organised and coordinated between countries. Germany is just behind the Netherlands and the Rhine. Their inland navigation system combines a modern fleet with well-maintained infrastructure and a high level of operation. Germany stands out for its strong integration with land transport systems and the high capacity of the main routes (Rhine, Elbe, and inland canals).

Belgium and Luxembourg demonstrate high quality in terms of system organisation, infrastructure, and fleet, although their operational scale is smaller. Belgium, especially Flanders, invests consistently in water infrastructure and promotes water transport as an element of sustainable logistics. Despite its territorial limitations, Luxembourg operates effectively as a system integrated with the Rhine. Switzerland and Austria are countries with a moderate but stable level of system development. In both cases, the infrastructure is mainly based on one route (Rhine/Basel and Danube), but good organisation and a relatively high level of operation have been achieved. In Austria, the strong link between navigation and environmental policy is noteworthy.

France has a large network of waterways, but it does not fully exploit it – there is no coherent policy for the development and modernisation of the fleet and infrastructure. Information flow remains limited, which negatively affects operational efficiency. Hungary has potential thanks to the Danube, but low financing and an outdated fleet limit development. There is also no coherent strategy for infrastructure modernisation. The Czech Republic, Poland, and Romania are countries with a low level of system maturity. All are characterised by an outdated fleet, insufficient financing of infrastructure, and a low level of digitalisation. Poland has the greatest growth potential in the region, but requires significant investments, especially in linear infrastructure (e.g. Oder, Vistula). Romania, despite its strategic location on the Danube and access to the Black Sea, does not fully exploit these resources. The Czech Republic, on the other hand, struggles with fragmented infrastructure and a lack of high-standard transit corridors.

The priority for systems with a low level of maturity should be investments in linear and point infrastructure and fleet renewal. An important step will be the development of staff competencies and the implementation of integrated information and traffic management systems (RIS). Highly developed countries such as the Netherlands can act as mentors and reference points in the development of policies for less advanced systems. Integration with the TEN-T network, interoperability, and process automation are key to the further sustainable development of European inland navigation.

The analysis carried out of the maturity of inland navigation systems in selected European countries using the author's maturity assessment model confirms the usefulness of such tools in diagnosing the state of development of individual elements of the transport system. Basing the model on three dimensions: fleet, infrastructure, and operating system allows for capturing both physical and organisational aspects of the functioning of navigation. Such an approach allows not only the identification of strengths and weaknesses in individual countries but also supports the formulation of directional political and investment recommendations. Maturity models, although sometimes perceived as qualitative tools, can provide significant support for decision-making processes, especially in the absence of uniform comparative data on an international scale. Their use also facilitates benchmarking analyses which, similarly to the industrial sector, can lead to the identification of good practices and development models that can be adapted in other geographical contexts. In this sense, the model presented in the article can be developed and adapted to the needs of broader European analyses, and also serve as a starting point for building harmonized tools for assessing inland navigation systems within the framework of EU policies.

Based on the results obtained, several general recommendations can be indicated. Firstly, for countries with low infrastructure maturity, it will be crucial to ensure stable and long-term investment programmes that aim to maintain and modernise the basic waterway network. Second, not less important are the actions for the digitalisation and integration of operational systems, which determine the increase in efficiency and competitiveness of water transport compared to other branches. Finally, the fleet - although often omitted in the public debate - requires a systemic approach to its renewal, both through financial support instruments and the creation of predictable market conditions encouraging investments.

The application of the maturity model to the assessment of inland navigation systems shows that a comprehensive approach to the development of this sector must combine infrastructure, technological, and institutional activities. Only then will it be possible to fully use the potential of water transport in achieving the goals of sustainable mobility in Europe.

REFERENCES

[1] “Inland Navigation Market.” [Online]. Available: https://inland-navigation-market.org/quarter/q1-en/?lang=en

[2] “Eurostat.”

[3] R. Wendler, “The maturity of maturity model research: A systematic mapping study,” in Information and Software Technology, Dec. 2012, pp. 1317–1339. doi: 10.1016/j.infsof.2012.07.007.

[4] A. Núñez, “Estimating the functional form of road traffic maturity”, doi: 10.1007/s11067-007-9049-0ï.

[5] V. Laine, O. Valdez-Banda, and F. Goerlandt, “Risk maturity model for the maritime authorities: a Delphi study to design the R-Mare matrix model,” WMU Journal of Maritime Affairs, vol. 23, no. 2, pp. 137–163, Jun. 2024, doi: 10.1007/s13437-023-00328-z.

[6] D. R. Utama, M. Hamsal, S. B. Abdinagoro, and R. K. Rahim, “Developing a digital transformation maturity model for port assessment in archipelago countries: The Indonesian case,” Transp Res Interdiscip Perspect, vol. 26, Jul. 2024, doi: 10.1016/j.trip.2024.101146.

[7] M. G. Yoon and J. K. Kim, “Evaluation methodology for safety maturity in air navigation safety,” J Air Transp Manag, vol. 98, Jan. 2022, doi: 10.1016/j.jairtraman.2021.102159.

[8] I. Hausladen and M. Schosser, “Towards a maturity model for big data analytics in airline network planning,” J Air Transp Manag, vol. 82, Jan. 2020, doi: 10.1016/j.jairtraman.2019.101721.

[9] E. T. Skupień, “Maturity model for transport system assessment,” 12th Carpathian Logistics Congress, CLC’2024 : conference proceedings, November 28 - 29, Kraków, Poland, 2025.

[10] E. T. Skupień, “The Maturity Model as a Tool for Assessing Transportation Systems on the Example of Inland Navigation,” Sustainability, vol. 17, no. 4, p. 1577, Feb. 2025, doi: 10.3390/su17041577.