

ADAPTIVE TRAINING SCENARIO GENERATION SYSTEM FOR INLAND WATERWAY CREWS BASED ON PERFORMANCE ANALYTICS IN A SIMULATED ENVIRONMENT

Abstract. The growing demands for safety and efficiency in inland waterway transport create a need for the modernization of crew training systems. Current simulator-based training programs are predominantly based on standardized scenarios that do not take into account the individual level of knowledge and skills of trainees. The aim of this paper is to present a concept of an adaptive training scenario generation system based on the analysis of performance data obtained during simulator training. The proposed model utilizes simulation performance data to identify areas with insufficient competency levels and subsequently recommends additional training scenarios aimed at addressing the identified deficiencies. The system links performance assessment with the requirements of European standards for professional qualifications of inland waterway crew members and provides a foundation for personalized training. The proposed approach may contribute to more effective competency development, improved navigation safety, and further digitalization of professional education and training processes in inland navigation.

Keywords: Adaptive Training, Navigation Simulator, Performance Analytics, Professional Competencies, Inland Waterway Transport, Navigation Safety

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Introduction

The development of inland waterway transport in Europe is increasingly influenced by digitalization, automation, and growing requirements for navigation safety. Alongside investments in transport infrastructure and vessel modernization, considerable attention is being devoted to the professional competencies of inland navigation crew members. Human factors continue to represent one of the most significant contributors to navigation incidents and operational errors, highlighting the importance of effective education and training systems capable of preparing crews for increasingly complex operational environments.

The European Union has responded to these challenges through the harmonization of qualification requirements for inland navigation personnel. Directive (EU) 2017/2397 established a common framework for professional qualifications, while the Delegated Directive (EU) 2020/12 introduced detailed standards of competence, practical examinations, and simulator-based assessment procedures. These regulations emphasize the acquisition and verification of competencies related to navigation, manoeuvring, communication, emergency response, risk management, and the operation of navigation technologies.

In recent years, navigation simulators have become an integral component of professional training in inland waterway transport. Modern simulators enable trainees to practice navigation tasks under realistic conditions while eliminating the risks associated with real-world operations. Unlike conventional training methods, simulator-based training provides a controlled environment where specific operational situations can be repeated, modified, and objectively evaluated.

Furthermore, simulators generate extensive operational datasets that can be used to analyse trainee behaviour and performance throughout the training process.

Despite the widespread use of simulators, most existing training programmes remain based on predefined training scenarios applied uniformly to all trainees. This approach provides standardization but does not adequately reflect individual differences in competency levels, learning progress, or specific performance deficiencies. As a result, training efficiency may be reduced, as participants are often exposed to scenarios that do not correspond to their actual training needs.

Similar challenges have been addressed in other safety-critical sectors, including aviation, healthcare, and military training, through the implementation of adaptive learning systems. These systems continuously evaluate trainee performance and dynamically adjust educational content according to identified strengths and weaknesses. Adaptive approaches have demonstrated the ability to accelerate learning processes, improve competency acquisition, and increase overall training effectiveness.

The growing availability of performance data generated by navigation simulators creates opportunities for the implementation of similar adaptive principles within inland navigation training. Parameters such as vessel trajectory deviations, reaction times, communication performance, collision avoidance behaviour, and navigational decision-making can be objectively measured and analysed. These data provide valuable insights into trainee competencies and create a foundation for the development of personalized training pathways.

At the same time, the ongoing digital transformation of inland waterway transport promotes the integration of data-driven approaches into education and training

systems. Modern concepts of competency-based education increasingly emphasize continuous assessment, evidence-based decision-making, and the utilization of operational data to support learning processes. Within this context, adaptive simulator training represents a promising direction for improving both training quality and navigation safety.

The objective of this paper is to propose a conceptual framework for adaptive training scenario generation based on performance analytics obtained from simulator-based training of inland waterway crews. The proposed model utilizes operational performance indicators to identify competency deficiencies and subsequently recommends targeted training scenarios designed to improve specific areas of professional competence. By linking performance assessment with competency requirements defined by European qualification standards, the framework aims to support individualized training, enhance learning effectiveness, and contribute to safer inland navigation operations.

1. Methodology

The methodological framework of this paper is based on a conceptual research approach combining literature analysis, review of European qualification standards, and the design of a competency-oriented adaptive training model. The research draws upon the requirements established by Directive (EU) 2017/2397, Delegated Directive (EU) 2020/12, and the European Standard for Qualifications in Inland Navigation (ES-QIN).

The study applies a qualitative analysis of competency requirements for inland waterway crew members and identifies performance indicators that can be obtained from simulator-based training environments. Subsequently, these indicators are linked to specific competency areas in order to create a framework capable of identifying performance deficiencies and recommending appropriate training scenarios.

The proposed adaptive training model was developed through the synthesis of competency-based education principles, simulator performance analytics, and adaptive learning concepts commonly applied in other safety-critical sectors such as aviation and maritime education.

The outcome of the methodological process is a conceptual framework describing the relationship between simulator-generated performance data, competency assessment, deficiency identification, and adaptive scenario selection.

2. Competency-Based Approach in Inland Waterway Crew Training

The development of professional qualifications in inland waterway transport has undergone significant changes in recent years. Traditionally, the assessment of crew members focused primarily on theoretical knowledge and practical experience acquired during vessel operations. However, increasing traffic density,

technological advancement, and growing safety requirements have highlighted the need for a more structured and competency-oriented approach to education and training.

Within the European Union, the competency-based approach has become the foundation of professional qualification systems for inland navigation personnel. The adoption of Directive (EU) 2017/2397 introduced harmonized requirements for the recognition of professional qualifications across Member States and established a common framework for crew education and assessment. The directive was subsequently supplemented by Delegated Directive (EU) 2020/12, which specifies standards of competence, practical examination requirements, simulator assessment procedures, and the use of modern training technologies.

Unlike traditional knowledge-based systems, competency-based training focuses on the ability of trainees to perform operational tasks safely and effectively in real-world situations. This approach combines theoretical understanding, practical skills, decision-making capabilities, communication competencies, and situational awareness into a unified framework of professional performance.

The European Standards for Qualifications in Inland Navigation (ES-QIN) define a comprehensive set of competencies that crew members must demonstrate during training and certification processes. These competencies are grouped into several areas including navigation and manoeuvring, cargo operations, communication, emergency response, safety management, and the operation of navigational equipment. The framework emphasizes not only technical proficiency but also the ability to react appropriately under dynamic operational conditions.

The increasing complexity of inland navigation operations requires training systems capable of evaluating these competencies in a realistic and measurable manner. Navigation simulators have therefore become an important component of modern maritime education. Simulators allow trainees to practice vessel handling, navigation decision-making, communication procedures, and emergency situations under controlled conditions while enabling instructors to observe and evaluate performance without exposing personnel or equipment to actual risks.

One of the main advantages of simulator-based training is the possibility of objective performance measurement. During simulation exercises, various operational parameters can be continuously monitored and recorded. These parameters provide valuable information regarding the trainee's ability to apply acquired knowledge in practice and offer a more comprehensive assessment than traditional examination methods.

Despite the existence of competency frameworks and simulator technologies, current training programmes often remain standardized and identical for all participants. Such an approach may not fully support the individual development of competencies, as trainees

frequently exhibit different strengths and weaknesses. Consequently, there is a growing need for training systems capable of adapting educational content according to the actual performance and competency profile of each trainee.

The implementation of adaptive training principles requires a clear relationship between professional competencies and measurable performance indicators. Establishing this relationship enables objective competency assessment and creates a foundation for data-driven training management.

Table 1 presents a proposed relationship between selected competency areas and performance indicators that can be monitored during simulator-based training.

Table 1. Relationship between Crew Competencies and Performance Indicators

Competency Area	Performance Indicator	Description	Assessment Objective
Navigation and manoeuvring	Track deviation (m)	Deviation from the planned navigation route	Assessment of vessel handling accuracy
Navigation and manoeuvring	Number of rudder corrections	Frequency of steering interventions during navigation	Assessment of manoeuvring stability
Situational awareness	Reaction time (s)	Time required to respond to a developing navigation situation	Evaluation of hazard recognition capability
Collision avoidance	Number of collision-risk situations	Recorded situations with collision potential	Assessment of safe navigation behaviour
Communication	Number of communication errors	Incorrect or incomplete communication procedures	Evaluation of crew coordination effectiveness
Emergency response	Emergency response completion time (s)	Time required to perform emergency procedures	Assessment of crisis management capability
Navigation equipment operation	AIS/ECDIS operation accuracy (%)	Correct use of navigational information systems	Evaluation of technical competence
Decision making	Correctness of operational decisions (%)	Proportion of appropriate decisions in simulated situations	Assessment of operational judgement
Traffic management	Compliance with navigation rules (%)	Degree of adherence to inland navigation regulations	Evaluation of regulatory compliance
Overall performance	Composite performance score	Aggregated evaluation of all monitored indicators	Overall competency assessment

Table 1 presents the proposed relationship between selected competency areas defined by European inland navigation qualification standards and measurable performance indicators obtained from simulator-based training. The identified indicators enable objective assessment of trainee

performance and provide the foundation for adaptive training systems capable of identifying competency deficiencies and recommending targeted training scenarios.

3. Performance Analytics in Simulator-Based Training

The increasing use of simulator technologies in inland waterway transport has significantly expanded the possibilities for objective performance assessment. While simulators have traditionally been used as training tools, modern systems also function as advanced data collection platforms capable of recording detailed information about trainee behaviour and operational performance. These capabilities create opportunities for a more comprehensive evaluation of competencies and support the implementation of data-driven training approaches.

One of the main advantages of simulator-based training is the ability to continuously monitor trainee actions throughout the entire exercise. Unlike conventional practical training, where performance assessment often depends on instructor observations, simulator environments automatically record operational parameters and generate measurable performance data. This enables objective evaluation and reduces the influence of subjective judgement.

3.1 Simulator-Generated Performance Data

Modern inland navigation simulators generate a wide range of operational data describing vessel movement, trainee actions, communication procedures, and responses to various navigation situations. These data can be divided into several categories.

The first category includes navigation data such as vessel position, heading, speed, track deviation, and route adherence. These parameters provide information about the trainee's ability to maintain safe and accurate vessel navigation.

The second category consists of vessel control data, including rudder commands, engine control inputs, manoeuvring actions, and course corrections. These indicators reflect the trainee's vessel handling skills and operational stability.

Safety-related data form another important category. Simulators can record collision warnings, near-miss situations, violations of safe distances, and responses to hazardous events. Such information is particularly valuable for assessing situational awareness and risk management capabilities.

Communication data may also be collected during simulator exercises. These data include radio communication procedures, reporting accuracy, and compliance with established communication protocols. Effective communication is a critical component of safe inland navigation and therefore represents an important area of competency assessment.

In addition, simulator systems can generate operational performance data related to task completion times, emergency response actions, and compliance with navigation regulations. These indicators provide further insights into trainee performance under different operational conditions.

Table 2. Examples of Simulator-Generated Data

Data Category	Example Indicators
Navigation data	Position, speed, heading, track deviation
Vessel control data	Rudder angle, engine commands, manoeuvring actions
Safety data	Collision alerts, near – miss events, safe distance violations
Communication data	Radio communication accuracy, reporting compliance
Operational data	Task completion time, emergency response performance

3.2 Performance Indicators for Competency Assessment

Although simulator environments generate large quantities of operational data, raw data alone do not provide meaningful information regarding competency levels. Therefore, it is necessary to transform recorded operational parameters into performance indicators that can be linked to specific competency areas.

Track deviation is one of the most commonly used indicators for evaluating navigation and manoeuvring performance. Significant deviations from the planned navigation route may indicate deficiencies in vessel control or situational awareness.

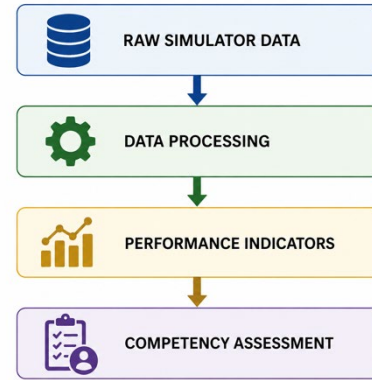
Reaction time represents another important indicator. It measures the period between the occurrence of a navigation event and the trainee's response. Shorter reaction times generally indicate higher levels of situational awareness and operational readiness.

Communication accuracy can be assessed through the analysis of radio communication procedures and message correctness. Errors in communication may reveal weaknesses in teamwork and operational coordination.

Collision-risk events provide valuable information regarding safety-related competencies. Frequent occurrence of near-miss situations may indicate inadequate hazard perception or inappropriate decision-making.

Decision accuracy evaluates the appropriateness of actions taken during simulated operational scenarios. This indicator is particularly important in complex navigation situations where multiple response options are available.

The transformation of simulator-generated data into performance indicators creates a structured basis for competency assessment and supports evidence-based training management.

**Fig. 1.** Transformation of Simulator Data into Performance Indicators

3.3 Benefits of Performance Analytics

The implementation of performance analytics offers several advantages compared with traditional assessment approaches. First, it enables objective evaluation based on measurable indicators rather than solely on instructor observations. Second, performance indicators can be monitored consistently across multiple training sessions, improving assessment reliability and comparability.

Performance analytics also supports personalized training by identifying individual competency deficiencies. Rather than applying identical training scenarios to all participants, instructors can use performance data to determine specific areas requiring improvement.

Furthermore, systematic performance evaluation contributes to enhanced training efficiency and supports competency-based education principles established within European inland navigation qualification frameworks.

The systematic collection and evaluation of simulator-generated performance indicators create a foundation for adaptive training systems capable of adjusting training content according to individual competency deficiencies. This principle forms the basis of the adaptive training framework proposed in the following chapter.

4. Adaptive Training Scenario Generation Framework

The growing availability of performance data obtained from simulator-based training creates opportunities for the implementation of adaptive learning principles within inland navigation education. Unlike traditional training programmes, where all trainees are exposed to identical scenarios regardless of their competency level, adaptive training systems continuously evaluate performance and dynamically adjust training content according to individual learning needs.

The proposed framework is based on the assumption that simulator-generated performance indicators provide objective information regarding trainee competencies. By

analysing these indicators, it becomes possible to identify performance deficiencies and subsequently recommend training scenarios specifically designed to improve the identified areas of weakness.

The proposed framework integrates performance assessment, competency evaluation, and adaptive scenario selection into a continuous training cycle aimed at supporting personalized competency development.

4.1 Framework Architecture

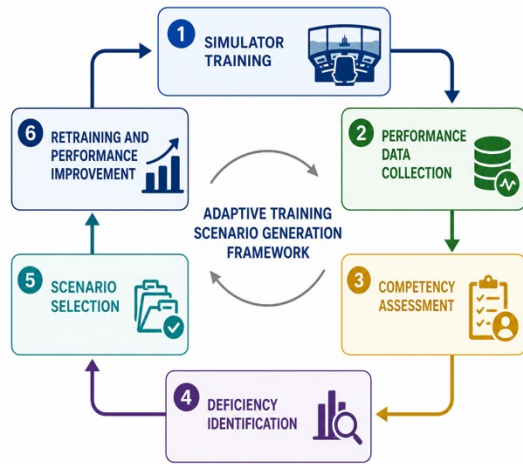


Fig. 2. Illustrates the proposed adaptive training scenario generation framework

The framework consists of six interconnected stages. The process begins with simulator-based training, during which operational data are continuously collected. The collected data are subsequently analysed and transformed into performance indicators representing measurable aspects of trainee behaviour and operational performance.

The identified indicators are then evaluated against predefined competency requirements. Based on the assessment results, competency deficiencies are detected and classified according to their severity. Finally, an appropriate training scenario is selected and assigned to the trainee in order to improve the identified competency gaps.

The entire process operates as a continuous feedback loop, allowing training content to evolve according to trainee progress and performance development.

4.2 Competency Deficiency Identification

The effectiveness of adaptive training depends on the ability to accurately identify competency deficiencies. This process is based on the comparison of observed performance indicators with predefined competency thresholds.

For example, excessive track deviation may indicate insufficient vessel handling skills, while delayed reactions to developing navigation situations may reveal limitations in situational awareness. Similarly, frequent communication errors may suggest deficiencies in

communication competency, and repeated collision-risk situations may indicate weaknesses in risk assessment and decision-making processes.

By linking measurable performance indicators to specific competency areas, the framework enables objective identification of training needs and supports evidence-based decision-making within simulator-based education.

The identification process may be implemented using simple threshold values or more advanced analytical methods capable of evaluating multiple indicators simultaneously.

4.3 Adaptive Scenario Selection

Following the identification of competency deficiencies, the framework recommends training scenarios specifically designed to address the detected weaknesses.

Rather than exposing trainees to a standardized sequence of exercises, the proposed approach allows training content to be adapted according to individual performance characteristics. As a result, trainees receive targeted practice in areas where improvement is required, while avoiding unnecessary repetition of already mastered competencies.

Table 3 presents examples of training scenarios that may be recommended based on identified performance deficiencies.

Table 3. Recommended Training Scenarios According to Identified Deficiencies

Identified Deficiency	Recommended Training Scenario
Poor manoeuvring performance	Narrow channel navigation
Delayed reaction time	Man overboard scenario
Communication errors	Intensive radio communication exercise
Radar interpretation deficiencies	Restricted visibility navigation
Collision avoidance deficiencies	High-density traffic scenario
Emergency response deficiencies	Fire on board scenario
AIS/ECDIS operation errors	Electronic navigation exercise

The proposed mapping between competency deficiencies and training scenarios may be further expanded according to specific training objectives and operational requirements.

4.4 Continuous Improvement Cycle

A key characteristic of the proposed framework is its cyclical nature. Following the completion of an adaptive training scenario, trainee performance is evaluated again using the same set of performance indicators. This enables continuous monitoring of competency development and allows the training system to dynamically modify subsequent learning activities.

The implementation of such a feedback mechanism supports personalized learning pathways and contributes to more efficient competency acquisition. Furthermore, the framework enables instructors to monitor long-term performance trends and evaluate the effectiveness of individual training interventions.

By integrating performance analytics with adaptive scenario selection, the proposed model establishes a foundation for data-driven simulator training and creates opportunities for future integration of artificial intelligence methods capable of automating training recommendations and predicting competency development.

5. Discussion

The increasing digitalization of inland waterway transport creates new opportunities for improving the effectiveness of crew education and training. The proposed adaptive training scenario generation framework represents an innovative approach that combines simulator-based training with performance analytics and competency assessment. Unlike traditional training programmes based on standardized exercises, the proposed model enables the personalization of training activities according to the specific needs of individual trainees.

One of the main advantages of the framework is its ability to objectively evaluate trainee performance using measurable indicators generated by navigation simulators. Such an approach reduces the dependence on subjective instructor assessment and supports evidence-based training management. Furthermore, the continuous collection and analysis of performance data provide valuable information regarding competency development throughout the training process.

The implementation of adaptive training principles may also contribute to more efficient utilization of simulator resources. By assigning training scenarios that directly address identified competency deficiencies, training sessions can become more focused and effective. Consequently, trainees may achieve the required competency levels within shorter training periods while maintaining high educational quality.

The proposed framework is fully compatible with the competency-based approach promoted by European inland navigation legislation and the ES-QIN standards. The integration of competency assessment with adaptive scenario selection supports the practical implementation of qualification requirements and contributes to the harmonization of training processes across Europe.

From the perspective of training centres, such as TMLG Academy, the framework offers opportunities for the development of advanced simulator-based education systems capable of continuously monitoring trainee progress and automatically recommending appropriate learning activities. The concept may also support instructor decision-making by providing objective information regarding trainee strengths and weaknesses.

Future developments may include the integration of artificial intelligence techniques capable of identifying complex performance patterns and generating training recommendations automatically. Additionally, the incorporation of real operational data, including AIS information, could further improve the accuracy of competency assessment and training personalization.

Overall, the proposed framework demonstrates the potential of performance analytics as a tool for enhancing simulator-based training and supporting safer inland navigation operations.

Conclusion

The objective of this paper was to propose a conceptual framework for adaptive training scenario generation based on performance analytics obtained from simulator-based training of inland waterway crews.

The study demonstrated that modern navigation simulators can serve not only as training platforms but also as valuable sources of operational performance data. Through the systematic collection and analysis of simulator-generated information, it is possible to assess trainee competencies objectively and identify specific areas requiring improvement.

The proposed framework integrates performance data collection, competency assessment, deficiency identification, and adaptive scenario selection into a continuous training cycle. This approach enables the personalization of simulator-based training and supports competency development according to individual trainee needs.

The framework is aligned with the competency-based principles established by Directive (EU) 2017/2397, Commission Delegated Directive (EU) 2020/12, and the European Standard for Qualifications in Inland Navigation (ES-QIN). Its implementation may contribute to more efficient training processes, improved competency acquisition, and enhanced navigation safety.

Future research should focus on the practical implementation and validation of the proposed framework within certified inland navigation simulator environments. Further development may also involve the integration of artificial intelligence methods and real-world operational data to support advanced adaptive training systems.

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