UNDERSTANDING RISK-DRIVING FACTORS, THEIR INDICATORS AND RESULTING DECISION CRITERIA: THE INTERDISCIPLINARY APPROACH IN GERMANY

by

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ABSTRACT

This paper presents an interdisciplinary research programme in context with the reliability of transport infrastructures. The programme initiated by the German Federal Ministry of Transportation and Digital Infrastructure (BMVI) aims at understanding underlying risk-driving factors, their indicators and resulting decision criteria. Using the example of the federal waterways in Germany illustrates the innovative approach.

1 BAW: TECHNICAL EXPERTISE REGARDING WATERWAYS IN GERMANY

With over 100 years of scientific tradition in the field of waterways engineering, the German Federal Waterways Engineering and Research Institute ("Bundesanstalt für Wasserbau", BAW) deals with a multitude of challenging tasks. The predecessor institution of the BAW was the Royal Research Institute for Hydraulic Engineering and Shipbuilding ("Königliche Versuchsanstalt für Wasserbau und Schiffbau"), which was founded in Berlin in 1903.

The BAW was assigned a technical and scientific mission, which covers all areas of waterways engineering relating to Germany's federal waterways. The BAW was also assigned responsibility for the building of special purpose ships for the Waterways and Shipping Administration (WSV). In addition, the BAW manages the construction planning of special purpose ships for other non-military federal authorities. Today the BAW operates from its headquarters in Karlsruhe and offices in Hamburg.

2 THE BMVI NETWORK OF EXPERTS: AN INTERDISCIPLINARY APPROACH

2.1 Background

In Germany, the infrastructure assets have a capital value of around 430 billion Euros. The consideration of the transport performance makes the added value impressively clear. In addition to passenger services, goods traffic with its approximately 655 billion tonne-kilometres plays a key role. In order to secure the transport performance, investments are urgently necessary. In view of the need to design and built a resilient and environmental-friendly transport system in Germany, the Federal Ministry of Transport and Digital Infrastructure (BMVI) is taking an innovative course of action. It pools the expertise and skills of its departmental research facilities and executive agencies in the BMVI Network of Experts (NoE) under the guiding principles "Knowledge – Ability – Action". The network, founded January 2016, is a new format of departmental research, which is formed by seven departmental research facilities and executive agencies of the BMVI (c.f. Federal Ministry of Transport and Digital Infrastructure 2017).

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The collaborating institutions are:

- Federal Highway Research Institute (BASt)
- Federal Institute of Hydrology (BfG)
- Federal Waterways Engineering and Research Institute (BAW)
- Deutscher Wetterdienst (German Meteorological Service, DWD)
- Federal Office for Goods Transport (BAG)
- Federal Maritime and Hydrographic Agency (BSH)
- Federal Railway Authority (EBA)

2.2 Organisation of the NoE

The NoE covers five distinctive research topics (see Figure 1). Each of these areas is subdivided into several key topics (KT) dedicated to specific fields of interest. At the administrative level, the steering committee establishes the direct link to high-level governmental and departmental authorities and administrations. Assisted by the scientific task force, the coordination board ensures a smooth cooperation between the involved parties by managing the administrative and organisation work.

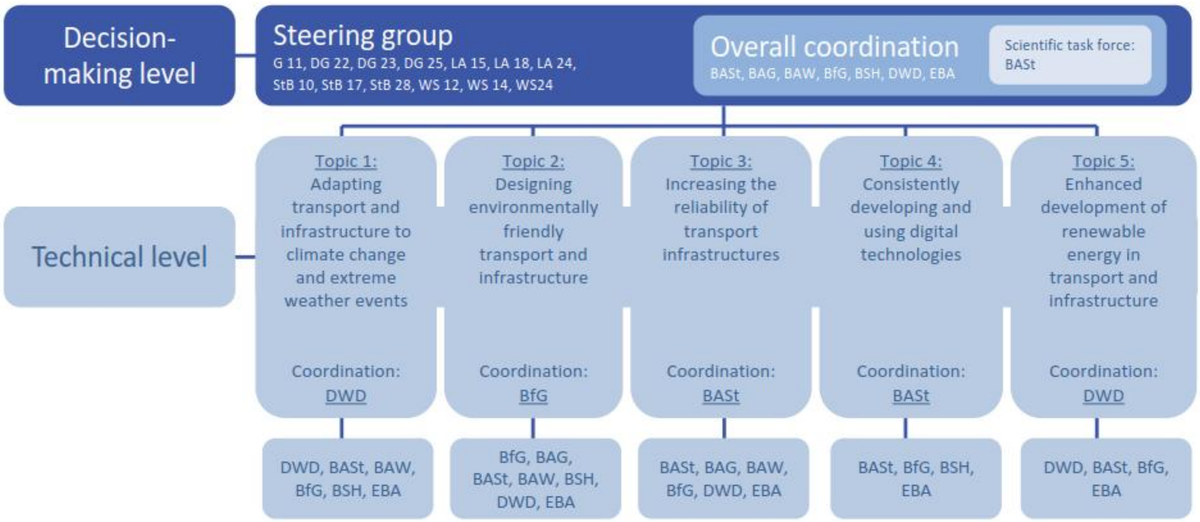

Figure 1: The BMVI Network of Experts Knowledge–Ability–Action

2.3 The BAW as part of the interdisciplinary approach

As technical advisor to the BMVI, the BAW is part of the NoE. The research activities of BAW consider the particular requirements of the waterway infrastructure. The NoE currently funds 10 R&D projects and 12 R&D positions of the BAW. Each of the projects is associated to one specific research area, which covers certain aspects regarding the understanding of risk-driving factors, their indicators and resulting decision criteria in context with civil engineering structures.

Topic 1: Adapting transport and infrastructure to climate change and extreme weather events

Topic 1 identifies the vulnerabilities to traffic and infrastructure caused by climate change and extreme weather events, and then develops appropriate adaptation options. Here, the resilience to extreme weather events and the consequences of climate change as well as the sustainable usability of the transport infrastructure are of particular importance. By linking the expertise of DWD, BSH, BfG, BAW, EBA and BASt, the respective specific knowledge on climate development will be combined with practical knowledge on the three modes of transport: road, rail and waterway.

Topic 1 is divided into nine key topics, which deal with the provision of data as well as concrete hazard scenarios. These include floods, storms, landslides and waterway-specific hazards. The results are included in a risk management system, which will be further developed in this topic. With regard to the projected impacts of climate change, adaptation options are being developed and tested, both for individual modes of transport and across modes of transport. Simulation models and analysis methods are applied and validated using two focal regions, coast and inland.

The BAW is represented in all key topics and contributes its experience as well as the knowledge gained in the context of the projects, in particular from analyses of numerical model examinations

Topic 2: Designing environmental friendly transport and infrastructure

Topic 2 has the goal to find solutions for a design of transport and infrastructure, which is environmental-friendly and sustainable. This objective is pursued in five key topics, dedicated to

- biodiversity and structural diversity of transport routes,
- invasive species (neobiota) being introduced and spread by the transport mode,
- transport-related material loads,
- building and construction-related emissions and
- reducing noise and noise emissions.

The BAW is involved in a project, which works on operational and technical improvements of inland navigation regarding the reduction of emissions. For this purpose, a dynamic vehicle model (FaRAO) is used to simulate inland waterway vessels. This model is extended by a special engine model, which also simulates the emissions of an inland vessel at different operating points of the engine. To calibrate and validate the engine model, vessel and engine data are surveyed under real operating conditions. The first test will be conducted in the area of the port of Duisburg. Eventually, the spread of emissions of all modes of transport using an air pollutant transport model with chemical reaction equations.

Topic 3: Increasing Reliability of Transport Infrastructure

The reliability of the infrastructures is regarded as essential aspect of a resilient transportation system. The bulk of the German transportation network lies on infrastructures that were constructed several decades ago and which actually require continuous maintenance and modernisation. Thus, combined effects of aging infrastructure, altered and generally higher traffic impacts over their lifetime as well as environmental stressors increase risks in terms of the reliability associated with these transportation infrastructures. In this regard, the past efforts in maintaining the infrastructures have been nowhere near sufficient, and have resulted in a considerable investment backlog.

In this context, Topic 3 investigates methods and concepts, which could help in increasing the reliability of the transportation infrastructure again. Reliability is defined as “ability of a structure or a structural member to fulfil the specified requirements, including the design working life, for which it has been designed.” (DIN EN 1990:2010) This definition implies that functional requirements (i.e. limit states), structural behaviour, actual and future live load scenarios, as well as possible deterioration processes are generally known, measureable, and continuously evaluated over the whole operational lifetime of the structure. In a consequence, an effective maintenance management system must also consider inevitable uncertainties associated with these aspects.

Topic 3 consists of four key topics:

- state-of-the-art field tests methods to assess the condition of the infrastructure
- modern reliability evaluation tools, both qualitative and quantitative
- availability and vulnerability of infrastructure under extreme weather events
- rehabilitation measures under operation

Altogether, these key topics aim at developing a proactive and future-oriented maintenance management system which helps to increase the reliability of the transportation infrastructure in Germany (see PANENKA et. al 2018).

Topic 4: Consistently developing and using digital technologies

The aim of Topic 4 is to positively influence digital technologies through networking of departmental research and BMVI technical authorities. The thematic focus is thus on the consistent use of the possibilities of information and communication technologies with a focus on interagency cooperation in the area of information provision and IT-use. The topic is currently in a conception phase. The BAW observes the development of this topic.

Topic 5: Enhanced development of renewable energy in transport and infrastructure

Topic 5 works on the various application and extraction potentials of renewable energies in an intermodal approach to transport and infrastructure. A cross-cutting pilot project on this topic will initially show the benefits of joint research in this area with the participation of different departmental institutions. The involved higher authorities work together to develop concepts for a significantly increased use of renewable energies in the transport infrastructure. This also includes the operation of maintenance and repair vehicles. Options and recommendations are being developed so that the modes of transport waterway, rail and road can increasingly make their contribution to climate protection in the future. Topic 5 is currently in a conception phase. The BAW observes the development of this topic.

3 INCREASING THE RELIABILITY OF THE WATERWAY INFRASTRUCTURES

The waterway infrastructure features a large number of structures with a high diversity. Thus, the determination of risks emerging from these structures requires profound technical knowledge and adequate evaluation tools. In this regards meaningful structural indicators in combination with additional data sources like geographic information systems (GIS) or advanced metrological weather models are essential for an efficient risk assessment. The combination of all information allows an understanding of risk-driving factors, which helps to define the essential decision criteria. This knowledge evokes an increasing demand for new technologies and methodologies helping to reduce both the actual impact of disruptive metrological events on the infrastructure and the potential risks of possible failure scenarios.

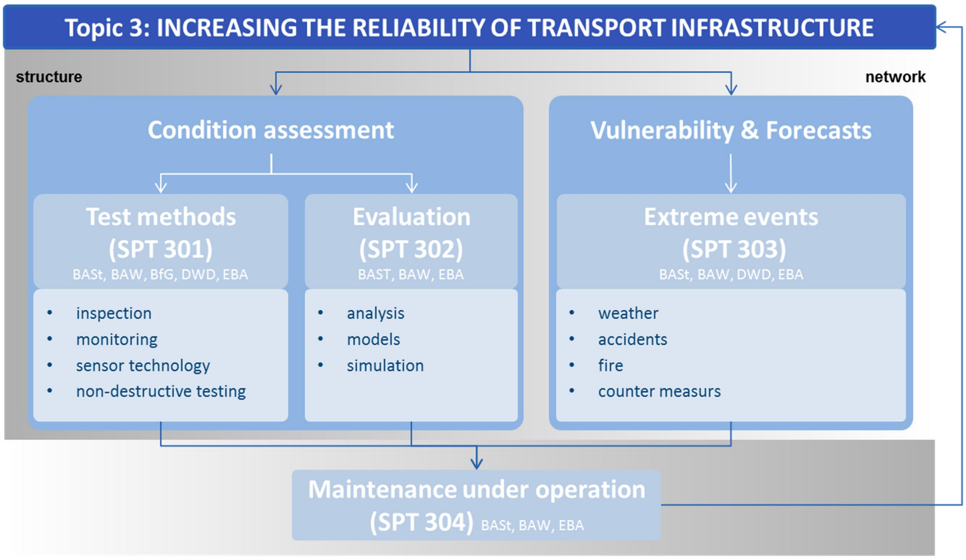

Figure 2: The organisation chart of Topic 3

In this context, the interdisciplinary research activities of Topic 3 in the NoE show first results, which especially support the need for an improvement of the reliability of waterway infrastructures.

3.1 Reducing the impact of disruptive events with smart water level control

The water level of the German waterways is usually subject to a strict water level control. Disruptive events for the automated water level control of impounded waterways are often caused by unknown lateral inflows, such as storm water overflow from urban areas after heavy rainfall events. In order to avoid violations of the water level tolerance and reduce discharge fluctuations, the BAW is developing a new control strategy. A smart water level control should be based on a model of the impounded river section, high-resolution precipitation forecasts for urban catchment areas and communication between neighbouring impoundments (KASPER, J. et al. 2017). The development process of a smart water level control shows the benefits of a close cooperation between institutions providing competences in meteorology, hydraulic engineering and control technology.

Essential risk factors are the prediction accuracy of extreme rainfall events and, subsequently, the precise control of the resulting discharge. The higher the difference between the summer base discharge and lateral inflow due to extreme weather events, the higher the requirements for the water level control system. The main indicator for the effectiveness of the water level control system is the extent of water level fluctuations in the waterways, which shall be minimized.

Figure 3 shows a schematic representation of smart water level control. A rainfall-runoff model estimates future lateral inflow using probabilistic weather forecast by the DWD. Based on these predictions and on information from upstream impoundments, the model predictive control system, developed by AMANN et al. (2000), calculates ideal water level and discharge trajectories using optimization procedures. In this way discharge fluctuations are homogenized, which increases the reliability of the affected transport infrastructure and thus the safety of shipping. A pilot project is being carried out for the Hofen impoundment at the river Neckar. This area was chosen because the lateral inflow due to extreme rainfall events during summer season may be considerably greater than the summer base discharge of the waterway.

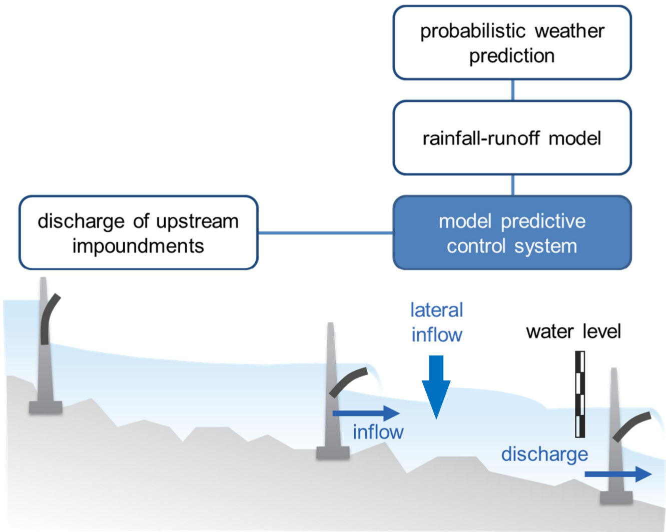

Figure 3: Schematic representation of smart water level control at navigable waterways

3.2 Eliciting expert knowledge about structural deterioration processes and damage scenarios

Assessing deterioration processes and damage development are crucial parts of a reliability analysis. Both they depend on strongly varying initial and boundary conditions. In this regard, the elicitation and usage of available expert knowledge is indispensable. So-called guided expert interviews (e.g. BOGNER, A. et al. 2009; MILES, M. B. et al. 2014) were used during the design process for a full-scale embankment model test. The interviews were conducted to analyse the long-term damage development of loose riprap embankments (SORGATZ, J. 2018). Based on results of the expert interviews, the model test was designed (see Figure 4). The model was finally erected in the wave basin of the BAW, which allows observing degradation caused by hydraulic loads after initial damage. The work is complemented by calculations using state-of-the-art reliability methods in analytical and numerical models (e.g. BAECHER, G.B. & CHRISTIAN, J.T. 2003) as well as a long-term field monitoring campaign. In order to monitor armour stone displacements laser scanner and the structure-from-motion technique are utilised (SORGATZ, J. & LEISMANN, K. 2018).

The project uses state-of-the-art engineering solutions as well as established methods known from social sciences. The interdisciplinary approach of the project attracted great interest within the NoE. Furthermore, it is an excellent example of how different data sources and expert knowledge may be combined to acquire profound technical knowledge, which eventually leads to a well-founded engineering solution.

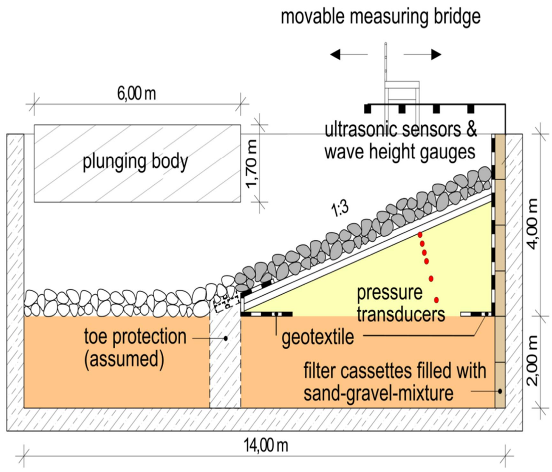

Figure 4: Model test design in the BAW wave basin

3.3 Risk assessment based on the structural condition of civil engineering structures

The detailed, i.e. quantitative, assessment of the structural reliability is a complex task and considered unfeasible when dealing with a large number of structures. In the field of mechanical engineering, qualitative methods are often used to assess the reliability of processes and products on a more general level. These methods are fairly unknown to civil engineers but prove beneficial in analysing inspection data and expert knowledge. The widely used Failure Mode and Effect Analysis (FMEA) was adapted to make use of data already available in the maintenance management system of the BAW (see Figure 5). The FMEA is a systematic and inductive method. Its fundamental idea is the assessment of every possible failure modes within any system, system member or product component. Likewise, possible failure consequences and failure causes are identified. Finally, the procedure leads to a risk assessment and the determination of optimization measures. The method aims at identifying risks and weak spots as early as possible in order to implement improvements early enough (BERTSCHE, B. & LECHNER, G. 2004). Furthermore, the method allows the consideration of both qualitative and quantitative data. The risk assessment results in a ranking of the identified failure modes supporting the prioritization of optimization measures for the most effective improvement in comparison to the actual situation.

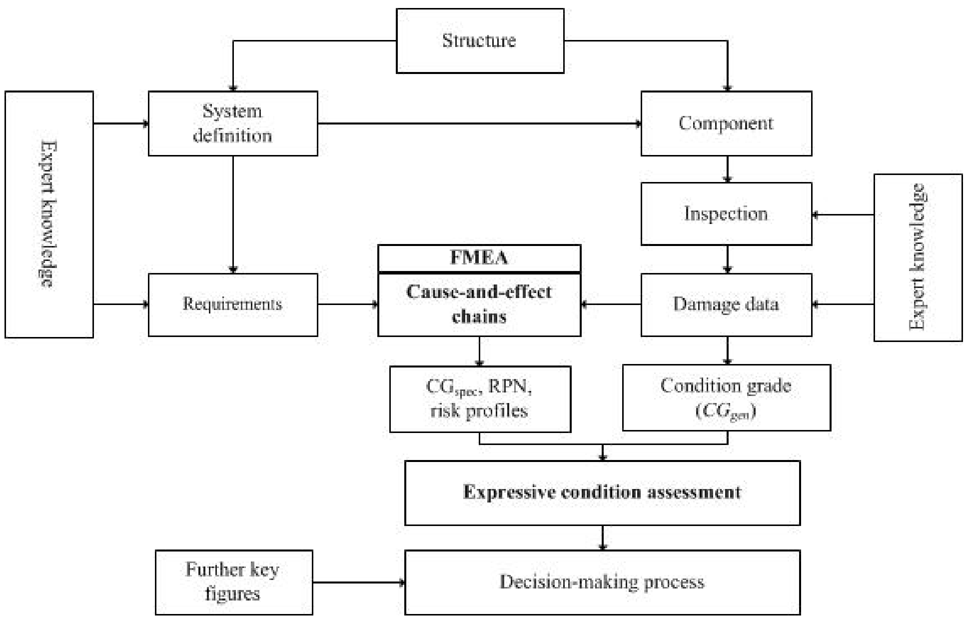

Figure 5: Implementation of FMEA in the condition assessment of civil engineering structures

The FMEA was enhanced with fuzzy logic-based evaluation methods providing comprehensive key figures for a comparative risk assessment on a large number of structures (PANENKA, A. & NYOBEU F., 2018a). In a second step, different structures may be compared based on the results of the first step (PANENKA, A. & NYOBEU F., 2018b). To do so, the results of the first step are summarized in a so-called risk profile of the structure (see Figure 6). The higher the risk profile the more risky is the condition of the structure. Such qualitative risk assessment then helps in the decision process about further actions such as intensifying rehabilitation measures or installing a smart water level control in order to reduce the water load variation on river weirs.

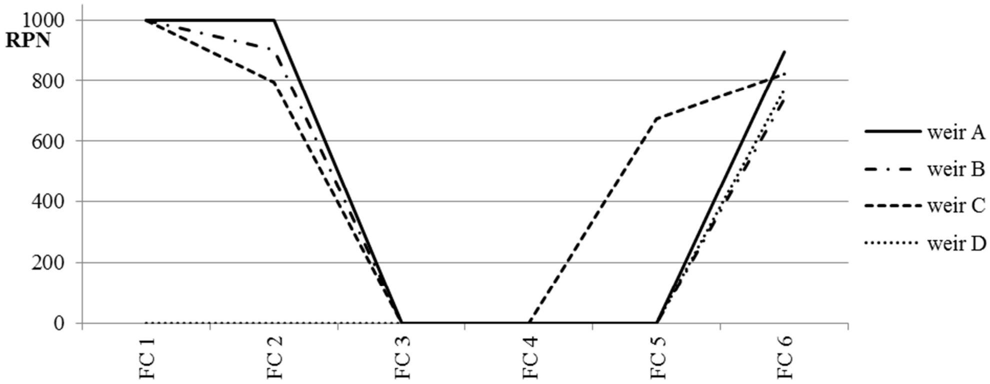

Figure 6: Risk profiles of four different weir structures based on failure causes 1 to 6

4 CONCLUSION

The presented projects demonstrate the benefits of interdisciplinary research approaches with regard to the understanding of risk-driving factors, their indicators and resulting decision criteria. The results achieved so far add profound and comprehensive information to the ongoing discussions about efficient investment strategies in order to reduce the risks emerging from an aging infrastructure. In this way, the research activities of the BAW contributes to the urgently required reduction of the maintenance backlog and, eventually, to a reliable, highly available infrastructure.

The NoE is a future-oriented approach to bundling the strengths of research facilities and authorities. It is accompanied by visionary roadmaps for the individual topics and a comprehensive strategic plan. At the technical level, contacts are established and a common methodological and technological knowledge base is built up. At the decision-making level, the necessary organizational structures and processes are developed and adapted to the needs of the experts involved in the projects. Already in this early phase of the NoE, several obstacles have been overcome in interagency cooperation. First publications at national and international level are in preparation or will be published soon. In 2018 and 2019, scientific and political events will be held more frequently in order to communicate the benefits of the BMVI Network of Experts to transport infrastructure operators and to decision makers in politics.

The projects are continuously presented on www.bmvi-expertennetzwerk.de/EN.

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