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Integration of resilience assessment aspects in life cycle management

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Abstract

Considering the increase of extreme weather events due to climate change and the unfavorable age distribution of transport infrastructure in Germany, more efforts are required to optimize and coordinate maintenance, upgrading and replacement of existing transport infrastructure. Increasing age of structures and changing impacts are reducing their structural reliability over the years. The paper presents a concept for the integration of resilience assessment aspects into a life cycle management for transport infrastructure.

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Keywords: transport infrastructure; resilience; life cycle management; disruptive events

1. Overview and Motivation

Providing a safe and reliable transport infrastructure and an efficient traffic management to ensure safe operation and high availability are essential prerequisites for sustainable mobility and economic growth. The unfavorable age structure of engineering structures, the predicted increase in freight traffic, as well as the increase in disruptive events, such as floods or cyber-attacks, require solutions to ensure the reliability and resilience of the transport infrastructure. Additional efforts in terms of current and future condition mapping, optimized, coordinated maintenance, upgrading and replacement of existing assets while maintaining traffic are required. In order to meet the above-mentioned challenges and to answer urgent traffic questions of the future, the need for targeted research arises with the aim of further ensuring the safety and reliability of the infrastructure and to be able to use the available resources in a prioritized and highly efficient manner.

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The BMDV Network of Experts was founded in 2016 as a cross-modal research format in departmental research under the guiding principle of "Knowledge - Ability – Action”. Seven departmental research institutes and specialist authorities within the portfolio of the Federal Ministry for Digital and Transport (BMDV) joined forces. For this purpose, the Research Strategy 2030 (https://www.bmvi-expertennetzwerk.de) was formulated with the vision of "making the transport system resilient and environmentally compatible".

In this present research a concept of an indicator-based life cycle management is presented, which integrates resilience assessment aspects, thus helping to increase the useful life of transport infrastructures and to adapt structures to evolving transport requirements. The concept addresses all elements of the resilience cycle and aim to provide managers and owners of transport infrastructure with a pragmatic approach that enable a comprehensive implementation of resilience in the entire life cycle of transport infrastructures. In this way, the results support infrastructure managers and owners in ensuring the reliability of structures over the entire life cycle, starting from planning, through construction, use and maintenance to demolition.

2. Methodology, results and main contributions

2.1. Resilience

Resilience can be described as the inherent capability of a system to absorb changes and disruptions of various kinds, to adapt to them and to retain its characteristic functionality. In the present paper, the following definition of resilience by Scharte et al. (2014) is used: “Resilience is the ability to repel, prepare for, take into account, absorb, recover from and adapt ever more successfully to actual or potential disruptive events. Disruptive events are either catastrophes or processes of change with catastrophic outcome which can have human, technical or natural causes.”

The resilience of a system can be assigned to five different sequential phases represented in the form of a resilience cycle in Fig. 1.

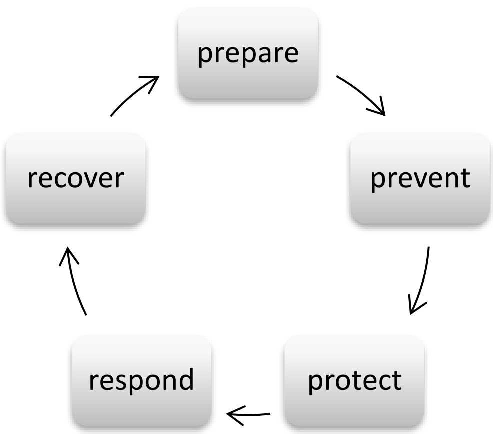

Fig. 1. Resilience cycle showing the five leverage points to increase the resilience of the system. (Scharte et al. 2014).

The first phase covers the preparation for disruptive events for example by implementing early warning systems (prepare). By reducing the underlying risk factors, the probability of occurrence of a disruptive event is decreased (prevent). If a disruptive event occurs, it is important that existing protective systems operate without defect and the negative impacts are minimized as far as possible (protect). By rapid, well-organized immediate measures, the extent of the damage resulting from the incident is reduced, and the functionality of the system retained as far as possible (respond). Finally, a resilient system is characterized by its ability to recover and adaptively learn from the event to be better equipped for future disruptive events (recover) (Anastassiadou et al. 2020).

Resilience measures can be assigned to one of the five phases of the resilience cycle shown in Fig. 1. Measures of the phase prepare are temporally decoupled, their purpose is to increase the understanding of the system and thus only have an indirect effect on the system's resilience as they reinforce the impact of measures in the other phases. E.g. the knowledge gained by advanced weather forecast models (prepare-measure) can improve the emergency planning (respond-measure). Measures, which can be assigned to the phases prevent, protect, respond and recover unfold their effect in a chronological order Deublein et al. 2021).

Resilience measures are understood to be those technical, planning and organizational measures on the individual structure (e.g. bridge or tunnel) or for the entire infrastructural network that exceed the specifications of regulatory texts in force (standards, design, codes etc.). For example, the use of high-performance concrete in bridges where only conventional types of concrete are actually specified in the standards for the planning situation).

An implementation-oriented methodology was developed in a previous study (Deublein et al. 2021) in order to ensure the functionality of the road infrastructure during and after disruptive events. The development of the methodology has been based on an international literature and research project review, considering the most promising approaches for resilience assessment in the context of road infrastructure management.

The methodological elements of resilience screening, measure evaluation, and resilience optimization are used to identify and prioritize suitable measures for increasing system resilience as efficiently as possible. The pragmatic approach used to estimate the influence of a measure to increase resilience is carried out in a way that is comprehensible to the user at the object level and afterwards aggregated in order to calculate the effect of the measure on the resilience of the overall system. Considering the annual costs of the measure, the developed methodology provides the decision-maker with four different parameters for each measure: the resilience effect, the cost-effectiveness ratio, the potential implementation period and the implementation probability (feasibility). On this basis, it is up to the decision maker to rank the measures to be implemented that are most appropriate for his or her situation and system, depending on strategic or policy objectives.

In order to establish the usability of the methodology, a resilience assessment software tool for practical implementation was also developed (Anastassiadou et al. 2022). The resilience assessment software tool is intended to help managers and owners of transport infrastructures to apply the developed methodology and assess the resilience of their infrastructure. In the tool, the definition of the system to be assessed, the netscreening and the hazard analysis serve as essential fundament for the resilience screening, the evaluation of resilience improving measures and the resilience optimization. Different infrastructure elements can be assessed on an object level (e.g. bridges, tunnels). The results of the procedure give an overview of possible resilience measures (Anastassiadou et al. 2020) and show their potential to be implemented easily and where more an in-depth analysis should be considered.

2.2. Life cycle management (LCM)

Interviews with various managers and owners of transport infrastructures have shown that the current maintenance management for engineering structures is characterized by a reactive approach. Damage is only detected when it is visible on the surface. In the long term, the current maintenance management is to be replaced by a preventive life cycle management. The aim is to optimally adapt the maintenance measures to the existing conditions and thus increase the availability, safety and durability of individual structures and the entire network (Hindersmann und Staub 2022b). A Life cycle management is the combination of all technical and administrative measures as well as management measures during the entire life cycle of a unit (e.g., Bridge) with the aim of optimizing use, resources and information across the entire life cycle (Lebhardt et al. 2020).

Currently, there is no concept for life cycle management across all modes of transport. However, some modes of transport have initial approaches to life cycle management or are already applying these approaches (Hindersmann und Staub 2022b).

One idea for a concept for LCM is shown in Fig. 2, with the PDCA cycle (**Plan - Do - Check - Act**) at its center. The basis for the LCM is information on the object and network level, remaining restrictions (scarce financial or personnel resources), specifications, regulations and laws as well as strategic foundations. Goals are derived from the requirements of the basic principles. In order to make the fulfilment of these goals traceable and measurable, quantitative and qualitative indicators are identified. In this way, the basics are constantly compared with the actual situation of the networks and structures. The LCM can have different modules on the network and object levels, it can include different life cycle phases and concern different modes of transport (Hindersmann und Staub 2021).

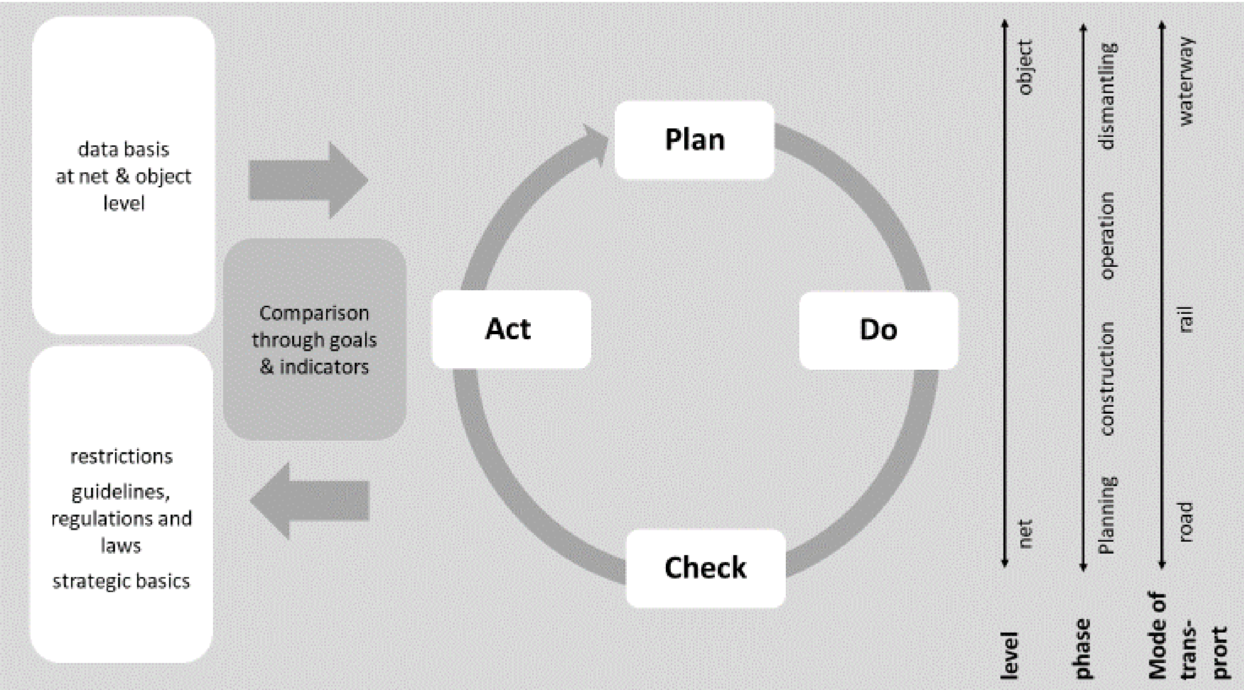

Fig. 2. Concept of a life cycle management (Hindersmann und Staub 2021).

The PDCA cycle describes the different phases of the implementation of objectives (Hindersmann und Staub 2022a):

- **Plan**: In the first phase, the problem and the current state are described, the causes of the problem are analyzed and the target state is formulated. In addition, metrics for achieving the target state are defined. If there are no numerical targets, the goal is to improve the current state. This actual state is described on the basis of the previously defined criteria. In addition to the definition of goals, strategies for implementation are selected, a categorization of the importance on network and object level (criticality analysis) takes place and a selection of the measures takes place according to the urgency.
- **Do**: This step describes the implementation of measures, i.e. the concrete planning of measures, implementation and quality control. In the second phase the measures are transferred into processes and the individual steps and results but also difficulties and ideas for improvement are documented.
- **Check**: In the third phase the results of the measures are checked and analyzed. A comparison of the expected goals with the achieved goals takes place. In this phase, new findings and any obstacles encountered are also documented and the experience gained in implementing the measures is reflected upon. If necessary, the measures are readjusted. Measures with the greatest effects can be identified and ineffective measures are eliminated, revised or replaced by new measures.
- **Act**: In the fourth and final phase, the data basis and possibly also strategies and goals are adjusted. Also, the experience gained in the process of problem solving is evaluated. From this, standards for the future procedure are derived. New solution approaches can also be implemented in this phase. With the transfer of these regulations into the planning process, the cycle begins anew.

2.3. Integration

One of the overriding goals of the German Federal Transport Plan is to eliminate bottlenecks in the federal road network (Deutscher Bundestag 2016). A criterion that must be fulfilled in order to reduce bottlenecks is the reduction of travel and congestion costs. An indicator to check the fulfilment of this criterion would be, for example, the average daily traffic volumes (DTV). In the **Plan** phase, it is found that one way to fulfil the set objective of removing bottlenecks is to raise the resilience of critical structures to minimize downtime. Once appropriate measures have been selected to raise the resilience of structures against extreme events, they are implemented in the **Do** phase. In the check phase, the extent to which the DTV figures have changed is checked. The individual steps of the measure are documented and backed up with the findings of the evaluation of the indicators. In the **Act** phase, the effects of the different measures are compared. Ineffective measures are reviewed and, if necessary, adjusted or replaced by others.

Fig. 3 illustrates a possible LCM cycle with integrated resilience aspects. In the **Plan** phase, objectives are set, critical structures are identified and suitable measures to increase resilience are prioritized.

In the **Do** phase, the measures are implemented, such as the creation of emergency plans, structural measures to strengthen critical structure elements or the use of new early warning systems. The individual work steps are documented in detail. The resilience assessment software tool can be used during the entire PDCA cycle. The tool provides the prioritized measures for individual structures.

In the **Check** phase, the effects of the measures are checked. On the one hand, it is tested whether the resilience of the infrastructure facilities and the network under consideration has increased and, on the other hand, whether the implementation of the measures has proceeded according to plan. If this is not the case, the implementation of the measures must be revised or replaced by other measures.

This happens in the **Act** phase. Here, measures are revised, technological and administrative innovations are implemented or replaced by other measures. On this basis, updated goals with adjusted criteria and suitable indicators are defined in the following **Plan** phase and the cycle begins again.

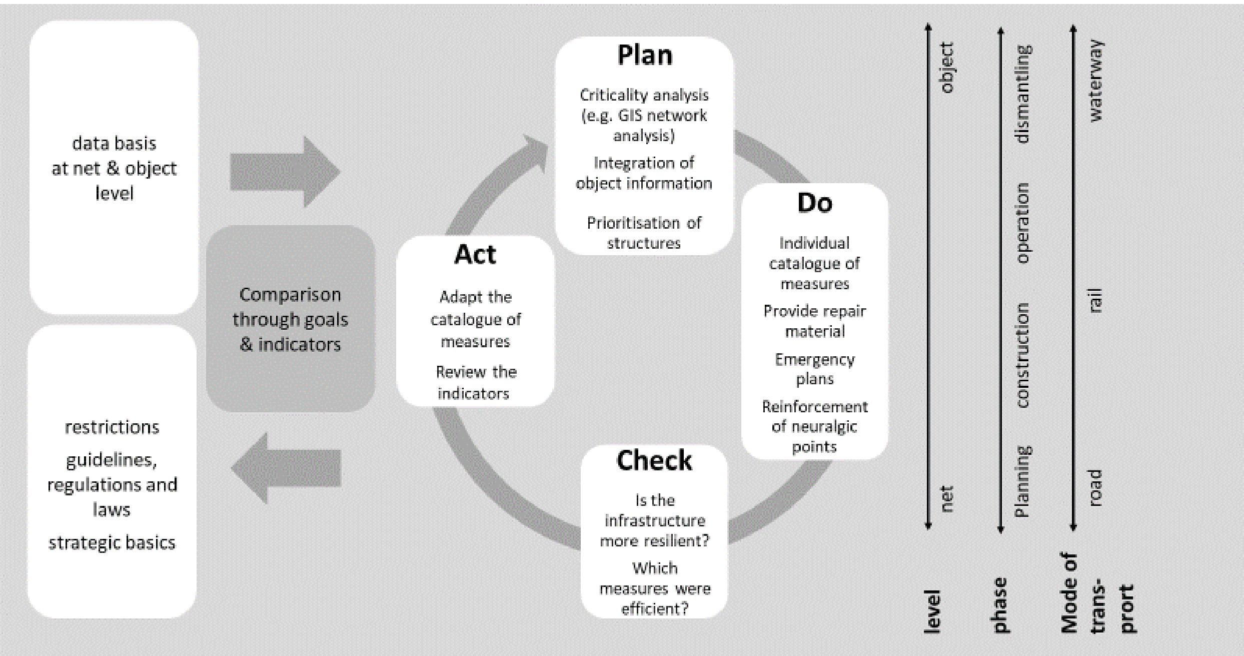

Fig. 3. Resilience aspects in a life cycle management (Hindersmann und Staub 2022a)

More generally, on the basis of a common understanding of the relationship between reliability, risk and resilience of transport infrastructures, a further development of the approaches to risk assessment and the approaches to assessing the reliability and resilience of engineering structures is being pursued. Based on this, there is a constant exchange of data and information between the individual modules, in this case the resilience module, and the superordinate LCM. The requirements to ensure that the exchange of this information functions are defined within various projects. The modelling and simulation of risk scenarios at object and network level are also being driven forward and a target group-oriented preparation of the results is being developed.

3. Conclusion and future works

By providing measures and practical guidelines, managers and owners of transport infrastructures will be supported in improving the performance during the complete lifetime of transport infrastructure. In this way appropriate actions can be taken to prepare infrastructure systems in order to handle the needs of the future and to be ready for unknown events that may occur.

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