# Data assimilation for remaining lifetime prediction and the infrastructure management cycle

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The authors are engaged in research and development on asset management technologies for road infrastructure. This involves development of management technologies for the road administrators that handle the maintenance of infrastructure assets in the first place, and in the second place, connecting the elemental technologies developed in the areas of mechanics, electronics, and ICTs to actual practice in the field of infrastructure stock management. Key idea is the PDCA multi-cycle (Fig. 1) which is composed from the maintenance cycle of infrastructure and the management cycle of infrastructure maintenance. To implement this PDCA multi cycle, four groups are pursuing the technical development and practical implementation.

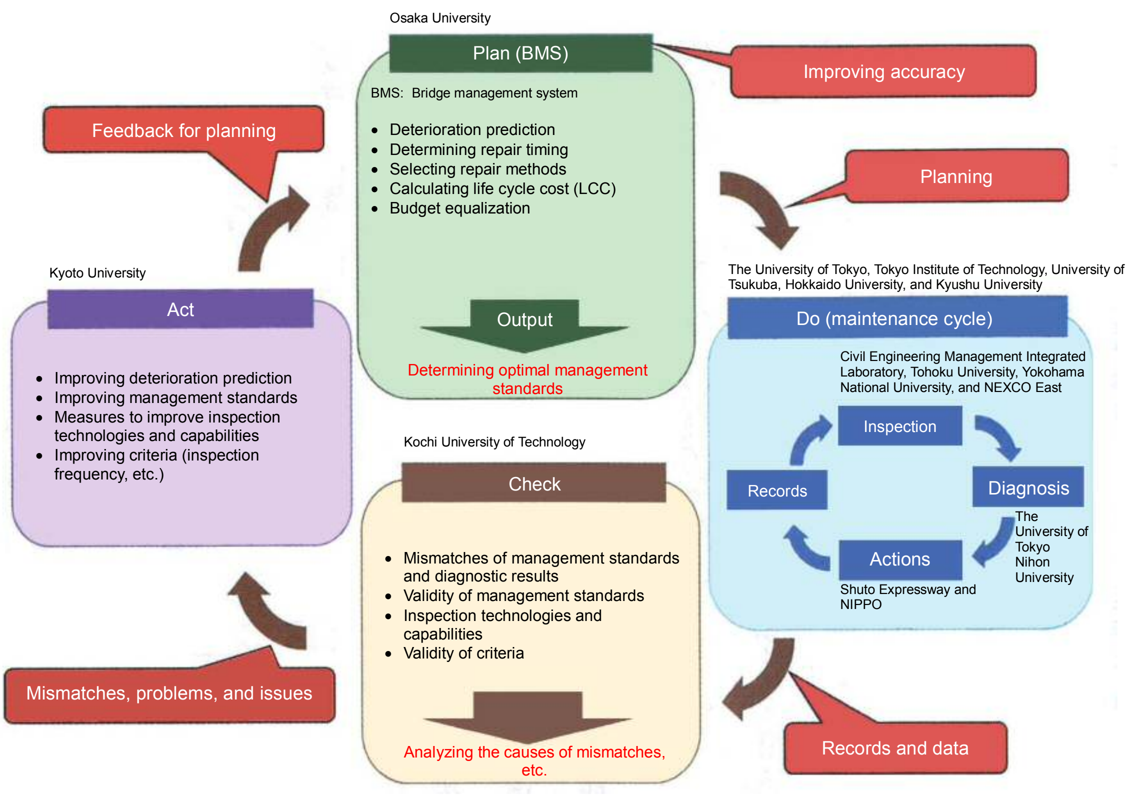


Fig. 1. Project implementation and the PDCA multi-cycle for individual structures

## Management cycle

With Kyoto University, Kochi University of Technology, and Osaka University playing a central role, the management cycle is beginning to operate in cooperation with the government administration side with regard to maintenance of the Hanshin Expressway and infrastructure in Kochi Prefecture, Kyoto Prefecture, and Vietnam. Management systems are being strengthened in areas such as obtaining, storing, and analyzing inspection information, estimating deterioration by statistical and physical methods, conducting budget allocation for entire facility groups, educating human resources for inspection work, and selection of repair and reinforcement methods.

Considering that each of the regional public entities that is an administrator of road assets is subject to different circumstances, including natural environmental conditions and financial situations, JSCE's Organization for Promotion of Civil Engineering Technology has established a committee on SIP to support asset management and regional implementation. This committee is working to compile examples of implementation and to create guidelines.

Our activities also cover international deployment, the detail of which is described in detail in other article in this special issue.

## Data assimilation for the utilization of technologies developed by SIP

To build a bridge that connects outstanding technologies developed outside civil engineering field with the practice of infrastructure maintenance, we are pursuing the strategy of setting up a portal site for inspection and diagnosis based on the PDCA cycle (right side of Fig. 1) for individual infrastructure. We are developing a protocol to connect NDT signals such as digital information derived from radar, ultrasound, X-rays, neutron beams, hammering soundwaves, and natural light (visual inspection and recorded images), with technologies for future prediction like structural analysis and material design software, etc. for infrastructures (Fig. 2). We have completed the stage of trial implementation and are planning to deploy this on actual roads, starting this year.

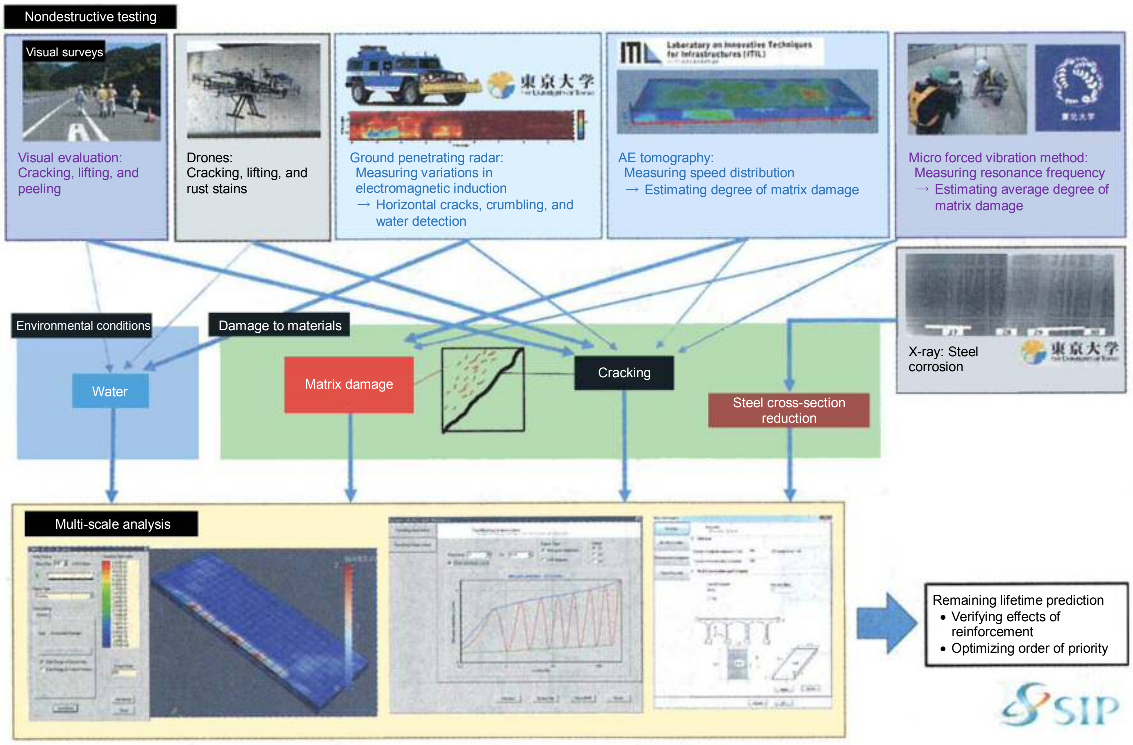


Fig. 2. Assimilation of inspection technologies and knowledge concerning infrastructure materials and structures

Inspection and monitoring data can only provide a portion of the information needed to demonstrate the current status of the relevant infrastructure facilities, and information on the majority of portions of these facilities is not known. Therefore, it is necessary to estimate the state of the undetermined portions, based on the limited amount of inspection information that can be obtained. With simple interpolation and extrapolation, the potential for error is large, because the phenomenon of damage and failure is a higher-order nonlinear problem. Estimation is based on the reliability of the inspection information, along with highly accurate physical and chemical theories and knowledge. By using estimates of the current status as a starting point for future predictions, we can make conclusions concerning the remaining lifetime, risk status, and locations and modes of damage. The goals of development include the promotion of local cycles of PDCA on this basis, as well as accelerating the macro-scale PDCA cycles of project execution.

## Remaining lifetime prediction for reinforced concrete decks

Information on the locations, directions, and widths of cracks, obtained from visual information and digital images of cracks on the underside of reinforced concrete bridge decks, can be used in a numerical model to estimate the current situation of damage (internal cracks, directions and widths, plastic deformation, and moisture conditions), and thereby to estimate the remaining lifetime based on future traffic loading and effects of the environment, as illustrated in Fig. 3.[1] Effects of poor construction and damages from past loading are also incorporated into the estimate indirectly. Data assimilation has the effect of supplementing the weaknesses of each type of information, while combining their respective strengths. Incidentally, it has been estimated that most of the costs of maintenance of road infrastructure will be for reinforced concrete decks that were produced according to the standards in effect until 1964.

An information platform with multiple layers, from the nano scale to kilometers, is used for material and structural analysis for data assimilation [2]. We considered that the creation of a protocol format on this basis would make it possible to connect with many more numerical analysis techniques that are expected to be developed in the future. After a one-year trial, we hope to propose and publish a standard protocol that will combine electronic communications, equipment, chemical sensors, and other inspection technologies with civil engineering materials, and structural design technologies, as one of the achievements of SIP. Through the trial implementation of data assimilation, it has become possible to generate specific and quantitative specifications for performance requirements for developing sectors of equipment, etc. from the civil engineering side. We hope that this kind of development will advance across multiple sectors. We recognize that the ICT environment has provided opportunities to formulate strategies based on collaboration that transcends conventional boundaries among different areas.

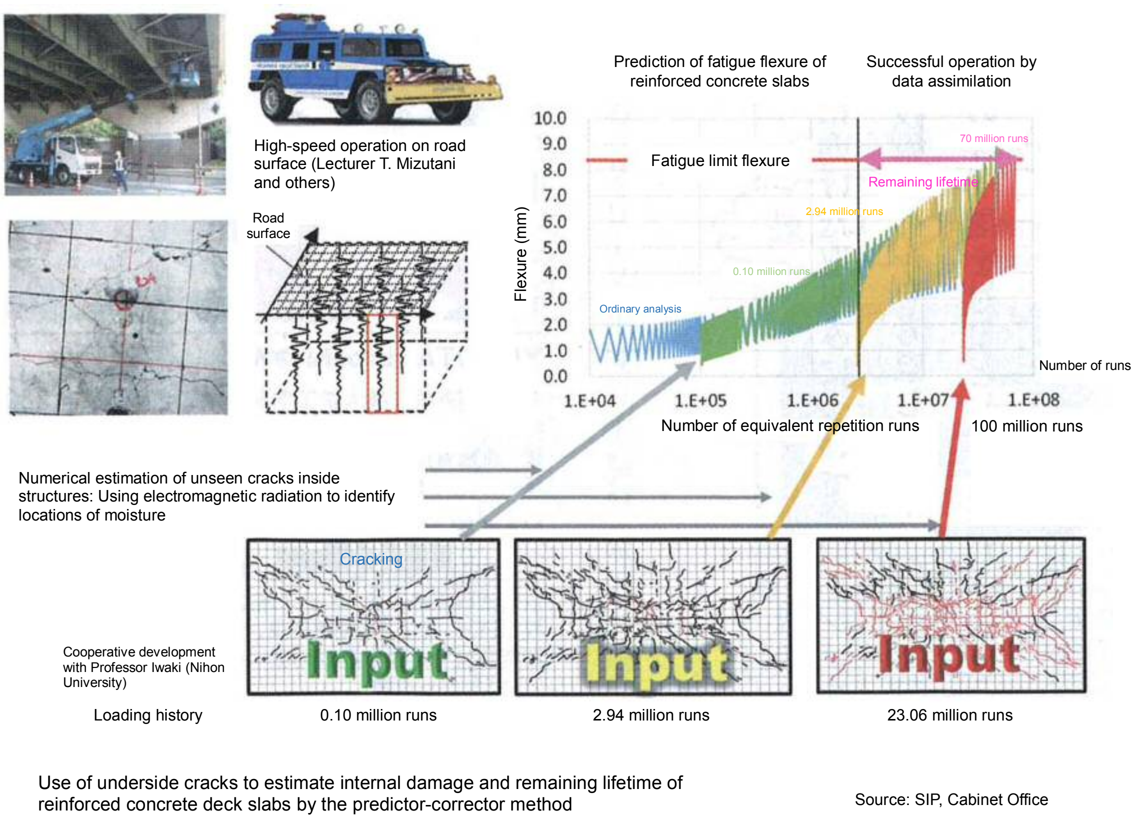


Fig. 3. Inspection information sharing and remaining lifetime estimation of bridge deck based on data assimilation

**References**

(1) Tanaka, Y., Maekawa, K., Maeshima, T., Iwaki, I, Nishida, T. and Shiotani, T.: Data Assimilation for Fatigue Life Assessment of RC Bridge Decks Coupled with Path-Integral-Mechanistic Model and Non-Destructive Inspection, Journal of Disaster Research, 12(3), 422-431, 2017.

(2) K. Maekawa, T. Ishida and T. Kishi: Multi-Scale Modeling of Structural Concrete, Taylor and Francis, 2008.