94 Data Model Centered Road Maintenance Support System Using Mobile Device

Satoshi Kubota

Abstract

Maintenance management is an essential operation that should be carried out effectively for maintaining, repairing, and rehabilitating highways and roads. It is necessary to accumulate information produced during the entire life cycle of roads in order to analyze problems and find solutions within a temporal sequence and to maintain them strategically and effectively. The primary objective of this study is to solve above problems on road maintenance and maintain the road efficiency. This paper proposed a road maintenance support system based on product data model using mobile devices. Product data models enable the exchanging and sharing of road information among those involved in road maintenance. The system consists of two use cases: in office and on site. In road administrator's office, the system is based on two-dimensional paper-based maps and three-dimensional printed models output by a three-dimensional printer. It supports the discussion of maintenance plans and enables sharing the maintenance plan and existing inspection results by using photographs from tablet computers and smartphones in combination with radiofrequency identification (RFID) tags. The system accumulates the photographs of notes and supports referring to them on-site using RFID, QR codes, and a global navigation satellite system. This system consists of two parts: a method of indicating important inspection points on-site by using AR markers, and reference management of inspection and rehabilitation data by using RFID and QR codes. The proposed system was evaluated the usability and capability. The evaluation results indicated usability and capability on site usage.

Keywords

Road maintenance • Inspection • Product data model • Mobile device

94.1 Introduction

Roads are networks that connect civil infrastructure and facilitate the delivery of emergency services. Because of their importance, they should be safe and kept in good condition. Maintenance management is an essential operation that should be carried out effectively for maintaining, repairing, and rehabilitating roads. It is important that the maintenance process is effective and that the quality of inspection is ensured. Cost-effective and high-quality maintenance depends on reliable inspection and assessment of conditions [1]. Furthermore, the need for reliable maintenance information influences management systems [2]. Because existing management systems do not use standardized information, they cannot exchange, share, and reuse information. For effective road maintenance, it is necessary to develop a system in which the latest and highest-quality road information can be used and shared. This would facilitate road planning, design, construction, inspection, and repair.

The primary objective of this study is to solve the above problems related to road maintenance and efficiency. This paper proposed a road maintenance support system based on product data model using mobile devices. Product data models enable

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the exchanging and sharing of road information among those involved in road maintenance. The system consists of two use cases: in office and on site. In road administrator's office, the system is based on two-dimensional paper-based maps and three-dimensional printed models output by a three-dimensional printer. It supports the discussion of maintenance plans and enables sharing the maintenance plan and existing inspection results by using photographs from tablet computers and smartphones in combination with radiofrequency identification (RFID) tags. The system accumulates the photographs of notes and supports referring to them on-site using RFID, QR codes, and a global navigation satellite system. The proposed system is evaluated the usability and capability. Field data were taken along the Shiraito Highland Way, Nagano Prefecture, Japan. Shiraito Highland Way is a road defined by the Road Transportation Act, and it is maintained and operated by a private company. It is around 10 km in length, and its elevation varies from 1000 to 1400 m.

94.2 Road Data Model

Road data models are constructed so that the information within the information management system can be shared among those involved in road management. A road data model is defined as the product data model of a road structure. Product data model is examined in respect of the method representing product and shape information over life cycle of the product. It is defined as the model including shape, technology information of composing members, production information for fabricating and inspecting members, management information of addition, amendment, and deletion, and information for assembling members. Product data models of civil infrastructure facilities have been developed by various organizations and research institutions [3–9]. However, the attributes defined in these data models and in the data model schemas differ from those in road data models.

Road data models can be classified into two types: geometry information models and business information models. Geometry information models contain information associated with the constituent parts of roads. Business information models contain the information necessary for road management work as well as the results of information analysis produced as the result of such work. In constructing the geometry information models, design and dimensional information was extracted from the models. This includes information about the composition of particular structures, information from the design and construction stages, and information that should be stored for use in future road management work. Information regarding the composition of structures includes information about roads, slopes, bridges, tunnels, and ancillary items. Information that should be stored includes the results of work such as inspections, repairs, and strengthening of structures. In constructing the business information models, the information resulting from construction, inspection, detailed inspection, and repair and strengthening was extracted. Figure 94.1 shows a road data model. The location-based expressions "GM_Point," "GM_Surface," and "GM_Polygon" are defined so as to connect the road data model to map information. An information management system was developed on the basis of the proposed idea. A road data model is constructed such that information within the information management system can be shared among those involved in road management.

94.3 System Design

94.3.1 Design Concept

In this study, a road maintenance system is proposed for sharing decision making with road administrators and inspectors with the aim of performing inspection operations efficiently. Figure 94.2 shows the concept of the system design. The system targets discussion of road inspection in the road administrators' office and at road inspection sites. In the discussion of inspection, the proposed system uses two-dimensional paper-based maps and three-dimensional printed models in Fig. 94.2(1, 2). The road administrators and inspectors in local government and road administration offices are used to using the two-dimensional paper-based maps on their road maintenance works. A physical model has the ability to improve communication of spatial understanding. This could lead to improved productivity, reduction of errors, and better quality for construction tasks. The three-dimensional printed models have the capability which the road administrator and inspectors can recall actual shapes on their maintained roads. For the reasons stated above, this system used two-dimensional paper-based maps and three-dimensional printed models.

At the inspection sites in Fig. 94.2(3), inspectors use a tablet computer for referring to the existed inspection and repair results and other maintenance information, based on QR codes or RFID tags attached to kilo-posts. The inputted data are stored as a text file and photographs of inspection results.

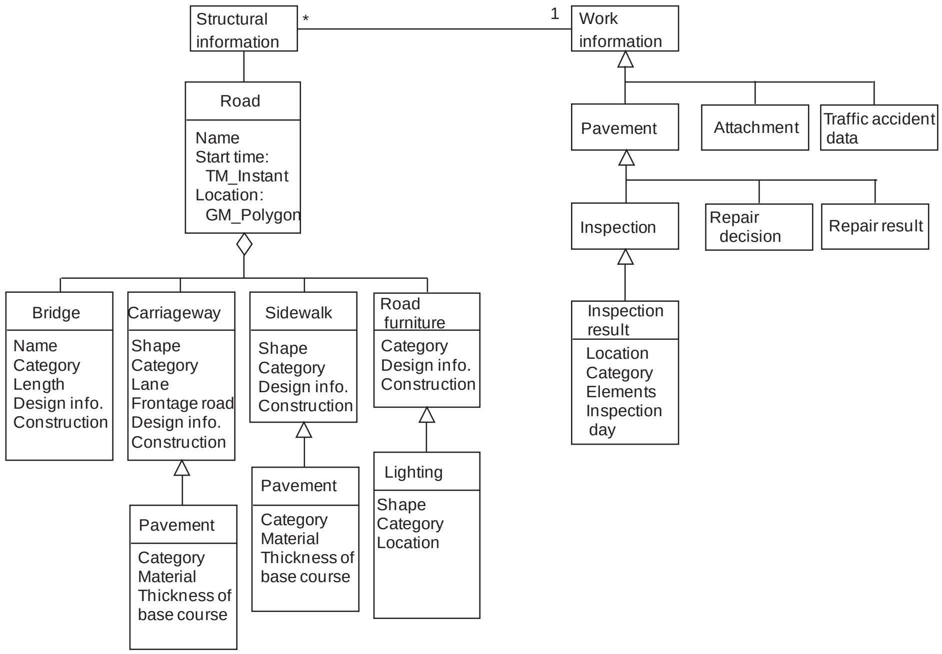

Fig. 94.1 Road data model

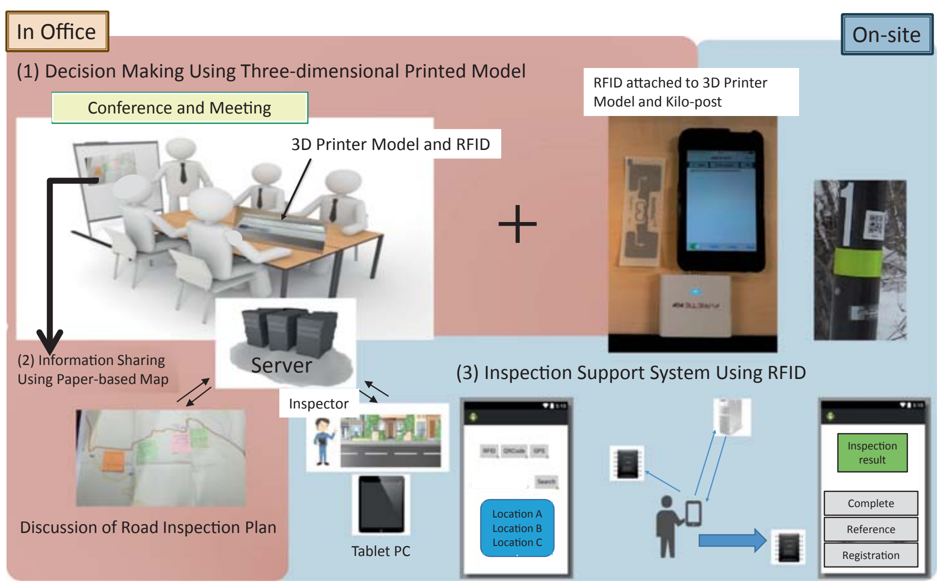

Fig. 94.2 System concept

94.3.2 Design Principles

Concept of Model Oriented Management System. For maintenance, a high-accuracy management system is required, and therefore, analyzed information in the life-cycle should be accumulated. This system is used in each phase of design, construction, inspection, soundness evaluation, deterioration forecasting, and maintenance planning. The system database serves to support each stage of the life-cycle. For operating the management system, standardized information should be accumulated and shared according to the product data models and the long-term service stage of roads. It is difficult to define

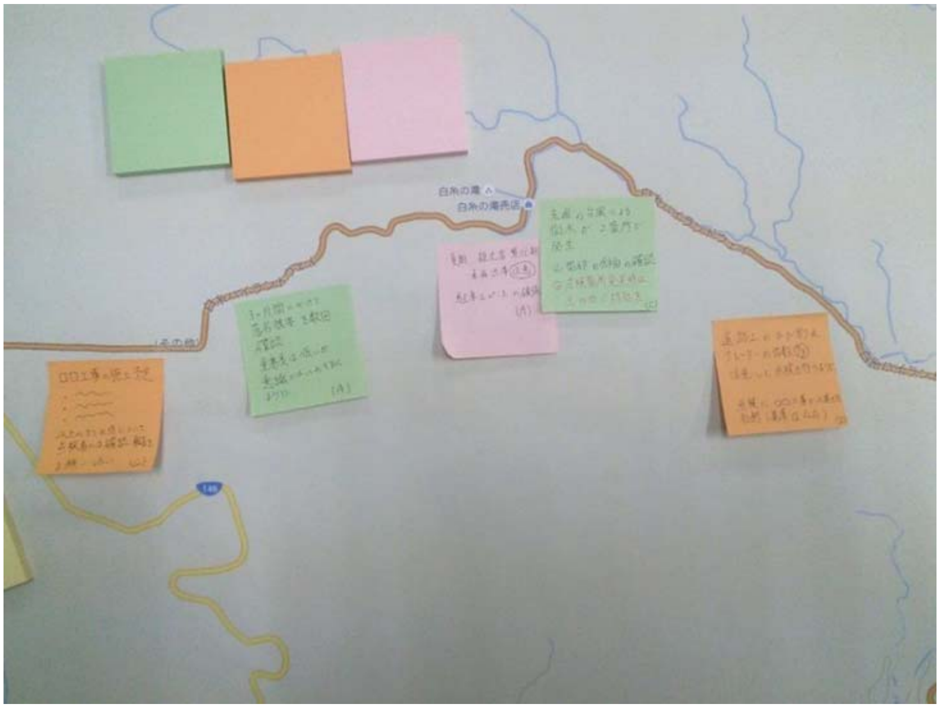

Fig. 94.3 Two-dimensional map for discussion

a unified set of information to be used in various existing systems and databases because of feasibility and operation. Standardized information can be exchanged and shared by exchanging maintenance information through the product data models in the maintenance management system and databases.

System Use in Discussion of Road Inspection. Road engineers discuss the important inspection points for constructing an inspection plan. In this system, two-dimensional paper maps (A0- or A4-sized), sticky notes, a three-dimensional printed model, RFID tags, and mobile devices are used. When road administrators discuss the inspection plan during a workshop, they record the key points to check during inspection and the points most likely to be overlooked on sticky notes and attach these notes to the two-dimensional paper map. The sticky notes capture details such as potholes, cracks, and wind-fallen trees. RFID tags are attached to the three-dimensional printed model. The three-dimensional model is used for understanding real landforms and the situation [10]. Figure 94.3 shows the two-dimensional map for discussion. Road engineers take a photograph of sticky notes and register them on the digital map of the system.

System Use at Inspection Sites. A road inspection support system is proposed and developed. This system has two main design principles, namely, the use of AR markers and QR codes, for accumulating and extracting maintenance information. An AR marker is used for indicating important inspection points, and a QR code is used for accessing and browsing maintenance information at the site. In this research field, it is difficult to use a global navigation satellite system because trees grow thickly over the road. Mobile devices such as smartphones and tablet PCs are used for reading the AR markers and QR codes.

94.4 Development of System

94.4.1 Construction of Three-Dimensional Printed Model

The road structures are printed in three dimensions by a three-dimensional printer. Models of this kind can represent the physical layout [10]. In this study, the three-dimensional printer was the MF-2000 (Mutoh Engineering). RFID tags were attached on the three-dimensional printed model.

94.4.2 RFID Usage

The three-dimensional model with attached RFID tags is used in the office. Road engineers discuss previous inspection results, using RFID tags attached to the model for understanding the inspection operation and previous results. The RFID reader has a range of about 1 m and can read multiple tags. This system uses RFID tags (rather than barcodes or QR codes) for collecting and retrieving maintenance information about the sites. Figure 94.4 show an RFID tag, a reader, and a three-dimensional printed model. And, it shows a three-dimensional printed model with RFID tags. The system uses ARETE POP (PHYCHIPS) for RFID readers, the corresponding SDK for system programming, and DogBone M4D Wet (SMARTRAC) for RFID tags.

94.4.3 System Functions

The proposed system has two functions: registration and serving as reference for registered information. The registration function has two subfunctions used in the office: registration of sticky notes on the paper map, as captured by photographs of the paper map after discussion; and reading and writing the tag information on the three-dimensional printed model, which is done by the Android application. There are two functions used at sites: inputting the inspection results and storing photographs of damage, cracks, and places chosen as relevant by inspectors. Maintenance information is registered using the markers on the digital map.

AR and QR Code Function. The AR function was used for indicating important inspection points on road structures. This function indicates these points using the AR marker method. It is difficult to use a marker-less method in this research field because there are cases in which a three-dimensional AR model cannot be represented owing to shade and other environmental characteristics. AR markers are attached to the past damage points of main girders, crossbeams, and drainages. Figure 94.5 left shows s three-dimensional model of an AR marker on a bridge (indicted by an arrow).

Fig. 94.4 RFID tag and compatible reader and three-dimensional printed model

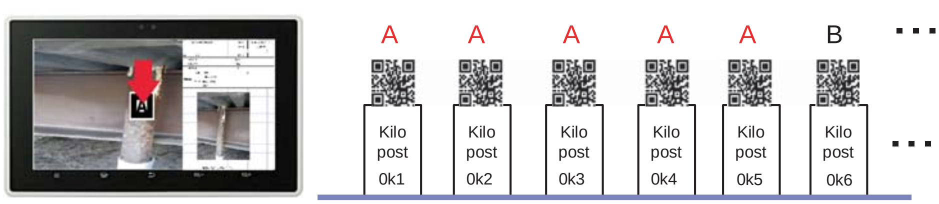

Fig. 94.5 AR marker on bridge and QR code on kilo post

The QR code function was used for referring to the inspection and repair data on-site. QR codes are attached to kilo posts, as shown in Fig. 94.5 right. When mobile devices read a QR code, they access the server and call up the inspection data of pavements, road slopes, directional arrows, and signs with kilo posts at 100-m intervals. Shiraito Highland Way is around 10 km in length. Therefore, there are 100 kilo posts, each with QR code. The inspection data, taken from 2013 data about Shiraito Highland Way, are stored in Microsoft Excel files, and they include the inspection and damage records of bridges, pavements, road slopes, directional arrows, and signs. The same QR code is attached to five kilo posts, 0k1, 0k2, 0k3, 0k4, and 0k5.

94.5 Evaluation of System

94.5.1 Experimental Scenario

The proposed system was evaluated on Shiraito Highland Way for confirming its usability, applicability for a local road administrator, and operation of the system. An experiment was conducted on January 29 and 30, 2015 and January 19, 2016. Four users participated in the evaluation, including three members of the road administration staff and one construction consultant engineer. In the experiment, QR codes were attached to the upper end position and side of 20 kilo posts from the origin to 2 km. A laptop PC was used as the server. The users used a tablet PC (Android ASUS Memo Pad HD7). Figure 94.6 shows a user reading the QR code and referring to the inspection data. In office, the participants discussed the inspection plan, using a prepared two-dimensional paper map and a three-dimensional printed model with RFID tags. The proposed system was used to register photographs and to both reference and register inspection results via RFID tags. And, Fig. 94.6 shows a scene from discussion using the proposed system. Finally, participants used the system at the site. An RFID tag was attached to the upper end position and side of the kilo-post. Figure 94.6 shows a user reading the RFID tag and referring to the inspection data. The proposed system displays are shown in Fig. 94.7.

94.5.2 Consideration

The authors conducted a semi-structured interview with the three users to evaluate the system. The KJ method (sometimes called the “affinity diagram method”) was applied to qualitatively analyze the interview results. The KJ method is a group consensus technique. It named for its inventor, Jiro Kawakita (the Japanese put their last names first), allows groups to quickly reach a consensus on priorities of subjective, qualitative data.

Figure 94.8 shows the result of the KJ method. The opinions of engineers were classified to usability and applicability of the system and function requirements. The KJ-Method really does work to get an objective group consensus out of a collection of subjective, opinionated data. It is simple and easy to do. It focuses the group on the task at hand and is excellent at eliminating unnecessary discussion and distractions from the goal.

Usability. The users could refer to inspection data without the need for detailed operating instructions and could understand which places were discussed because the two-dimensional map was matched to a digital map by the system. The

Fig. 94.6 Experimental scenes in office and on site

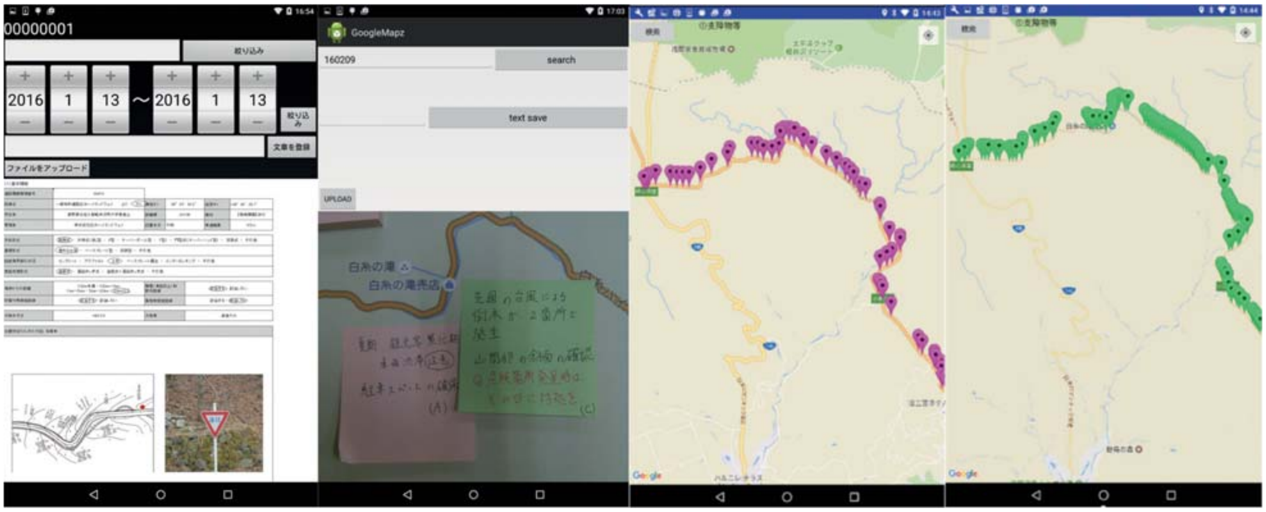

Fig. 94.7 Screenshots of proposed system

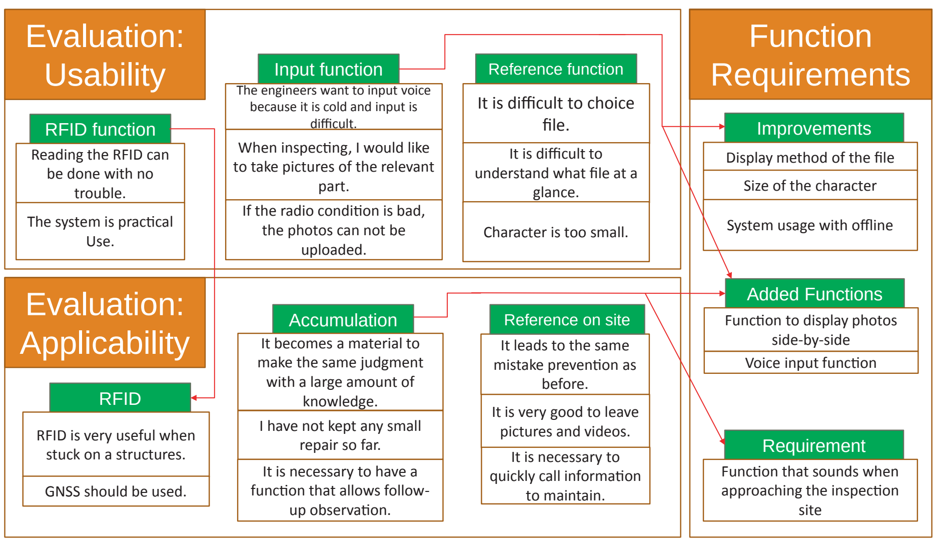

Fig. 94.8 Interview result using KJ method

design concept is suitable because road administrators can use the system with a tablet computer both in office and on-site without requiring a detailed manual. However, the users said that it was difficult to coordinate files without support from the system for Japanese-language file names and that a voice input function would improve usability. The users said that it was useful to refer to the inspection data of pavements, directional arrows, and so on based on the nearby kilo posts. By providing the ability to refer to inspection data on-site, the need to bring road ledgers is avoided. Furthermore, the user said that the system would be more effective if daily inspection data, the amount of which will continually increase, are stored and managed in this system.

Applicability. In terms of application capability, the system can be used to share the decision-making process between engineers in an office and inspectors at the field site. The system has some useful features, such as indicating important inspection points using AR markers and managing the temporal nature of the stored data by using QR codes. And, by using a two-dimensional paper-based map, the inspectors can check the points which have an inclination to miss on the sites in an accustomed manner. It seems to indicate that using a mobile device to access data is helpful using product data model concept. It is better to share the discussion information between office and site than the existing method using only information system. By using a three-dimensional printed model and RFID tags, inspectors could understand the inspection location visually. The proposed system can indicate important inspection points and manage the maintenance information. This system seems likely to be practical for use in road maintenance. The system has some useful features, such as indicating important inspection points by using RFID tags on a three-dimensional printed model.

However, it has a few shortcomings that may limit its practical use, as mentioned above. The AR marker and QR code should be used together. The AR markers could be used in an office meeting to represent the three-dimensional model of road structures and road curves using AR. The QR codes could be used for maintaining construction equipment. Furthermore, the system should provide registration function for inspection and repair data. And, the three-dimensional printed model and two-dimensional paper map could be used in an office meeting to support making decisions about inspection. Furthermore, the users said that the system would be more effective if daily inspection data, the amount of which will continually increase, were to be stored and managed in this system.

94.6 Conclusion

This study proposed a road maintenance system for sharing maintenance information between engineers of different skill levels and for understanding decision-making about inspections. This system used AR markers for indicating important inspection points and QR codes for referring to the inspection data of pavements, road slopes, directional arrows, and signs. And the system is based on two-dimensional paper-based maps and three-dimensional printed models output by a three-dimensional printer. A road data model was constructed based on the product data model concept.

The proposed system supports discussion and sharing of maintenance plans and retrieving maintenance plans and existing inspection results by using photographs taken with a tablet computer and smartphone along with RFID tags. The discussion results are attached to the two-dimensional map after being written on sticky notes. The system accumulates photographs of the sticky notes and supports referring to them at the site; for this, it uses RFID tags, QR codes, and a global navigation satellite system. A three-dimensional printed model is constructed to simulate the road structures, and RFID tags are attached to the model.

The suitability of the proposed system was evaluated through experiments on Shiraito Highland Way, Nagano Prefecture, Japan. The results indicated that the system is suitable for discussing and sharing maintenance information in office and on site and is suitable for its task. The proposed system could possibly be used practically for road maintenance.

The main contribution of this study is a significant effort to extend the applicability of the product data model. The system approach is based on a road data model. It is necessary to update the road data model to use these data for maintenance operations. The proposed system has a data model framework that can be applied to road asset management.

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