

Development of a remote condition assessment system for road infrastructures

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Abstract

This paper describes a Remote Collaborative Visual Inspection System for integrated management by linking digital movie captured by a running vehicle and online road drawings. The newly developed road condition assessment system consists of commercially available on-board high-resolution video cameras during the visual inspection of road pavements and road appurtenances and a Web connection system. The system enables users to select a road section in a road register on an on-screen map and visually observe not only pavements but also road facilities, slopes, the state of vegetation, and road-occupying structures. The system, therefore, can be expected to help reduce visual detection failures compared with conventional visual observation from moving vehicles and make highly objective evaluation possible through observation by two or more persons. By using image data, the system also provides basic data that can be used for not only maintenance but also road planning.

Keywords: road infrastructure, digital movie, condition assessment, online drawing, diagnosis

1. Introduction

There is concern about the growing cost of maintenance, such as reconstruction and repairs, of a large stock of road infrastructure accumulated during and after the period of rapid economic growth. In view of the aging of infrastructure including road facilities and of the needs of society, there is growing demand for reasonable maintenance including preventive maintenance under tight budget and human resource constraints [1].

For road pavements, the Maintenance Control Index (MCI) is widely used in Japan as an index for asphalt pavement damage [2]. MCI parameterizes the cracking ratio, roughness and rutting depth, but it can also be used as an index based on two attributes or one attribute. In the United States, the present serviceability level of pavements is expressed with AASHTO's Present Serviceability Index (PSI) [3]. Research comparing this index with other indices is also underway [4]. The World Bank has proposed the International Roughness Index (IRI) as an indicator, focusing mainly on ride quality, of the roughness of road surfaces including but not limited to asphalt pavements [5, 6].

For the indices mentioned above, the soundness of road pavements is usually evaluated by using a road inspection vehicle. A road inspection vehicle is capable of

accurate quantitative evaluation, but its initial cost and operating cost are usually relatively high, and the frequency of use of road inspection vehicles tends to be low. There are also constraints due to the road width, radius of curvature, slope, etc., that can be measured with a road inspection vehicle.

Besides the pavement mentioned above, there are many road elements that should be checked regularly, such as road appurtenances, filled and cut slopes. The assessment of non-pavement elements, however, relies in many cases on qualitative and subjective judgment such as visual inspection from maintenance patrol vehicles and information provided by drivers and local residents. It is not uncommon, therefore, that considerable amounts of time and cost are spent before repair or other maintenance measures are taken.

In this study, views from a maintenance patrol vehicle were recorded to supplement visual inspection from the vehicle and obtain objective and repeatable inspection results. The purpose of the study is to develop a system for visual assessment of the present state of not only pavements but also road structures including appurtenances, slopes and vegetation (*Remote Collaborative Visual Inspection System*).

2. Present state of maintenance of road structures

2.1 Maintenance at prefectural level

The Yamaguchi Prefectural Government, for example, is responsible for a road network with a total length of 3,388 km (see Figure 1). In Yamaguchi Prefecture, road

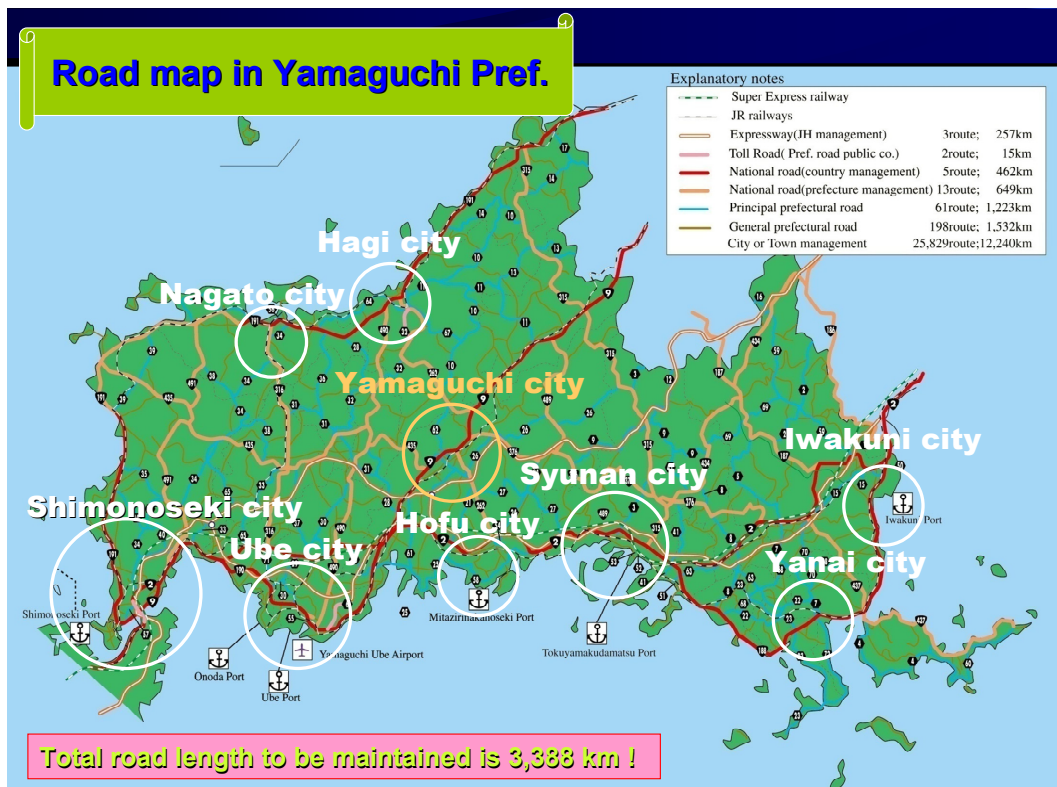


Figure 1. Road network managed by Yamaguchi Prefecture and total road length.

sections are classified according to the degree of importance of each road section, and road inspection vehicle surveys and visual surveys by pavement contractors are conducted in seven-year cycles. The survey results are documented in specified formats and used by maintenance-related departments. Daily maintenance patrol of roads is performed by contractors, and each road section is assessed by one evaluator. Pavement conditions are diagrammatically recorded on paper in the road register. Since, however, these diagrams are difficult to relate to the actual road locations, it cannot be said that the diagrams are being used effectively.

Information indicating the present state of roads includes the road register, the preparation of which is required by the Road Act. In the road register of Yamaguchi Prefecture, a 1/1000-scale plan view of a 500-meter-long road section is shown in the upper half of each data sheet, and the road length, road width and the radius of curvature are shown in the lower half (see Figure 6). The longitudinal slope, however, is not indicated. Each data set kept at each local office consists of one set of A2-size Mylar original drawings for a road section, one set of their paper copies, and hard covers to protect the Mylar and paper drawings. To use register data, usually, copies are made, on an as-needed basis, of necessary data sheets in the bound volumes. More efficient management of information in these registers is being hoped for in order to respond to public complaints or explain project details promptly.

2.2 Road structure data in electronic form

Research and implementation efforts are underway to digitize and standardize data on roads and road appurtenances. Examples are JHDM (Japan Highway Data Model) [7], which has been developed by NEXCO (former Japan Highway Public Corporation), CAD-based LandXML [8] and IFC-Road [9], which is a standardization effort of IAI (International Alliance for Interoperability). Huge amounts of time and cost would be required, however, if local governments that manage information on many existing roads on paper were to standardize their registers by using the data models mentioned above. There is a need, therefore, for a method of seamless transition from the present maintenance scheme to a scheme based on the use of information in electronic form.

3. System development

3.1 Sharing images obtained by maintenance vehicles and road register data

By linking and sharing digitized road register data and corresponding images captured by road inspection vehicles, this study aims to enable two or more evaluators to identify and locate road and road facility damage and roadway problem areas in the captured images in order to enhance the objectivity of assessment and reduce detection failures. Because images captured by road inspection vehicles can be evaluated visually, they make it possible to make effective use of the advantages of sharing. The digitization of register data greatly contributes to labor saving because the management of information recorded on paper is no longer necessary.

3.2 Digitization work flow

Information recorded on paper such as existing road registers and summery plots and district maps in registers was scanned and saved in the PDF format. Images captured with high-definition cameras were saved in the fairly common MPEG-2 format. Figure 2 illustrates the digitization work flow.

It is believed that in the digitizing effort in the coming years, the incorporation of road register data into a CAD system and the development of databases of register data items will be essential. This study, however, goes only as far as digitizing information by the method mentioned above in order to assist and enhance efficiency in visual inspection with a relatively small amount of effort and without creating excessive workload for maintenance personnel.

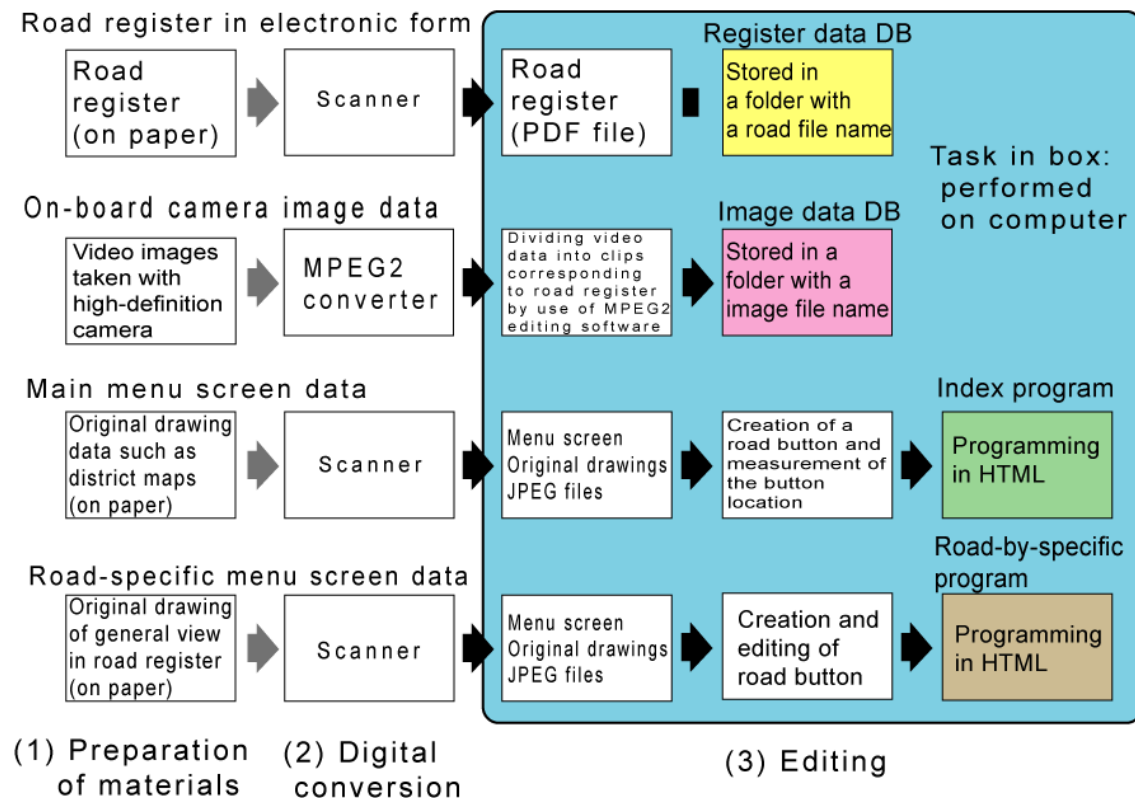


Figure 2. Procedure for digitizing road information.

3.3 Data binding

As shown in Figure 2, HTML (HyperText Markup Language), a widely used Web page scripting language [10], was used to relate the digitized data and create the user interface. HTML was used because hyperlinks facilitate data linking (e.g., linking road register data and on-board camera image data) and future extension into a Web-based system including database implementation. In the case of a relatively small-scale data system like the road condition assessment system developed in this study, hyperlinks can be maintained with relative ease through HTML modifications.

3.4 Data hierarchy

The road condition assessment system consists of three levels as shown in Figure 3. The first level is the menu screen of the system that displays three roads to be managed. The second level shows road-by-road registers. At the third level, road registers and captured images linked to the register data are stored. Users can select a road on the menu screen (Figure 4), select the number representing the road register at the second level (Figure 5) to display the road register data (Figure 6) or captured images (Figure 7). In Figure 5, black boxes (hand-shaped pointer 1) represent links to the road register; the red boxes (hand-shaped pointer 2) represent links to the images captured from a vehicle running from the start point and the end point corresponding to the register data; and the white boxes (hand-shaped pointer 3) represent links to the images captured from a vehicle running from the end point to the start point corresponding to the register data. The red (hand-shaped pointer 4) and white triangles represent links to the images captured from a vehicle running from the start point to the end point of the road and from the end point to the start point.

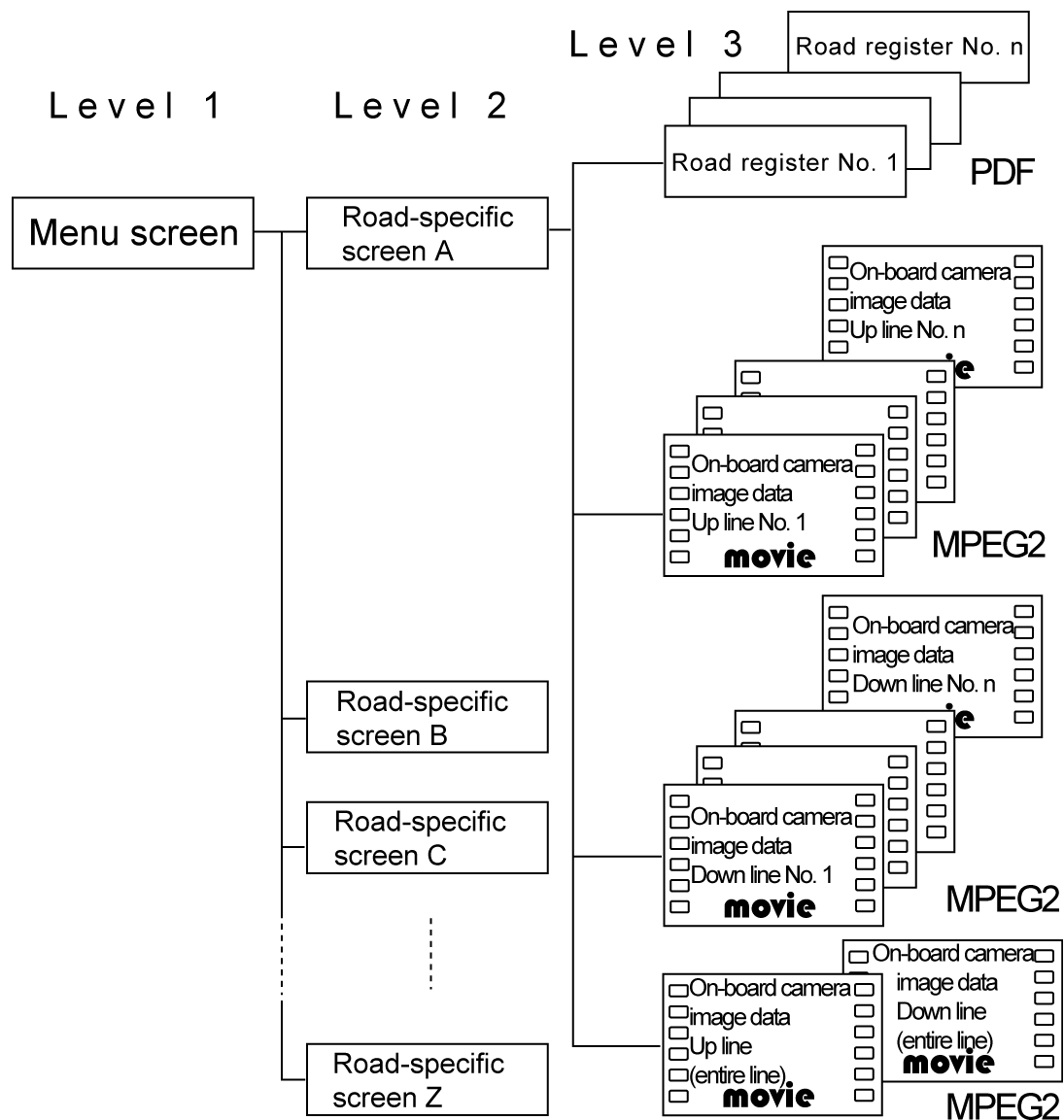


Figure 3. Data hierarchy.

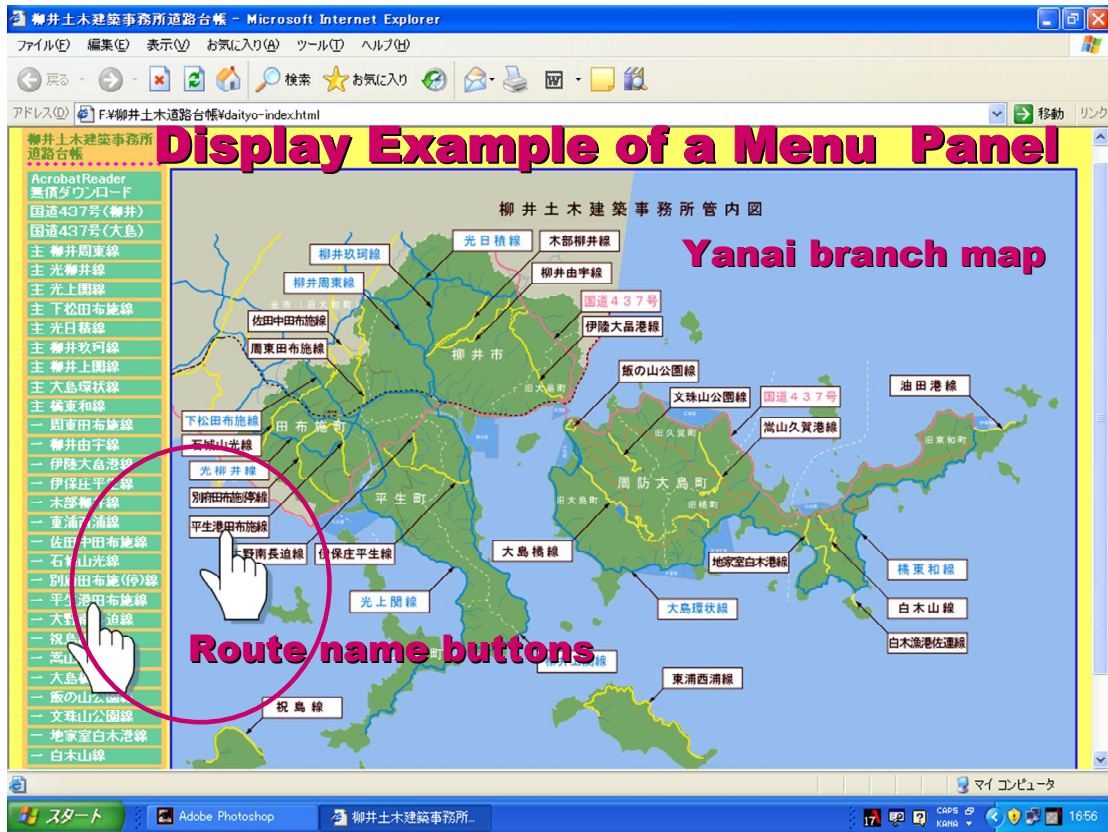


Figure 4. Example of road menu (Level 1).

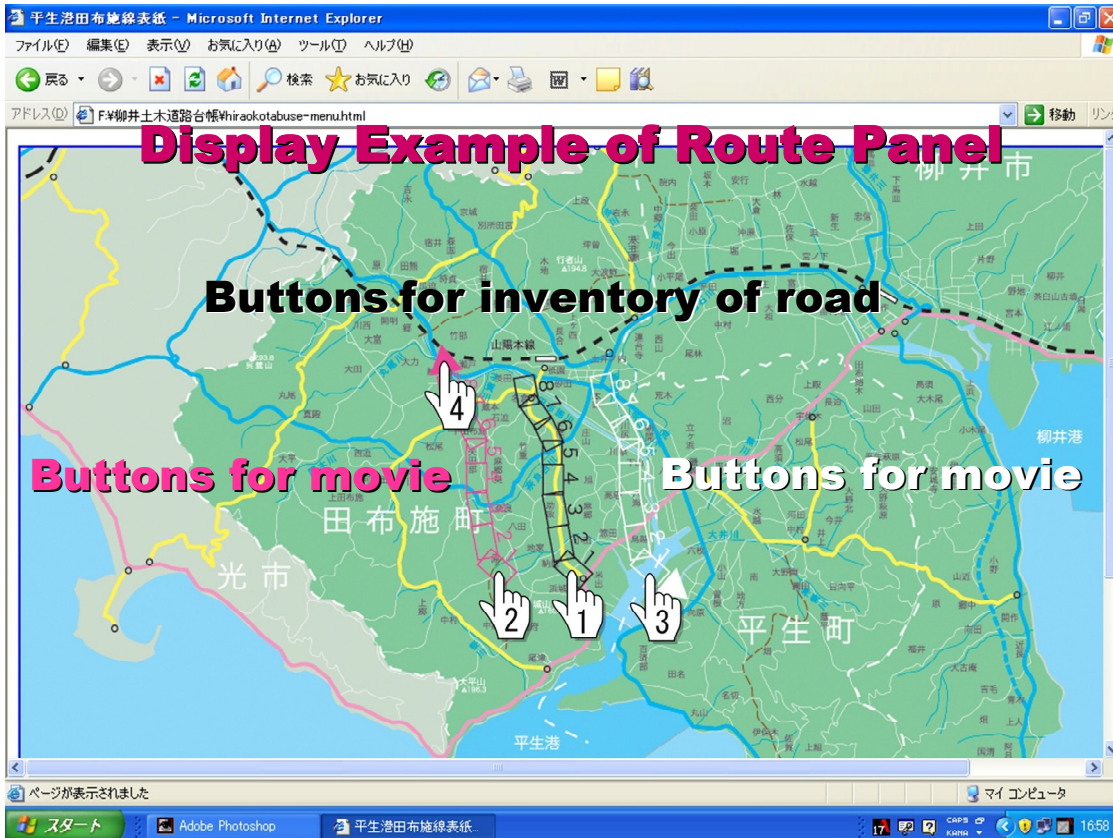


Figure 5. Example of road-specific menu (Level 2).

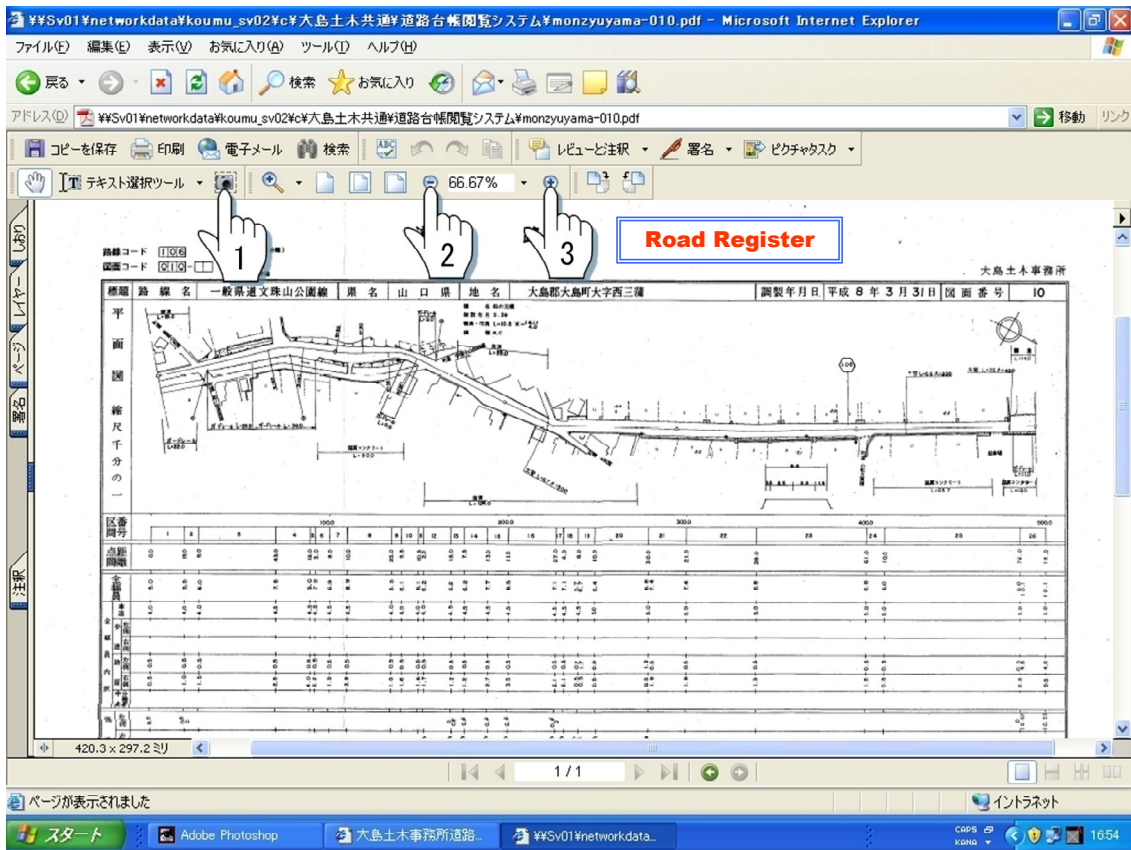


Figure 6. Example of road register screen (Level 3).

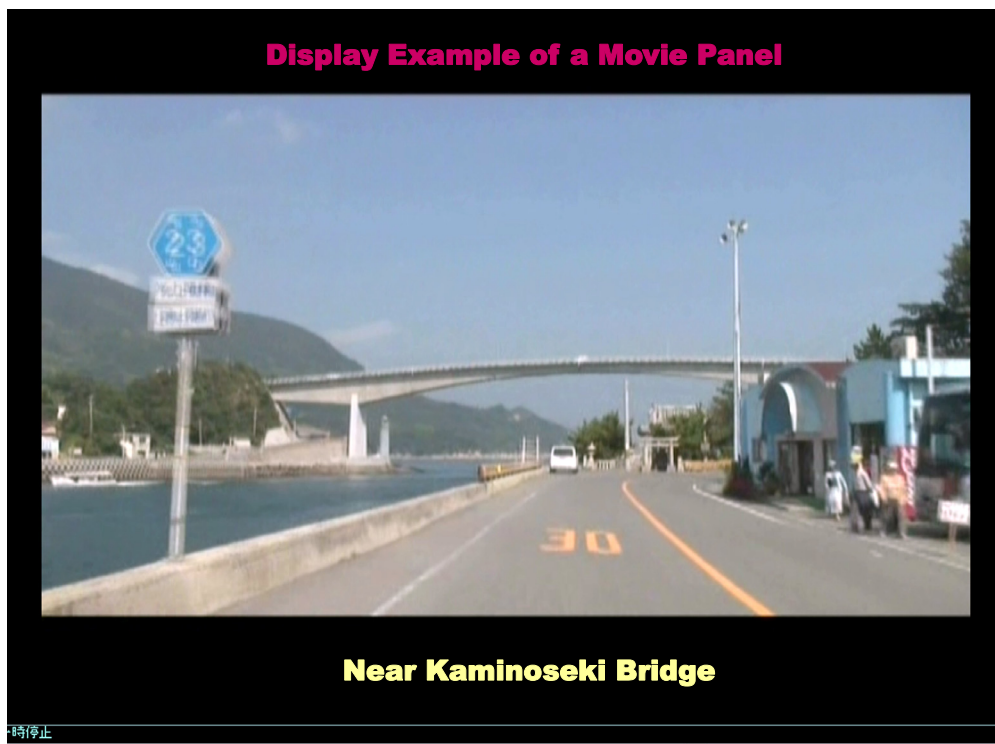


Figure 7. Example of on-board camera image (Level 3).

4. Image acquisition and links to road register data

4.1 Image acquisition

To obtain images from a vehicle, a commercially available high-definition video camera, a monopod for supporting the camera, and a voltage converter for 12V DC connection. To prevent the windshield from reflecting light, the dashboard was covered with black cloth. Figure 8 shows the setup for video shooting. During video shooting, the vehicle speed was kept at 50 km/h or less. In curved road sections, the camera was turned sideways from direction A to direction B so that the center of the roadway stayed at the center of the image frame (see Figure 8). The captured images were converted to MPEG-2 for video viewing convenience. The use of higher-resolution formats will also be considered in future studies.

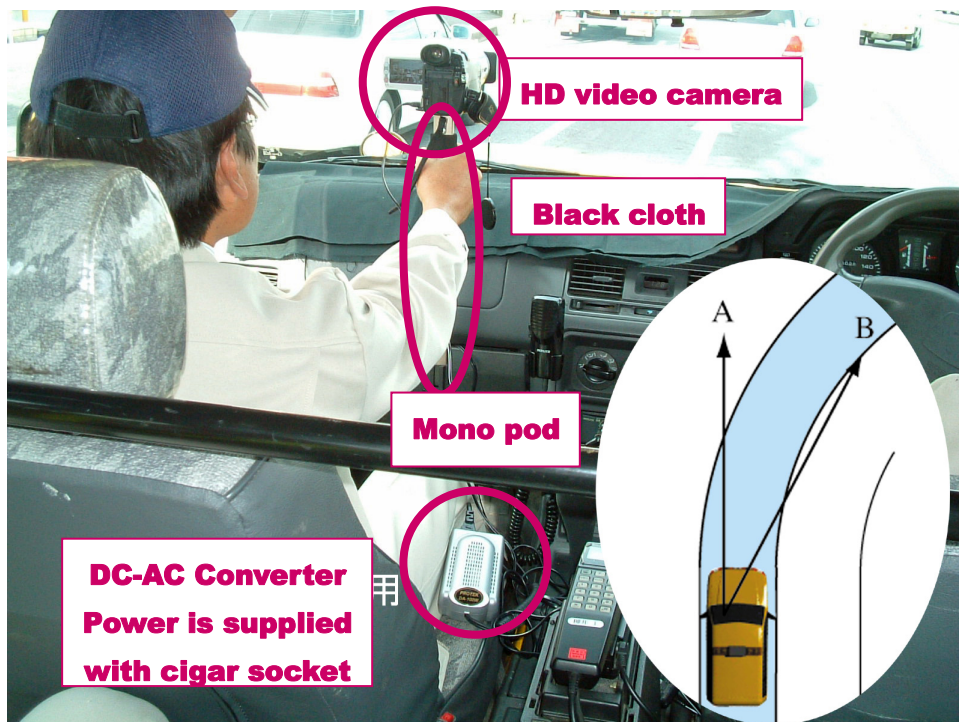


Figure 8. Setup of on-board video camera.

4.2 Linking images and road register data

Video clips corresponding to road register data were prepared from the captured video data by using video editing software and visually interpreting the images mainly by the human eye. The video clips and road register data were related through HTML files showing road maps. The tasks at this stage consisted mainly of video editing and data linking performed manually. The next goal, therefore, is to shorten the time required for editing by performing GPS data measurement simultaneously to link video data and time during video shooting and pick up the time at which the start and end point coordinates in the road register are passed.

5. Use and evaluation of the system

5.1 Example of use of road register and image data

Figure 9 is a screenshot showing an example of a system screen. In this example, the screen displays the road register data, and a video clip showing the corresponding road section is being played back by media player software. The video images were captured by a vehicle moving from right to left of the map, and the image in Figure 9 shows the area on the near side of the municipal road and the intersection in the left half of the plan view. The road-specific menu screens for the roads in Yamaguchi Prefecture have already been completed, and the road register data for all roads in the prefecture can be viewed on the system. Video image data for the roads managed by “Yanai” branch office of the Yamaguchi Prefectural Government are already available, and the preparation of video image data for the roads managed by “Ube” branch office of the Yamaguchi Prefectural Government is currently underway. The total disk space needed to store image data for all roads in the prefecture is estimated to be about 1.0 TB. It is relatively easy to develop a highly redundant Web-based system by using a distributed data server system.

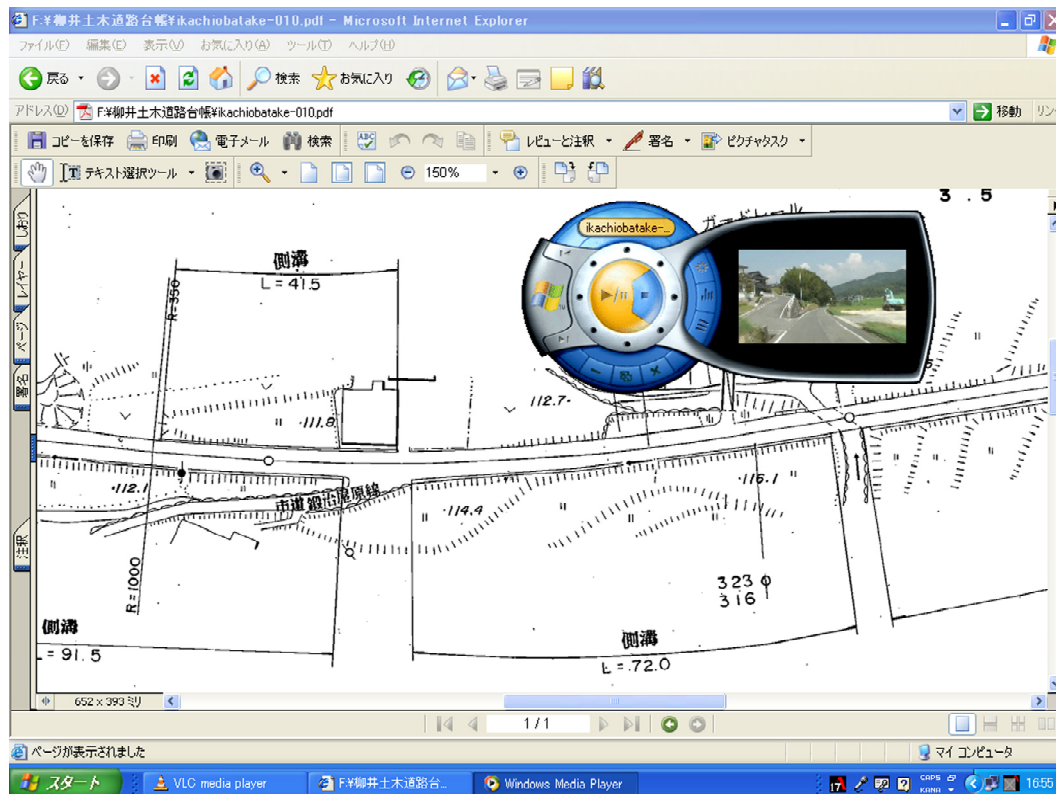


Figure 9. Using the system.

5.2 Proposed approach to pavement asset management

Figure 10 shows a sample workflow for pavement repair by use of the road condition assessment system. As the first step, video images and audio clips are played back (see Figure 7), and pavement damage areas are identified by the eye and ear of the estimators. As the next step, field surveys of the identified damage areas are conducted to identify the areas to be repaired and prioritize the repair needs. Because

of budgetary constraints, the prioritization of pavement maintenance needs is essential. The authors, therefore, propose that damage areas identified through field surveys be prioritized into three repair priority levels, namely, “red”: urgent repair needed (MCI < 3, cracking ratio: 30% or more, rutting depth: 30 mm or more); “orange”: repair needed (3

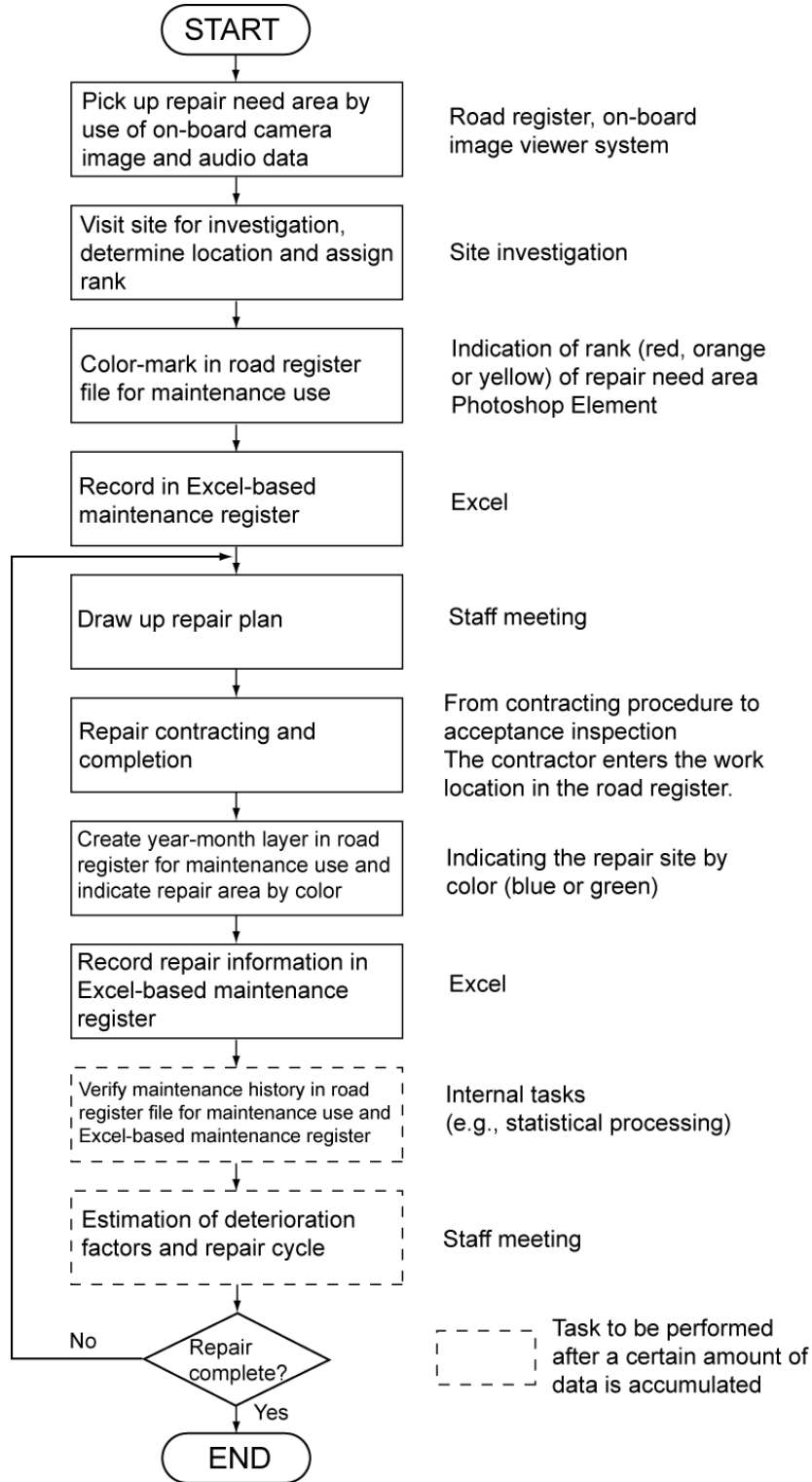


Figure 10. Example of workflow for road pavement repair.

Table 1. Example of pavement repair register.
 (a) Repair need register

Road code number	Register number	Area number	Year	Pave-ment area	Resurfac- ing	Overlay	Patch- ing
437	14	1	2006	100	0	100	0

(b) 2006 pavement repair register

Road code number	Register number	Area number	Year	Pave-ment area	Resurfac- ing	Overlay	Patch- ing
437	14	1	2006	70	0	70	0

(c) 2007 pavement repair register

Road code number	Register number	Area number	Year	Pave-ment area	Resurfac- ing	Overlay	Patch- ing
437	14	1	2007	30	0	30	0

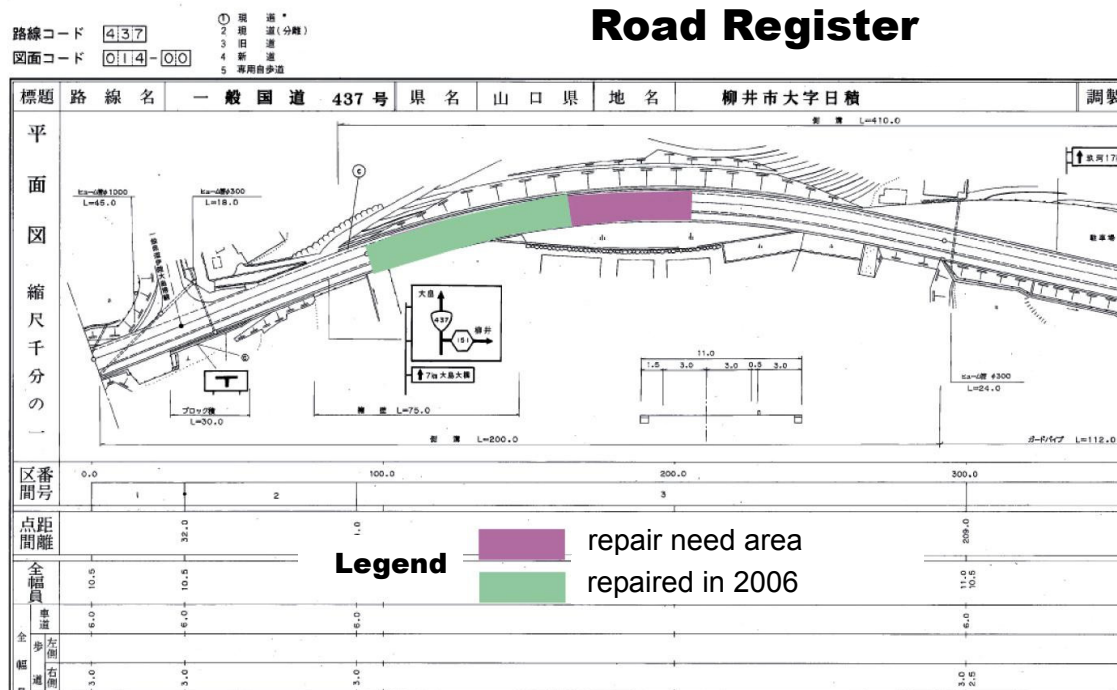


Figure 12. 2006 repair area map.

The procedures described above are repeated every year. As repair information is accumulated, statistical processing of pavement repair information becomes possible. Because colored data entered in the road register are accumulated in layers as shown in Figure 14, the repair history can be visualized. Drawing management can be made easy, therefore, by having the contractor submit road register data indicating the repair area after completion of the repair work.

Statistical processing of data makes it possible to estimate repair cycles and discover structural problems of roads. By updating the image data periodically, namely, once a year, and storing and comparing image data, changes in the condition of road surfaces and road facilities over time can be determined. This method is sufficient for the

Road Register

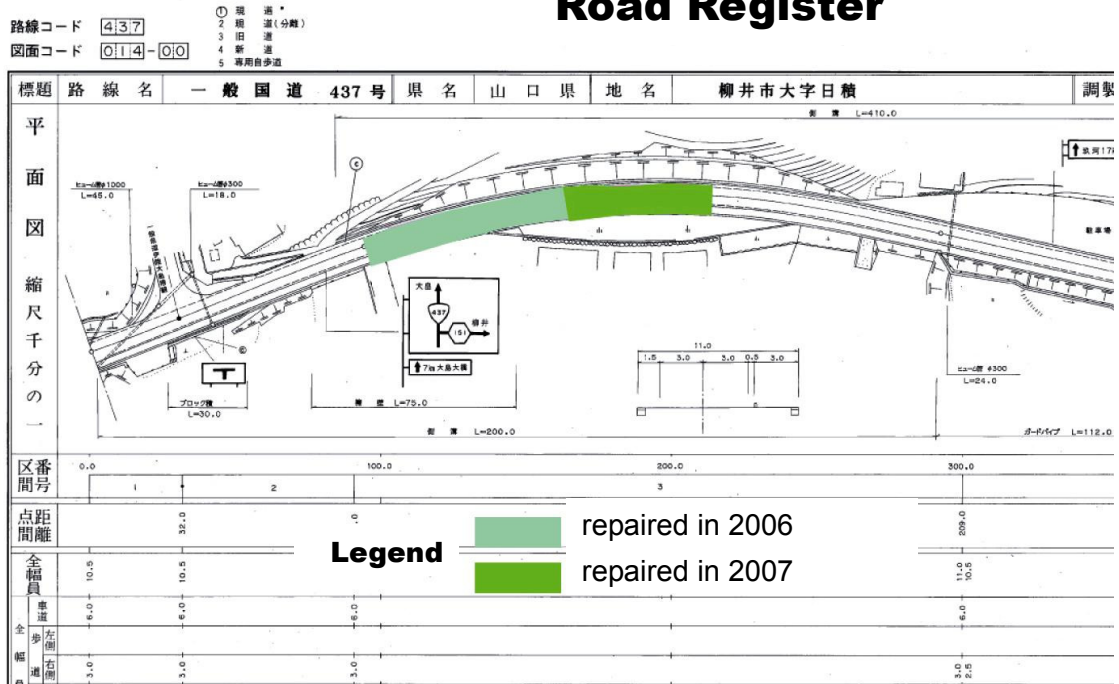


Figure 13. 2007 repair area map.

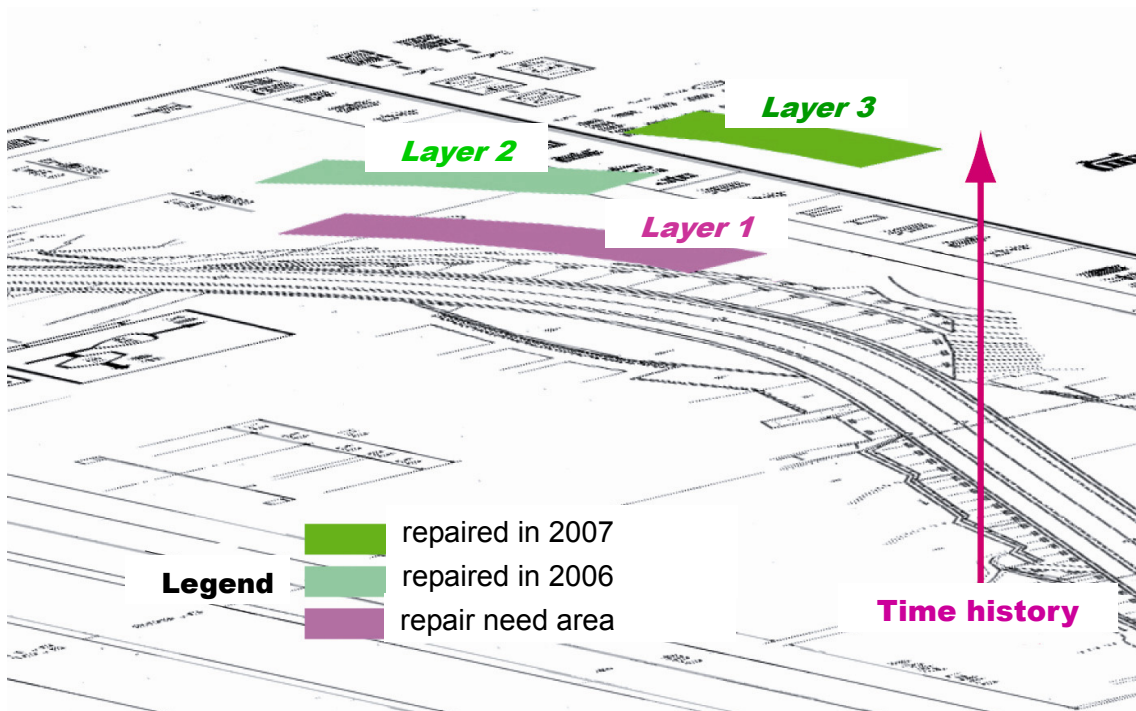


Figure 14. Example of layered view.

management and monitoring of a relatively small road network. For data that will increase in the coming years, however, it will be necessary to carry out system extension into a repair history database system linked with a geographic information system (GIS), instead of using map image files and spreadsheet software. It is believed, however, that a transition to a large-scale server-based system will be easy

because design schemes for the management of map data, video images and repair history data have already been developed in this study.

5.3 System evaluation

After the road condition assessment system went into operation at the “Yanai” branch office of the Yamaguchi Prefectural Government, the maintenance and construction department personnel who actually used the system were interviewed to hear their views. The results can be summarized as follows:

[Complaint handling]: When the maintenance and construction personnel received complaints by phone, they were able to talk about the complaints while viewing the images of the roadside areas concerned. This made it possible to prepare for site investigation, take appropriate and timely measures and record site information and complaint details easily in the road register.

[Easy operation]: The district map can be called up by one click of the mouse, and a click on the desired road opens the road register, and, if desired, images corresponding to the road register page in question can be viewed. The simple operation and functions are easy to understand and operate. The video data for one road section (500 m) takes only 30 to 40 seconds to play back. Thus, the system is stress-free, and video data can be paused for examination of details.

[Shorter travel time]: Site investigation is sometimes difficult, for example if the problem area is located on a remote island. The system, therefore, is useful.

[Approval support]: The system is useful because site conditions can be checked in connection with the approval procedures related to the use of road areas, road work, etc. Another advantage is that prior to boundary confirmation, site conditions can be viewed in advance.

[Improved accuracy of register data]: Register data can be easily checked at the desktop at the time of updating. As a result, the accuracy of register data has improved.

[Disaster response support]: In the event of a disaster, images showing the pre-disaster road conditions were easily made available because image data had been digitally archived.

Thus, overall, the interviewees found the system useful in performing maintenance tasks and collecting information on site conditions and had positive impressions of the operability of the system.

A survey on the frequency of use of the system revealed that the maintenance personnel used the system every day. The likely reason for this is as follows. Figure 15 shows a breakdown of public complaints about the road conditions received by the “Ube” branch office of the Yamaguchi Prefectural Government in 2005 to 2007, along with the percentages of different types of complaints. As shown, on average, about 500 complaints (an average of two complaints per day) were received every year. The complaints concerning places that can be identified by using the system (excluding the complaints in the “Others” category) account for about 90 percent of the total, and the personnel who received the phone calls used the system to identify the places in question before conducting site investigations. Improvements desired by the users included higher resolution of still images, higher shooting angles, seminars on data update methods, and linking with bridge registers and signage registers. There is

another area in which an improvement can be made. Although the system enables users to view the present state of problem areas, it is necessary to have some kind of quantitative indices for the assessment of road conditions.

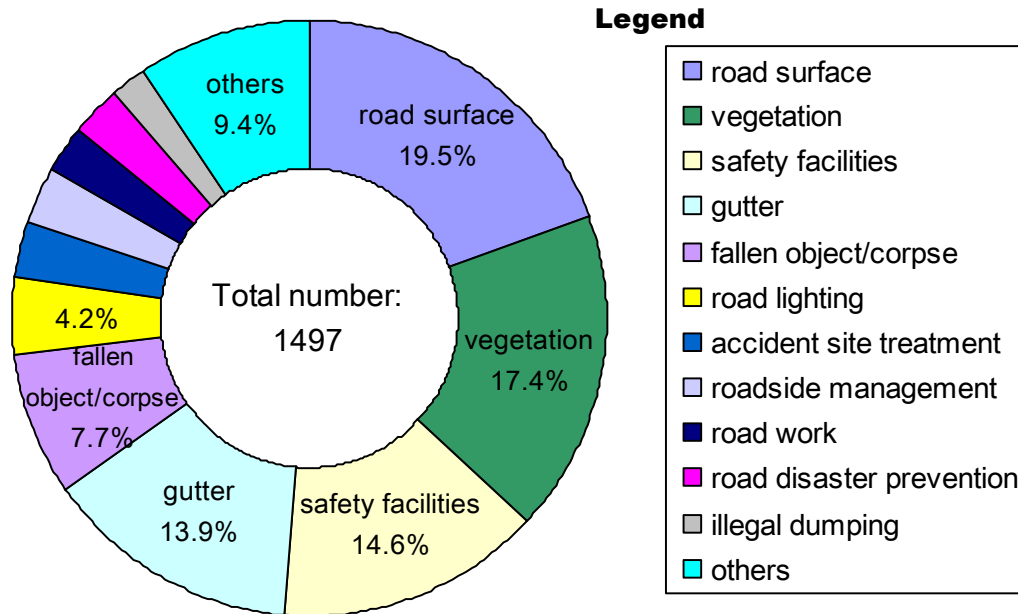


Figure 15. Breakdown of complaints about road conditions in the district managed by Ube branch office of the Yamaguchi Prefectural Government (from 2005 to 2007).

5.4 Possible applications in the coming years

Price reductions in the area of video equipment in recent years and high-resolution video images provided by high-definition video recording have made possible the assessment of the state of a remote site by two or more users. Possible applications of the road condition assessment system include not only the use of video data for the management of the maintenance of road facilities but also support for building certification and support for crisis management in times of wild weather. As data are accumulated in the system, it will be possible to assist in road planning in the areas listed below so that the quality of plans can be enhanced:

- 1) By identifying data patterns, vehicle movement and sight distances at different radii of curvature can be estimated.
- 2) Examples of successful construction projects including details such as the alignments, slope configuration and appurtenances of in-service roads can be looked up.
- 3) In the event of road damage caused by a disaster, video images of the pre-disaster conditions provide invaluable information.

6. Conclusions

In this study, a Remote Collaborative Visual Inspection System which designed mainly to assist in visual inspection conducted as part of road patrol and maintenance

activities has been developed. The system has made it possible to assess road conditions from a remote location in order to make maintenance/repair decisions. Because video images taken from a road inspection vehicle are used, not only pavement conditions but also the state of road appurtenances can be observed so that collected information can be shared and evaluated by two or more inspectors. Although further study is needed on database structure and data modeling, this study has shown that digital data made available in connection with the newly developed system can be used extensively in the road management and construction departments.

Video images captured by road maintenance vehicles are advantageous because they make it possible to obtain visual information and repeatable inspection results while reducing detection failures. Decision making, however, can still be influenced by subjective elements. In order to solve this problem, it is necessary to apply image processing methods, combine video data with audio data or develop objective and quantitative indicators used in conjunction with other sensors. Then, the needs for some quantitative and data-driven indices that describe road condition without any ambiguity would be our next challenge to work on.

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