Manipulating Data to Maintain Transportation Infrastructure

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It is becoming a major headache for the national government, prefectures and municipalities in Japan to properly and adequately maintain transportation infrastructure such as roads and bridges in order to improve people's quality of life and be prepared for natural disasters. While the budget for its maintenance has been falling in the past couple of decades, those authorities must efficiently and appropriately maintain such infrastructure. In view of statistics showing a huge increase in the number of transportation facilities that are over 50 years old, we have to establish a completely new maintenance scheme. Fujitsu is the leading information and communications technology (ICT) company delivering a wide range of services for transportation infrastructure management at the moment. It is now introducing a brand new system for monitoring roadways that makes it possible to collect road condition data automatically by using portable telecommunication devices.

1. Introduction

In the U.S., where 50 years have passed since a large number of road bridges were constructed in the New Deal project of the 1930s, accidents involving such social infrastructure began to occur in the 1980s, and the inadequate maintenance up to then has been pointed out as a major cause of those accidents.[1] Japan is facing a crisis because it is experiencing the US case right now. A large number of bridges were built in the high economic growth period of the 1960s, and most of them will reach 50 years of age between 2010 and 2025; this fact has given rise to the issue of safety with social infrastructure. To tackle this problem, the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) began to study and take measures for extending the life of social infrastructure, and local governments have also been exploring measures for maintaining their social infrastructure, with the help of local residents.[2),3)]

With this in the background, the collapse of the roof of the Sasago Tunnel on the Chuo Expressway in December 2012[4] further increased awareness about the need to manage the old social infrastructure. This accident triggered an amendment of the Road Act in May 2013, including provisions such as "the MLIT can rebuild and repair large constructions with complicated structures on local roads on behalf of the local government" and "it shall be made clear that road administrators should inspect roads from the perspective of preventive maintenance."

Under these circumstances, Fujitsu started offering SuperCALS Bridge Inspection Support (bridge inspection support system), which assists bridge inspectors, to local governments in May 2010. In order to further promote this kind of service, we decided to properly understand the real challenges faced by local governments and their day-to-day needs, starting in spring 2011, with the cooperation of Gifu Prefecture.

2. Utilization of technological elements owned by Fujitsu

Of all the 47 prefectures in Japan, Gifu Prefecture has the largest number of bridges and longest roads under prefectural management, and has been proactively working on "maintenance of social infrastructure with local residents" and "education for engineers for social infrastructure management in both the public and private sectors with the same technological standards."[5),6)]

As a result, it was confirmed anew that the ultimate answer to the challenges and needs of the local governments is to enhance functions commonly known in infrastructural engineering as "asset management":

1) Comprehensive risk management of a road network composed of bridges, tunnels and slopes
2) Establishment of a comprehensive body to deploy scheduled maintenance of social infrastructure

Moreover, it was even a bigger surprise to find out that nobody had a complete grasp of the state of road surfaces, even though roads are the most familiar and largest social infrastructure in our daily life. Even worse, as shown in **Figure 1**, the length of roads under the jurisdiction of local governments accounts for approximately 95% of the total length (1.2 million km) of all the roads in Japan, and taking prompt measures for this problem by using the existing schemes and concepts seemed far from reality.

Then, we considered how to use the Fujitsu Group's expertise in information and communications technology (ICT), and conducted an investigation on whether the image recognition technology owned by Fujitsu Laboratories would work or not, only to find out it would not at the moment, since imaging of roads posed some problems such as:

- To capture a large number of images, you must keep the speed of the car at 60 km/h regardless of the traffic rules that apply to each particular road.
- Provided that the images are to be captured during the daytime, shadows of roadside objects should be recognized in the sunlight, and rainy weather should be considered.

Next, we considered setting various types of sensors on the cars, but it turned out that this would require a huge cost, and that we would not be able to expect an immediate effect, so we concluded that it was not practicable.

Then, we changed our perspective and examined whether it would be possible to use DTS-C1D, a digital tachograph with a built-in drive recorder (**Figure 2**), manufactured and released in October 2011 by Transtron Inc., a company jointly owned by Fujitsu and Isuzu Motors Ltd., in order to take advantage of vehicle vibration data as the core technology. This device can collect the speed, time and distance digitally for vehicle operation management, it can help people to drive safely and economically, and above all, it can improve operational efficiency. In addition, we found that it can accurately acquire geographical data with a GPS function, and acceleration data in three directions (G sensor values) and we decided to proceed with our research based on this technology.

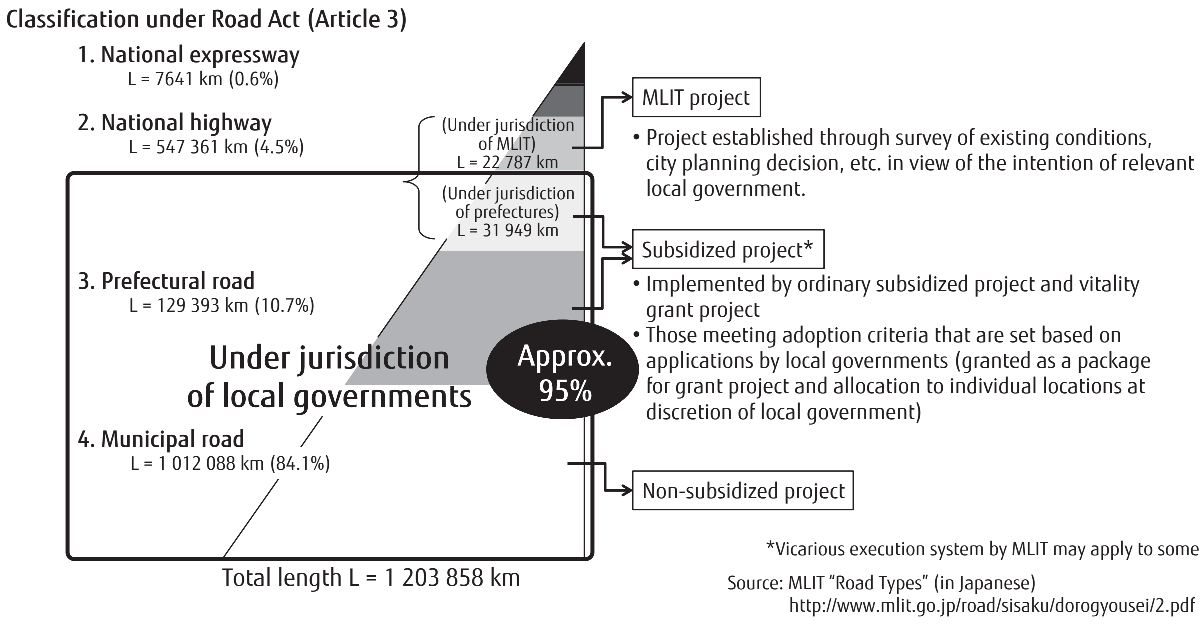


Figure 1
Road management entities.

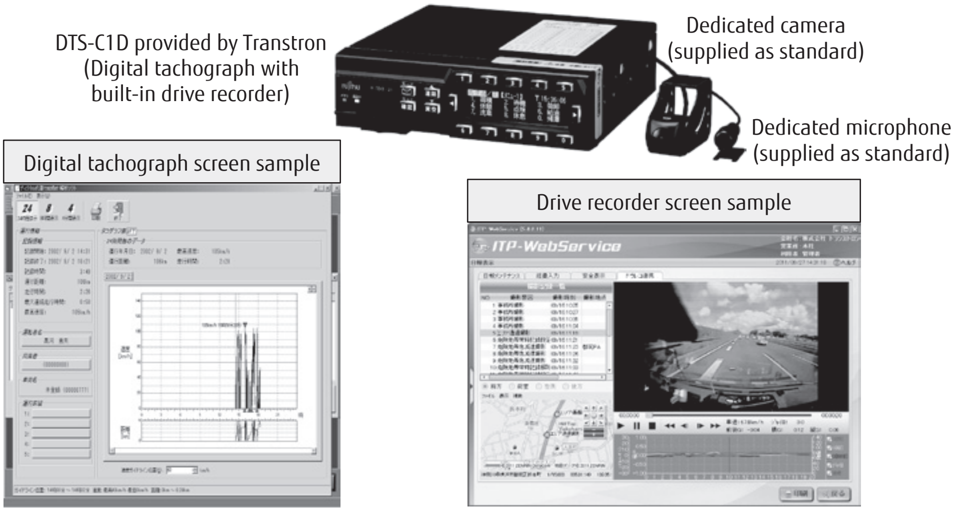


Figure 2
Digital tachograph.

Furthermore, it seemed impractical for each and every road administrator ranging from the national government through prefectures to municipalities to have their own server to use this service, so we decided to adopt the cloud computing technology that was beginning to be widely accepted by local governments.

3. Field testing in terms of technology

However, road surface surveys require expertise in construction technology, and Fujitsu is not specialized in this. So we chose to cooperate with the Center for Infrastructure Asset Management Technology and Research of Gifu University, which has a long history of study in this field, and up-to-date information on this particular industry. In January 2012, we started joint research with Gifu University, which has proactively led the "development of engineers in both the public and private sectors" as mentioned above in cooperation with Gifu Prefecture and the local construction industry.

Gifu University has traditionally had multifaceted research capabilities with experts in areas such as damage assessment, analysis and repair of bridges and roads, together with academic and human resource skills, which it has utilized to provide technical support for local governments in the Chubu district (the central area of Japan's main island) including Gifu and Mie Prefectures. We decided to make use of these strengths of Gifu University to verify the feasibility of our scheme.

Starting in January 2012, we drove along roads in Gifu that were under the management of the prefecture in a vehicle with a digital tachograph and video camera installed to verify the relationships among the image, G sensor and pavement roughness (**Figure 3**). A prototype piece of software was also developed for analyzing the acquired data and showing the result on a map.

In March 2012, we presented the result of this research at the Public Meeting on Use of Maintenance Operations Support System consisting of social infrastructure management staff from nine local governments in Gifu Prefecture. At the meeting, their actual conditions and issues that we had not recognized until then were presented:

1) Municipalities in the prefecture do not own vehicles exclusively dedicated for road inspection, and the inspection itself is mainly done by using official vehicles for general use, responding to occasional telephone calls from local residents.
2) The results of the inspections are recorded mostly on paper maps and handwritten documents, and digital recording of location information and photos alone seemed to be effective.
3) Inspecting the conditions of slopes, roadside trees and side ditches is as important as inspecting road surface roughness.

To deal with the issue of local governments that do not have dedicated inspection vehicles with a digital tachograph, in June we started to use a smartphone,

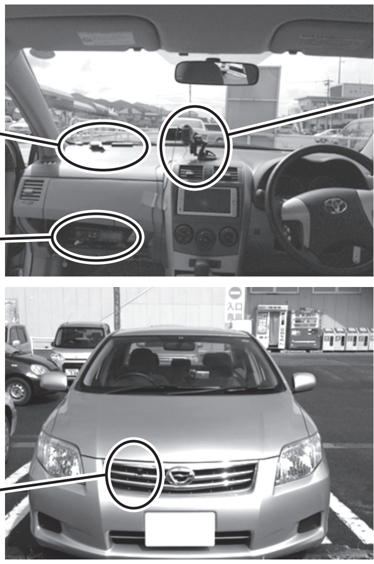


Figure 3
Running vehicle during field testing.

which can also acquire GPS location information and G sensor value, and can easily capture photos as well. In July, we drove along roads that were under the management of Gifu Prefecture and on which the prefecture had conducted a road surface survey in fiscal 2011 to measure the maintenance control index (MCI)[note), and compared both the results. The results showed that spots with an MCI of 5.0 or lower, a level indicating partial damage, were detected as having such damage with a probability of around 80%. The spots with an MCI of 4.0 or lower, which is regarded as a certain degree of damage, were detected as such with a probability of 90% or higher. It was also confirmed, on the other hand, that driving over manholes and bridge expansion joints caused erroneous detection.

4. MLIT standards and actual conditions and needs of local governments

After making this much progress in the field testing, we decided to understand the actual conditions of more local governments and their needs to clarify how this service could be positioned in society.

For the roads defined under Article 3 of the Road Act (national expressways, national highways, prefectural roads and municipal roads), Article 42 of the Act describes the road administrators' responsibility for maintenance and repair, and the MCI described above is defined to be one measure to fulfil this responsibility. The measurement costs 50 000 to 100 000 yen/km and, in reality, it is conducted once every few years in most prefectures and only for some of the roads under management, including national highways under the management of prefectures. Measurement is seldom conducted in municipalities except ordinance-designated major cities such as Tokyo, Osaka, Kobe, Fukuoka and Sapporo.

Regarding daily road inspection, each prefecture has 20 to 30 road inspection vehicles for visual inspection and simple repair of roads under management once every week or every other week. However, regular inspections are not carried out in most municipalities except ordinance-designated cities, and phone calls from local residents trigger personnel to go to the reported sites for temporary measures. As for repair plans, while some prefecture-level local governments decide road repair priority based on the MCI, many municipalities only take stopgap measures within the annual budget according to the priority determined

note) Maintenance control index developed by the MLIT for the purpose of objectively determining the serviceability of pavement. Measured in units of 100 m in principle and evaluated on the basis of 10 points.

manually by the administrator.

This study showed that municipalities need a kind of system that does not drastically change the day-to-day inspection operations or lead to extra work, and that can digitally document inspection reports at low cost, so that it can make road conditions visible and lead to the making of systematic maintenance plans.

5. Field testing of feasibility

By August 2012, we applied the results of the issues in the "Field testing in terms of technology" section above, to the improvement of the initial prototype and enhanced the digital tachograph and smartphone software versions.

In October 2012, we delivered a system based on the digital tachograph to the Construction Research Center of Gifu Prefecture for system verification. In addition to simply assessing the road surface with a G sensor, this version can record two still images a second, and these images make it possible to visually check locations judged as being deteriorated based on the acceleration value. The Center, which is entrusted by Gifu Prefecture to carry out daily road patrols, collects data during regular patrols and has cooperated with us since the initial prototype version was verified as effective.

We delivered the smartphone version to the city of Mizunami in November and the city of Nakatsugawa in December. The two municipalities created inspection reports with smartphones and assessed the road surface by automatically analyzing data collected in the course of their daily inspections.

These field tests showed that while many municipalities found road surface images offered by the digital tachograph version effective, they liked the user-friendliness of the smartphone version even better. Accordingly, we decided to bring forward the official release of the smartphone version.

6. Overview of Roadway Patrol Support Service

The Roadway Patrol Support Service[7] uses Fujitsu's cloud to analyze the road inspection data and offers the evaluation result as information (value) for road facility maintenance. **Figure 4** shows the overall framework of this system. This service features collection and analysis of data automatically recorded to provide new information (value). The service use scenes can be roughly classified into two.

One is use in on-site operations such as regular road inspections by car in response to the phone calls from local residents and the following road repairs. Either simple and convenient smartphones or digital tachographs can be used when moving by car. Smartphones can also be used for making operation records such as photographing and commenting on site.

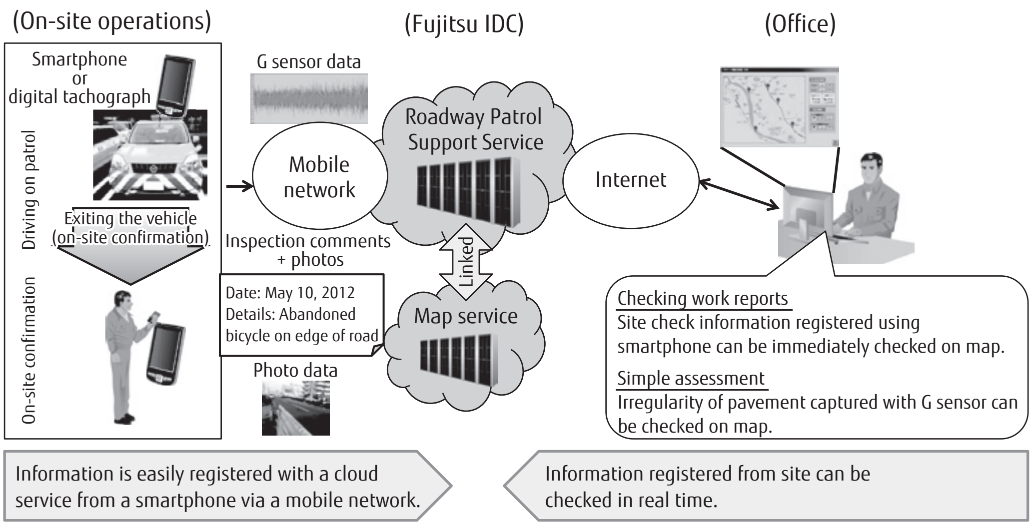


Figure 4
Overview of Roadway Patrol Support Service.

As an official commercial version, we started offering the smartphone one in June 2013.

Another location of use is in road administration offices. The data uploaded from smartphones and digital tachographs to Fujitsu cloud servers can be used to check the inspection status and to create inspection reports. In addition, information required for road maintenance including estimates of road deterioration and comparisons with past conditions can be grasped and analyzed based on the results collected by the G sensor.

The following outlines the respective functions.

1) Collection of drive data

The drive location, time and acceleration values for the forward-backward, left-right and up-down directions are recorded at regular intervals by using a smartphone or digital tachograph. With a digital tachograph, still images are also collected by using the drive recorder function to check the road conditions afterwards. With a smartphone, still images cannot be recorded while driving, but the locations of obstacles and other objects detected can be recorded automatically.

2) Operation site records

A smartphone can be used for recording the results of observation and repair of spots specified in reports or found during patrols together with photos and comments recorded on site. Data can be immediately sent to the office via the server if prompt measures must be taken. In the office, the data can be checked in real time on a map to give instructions to contractors later. This could effectively work in emergency and disaster situations.

3) Function to check inspection spots

Driving routes and operations and observations spots can be shown on a map, and images automatically recorded by the drive recorder and photos of operation sites taken by a staff member's smartphone can be used to grasp the state of patrol and to give operation instructions.

4) Report creation function

This feature creates reports on patrols and operations based on records of operation sites. Formats are automatically built that integrate maps indicating operation locations as well as photos and comments manually recorded in a smartphone on-site, which allows reports to be easily created.

5) Function to estimate roadway deterioration

The acceleration values from sensors while driving are used for statistical processing to estimate the degree of roadway deterioration, and the result is shown on a map. The state of deterioration is shown with points for spots and with rectangles for sections that are color-coded with red (major deterioration) and yellow (minor deterioration), and they look black (major deterioration) and light gray (minor deterioration) because of the monochrome display (**Figure 5**). This provides an at-a-glance view of whether a certain area of deterioration is in a pinpointed spot or a section that stretches over tens of meters. However, the spots and sections shown also include objects essentially irrelevant to pavement deterioration such as manholes and bridge joints, and we are now trying to automatically exclude them.

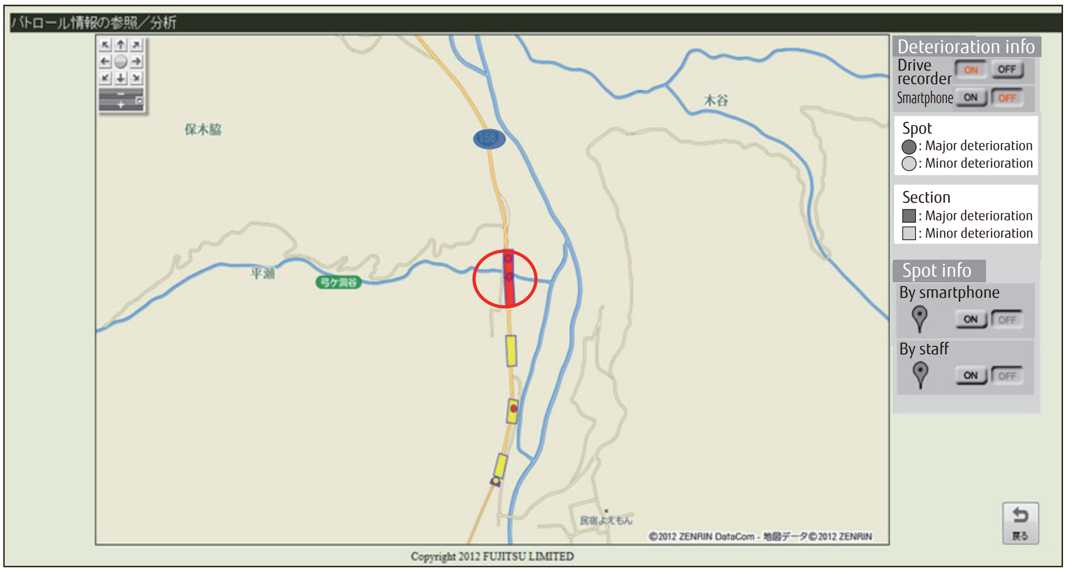
6) Comparison analysis function

This feature provides an overlapped view of two deterioration estimation results. A chronological comparison between results for the same route allows the progress of deterioration to be detected and new spots with estimated deterioration to be found.

Regarding commercialization, we released the smartphone version in June 2013 mainly for municipalities. This function was covered by NHK (Japan Broadcasting Corporation) news on June 15, 2013, and it generated strong public interest. At present, it is being used by Mizunami and Nakatsugawa in Gifu Prefecture on a trial basis, and we are gradually making enhancements such as the "automatic calibration function" for automating threshold adjustment according to different vehicle models and tires, and the "function to register local residents' reports" to allow a response to be triggered by residents' reports rather than regular road expectations. In addition, a digital tachograph version mainly for prefectures is being developed for early commercial release.

As a premise of provision of this service, we have filed for patents to guarantee functions so that our customers can use the service for an extended period of time.

Another point to note was that, in view of utilization of massive amounts of data, we had to be careful about the data sources and their quality management. That is, we needed to keep the quality of data high. Specifically, we aim to ensure data accuracy by making



*This service uses maps provided by Zenrin Co., Ltd.

Figure 5
Function to estimate roadway deterioration.

a definite distinction between data acquired by a digital tachograph and by smartphones.

7. Future issues

This service itself has just begun to take shape and we will continue to enhance the functions. Specifically, we are considering a "simplified function to register roads" that indicates repair history and plans, in addition to patrol results, on a map and a "function to link with a road register" that allows linkage with a geographic information system (GIS).

We are also considering applying the "Frequent Sudden Braking Spotting Service," which is already being offered by Fujitsu. This provides information about spots where sudden braking frequently occurs, as identified from operation data of commercial vehicles (mainly trucks of 8 tons or heavier), which amount to 20 000 locations nationwide. At present, the service is used to notify commercial vehicle drivers and operation managers of dangerous zones to help ensure safe and economical driving. Recently, we found that "spots where sudden braking by large vehicles occur" coincide with deteriorated spots of roads, and that the spot information apparently corresponds to spots requiring inspection. In addition, "heavy vehicle traffic information" complements information acquired in a traffic census that is generally conducted once every few years and this is also considered to be applicable to estimating the deterioration of roads and bridges (**Figure 6**).

Manipulation of all this information in the future is believed to further contribute to much better road maintenance. Along with the engineering approaches described up to now, we plan to verify the effectiveness of mathematical (especially statistical) approaches. Specifically, information from G sensors can be statistically analyzed to automatically detect manhole locations as exceptions, and predict emergence of potholes (holes in road surfaces), for example. While these are still in the stage of desktop study, we think that they can be realized by collecting an even larger amount of data in the future.

8. Conclusion

The field described in this paper has traditionally been explored by local governments and the construction and its consultant industries nationwide. For these interested parties, and, above all, for local residents to be able to live peacefully, Fujitsu wishes to make the greatest possible contribution.

For that purpose, we have been creating a new industry-academia-government scheme. In other words, we think it is best to build and use a system that allows the construction and its consultant industries (industry), universities including Gifu University (academia)

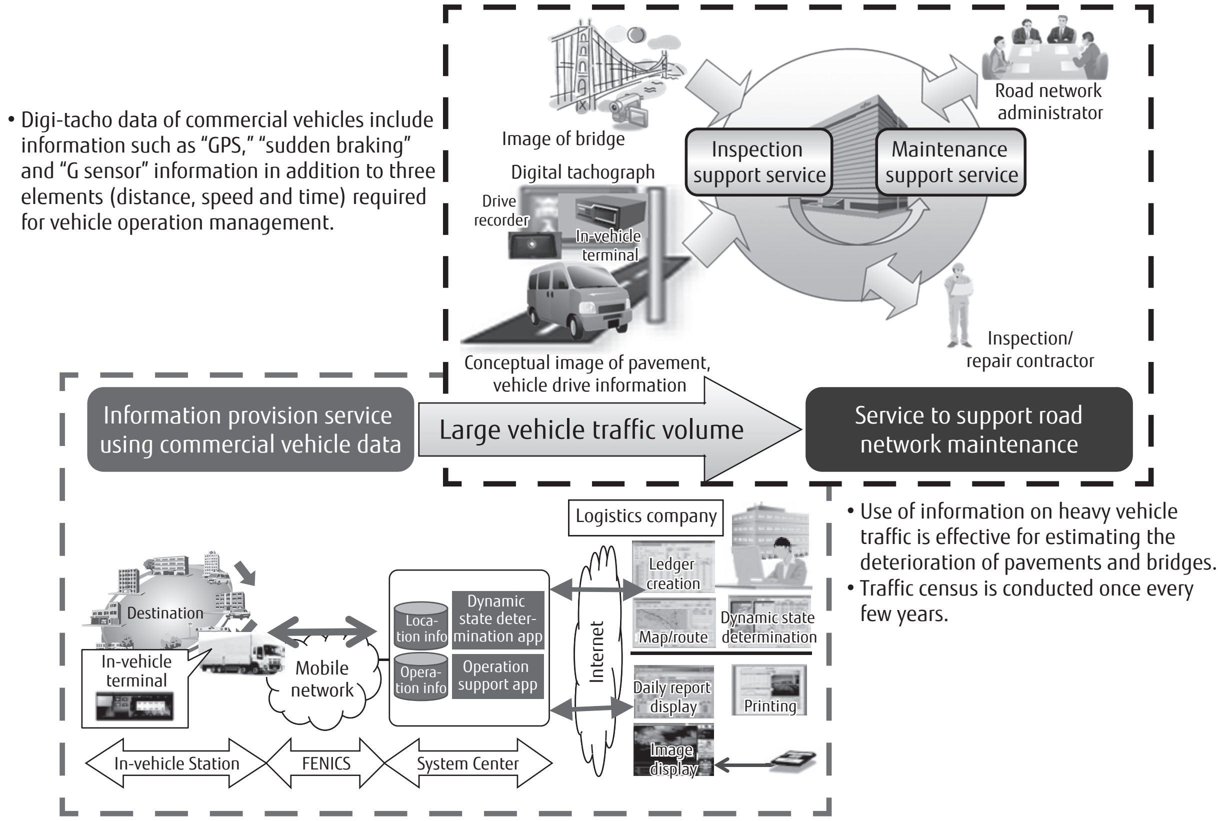


Figure 6
Complex use of diverse data.

and local governments across the boundaries of prefectures and municipalities (government) to collaborate for continuously working on maintenance of social infrastructure.

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