Development of a track facility monitoring device started in fiscal 2008. Then, from May 2013 on, the device has been installed on trains in commercial operation on six lines starting with the Keihin-Tohoku Line. We have further studied and developed the components of the system to put it into practical use. In this paper, we will describe the development of the device first. Then we will discuss the possibility of using the data collected by the developed device while referring to some of the analysis results. After introducing the development of a decision-making support system based on the concept of CBM, we will finally discuss future prospects.

**Keywords:** Smart maintenance, Track maintenance, Monitoring

## 1 Introduction

The track facility monitoring device is currently deployed on six pilot lines, starting with the Keihin-Tohoku Line in fiscal 2013 followed by the Chuo Line, Yamanote Line, Nikko Line, Tohoku Main, and Echigo Line.

One of the objectives of introducing the track facility monitoring device is to achieve “smart maintenance” through condition-based maintenance (CBM). CBM differs from time-based inspection and repair, and it involves a major innovation in maintenance. Fig. 1 shows the CBM work cycle.

This paper covers the present development state and future prospects in data obtaining, data analysis, and decision-making stages of the CBM work cycle.

## 2 Data Obtaining

### 2.1 Track Facility Monitoring Device

The track facility monitoring device consists of a track irregularity measuring device that measures track irregularity and a track material monitoring device that judges the condition of track material such as rail fasteners. The largest advantage of the device is that it can be installed on trains in commercial operation and allow highly frequent data obtaining.

The device is now deployed on the six pilot lines to achieve CBM by analyzing frequently obtained data (Fig. 2).

### 2.1.1 Track Irregularity Measuring Device

(1) Overview

The track irregularity measuring device is a device that employs the inertial mid-chord offset method (IMOM) developed by the Railway Technology Research Institute (RTRI). The device previously could be used only on the East-i special inspection car, but it has been improved to be installable on trains in commercial operation to measure track irregularity (Fig. 3), allowing track irregularity data to be obtained frequently.

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In order to enable more precise measurement control and correct positioning, we have updated the device’s automatic measurement mechanism. The updated functions include recognition of completion of measurements at inspection sheds and the like, recognition of track numbers in the station yard, and logic to start measurement on single tracks.

(ii) Correction of position disagreement in measurement data
The track irregularity measurement device obtains position information from the aforementioned data depot and a tachometer generator (number of rotations of wheels); however, position information is sometimes in disagreement due to wheel slip and skid. We have therefore added to the device a positioning correction function using the cross correlation coefficient command of LABOCS, a track maintenance management database system developed by RTRI (Fig. 4). The new function prevents position disagreement between measurement data, enabling more precise analysis of time series data at the same position.

(3) Issues and prospects for the future
The current track irregularity measuring device cannot be installed to DMUs in commercial operation due to limited underfloor space in cars, while it can be installed to EMUs almost as is. We are presently conducting research on a track irregularity measuring device that can be mounted to DMUs, looking to technologies developed overseas as well to accomplish this.

2.1.2 Track Material Monitoring Device
(1) Overview
JR East has been developing a track material monitoring device since 2008. It consists of an onboard device equipped to the underfloor space of trains in commercial operation to obtain three-dimensional range images (Fig. 5) and two-dimensional gray scale images at up to 130 km/h and a processor that judges whether or not rail fasteners and fish bolts are missing using the three-dimensional images obtained. The three-dimensional images show height information of track materials in 256-step gray scale. The images obtained are saved on a large-volume solid-state drive (SSD) and retrieved when the train enters the depot. Then, the processor placed at the rolling stock center office automatically judges the condition of track materials (Fig. 6). The processor also has a function for detailed checking of two-dimensional gray scale images of the designated position. This allows for checking of the condition of track materials and the like within the range recorded without visiting the site (Fig. 7).

(2) Development status
(i) Improvement of accuracy of judging rail fasteners to be missing
As three-dimensional images are recorded using laser beams, conditions such as direct sunlight or rain can lower the accuracy of judging rail fasteners to be missing. We therefore improved both the onboard device and the processor for more accurate judgment.

(a) Improvement of the onboard device
In image saving, we gave priority to images obtained under conditions with no direct sunlight (images taken after 19:00). We further gave priority to the images with high image quality after analyzing multiple images of the same rail fasteners by the onboard device.

(b) Improvement of the processor
We enabled the processor to compensate using complete images of the surrounding area to perform analysis when pixels are omitted in three-dimensional images.

Table 1 shows the results of improvements a) and b) above. For all of the 78,165 rail fasteners judged by the device, we carried our visual judgment as well and compared the results with each other. As shown in Table 1, more than 99% accuracy was achieved in the judgment of normal rail fasteners.

(2) Improvement of accuracy of judging track material condition

<table>
<thead>
<tr>
<th>Track material condition</th>
<th>Visual judgment</th>
<th>Mechanical judgment</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>O</td>
<td>78,444 (98.75%)</td>
<td>120 (0.15%)</td>
<td>78,564</td>
</tr>
<tr>
<td>x</td>
<td>(99.94%)</td>
<td>(37.50%) (62.50%)</td>
<td></td>
</tr>
<tr>
<td>▲</td>
<td>78 (0.09%)</td>
<td>0 (0.00%)</td>
<td>78,342</td>
</tr>
<tr>
<td>×</td>
<td>(25.4%)</td>
<td>(0.4%) (9.6%)</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>78,165</td>
<td>134</td>
<td>6</td>
</tr>
</tbody>
</table>

Table 1 Comparison between Mechanical and Visual Judgment
(ii) Improvement of accuracy of judging fish bolts to be missing

The track material monitoring device judges missing fish bolts on the outer side of tracks. As shown in Fig. 8 (right), fish bolts are inserted in alternating directions; so, sometimes bolt heads are not clearly shown in the images. This causes incorrect judgment of fish bolts being missing even though they are inserted normally.

We therefore modified placement of the laser irradiator for obtaining three-dimensional range images to increase intensity of laser beam reflection from bolt heads. As a result, bolt heads were properly detected in positions where they could not be detected before, as shown in Fig. 9. After this improvement, all 143 of the fish bolts that were not detected before could be correctly judged.

(3) Issues and prospects for the future

The improvements so far have greatly raised accuracy of automatic judgment. We will work on further expanding items for automatic judgment because other track materials are also included in the images obtained.

3 Data Analysis

3.1 Time Series Analysis of Track Irregularity

Fig. 10 shows the time series data for three months after position disagreement is corrected to remove the impact of wheel slip and skid on 10 m chord longitudinal level irregularity data for the past year. The irregularity is measured by the track irregularity measurement device at a certain point on a line. Comparing with the data obtained by East-i inspection car, which carries out track inspection four times a year, we were able to confirm that the measurement values were almost equal to each other. In addition, past research indicated that track subsidence progresses exponentially immediately after track maintenance and then progresses linearly. The data obtained frequently sufficiently agrees with the formula for predicting track deterioration based on the past research (the prediction formula line in Fig. 10), proving the same tendency.

Further time series detailed analysis of the data on track subsidence revealed that the deterioration characteristics of 10 m chord longitudinal level irregularity after continuous tamping (one of track maintenance jobs) can be categorized into four types as shown in Fig. 11.

1) Gradual deterioration
   - Reaches maintenance target value within 12 months

2) Acute deterioration
   - Reaches maintenance target value within 3 months

3) Stop after initial deterioration
   - Initial deterioration progresses more than 4 mm; then deterioration stops and does not reach the maintenance target value after 12 months

4) No change
   - Less than 4 mm initial deterioration, or initial deterioration that has finished before measurement and shows no change for 12 months

Fig. 11 Types of Deterioration Trends of 10 m Chord Longitudinal Level Irregularity after Continuous Tamping

3.2 Analysis of Track Condition before and after Maintenance Using a MTT

The P value is a track condition evaluation index of JR East, indicating the rate of 10 m chord longitudinal level irregularity of more than 3 mm. Time series analysis of the P values of the section shown in Fig. 12 that underwent maintenance work using a multiple tie tamper (MTT) shows that the P values of that section were remarkably improved after the maintenance work and the slope of the deterioration line became gentler. Analysis of MTT work data from the MTT recorder mounted in advance and from the track condition suggests that increase of squeezing time (tamping time) helped maintain improved track condition after

Fig. 12 Example of Significant Improvement of Track Condition by Repair using MTT

Amount of lift: 2.52 mm
Squeezing time: 1.29 s

Fig. 10 Example of Track Subsidence Characteristics after Track Maintenance

Days after repair

Amount of lift: 2.52 mm
Squeezing time: 1.29 s
the work. However, in actual work, squeezing time and length of track work is performed on conflict with each other. We therefore intend to propose an efficient working method for individual work sections without increasing squeezing time uniformly.

4 Construction of a New Decision-making Support System

4.1 Decision-making Support System

(1) Overview
A decision-making support system proposes optimal repair timing and methods by utilizing big data obtained by means such as the track facility monitoring device. With an aim of building a system that can support front-line engineers with decision-making in their daily maintenance jobs, we have been proceeding with development work. A prototype system has been already constructed and put into test operation.

(2) Development status
We are currently conducting development work to further improve functions to support decision-making. The major development subjects are as follows.

(i) Development of a function for identifying acute changes
This is a function where the CBM support system calculates the amount of change in track irregularity from data measured a week before and identifies positions with large change as positions with acute deterioration.

(ii) Development of a function for lot evaluation of rail fasteners
Utilizing the data of the track material monitoring device, we are working on development of a function for indicating lot defect rate evaluation results for rail fasteners.

(iii) Improvement of MTT operation scheduling support system
The MTT operation scheduling support system currently in use can produce an annual MTT operation schedule to achieve the target track condition based on track irregularity data. On the other hand, its operability is not entirely satisfactory. It is installed only to terminals in JR East branch offices, and moreover, it cannot easily produce MTT operation schedules for more than one section. We are therefore making efforts to improve visibility and functionality to enable easier and more effective scheduling.

(iv) Development of a function for detecting abnormalities in track material by image processing
We will develop a function where any abnormality in track materials such as rails and rail bonds can be detected by analyzing images obtained by the track material monitoring device.

4.2 Future Direction
Aiming for a smarter system, we will integrate diverse data obtained from the track facility monitoring device and other devices and reflect comments and requests of front-line engineers.

Fig. 13 Example of Functions of Current CBM Support System

However, in view of establishing a common platform across JR East in the future, we need to adapt the decision-making support system to a cloud-based environment. Here we introduce a new decision-making support system (a CBM support system) under development.

Based on the efforts covered in this paper, JR East is planning to deploy the track facility monitoring device to all electrified sections in its operating area. We will provide front-line staff with further support on the track facility monitoring device to be gradually deployed and proceed with development of a support tool to further CBM utilizing large volume of monitoring data and optimize maintenance work. Also, we will continue working on technical development to deploy the device to more sections including the sections not yet electrified.

5 Conclusion

Reference:
4) Yoshikyo Sato, Toshiyuki Umezawa, Senryu Kogakute [in Japanese], (Japan Railway Civil Engineering Association, February 1994)