Data Collection and Their Usages for Airport Pavement Management System in Japan

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ABSTRACT

Once an airport pavement has been opened to traffic, proper maintenance and rehabilitation works are essential for maintaining its functionality at a satisfactory level and maximizing its service life. For these purposes, an airport pavement management system (APMS) allows airport administrators and engineers to allocate funds, personnel, and resources most effectively. Some subsystems of APMS have come into practical use in Japan. The maintenance and rehabilitation subsystem, one of the subsystems, consists of three phases: an inspection and maintenance phase, a soundness evaluation phase, and a rehabilitation optimization phase. The data collection and analysis procedures in each phase are described in detail.

In the inspection and maintenance phase, an inspection patrol system is adopted to increase the efficiency of inspection, to rationalize data management, and to normalize the maintenance strategy. Through the inspection patrols, various data on pavement distress can be quantified and traced, and then remedial actions could be determined automatically.

In the soundness evaluation phase, two systems are provided for preserving and strengthening the pavement. In the first, the pavement rehabilitation index (PRI) is used to quantify the pavement surface condition. In the second, the load-carrying capacity, safety for aircraft operation, and durability of surface materials are evaluated when the pavements need to be strengthened.

In the rehabilitation optimization phase, in order to perform rehabilitation work appropriately, the system called AirPORTS is used, which leads to optimization of the rehabilitation implementation time and construction method, minimization of the life cycle cost, and optimal spreading of the rehabilitation expenses.
INTRODUCTION

The performance of airport pavements should be maintained at a satisfactory level for their entire design lives. Maintenance and rehabilitation works are often required to prevent deterioration caused by repeated aircraft loading and by environmental action. The recent introduction of large aircrafts and the increase in aircraft operations have accelerated the process of deterioration. However, because of limited budget, maintenance and rehabilitation expenditure needs to be optimum. To accomplish this, a systematic procedure for scheduling maintenance and rehabilitation works, which optimizes the benefits for airport users and minimizes the costs to the airport administrators, is desired. An airport pavement management system (APMS) allows the administrators to allocate budgets, personnel, and resources in an efficient manner (1). Some subsystems of a complete APMS, including the design, evaluation, and rehabilitation subsystems, have come into practical use in Japan (2).

Once an airport pavement has been opened to traffic, proper maintenance and rehabilitation works are essential to maintain the functionality of pavement at a satisfactory level and to maximize its service life. Maintenance and rehabilitation strategies were conventionally based on empirical and subjective judgments by airport administration staffs, such as airport engineers. Therefore, a systematic method for implementing maintenance and rehabilitation works has been developed.

The maintenance and rehabilitation subsystem of APMS consists of three phases: an inspection and maintenance phase, a soundness evaluation phase, and a rehabilitation optimization phase. In the maintenance and rehabilitation subsystem of APMS, airport pavements are inspected periodically and emergently, properly maintained, and then evaluated and rehabilitated when necessary. In addition to the existing tools, two smart tools have been developed in the present study and incorporated into the APMS: an inspection registration tool and a rehabilitation budget allocation tool.

This paper describes the current state of the maintenance and rehabilitation subsystem of an APMS for asphalt pavements, mostly used in runways and taxiways at airports in Japan. First, an outline of the maintenance and rehabilitation subsystem is presented. Next, the inspection registration tool in the inspection and maintenance phase is described, and then some tools used in the soundness evaluation phase to evaluate the surface condition, structural condition, roughness, and the durability of surface materials are briefly described. Finally, the rehabilitation budget allocation system, Airport Pavement Optimal Rehabilitation Timing System (AirPORTS), for rehabilitation optimization is described.

EVALUATION AND REHABILITATION SUBSYSTEM OF APMS IN JAPAN

On the basis of various studies of airport pavements, such as investigations on surface condition evaluations, structural evaluations, prediction of distress and performance, and maintenance and rehabilitation strategies, the procedures for design, evaluation, and rehabilitation, which form subsystems of a complete APMS were developed (2). The maintenance and rehabilitation subsystem consists of three phases as shown in FIGURE 1: an inspection and maintenance phase, a soundness evaluation phase, and a rehabilitation optimization phase.

Inspection and Maintenance Phase

In the inspection and maintenance phase, airport pavements are visually inspected periodically (daily and monthly) and emergently when a large earthquake happens, and then some maintenance works will be executed if necessary. In addition, the necessity of the detailed inspection is judged based on the visual inspection.

An inspection patrol system is adopted to increase the efficiency of monthly inspection, to rationalize data management, and to normalize the maintenance strategy. Through the monthly inspection patrols, various data on pavement distress can be quantified and traced, and then remedial actions which can be determined automatically will be executed. The inspection patrol system is described in detail subsequently.

Soundness Evaluation Phase

In the soundness evaluation phase, a detailed inspection on the pavements is conducted basically at three-year interval and whenever required in the inspection and maintenance phase, and then the soundness of pavements
is evaluated from a viewpoint of keeping their functions satisfied. The detailed inspections and their evaluation are conducted as follows:

1) Surface distress evaluation, which is quantified by the use of the Pavement Rehabilitation Index (PRI), calculated based on three kinds of distress.
2) The necessity of pavement strengthening, which is judged based on either the changes in the design conditions for the pavement or the remaining life of the existing pavement.
3) Pavement strengthening, in which the information needed to strengthen the pavement is collected and the pavement structural design for improving the surface distress and the structure is examined. The load-carrying capacity, safety for aircraft operation, and durability of surface materials are evaluated in this step.
4) Pavement preserving, in which the pavement structural design for improving the surface distress is examined.

The procedures for evaluating the surface distress, the load-carrying capacity, safety for aircraft operation, and durability of surface materials are described at large afterwards.

Rehabilitation Optimization Phase
In the rehabilitation optimization phase, in order to perform rehabilitation work appropriately, the system called AirPORTS is used, which leads to optimization of the rehabilitation implementation time and construction method, minimization of the life cycle cost, and optimal spreading of the rehabilitation expenses. The application of AirPORT to Osaka Itami Airport is explained at the end of the paper.

![Inspection Patrol System of Airport Pavements](image)

**FIGURE 1** Outline of maintenance and rehabilitation subsystem of APMS.

**INSPECTION PATROL SYSTEM OF AIRPORT PAVEMENTS**

Airport facilities are managed by following the applicable guides and manuals in order that the service they provide is maintained consistently satisfactory. However, the tasks of identifying and recording distress modes are time consuming since the pavements in airports are extremely large. The simple inspection patrol system for airport pavements has been developed to increase the efficiency and accuracy of the inspection regime.

**Components of the New Inspection Patrol System for Airport Pavements**

The current procedure for inspection of airport pavements consists of several steps, such as identification, evaluation, treatment, description, photographing, and reporting distress. On the other hand, the system developed in this study uses a mobile PC and a differential global positioning system (DGPS), to lessen the inspector's work.
1) Mobile PC: usable in all weather conditions and both during the day and night, with a touch-screen, and having high portability and durability

2) DGPS: comparatively inexpensive, cost-effective, and having high portability

PHOTO 1 shows an inspection patrol working on the airport pavements using this system. FIGURE 2 shows the decision flowchart for the inspection patrol system.

PHOTO 1  Inspection patrol working on airport pavements using the new system.

FIGURE 2  Decision flowchart for the new inspection patrol system.
Process Summary of the New Inspection Patrol System for Airport Pavements

The process of the new inspection patrol system for airport pavements is summarized as follows:

1) Identification of distress
In a conventional inspection system, the position of any distress is described as the distance from an adjacent lighting unit embedded in the pavement, and is measured with a tape. In the new inspection patrol system developed in this study, the position is instead obtained using the DGPS and displayed in plan view on the PC screen. Simultaneously, the position coordinates, the name of the pavement where the distress is found, and the type and state of the distress can be easily recorded. The error associated with the coordinates falls in less than 1 m by averaging three measured DGPS data and using correcting information from a Multifunctional Transport Satellite (MTSAT) with a Multifunctional Satellite Augmentation System (MSAS).

2) Evaluation and treatment of distress
In the new inspection patrol system, the evaluation and the necessary treatment of the distress could be determined automatically when the type and the state of distress is known. This is performed by the judgment system that is based on both past experience of distress treatment and the opinions of highly experienced inspection engineers. This could help the less-experienced inspection engineers to respond appropriately to the distress and could decrease differences in opinion among the inspection engineers.

This system can be used for dealing with ten types of distress: that is, FOD (foreign object debris), oil spillage, tire rubber adhesion, trouble in marking, trouble in pavement surface, trouble in grooving, collapse, abrasion, deformation, cracking.

3) Description and photographing of distress
Because a geographic information system (GIS) is used in the new inspection patrol system, different layers can be assigned to the airport plan view, facility inventory figures, surface condition survey units, inspection routes, and past inspection history so that they can be managed efficiently. The inspection engineers can select the required layers and examine the overall situation on site. FIGURE 3 shows a PC screen displaying the pavement surface condition in plan view.

4) Reporting of distress
Distress information has traditionally been managed using a registration book in accordance with the airport facility management manual. The new inspection patrol system can store all the data in a comprehensive database system and create the register in a semi-automatic manner.

FIGURE 3  PC screen displaying the pavement surface condition in plan view.
EVALUATION OF PAVEMENT SURFACE CONDITIONS USING THE PAVEMENT REHABILITATION INDEX

The airport pavement surface condition is surveyed with an automatic distress measuring vehicle in the soundness evaluation phase. The primary objective of this inspection and evaluation is to determine the necessity of rehabilitation. When the physical condition of the surface is judged to have seriously deteriorated, certain rehabilitation work may become necessary.

Distress Types
Many types of distress, which are characterized by their severity and extent, appear on the surface of airport pavements. Both collecting and analyzing distress data are costly and time consuming, and hence only the data required for the evaluation procedure should be collected. The accuracy of the data depends on techniques for measuring the severity and extent as well as the type of distress.

Evaluation Method
Various procedures for evaluating the distress have been developed for airports including PCI in the USA (3). The main differences in them are the number of distress types and distress measuring method used. To lessen the time and expenditure needed to measure the distress, the number of distress is limited and the speedy method with the automatic distress measuring vehicle is adopted in Japan.

The equation used for evaluating pavement surface conditions was developed by comparing the opinions of pavement engineers with objective measures representing the pavement surface condition (2). The results of the questionnaire were formulated using quantification theory. Ultimately, considering their ease of measurement, three indices were selected as suitable for evaluating the pavement surface condition. This study was conducted using a 21 m wide and 30 m long section of pavement. The three indices for asphalt pavements are as follows:

1) Cracking, CR (%): the crack ratio, defined as the cracked area divided by the section area and expressed as a percentage
2) Rutting, RD (mm): the maximum rut depth in the section
3) Roughness, SV (mm): the standard deviation of roughness as measured in the section using a 3 m profilometer

Finally, an equation relating the engineers’ opinions to these objective measures was developed. This equation forms a polynomial in which the above three indices are explanatory variables. The result of this equation gives the PRI, and is expressed as follows:

\[
PRI = 10 - 0.450CR - 0.0511RD - 0.655SV
\]  

Therefore, it clearly indicates that higher the PRI value, the better will be the pavement condition. The need for rehabilitation work in a section is judged by ranking PRI values into three categories, as follows:

1) Rank A: rehabilitation work is unnecessary
2) Rank B: rehabilitation work will be necessary in near future
3) Rank C: rehabilitation work is necessary immediately

| TABLE 1 | lists the threshold values between these ranks, which differ by facility. That is, very strict control of the surface is necessary for a runway, while the surface condition is not as critical for apron pavements, where aircraft are stationary or moving only slowly.
TABLE 1  Necessity of Rehabilitation Works Based on PRI

<table>
<thead>
<tr>
<th>Facility</th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Runway</td>
<td>more than 8.0</td>
<td>8.0–3.8</td>
<td>less than 3.8</td>
</tr>
<tr>
<td>Taxiway</td>
<td>more than 6.9</td>
<td>6.9–3.0</td>
<td>less than 3.0</td>
</tr>
<tr>
<td>Apron</td>
<td>more than 5.9</td>
<td>5.9–0.0</td>
<td>-</td>
</tr>
</tbody>
</table>

Distress Measuring Equipment

Automatic surface distress measuring vehicles have been used to quantify the abovementioned three types of distress of asphalt pavements; that is, cracking, rut depth, and roughness. The pavement surfaces are photographed with a high-resolution camera or video that allows the detection of cracks having at least 1 mm width, and then the films or tapes are analyzed. Laser scan beams are applied transversely on the surface and pictured to measure the rut depth. Noncontact displacement sensors using laser beams, attached under the vehicle, are adopted to measure the roughness. The abovementioned apparatus used to detect the three types of distress is mounted on a single vehicle to enable simultaneous measurement of the three kinds of distress.

EVALUATION OF STRUCTURAL CONDITION WITH FALLING WEIGHT DEFLECTOMETER

Deflection Measurement with Falling Weight Deflectometer

The evaluation of the structural condition can be rationalized when it is directly connected to the subsequent rehabilitation strategy for the pavement. For this procedure, a falling weight deflectometer (FWD) has been adopted, which is widely used to measure deflections in response to known loads. The FWD system can apply a maximum load of 200 kN through a 450 mm-diameter loading plate. Deflections are obtained at seven points (0, 300, 450, 600, 900, 1,500, and 2,500 mm from the center of the loading plate).

With increasing popularity of large aircrafts and increasing aircraft traffic, cracking and other forms of distress have appeared more frequently, because such size and frequency of loading were not taken into account in the so-called CBR method adopted as a part of the airport asphalt pavement design method in Japan. Because cracking and rutting are important for judging the necessity for the repair of a pavement, they must be considered in the structural evaluation and rehabilitation design of the pavement. Based on past studies, the horizontal strain at the bottom of asphalt mixture layer ($\varepsilon_t$) was used to investigate cracking, while the vertical strain at the top of the subgrade ($\varepsilon_v$) was used to evaluate rutting. In structural evaluations, these must be considered according to the critical values (4).

Structural Evaluation Process

In the center portion of each unit used in the surface distress evaluation, the deflection bowls caused by the FWD load and the surface temperature are measured. As the temperature and loading conditions vary for each measurement, the structural evaluation focusing on the horizontal and vertical strains is conducted according to the following steps:

1) Assume that the pavement consists of three layers (asphalt mixture, granular material, and subgrade), and find the modulus of elasticity of each layer by back-calculation from the FWD deflections. The layer thicknesses are obtained from the design document.
2) Find the subgrade CBR by dividing the elastic modulus of the subgrade (in MPa) by a factor 10.
3) Convert the elastic modulus of the asphalt mixture into a standardized value for the conditions of 2 Hz or 10 Hz, and 20 °C.
4) Calculate $\varepsilon_v$ and $\varepsilon_t$ for the design load for the elastic moduli obtained in steps 1) and 3).
5) Perform a pavement structural evaluation by comparing the obtained values to the critical values.
6) Determine the overlay thickness using a method by focusing on the strain changes with the overlay thickness.
The runway profile is extremely important in maintaining the safety and riding comfort of the aircraft at the time of takeoff, landing, or taxiing. It might be necessary to monitor the long wavelength conditions regularly, because aircraft must move at very high speeds on the runways.

**Measuring Equipment**

Absolute profiles of a runway were accurately measured by noncontact type laser profilometer with GPS. This combined system enables the measurement of both long and short wavelengths of a runway surface. The roughness and comfort level are then evaluated on the basis of the aircraft’s vertical movement simulated using software.

The noncontact type profilometer used for measuring the short wavelength of the pavement employs the sequential-two-points method to measure the profile. The response frequency of the laser distance meter is 4 kHz and can cover 144 km/h at a measurement interval of 10 mm. Using the profilometer, the short wavelength range of at least 1 mm can be measured; however, it is not possible to measure the long wavelength range, because errors accumulate resulting in considerable distortion in the long wavelength range.

To obtain accurate profile data for both short and long wavelengths, GPS has been combined with the profilometer. Point positioning GPSs have often used satellite navigation systems without a fixed station and have had an accuracy of 30 m or more. Such accuracy is inadequate for profiling purposes, and thus, a real-time kinematics-type GPS has been used. This GPS has an accuracy of 20–30 mm in a vertical direction, and allows the measurement of one elevation data point per second. **FIGURE 4** shows the schematic of the system (5).

**Results of Runway Profile Measurements**

The surface elevations of the runway pavement were determined using the above-described system. Absolute vertical profiles were accurately obtained by combining the two data for a considerable length (3,000 m) of the runway of Tokyo Haneda International Airport.

An example of the measured absolute vertical elevation data is shown in **FIGURE 5**. Both the profiles, the measurement of which started from different runway ends (34R and 16L), are completely consistent. The standard deviation of its error is negligible.
To quantitatively evaluate the results, two procedures are available: the International Roughness Index (IRI) and aircraft responses. The IRI is based on the ratio of a standard vehicle’s accumulated suspension motion divided by the distance traveled by the vehicle during the measurement (such as in mm/m). Aircraft movement software simulations on the runway at takeoff and landing can be performed to simulate aircraft responses (6).

EVALUATION OF THE DURABILITY OF SURFACE MATERIALS

The durability of surface materials is evaluated by relevant, appropriate tests using cores extracted from the site or specimens prepared in the laboratory. The number of specimens should be appropriately determined; three specimens are typically used. The durability of grooved runway surface materials is described below as an example (7).

Runway grooving is becoming a common practice worldwide. The standard configuration specified by the Federal Aviation Administration is presently used in Japan: 6 mm deep, 6 mm wide, and spaced 32 mm apart center-to-center. The grooving is installed two or more months after the pavement construction to ensure its durability according to the current specification in Japan. The effectiveness of the grooving is reduced if the grooves collapse under heavy aircraft loads. It will also be reduced through a loss of groove volume due to deformation of the asphalt mixture in hot weather and abrasion of the asphalt mixture in cold weather. The former case is examined as described below.

The wheel tracking test was used to evaluate the loss of groove volume at high temperatures. An asphalt mixture was compacted into a 300 mm wide, 300 mm long, and 50 mm deep mold to a compaction degree of 98 % or higher. After curing, grooves were cut into the mixture surface using a cutter with diamond-tipped heads. The wheel tracking test was then conducted on the specimen using a partly modified standard testing procedure (8). The test conditions, in which the test temperature was changed from that in the original procedure for road pavements to distinguish the influence of asphalt mixtures on the groove collapse, are shown as follows:

1) Temperature: 40 °C
2) Wheel type: Solid tire
3) Wheel size: 200 mm in diameter and 50 mm in width
4) Load: 700 N
5) Tracking speed: 42 times/min.

The wheel repeatedly tracks back and forth on the specimen until the number of tracking reaches 5,000. The test results are quantified as the loss of groove volume by the use of Equation 2.
\[ LV = \frac{a_i - a_0}{a_0} \times 100 \% \]

where, \( LV \): loss of groove volume, \( a_0 \): initial groove volume, and \( a_i \): final groove volume.

**REHABILITATION SCHEDULING WITH AirPORTS**

**Development of AirPORTS**

Currently, maintenance and rehabilitation works are conducted after certain distress and damage are found. This may lead to the situation that the budget needed in the fiscal year becomes high due to the increase in rehabilitation expense when large-scale rehabilitation work is required, and thus causing difficulty in airport management (9). Therefore, both preventive maintenance and budget allocation need to be optimized, and this can be achieved by systematizing the management system taking into consideration the life cycle cost based on factors such as the rehabilitation history and the pavement surface condition history. In order to realize this, various pavement management systems like microPAVER have been developed (10). In Japan, the highly precise Airport Pavement Optimal Rehabilitation Timing System (AirPORTS) has been developed using data including PRI, rehabilitation cost, etc. on actual airport pavements.

In the soundness evaluation phase of the airport pavement management system, the need for rehabilitation works is determined using the PRI. If rehabilitation works are necessary, suitable works will be selected and then carried out. Therefore, it is indispensable to quantify appropriately the yearly changes in the PRI and the degree of recovery of the PRI due to rehabilitation work. The decrease of the PRI with time and its recovery after rehabilitation work is schematically described in **FIGURE 6**. They could be clarified by collecting and analyzing the data in an actual airport.

![FIGURE 6 Decrease in PRI with time and its recovery due to rehabilitation work.](image)

**Osaka Itami Airport**

The surface distress conditions of the airport pavements of Osaka Itami Airport, one of the largest airports in Japan, were analyzed. This airport was selected because its pavement layout has remained unchanged over the recent past, various pavement structures have been used, and large-sized aircraft have been introduced. Since the PRI has been measured for about 20 years, both the yearly changes in the PRI and the recovery of the PRI due to rehabilitation works could be easily calculated.

The surface conditions of runways, taxiways, and aprons were evaluated in 163, 273, and 101 units, respectively. When the yearly changes in the PRI and its recovery due to rehabilitation works are analyzed by each unit; the results vary markedly, even if the units are within the same pavement facility. Therefore, the units were summed into several groups as shown in **FIGURE 7**. Runways A and B were separated into three blocks (two end parts and one intermediate part), while the aprons were divided into nine blocks, according to the aircraft guide lines. The taxiways were divided into perpendicular taxiways, high-speed exit taxiways, and parallel taxiways.
When calculating the yearly change in the PRI, only the data measured three or more times between the rehabilitation works were used. The average yearly changes in the PRI for runways and taxiways were 0.1–0.2 and 0.1–1.2, respectively. The recovered PRI due to the rehabilitation works varied little for the rehabilitation works conducted at Osaka Itami Airport. The recovery of the PRI due to the rehabilitation works becomes greater when the PRI before the rehabilitation work is smaller, as a result of analyzing the changes of PRI for the various rehabilitation procedures.

System Composition

The newly developed AirPORTS was built using general-purpose software (Excel and Access). FIGURE 8 shows the result of a sample analysis on the PC screen displaying an optimal rehabilitation plan with the application of the AirPORTS. The AirPORTS consists of the following four subsystems:

1) Database subsystem
   The rate of change in the PRI, the degrees of recovery after rehabilitation works, and the construction unit prices are stored for each rehabilitation work.

2) Optimal construction method selection subsystem
   The optimal rehabilitation procedure that satisfies the lowest required PRI is selected automatically according to the changing rate of the PRI, the degree of PRI recovery, and the rehabilitation expenses.

3) Yearly rehabilitation expense prediction subsystem
   Yearly rehabilitation expenses are automatically predicted for the designated period; that is, the timing, the pavement areas, and the rehabilitation expenses are predicted.

4) Budget equalization subsystem
   The rehabilitation expenses are automatically rationalized according to the yearly maximum budget. In this process, various strategies to accomplish the works within the budget are adopted, such as the moving forward of the scheduling of rehabilitation works or changing the lowest required PRI.
FIGURE 8  Screen capture of the optimal rehabilitation plan using AirPORTS.

CONCLUDING REMARKS

The collection and their usages of the data needed to utilize the maintenance and rehabilitation subsystem in the airport pavement management system were described. The maintenance and rehabilitation subsystem described above is applicable to airports not only in Japan but in other countries, regardless of the inspection and evaluation tools adopted in each airport.

The maintenance and rehabilitation subsystem consists of three phases: an inspection and maintenance phase, a soundness evaluation phase, and a rehabilitation optimization phase. The data collection and analysis procedures in each phase are described in detail.

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