Assessment Framework for Runway Pavement Distress Location

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Abstract:
Airport pavement requires a reliable method of updating the details of its performance. The performance of the airport pavement can be identified through the reported condition based on periodic field inspection. However, due to limitation of the resources, the maintenance planning may be delayed and results in high maintenance cost. This paper attempts to provide the assessment method to determine the possible distress location. The pavement distress location was determined through examined the characteristics of aircraft operated, i.e. the landing gear configuration, jet engine exhaust distribution, and frequency of aircraft movements. The method includes some other evaluation stages that are required to conduct prior to the determination of the distress location. The sequence of the framework to estimate the location of pavement distress may be utilized for maintenance planning purpose.

Keywords: preventive maintenance, assessment framework, airport pavement, distress location

1. INTRODUCTION

The airport pavement distress includes pavement structural and functional defects. The airport pavement structural defects are not intended to be the point in this study. The airport pavement structural defects are not intended to be the point in this study. The pavement thickness design quality by FAA [3] is in accordance with FAA design ideal for 20-year design life [4]. On the other hand, the functional performance of the airport pavement has to fulfil its role in providing safe and comfortable ride of the aircrafts. This aspect is critical for the runway pavement since the process of departure and landing require specific velocity and no option to reduce the speed when confronting the rough surface [5].

Considering the necessity of the pavement performance, especially on the runway section, the stage of pavement inventory and pavement condition assessment become crucial. Regular monitoring needs an effort to maintain its frequency, which depends on the available resources. This paper is aimed to provide an alternative method in predicting the location of the pavement functional distress.
may occur. The predicted location is presented as an area that identical to the location to take off and landing. This area is considered receiving the most load due to the aircraft movements.

All airports are encouraged to perform Airport Pavement Management System (APMS) in order to assist the airport manager in making pavement management decisions [6]. The decision includes such factors as loads, environment, strategy alternatives, economics, construction and maintenance. It is well known that there are two key elements contributing to pavement deterioration. Those are the gradual effect of weathering and the activities of traffic [7]. According to Cechet (2005), there was a slight decrease (between 0% and 3%) in the required pavement maintenance budget based on climate change factors. This percentage may not be applicable to other region. However, due to the difficulty of having separate data on the sole effect of climate on the pavement, the analysis of the two elements causing pavement deterioration was not separated.

APMS is a group activities that require qualified personnel, consistent and reliable strategy. Methodology in implementing the APMS depends on the resources available at each airport. These methodologies were designed to enhance the capability in selecting the appropriate strategies to repair the pavement distress. A neural network decision model was adopted to establish rubber-removal decision model [9] and rigid pavement maintenance strategy [10] [11]. Another method was using non destructive test deflection to determine the pavement performance [12]. The non destructive testing of pavement performance has been established by FAA as a web-based APMS [13]. The program is named PAVEAIR and supports a simultaneous entry of inspection data by multiple users. For small and medium airport, having the staffs with qualification to install and operate a PMS may costly [14]. Therefore, Public Works of Canada suggested hiring a professional consultant that can assist in using a computerized pavement management system.

The pavement management system requires the pavement inventory that necessitates the qualified personnel to record and determine the location, area, and severity level of each pavement distress type. The probability of having unreliable data related to the location and area of the severity can be minimized by corroboration of data traffic. This study presents the framework of identification of the pavement distress location. This identification does not mean the exact location but set about the area. Having the results of this alternative prediction of the pavement deterioration, the airport manager may prepare the cost of routine maintenance effectively. The prediction of the pavement operating condition can be updated regularly based on the current traffic.

2. IDENTIFICATION PROCESS OF AIRPORT PAVEMENT CONDITION

The identification process of airport pavement condition within this framework is comprised of two parts. The first part is on the evaluation of pavement condition through three different stages, i.e evaluation of structural adequacy, evaluation of pavement strength, and evaluation of pavement maintenance history. The second part is the establishment of loading path. The schematic drawing of the identification process is presented in Figure 1.

Figure 1 shows a diagram of the identification method to determine the pavement distress location. The grey shaded area is the first part, which is adopted from Ahyudanari [15]. According to Ahyudanari (2010), the airport manager could estimate the type of pavement defect, whether it is structural or functional, through evaluation of the pavement structure adequacy, pavement strength, and pavement maintenance history. The assessment was aimed to assist the inspector to have supporting figure of the pavement condition.
The supporting predicted information of pavement condition may facilitate the airport manager to have a preliminary plan to estimate the budget for maintenance or rehabilitation of the pavement. This study attempts to enhance the capability of the airport staffs in preparing the maintenance and rehabilitation cost by identifying the predicted area of pavement distress. Therefore, the second stage of the Figure 1, shows the incorporation of the loading path and the traffic characteristics to determine the pavement distress location. The loading path for the load is formed by the length of take-off or landing process, and the width of the main landing gear and the width of thermal load. The heat load in this study includes solar radiation and jet engine exhaust. The climatic effect on the airport pavement only considers the solar radiation and exclude other elements such as moisture and wind. The rationale behind this assumption is that the water infiltration involves the rain and drainage system that could increase the complexity of the proposed framework to determine the pavement distress location. However, these variables may be considered in further study.

The other required element is traffic characteristics that involve the type of the operated aircraft and the frequency of movements. The type of aircraft determines the landing gear configuration and heat load produced by its jet engines.

The loading path is measured from the centerline of the runway. The assumption here is that the lateral distribution of the aircraft's wheel path relative to the runway centerline followed a normal distribution [16].

The aircraft manufacturer also provides information regarding the jet engine exhaust that determines the loading path of the heat load. The required information related to the jet engines is the temperature and velocity profile of the exhaust, the width and length of the exhaust contours that may affect the pavement surface. Figure 2 describes the characteristics of the jet exhaust of A330 that use three different engines, i.e. RR Trent 775, GE CF6-80E1A4, and PW 4174. The figure presents the data related to characteristics of jet exhaust that is represented by the variation in velocity and temperature of the exhaust. The figure indicates that different jet engine used will result different characteristics of the jet exhaust.

The discussion above drives the assumption that the loading path of the runway is comprised of the loading path due to solar radiation, jet exhaust and wheel load. The loading path of solar radiation envelopes the entire runway, whereas the loading path due to jet exhaust and wheel load are associated with the aircraft characteristics.

The analysis of the determination of the loading path does not consider the presence of a crosswind. The location of the airport is assumed at sea level In addition, the information related to jet exhaust as presented in Figure 2 was obtained on the condition as dictated
3. PAVEMENT FUNCTIONAL RESTORATION

Pavement functionalities need to be maintained at the optimum level, to serve the safety operation of the aircrafts. The selected airport used in this study is Juanda International Airport, Surabaya, Indonesia. The pavement functional distress that frequently occurred at Juanda International Airport is raveling and rubber deposit. Rubber deposit is related to the reducing of skid resistance. Both pavement distress, raveling and rubber deposit, are classified as sub-levels of considerable pavement defects for asphalt concrete pavements [17]. These pavement surface defects are produced by the traffic, which means the location of the defects can be predicted.

Pavement condition restoration depends on the life cycle of the designed pavements, which also depends on the traffic characteristics. Therefore, each airport needs to develop its own manual to preserve the pavement functional condition.

Ravelling is a progressive loss of pavement material from the surface downward, which is caused by stripping of the bituminous film from the aggregate, asphalt hardening due to aging, poor compaction especially in cold weather construction, or insufficient asphalt content [18]. Debris from raveling may damage the aircraft. Moisture remaining within the aggregates after production lead to stripping of the asphalt binder film from the aggregates. This situation has resulted in the increased occurrence of raveling [19]. The average stripping was rated higher for cores located in the wheel path [20]. This means that the area where receive more frequent loading occurrence can be assumed as the ravelling location. The other cause of raveling is asphalt hardening, which is caused by the oxidation process. The oxidation process occurs due to air intrusion [18] and temperature [21].

Rubber deposits develop as the results of high temperature generated between tire and pavement surface. Rubber deposits commonly find in the touchdown and braking area. The landing process leaves, in average, as much as 1.4 lb (700 g) of rubber in a thin layer on the runway [22]. The rubber deposits fill the micro and macro texture of pavement surface and results in reducing the skid resistance of the pavement. Even though, the micro and macro texture is highly affected by the aggregate characteristics [23], the rubber deposits accumulation will affect the required skid resistance. The sufficient skid resistance is required to guarantee the safety of aircraft operation as stated in FAA Advisory Circular [24]. The presence of rubber deposits can be shown as darken area on the landing zone and needs to be periodically removed.

These two types of airfield pavement surface defects, raveling and rubber deposits, most likely to have similarity in the location of its occurrence. Therefore, the location of the pavement surface defects can be predicted. The predicted location also means the area of the affected pavement surface. Results from this estimation can be used to calculate the budget plan of regular maintenance.
4. DETERMINATION OF LOADING PATH

The loading path can become a basis of determination of the area of pavement surface defects. A runway may available to serve aircraft movements from both directions of its runway ends. This depends on the permissible of the wind direction. For runway with this characteristic, there will be an imbrication of the loading path around the middle of the runway

a. Ground phase     Air phase

b. Air phase Ground phase

Figure 3. Length of the loading path for (a) take off and (b) landing

Figure 3 represents an illustration of the length of the loading path for both take off and landing process. The loading path for take off starts at the near end of the runway to the point when the aircraft starts to lift up. The landing loading path starts at the touchdown point to the respected exit taxiway.

4.1. Loading Path due to The Wheel Load

The loading path associated with the wheel load is subjected to receive high tire pressure load and tire friction. High tire pressure tends to be applied following the increasing of the aircraft gross weight. The main high pressure impacts are shear failure, rutting and raveling [25]. The pavement response to the occurrence of the high tire pressure was not designed to consider the tire speed and loading frequency [26].

The tire friction on runway pavement is mainly to provide deceleration of aircraft after landing, maintenance directional control, and wheel spin up at touchdown [9]. The tire friction decreases in line with the increasing number of aircraft movements. The tire friction generates heat and rubber deposits. An average landing leaves as much as 1.4 lb (700 g) of rubber in a thin layer on the runway [22].

The loading frequency of each aircraft operated at Juanda International Airport is presented in Figure 4.

Figure 3. Length of the loading path for (a) take off and (b) landing

Figure 4. Various aircraft operated with different frequency and gear position from runway centreline.

Figure 4 shows that B737 dominates the annual movements at Juanda International Airport with nearly 45,000 movements annually, followed by MD80 and A319 in 12,000 and 5,000 movements respectively. The distance from the runway centerline is in meter unit, which determines the position of the loading path. The area of the surface defects most probably occurs in the range of 1.5 m to 5.5 m laterally from the runway centerline.

The loading path is determined referring to the area which is the most affected by the aircraft movement. The aircraft used for further analysis is B737, A319 and MD80 as aircrafts with the most frequent movements.

Take off process has two phases (Figure 3(a)), namely ground phase and air phase. The air phase is calculated from the aircraft starts to lift up until reach 10.67 m above the surface. The angle of the lift up, called angle of attack, depends on the weight of aircraft, velocity, wing area, and air density. TOD is a
total of both phases. The loading path requires only the ground phase.

TOD and LOD are available for each type of aircraft. Those values need to be adjusted following the environmental condition of the airport location. The next step after the adjustment is the determination of the ground phase. The ground phase equals deduction of the air phase from TOD. The air phase is calculated following this equation:

\[
\text{Air phase} = \frac{10.67 \, m}{\tan \alpha}
\]

The equation above shows the ratio of the required height during lift off process, which is 10.67m, and the tangent of angle of attack (\(\alpha\)). The average value of \(\alpha\) is 4.5° \([27][28]\). Therefore, the average value of air phase is 2.3 m. Since the distance of air phase is around 1% of the TOD, herein and after, the length of air phase is neglected. The results of the representative aircrafts are presented in Table 1.

Table 1. The length and width of loading path

<table>
<thead>
<tr>
<th>TYPE</th>
<th>TOD (m)</th>
<th>LOD (m)</th>
<th>Width (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A319</td>
<td>1750</td>
<td>1350</td>
<td>1.29</td>
</tr>
<tr>
<td>B732</td>
<td>1830</td>
<td>1400</td>
<td>1.14</td>
</tr>
<tr>
<td>MD80</td>
<td>2052</td>
<td>1585</td>
<td>1.01</td>
</tr>
</tbody>
</table>

The length of LOD was calculated the same as a determination of TOD. The LOD starts from touch down point to exit taxiway. The air phase (Figure 3b) is similar to the air phase for TOD. Therefore the LOD presented in Table 1 follows the LOD after the location adjustment.

Table 1 also presents the width of loading path that was determined based on the wheel load, tire contact pressure. The width of the loading path is less than 1.5 m. This channelized load is potential in causing rutting.

4.2. Loading Path due to The Heat Load

The heat load induced on the airport pavement is caused by solar radiation and jet engine exhaust. The loading area for solar radiation is the entire airport pavement area. Thus, there is no particular calculation of the loading path due to solar radiation. The heat load caused by the jet engine exhaust needs a knowledge of the characteristics of the jet exhaust in distributing the heat load to the pavement surface.

The assumption taken for determination of the loading area due to jet exhaust is that both temperature and velocity of gases ejected from the jet engine form a parabola shape. The parabola is symmetric to the x axis. This assumption is relevant to the presentation of Somani \([29]\) that fluid flow has a form of a parabola in time and elliptic in space. The ellipse shape in this context is the shape reflected on the pavement surface. The ellipse shape on the pavement surface starts from the A point as shown in Figure 5. Since each aircraft may have more than one contour of temperature and velocity of jet exhaust, the number of ellipses form is following the number of contours.

Figure 5. Assumption engaged to determine the A point

The loading area due to the jet exhaust is presented based on the plan view as shown in Figure 6. The ellipses start at a certain distance from the end of the jet engines and end up following the length of the contours. The width of ellipses is the maximum width of the contours. The data presented here are based on the data available on the aircraft manufacturer at the static airplane, sea level, zero wind, and standard day.

Figure 6. The assumption temperature contours of the jet exhaust
The point A is the point of the ellipses of the heated area on the pavement surface. The ellipses form represents the moving heat source along the runway with time. The assumption engaged in this research refers to the moving heat source that is caused by a welding process [30]. Based on these references, the heated area of the pavement surface is then assumed to be similar to the Figure 6.

In Figure 6, number 1, 2, and 3 indicate the number of contours and those may be increased based on the number of contours available in the aircraft manual. Therefore, T1, T2, T3 is the temperature value of each temperature contour. In this figure, T1>T2>T3. W is the maximum width of the ellipse and L is the maximum length of the ellipse. The z_j is the distance from the nozzle to the centre of the fuselage or runway centerline.

The chart is presented in Error! Reference source not found. as bar charts. The length of the bar represents the width of heated area. The position of the bar from the axis indicates the part of the runway being heated as the axis represents the runway centre line. Each bar may have more than one colour that denotes different temperature imposed on the pavement surface.

As shown in Figure 2, the jet engines may produce the thermal load that has two different temperatures affected to the pavement surface. Figure 7 presents the predicted the width of loading area due to the thermal load produced by jet engines. A319 shows two different temperatures affected on the pavement surface. The temperatures induced on the pavement surface for A319 are 30°C and 55°C, which are indicated by the dark colour and lighter colour respectively. B737 produces 40°C thermal load. MD80 is considered has similar effect as A319, since there is no data of the jet exhaust profile for MD80.

Figure 7 shows the width of the jet exhaust after distributed on the pavement surface. Each aircraft has its own pattern of the jet exhaust; i.e the width and the temperature of the exhaust. The most frequent area received the heat load potential to have premature asphalt oxidation. From the picture can be identified that the area at the distance of 4m to 6m from the runway centreline received heat load more than another part of the runway.

5. ANALYSIS AND DISCUSSION

The aircraft movement generates two different loads, the wheel load and thermal load. These loads intervals depend on the position of the wheels on the main gear and the position of A point as drawn in Figure 5.

The location of the wheel load based on the most frequent movement is around 2.5 m to 4 m from the runway centreline as shown in Figure 4. This location has an overlapping with the location of the thermal load that occurs at around 4m to 6m from the runway centreline. This assumption of the overlapping is based on the wander position during the lateral aircraft movements that forms normal distribution.

These two different loads are potential in generating different pavement distress after certain load repetition. The available equation to determine the number of load repetition that incorporation of a pavement thickness is to predict the cause of pavement to failure. However, the equation available is not encountered the effect of thermal load. In addition, the equation is not applicable to answer the number of load repetition to cause the functional pavement decreased.

The decreasing of the pavement functional may be approached to the presence of rubber deposits. The rubber deposits are only generated during the landing process. The accumulation of rubber deposits on the pavement surface could reduce the skid resistance.

The thickness of rubber deposits depends on the number of aircraft landed, tire
properties, and climatic condition [9]. To determine the area that is predicted to be covered by rubber deposits, the rubber left after landing process is divided by its specific gravity. The result determines the area covered by a thin layer of rubber deposits. The accumulation of the thin layer of rubber deposit needs to be monitored and maintain to be less than the thickness of macrotexture. The thickness of macrotexture of the pavement material is in the range of 0.2-3 mm [22].

The aircraft tire technology is designed as a highly engineered composite structure. The composition by weight is 50% rubber, 45% fabric and 5% steel [31]. This composition is not always the same amongst aircraft tire manufacturer. In addition the type of aircraft influences the tire type selection.

The predictive thin layer of rubber deposit requires further evaluation. The tread of the tire may be designed has all rubber or fabric-reinforced rubber [32]. These different tread designed effect the amount of rubber left on the pavement surface. The friction level developed between tire and the pavement surface also may affect the development of rubber deposit.

6. CONCLUDING REMARK

The need of frequent maintenance for runway may be fulfilled through a good maintenance management. The maintenance management requires regular monitoring on pavement condition. The obstacles in conducting regular monitoring are the availability of the skilled staffs and the tight schedule of the airport operation.

An alternative approach to determine the location of the pavement distress is proposed in this study. The location of pavement distress can be estimated through the availability of data related to aircraft movements and types.

This study presents a framework to determine the pavement distress location. The framework incorporates the loading path and traffic characteristics. The loading path comprises both wheel load and thermal load.

The maintenance schedule can be estimated as well as the area to be rehabilitated.

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