The effect of cumulative damage factor value on existing runway life service

Eduardi Prahara¹, Hanna Annisa Rachma¹
¹ Civil Engineering Department, Faculty of Engineering, Bina Nusantara University, Jakarta, Indonesia 11480
Corresponding email: hanaarch2@gmail.com

Abstract. Safety and convenience are the most important thing in running of an airport, the runway condition must always be considered especially in maintenance to prevent and repair the damage. In this analysis an evaluation of the conditions of the existing runway pavement of an airport in Indonesia is conducted by analyzing the pavement service life condition with the Cumulative Damage Factor (CDF) value. Considering data confidentiality, the airport will be called just by the sample airport. Furthermore, CDF will be calculated and graphed using the FAARFIELD program. The results show that the CDF value of the existing pavement of the sample airport is 10.42, with the largest CDF contribution from the B737-800 aircraft of 4.40 and A320 of 3.32. Concluding there is a correlation where if a surface layer is added, there will be a decrease in the value of CDF where an extension of the life of the pavement will occur.

Keywords: Runway, Flexible Pavement, Wheel Configuration, CDF, FAARFIELD

1. Introduction

The airport is an important aspect of the provision of air transportation in Indonesia with its geographical conditions as an archipelagic country [1]. Air transportation is also more desirable because it saves travel time so that passengers and goods. Therefore, in Indonesia, there has been a rapid increase in the movement of passengers and goods. In order to overcome this issue, a variety of different aircraft has been produced on market which has a variety of types of use, size, weight, and wheel configuration. These various modern aircraft models have already operated in any airports in Indonesia.

An airport requires good planning and maintenance especially its intermodal facilities, specifically the landside and the airside. Brian et al (2016) stated that one of the most important airside facilities is the runway that must have standards, both in its strength and dimensions [2]. Therefore, the runway condition is the most important airside facilities which should always be considered to support and maintain security, continuity, and convenience of airport operations.

The condition of runway pavement matters in determining how maintenance will carry out to avoid damage. Shafabakhsh et al (2014) mentioned that Cumulative Damage Factor (CDF) is the amount of the structural fatigue life of a pavement which has been used up [3]. Thus the structural condition of the runway pavement determined by its remaining life. Using the existing runway pavement in sample airport, CDF contribution analysis will be performed to evaluate whether the existing runway pavement of sample airport was still able to restrain a load of operating aircraft in the future. It was agreed due to data confidentiality the sample airport name will be unmentioned.
The aim of this analysis is to evaluate the condition of the sample airport runway pavement in Indonesia. The purposes of this study are to determine the condition of the existing runway pavement by identifying the fatigue life by looking for the value of the sample airport runway Cumulative Damage Factor (CDF), indicate the pavement ability of the existing runway to bear the burden of variations in aircraft types, and to produce outcome which is a correlation between the pavement itself with CDF value and pavement life service.

2. Method

The structural design of an airport rigid pavement carrying mixed traffic should be based in principle upon fatigue cracking criterion, as stated by the PCA method [4]. The evaluation by analyzing the CDF value is an analysis of structural conditions that focus on the pavement fatigue life. CDF value calculation uses mixed traffic concepts. From the annual departure data of the sample airport, 20 types of planes with the highest gross weight and annual departures were chosen at the sample airport. This analysis used the FAA software program, FAARFIELD v 1.42.

Every departing aircraft is assumed to cause certain damage in the pavement that corresponds to the flexural stress level occurring therein. When the cumulative total damage reaches 100% at the end of its design life, the pavement is expected to experience fatigue cracking within the wheel path of a certain aircraft [5]. Cumulative Damage Factor (CDF) is fatigue cracks or the amount of structural fatigue life from pavement that has been drained. It expressed as a comparison between the repetition of applied loads and the repetition of the possible burden of failure. CDF for aircraft is a value between 0 and 1 which states the contribution to pavement failure from the number of movements projected for each type of aircraft using pavement. According to Miner's law, a traditional theory that estimates the amount of usage to pavement failure, to determine the value of CDF in a particular plane is determined by equation 1 and equation 2 below.

$$CDF = \frac{(\text{annual departure}) \times (\text{life in years})}{(\text{pass coverage ratio}) \times (\text{covered to failure})}$$  \hspace{1cm} (1)

$$CDF = \sum \left( \frac{n_i}{N_i} \right)$$  \hspace{1cm} (2)

- $n_i$ = Number of coverages applied to a pavement by aircraft;
- $N_i$ = Number of coverages to failure for aircraft.

Analyzing individual wheel loads of aircraft that have a high CDF has the potential cause of damage. Furthermore, conclusions and suggestions are given as the final step in this research. the results plotted into a graph. At the end of the analysis found the value of variation between pavement thickness and CDF value, along with the effect between the value of the variation of pavement thickness and pavement life. This research was conducted on the existing runway at the sample airport.

Data processing assisted by using FAARFIELD software v 1.42. Federal Aviation Administration Rigid & Flexible Iterative Layered Elastic Design (FAARFIELD) is a computer program for airport pavement designs that operate based on elastic layered theory and finite element methods. This program was developed by FAA. the latest version of FAARFIELD v 1.42 presented in 2017 and used for rigid and flexible pavement designs.

CDF contribution analysis was performed to evaluate whether the existing pavement at the sample airport was still able to restrain a load of operating aircraft in the future with the growth of aircraft movements per year at the sample airport for the next 20 years. CDF contribution analysis using the FAARFIELD program to determine the fatigue life of the runway. So that it can be estimated the remaining age of the runway pavement. A similar study published in 2014 by Shafabakhsh et al "Effect of Aircraft Wheel Load and Configuration on Runway Damages" [3]. Which discuss the analysis of individual wheel loads on aircraft with mixed traffic designed for runways at the sample airport.

2.1 FAARFIELD Manual Application
FAARFIELD home window contains tabs to create or copy new, there is various type of airside pavement facility that has been provided. To evaluate the air-side pavement facilities, adjust the existing pavement type of content, and its info illustrated by the pavement structure layer in the program. There is also tab to enter aircraft data library. To start calculating pavement life with mixed traffic that has been entered in the list there is a life command-tab. The value of CDF contributions for each plane can be seen in the list of aircraft by sliding to the right and the graphs can be shown in the CDF graph command-tab.

3. Data Collection

Secondary data needed in this analysis obtained from the Transportation Engineering Group Research based in Indonesia.

3.1 Existing Pavement Structure Data at the sample airport

The existing runway at the sample airport is a single runway with a 3000m x 45m dimension size. It is a flexible pavement with PCN value 86 F / C / X / U. Figure 1 below is the layout of the existing runway, following Table 1 shows data of pavement structure thickness at the airport runway X. the existing runway has a CBR value = 6 and the total thickness of the flexible pavement structure is 26.38 inch or 67 cm, which consists of: Hot-mix Asphalt (surface) layer 14 , 57 inch or 37 cm; the base course is a 6.69 inch or 17 cm of stone; and the bottom layer (sub-base) of sand is 5.12 inch or 13 cm.

![Figure 1. Runway layout of the sample airport](image)

| Layer | Type      | Thickness (cm) |
|-------|-----------|----------------|
| 1     | HMA       | 37             |
| 2     | Gravel 5/7| 17             |
| 3     | Sand      | 13             |
|       | Total     | 67             |

Table 1. Existing pavement structure thickness data at the sample airport
3.2 Mixed Traffic Data at the Sample Airport

From the flights' annual departure data at the sample airport, 20 aircraft with the highest gross weight and highest rate annual departures were selected. Shown in Table 2 below.

| No. | Aircraft          | MTO W (lb) | Gross Weight (lb) | Annual Departure [R2] | Wheel Load [W2] | Wheel Load Design [W1] | Log R1 | Equivalent Annual Departure [R1] |
|-----|-------------------|------------|-------------------|-----------------------|-----------------|------------------------|--------|----------------------------------|
| 1   | B737-800          | 174,200    | 174,900           | 8,429                 | 41808           | 218400                 | 4      | 3688                             |
| 2   | A320              | 172,000    | 174,842           | 12,574                | 41280           | 218400                 | 4      | 5467                             |
| 3   | B747-400ER        | 910,000    | 913,000           | 162                   | 21840           | 218400                 | 2      | 162                              |
| 4   | B777-300          | 660,000    | 662,000           | 128                   | 15840           | 218400                 | 2      | 109                              |
| 5   | B737-900ER        | 187,700    | 188,200           | 128                   | 21840           | 218400                 | 1      | 17                               |
| 6   | B737-BBJ          | 171,500    | 171,500           | 176                   | 41160           | 218400                 | 2      | 76                               |
| 7   | B767-400ER        | 450,000    | 451,000           | 8                     | 10800           | 218400                 | 1      | 6                                |
| 8   | A340-600          | 813,947    | 815,900           | 3                     | 19534           | 218400                 | 0      | 3                                |
| 9   | A330-300          | 533,519    | 535,503           | 7                     | 12804           | 218400                 | 1      | 5                                |
| 10  | B767-300ER        | 412,000    | 413,000           | 17                    | 98880           | 218400                 | 1      | 11                               |
| 11  | A321neo           | 206,000    | 207,014           | 2                     | 49440           | 218400                 | 0      | 1                                |
| 12  | B767-200ER        | 395,000    | 396,000           | 5                     | 94800           | 218400                 | 1      | 3                                |
| 13  | B777-300 ER       | 775,000    | 777,000           | 1                     | 18600           | 218400                 | 0      | 1                                |
| 14  | MD-83             | 160,000    | 161,000           | 13                    | 38400           | 218400                 | 1      | 5                                |
| 15  | AN 124-200        | 893,000    | 893,000           | 1                     | 21432           | 218400                 | 0      | 1                                |
| 16  | B737-300          | 139,500    | 140,000           | 874                   | 33480           | 218400                 | 3      | 342                              |
| 17  | B737-500          | 136,000    | 136,500           | 428                   | 32640           | 218400                 | 2      | 165                              |
4. Results and Discussion

4.1 CDF Contributions at the Sample Airport with Mixed Traffic by FAARFIELD

CDF analysis is performed to evaluate whether the existing pavement at the sample airport is still able to resist loads of aircrafts operating in the future by calculating growth of 1.6% per year to the next 20 years. Figure 3 below shows the output of CDF calculation from FAARFIELD program. It can be seen that with the frequency of departure, B737-800 plane has the highest CDF value than the others in the CDF calculation which is 4.4. The reason is because the CDF calculation on FAARFIELD is also based on conventional FAA calculations that frame the calculation with the departure frequency parameters, where the B737-800 is one of the most often operating aircraft.

Figure 4 shows the results graph calculation of CDF contribution on existing runway flexible pavement with data on the frequency of mixed traffic departures at the sample airport. The results of CDF contribution calculations using FAARFIELD shows 3 aircrafts that have CDF value above 1, which are Boeing B737-800 has the highest CDF value with 3.4% excess, Airbus A320 has a CDF value with an excess of 2.32%, Boeing B747-400ER has a CDF value with an excess of 0.73%.

CDF value of mixed traffic at the sample airport is 10.42. This means that the frequency of departures at the sample airport which keeps increasing will effect in existing runway pavement spend its fatigue life and potential pavement failure in the next 20 years.

![Figure 3. FAARFIELD program output CDF graph at the sample airport](image)

![Figure 4. CDF contribution of existing runway at the sample airport](image)
4.2 Correlation between Pavement Thickness – CDF Value and Pavement Thickness – Pavement Life

Table 3 shows various designs of layer thickness and CDF values obtained from the FAARFIELD program calculation. As for the correlation graph between CDF values and pavement, the thickness can be seen in Figure 5. The exponential line shown in Figure 5, shows the effect of the pavement structure thickness on the value of CDF if the pavement thickness is added or by overlaying the pavement, Max CDF value will get smaller. This applies to the existing airport runway pavement sample case with mixed traffic existing at the sample airport.

| Pavement Thickness (cm) | CDF Max (20 Tahun) |
|-------------------------|--------------------|
| 67                      | 10.42              |
| 72.5                    | 2.25               |
| 73.5                    | 1.6                |
| 74.5                    | 1.25               |
| 75.5                    | 1                  |
| 76.5                    | 0.75               |
| 77.5                    | 0.57               |
| 78.5                    | 0.43               |
| 79.5                    | 0.31               |

**Figure 5.** Correlation graph between pavement thickness - CDF value

Table 4 shows the various design of additional layer thickness and pavement life obtained from the FAARFIELD program calculation. As for the correlation graph between Pavement life and pavement thickness can be seen in Figure 6. The exponential line shown in Figure 6, shows the effect of the layer thickness on the pavement life. If the pavement thickness is added or an overlay of the pavement is added, the pavement life will increase over time. This applies to the existing airport runway pavement sample case with mixed traffic existing at airport X.

| Pavement Thickness (cm) | Pavement Life (Tahun) |
|-------------------------|-----------------------|
| 67                      | 2                     |
| 72.5                    | 10                    |
| 73.5                    | 12                    |
| 74.5                    | 16                    |
| 75.5                    | 20                    |
5. Recommendations

In order to extend the pavement life of the sample airport. There are 2 recommendations that can be taken, which are:

5.1 Overlay Design

On the existing runway condition, it is known that the fatigue life of the existing pavement structure will be exhausted in the next 20 years. From the FAARFIELD program, it is known that the airport runway sample structure is included in the non-standard structural. It is recommended to conduct corrective maintenance, by adding overlay to increase pavement life.

By using departure frequency data at the sample airport, the FAARFIELD program designs overlay layers to increase fatigue life with existing structures below them. It is known from Table 3, the value of CDF becomes 1 when it is designed to add an overlay of 3.31 inches or 8.4 cm. So that the thickness of the structure becomes 29.69 inches or 75.4 cm. This means that with the thickness of the pavement increasing by 8.4 cm, the runway pavement will be expected to spend its fatigue life in the next 20 years.

![Figure 6. Correlation graph between pavement thickness – pavement life](image)

![Figure 7. Pavement structure recommendation with mixed traffic at the sample airport](image)
The functional conditions of the existing airport runway pavement sample are stated in bad conditions where a lot of damage occurs. The damage can occur because of unfavorable structural conditions and different types of aircraft movements that contribute to the damage, which are the A340-600, B777-300ER, B777-300, and A330-300 in this case. However, to evaluate the structural conditions and the effect of aircraft movements on the runway pavement, Damage factor value analysis has also been performed and shows the type of aircraft that most contributes to structure life spending and how the conditions of the pavement in the future are known. So that it can be chosen the best way to maintain the sample airport runway.

The result stated that the existing runway pavement would have spent its service life for the next 20 years. Therefore, to prevent structural failure it is recommended to conduct preventive maintenance. That is recommended to add additional overlay asphalt layers to the surface. Along with the increased thickness runway pavement at the sample airport, the CDF value becomes smaller and the age of the pavement increases. A correlation graph between thickness overlay design and the CDF value and correlation graph between thickness overlay design added and the age of the pavement.

5.2 Reconstruction Design

Reconstruction is needed if pavement condition suffered heavy damage. This pavement maintenance option is intended to improve the entire structure of the runway pavement. However, it required further deformation analysis to recommend a reconstruction. If it needed to conduct a reconstruction, it is necessary to design construction for the new runway. The pavement life is to be planned for 20 years. And so, the design can also use the FAARFIELD software.
Figure 10. New runway pavement design structure for reconstruction at the sample airport

Figure 11. New runway pavement design CDF value

Figure 12. New structure pavement design recommendation for runway at the sample airport
By using FAARFIELD program designs for runway pavement at the sample airport, it is designed for the new structure consists of 47.89 cm (18.74 inch) sub-base layer, 19.05 cm (7.50 inch) base layer, and 10.16 cm (4 inch) surface layer. The total thickness of the structure is 30.24 inches or 76.8 cm. the new structure is expected to spend its fatigue life in the next 20 years.

6. Conclusion

Based on the results of the analysis carried out in this study, the analysis using the program shows the effect of CDF value on pavement life service by the case study of an existing runway condition in the sample airport. It can be shown the aircraft which had the highest CDF contribution value operating on the existing runway at the sample airport are Boeing B737-800 at 4.40 followed by Airbus A320 at 3.32 with high annual departure frequency. Moreover, that existing runway of the sample airport has remaining pavement life service in 2 years from this analysis conducted. This indicates that its structural conditions need more maintaining attention. In addition to supporting the operation of the sample airport, it is recommended to immediately perform preventive maintenance e.g. overlay or reconstruction to prevent physical damage or structural failure. However, it required further deformation analysis such as FWD deflection to recommend a reconstruction.

Furthermore, from the analysis of Cumulative Damage Factor (CDF) value variations generated using the program obtained the exponential regression equation that shows the effect of CDF value on pavement life. First, if pavement thickness increases or if overlay added on the pavement, the maximum CDF value will get smaller, this applies to the airport runway pavement sample case with mixed traffic at the sample airport. Second, if the pavement thickness is added or if overlay added on the pavement, the pavement life will increase over time. This applies to the existing runway case of sample airport with mixed traffic.

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