

Multi-Criteria Analysis in Assessment of the Degree of Degradation Pavement Elements Functional Airports Made of Cement Concrete

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Abstract. An important factor that affects the safety of flight operations is the proper management of airports, which should be based on the obtained in systematic way information about the state of the surface of the functional elements. One of the characteristic quantities of the technical condition of airport indicator is the assessment of the degree of degradation. It should be noted that the degradation is a slow process extended in time and is the lowering of the properties of the structure by external influences, which in turn generates the changes in their structure. Rating degrade surface should be conducted periodically, which period shall be estimated on the basis of information obtained from the process of the operation of aircraft. Demotions surface is determined on the basis of the type and quantity survey found damage and made repairs. The basis for evaluating the degree of surface degradation is to obtain data from surveys conducted using the method of visual and inventory of them. Research by visual method, despite its apparent simplicity, it is difficult to implement. Qualification of damage or repairs to the appropriate group is often not clear, and therefore the inventory process is described in the documentation of quality management system. The multi-criteria analysis is a method of evaluating the weighted supporting estimating the degree of degradation airfield pavements based on data obtained through inspections performed. Its base is included in the determination of a number of criteria for the selection variant, taking into account different weights to each criterion. The value of the indicator characterizing the degree of surface degradation in relation to estimated criteria allows you to schedule the necessary resources needed to carry out repairs and rational planning of repairs.

Keywords: multi-criteria analysis, airfield pavements, safety of flight operations, degree of degradation.

Conference topic: sustainable urban development.

Introduction

The article contains a selected part of a wide-ranging work aiming to the development of the indicator characterizing the degree of degradation airfield pavements made of cement concrete on the basis of visual inspection for damage and repair, and their inventory based on a catalog of typical damages (Shahin 2007) and defined rules quantity survey of damage and repairs. Used author method for assessing the degree of degradation airfield pavements made of cement concrete on the basis of the evaluation criteria of individual parameters characterizing the damage and repair the surface (24 parameters) taking into account the weights characterizing the impact of damage and repairs as well as individual parameters on the degree of degradation airfield pavements, and effect on the degradation of replacement of slabs or lack thereof.

In the literature and operational practice (ASTM 2012; FAA 2004a, 2004b), many terms related to the life phases of airport facilities, such as, e.g. durability, service life, labour resource, technical service life resource, service life resources between repairs, are used, and thus: durability is a feature of the facility that is based on the fact that the facility is fit for use for a given time period in specific conditions. In terms of the quantity, the durability is measured by: the number of operations for take-off and landings of aircraft taking into account their weight and calendar service life. The durability is counted from the start of operation of the facility to the moment in which its further use becomes pointless due to technical or economic reasons. The service life is an experimentally and theoretically determined operation period of the facility measured by: operating time, the number of take-offs and landings, the calendar period of operation, during which the safety and operation efficiency is guaranteed at a certain level, and after the exceeding of which, its further operation is not allowed. The operation resource is experimentally and theoretically determined actual amount of the facility's operation based on criteria characterising the operation process.

In Figure 1, operation strategies of the airport pavement functional elements were graphically presented. The characteristic feature of the adopted approach to the deterioration degree analysis of airport pavements includes the fact that in case of the assessment, identified damage and carried out repairs for a given day are taken into account. Such an approach allows to plan essential resources necessary to carry out repairs and rationally plan overhauls. The offered indicator for assessing the deterioration degree, calculated on the basis of measured damage and repairs, allows for comprehensive assessment of the technical condition of the examined pavement's surface. The basic information

necessary for the pavement deterioration degree assessment is to obtain data of the carried out inventory. The inventory is carried out on the basis of a catalogue of typical damage to airport pavements and principles of carrying out the measurement. The elements supporting the inventory process includes a legend of damage and repairs as well as the marking of parameters and their units. Based on the obtained data on damage and conducted repairs, the deterioration degree of airport pavements is analysed, and the assessment criteria are defined.

The method experts, on the basis of which chosen the weight of indicators for assessing airfield pavements based on 5 professionals engaged in research airfield pavements. Compiled and ranked factors according to rang. Each factor is assigned by the experts of the appropriate weight taking into account the impact on the technical condition airfield pavements after the review and having regard to the safety of aircraft operations. The results was developed through the analysis of the dispersion and coefficient of variation, which represent a compliance rates of views of experts in relation to a given factor. The average weight of expert assessment and coefficient of variation are the criteria for suitable scales.

It should be noted that testing with the use of a visual method, despite its apparent simplicity, is difficult to implement. The classification of damage or repairs to the appropriate group is not often clear, therefore, the inventory process should be standardised. The proper management of airports as well as the provision of accurate information on their condition constitute important factors, which affect the safety of carried out flight operations.

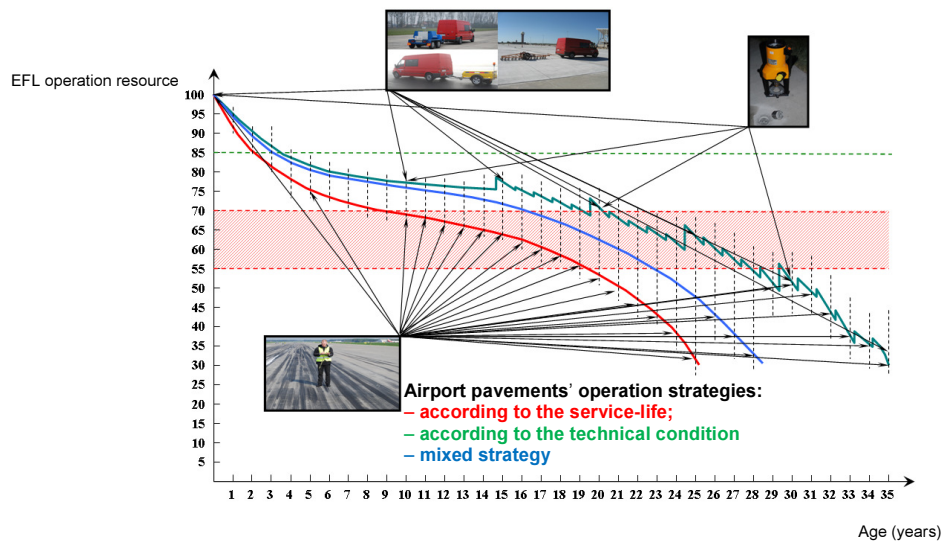


Fig. 1. Operation strategies of the airport functional elements' pavements

Algorithm of estimating the deterioration degree of airport pavement functional elements made of cement concrete

The algorithm, presented in Figure 2, shows the way of assessment of the deterioration degree of the airport functional element's pavement.

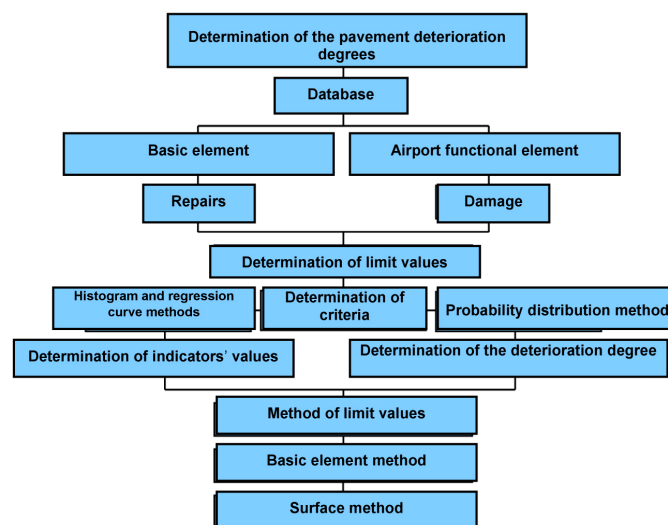


Fig. 2. Algorithm of assessing the deterioration degree of airport pavements

In order to assess the pavement deterioration degree, a finite sequence of defined activities is performed, and it includes:

- determination of the parameter limit values of relative functional elements of airports on the basis of the analysis of: histogram and regression curve, probability distribution;
- determination of the parameter limit values characterising deterioration of a single slab based on the analysis of: histogram and regression curve, probability distribution;
- determination of assessment criteria related to the deterioration degree of airport pavements;
- determination of the indicators' values characterising the pavement deterioration;
- determination of the pavement deterioration degree.

Methods of estimating the deterioration degree of airport pavement functional elements made of cement concrete

Deterioration is a slow and spread over time process. It mainly involves the reduction of construction properties by the impact of external factors, which as a result, generates changes in its structure. The deterioration degree of the airport functional element's pavement is affected by damage and performed repairs. This quantity was determined on the basis of 13 defined types of damage and repairs. In order to optimally select an indicator characterising the actual deterioration degree of the pavement surface, two variants of calculation are considered, where it is assumed that the performance of repairs affects the pavement deterioration in 20% or 50%. While analysing the indicators characterising the pavement deterioration, the impact of the types of damage and repairs on the aircraft operation safety is taken into account by the introduction of properly selected weights. The indicator for assessing the deterioration degree of the airport functional elements' pavement with the use of a method of occupied surface including the impact of a specific parameter on the aircraft operation safety is calculated on the basis of data obtained during the inventory in accordance with the following formula:

$$\overline{D_{BC}^{MF}} = w_{BC}^U \times W_{BC}^{UF} + w_{BC}^N \times W_{BC}^{NF} ; \quad (1)$$

$$W_{BC}^{wUF} = \frac{\sum_{i=1}^{13} \frac{(w_{Ob}^U)_i \times (Ob_{BC}^U)_i \times (p_{BC}^U)_i}{F} \times 100}{\sum_{i=1}^{13} (w_{Ob}^U)_i} ; \quad (2)$$

$$W_{BC}^{wNF} = \frac{\sum_{i=1}^{13} \frac{(w_{Ob}^N)_i \times (Ob_{BC}^N)_i \times (p_{BC}^N)_i}{F} \times 100}{\sum_{i=1}^{13} (w_{Ob}^N)_i} , \quad (3)$$

where: $\overline{D_{BC}^{MF}}$ – pavement deterioration of the airport's functional element made of cement concrete; p_i – conversion rate of the parameter characterising damage and repairs on the surface including damaged and repaired areas; w_{iBC} – statistical weight of the importance of damage and repairs in the assessment of deterioration of the airport's functional element pavement; w_{iOb} – statistical weight of the validity of specific damage and repairs in the assessment of deterioration of the airport's functional element pavement; Ob_i – measurement of damage and repairs of the airport's functional element pavement; F – total area of the tested pavement of the airport's functional element; U – damage to the airport's functional element pavement, N – repairs of the airport's functional element pavement.

The indicator for assessing the pavement deterioration degree of the airports' functional elements with the use of a method of limit values is calculated on the basis of data obtained during the inventory in accordance with the following formula:

$$\overline{D_{BC}^{MG}} = w_{BC}^U \times W_{BC}^{wUG} + w_{BC}^N \times W_{BC}^{wNG} ; \quad (4)$$

$$W_{BC}^{wUG} = \frac{\sum_{i=1}^{13} \frac{(w_{Ob}^U)_i \times (Ob_{BC}^U)_i}{F \times (WG_{BC}^U)_i} \times 100}{\sum_{i=1}^{13} (w_{Ob}^U)_i} ; \quad (5)$$

$$W_{BC}^{wNG} = \frac{\sum_{i=1}^{13} \frac{(w_{Ob}^N)_i \times (Ob_{BC}^N)_i}{F \times (WG_{BC}^N)_i} \times 100}{\sum_{i=1}^{13} (w_{Ob}^N)_i}, \quad (6)$$

where: D_{BC}^{MG} – pavement deterioration of the airport's functional element made of cement concrete; WG_i – limit value for specific types of damage and repairs.

The unloaded indicator for assessing the pavement deterioration degree of the airports' functional elements with the use of a method of occupied surface is calculated on the basis of data obtained during the inventory in accordance with the following formula:

$$\overline{D_{BC}^{MF}} = w_{BC}^U \times W_{BC}^{UF} + w_{BC}^N \times W_{BC}^{NF}; \quad (7)$$

$$W_{BC}^{UF} = \sum_{i=1}^{13} \frac{(Ob_{BC}^U)_i \times (p_{BC}^U)_i}{F} \times 100; \quad (8)$$

$$W_{BC}^{NF} = \sum_{i=1}^{13} \frac{(Ob_{BC}^N)_i \times (p_{BC}^N)_i}{F} \times 100. \quad (9)$$

The unloaded indicator for assessing the pavement deterioration degree of the airports' functional elements with the use of a method of limit values is calculated on the basis of data obtained during the inventory in accordance with the following formula:

$$\overline{D_{BC}^{MG}} = w_{BC}^U \times W_{BC}^{UG} + w_{BC}^N \times W_{BC}^{NG}; \quad (10)$$

$$W_{BC}^{UG} = \sum_{i=1}^{13} \frac{(Ob_{BC}^U)_i}{F \times (WG_{BC}^U)_i} \times 100; \quad (11)$$

$$W_{BC}^{NG} = \sum_{i=1}^{13} \frac{(w_{Ob}^N)_i \times (Ob_{BC}^N)_i}{F \times (WG_{BC}^N)_i} \times 100. \quad (12)$$

The indicator for assessing the pavement deterioration degree of the airports' functional elements is calculated in accordance with the following formula:

$$D = w_{BC}^U \times W_{BC}^U + w_{BC}^N \times W_{BC}^N; \quad (13)$$

$$W_{BC}^U = w_{BC}^{wUG} \times W_{BC}^{wUG} + w_{BC}^{wUF} \times W_{BC}^{wUF} + w_{BC}^{UG} \times W_{BC}^{UG} + w_{BC}^{UF} \times W_{BC}^{UF}; \quad (14)$$

$$W_{BC}^N = w_{BC}^{wNG} \times W_{BC}^{wNG} + w_{BC}^{wNF} \times W_{BC}^{wNF} + w_{BC}^{NG} \times W_{BC}^{NG} + w_{BC}^{NF} \times W_{BC}^{NF}. \quad (15)$$

Assessment of the deterioration degree of airport pavement functional elements made of cement concrete

While estimating the pavement deterioration degree, the test results, obtained during the inspections with a visual method of surfaces of the airport facilities' pavements, were taken into account. The analysis was carried out for the airport's functional element taking into account the fact whether the slab was replaced or not. The analysed spectrum of tested facilities was divided into 7 groups, and the limits of ranges characterising the assessment criteria of the pavement deterioration were determined. The indicators, on the basis of which the values of assessment criteria of the pavement deterioration were estimated, includes D^{UN} unloaded indicator and $D^{w(UN)}$ weighted index of the deterioration degree of the airports' functional elements, which are defined on the basis of an indicator characterising W^U damage and W^N repairs of the airport's functional element. The values, which were achieved by indicators characterising the deterioration of airport pavements while taking into account appropriately selected weights, are shown in Figures 3

and 4. However, it should be noted that for a complete view of the pavement deterioration state, it is important to analyse indicators characterising damage and repairs, which were presented in Figures 5 and 6 including the fact of replacement or without replacement of slabs that constitute a sample.

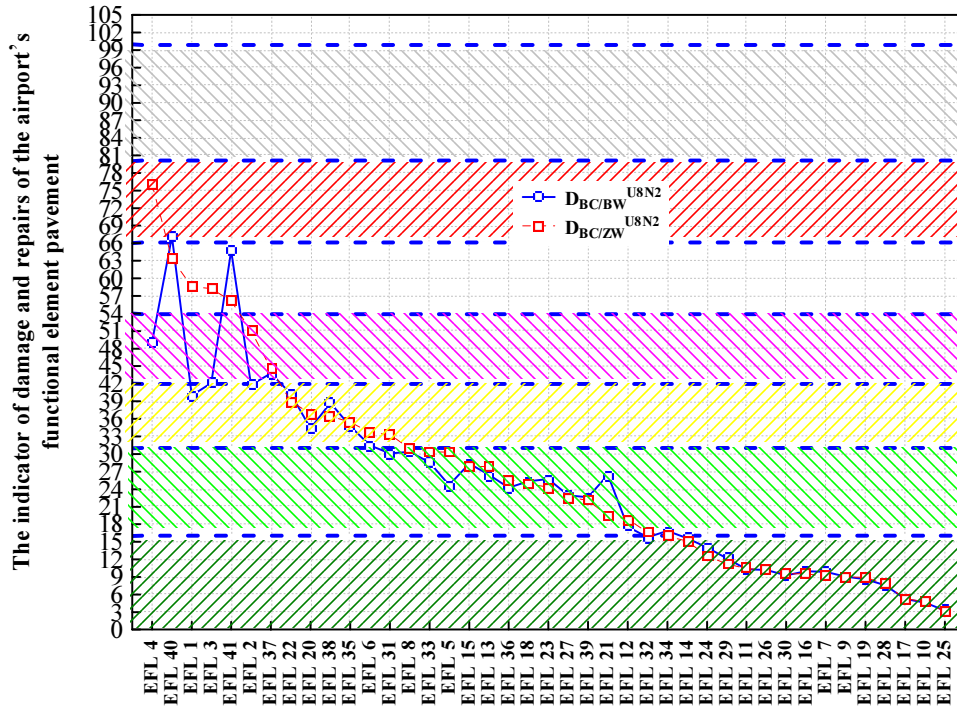


Fig. 3. D_{BC}^{U8N2} deterioration degree of the airport's functional element pavement (Barszcz, Wesołowski 2015)

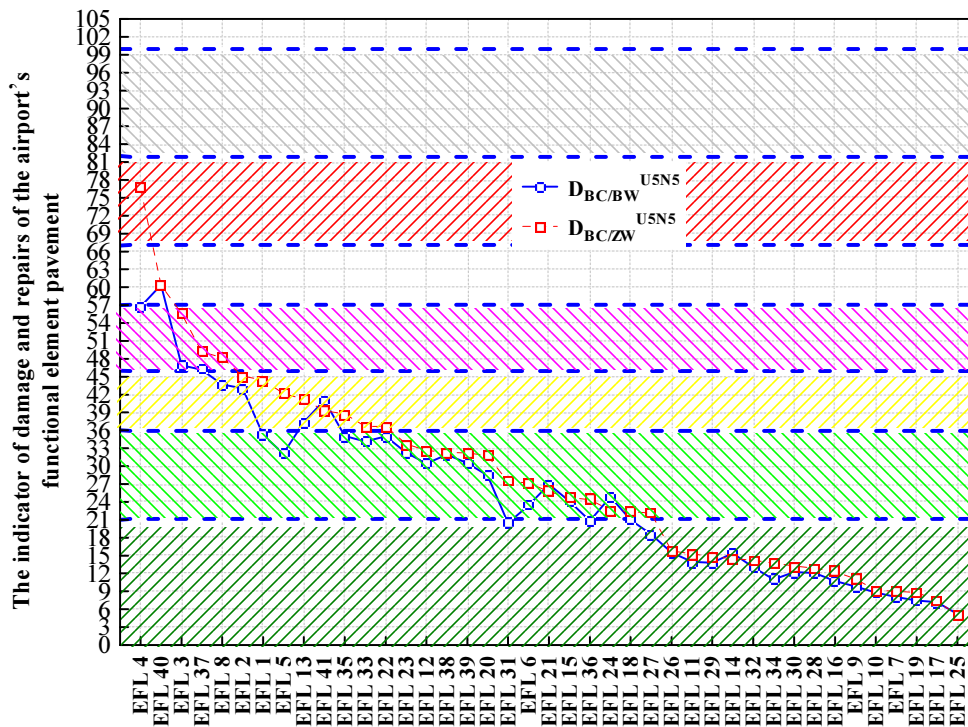


Fig. 4. D_{BC}^{U5N5} deterioration degree of the airport's functional element pavement (Barszcz, Wesołowski 2015)

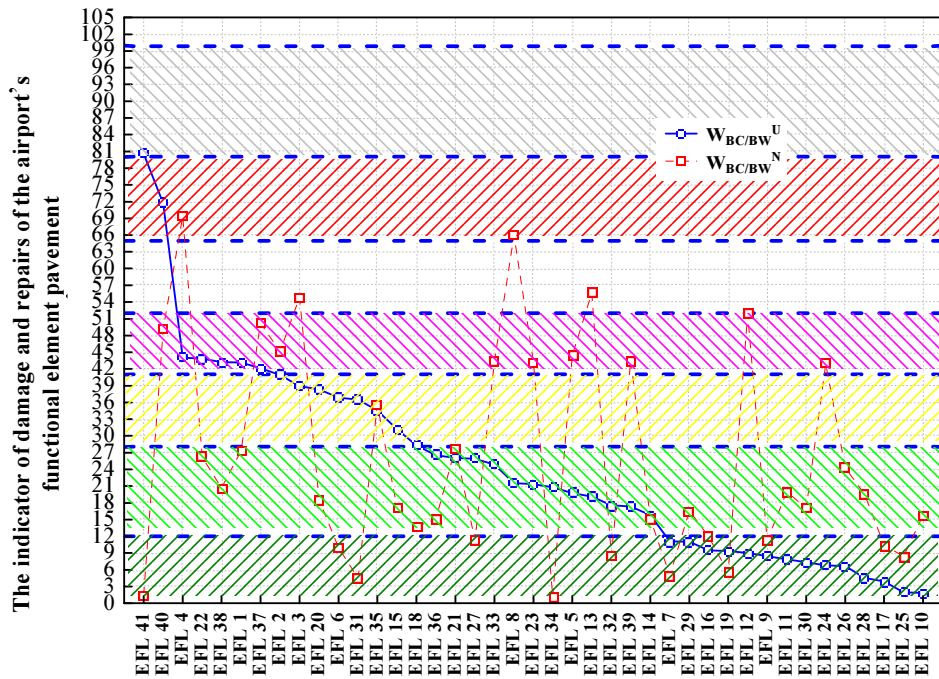


Fig. 5. Indicators of damage and repairs of the airport's functional element pavement (Barszcz, Wesołowski 2015)

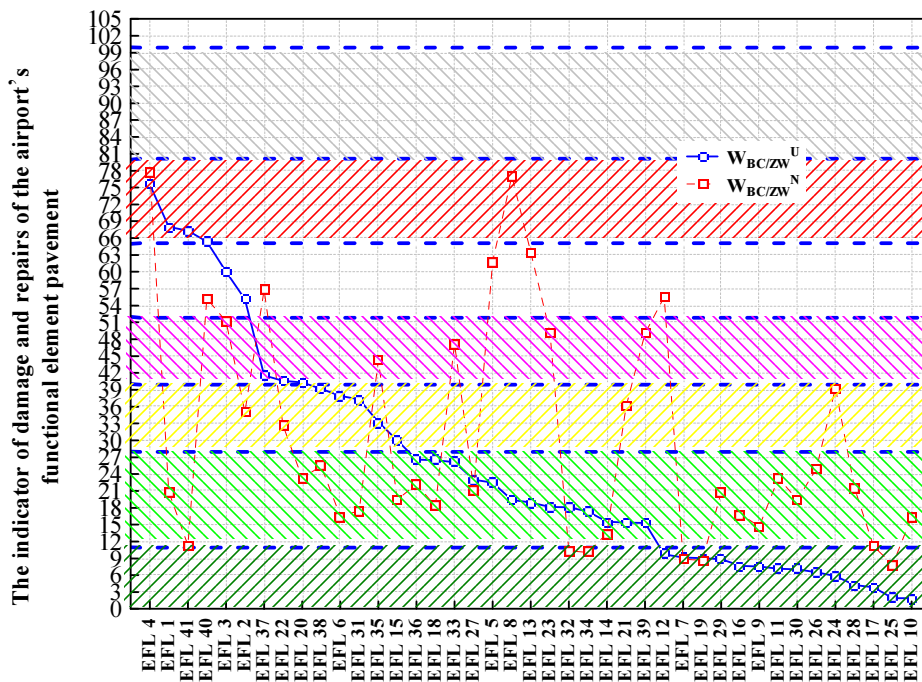


Fig. 6. Indicators of damage and repairs of the airport's functional element pavement (Barszcz, Wesołowski 2015)

The Histogram, presented in Figure 7, which has a bar graph form, was used in order to graphically display the variability of a particular set of data characterising the pavement deterioration. The organisation of a set of raw data is based on the division into ranges, the so-called classes. It allows to present the empirical distribution of characteristics for quantitative variables, and it determines the values at which the majority of results is located.

Based on the probability distribution analysis, the corresponding distribution relevant to the nature of the probability density function was selected. The probability refers to the possibility of the occurrence of an event or several events. With data of the index development characterising the pavement deterioration degree, the probability of the occurrence of a specific event, which adopts a value in the range from 0 to 1, was determined. The probability

scope of the event occurrence was divided into seven ranges and the possibility of the occurrence of a specific event with the specified probability was calculated.

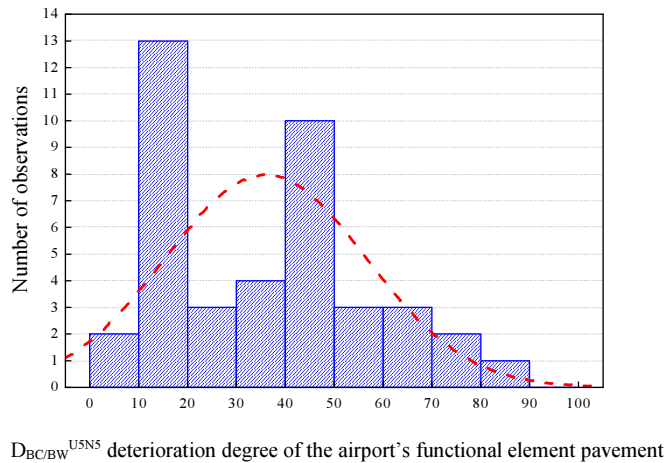


Fig. 7. Standard distribution of the variability assessment indicator of the deterioration degree of the airport's functional element pavement

The indicator offered by Air Force Institute of Technology, which characterises the pavement deterioration degree of the airport's functional elements, is within the range from 0 that means the perfect condition pavement to 100 that means the pavement unfit for further use. The calculation of D indicator is based on visual inspection results, during which different types of damage and repairs as well as their measurement are determined. The impact of a type of damage and repairs on the aircraft operation safety is included in the calculation by adopting weights (Smirnow, Ickowicz 2002) estimated on the basis of the experts' method.

The standard assessment scale of the pavement deterioration degree includes 7 levels, however, it is also possible to apply a simplified scale, where there are three decision-making levels of a description of the deterioration degree of the airport's functional element pavement. For each level, classes determining the pavement condition were assigned. The first one is a desired level, which includes new, renovated and operated pavements, with the assumption that these pavements will not require planned renovation works over the next five years.

The indirect warning level identifies the pavement condition as the one in which it is reasonable to perform detailed tests in terms of conducting treatments in order to improve the pavement condition. The last one is a critical level, which determines the prompt performance of technical and operational research, in order to define activities aimed at the introduction of procedures to improve the pavement condition or taking the facility out of service. Figure 8 shows the relationship between decision-making levels and classes of the deterioration state of the airport's functional element pavement. Interpretation of the pavement classes is shown in Table 1.

The critical value of D indicator is a value, after the achievement of which, the pavement condition begins to rapidly deteriorate.

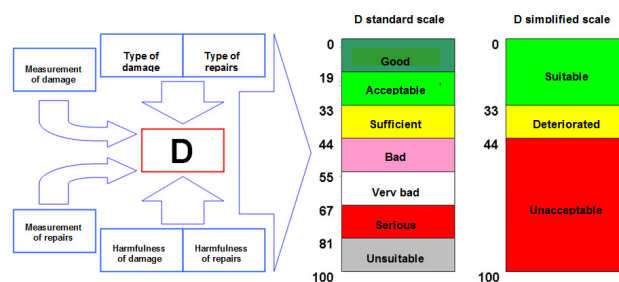


Fig. 8. Assessment criteria of the deterioration degree of the airport's functional element pavement offered by Air Force Institute of Technology (Barszcz, Blacha 2016)

Table 1 shows the criteria for the degree of degradation of cement concrete pavement with and without replacing the plate having regard to 80% or 50% the impact damage and 20% or 50% the impact repairs on the index value of degradation pavements. Figure 3 shows the criteria for the degree of degradation of the pavements, and without changing the plate having regard 80% the impact of damage and 20% the impact of repairs on the value of the indicator surface degradation. Figure 4 shows the criteria for the degree of degradation of the pavements, and without changing

the plate having regard 50% the impact of damage and 50% the impact of repairs on the value of the indicator pavements degradation. Figure 5 shows the criteria indicator of damage and repair of the cement concrete without changing the plate. Figure 6 shows the index criteria damage and repairs for replacement of cement concrete the plate.

Table 1. Assessment criteria of the technical condition of the airport's functional element pavement obtained with the use of methods developed by Air Force Institute of Technology (Barszcz, Blacha 2016)

Sate	$D_{BC/BW}^{U8N2}$	$D_{BC/ZW}^{U8N2}$	$D_{BC/BW}^{U5N5}$	$D_{BC/ZW}^{U5N5}$	D_{BC}
Good	0÷18	0÷14	0÷22	0÷20	0÷19
Acceptable	19÷31	15÷30	23÷37	21÷35	20÷33
Sufficient	32÷43	31÷41	38÷47	36÷45	34÷44
Bad	44÷55	42÷54	48÷57	46÷56	45÷55
Very bad	56÷67	55÷66	58÷67	57÷67	56÷67
Serious	68÷80	67÷80	68÷82	68÷82	68÷81
Unsuitable	81÷100	81÷100	83÷100	83÷100	82÷100

Conclusions

On the basis of verified parameters characterising the deterioration degree of airport pavements, it is possible to predict and estimate a period of safe operation of a particular functional element of the airport, which as a result, provides the proceeding to operation of the airport's functional element pavement in accordance with the technical condition. The airport pavement deterioration degree is estimated based on accepted indicators calculated with the use of selected weights verified according to the experts' method. In order to reliably predict the condition of airport pavements, it is necessary to use an objective, repetitive assessment system. Designing of an IT support system for managing pavements of the airport's functional element should be preceded by the analysis of processes, which operate within the organisational unit. The deterioration assessment of a single slab often requires a different approach than the analysis of the airport's functional element. Therefore, it would be advisable to select proper parameters and indicators characterising the technical condition and the slab deterioration degree. Currently, while estimating the assessment criteria of the technical condition, a verified base of data, which was obtained during testing of the functional elements' pavements of civil airports, is used. While calculating the criteria, it is important to focus on parameters characterising the deterioration degree of airport pavements, both of civil and military facilities; therefore, it is important to diagnose these airport pavements within the framework of current five-year inspections, and to carry out inspections in order to inventory damage and repairs within the annual intervals.

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