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M&R STRATEGIES BASED ON PCI EVALUATIONS IN THE FRAMEWORK OF A PAVEMENT MANAGEMENT PROGRAM WITHIN A MILITARY AIRPORT NETWORK

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Abstract: The main objective of this work is to present analysis results from airport pavement assessments within the framework of a military Airport Pavement Management System (PMS) being developed by the Diretoria de Infraestrutura da Aeronáutica (DIRINFRA). The monitored network comprises 18 airports with pavements managed by the Brazilian Air Force, evaluated between 2018 and 2021, accounting for approximately 4.2 million square meters of surface distributed throughout the national territory. The analyzes considered data from evaluations carried out using the Pavement Condition Index (PCI) method, performance forecast, regional costs per intervention adopted and investment policies for proposing Maintenance and Rehabilitation (M&R) services. Indicators were developed to support decision-making for the monitored airport network and scenario projections were carried out according to strategies that varied between "doing nothing", annual budget restriction and "ideal interventions" in terms of performance for an analysis period of 15 years. The results are presented synthetically in the form of multiannual intervention plans, with the financial and operational impacts resulting from the adoption of each strategy. The importance of adopting an PMS at the airport network level is highlighted, especially by central entities managing airport infrastructure, as found in the scope of Public Administration.
Keywords: Airport Pavement Management System (SPGA); Airport infrastructure; PCI.

INTRODUCTION

The natural deterioration of airport pavements on runways (RWY), taxiways (TWY) and aircraft aprons (AP) is mainly due to the effects of traffic and climate (SHAHIN, 2005). Therefore, naturally its rolling quality in terms of comfort, tire-to-road grip and safety, translated into a serviceability index, tends to decrease over time, as observed in experiments in the 1960s carried out on experimental tracks by AASHO. The variation in the level of usefulness of the pavement is conceptualized as the performance. (Bernucci et al., 2011).

In view of the large amount of airport pavements present in military air bases (CORDOVIL, 2010) and the deterioration inherent in the use of these structures, it is essential to systematize the diagnosis, monitoring and control of their functional and structural qualities through a Airport PMS (HAAS, HUDSON and ZANIEWSKI, 1994; SHAHIN, 2006).

The use of the Pavement Condition Index – PCI method (ASTM, 2020) to determine the functional quality of the surfaces of airport pavements is an important tool to support an efficient PMS (ANAC, 2017). The PCI consists of a practical method for objectively determining a score from 0 to 100, translated as a usefulness indicator widely used internationally and nationally (SHAHIN, 2005; FAA, 2014; ANAC, 2017). Objectively, the method considers pavement surface defects in terms of severity and density in a sample evaluation.

Allied to analysis of Maintenance & Rehabilitation (M&R) strategies, a PMS must not only provide a diagnosis of the situations of airport pavements, but also predict their performance, enabling the generation of decision-making scenarios, taking into account the availability of future budgetary resources (BATISTA, 2015).

This paper presents the results of applying a decision support method based on PCI assessments at 18 airports between 2018 and 2021, pavement performance forecast models, assumptions of M&R strategies and different management strategies at the level of network of airport pavements, culminating in scenarios between "doing nothing" and "ideal interventions". The purpose of such analyzes is to mature the discussion on an effective PMS within the scope of public administration, especially in the sphere of military sites, of peculiarity due to territorial scope and possible distant presences, making it difficult for the private sector to participate (BRASIL, 2018).

MATERIALS AND METHODOLOGY

In the PCI method, airport pavements are divided into Branches (BR) that represent parts of the pavement network with different functions and constructive characteristics, such as RWY, TWY and PA. BRs are divided into Sections (SC) that have different characteristics of traffic, load intensity, constructive characteristics and history of interventions. The SCs are composed of Sample Units (SU) that have standardized dimensions (ASTM, 2020). As this is a sampling method, part of the SUs are evaluated. The number of defects and their severity on the evaluated SU surfaces are reported on sheets and used to calculate the numerical value of the PCI, which varies from 0 to 100, with 0 representing the worst possible condition and 100 the best.

The PCI method is not intended to determine the structural capacity of the pavement, nor to provide direct measurements of tire-pavement friction or roughness. However, it is directly related to needs for M&R services and indirectly to structural integrity and indicators of pavement functional conditions (SHAHIN, 2005).

Assessments using the PCI method were carried out at 18 airports, of which 14 are exclusively for military use and four are shared with civil use. Airports have a reference code ranging from 3C to 4E, according to the ICAO reference (ANAC, 2021). It is estimated that the network has five million square meters, of which around 800 thousand are in airports not yet evaluated (16 airports). The Figure 1 presents a distribution of the network throughout the national territory.

Data from assessments carried out at the 18 airports between 2018 and 2021 were compiled in a database structured in electronic spreadsheets. A total of 504 SC were assessed, of which 206 in RWY, 145 in TWY and 153 AP. Information on the type of coating, SC area, types of defects found by SC and respective PCI values were added. An example of compiled data is shown in Table 1.

Based on the records available at the former Diretoria de Engenharia da Aeronáutica (DIRENG), Batista (2015) developed models calibrated by regressions to predict the degradation of the pavements of some Air Bases in terms of PCI over time, according to mathematical equation 1.

$$PCI = \beta_0 + \beta_1 \cdot I + \beta_2 \cdot I^2 + \cdots + \beta_x \cdot I^x \quad (1)$$

where β_x are the model coefficients and I is the age of the pavement, in years.

The models consider traffic and climate effects intrinsically, since they were calibrated and validated for the conditions they were subjected to. The airports in the cited study are located between the Northeast, Southeast and South regions of the country.

The Table 2 presents the values of the coefficients of some of the developed models, the determination coefficients (R^2) and the number of observations used in the calibration (n), according to the study by Batista (2015), by airport presented by its ICAO code.

The Figure 2 contains a graphical representation of the PCI prediction models.

Due to the proximity of the results in PCI quality ranges, it was decided to use the general model of performance at airports where there was no specific calibrated and validated model. It is known that this attitude can give rise to inaccurate results, but capable

Figure 1: Geographic location of evaluated and non-evaluated airports (Author, 2022).

Homogeneous Section	coating type	Area (m²)	Defect	PCI
PP1C	Rigid	3,000	Joint Seal Damage	78
PP1C	Rigid	3,000	Spalling-corner	78
PP2C	Rigid	3,000	Joint Seal Damage	76
PP2C	Rigid	3,000	Transverse, longitudinal and diagonal cracks	76
PP2C	Rigid	3,000	Scaling/Map Crack/Crazing	76
PP2C	Rigid	3,000	shrinkage cracks	76
PP-SWY11	Flexible	15,750	Raveling	58

Table 1: Example of evaluation data compiled by Homogeneous Section (Author, 2022).

Coefficient	SBSC	SBAN	SBBR	SBRF	SBCO	SBGW	GENERAL
$\beta 0$	100	100	100	100	100	100	100
$\beta 1$	-4,221	-1.0118	-4.9336	-10,895	-3.4473	-9.1921	-4.5705
$\beta 2$	0.3582	-0.5207	0.3182	0.9329	0.0058	0.9265	0.2141
$\beta 3$	-0.0169	0.039	-0.0122	-0.0278	0	-0.0319	-0.0071
$\beta 4$	0	-0.0009	0	0	0	0	0
R^2	0.85	0.84	0.85	0.89	0.98	0.79	0.82
n	29	50	17	15	8	10	128

Table 2: Examples of PCI model coefficients as a function of the age of flexible pavements in Air Bases (BATISTA, 2015).

of guiding M&R strategies, since the method chosen for adopting the service strategy was based not only on the PCI, but also on the types of defects found by SC, as explained later.

Cordovil (2010) studied the application of a PMS in air bases in the southern region of the country. The author elaborated categories for M&R services according to the pavement surface (rigid or flexible), types of defects and PCI ranges. Based on this study, PCI increment values were stipulated after M&R interventions by intervention zone. These values were determined based on the experience of engineers belonging to the DIRINFRA staff, subject to future calibrations. The results are shown in table 3.

Costs are calculated according to the estimated percentage of the SC area that will undergo the chosen M&R service. It is to be expected that the percentage of area will increase, or the service will change, according to the severity of the defect present in the pavement and with the PCI decrease verified in the evaluation. Thus, it is expected that longitudinal cracks associated with a high PCI will be directed to a crack sealing service in a small area of the section (*a.g.* 10%), whereas "alligator crack" and a low PCI already give rise to needs of overlay. The percentage of area to undergo intervention was given the name of Need Factor (Fn). This method intrinsically considers, through the PCI, the defect density by SC.

To achieve such results, compositions of the services presented in theTable 4 had their costs parameterized in BRL/m². For this, it was assumed, for example, that the overlay service would consist of milling 5 cm of the existing coating, mechanical sweeping of the area, application of a primer layer, transport, supply and application of a new layer of Hot Mix Asphalt (HMA) of 5 cm. This method was applied to all services considered in the study (partially demonstrated in the Table 4). In addition, all services or materials had their costs or cost compositions extracted from official government sources (BRASIL, 2013). BDI and costs of mobilization and demobilization, construction site and central administration were incorporated, in accordance with the ranges recommended by the Tribunal de Contas da União for road works (TCU, 2013).

Considering a trigger to trigger interventions at a given airport, analyzes were carried out that culminated in intervention scenarios with specific M&R strategies. The criterion for triggering the intervention in an ideal scenario was reaching an average PCI of 70 per BR. This value was chosen based on the theoretical basis presented by ANAC (2017), referring to the critical maintenance value.

The Table 5 presents an example of the cost of the overlay service, in reais per square meter, for the state of Rio Grande do Sul. The estimate is intended to support the cost analysis of the M&R strategy adopted for each SC with defects and PCI condition determined.

An inflation rate of annual 6,5% (FGV, 2021), referring to the average value of the historical series between 2006 and 2020 (15 years), was incorporated into the costs for the entire 15-year period of analysis, in order to characterize the inflationary effects on the need for budgetary resources.

In addition to calculating performance and costs individually for each pavement network per airport, intervention schedules were prepared considering the entire network of 18 airports evaluated and a planning horizon of 15 years (2022 – 2036). Thus, it was possible to determine an estimate of the annual cost of interventions in the scenarios elaborated in scale of the airport network. A scenario was also studied considering a specific budget restriction, or spending ceiling, where

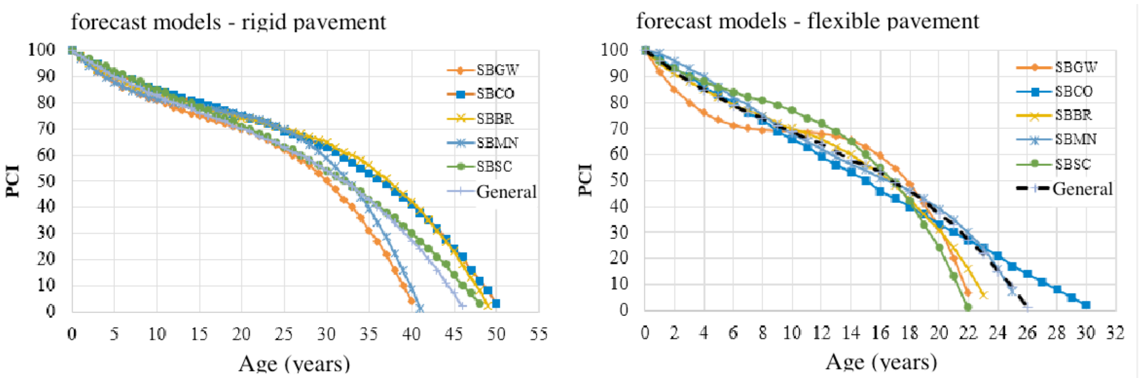


Figure 2: Graphic representation of the models developed by Batista (2015).

		Flexible		Rigid	
PCI range	**Intervention Zone**	**PCI increment**	**Intervention**	**PCI increment**	**Intervention**
71 - 100	Conservation	10	Crack Sealing	10	Crack Sealing
			Patching, 5sf		Sealing Joints
			Rejuvenation		Patching < 5sf
26 - 70	Rehabilitaion (Repair)	25	Crack Sealing	25	Crack Sealing
					Sealing Joints
			Patching Utility Cut		Patching > 5sf
		40	Overlay	40	Slab Replacement
0 - 25	Reconstruction	Becomes 100	Reconstruction	Becomes 100	Reconstruction

Table 3: Matrix of proposed interventions (DIRINFRA, 2022).

Defect	**Measurement**	**Condition**									
		100 - 86		**85 - 71**		**70 - 56**		**55 - 41**		**40 - 26**	
		Excellent		**Very Good**		**Good**		**Regular**		**Poor**	
		Intervention	**Fn**	**Intervention**	**Fn**	**Intervention**	**Fn**	**Intervention**	**Fn**	**Intervention**	**Fn**
Longitudinal & Transverse Cracking	m	Crack Sealing	0,10	Crack Sealing	0,15	Patching / Utility Cut	0,15	Overlay	1,00	Overlay	1,00
Block Cracking	m	Crack Sealing	0,10	Crack Sealing	0,15	Patching / Utility Cut	0,15	Overlay	1,00	Overlay	1,00
Alligator Cracking	m²	Patching, 5sf	0,05	Patching, 5sf	0,10	Patching / Utility Cut	0,15	Overlay	1,00	Overlay	1,00
Joint Reflection Cracking	m	Crack Sealing	0,05	Crack Sealing	0,10	Patching / Utility Cut	0,15	Overlay	1,00	Overlay	1,00
Depression	m²	Patching, 5sf	0,05	Patching, 5sf	0,10	Patching / Utility Cut	0,15	Patching / Utility Cut	0,20	Overlay	1,00
Corrugation	m²	Patching, 5sf	0,05	Patching, 5sf	0,10	Patching / Utility Cut	0,15	Patching / Utility Cut	0,20	Overlay	1,00
Slippage Cracking	m²	Patching, 5sf	0,05	Patching, 5sf	0,10	Patching / Utility Cut	0,15	Patching / Utility Cut	0,20	Overlay	1,00
Raveling/ Weathering	m²	Rejuvenation	0,75	Rejuvenation	1,00	Overlay	0,75	Overlay	1,00	Overlay	1,00
Patching	m²	Patching, 5sf	0,05	Patching, 5sf	0,10	Patching / Utility Cut	0,15	Patching / Utility Cut	0,20	Overlay	1,00
Rutting	m²	Patching, 5sf	0,05	Patching, 5sf	0,10	Patching / Utility Cut	0,15	Patching / Utility Cut	0,20	Overlay	1,00

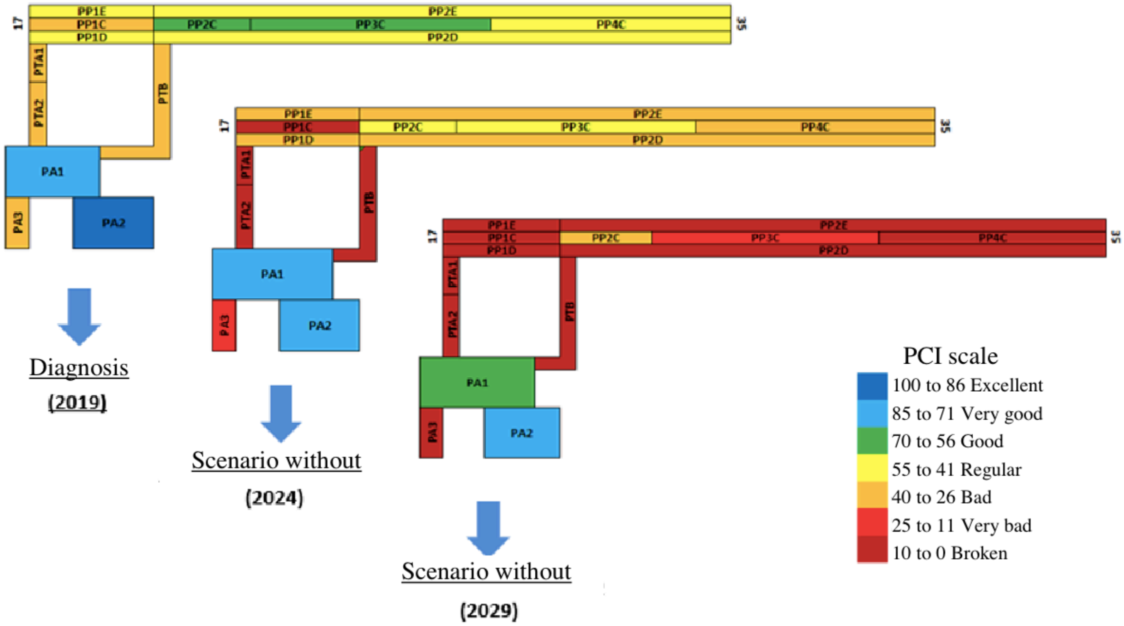
Swell	m²	Patching, 5sf	0,05	Patching, 5sf	0,10	Patching / Utility Cut	0,15	Patching / Utility Cut	0,20	Overlay	1,00
Polished Aggregate	m²	Nothing to do	-	Nothing to do	-	Overlay	0,75	Overlay	1,00	Overlay	1,00
Shoving from PCC	m²	Patching, 5sf	0,05	Patching, 5sf	0,10	Patching / Utility Cut	0,15	Patching / Utility Cut	0,20	Overlay	1,00
Jet Blast	m²	Rejuvenation	0,75	Rejuvenation	1,00	Overlay	0,75	Overlay	1,00	Overlay	1,00
Bleeding	m²	Nothing to do	-	Nothing to do	-	Overlay	0,75	Overlay	1,00	Overlay	1,00
Oil Spillage	m²	Nothing to do	-	Nothing to do	-	Overlay	0,75	Overlay	1,00	Overlay	1,00

Table 4: Need Factors for M&R services on flexible pavement (DIRINFRA, 2022).

Service	Service	Und.	Source	Code	state	Date	Cost	Und. consumed per m²	BDI x Qty x C. Unit	Cost (BRL/ m²)
resurfacing	Milling (5 cm)	m²	SINAPI	96001	LOL	Dec/19	4.59	1	5.55	75.79
	Mechanized loading and unloading of milled material	m³	SINAPI	72898	LOL	Dec/19	3.17	0.05	0.19	
	Transport of milled material (5cm, 2.4 ton/m³, DMT = 15 km)	t.km	SICRO 3	5914622	LOL	Dec/19	1.02	1.8	2.22	
	Printing with CM-30	m²	SICRO 3	4011351	LOL	Jul/19	0.24	1	0.29	
	HMA transport (5 cm, 2.4 ton/m³, DMT = 15 km)	t.km	SICRO 3	5914613	LOL	Jul/19	0.54	1.8	1.18	
	Execution of HMA (5 cm)	m³	SINAPI	95995	LOL	Dec/19	1097.09	0.05	66.36	

Table 5: Estimates of resurfacing costs per m² of recovered pavement (DIRINFRA, 2022).

Figure 3: Image of the airport evaluated and included in the analyzes of the COMAER PMS.



Cost of intervening in the last year only: BRL 33.5 Mi

Figure 4: Performance projections and estimated costs (DIRINFRA Technical Report No. 02/EPGA/2022).

the airports that presented the worst PCI conditions observed in addition to strategic criteria were selected as a priority.

RESULTS AND ANALYSIS

Figure 3 contains a satellite image of one of the evaluated airports, located in the state of São Paulo, and illustration of examples of defects found in its pavements (corner crack of low severity in rigid pavement in AP and disintegration/aging in high severity on flexible RWY pavement).

Several scenarios were developed containing projections for the strategies adopted, according to the Annual Report on Pavement Management at Military Airports (RT nº 02/EPGA/2022) developed by DIRINFRA (2022).

SCENARIO 1 – NO INTERVENTIONS ("DO NOTHING")

The Figure 4 presents, in summary, the result of an assessment carried out in 2019 and future projections for the years 2024 and 2029 at the airport presented in the Figure 3, with presentation of the total accumulated cost for the period of analysis corresponding to the "do nothing" scenario.

In this vein, the individual projections developed for each airport were brought together in a general behavior of the airport network, as shown in the Figure 5. The indicators are: average PCI values of the network, average of the highest PCI values, average of the lowest PCI values, percentage of pavements in need of reconstruction, in need of rehabilitation and conservation.

It appears that the models adopted predict a continuous reduction in service levels for the entire analysis period, corroborating the results found by Henrique and Motta (2013). next 15 years, jumping from values of 23% in 2022 to 50% in 2036.

The results of the financial analysis point to estimates of around BRL 1.6 billion in accumulated costs in the year 2036 (BRL 632 million in terms of values in 2022). The Figure 6 presents the evolution of the accumulated cost between 2022 and 2036.

SCENARIO 2 - INTERVENTIONS WITH BUDGET CONSTRAINTS

The Figure 7 presents, in summary, the performance result of the pavements with the adoption of a strategy with budget restrictions, or spending ceiling, annual around BRL 25 million for the entire network of 18 airports, with proposed interventions in 2031 (RWY) on the site of the Figure 3.

In this case, due to the strategic prioritization between airports, it was decided to propose intervention on the pavements in question only in 2031, as there were only resources to recover the runway (RWY), estimated at BRL 25.4 million, in that year. The Figure 8 presents the forecast of performance of the pavements of the airport network for the scenario of budget constraint.

Examining the constant network behavior in figure 8, it is observed that there was stabilization of the average PCI index with a value around 60 (good) throughout the analysis period, as well as there was practically no increase in the areas to be rebuilt, configuring a situation with operational conditions superior to those of Scenario 1, although there is still a predominance of need for heavy interventions, such as rehabilitation services (63% in 2036).

The absence of monetary corrections to the spending ceiling in this scenario was made explicit in order to emphasize the importance with which M&R planning in infrastructures, which are inherently large, are accompanied by economic and financial analyses. The Figure 9 contains estimates of annual investment costs in this scenario.

In terms of values in 2022, the total

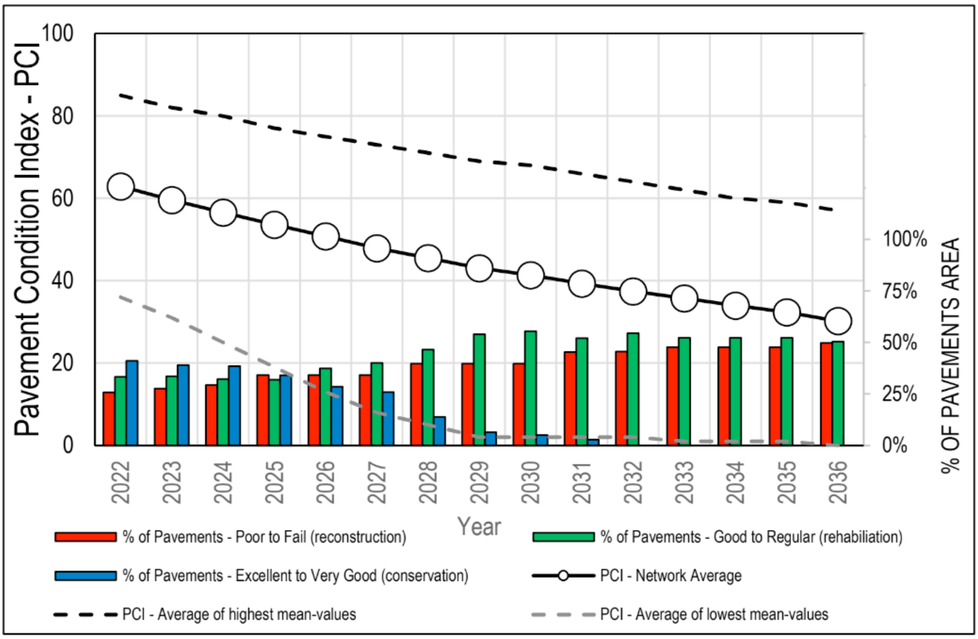


Figure 5: Evolution of performance indicators, in terms of average PCI of the pavements of the evaluated airport network.

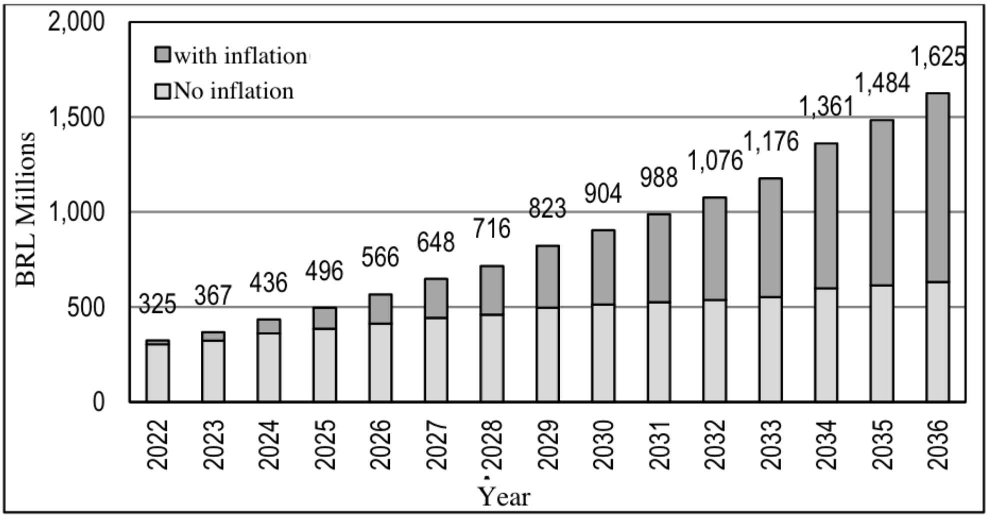


Figure 6: Evolution of the accumulated cost, with average inflation of annual 6,5% for the scenario without interventions in the airport pavements of the evaluated network.

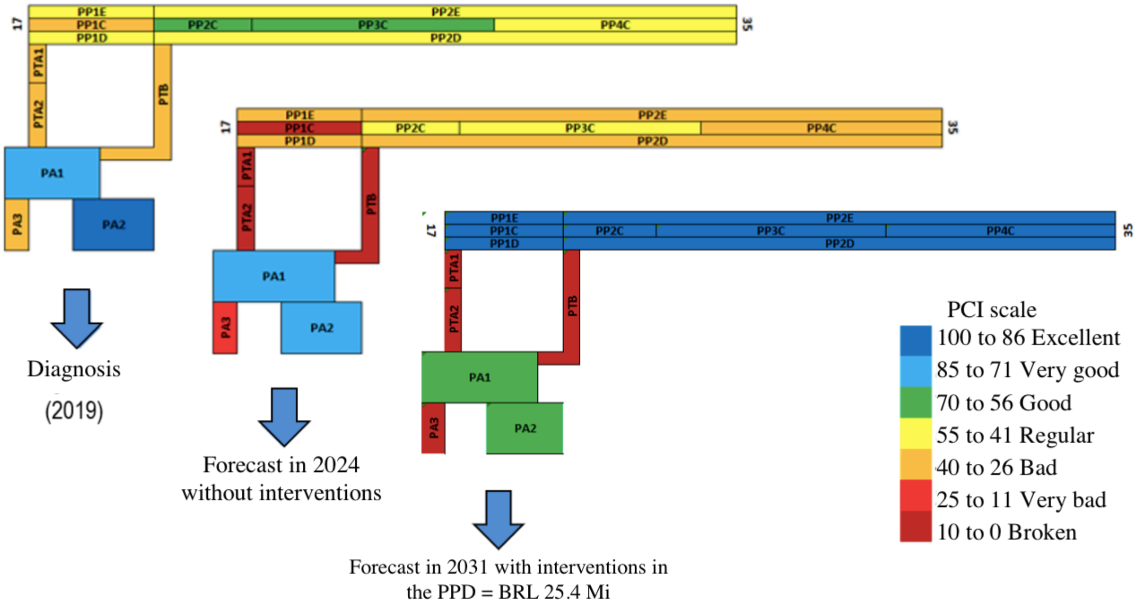


Figure 7: Pavement performance forecast if interventions are carried out in 2031 at RWY.

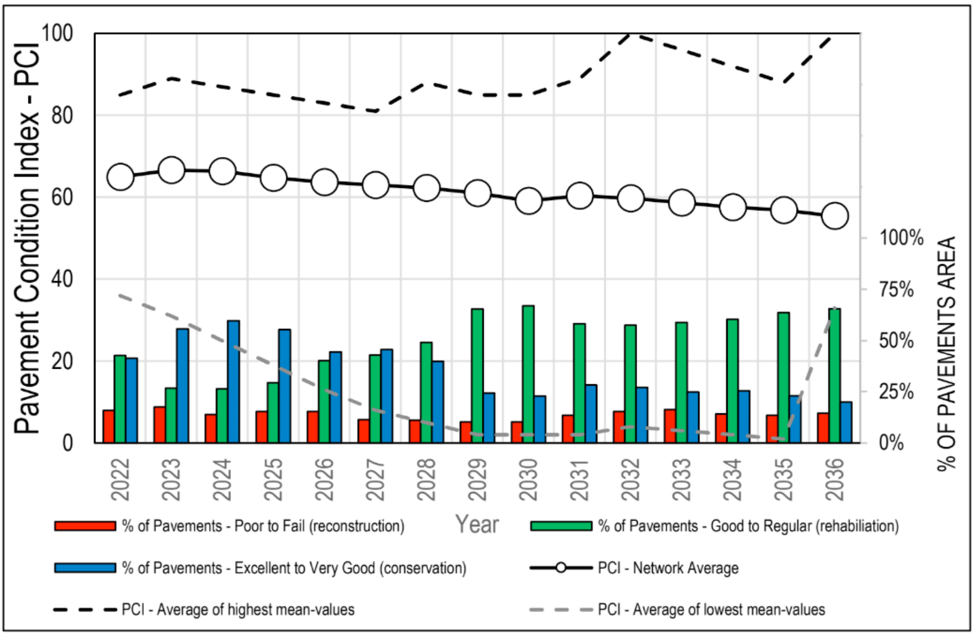


Figure 8: Network performance forecast for the annual budget constraint scenario.

investments planned for the entire analysis period is BRL 237 million, that is, lower than the alternative of delaying interventions until the last year (Scenario 1).

SCENARIO 3 - INTERVENTIONS WITHOUT BUDGET RESTRICTIONS

The Figure 10 represents, in summary, the plan adopted in this scenario, contemplating the diagnosis of the airfield pavements carried out in 2019 and the gains resulting from the works planned for the years 2026, in which it would be possible to carry out interventions in all sections of pavements, and in 2032, where only RWY and TWY would need interventions.

The same approach was applied to the other airports in the network, making it possible to observe their behavior through the Figure 11.

Examining the evolution of network performance, an accelerated decay of reconstruction needs is observed. There was also a forecast of a significant reduction in the number of pavements requiring rehabilitation measures. The pressing need for rehabilitation and reconstruction services in 2022 impacts on the need for high resources in the first years of the proposed plan. As these services are executed, a relative stabilization and seasonality of the expenditure of resources can be noticed, as visually verified in the costs without inflation in the Figure 12.

A total of BRL 565 million (values in 2022) of investments was estimated for the entire analysis period in this scenario. This alternative proves to be financially advantageous when compared to Scenario 1, of doing nothing, where an accumulated cost of BRL 632 million is found in 2036 (in 2022 values). In addition, this scenario strategy also raises the operational performance standards of airport pavements above Scenario 2.

CONCLUSIONS

The PCI assessments carried out between 2018 and 2021 at 18 airports recorded the presence of distresses on the surface of airport pavements managed by the Brazilian Air Force. The results were compiled in a database and analyzed in assumptions within the scope of M&R strategies, with the demonstration of scenarios between "doing nothing", annual spending cap limited to BRL 25 million and "ideal interventions" in operational aspects.

Despite lacking improvements in the collection of evaluation data, such as macrotexture, friction or structural evaluations (destructive or non-destructive), the systematization of surveys through the PCI method, combined with M&R strategies, in addition to cost estimates in intervention plan, proved to be effective in permeating and spreading the organizational culture of airport pavement management.

Despite not having the objective of specifying estimates that support the elaboration of budgets in engineering projects, for example, nor to determine structural indicators of the pavements, the results presented here guide the decision making through parametric analyzes of the surface conditions of pavements at different airports, making it possible to direct attention to more deficient infrastructures.

It is expected that, combined with data from surveys on macrotexture, friction and non-destructive structural tests (Falling Weight Deflectometer), in the current collection phase, data management will enable the formation of more holistic indicators and closer to reality. In addition, the calibration and validation of new PCI performance models, the assumptions for choosing M&R strategies and the cost compositions used in each service are studied.

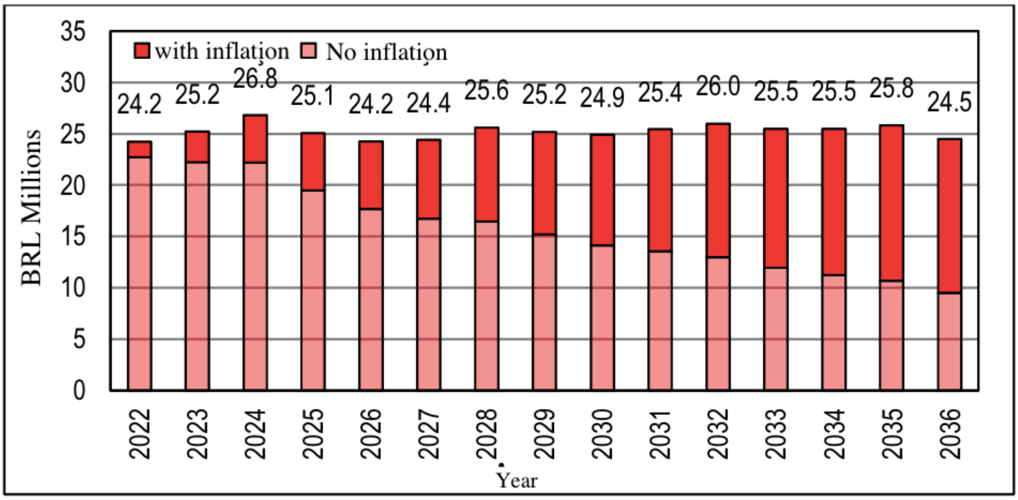


Figure 9: Investments for the scenario with fixed annual budget constraint.

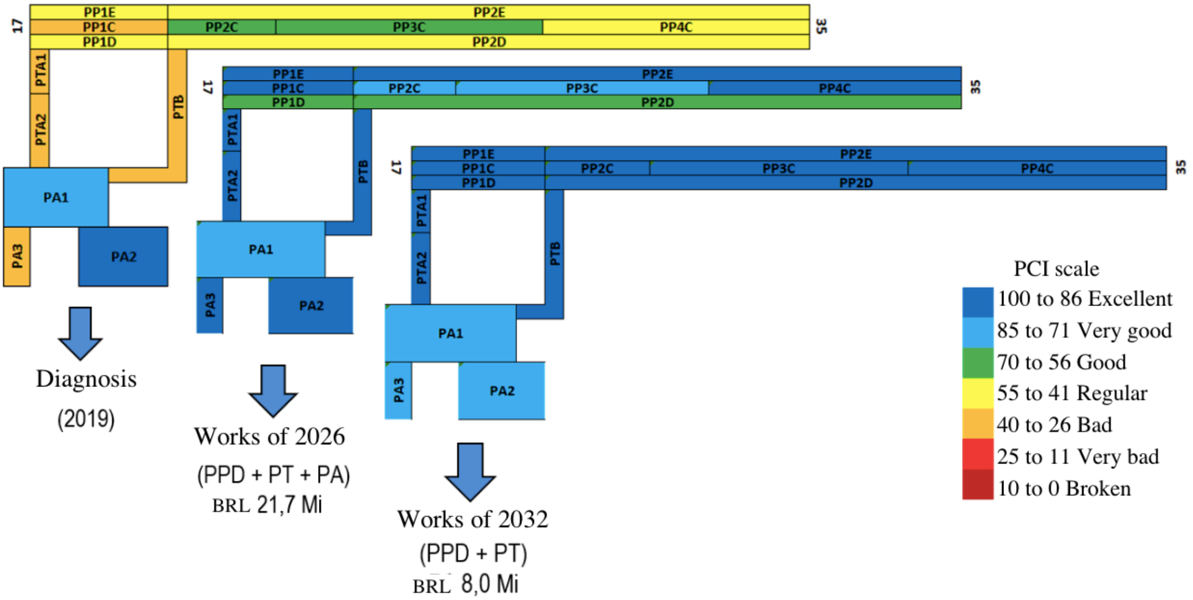


Figure 10: Multi-year plan for the aerodrome evaluated in 2019 considering ideal interventions.

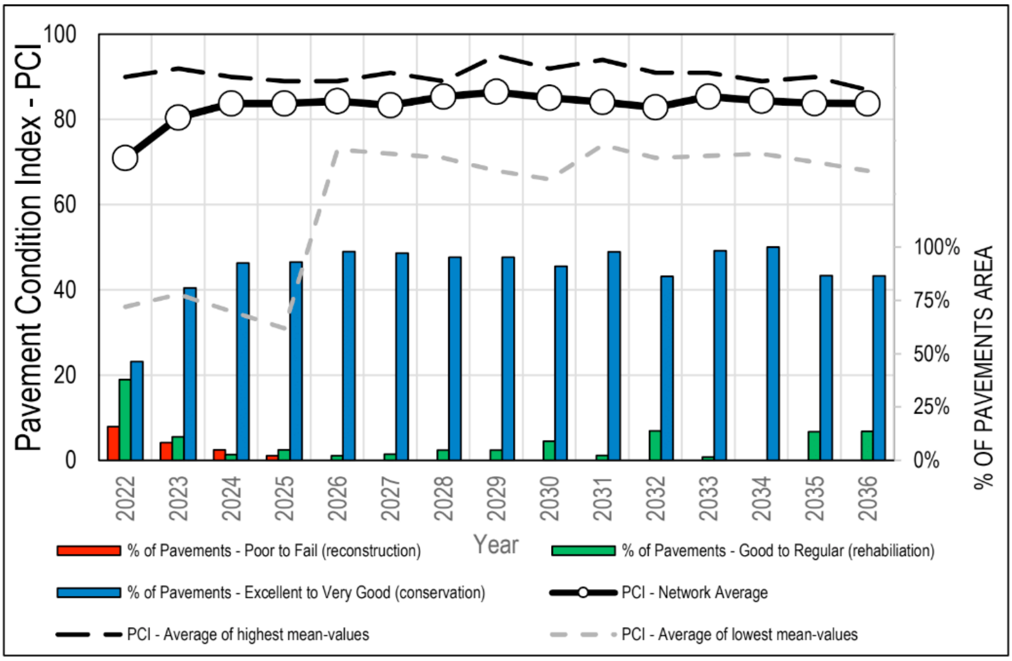


Figure 11: Network behavior for the scenario without budget constraints.

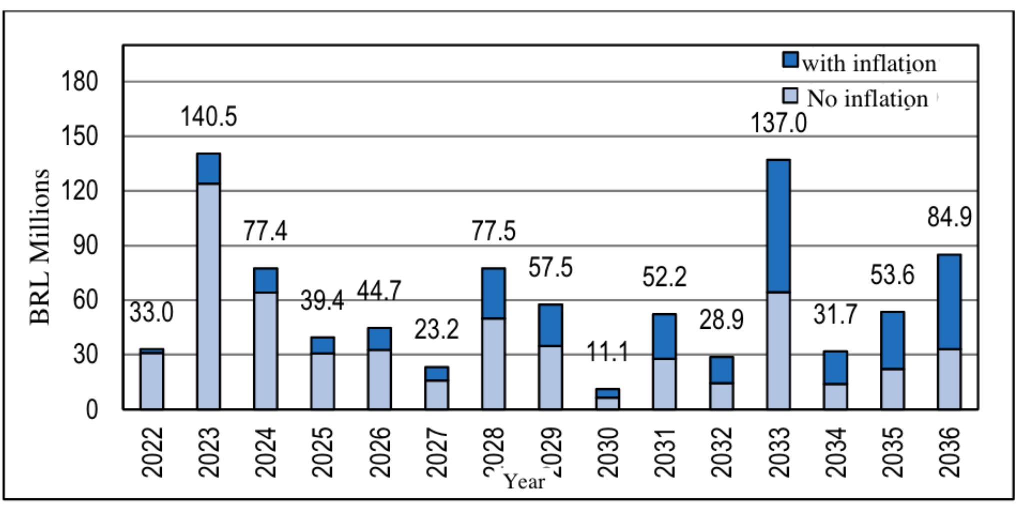


Figure 12: Investments for the scenario without budget restriction.

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