BENEFITS OF A PAVEMENT MANAGEMENT PROGRAM WITH PCI-BASED ANALYSES WITHIN MILITARY AIRPORTS

Anthony Belo Vasconcelos Santos[1], Ricardo Miranda Cordovil [2], Rafaela Malafaia Nassif Dagher [3], Hudson Gomes de Moraes [4].
Diretoria de Infraestrutura da Aeronáutica (DIRINFRA), Comando da Aeronáutica.

Corresponding author e-mail address: anthonyabvs@fab.mil.br [1]; cordovilrmc@fab.mil.br [2]; rafaelarmnd@fab.mil.br [3]; moraeshgm@fab.mil.br [4]

PAPER ID: SIT142

ABSTRACT

The main objective of this paper is to present analyses of a Pavement Management Program (PMP) within airside pavements managed by the Brazilian Air Force. The assessed pavement network sums up 4.2 million square meters of pavement surfaces along territory of Brazil. Pavement data comprehends Pavement Condition Index (PCI) evaluations. Analyses tools incorporate PCI prediction models, premises for choosing Maintenance and Repair (M&R) services, estimated service costs and network level analyses. PCI-based indicators were generated within the assessed pavement network. Projections were developed among strategies of "do-nothing", budget-restriction, and ideal performance scenarios for a time horizon of 15 years. Results are presented summarized in multi-annual interventions plans, highlighting financial and pavement performance impacts as consequence of each strategy presented by each scenario. It is emphasized a PMP adoption on an airports network level, specially by central managers responsible for managing infrastructures as a central entity, as commonly found on public administration scale.

Keywords: Airport Pavement Management Program (PMP); Pavement Management System (PMS); Pavement Condition Index (PCI).

1. INTRODUCTION

It is expected that pavement surface condition on runways, taxiways and aprons deteriorate due to traffic and climate actions over time. Therefore, pavement condition indexes, mainly used upon engineering assessment methods, are broadly used by authorities for pavement management purposes (Shahin, 2005; Bernucci *et al.*, 2022).

Main airports infrastructures cover great surface areas. Therefore, deterioration of these areas must be accounted upon budget planning by airport infrastructure managers. Hence, it is pressing the need for diagnosis, monitoring and rational intervention on surface and infrastructures related to operational airport pavements on airside in a systematic Pavement Management Program (PMP), also commonly referred as Pavement Management System (PMS) (Haas, Hudson and Zaniewski, 1994; Shahin, 2005).

The use of the Pavement Condition Index – PCI (ASTM, 2020) to determinate the functional quality on airside pavement surfaces is an important tool to support an efficient PMP (USAF, 2017; ANAC, 2017). The PCI consists of a practical method to determine, in an objective way, a condition score from 0 to 100, giving a rational and objective basis for determining M&R needs (Shahin, 2005; FAA, 2014; ANAC, 2017).

Combined with Maintenance and Repair (M&R) premises and analysis, a PMP should not only give an actual diagnostic of present pavement conditions but can also be used to predict pavement performance and forecast budget needs.

This paper presents results of an engineered assessment method for supporting decision-making and airport authorities over M&R strategies using PCI as main index. Its main goal is to give authorities a criterion for directing M&R services to better efficiency practices, answering main questions as *where*, *when* and *how much*. It has proven to be an efficient tool not only for that aim, as well as to spread PMP culture.

Analyses were conducted within data from PCI evaluations on 18 airports between 2018 and 2021, accounting for more than 4,2 million square meters of pavement surfaces. The airports network evaluated is scattered among all Brazilian territory. PCI evaluations were combined with PCI predicting models, M&R strategies premises and estimated costs of interventions. Results are presented on three scenarios: do-nothing; annual budget restriction; and ideal performance within no budget restriction. Analyses are conducted for a 15-year horizon of planning.

Results also conclude for an alternative way of processing data from different airports within a network managed by a single main manager, such as found on public-levels administration.

2. METHOD

Within PCI evaluations, airport pavements are divided into Branches as a single entity according to its function (*a.g.*. runways, taxiways and aprons). Branches are divided into Sections according to surface conditions, service history and function. Each Section is divided into Sample Units where pavement surface distresses are noted by quantity, type and severity on a sample method that determines the number of inspected Sample Units. The distress data is used to calculate the PCI for each Sample Unit inspected, and, therefore for Sections (ASTM, 2020).

Although PCI evaluation does not have the purpose of structural evaluation (capacity), nor to give direct roughness and friction indications, it relates directly with M&R needs and indirectly with structural and functional integrity (Shahin, 2005).

This paper presents PCI evaluations conducted on 18 airports, from where 14 belonged to exclusive military facilities and 4 within airports that also have pavement managed by civil authorities. The airports network has 3C and 4E categories according to ICAO (ANAC, 2021). It is estimated that the whole pavement inventory, which comprehends airports that have not been evaluated yet, accounts for 5 million square meters of pavement surface, from where 800,000 m² were not inspected until the end of 2021 (14 shared civil-military and 2 only military airports). Figure 1 shows distribution of the airfields on Brazil territory.

Figure 1. Geographical locations of inspected and not inspected airports.

Pavement data from the inspected pavements surfaces were compiled within a structured database on Excel sheets. The entire evaluated pavements inventorying comprehends 504 Sections, which 206 are on runways, 145 on taxiways and 153 on aprons. Information about pavement surface type (*i.e.* Asphalt Concrete – AC or jointed Portland Cement Concrete - PCC), distresses, PCI and Section area were compiled in a single airport-database for each airport.

Data of PCI evaluations among military airfields were used by Batista (2015) for developing specific PCI prediction models. These models were calibrated by polynomial regressions and uses time, in years (I), as main variable. Other parameters such as climate and traffic effects were incorporated intrinsically, since pavements were exposed to degradation inherent to those effects over the years.

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

Where β_x are calibration coefficients. The airfields used by Batista (2015) to calibrate and validate these models are scattered along Northeast, Southeast and South regions of Brazil. Table 1 shows models coefficients as well as the coefficient of determination (R^2) for validated models, showed by each ICAO code. A "general" prediction model was also validated, obtained from a calibration from all combined data. Figure 2 shows a chart representation for the presented models.

Table 1. Models used in analyses over pavement PCI performance prediction. Source: Batista (2015).

Coefficient	SBSC	SBAN	SBBR	SBRF	SBCO	SBGW	GERAL
β_0	100	100	100	100	100	100	100
β_1	-4,221	-1,0118	-4,9336	-10,895	-3,4473	-9,1921	-4,5705
β_2	0,3582	-0,5207	0,3182	0,9329	0,0058	0,9265	0,2141
β_3	-0,0169	0,039	-0,0122	-0,0278	0	-0,0319	-0,0071
β_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

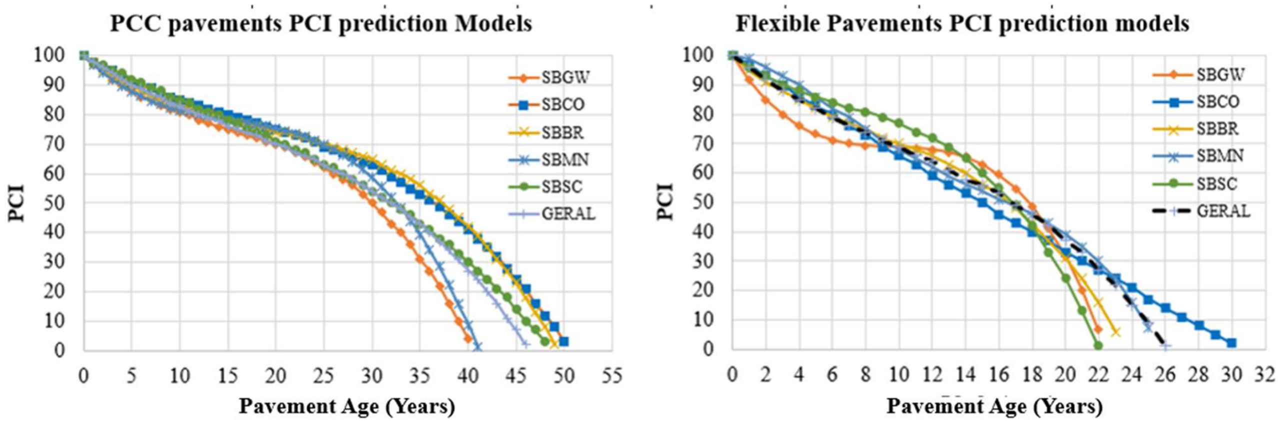

Figure 2. Chart representation from calibrated and validated models for AC and PCC pavements. Source: Batista (2015).

For airfields that do not have a calibrated and validated model, it was chosen to apply the general model. It is known that this approach might cause impact on data reliability, but the proximity between curves and results presented in Figure 2 corroborate for reliable data application in a network level analyses.

Cordovil (2010) studied a PMP practical applicability on military airfields in South Region of Brazil. The author elaborated categories for M&R services according to pavement surface characteristics (CA or PCC) and range of PCI. From this study, it was estimated PCI increase after M&R services per "intervention zones". These values were estimated based on an empirical database from expertise of engineers and previous experiences within engineering assessment. The values for PCI increase per intervention zone and respective M&R service are shown in Table 2.

Table 2. Intervention Zone for each PCI interval expected PCI increase and M&R associated. Source: authors.

PCI interval	Intervention Zone	Expected PCI Increase	M&R Service
71 - 100	Localized (Preventive Maintenance)	10	Crack Sealing
			Partial-Depth Patching
			Rejuvenation
26 - 70	Global (Repair)	25	Crack Sealing
			Full-Depth Patching
		40	Overlay
0 - 25	Major (Reconstruction)	100	Reconstruction

Service costs are calculated according to estimated Section area that will receive the suggested M&R service. This approach considers the distress types and PCI values. It is expected that the repaired area increases as distress severities get worse, or even implying in change of scope of the service if too deteriorated.

To better exemplify this approach, it is expected that transverse and longitudinal cracks associated with higher PCI, as an excellent condition (86 – 100), would imply in crack sealing in 10% of Section surface area as a M&R service choice, whereas the same distress type associated with a fair PCI condition would imply the same M&R solution in 20% of Section area. Similarly, the same distress associated with a very poor to serious PCI Section (10 – 40), which is a result of greater severities or combination with other distress types, would imply in overlay or reconstruction as M&R services.

Those values were empirically calibrated and are being object of current monitoring at on-going studies. It is emphasized that this approach has been used for network level analyses in PMP purposes, not being used or recommended for project level analyses.

In addition to M&R service selection premises, costs are estimated by service components within M&R techniques. These costs, elaborated for each M&R service, are parameterized on R$/m² for every airfield within the analyzed network. To accomplish that, services patterns are incorporated for component consumption, as assuming a 5 cm milling depth for every milling service, or, similarly, a 2,4 ton/m³ as Hot Mixture Asphalt (HMA) specific gravity.

Components and compositions costs are extracted from official database as found in SINAPI and SICRO 3 cost systems (BRAZIL, 2013). Mobilization, construction site and indirect costs (overhead, equipment and labor burden) are also considered following interval recommendations from the *Tribunal de Contas da União* (official governmental entity).

To accomplish the pavement intervention planning within network level analyses, a trigger for M&R intervention is needed. For solving this problem, it was used criterion defined by ANAC (2017), as recommended by Shahin (2005), where 41 < PCI < 70 would imply on repair techniques. Using this approach, PCI average were calculated for every airfield Branch within the airfields network. The average is chosen for best sampling the great amount of data from 18 different airfields.

Different scenarios were created using the presented approaches and premises within 15 years as time horizon (2022 – 2036). A do-nothing scenario was generated for comparison purpose. A budget-restriction scenario was created, assuming a R$ 25 million per year as budget constraint for the assessed network. An ideal performance was created using a mean of PCI under 70 per Branch as trigger for action. Similarly, a 41 < PCI < 70 criterion were used for a "minimal performance" scenario, where PCI reaching 70 was used as trigger for M&R intervention on runways and PCI reaching 41 as trigger for taxiways and aprons. The results of this last scenario are not demonstrated in this paper due to limited content and summarizing purposes.

Some inflation had to be added to cost analyses. The value of 6,5% per year was used from FGV (2021) references as *Índice Nacional da Construção Civil* - INCC database for historical data (2007 – 2021). This index is commonly used in Brazil for constructions-related budget assessments.

3. RESULTS

Figure 3 shows a satellite image of one of the evaluated airfields. Some examples of pavement distresses are shown for AC (high severity raveling resulted from advanced aging) and PCC (medium severity spalling-corner).

Figure 3. Satellite image of one of the evaluated airfields showing some distresses found on pavement surfaces. Source: authors.

Next sections show each elaborated scenario: do-nothing (Scenario 1); budget-restriction (Scenario 2); and ideal performance (Scenario 3).

3.1. Scenario 1 – Do-nothing

Figure 4 presents a sketch of PCI results of PCI evaluation data processed within a do-nothing scenario for the airfield showed in Figure 3. This way of presentation of Sections is chosen for processing data over Excel sheets. Accumulated costs are also shown as result of doing nothing within M&R solutions over time.

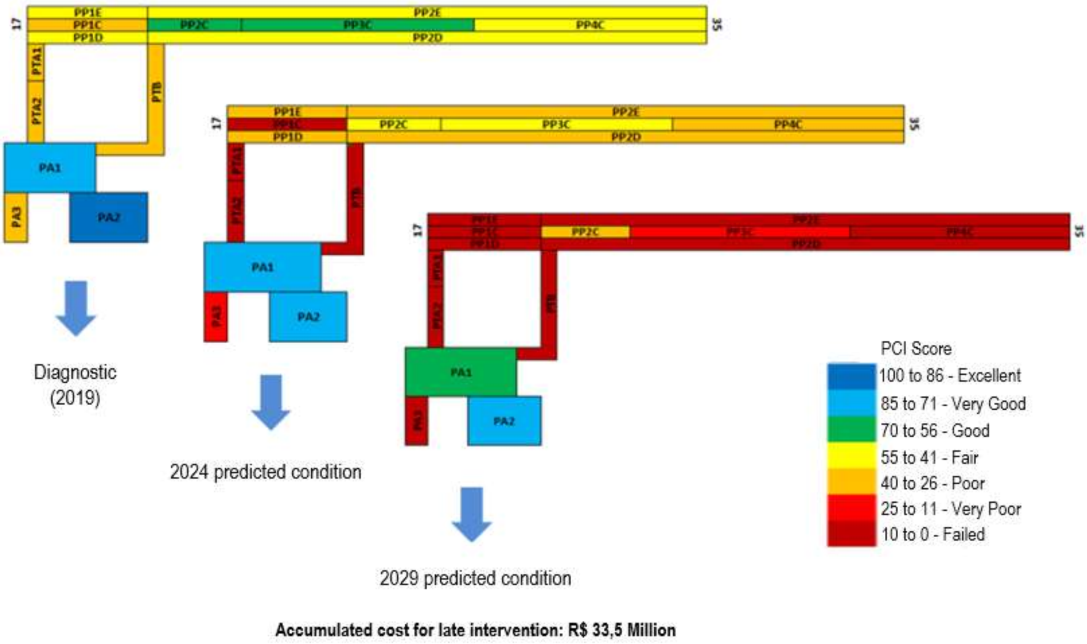

Figure 4. Projections of PCI performance per Section in evaluated airfield within the airfields network.

Similar projections within this scenario were compiled in a single chart with main indicators for the evaluated pavement inventory, which comprehends 4,2 million m² of pavement surface. The indicators are PCI-based and are obtained from every Branch in each airfield and are: overall PCI average for the whole pavement inventory, which takes into account Branches areas for calculating weighted averages; Maximum PCI average; Minimum PCI average; percentage of pavement surface area in worst conditions (reconstructions required); percentage of pavement under repair needs (41 < PCI < 70); and percentage of pavement under preventive maintenance needs (PCI > 70). The compiled information is shown in Figure 5.

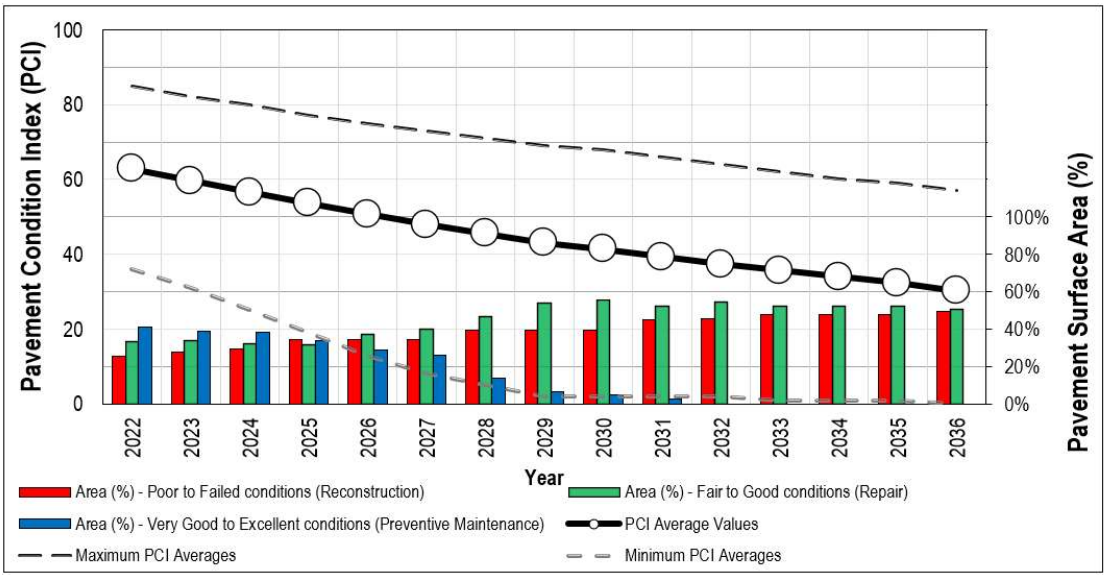

Figure 5. Time horizon of analyses compiling main PCI indicators for the whole pavement inventory.

The PCI-based indicators show a reduction in overall PCI quality over the years. This is expected due to PCI prediction models developed by Batista (2015) and as also demonstrated by Henrique & Motta (2013). It is expected an increase from 23% in 2022 to 50% in 2036 on pavement Reconstruction needs. It is expected a decrease from 41% in 2022 to 0% in 2036 of Preventive Maintenance needs. This is due to overall pavement deterioration in a do-nothing scenario.

Financial analysis shows a R$ 1,6 billion deferred maintenance backlogs by 2036 in pavement M&R services (50% reconstruction and 50% repair), which is equivalent to R$ 632 million brought to 2022 values (6,5%/year). Figure 6 shows the accumulated cost on 15 years as time horizon with inflation and without it. The no-inflation costs are shown to highlight intervention needs generated exclusive by pavement deterioration. The no-inflation analyses show an increase from R$ 325 million to 673 million in 2036, which sums up more than twice the value for M&R needs after 15 years of no intervention. This calculation indicates the cost of "doing nothing", important indicator for decision-makers and to spread pavement management culture.

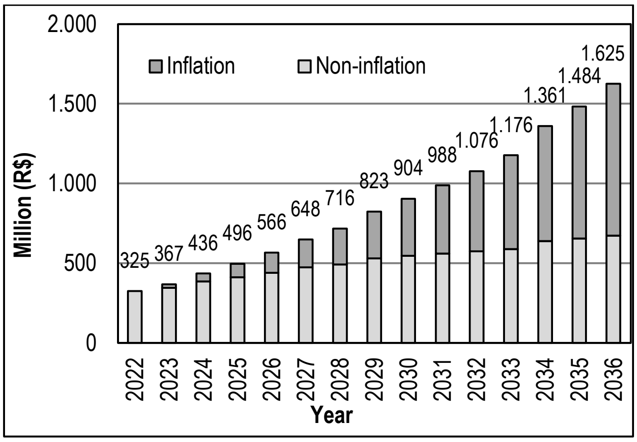

Figure 6. Accumulated costs for M&R need in a do-nothing scenario.

3.2. Scenario 2 – Budget-restriction for M&R services

Figure 7 shows same projection showed at Figure 4, but within a budget-restriction of R$ 25 million by year for the entire network (18 airports). Due to budget restriction, airfields had to be ranked to proceed Section prioritizing. In this case, it is proposed a M&R intervention on the runway Branch of the airfield showed in Figure 3 by the year of 2031, which is estimated to cost R$ 25,4 million.

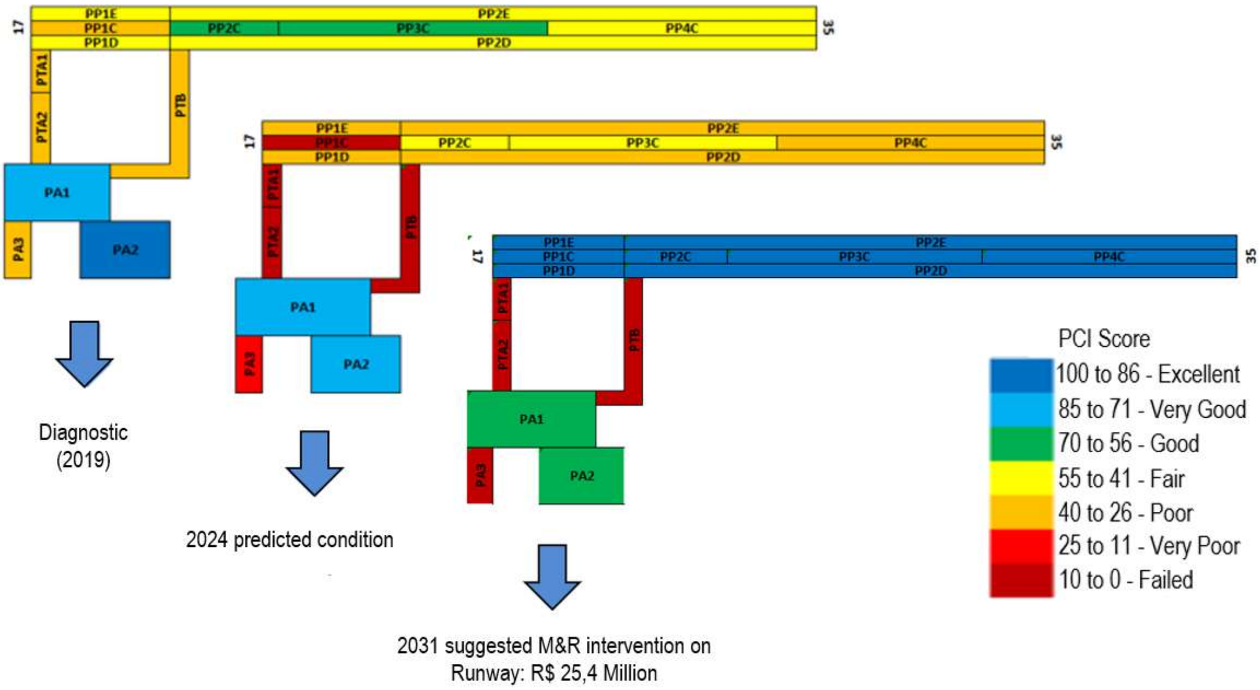

Figure 7. Projections of PCI performance within a budget-restriction scenario.

It is noticed that other Sections of the presented airfield continue to have deteriorated conditions (very poor to failed Sections). This is due to insufficient resources to a holistic M&R intervention and prior prioritized intervention in other airfields. It is also noted a late-M&R intervention, with deteriorated condition already by 2024. This is caused by the same explanation presented before.

Figure 8 shows PCI-based indicators for the whole pavement inventory within the yearly budget-restriction scenario.

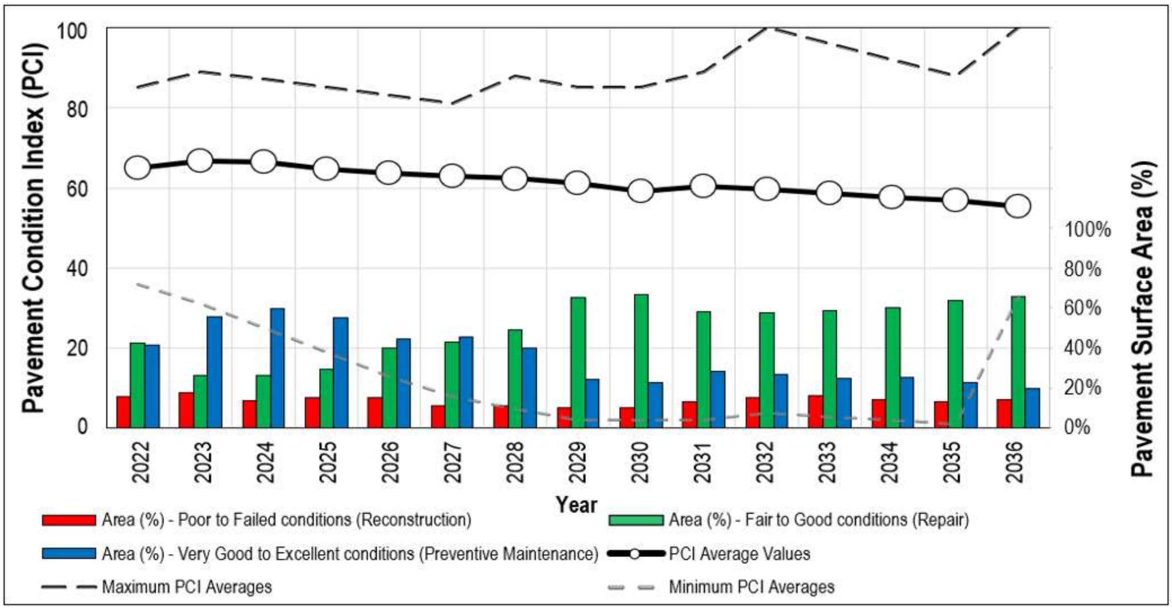

Figure 8. PCI-based indicators for pavement inventory on budget-restriction scenario.

The PCI-based indicators presented at this scenario show a better prognostic than scenario 1, with PCI average values of the whole network swinging by 60 (good conditions) during the horizon time and showing stable reconstruction needs. However, besides being steady, the overall indicators show no improvement of actual conditions (diagnostic) and deterioration of some indicators, as Minimum PCI Averages and decreasing of Preventive Maintenance needs. It also shows a persistent increase of repair needs (63% by 2036). In other words, this scenario switches approximately 20% of conservation needs to repair needs, not changing percentage of reconstruction needs, pointing to worst conditions than present diagnostic.

Figure 9 shows costs estimated within this scenario between 2022 and 2036. In terms of present values, the total amount implemented on M&R solution over the presented years is equivalent to R$ 237 million. This value is significantly inferior than only applying M&R services by the last year, 2036 (R$ 632 million as showed in Scenario 1).

This cost analyses also show that budget planning must follow up with inflation predictions, at least for inflation corrections and monetary conservation of M&R services. That is due to decrease in quantities of services implemented by the same amount of monetary value in future years, as shown in Figure 9.

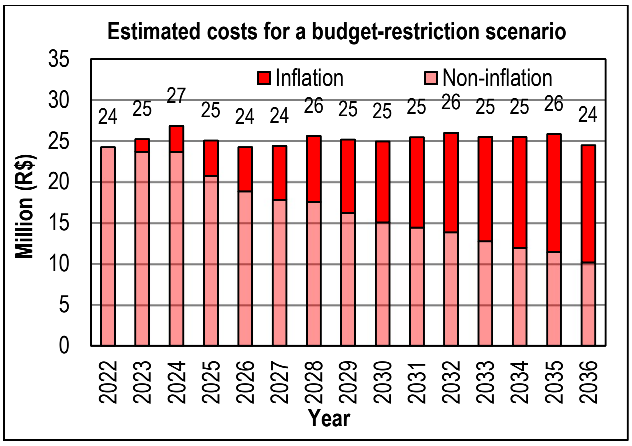

Figure 9. Estimated costs for scenario where about R$ 25 million per year is considered as limit for the entire pavement inventory

3.3. Scenario 3 – Ideal PCI performance

Figure 10 shows same projections as showed at Figure 4, but within an ideal performance scenario where no budget restriction is applied. The only limitation considered at this scenario is the need for airfield availability within same State areas, so no simultaneous intervention is chosen at these locations. The same approach as showed before for PCI-based indicators is show in this scenario at Figure 11.

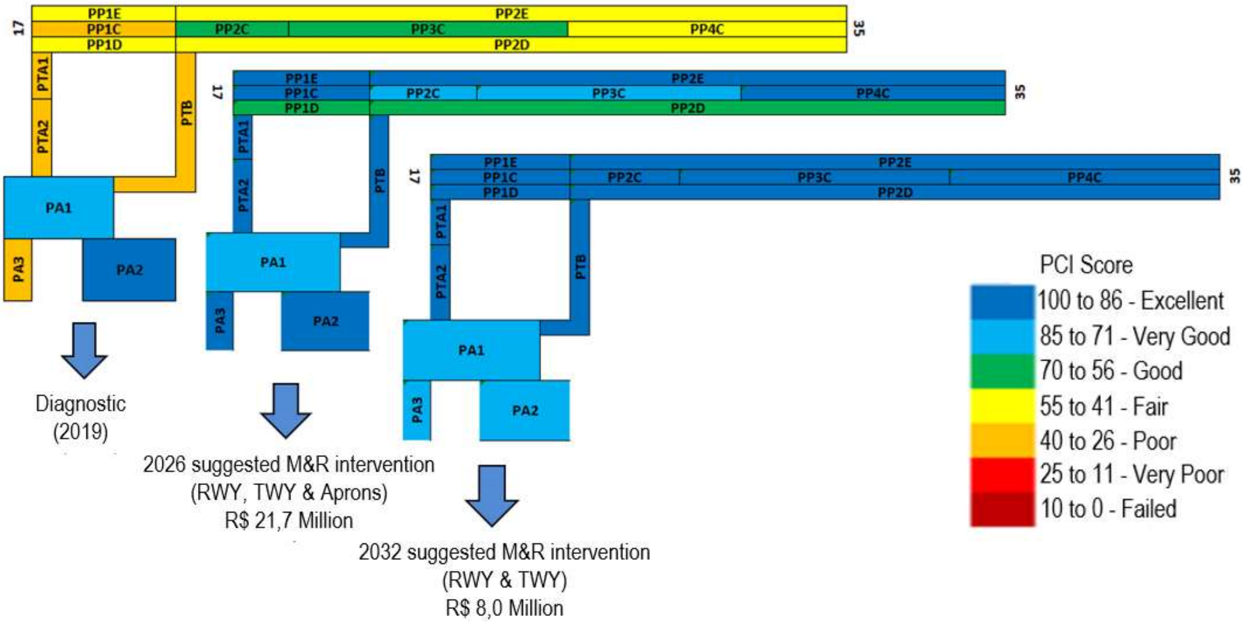

Figure 10. Projection of PCI performance as well as value of M&R services for evaluated airfield.

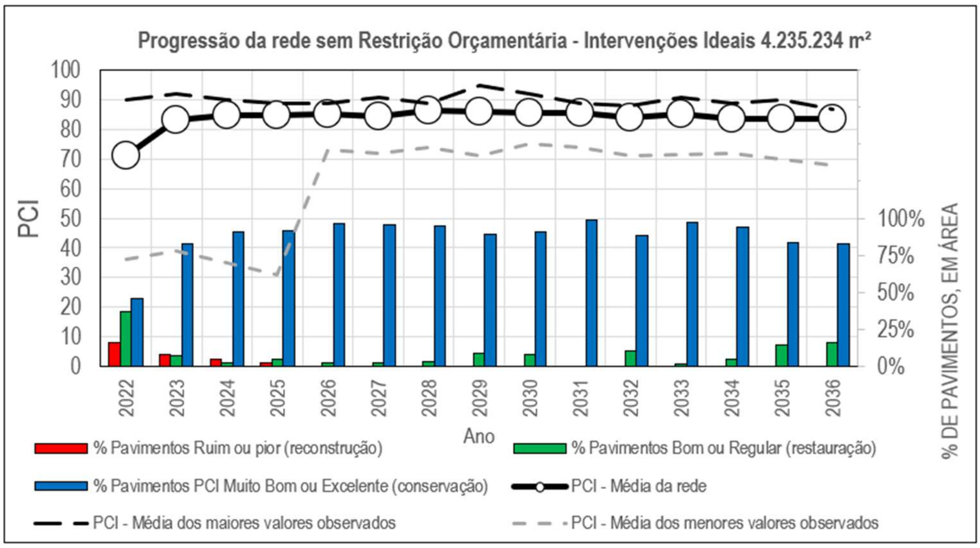

Figure 11. PCI-based indicators performance prediction on a ideal-performance with no budget restriction scenario.

Considering the PCI-based indicators, this scenario shows substantial better prognostic. PCI averages increase between 2022 and 2024, as showed by great increase of Preventive Maintenance over Repair and Reconstruction needs.

It is also noted similar values between maximum average and main average, which indicates a better consistency and convergence for overall conditions at very good to excellent levels.

The late increase of Minimum PCI Average values is due to the prior stated restriction, where some airfields located in same States must not be unavailable (*i.e.* execution of construction works at same time), aiming minimal network availability. Figure 12 shows estimated costs over the years within this scenario.

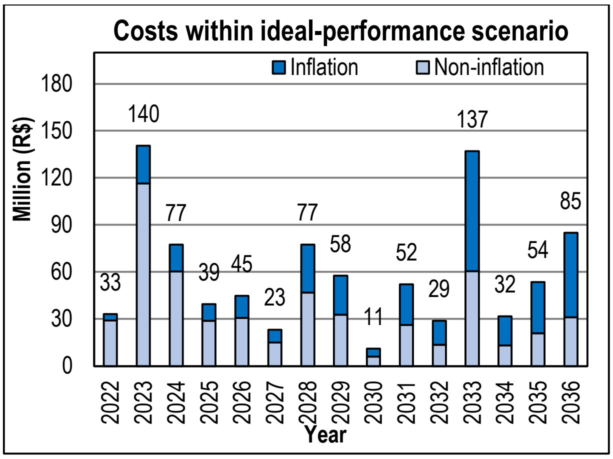

Figure 12. Estimated costs on a no-budget-restriction scenario.

It is noticed a significant budget need within first three years of estimated costs analyses. The year of 2022 is the first year of analysis, thus is assumed as year for intervention planning, project development, bidding, and execution of construction works. So, the estimated cost for that year is only for ongoing projects and construction plans in prior years. The considerable budget need afterwards is due to great repairs needed at diagnostic year, which also indicates some reconstruction needs. It is noted that while performing extensive services over first years, and therefore requiring considerable budget, M&R needs decrease after that period and tend to stabilize, as viewed on no-inflated values.

The estimated cost in this scenario sums up R$ 565 million (2022 values) of M&R services. This case demonstrates financially worthwhile when compared with intervention only at last year (2036), as shown in scenario 1, where a R$ 632 million would be required. In addition to that, this scenario performs better than scenario 2 under PCI-based indicators, as well as implying on greater availability levels for airfield pavement infrastructures.

4. CONCLUSION

PCI evaluations performed between 2018 and 2021 over 18 airfields were conducted as an engineering assessment method on a Pavement Management Program within the Brazilian Air Force. Results were gathered on a database of pavement surface conditions and associated with PCI prediction models, M&R services decision premises, estimated costs of M&R techniques, as well as other discussed propositions.

Scenarios were created between do-nothing, budget restriction of R$ 25 million per year for the whole pavement inventory, and ideal performance of PCI-based indicators under no-budget restriction.

A do-nothing scenario revealed accumulated costs of R$ 1.6 billion by 2036 on deferred M&R services, while the value proposed as budget restriction performed as insufficient for the evaluated pavement inventory. The ideal performance revealed great needs for M&R services within next three years (2023 – 2025), but significant reduction afterwards.

Although presented methods and premises do not aim to predict project level interventions and precise budget allocation needs, results were sufficient to better aim M&R needs within a network level of analysis. The suggested approach also shows significant benefits for preventive maintenance over late interventions, meeting similar results found in literature (Shahin, 2005; Cordovil, 2010; Henrique & Motta, 2013; Batista, 2015). The benefits are observed not only on financial terms, but also on PCI performance and infrastructure availability, as shown in comparisons conducted between scenarios. This paper also achieves another objective of reaching decision-makers and enhancing the pavement management culture in an organizational manner.

It is expected that ongoing collection of structural data, as surface deflections, measured by the Falling Weight Deflectometer and pavement sample extractions, as well as future collection of friction and texture data, will enhance the proposed methods and make the suggested PMP more holistic. Therefore, it is expected that a structured PMP will drive decisions to more efficiency of public-budget needs.

5. REFERENCES

ASTM. (2020). D5340-20 *Standard Test Method for Airport Pavement Condition Index Surveys. West Conshohocken.* American Society of Testing Materials.

ANAC (2017). *Agência Nacional de Aviação Civil. Manual de Sistema de Gerência de Pavimentos Aeroportuários - SPGA. Superintendência de Infraestrutura Aeroportuária*.

ANAC (2021). *Agência Nacional de Aviação Civil. Regulamento Brasileiro de Aviação Civil –* RBAC n° 154: *Projeto de Aeródromos*.

Batista, N. A. (2015). *Uma Proposta para Sistema de Gerência de Pavimentos Aplicada a Aeroportos Militares. Dissertação de Mestrado. Instituto Militar de Engenharia* – IME.

Bernucci, L. B., Motta, L. M G., Ceratti, J. A. P e Soares, J. B. (2022). *Pavimentação Asfáltica – Formação Básica para Engenheiros*. 2nd Edition. Petrobras, Rio de Janeiro.

Brasil. (2013). *Decreto Federal* nº 7.983, de 8 de abril de 2013. Sets rules and criterion for budget creation within construction and engineered services contracted within public funds, and other measures. Planalto.

Cordovil, R. M. (2010). *Um Programa de Gerência de Pavimentos para o Comando da Aeronáutica - Estudo de caso: Bases Aéreas da Região Sul*. Master's Dissertetation. Universidade Federal do Rio Grande do Sul – UFRS.

DIRINFRA (2022). Diretoria de Infraestrutura da Aeronáutica. *Relatório Técnico* nº 02/EPGA/2022 – Relatório *Anual de Gerência de Pavimentos de Aeroportos Militares*. Available by authors upon request. São Paulo, SP.

FAA. (2014). Federal Aviation Administration Airport Pavement Management Program (PMP). Advisory Circular 150/5380-7B. US Department of Transportation, Washington, DC.

FGV (2021). Fundação Getúlio Vargas. Série histórica do Índice Nacional de Custo da Construção Mensal– INCC – M. Obtido em: https://extra-ibre.fgv.br/IBRE/sitefgvdados/consulta.aspx, acessado em dezembro de 2021.

Haas, R., Hudson, W. R. e Zaniewski, J. (1994). Modern Pavement Management. Krieger, FL, United States.

Henrique, Y. F. e Motta, L. M. G. (2013) *Método de Avaliação de Pavimentos Aeroportuários – Aplicação a um Aeródromo Militar. Associação Nacional de Pesquisa e Ensino em Transportes - ANPET. XXVI Congress*. Belém, PA.

Shahin, M. Y. (2005) Pavement Management for Airports, Roads and Parking Lots. 2nd Edition. Springer.

TCU. (2013). Tribunal de Contas da União. *Acórdão nº 2.622/2013 – Plenário*.