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Proposal and Implementation of a Heliport Pavement Management System: Technical and Economic Comparison of Maintenance Strategies

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Abstract: Maintenance and rehabilitation (M&R) scheduling for airport pavement is supported by the scientific literature, while a specific tool for heliport pavements lacks. A heliport pavement management system (HPMS) allows the infrastructure manager to obtain benefits in technical and economic terms, as well as safety and efficiency, during the analyzed period. Structure and rationale of the APSM could be replicated and simplified to implement a HPMS because movements of rotary-wing aircrafts have less complexity than fixed-wing ones and have lower mechanical effects on the pavement. In this study, an innovative pavement condition index-based HPMS has been proposed and implemented to rigid and flexible surfaces of the airport of Vergiate (province of Varese, Italy), and two twenty-year M&R plans have been developed, where the results from reactive and proactive approaches have been compared to identify the best strategy in terms of costs and pavement level of service. The result obtained shows that although the loads and traffic of rotary-wing aircrafts are limited, the adoption of PMS is also necessary in the heliport environment.

Keywords: heliport pavement; pavement management system; M&R; PCI

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1. Introduction

Since the 1970s, pavement management systems (PMS) have been applied to roads and airports, and currently, they are considered a good and useful aid for the infrastructure manager [1–4]. A PMS provides a systematic and consistent method for assessing the current state of a pavement, predicting its future condition, determining priorities and the optimal time for repair, and selecting maintenance or repair and rehabilitation (M or R&R, respectively) needs [5]. This process has overturned how to approach the maintenance of transport infrastructure pavements. Indeed, in the past, the pavement maintenance was performed only when needed, without a work plan over time, and carrying out the repeated application of some alternatives of M&R based on past experience, without considering better alternatives. With the introduction of the PMS, the importance of monitoring the pavement conditions and planning the M&R has been understood and implemented, and the adoption of the best alternative among the available ones is a consequence of these actions [6]. In addition, a proper definition of PMS allows the reduction of overall pavement costs (both construction and maintenance) as well as traffic disruptions and their related risks. Moreover, the methodology of system dynamics could support PMS in order to identify the interrelationship between the elements of the systems, to distinguish causes and effects, and to investigate which parameters are pivotal to improve the system's behavior [7].

A PMS includes several steps: pavement distress survey [8,9], pavement evaluation [1], life-cycle cost analysis (LCCA) [10], and finally, definition of the maintenance strategies [11–13]. M&R planning for airport pavements complies with the airport pavement management system (APMS) method [6]. Starting from data collection and storage of data about pavement smoothness, adherence, and distresses, APMS permits:

- To assess current conditions of the pavement,
- To predict the future condition of the pavement using performance prediction models,
- To identify the optimum when implementing the best M&R option, optimizing currently available resources and avoiding greater future costs,
- To define a priority list of interventions,
- To assess the economic resources needed for M&R.

The International Civil Aviation Organization (ICAO) prescribes that airports adopt APMS in order to maintain the optimal conditions of their pavements to the required operating conditions (e.g., safety, regularity, and efficiency) without compromising air navigation for a defined period [14] in ordinary and emergency exercise [15].

In the past, most of the PMS were created to manage large networks, and therefore they refer to major road and airport infrastructures [16,17]; in recent years, PMS has been implemented to sidewalks and urban shared areas in order to assess pavements' quality conditions for pedestrians and to improve walking comfort for vulnerable users [18–20]. This paper adapts conventional PMS methodologies to a heliport (i.e., an aerodrome for use by helicopters only according to [21]). Indeed, it deals with the implementation of a PMS to develop strategies to maintain, preserve, and rehabilitate heliport infrastructures (HPMS). In order to extend the implementation of PMS to heliport pavements, the structure and management of APMS should be modified considering the different traffic (both dynamics and weight). Indeed, rotary-wing vehicles have low effects on pavements compared to fixed-wing aircrafts; in some cases, helicopters move without touching the pavement, and in any case, the weight of helicopters is generally much lower than that of aircrafts. Nevertheless, the pavement condition should be monitored to avoid potential foreign object debris (FOD) and the consequent damage, although this problem differs from that observed at airports. While in the latter FOD represents a real danger for the integrity of the aircraft engines, in heliports, it generates damage to the helicopter bodywork, which in any case involves a considerable economic commitment. For these reasons, unlike APMS, HPMS of pavements designed for rotary-wing vehicles does not consider smoothness and adherence, it only considers the pavement condition index (PCI), a common distress survey method that rates the general condition of a pavement considering the extent and severity of the surface defects. The proposed method includes the creation of the heliport network inventory, the visual surveys of the pavement, and the evaluation of its condition by PCI [5], and it allows analysis and modeling for heliport managers to compare alternative maintenance strategies and define the priority needs on their managed network. Moreover, the proposed method can be easily adapted to all the infrastructures in the heliport and it does not require a large amount of time and money for its implementation.

2. Methods

The main objective of this study is the implementation of a HPMS to assess the pavement condition through visual surveys according to the American Society for Testing and Materials for roads [22] and airports [23]. In this context, three hierarchical management levels are usually identified:

- Network level: The highest level of the hierarchy. It considers the overall network of pavements (e.g., all the pavements of the heliport).
- Branch level: The middle level of the hierarchy. It includes a specific portion of the network identified for its specific functions. Each branch is composed of at least one section.

- Homogeneous section: The lowest level of the hierarchy. It is a part of a branch with uniform construction, maintenance, service life, superficial condition, traffic mix, and traffic volume.

In order to develop an efficient HPMS, a database with a pavement inventory, history of M&R, superficial condition, and traffic data should be structured and updated. This information allows the prediction of future pavement conditions and identification of the best M&R procedure. First, the inventory of pavements within the system [6] includes the following types of data: construction year, maintenance history, pavement type (e.g., rigid, flexile, semirigid, modular) and structure (e.g., thickness of layers, slab dimensions if rigid), traffic composition and repetitions, performed function (e.g., touchdown and lift-off area, taxiway, safety area, apron), and rank (i.e., primary, secondary, tertiary). The history of both preventive and reactive M&R strategies should contain information about repair history [6]: date, type, and cost of rehabilitation works, size of rehabilitated area, materials' properties, and layers' thickness. PCI calculation complies with the standards ASTM D 5340-20 [23] and ASTM D 6433-20 [22], where the former is specific to the airport, where rotary-wing vehicles autonomously move on the pavements, and the latter is specific to roads or where rotary-wing vehicles are pulled. Both methods prescribe that the pavement should be divided into homogeneous sections and the sections into sample units to be surveyed [22,23]. With regard to traffic data, the number of yearly movements and the rotary-wing vehicles found to be moving should be considered to distinguish homogeneous sections in branches.

Predictive models permit to adapt the deterioration curve to the decay evolution of a pavement or a series of pavements that have homogeneous sections with similar decay characteristics: function, rank, and type. Forecasting of the pavement condition derives from treatment of data collected during survey campaigns, using several regression curves, such as straight-line extrapolation, mechanistic empirical, polynomial constrained least square, S-shaped curve, probability distribution, and Markovian. The simplest regression model is based on a straight-line extrapolation of the last two condition points [5,24]. This method can be used when the monitoring of the pavement is in the starting phase and consolidated data are not available. However, at a minimum, availability of data required is: the year of the construction or reconstruction, when the PCI can be assumed equal to 100, and the PCI calculated on the last (probably the only one available) survey. The straight-line extrapolation is applicable only for single-section branches and it cannot be used with other pavement sections [5].

Four types of M&R could be implemented [11] depending on the PCI value with respect to the critical PCI (i.e., value at which PCI rapidly decreases with time or the time when the cost of localized preventive maintenance significantly increases) [11] and based on the performance or characteristics of the pavement to be improved [25–27]:

- Localized preventive M&R: Consists of localized distress maintenance activities (e.g., cracking sealing or patching) to slow the rate of distress progression. Localized preventive M&R can be implemented when pavement PCI is above the critical value.
- Global preventive M&R: Consists of maintenance activities applied to the whole section (e.g., rejuvenation, thin overlay or joint sealing for concrete pavements) to slow the rate of distress progression. Global preventive M&R is cost-effective if pavement PCI is above the critical value.
- Major M&R: Consists of activities applied to the entire pavement section to correct or improve its structural or functional performance. Major M&R is applied to pavements both below and above the critical PCI.
- Localized stopgap (safety) M&R: Localized activities to keep the pavement in safe and operational conditions when economic resources for higher M&R activities are not available. Localized stopgap (safety) M&R can be implemented when the PCI pavement is below the critical threshold.

Calculation of the discounted M&R cost in the specific year during the analyzed period complies with the economic model proposed in the Technical Manual No. 5-623 Pavement Maintenance Management [28].

The software PAVEair has been used [29]. It has been developed by the FAA to fulfil the requirements of an APMS according to [6] and it is designed to support infrastructure managers in evaluating, managing, and maintaining their pavement networks [29].

The proposed model has been adopted to implement a HPMS to the pavements of the airport in Vergiate (Varese province, Italy), owned by Leonardo. This proposal aims to have an effective 20-year-long plan to maintain safe and operational conditions of surfaces where rotary-wing vehicles move.

3. Results

Figure 1 shows the geometrical and functional layout of the Vergiate airport and its pavement types.

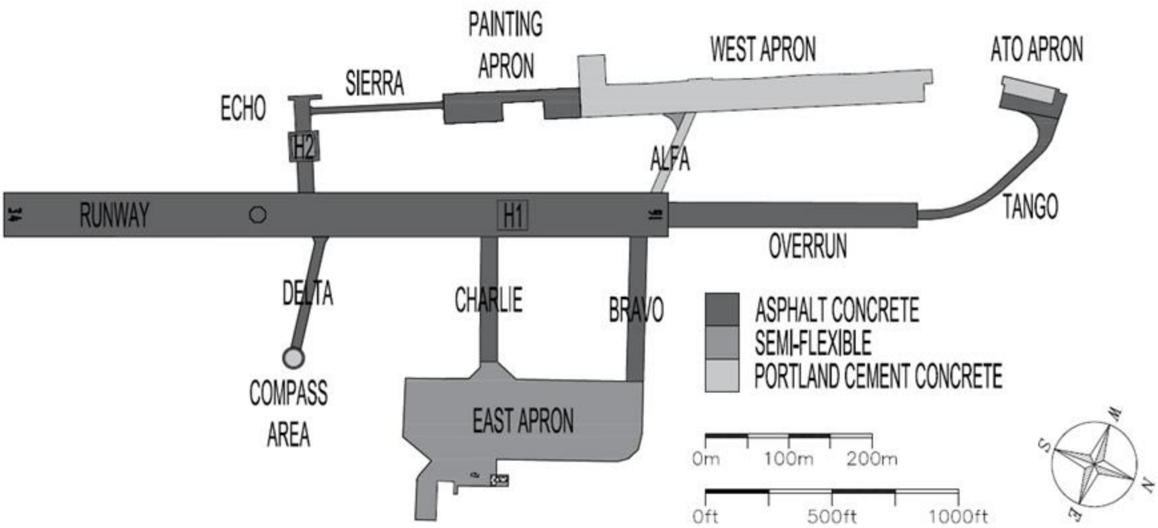

Figure 1. Layout of the Vergiate airport.

All the heliport pavement has been divided into branches, and each branch into homogeneous sections, as listed in Table 1. All section details have been implemented in the software PAVEAIR. There are three types of pavement surface: asphalt pavement (AC), concrete slab pavement (PCC), and semi-flexible. The latter is an open-grade asphalt concrete with the voids filled with a high-strength cement-based mortar. This material combines the flexible properties of asphalt concrete with the high bearing capacity and durability of concrete [30,31]. The load-bearing capacity of the subgrade is good: the California Bearing Ratiois more than 25% throughout the airport. All sections belong to primary and secondary rank.

Table 1. Pavement inventory.

Heliport Functional Element	Section	Surface (m^2)	Type of Pavement Surface	Rank
Runway	A	9020.6	AC	P
	B	16,227.1	AC	P
	C	15,511.3	AC	P
	D	9018.0	AC	P
Helipad H1	A	1296.0	AC	P
Helideck	A	400.0	AC	P

Table 1. *Cont.*

Heliport Functional Element	Section	Surface (m^2)	Type of Pavement Surface	Rank
Helipad H2	A	719.2	semi-flexible	P
	B	573.0	AC	P
East Apron	A	21,948.6	semi-flexible	P
	B	9894.1	semi-flexible	P
West Apron	A	17,086.0	PCC	S
ATO Apron	A	1453.0	PCC	S
	B	1239.9	AC	S
Painting Apron	A	3169.4	AC	S
	B	1599.7	AC	S
Compass Area	A	349.0	PCC	P
	B	177.4	AC	P
Alfa Taxiway	A	1487.8	PCC	S
	B	230.8	semi-flexible	S
Bravo Taxiway	A	3539.7	AC	P
Charlie Taxiway	A	3066.9	AC	P
Delta Taxiway	A	1598.5	AC	P
Echo Taxiway	A	708.7	AC	P
	B	914.5	AC	P
Sierra Taxiway	A	1143.3	AC	S
Tango Taxiway	A	2660.6	AC	P

Figure 2a–d represents the cross-section of runway sections A, B, C, Helipad H1, and Helideck, Runway section D, East Apron section A, and East Apron section B, respectively.

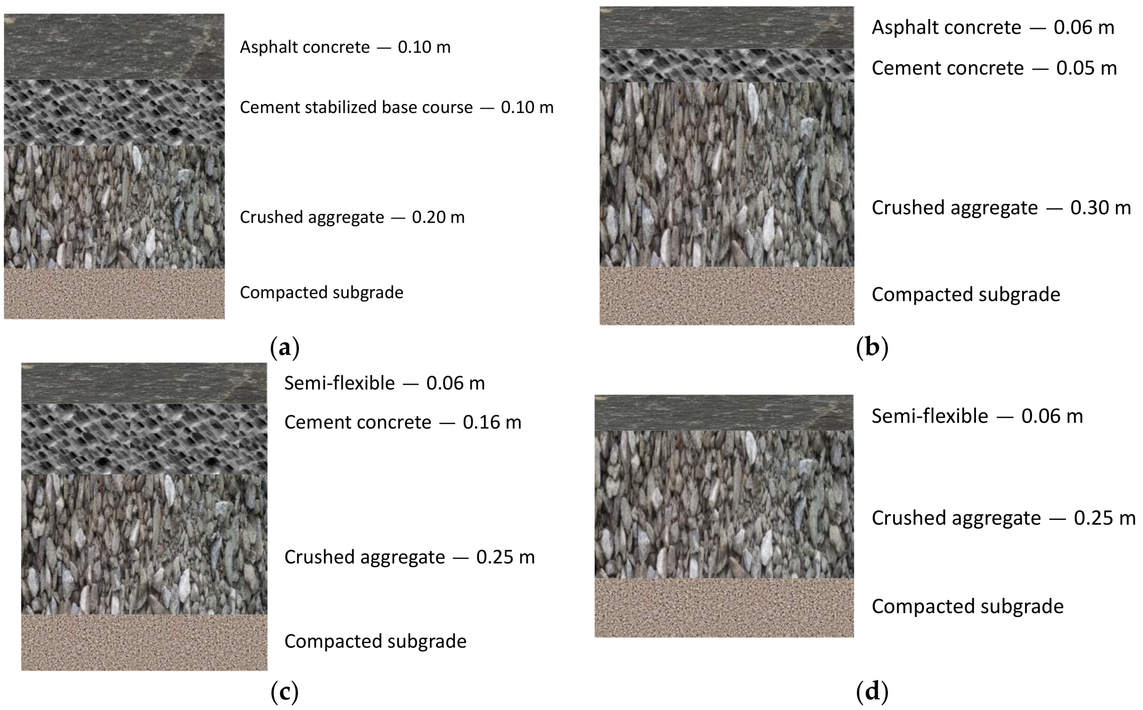

Figure 2. Cross-section of (**a**) runway sections A, B, C, Helipad H1, and Helideck, (**b**) runway section D, (**c**) East Apron section A, and (**d**) East Apron section B.

Table 2 lists the M&R activities applied to the identified sections. Work details have been added to the model in PAVEAIR to complete the pavements' description.

Table 2. History of applied M&R activities.

Heliport Functional Element	Section	Date	M&R	M&R Type	Quantity (m^2)
Runway	A	25/11/2018	Reconstruction—AC	Major	516.7
		25/11/2018	Patching—AC	Localized preventive	1327.4
	B	25/11/2018	Reconstruction—AC	Major	2109.2
		25/11/2018	Patching—AC	Localized preventive	2623.0
	C	25/11/2018	Patching—AC	Localized preventive	1819.1
	D	25/11/2018	Patching—AC	Localized preventive	85.8
Helipad H1	A	25/11/2018	Reconstruction—AC	Major	1296.0
Helideck	A	25/11/2018	Reconstruction—AC	Major	400.0
West Apron	A	30/11/2009	Reconstruction—PCC	Localized preventive	22.1
		30/11/2009	Patching—PCC	Localized preventive	60.7
		30/11/2015	Reconstruction—Semiflexible	Major	1136.3
ATO Apron	A	30/11/2018	Patching—PCC	Localized preventive	14.2
Alfa Taxiway	A	30/11/2015	Reconstruction—PCC	Major	0.4
Bravo Taxiway	A	30/11/2018	Patching—AC	Localized preventive	15.3
Charlie Taxiway	A	30/11/2018	Patching—AC	Localized preventive	16.9
Delta Taxiway	A	30/11/2017	Patching—AC	Localized preventive	14.3
Echo Taxiway	B	30/11/2018	Patching—AC	Localized preventive	0.3

High-definition georeferenced images from surveys carried out on 1 June 2019 allowed identification of distresses. Figure 3 represents the surveyed distresses of the semi-flexible pavement in the East Apron: blue lines represent damaged joints, pink lines represent sealed joints, green lines represent <0.5 cm wide cracks, yellow lines represent 0.5–1 cm wide cracks, red lines represent >1 cm wide lines, and green and black squares represent existing patches and all-depth M&R treatments, respectively.

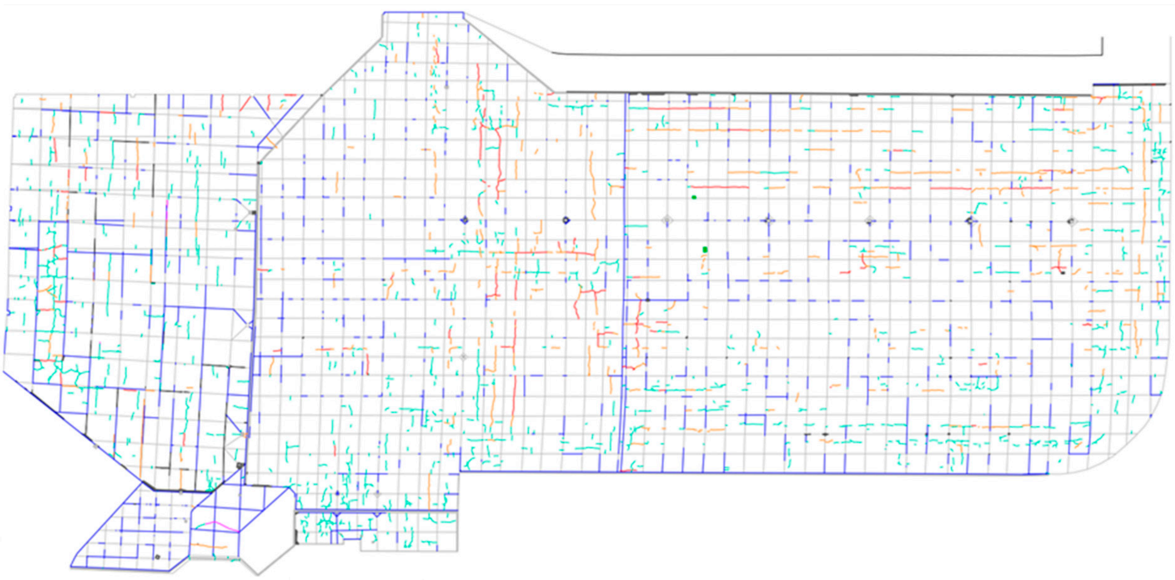

Figure 3. Distresses on the East Apron.

Surveyed distresses were implemented in PAVEAIR to calculate the PCI value for each homogeneous section (Table 3): ASTM D 5340-20 [23] has been considered to assess PCI of surfaces where rotary-wing aircrafts move by themselves, while ASTM D 6433-20 [22] was considered for surfaces where rotary-wing aircrafts are pulled by a tractor.

Table 3. PCI values.

Heliport Functional Element	Moving/Towed Helicopters or Vehicles	Section	Sample Unit Number	PCI	Comment
Runway	Moving helicopters	A	15	10	Failed
		B	27	19	Very poor
		C	25	7	Failed
		D	15	20	Very poor
Helipad H1	Moving helicopters	A	3	100	Excellent
Helipad H2	Moving helicopters	A	2	95	Excellent
		B	1	94	Excellent
Helideck	Moving helicopters	A	1	100	Excellent
East Apron	Moving helicopters	A	47	68	Good
		B	16	59	Good
West Apron	Towed helicopters	A	46	76	Very good
ATO Apron	Vehicles	A	4	43	Fair
		B	4	100	Excellent
Painting Apron	Towed helicopters	A	6	98	Excellent
		B	3	100	Excellent
Compass Area	Moving helicopters	A	1	73	Very good
		B	1	94	Excellent
Alfa Taxiway	Towed helicopters	A	5	37	Poor
		B	1	69	Good
Bravo Taxiway	Moving helicopters	A	7	48	Fair
Charlie Taxiway	Moving helicopters	A	6	57	Good
Delta Taxiway	Moving helicopters	A	3	56	Good
Echo Taxiway	Moving helicopters	A	2	91	Excellent
		B	2	91	Excellent
Sierra Taxiway	Moving helicopters	A	3	96	Excellent
Tango Taxiway	Moving helicopters	A	6	72	Very good

Figure 4 shows a chromatic layout of the calculated PCI values, and the PCI rating scale complies with [5].

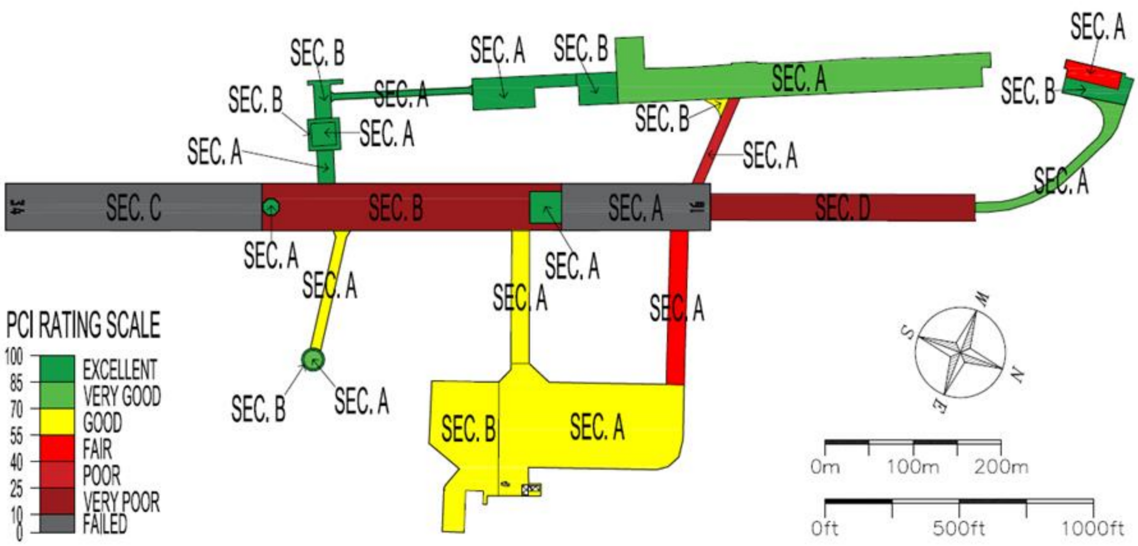

Figure 4. PCI rating on 1 June 2019.

The prediction of the pavement condition has been performed by a straight-line extrapolation (PCI-time) because no data are available on past surveys, and in the literature, decay curves for heliport pavements are not available. In addition, the pavements cannot be considered as included in the same family because their characteristics in terms of traffic and structure are too different from each other. Table 4 lists the yearly PCI decay obtained for each section, which derives from Equation (1):

$$\text{yearly PCI decay} = \frac{100 - \text{PCI}_{2019}}{2019 - \text{Y}} \quad (1)$$

where PCI_{2019} refers to the PCI values listed in Table 3 for each section and Y is the year of construction or the year of the last rehabilitation works.

Table 4. Yearly PCI decay.

Heliport Functional Element	Section	Construction Year	Reconstruction Year	PCI at 01/06/2019	Yearly PCI Decay
Runway	A	1937	1980	10	2.3
	B	1937	1980	19	2.1
	C	1937	1980	7	2.4
	D	1960	1980	20	2.1
Helipad H1	A	1980	2018	100	2.0
Helipad H2	A	2008	-	95	0.5
	B	2008	-	94	0.5
Helideck	A	1980	2018	100	2.0
East Apron	A	1980	2008	68	2.9
	B	2008	2008	59	3.7
West Apron	A	1937	-	76	0.3
ATO Apron	A	1937	1960	43	1.0
	B	1937	2010	100	1.0
Painting Apron	A	1970	2015	98	0.5
	B	1970	2015	100	0.5
Compass Area	A	1980	-	73	0.7
	B	1980	-	94	0.2
Alfa Taxiway	A	1937	-	37	0.8
	B	1937	2015	69	0.8
Bravo Taxiway	A	1980	-	48	1.3
Charlie Taxiway	A	1980	-	57	1.1
Delta Taxiway	A	1980	-	56	1.1
Echo Taxiway	A	1980	2008	91	0.8
	B	1980	2008	91	0.8
Sierra Taxiway	A	1980	2013	96	0.7
Tango Taxiway	A	1980	2010	72	3.1

For pavements whose PCI value was 100 on 1 June 2019, the yearly PCI decay has been assumed 1 for the ATO Apron, and 0.5 for the Painting Apron according to the yearly decay obtained for the same functional elements in the branch (e.g., the yearly decay of section B of the ATO Apron coincides with that of section A). For functional elements composed of only one section, the yearly decay has been obtained from that of a section in a different branch on the basis of the traffic type and volume (e.g., the yearly PCI decay of Helipad H1 is four times that of Helipad H2 because the traffic in the former is four times the traffic in the latter).

In August 2020, sections in Table 1 were surveyed to assess PCI_{2020} and monitor its trend. The obtained results confirmed more than 70% of the values of yearly PCI decay listed in Table 4. Due to the effects of COVID-19 on movements in the period from March to August 2020, the authors assumed the yearly PCI decay values in Table 4 to define the maintenance strategies. Particularly, two M&R strategies have been developed:

1. A proactive M&R plan which provides for local and global preventive M&R activities. The plans are not expensive but guarantee good conditions during the entire twenty-

year analysis period and guarantee the absence of detached elements on the surface, avoiding additional costs for FOD. Table 5 shows the M&R plan for section A of the Tango taxiway and the before/after values of PCI, as an example.

2. A reactive M&R plan which provides for major M&R reconstruction interventions at the end of the pavement service life. Activities are expensive and do not guarantee the absence of FOD whose related costs should be added to the cost of the M&R plan. In the literature, there are not costs for FOD in the heliport, therefore, data from airports have been considered, however the reference is not disclosed herein due to privacy reasons. Table 6 shows the M&R plan with a reactive approach for section A of the Tango taxiway and the before/after values of PCI, as an example.

The proactive and reactive M&R plans are shown in Tables 5 and 6, respectively. The discounted costs have been calculated according to [23].

Table 5. Proactive M&R plan for section A of the Tango taxiway.

Year	Intervention	Present Worth (EURO, €)	PCI_{BEFORE}	PCI_{AFTER}
2020	-	-	69	69
2021	Localized preventive M&R (crack sealing)	28	66	74
2026	Localized preventive M&R	1135	58	67
2031	Bituminous emulsion Global preventive M&R (overlay 5 cm)	3523 34,611	51	100
2036	Localized preventive M&R	817	84	93
2040	-	-	80	80

Table 6. Reactive M&R plan for section A of the Tango taxiway.

Year	Intervention	Present Worth (EURO, €)	PCI_{BEFORE}	PCI_{AFTER}
2020	-	-	69	69
2025	-	-	53	53
2030	-	-	38	38
2035	Milling 10 cm Major M&R (reconstruction 10 cm)	9743 86,240	22	100
2040	-	-	84	84

Figure 5 compares the curves of the discounted costs obtained for the examined M&R solutions (Tables 5 and 6) and their PCI values.

The benefit from the initial low maintenance costs of the reactive approach disappears after 15 years (i.e., in 2035), when the first reactive activity has higher costs than the cumulative one compared to the proactive approach. Over the 20-year service period, the proactive approach implies 40,114 EUR M&R activities, while the reactive one 965,983 EUR. Moreover, the curve of PCI highlights that the latter strategy implies an average PCI during the observed period equal to 60, which is lower than that ensured by the former one (i.e., 75). The lower PCI value obviously increases the danger of FOD, because the worst condition of the pavement leads to an evident danger of detachment of material from the pavement.

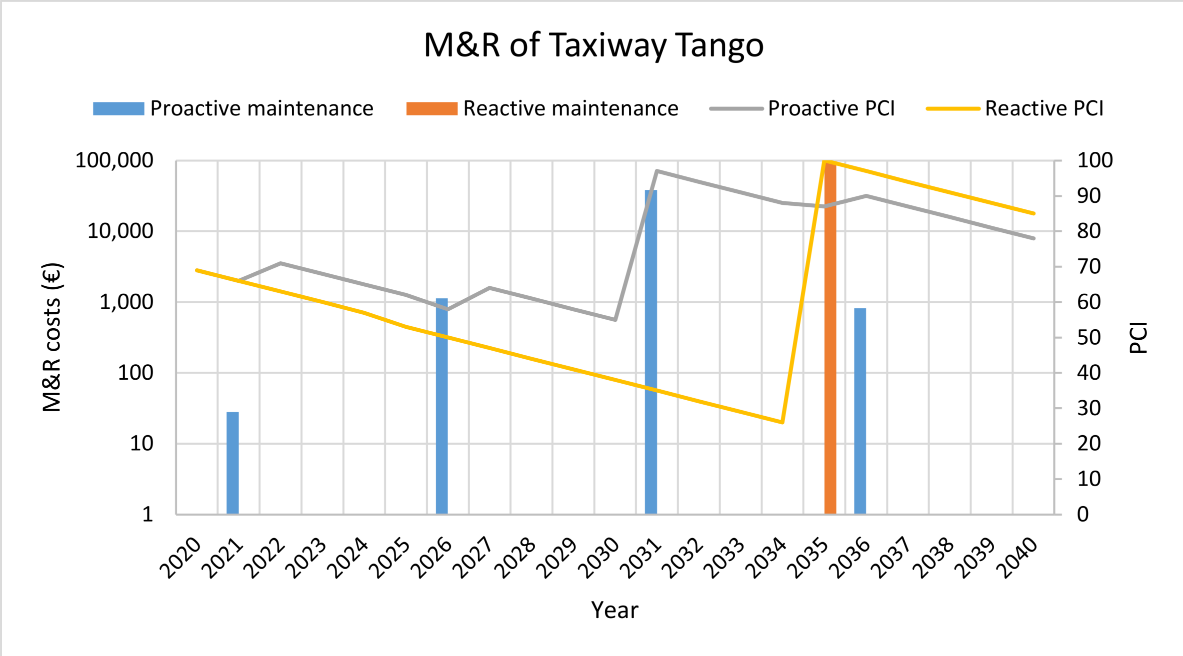

Figure 5. M&R alternatives for the Tango taxiway.

The same comparative approach has been implemented to the whole pavement network (Table 7).

Table 7. Network level M&R alternatives.

	Proactive M&R Plan	**Reactive M&R Plan**
Year	**M&R Present Worth (EURO, €)**	**M&R Present Worth (EURO, €)**
2020	-	-
2021	694,305	470,468
2025	12,243	-
2026	16,935	-
2028	78,674	-
2030	11,696	564,537
2031	56,158	-
2035	438,621	1,245,655
2036	15,237	-
2040	14,044	230,509
	Proactive M&R plan total cost (€) 1,337,913	Reactive M&R plan total cost (€) 2,511,169

4. Conclusions

A pavement management system helps transport infrastructure agencies in the decision-making process: it provides procedures to evaluate the distress pavement condition and to evaluate the best M&R strategies. Although evenness and skid resistance are not meaningful for heliport pavements and distress rates of pavements used by rotary-wing vehicles are less than those of pavements used by fixed-wing vehicles, PMS is necessary to manage heliport pavements, but in the scientific and technical literature, there are no tools available for these surfaces. Therefore, this study adapted the structure of an APMS to the Vergiate Heliport and tried to fill this gap in the sector. A conventional PMS includes technical and economic steps: pavement distress survey, pavement evaluation, life-cycle cost analysis (LCCA), and finally, definition of the maintenance strategies. HPMS is simpler than APMS because movements of rotary-wing vehicles are not affected by surface unevenness: HPMS depends on the current and predicted PCI values in order to identify the M&R option which balances safety, economic, and technical issues. Twenty-six homogeneous sections identified in the functional elements of the airport have been surveyed and their PCI has been calculated. For each section, the prediction of the pavement condition has been performed by a straight-line extrapolation in order to predict the future pavement condition and identify the time when maintenance or rehabilitation are needed. Two M&R options have been proposed to manage the surveyed surfaces: the former has a proactive approach, while the latter complies with a reactive approach. The comparison between them highlighted that the proactive option implies less costs than the reactive one, without FOD during the twenty-year analysis period.

The obtained results confirm that even in the heliport environment, despite the limited loads and traffic of rotary-wing vehicles, M&R programming through HPMS is necessary, and it should be developed according to a proactive approach. Particularly, the presented case study could be improved by carrying out regular surveys of the surface conditions in order to monitor their evolution. Ongoing technology development could support this process, and in recent years, remote sensing methodologies for pavement management and assessment have been under development. Indeed, nondestructive methods provide frequent, comprehensive, and quantitative surveys of surface infrastructures that are useful to collect data and identify critical conditions. Different heliport sites could apply the proposed process in order to implement network level maintenance strategies and to organize maintenance and rehabilitation works according to a so far not available methodological approach.

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