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Cost and time reduction in the evaluation of functional failures in flexible pavements through photographic imaging and PCI methodology.

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Abstract- Despite the importance of maintaining flexible pavements in optimal conditions to guarantee the trafficability and comfort of users, the evaluation of failures in these pavements is usually a slow and costly process. Early detection of these failures is essential to prevent them from escalating and generating higher rehabilitation costs. Furthermore, in some areas of the city of Lima, the lack of government budget and availability for road maintenance further complicates the situation. This article addresses the evaluation of functional failures in flexible pavements, incorporating the use of mobile technology and image processing through the use of the MATLAB tool compared to the conventional method of Pavement Condition Index (PCI) according to ASTM D6433. The implementation of mobile technology together with the processing of photographic images for the evaluation of the PCI of the pavement generates a saving of 44.20% of the total cost for the evaluation using the traditional method. Likewise, the implementation of this method significantly reduces the PCI evaluation time by 15% concerning the traditional method in the evaluation of functional failures in flexible pavements.

Keywords— ***Cost; time; functional failures; flexible pavements; photographic images; PCI.***

I. INTRODUCTION

Flexible pavements represent a necessary infrastructure to guarantee vehicle transit, which can affect travel time and user comfort. However, over time they can experience various failures and problems due to factors such as constant vehicle loading, adverse weather conditions, and natural wear and tear. Therefore, maintenance is very important to prevent these failures from intensifying, carrying out their evaluation and detection on the roads [1]. Unfortunately, this process tends to take a long time, generating additional costs, since as more time passes without addressing the detected failures, they are likely to worsen and further deteriorate the state in which they are found [2]. Therefore, this article uses the PCI methodology in its conventional form and with the use of photographic images proposed as an innovative methodology, which impartially classifies the quality of pavements, this is based on the results of a visual inspection. of the situation of the urban road, in which the category, severity, and density of each type of deterioration are determined. Furthermore, this is It is characterized by its simple application and does not require the use of specialized tools additional to those already integrated into the system.

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The present investigation is carried out along the entire Av. Central is located in a residential area in the city of Lima-Peru that includes 0.5 km, which presents a road of flexible pavements, where we will measure and analyze the various faults which are found as gaps, longitudinal cracks, transverse cracks, edges, and crocodile skin. Finally, the objective of this research is the evaluation of flexible pavements by incorporating mobile technology and image processing, minimizing time and reducing costs without compromising the quality of the results to streamline the process and take measures for its proper maintenance.

II. STATE OF THE ART

The article titled “Defects in Flexible Pavements: An Evaluation of the Relationship of Problems in a Low-Cost Pavement Management System” investigates the possible failures that can occur in flexible pavements and the relationships that exist between them. In addition, they provide better management to road management authorities in developing countries to be able to make effective decisions for their respective rehabilitation. This study provides the identification of the main defects in flexible pavements, such as potholes/sinking, fatigue cracks, wear and tread depth, and their relationships between them, to develop a low-cost pavement management system model [3]. The article titled “Process Improvement and Application of Pavement Management System based on Pavement Conditions in Jeju Island” develops a maintenance and rehabilitation method that proposes a satisfactory level of service for road users. Additionally, the author seeks to develop an efficient and systematic pavement management system that reflects regional characteristics, including physical and climatic factors that can affect pavement performance. To this end, he develops a pavement condition index (PCI) that reflects the characteristics of road surfaces resulting from failures and management states in a given region [4]. The article titled “Prediction of Pavement Condition Index Using Artificial Neural Networks Approach”, wishes to solve the problem of road quality assessment and maintenance in Palestine, using Artificial Neural Networks (ANN) to predict Pavement Condition Index (PCI) and prioritize rehabilitation programs to calculate budget effectively.

Likewise, it seeks to identify the main causes of failures and develop an innovative approach to estimate the PCI, considering factors such as the density and severity of the failures and the number of manholes in each section. [5]. The article titled "Using PAVER 6.5.7 and GIS Program for Pavement Maintenance Management for Selected Roads in Karbala City" provides information on pavement maintenance management based on flexible pavement deterioration, specifically on two types. of failure classified as structural deterioration and functional deterioration. Likewise, it mentions five main categories of common runway surface failures, as well as describes the use of tools and techniques to evaluate the PCI of different roads in Saudi Arabia. [6].

III. METHODOLOGY

The methodology is based on five stages as shown in Fig. 1, which were delimited based on data collection. Firstly, the delimitation of the study area was carried out, the length of the road to be evaluated was determined, which covers 0.5 km, and relevant parameters for the analysis were identified, such as vehicular traffic and the climatic conditions of the area. zone. Next, data collection was carried out from the study area, and then the conventional PCI method was applied to evaluate the pavement condition. During this process, detailed data on pavement functional failures, such as crocodile, edge, longitudinal/transverse, and void cracks, were collected by AASHTO 93 [7]. Likewise, the use of mobile technology was implemented to capture high-resolution images of the pavement surface. These images were subsequently processed using MATLAB for a detailed analysis of the pavement conditions. On the other hand, a comparative analysis of the results obtained in the previous stages was carried out, evaluating the efficiency and precision of both methods. In the final stage, a comparison is made regarding the cost and delay time in the evaluation of pavement failures by both methodologies.

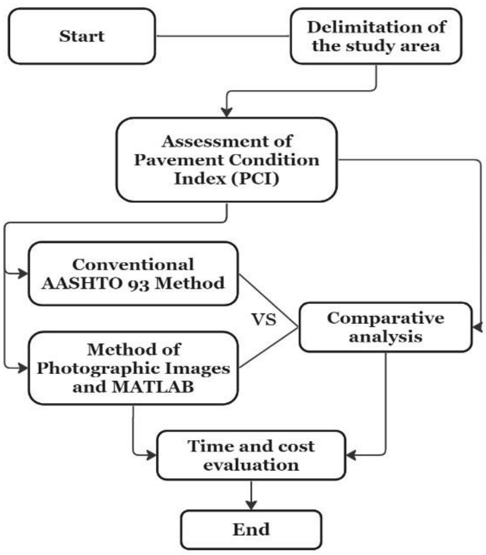

Fig. 1. Activity diagram.

IV. STUDY OF THE AREA OF ANALYSIS

The delimited study area is Central Avenue located in a residential area in Lima-Peru. There are various residences, condominiums, and some shopping centers. In addition, it is access to reach other main places. The entity in charge of managing said area is the municipality of this same district, which has few resources to be able to take charge of the rehabilitation process of these roads. For this reason, this research area was chosen, where the functional failures in the pavements of the round-trip lanes will be evaluated, comprising a total of 0.5 linear km as shown in Fig. 2, to reduce the time and cost of said process.

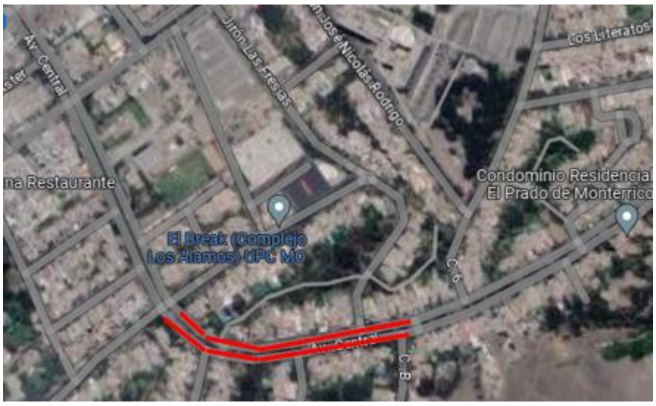

Fig. 2. Study area, Av. Central Lima- Peru.

V. ICH EVALUATION

<u>EVALUATION PROCESS</u>

ASTM D6433 [8]. It mentions that the sampling area should be 225 ± 90 m2. To do this, the width of the road on Central Avenue was measured, which is equivalent to 7.10m, to then determine the length to be divided and evaluated. In this case, 11 sample units were determined with lengths of 44 meters each, obtaining an area of 312.40 m2 per sample unit. Finally, it was classified as having the range of values shown in Figure 3 that the standard recommends.

RANK PCI%	COLOUR	STATE
0-10		Fault
11-25		Very bad
26-40		Bad boy
41-55		Regular
56-70		Well
71-85		Very good
86-100		Excellent

Fig. 3. PCI classification range, according to ASTM D6433.

VI. MATERIALS AND INSTRUMENTS

- CONVENTIONAL

To carry out the analysis of failures in the pavement network, various materials and instruments indicated in Standard ASTM D6433 [8] are used. These include 50m and 5m measuring tapes, to measure the lengths of each section and the dimensions of the identified faults, wood, or a ruler to measure the unevenness of the faults, such as gaps, to obtain accurate data. A field notebook will be used to record observations and possible altercations that may arise during data collection in the field. Likewise, there will be a dedicated record sheet or format to record in detail the identified failures, their severities, and the corresponding quantities.

• INNOVATIVE APPROACH

For the development of low-cost failure evaluation, it will not be essential to use laboratories or real projects. We will apply a methodology that serves to analyze the Pavement Condition Index (PCI). This methodology leverages mobile technology to perform a detailed assessment of pavement failures. Using photographic images as the basis for PCI analysis allows for efficient and cost-effective data collection in the field. This simplifies the process and reduces the costs associated with implementing the proposal.

Some requirements necessary to carry out the following are:

A. MOBILE DEVICE WITH HIGH RESOLUTION CAMERA TO CAPTURE DETAILED IMAGES OR VIDEOS: This facilitates accurate identification of faults and ensures quality data for analysis.

B. MATLAB SOFTWARE: This becomes an essential tool at this stage. Preprocessing techniques are applied to improve the quality of images. This may involve brightness adjustments, contrast correction, noise removal, and any other optimizations necessary to facilitate subsequent analysis. Additionally, segmentation techniques are involved to highlight flaws identified in the image, ensuring that the analysis focuses on the relevant parts of the image.

Below are the codes used in the MATLAB tool:

a) IMAGE CAPTURE: For the process of capturing images from a recorded video of pavement failures with the help of the mobile device, the following MATLAB code is used as shown in Fig. 4.

```
% Read the video file
video = VideoReader ("TRAMO X.mp4")
% Here you will the total number of
% frames in this video
numberFrames= video.NumberOfFrames;
n=numberFrames;
%Now lets access each frame of video
% by vritting a for loop

for i=1:2:n
   %vhere  n consist the total number of frames
   % this loop vill start from
   %the firts frame and vill continue untill the
   % last frame
   frames=read(video,i)
   %Here I vill save back the frames I got
   % in the directory
   imwrite(frames,['Images' int2str(i),'.jpg']);
   im(i)=image(frames);
end
```

Fig. 4. Matlab code to capture videos into images.

b) DESIGNATION OF RULE OR UNIT OF MEASUREMENT IN MATLAB: To measure the dimensions of the faults found in the images, a measurement tool is assigned in MATLAB using the code as shown in Fig. 5.

```
%Remplazar por el nombre de su imagen
I = imread('ImagesX.jpg');
%Muestra la imagen en una ventana
im = imshow(I);

%Crea 2 herramientas para medir distancia.
%La distancia esta en pixels

%Primera herramienta dTool1
dTool1 = imdistline();

%Segunda herramienta dTool2
dTool2 = imdistline();

%le ponemos color rojo
setColor(dTool2,'blue');
%cambiamos la posición
setPosition(dTool2,[1000 1500; 1000 2500]);
```

.

Fig. 5. Matlab code to assign a measurement tool.

RESULTS PRESENTATION

Once the failure measurement of the 11 sections in the field has been carried out, it is compared with the maximum deduced value to classify the state of the pavement. To understand it better, tables 01 and 02 show the results obtained with their respective colors that indicate the condition of the pavement in a range from very bad to very good.

TABLE 01.

Traditional Pavement Condition Rating Summary

PCI-MANUAL CLASSIFICATION SUMMARY					
SAMPLE UNIT	AREA (m2)	MAX V.D.	(PCI) CALCULATED	PAVEMENT CLASSIFICACTION	SIMBOLOGY
M - 01	312.4	72.08	28	BAD	
M - 02	312.4	55.70	44	REGULAR	
M - 03	312.4	64.34	36	BAD	
M - 04	312.4	82.00	18	VERY BAD	
M - 05	312.4	33.00	67	GOOD	
M - 06	312.4	71.00	29	BAD	
M - 07	312.4	68.83	31	BAD	
M - 08	312.4	28.00	72	GOOD	
M - 09	312.4	74.65	25	BAD	
M - 10	312.4	46.00	54	REGULAR	
M - 11	312.4	63.00	37	BAD	

TABLE 02.

Pavement Condition Classification Summary Imaging Methodology

PCI-IMAGE CLASSIFICATION SUMMARY					
SAMPLE UNIT	AREA (m2)	MAX V.D.	(PCI) CALCULATED	PAVEMENT CLASSIFICACTION	SIMBOLOGY
M - 01	312.4	71.67	28	BAD	
M - 02	312.4	48.49	52	REGULAR	
M - 03	312.4	74.89	25	BAD	
M - 04	312.4	82.03	18	VERY BAD	
M - 05	312.4	33.02	67	GOOD	
M - 06	312.4	71.00	29	BAD	
M - 07	312.4	61.93	38	BAD	
M - 08	312.4	30.64	69	GOOD	
M - 09	312.4	75.21	25	BAD	
M - 10	312.4	48.37	52	REGULAR	
M - 11	312.4	64.25	36	BAD	

On the other hand, the results of the total costs and times are presented according to each method applied for the evaluation of pavement failures as shown in Tables 03 and 04.

TABLE 03.

Estimated total cost of traditional PCI and PCI with photographic image methods

TOTAL COST IN THE APPLICATION OF THE TRADITIONAL PCI METHODOLOGY ACCORDING TO THE STANDARD	TOTAL COST IN THE APPLICATION OF THE TRADITIONAL PCI METHODOLOGY ACCORDING TO PHOTOGRAPHIC IMAGES
S/ 988.60	S/ 551.68

TABLE 04.

Total time spent in (days) for traditional PCI and PCI with photographic image methods

TOTAL WORKING TIME IN THE APPLICATION OF THE TRADITIONAL PCI METHODOLOGY ACCORDING TO THE STANDARD (hours)	TOTAL WORKING TIME IN THE APPLICATION OF THE TRADITIONAL PCI METHODOLOGY ACCORDING TO PHOTOGRAPHIC IMAGES (hours)
18.80	15.80

ANALYSIS OF RESULTS

Below, the results of the evaluation of the condition of the pavement are presented, taking into account all the guidelines established by the PCI and the ASTM D6433 – 18 standards [8]. Likewise, a comparative analysis will be developed regarding the results of the traditional method and the new applied technology, which is the use of a mobile phone and MATLAB software.

A. Pavement Condition Index

Accordingly, with the applied methodology, a total of 345 faults were identified in the 11 sections evaluated, of which 101 hollow-type faults, 31 crocodile-type faults, 68 edge-type faults, and 144 crack-type faults, both longitudinal and transverse, were found. In Fig. 6 you can see some of these faults found in the field where they present a medium-high severity.

Fig. 6. Failures found in the pavement with different severity.

By evaluating all the results obtained in the field and classifying them according to the status to which they belong according to the severity of each failure, it was deduced that this road is in a critical state since most of the sections have a classification of "Bad" and " Very bad" as shown in figure 02, where sections 01, 03, 07, 06, 09 and 11 have 215 faults in total, where 44.65% represents the hole, so it is in a very bad state. Likewise, sections 02 and 10 represent a regular state where the most recurrent failure is cracking with 78% of 55 failures. Finally, sections 05 and 08 present a very good and good condition, since it has 50 faults of which 34% are transverse and longitudinal cracks. Table 4 shows the summary of the number and percentage of failures in the evaluated sections.

TABLE 05.
Percentages and number of faults found in the various sections

N° OF SECTIONS	AMOUNT	% OF FALLS	FAILURE TYPES
1,3,6,7,9,11	215	44.65%	Hole
2,10	55	78%	Cracks
5,8	50	34%	Cracks

B. Image processing using Matlab

As a result of the entire route of the road through a video taken by a mobile device and by the use of codes for image processing using MATLAB software, more than 700 images were obtained approximately every 44 meters, equivalent to a stretch, of which a selection of photos was made for proper measurement and calculation of the PCI, leaving 35 to 40 images depending on the visualization of the various faults. The result of this processing, as shown in Fig. 07, revealed that section 4 is the only one in its Very Bad category, while sections 1,3,7, 9, and 11 present a Bad condition. This represents that more than 55% of the evaluation of this pathway is critical. Likewise, sections 2 and 10 have regular status, sections 5 and 6 have a good classification and finally section 8 has a very good classification.

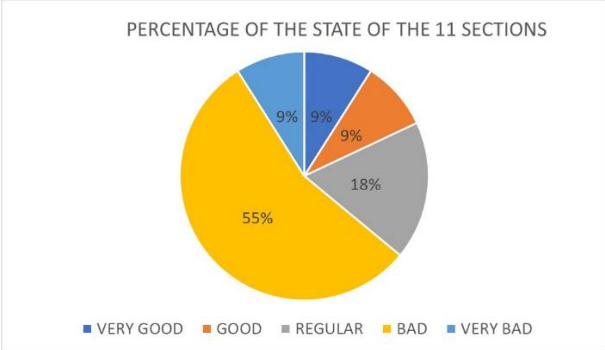

Fig. 7. Percentage of failure according to MATLAB processing.

The results of this processing are similar to what was evaluated in the field as shown in Fig. 08, since in some sections such as 8, 10, and 11 they have a difference of 1 to 3 figures greater than what is reflected in the results of the aerial research. On the other hand, sections 2,3 and, 7 do manage to exceed 8 to 11 figures. However, this does not change the condition of the pavement according to the standard table Fig. 3. Finally, it should be noted that the other sections, which are 1, 4, 5, 6, and 9, are the same as what was done in the field. In total this gives us an 86% similarity of everything evaluated in the 2 proposed ways and an error percentage of 7.45% concerning the field shot, which indicates that it does not vary in almost anything.

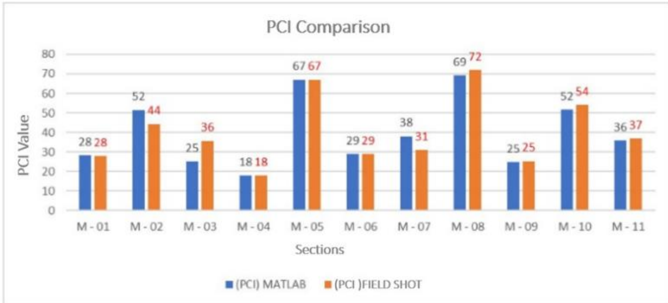

Fig. 8. Comparison between traditional PCI and photographic images.

Moreover, a detailed analysis of each section was carried out regarding the percentage of coincidence and error of what was carried out in the field and the office, giving 91.8% similarity and 8.2% error, which can be seen in Table 06.

TABLE 06.
Percentages and number of faults found in the various sections

N° SAMPLE	(PCI) IMAGES	(PCI) MANUAL	PCI MANUAL/PCI IMAGES	%ERROR BY SECTION
M-1	28.33	27.92	98.55%	1.4%
M-2	51.51	44.30	86.00%	14.0%
M-3	25.11	35.66	142.02%	42.0%
M-4	17.97	18.00	100.17%	0.2%
M-5	66.98	67.00	100.03%	0.0%
M-6	29.00	29.00	100.00%	0.0%
M-7	38.07	31.17	81.88%	18.1%
M-8	69.36	72.00	103.81%	3.8%
M-9	24.79	25.35	102.26%	2.3%
M-10	51.63	54.00	104.59%	4.6%
M-11	35.75	37.00	103.50%	3.5%
		% FINAL ERROR		8.2%
		% COINCIDENCE		91.8%

Likewise, a detailed analysis was carried out about two important aspects: the time and cost associated with collecting and processing data collected from the study area. The evaluation of these two elements is a fundamental pillar to understanding operational efficiency and strategic resource management, which offers a precise vision of the temporal performance and economic investment of the task performed.

C. *Analysis of cost and time in the manual evaluation of PCI according to ASTM D6433 Standard VS analysis of cost and time in the evaluation of PCI through photographic images*

For both cases, the cost per hour worked by one (1) field support staff for data collection was evaluated, taking into account that the cost per day is S/. 59.80 according to the FTCCP (2023-2024). Likewise, other common expenses were considered, such as food and transportation for staff. All this is for on-site work, that is, data collection in the field. The cost is detailed in Table 07.

TABLE 7.
Cost of the day for support staff traditional method ASTM D6433 standard

	Concept	Quantity	Hours	Daily Wage/Cost	Unit Cost (soles)	Total Cost (soles)
Indirect cost	Personnel	1	6	S/ 59.80	S/ 44.85	S/ 44.85
	Food	1	0	S/ 20.00	S/ 20.00	S/ 20.00
	Transportation fare	1	0	S/ 8.00	S/ 8.00	S/ 8.00
TOTAL					Field Personnel (per 6 hours)	S/ 72.85
					Office Personnel (per 6 hours)	S/ 64.85

For data collection with the traditional method, an average of 6 hours of work per day was estimated, thus having a total of S/. 72.85 per day. Likewise, for office work personnel with a total of S/. 64.85 per day, deducting the cost of the ticket.

Regarding data collection by applying the methodology of photographic images, the following is available:

TABLE 08.
Cost per day for support staff method photographic images

	Concept	Quantity	Hours in the field	Hours in the office (H)	Daily Wage/Cost	Unit Cost (soles)	Total Cost (soles)
Indirect cost	Personnel	1	0.3	6	S/ 59.80	S/ 2.11	S/ 2.11
	Food	1	0	0	S/ 20.00	S/ 20.00	S/ 20.00
	Transportation fare	1	0	0	S/ 8.00	S/ 8.00	S/ 8.00
TOTAL						Field Personnel (per 6 hours)	S/ 30.11
						Office Personnel (per 6 hours)	S/ 62.21

An average of 0.3 hours of work per day was estimated (video recording of the section), thus having a total of S/. 30.11 per day in the field. Likewise, for office work personnel with a total of S/. 62.21 per day, deducting the cost of the ticket and considering 6 hours of work.

From what was shown above, it can be seen that there is a considerable cost reduction in terms of the payment of support personnel per day, this varies by the number of hours worked in a day. For data collection by the traditional method, it was calculated as 6 hours, while for the photographic image method only 0.3 hours.

On the other hand, the costs for materials, tools, accessories, and services used to obtain the PCI by both methods used in the study area were evaluated.

Below are the costs of each of the tools and materials used on-site to collect data for the evaluation of pavement failures in its traditional method as governed by the ASTM D6433 standard, as shown in table No. 09.

TABLE 09.
Cost of tools and material for data collection traditional method ASTM D6433 standard

	Supplies	Unit	Quantity	Unit Cost (Soles)	Total Cost (Soles)
Indirect cost	Board	und	4.00	7.00	S/ 28.00
	Record sheet	und	50.00	0.10	S/ 5.00
	Pen	und	4.00	2.00	S/ 8.00
	5-m tape measure	und	4.00	19.90	S/ 79.60
	50-m tape measure	und	1.00	54.90	S/ 54.90
	Chalk	und	10.00	0.50	S/ 5.00
	Cones	und	2.00	20.00	S/ 40.00
	Vests	und	4.00	13.90	S/ 55.60
	TOTAL				S/ 276.10

The tools and materials shown in Table 09 were used and a total of S/. 276.10 in the acquisition of them.

Likewise, Table No. 10 shows the costs of the tools and services used to collect data for the evaluation of pavement failures according to the photographic image method.

TABLE 10.
Cost of tools and material for data collection using photographic images.

	Supplies	Unit	Quantity	Unit Cost (Soles)	Total Cost (Soles)
Indirect cost	Camera	und	1.00	50.00	S/ 50.00
	Vehicle	und	1.00	70.00	S/ 70.00
	Electrical Services	mes	2.00	30.00	S/ 60.00
	Computer	mes	2.00	propio	
	Internet Services	mes	2.00	90.00	S/ 180.00
	TOTAL				S/ 360.00

For the method of photographic images, the materials and services shown in Chart 10 were used, which estimated a total of S/. 360.00 in the total cost for the PCI evaluation.

The total labor cost in collecting data for the evaluation of pavement failures using both methods already mentioned is detailed below. Taking into account the number of hours worked, the number of days worked, and the number of personnel required per day

With the traditional method, a total cost of S/. 582.80 in labor for data collection. Because this collection was carried out in 6 hours, with a quantity of 8 personnel.

On the other hand, with the use of the photographic image method. A total cost was estimated at S/. 30.11 in labor for data collection. Because this collection was carried out in 0.5 hours, with 1 support staff.

Table 9 shows the comparison of cost and time between the traditional methods and images.

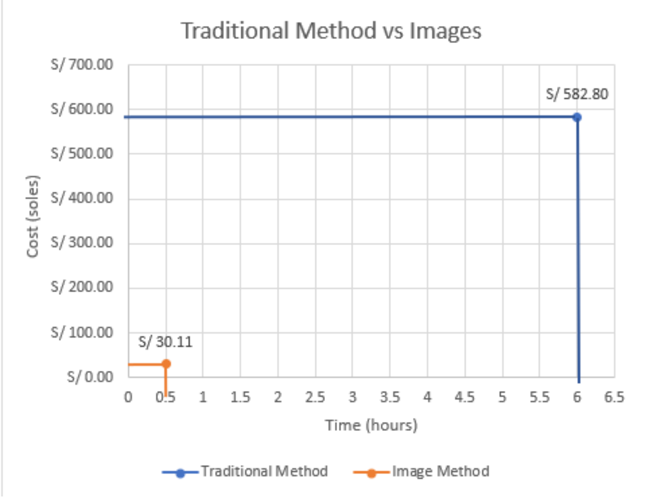

Fig. 9. Comparison of cost and time in data collection Traditional method vs images.

Finally, the time and total cost of work carried out for the evaluation of pavement failures in the office for both methods were evaluated.

By the traditional method governed by ASTM D6433[8]. A total cost was estimated at S/. 129.70 taking into account that there are two personnel to carry out said activity. Moreover, a total of 770 minutes equivalent to 12.8 hours were estimated between both personnel to carry out this evaluation and obtain the final results as shown in Table 12.

TABLE 11.

Total time in the application of the PCI methodology for the traditional method

Traditional Method	Quantity	Unit
Total estimated days for pavement evaluation in the field, traditional method	6	Hours
Total estimated days for pavement evaluation in the office, traditional method	12.8	Hours
Total hours worked	18.8	Hours

In the same way, the analysis was carried out for the method with photographic images and a total cost of S/. 161.57 taking into account that there are two personnel to carry out said activity. Also, a total of 935 min was estimated, equivalent to 15.5 hours between both personnel, to carry out this evaluation and obtain the final results as shown in Chart 12.

TABLE 12.

Total time in the application of the PCI methodology for photographic image methodology

Metodo Imágenes fotograficas	Quantity	Unit
Total estimated days for pavement evaluation in the field with images	0.3	Hours
Total estimated days for pavement evaluation in the office with images	15.5	Hours
Total hours worked	15.8	Hours

The total costs of the application of both methods for the evaluation of PCI in the pavement are presented below.

The following table 13 shows the total cost of the evaluation of pavement failures by both methods, considering the first day of the data collection, calculation of the PCI, and materials used in said activity.

TABLE 13.

Total cost in the application of the PCI methodology for both methods.

Method	Activity	Cost (Soles)	Total Cost (Per method)
Traditional ASTD64 33	Data collection	582.80	S/ 988.60
	Office work	129.70	
	Materials	276.10	
Photographic Images	Data collection	30.11	S/ 551.68
	Office work	161.57	
	Materials	360.00	

These total values were estimated with the sum of the partial costs. For example, for the traditional method: the labor cost in data collection of S/. 582.80, the cost of cabinet work S/.129.70, and the tools and materials used: S/. 276.10 in this way obtaining a total sum of S/. 988.60. On the other hand, for the photographic image method, the labor cost in data collection was demonstrated to be S/. 30.11, the cost of cabinet work S/.161.57, and the tools and materials used: S/. 360.00 in this way obtaining a total sum of S/. 511.68. Figure 09 shows a graphical representation of the total cost of both methods.

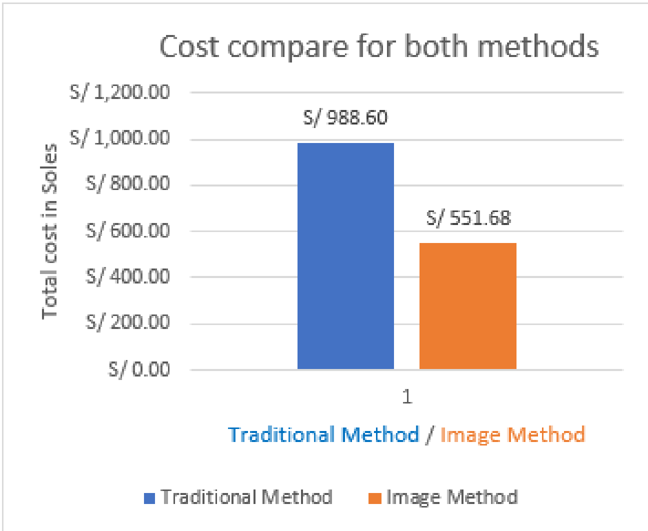

Fig. 10. Comparison of times between both methods

Based on the cost of the traditional method (S/. 988.60), it can be estimated that the cost generated by the photographic image method (S/. 551.68) is 55.80% of the total cost. In this way, it is estimated that the savings are 44.20% compared to the traditional method.

On the other hand, the total time (in hours) was estimated as shown in tables 09 and 10 used to carry out the PCI evaluation on the selected Av. by both methods explained above.

A total of 18.8 hours of work was estimated both in the field: in data collection; in the office: and failure evaluation. To obtain the PCI according to the traditional method as indicated in the ASTM D6433 standard [8]. According to the method of photographic images, a total of 15.8 hours of work was estimated both in the field: data collection; and in the office: failure evaluation. This comparison is shown in Figure 10.

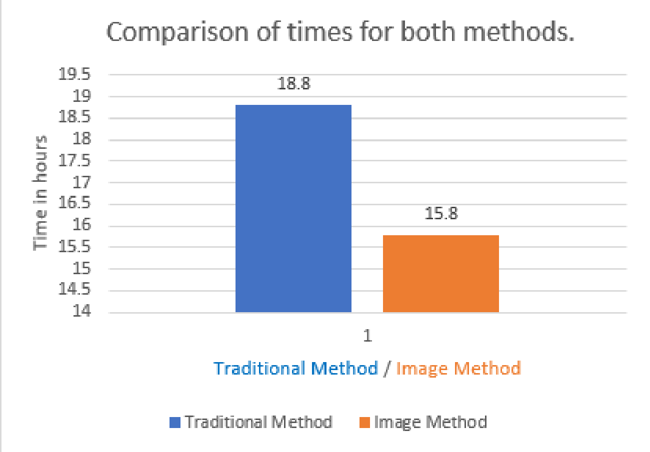

Fig. 11. Comparison of times between both methods

From the above, it can be stated that the time used for the PCI analysis of the pavement is less compared to the photographic image method, while the traditional method is 15% longer.

CONCLUSIONS

The evaluation of failures in flexible pavements through the traditional PCI method is a process that requires considerable time and the need for personal dedication. This leads to higher costs, both for the acquisition of tools and for the hiring of labor, added to the expenses associated with lunches and other necessary resources. This is stated because the total cost value for the traditional method is S/. 988.60, while using the method of photographic images a value of S/. 551.88.

The implementation of mobile technology together with the processing of photographic images for the evaluation of the PCI of the pavement generates a saving of 44.20% of the total cost concerning the evaluation using the traditional method according to the ASTM D6433 standard.

The implementation of the photographic image method through MATLAB significantly reduces the evaluation time (15.80 hours) of the PCI by 15% compared to the traditional method (18.8 hours) in the evaluation of functional failures in flexible pavements. Additionally, this approach allows the assessment to be carried out remotely, either from an office or even from home.

MATLAB software is viable to easily detect various pavement failures since it allows the use of technology such as mobile devices, which provides a reduction in time and cost, which is useful for good management. In addition, it was possible to identify the sections with the highest critical status.

The validation of the use of this technology to detect the condition of the pavement has been satisfactory. Data collected in the field were compared with data from image processing. The validation was based on the detection of the severity of each of the failures to be able to classify them by the ASTM D6433 standard and then be able to obtain the PCI and values that show a very strong classification of the information carried out in the field. Having a coincidence percentage of 91.8% and an error of 8.2%, which means that this research can be used in various flexible pavement condition evaluation projects.

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