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Technical Analysis Applied in the Inspection of Distress on the Surface of Asphalt Pavement using Remotely Piloted Aircraft (RPA)

Análise Técnica Aplicada na Inspeção de Danos na Superfície de Pavimentos Asfálticos Utilizando Aeronaves Remotamente Pilotadas (ARP)

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Abstract:

The transport sector can be considered one of the most important in promoting urban mobility in Brazil. The lack of efficient road planning and transport greatly affects people's daily journeys. Another important factor is the increase in the number of vehicles in Brazilian municipalities, which also contributes to the negative outlook regarding traffic in Brazil. This work aimed to use Remotely Piloted Aircraft (RPA) to obtain images that enable analyzes of the surface conditions of the asphalt pavement. The place where the study was carried out was the BRT TransOeste corridor in Rio de Janeiro, which connects the Barra da Tijuca region to Santa Cruz and Campo Grande, passing through Guaratiba and Recreio dos Bandeirantes. The following procedures were adopted: flight planning with RPA, observing the Ground Sample Distance (GSD) recommended by scientific literature, field support using Global Navigation Satellite System (GNSS) Networked Transport of Radio Technical Committee for Maritime Service (RTCM) via Internet Protocol (NTRIP) technology, processing of images obtained using Agisoft software, generation of orthophoto orthorectified and assessment of distress on the asphalt surface based on the analysis of images obtained with RPA using the Pavement Condition Index (PCI).

Keywords: Highways; Photography; Pathologies on the asphalt surface

Resumo:

O setor de transportes pode ser considerado um dos mais importantes na promoção da mobilidade urbana no Brasil. A falta de um planeamento rodoviário e de transportes eficientes afeta grandemente as viagens diárias das pessoas. Outro fator importante é o aumento do número de veículos nos municípios brasileiros, o que também contribui para o panorama negativo em relação ao trânsito no Brasil. Este trabalho teve como objetivo utilizar Aeronaves Remotamente Pilotadas (RPA) para obtenção de imagens que possibilitem análises das condições superficiais do pavimento asfáltico. O local onde o estudo foi realizado foi o corredor BRT TransOeste, no Rio de Janeiro, que liga a região da Barra da Tijuca a Santa Cruz e Campo Grande, passando por Guaratiba e Recreio dos Bandeirantes. Foram adotados os seguintes procedimentos: planejamento de voo com RPA, observação da Ground Sample Distance (GSD) recomendada pela literatura científica, apoio de campo utilizando tecnologia Global Navigation Satellite System (GNSS) Networked Transport of Radio Technical Committee for Maritime Service (RTCM) via Internet Protocol (NTRIP), processamento de imagens obtidas através do software Agisoft, geração de ortofoto ortorretificada e avaliação de desgaste no asfalto superfície com base na análise de imagens obtidas com RPA utilizando o Pavement Condition Index (PCI).

Palavras-chave: Rodovias; Fotogrametria; Patologias na superfície asfáltica

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1 Introduction

The Public Transport System is an articulated set of different means of transporting passengers in a city and aims at greater connectivity in public space with equitable access and low cost. This system aims to "provide efficient, fast, comfortable and safe travel for people" (Tejada 2002).

According to Ciriquian and Medina (2018) urban mobility and investments in public transport began to be seen within the integrated system that seeks the combined use of different mechanical means, such as trams, buses, trains, subways, etc.

According to Tomasiello (2016), transport is made up of three elements: i) the supply of infrastructure (location); ii) passenger demand; and iii) the comparison between the first two that provides information on traffic, travel time, service costs and effort to reach a destination.

In addition, it also has three types of services: i) private, which means it is operated by the owner and circulates on the lanes/roads provided by the state; ii) rented transport, which is used by those who pay a fee for the vehicle such as taxi or Uber; and iii) public, which is transport that operates with fixed routes and pre-determined times, has fixed payment and is used by anyone (Universidad Del Cuyo 2017).

Thus, for Hernández (2017) public transport plays a fundamental role in facilitating people's access to opportunities available in territories, in addition to the capacity to produce and reproduce social structures. Unlike other means of transport, such as private transport, public transport imposes a smaller financial burden on users, making it the means of transport that most democratizes mobility in theory.

Several works are found in the literature whose objective is to detect distress in asphalt pavements from aerial images obtained by RPA, whether using neural networks, techniques related to texture, and even some that make use of more modern techniques such as Machine Learning (Castelo Branco 2016). Nowadays in literature we can that RPA constitute an emerging technology in the transport context (Herold & Roberts 2005; Herold et al 2008).

RPAS is a technology resulting from disruptive innovation that has significantly increased efficiency and productivity in various sectors of the economy, such as Engineering, Environment, Precision Agriculture, Energy, Mining, Cartography, Archeology, Public Security, among others. The use of geotechnologies is increasingly present in engineering work because it is a quick way to acquire information and, in the specific case of RPAS, has a low implementation cost.

2 Methodology

The methodology adopted for the development of the project in question consisted of several sequential steps that correspond to the project implementation phases, as highlighted in the diagram in Figure 1.

Next, the main materials and methods that were used in this research will be presented, considering the study area, the motivation for choosing the area to carry out the work in question, as well as the specifications of the equipment and software used in the entire mapping process. It is worth remembering that to classify distress, the DNIT 005/2003 standard was used (DNIT 2003): distress in flexible and semi-rigid pavements: terminology and the work published by Fernandes Jr. et al (2022). The main types of distress are fatigue cracking, rutting, corrugations, potholes or pans and patches.

2.1 Study Area

BRT represents articulated transport that travels in an exclusive corridor and, therefore, is a faster travel alternative for passengers. In the city of Rio de Janeiro, the BRT was inaugurated in June 2012, with the TransOeste corridor, connecting the neighborhoods of Santa Cruz and Barra da Tijuca. The system also has two other corridors: TransCarioca and TransOlímpica, opened, respectively, in 2014 and 2016 (Figure 2). The place where the study was carried out is a section of the BRT Transoeste corridor in Rio de Janeiro, which connects the Barra da Tijuca to Santa Cruz and Campo Grande, passing through Guaratiba and Recreio dos Bandeirantes. Within this corridor, the study area in question is the connection between Pontal station, to Dom Bosco station, which corresponds to a strip approximately 750m long, indicated by the red fill yellow rectangle below.

2.2 Remotely Piloted Aircraft (RPA)

For the images aquisition, the RPA Phantom 4 Pro from the DJI brand, owned by one of the authors of the article, was used (Figure 3). The aircraft is equipped with a 20-megapixel 1-inch sensor capable of recording 4K video. Additionally, its Flight Autonomy system includes two rear vision sensors and infrared detection systems for a total of 5 obstacle detection directions and 4 obstacle avoidance directions. Along with the radio control, a smartphone was used that connects to the radio control via Bluetooth technology to upload data. This device was used to upload flight plans and monitor the BRT Transoeste mapping process. The PIX4D Capture software was used for flight planning and for monitoring during the Phantom 4 Pro flight, the application used was DJI GO 4.

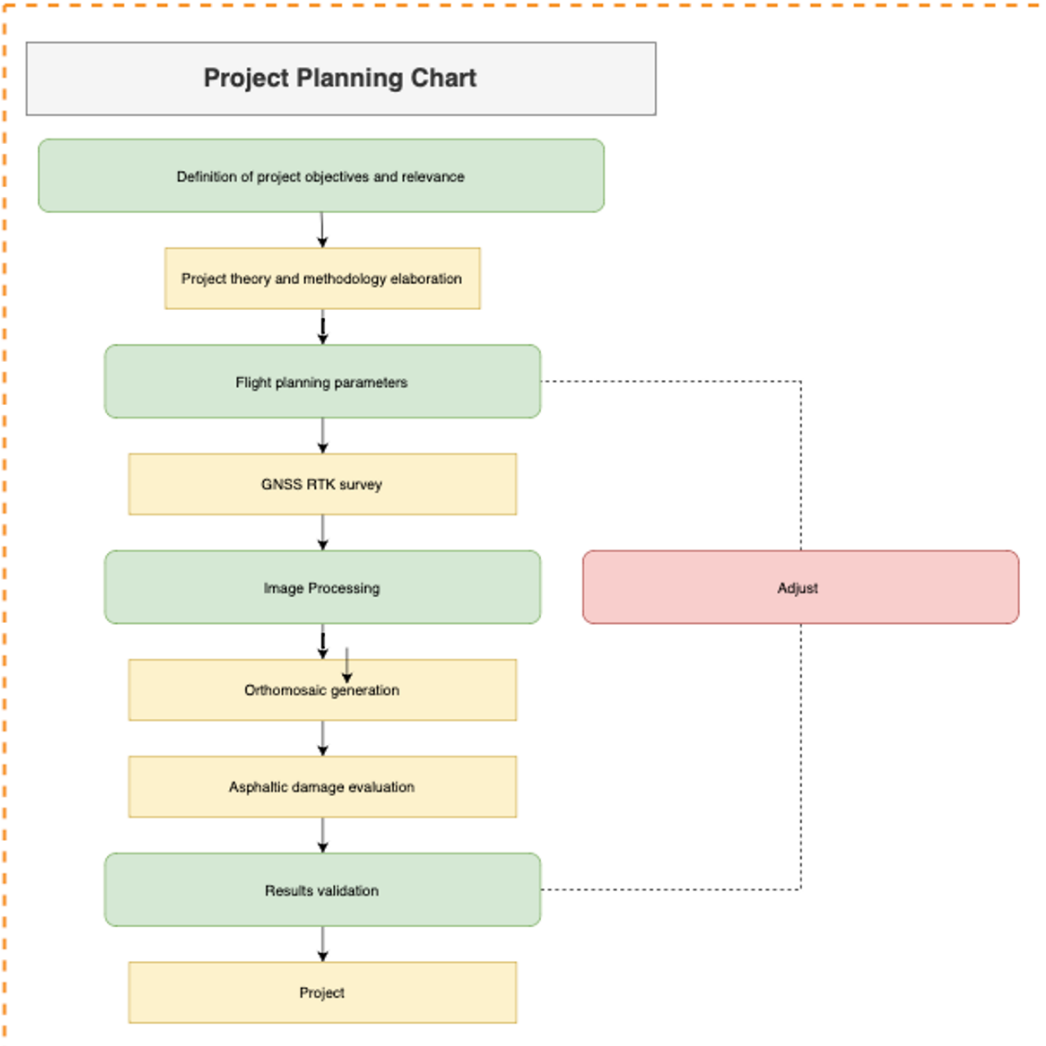

Figure 1 Project development stages.
Source: Authors (2023).

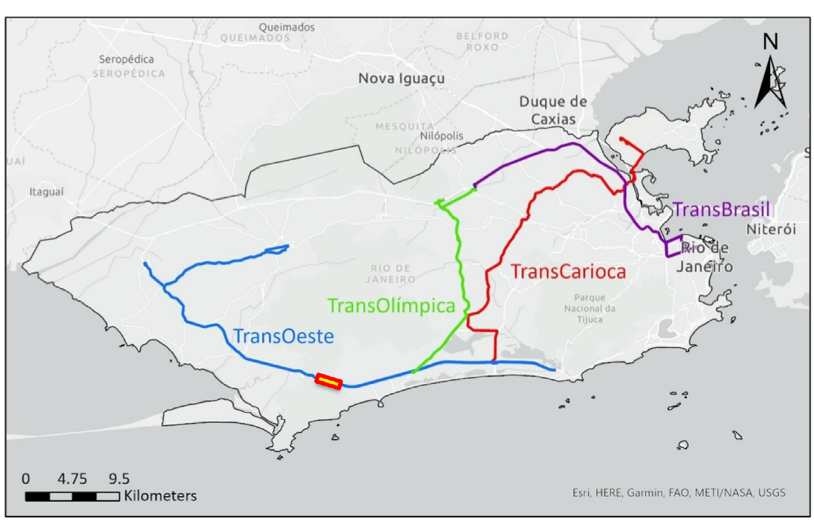

Figure 2 Location of study area: BRT Transoeste corridor between Dom Bosco and Pontal Stations marked yellow.
Source: Adapted from Drost (2021).

Figure 3 RPA equipment used.
Source: Adapted from TechReview (2023)

2.3 Field Survey

Real-time relative positioning called Real-Time Kinematic (RTK) has been widely used, as it allows the user to determine their accurate position in real time (Barbosa et al 2010).

This method can achieve centimeter accuracy, without the need for further data processing, if the solution to the ambiguities obtained is reliable (Dai et al 2003). In network RTK, instead of just one reference station, there are several continuous monitoring stations connected to a central server, from which correction data is distributed to mobile receivers via the Internet INCRA (2013), as shown in Figure 4.

A network RTK service is provided free of charge by Brazilian Institute of Geography and Statistics (IBGE), which provides correction data via the Internet protocol known as Networked Transport of RTCM (Radio Technical Committee for Maritime Service) via Internet Protocol – NTRIP (INCRA 2013). The possibility of performing kinematic relative positioning in real time, using this service, has greater precision in locations located close to reference stations of the Brazilian Network for Continuous Monitoring of GNSS Systems (RBMC).

To collect the mapping control points, a CHC brand GNSS X900U+ receiver was used (Figure 5), it is a Post-Processed GNSS with 432 channels and the possibility of correction via RTK NTRIP (CHC 2023)

In the field, when using the GNSS receiver following the surveyed path, the collected coordinates are corrected and sent via the cell phone's internet, constantly through the GNSS base, which in the case of the work in question, was the RBMC (Brazilian Continuous Monitoring Network) station identification as ONRJ, located inside the National Observatory in Rio de Janeiro (SAT Code: 93921.37), since with the distance between the reference station and the study area of approximately 30 km, it was possible to obtain results with horizontal and vertical accuracies of less than 5 and 7 cm, respectively.

2.4 Planning and Flight

For the planning flight, some properties of the RPA must be considered, such as the sensors, the autonomy of the battery system and the image overlay with the aim of pre-determining the characteristics of the cartographic products that are desired to be obtained (Silva and Botelho 2017)

In Brazil, RPAS has been gradually evolving with the dissemination of technology, allowing access and use in different sectors and, as a result, the definition of rules regarding flying are very recent. The National Civil Aviation Agency (ANAC) put into force the regulation, known as "RBAC-E 94" (Special Brazilian Civil Aviation Regulation No. 94/2017), in May 2017 (ANAC 2017). Currently, there are several standards and requirements for an RPAS flight is carried out. Presently the 3 main bodies that regulate the use of RPAS in Brazil are: National Telecommunications Agency (ANATEL), Airspace Control Department (DECEA) and ANAC, mentioned before.

A flight authorization was requested from DECEA, a check was carried out on the aircraft systems, as well as the RPA and radio control batteries. Furthermore, it was ensured that the RPAS had its document linked to the Brazilian Unmanned Aircraft System (SISANT) up to date. On the ground, analyzes were also carried out to verify that there were no obstructions that could impede the flight. Using the

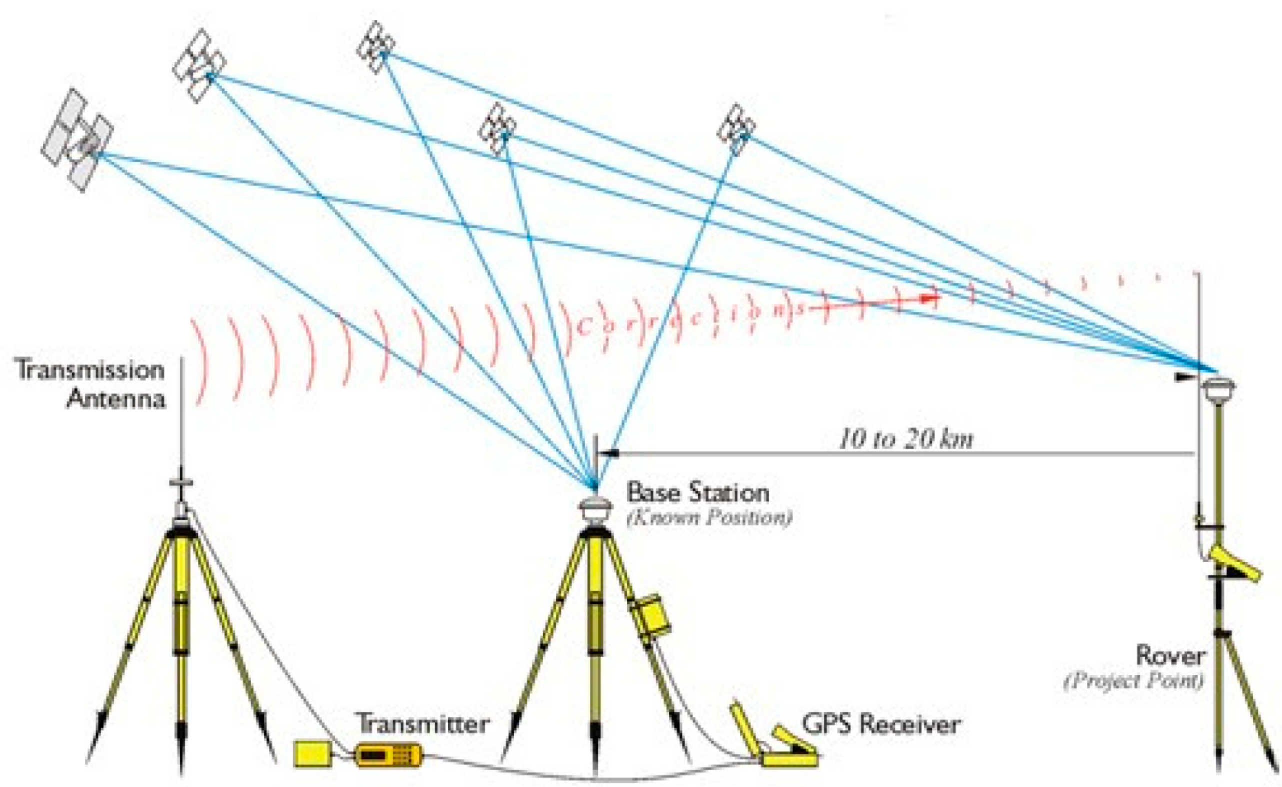

Figure 4 Network RTK method.
Source: Adapted from Van Sickle (2015).

Figure 5 GNSS receiver used.
Source: Adapted from CHC (2023).

Pix4D Capture application, flight planning was carried out to obtain images to generate the orthorectified orthomosaic. Normally, in conventional photogrammetry, the longitudinal superposition used in images along the flight range is 60% and lateral superposition of 20% (Haala 2011).

It is worth remembering that the higher the overlap rate, the greater the abundance of photos and tie-in points between them. Therefore, the flight was carried out on May 22, 2021, in the morning, with the following photogrammetric parameters: 80 meters high and longitudinal and lateral overlaps of 75% (seventy-five percent). It is necessary to guarantee at least 60% lateral overlap and 70% longitudinal overlap (Ferreira et al 2013).

Lateral and longitudinal overlaps have an influence on the quality of the generated orthomosaic, since the greater the overlap, the greater the number of common points that the computational algorithm will detect. The Ground Sample Distance (GSD) is directly linked to the drone's flight height when mapping. It was defined that the recommended value for the objective of this work corresponds to 2.5 cm.

A corridor mapping is characterized by a long, narrow area. This type of technique is very common, especially on highways. The chosen flight direction was Southeast – Northwest, precisely so that the flight range would be longer, making the RPA gain battery autonomy throughout the flight. In total, three flight lanes were needed to cover the BRT Transoeste area between Pontal and Dom Bosco stations, as shown in Figure 6.

Normally, at least 5 control points are used, distributed homogeneously, covering the entire area over which the aerial survey with RPA will be carried out. Considering the objective of mapping, the precision required for the final product, as well as in very large areas that have significant variation in altitude, it is possible that a greater number of control points will be allocated. Hence, the greater the number of control points, the better the products generated, this quantity will depend on the extent of the area that you wish to survey (Brito 2007).

However, it is worth checking to what extent it is economically viable to install so many control points. In this work, 12 support points were collected within the area of interest, as shown in Figure 7, to support the RPAs survey. These points were raised using the RTK NTRIP technique. It should be noted that 1 point was removed from the survey due to a high positional error. Finally, the distribution was as follows:

- 8 points were used as control points;
- 3 points were used for checking.

2.5 Data Processing

Data processing was carried out with the Agisoft Metashape software version 1.5.3 (AGISOFT 2020) which is software for aerial photogrammetry with the ability to analyze images taken by RPA to generate digital cartographic models such as points clouds, georeferenced orthomosaics, Digital Terrain Model (MDT) and Digital Surface Model (MDS), measurement of area, volume, distances. It is worth mentioning that for the work in question, the evaluation license offered by the platform was the trial version.

Aligning the images is the first stage of execution in the workflow where the Phototriangulation process is carried out, which is the photogrammetric technique, where, through the search for homologous points, the terrain coordinates are determined in relation to a reference. As a result of this technique, the cloud of mooring points is generated, which has the function of materializing the terrain coordinate system. At this stage, support points collected in the field are also inserted, used to improve the positional accuracy of the point cloud. In total, 147 images of the terrain were obtained during the RPA flight, which went through this process to generate the sparse point cloud.

After aligning the photos and generating the sparse point cloud, the dense cloud is generated. The main function of this step is to densify the sparse point cloud. In this case, the software increases the number of points in the cloud, reducing empty spaces to better represent the mapped area. The dense cloud is the basic product that serves as the basis for generating digital terrain and surface models. From the dense cloud, it is possible to generate three-dimensionais surfaces in the terrain software in question. The 3D model is interesting due to its ability to faithfully represent the three-dimensionally mapped terrain.

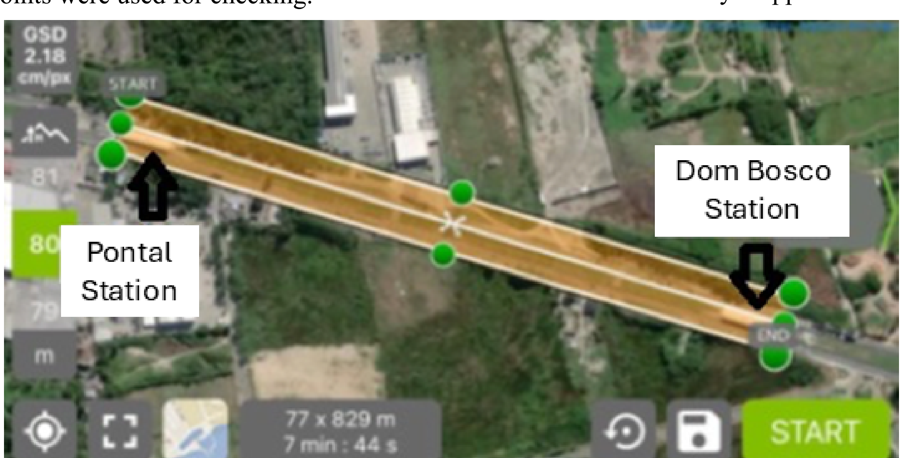

Figure 6 Flight planning.
Source: Authors (2022)

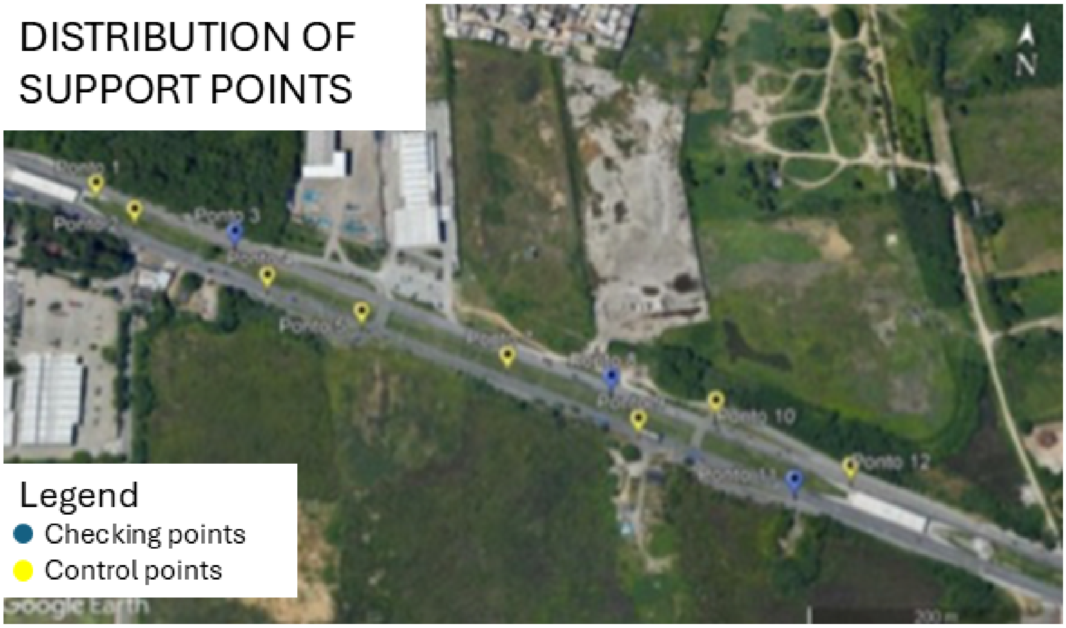

Figure 7 Distribution of support points.
Source: Authors (2022).

2.6 Assessment of Distress on the Asphalt Surface

Generally, the survey of distress in the field is carried out on site using spreadsheets, where the severity level and dimensions of the respective distress are noted for each type of distress. To do this, it is necessary to close the road during the day, which makes the work difficult, as depending on the location, the closure is only permitted at night, making it difficult to carry out the field assessment.

In this work, the survey of pavement surface distress was carried out based on the evaluation of images obtained by RPA. To map the distress, the study section was divided into 5 sections of 150.0 m in length, as shown in Figure 8.

The field survey involves marking the areas affected by different types of distress, which can be represented by appropriate symbols (Figure 9) and identified by a number corresponding to the type of distress, followed by the severity level (Low, Medium, High). So, for example, a patch (distress 7) with medium severity is identified as "7M".

3 Results

It is important to highlight that the purpose of this work is not to evaluate the accuracy of the cartographic product resulting from flight processing in Metashape. When building the Digital Elevation Model (DEM), the products generated are a 2D representation in raster format (image) of the digital surface model. It is a georeferenced matrix where each pixel has an elevation value. For the work in question, this is the most important product for the study, as it allows, among other features, a visual interpretation linked to the geometric calculation of asphalt surface irregularities. With the studies carried out using the methodology described in this document, it was possible to analyze the products obtained by the aerial survey, mainly the orthomosaic, from the perspective of Transport Engineering guidelines for classifying and measuring asphalt surface irregularities. Based on the statistical results contained in the Agisoft Metashape Processing Report after data processing, it is possible to verify the accuracy of the aerial survey. Table 1 presents the error estimate in X, Y, Z and for XY direction.

It was found that the survey obtained a planimetric error of approximately 5 cm and an altimetric error of approximately 2 cm, which is a very satisfactory result for identifying and characterizing asphalt surface faults. Since, for engineering work carried out with RPA, centimeter accuracy is expected and meets the requirements.

According to Costa and Amorim (2009), the average Ground Sample Distance (GSD) is one of the most important variables to be previously defined in aerial mapping, responsible for the level of detail desired in orthophotos. It is the representation of an image's pixel in terrain units, and is directly related to the flight altitude. In aerial photogrammetry, GSD is one of the most important variables that guarantees the spatial resolution of the work. It is worth mentioning that your choice directly influences the sharpness of the mapping. In the research being carried out, the average GSD obtained by aerial survey was 2.18 cm/pixel. Which means that one pixel of the image will represent an average of 2.18 cm of the terrain.

Figure 8 Division into 150.0 m long sections.
Source: Authors (2022).

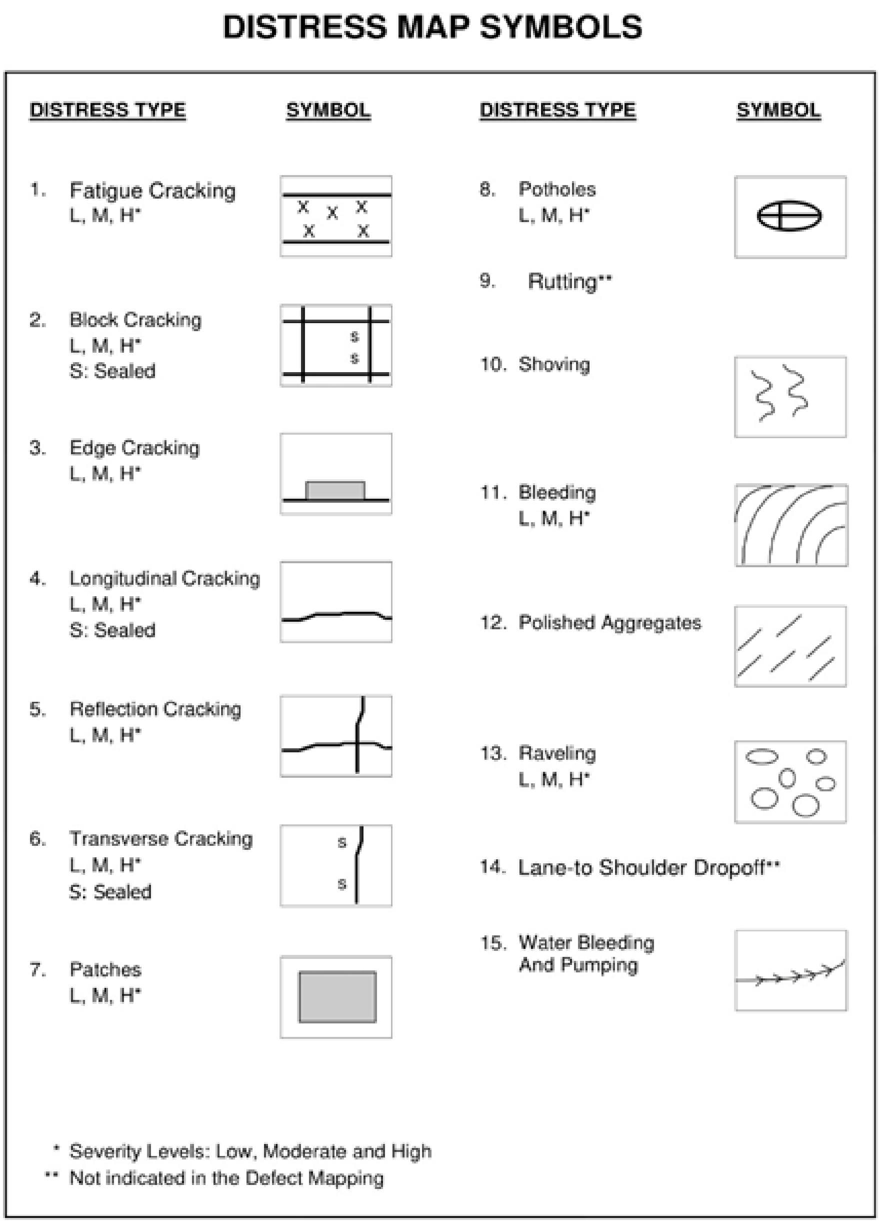

Figure 9 Symbols used to represent distress.
Source: Fernandes Jr et al (2022) adapted from SHRP (1993).

Table 1 Error estimations.

X error (cm)	Y error (cm)	Z error (cm)	Planimetric error (cm)	Total error (cm)
3.570	4.043	1.832	5.394	5.697

Source: Authors (2022).

For engineering purposes and for the work in question, this spatial resolution is quite satisfactory as visual clarity of details was achieved. Considering that the spatial resolution obtained is in accordance with that recommended for identifying asphalt surface faults, planimetric measurements can be carried out with sufficient precision.

From the images obtained by RPA, the conditions of the asphalt pavement surface were assessed, where the identified distress were mapped using the corresponding symbols, as well as the severity level (Figure 10).

Figure 11 shows the spreadsheets filled in with the results of the distress survey of Section 01.

From the evaluation of the images obtained by RPA, it was possible to verify that all sections had already been subjected to intervention, where the main maintenance activity was patching. However, the quality of the existing patches is very low, and in several sections the presence of potholes or pans can be observed. Furthermore, in places where interventions have not yet been carried out, high severity fatigue cracking are also present and are visible in the images produced by RPA. Figure 12 clearly shows the presence of distress (patches, potholes, and fatigue cracking) in Section 01.

Figure 10 Mapping of distress in Section 01.
Source: Authors (2022).

WORKSHEET 1

DISTRESS SURVEY IN THE FIELD

SECTION IDENTIFICATION: SECTION 1
DIRECTION: Pontal Station - Dom Bosco Station
SURVEY DATA (DAY/MONTH/YEAR):
TECHNICIANS:

DISTRESS TYPE	SEVERITY LEVEL LOW	MODERATE	HIGH
1. FATIGUE CRACKING (m^2)	0,0	0,0	116,8
2. BLOCK CRACKING (m^2)	0,0	0,0	0,0
3. EDGE CRACKING (m)	0,0	0,0	0,0
4. LONGITUDINAL CRACKING (m)			
4a. Wheel path longitudinal cracking sealed (m)	0,0	10,2	0,0
4b. No wheel path longitudinal cracking sealed (m)	0,0	0,0	0,0
5. REFLECTION CRACKING			
Number of cracks	0	0	0
Transversal cracking (m)	0,0	0,0	0,0
Sealed	0,0	0,0	0,0
Longitudinal cracking (m)	0,0	0,0	0,0
Sealed	0,0	0,0	0,0
6. TRANSVERSAL CRACKING (m)			
Number of cracks	0	0	0
Extension (m)	0,0	0,0	0,0
Sealed	0,0	0,0	0,0
7. PATCHES (Number)	0	2	7
Area (m^2)	0,0	175,5	157,3

WORKSHEET 2

DISTRESS SURVEY IN THE FIELD

SECTION IDENTIFICATION: SECTION 1
DIRECTION: Pontal Station - Dom Bosco Station
SURVEY DATA (DAY/MONTH/YEAR):
TECHNICIANS:

DISTRESS TYPE	SEVERITY LEVEL LOW	MODERATE	HIGH
8. POTHOLES (Number)	1	5	1
Area (m^2)	0,4	5,0	2,0
9. RUTTING (% of section extension)	0,0	0,0	0,0
10. SHOVING (Number)	0	0	0
11. BLEEDING (m^2)	0,0	0,0	0,0
12. POLISHED AGGREGATES (m^2)	0,0	0,0	0,0
13. RAVELING (m^2)	0,0	0,0	0,0
15. WATER PUMPING (Number)	0	0	0
Extension (m)	0,0	0,0	0,0
16. OTHER (Describe)	0,0	0,0	0,0

OBSERVATION:
REGISTER "0" FOR DISTRESS TYPES AND/OR SEVERITY LEVEL NOT FOUND.

Figure 11 Distress survey spreadsheets for Section 01.
Source: Haala (2011).

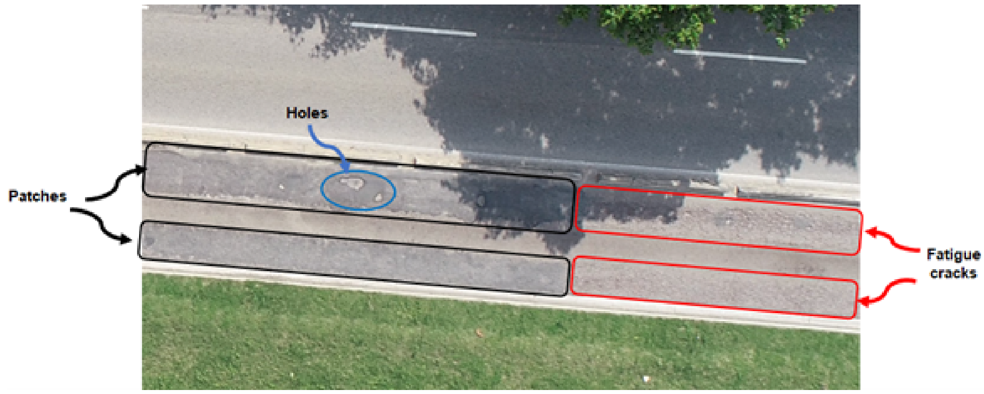

Figure 12 Presence of patches, potholes, and fatigue cracking in Section 01.
Source: Authors (2022).

With the results of the distress assessment, the pavement condition index, PCI, was determined. To this end, the dimensions and severity of each distress identified in the pavement presented in Figure 11 were considered. Considering the dimensions and severity, certain distress has a greater influence on the loss of the pavement's usefulness, which can reduce its useful life. Therefore, each severity level of a given distress must be associated with a weighting factor, wf. Weighting factors must also be adjusted to the operational and environmental conditions of the location where they will be used. The main distress, which can accelerate the pavement deterioration process, are fatigue cracking and rutting, whose weighting factor is 2.5. Another distress, which often originates from the lack of maintenance of cracks, are the potholes, whose weighting factor is 2.0.

Furthermore, for each distress identified in the pavement, deductible points, dp, are considered and are used in the calculation of the PCI. For example, if a fatigue cracking distress is identified, depending on the severity level and extent, the number of deductible points can reach 15 points.

In this work, as only 6 distress of the 15 possible distress were identified (fatigue cracking, longitudinal cracking, edge cracking, patches, potholes, and raveling), weighting factors were determined for each distress found, considering the influence of the respective distress on performance. of the pavement.

The weighting factors, wf and deductible points, dp, for distress found in pavements are:

- fatigue cracking: wf = 2.5 and dp = 0 to 15;
- longitudinal cracking: wf = 1.0 and dp = 0 to 5;
- edge cracking: wf = 1.0 and dp = 0 to 5;
- patches: wf = 2.0 and dp = 0 to 10;
- potholes: wf = 2.0 and dp = 0 to 10;
- raveling: wf = 1.5 and dp = 0 to 10.

Figure 13 presents the PCI calculation spreadsheet used to evaluate pavements in Section 01, containing the distress considered in the SHRP Research Program (Haala 2011). Figure 14 presents the summary of the PCI results of the sections evaluated in the Pontal Station - Dom Bosco Station direction and Figure 15 presents the summary of the PCI results of the sections evaluated in the Dom Bosco Station - Pontal Station direction.

The value of the pavement condition index, PCI, can give an indication of which maintenance and rehabilitation strategy, M&R, to adopt, as shown in Figure 16.

According to Fernandes Jr. et al (2022), the most used maintenance activities are patches, crack sealing and sealing layers. The main rehabilitation activities consist of milling, recycling, and structural resurfacing (reinforcement). Reconstruction is generally necessary when the pavement does not receive M&R activities and the deterioration process occurs quickly. In many cases, the cause of distress is inefficient or inadequate drainage. Therefore, before applying M&R services, as well as reconstruction, the installation of the appropriate drainage system must be carried out.

In Brazil, a widely used combined index is the Global Severity Index (GSI or IGG - in Portuguese), defined as a numerical parameter that allows the assessment of deterioration of road segments, whose design, in addition to reflecting the state of each segment considered in isolation, allows comparison relative between the states presented by different segments (Fernandes Jr. et al 2022). The IGG calculation is based on the DNIT 006/2003 standard (Objective evaluation of the surface of flexible and semi-rigid pavements - Procedure), which establishes a methodology for the numerical quantification of distress.

WORKSHEET FOR PAVEMENT EVALUATION

Road: BRT TRANSOESTE
Direction: Pontal Station - Dom Bosco Station

DISTRESS			EVALUATION									
			SECTION 1		SECTION 2		SECTION 3		SECTION 4		SECTION 5	
	dp	wf	dp	wf x dp	dp	wf x dp	dp	wf x dp	dp	wf x dp	dp	wf x dp
1. Fatigue Cracking	0-15	2.5	12	30.0	15	37.5	12	30.0	10	25.0	9	22.5
3. Edge Cracking	0-5	1.0	0	0.0	0	0.0	0	0.0	0	0.0	3	3.0
4. Longitudinal Cracking	0-5	1.0	3	3.0	0	0.0	0	0.0	0	0.0	3	3.0
7. Patches	0-10	2.0	9	18.0	9	18.0	9	18.0	10	20.0	10	20.0
8. Potholes	0-10	2.0	6	12.0	0	0.0	8	16.0	10	20.0	7	14.0
13. Raveling	0-10	1.5	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Sum of distress = Σ(wf x dp)				**63.0**		**55.5**		**64.0**		**65.0**		**62.5**
PCI =				37.0		44.5		36.0		35.0		37.5

PAVEMENT CONDITION INDEX: PCI = 100 – Sum of distress
dp = deductible points
wf = weighting factor

Figure 13 PCI calculation spreadsheet for Section 01.
Source: Fernandes Jr et al (2022) adapted from Asphalt Institute (2007).

WORKSHEET FOR PAVEMENT EVALUATION

Road: BRT TRANSOESTE — County: RIO DE JANEIRO
Section Code: SECTION 1 - Pontal Station - Dom Bosco Station
Extension: 150.0 m — Total Area Evaluated: 525.0 m
Width: 3.5 m — Date:
Type of Pavement: FLEXIBLE

DISTRESS			EVALUATION	
	dp	wf	dp	wf x dp
1. Fatigue Cracking	0-15	2,5	12	30,0
3. Edge Cracking	0-5	1,0	0	0,0
4. Longitudinal Cracking	0-5	1,0	3	3,0
7. Patches	0-10	2,0	9	18,0
8. Potholes	0-10	2,0	6	12,0
13. Raveling	0-10	1,5	0	0,0
			Sum of distress = Σ(wf x dp)	**63,0**

PAVEMENT CONDITION INDEX: PCI = 100 – Sum of distress
dp = deductible points — PCI = 100 – 63,0
wf = weighting factor — PCI = 37,0

Figure 14 Summary of the results of the sections evaluated in direction Pontal Station - Dom Bosco Station.

WORKSHEET FOR PAVEMENT EVALUATION

Road: BRT TRANSOESTE

Direction: Dom Bosco Station - Pontal Station

DISTRESS			EVALUATION									
			SECTION 1		SECTION 2		SECTION 3		SECTION 4		SECTION 5	
	dp	wf	dp	wf x dp	dp	wf x dp	dp	wf x dp	dp	wf x dp	dp	wf x dp
1. Fatigue Cracking	0-15	2.5	11	27.5	13	32.5	15	37.5	15	37.5	14	35.0
3. Edge Cracking	0-5	1.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
4. Longitudinal Cracking	0-5	1.0	5	5.0	0	0.0	0	0.0	0	0.0	3	3.0
7. Patches	0-10	2.0	8	16.0	10	20.0	8	16.0	10	20.0	8	16.0
8. Potholes	0-10	2.0	0	0.0	6	12.0	0	0.0	0	0.0	0	0.0
13. Raveling	0-10	1.5	8	12.0	0	0.0	0	0.0	0	0.0	7	10.5
Sum of distress = Σ(wf x dp)				60.5		64.5		53.5		57.5		64.5
PCI =				39.5		35.5		46.5		42.5		35.5

PAVEMENT CONDITION INDEX: PCI = 100 – Sum of distress

dp = deductible points

wf = weighting factor

Figure 15 Summary of the results of the sections evaluated in direction Dom Bosco Station - Pontal Station.

PCI	M&R STRATEGY
85 – 100	MAINTENANCE
71 – 84	MAINTENANCE
56 – 70	REHABILITATION
41 – 55	REHABILITATION
26 – 40	RECONSTRUCTION
11 – 25	RECONSTRUCTION
0 – 10	RECONSTRUCTION

Figure 16 Maintenance and rehabilitation strategy indicated based on the PCI.

Source: Fernandes Jr et al (2022) adapted from Asphalt Institute (2007).

The surface is assessed by sampling and the survey is carried out on foot, recording the types of distress on a spreadsheet. To calculate the IGG, ten distinct occurrences or events are considered. Each event considered separately corresponds to a specific value called the Individual Severity Index (ISI or IGI), established according to the weight or "level of responsibility" of each event. Therefore, each distress is given a weighting factor, wf. However, the main limitations of the Global Severity Index (IGG) are that it does not consider the severity level, only the type of distress (except for cracks) and only considers the number of occurrences and not the extent. For this reason, the PCI was adopted in this work.

4 Conclusion

The approach employed to detect flaws in the asphalt pavement of the Transoeste Bus Rapid Transit (BRT) System in Rio de Janeiro has demonstrated promise, offering swift and precise outcomes. This method serves as a valuable resource for identifying and restructuring the asphalt within the system. Employing RPAS (Remotely Piloted Aircraft Systems) for surveying significantly streamlines the identification of asphalt issues, contrasting with the traditional method requiring an employee to traverse the entire area, meticulously measuring all irregularities in the asphalt.

For future investigations, it is recommended to conduct a comparative analysis of the resultant orthophotos processed in both proprietary software like AGISOFT and open-source software such as OPENDRONEMAP. This comparison could be executed using tools like GEOPEC software, known for its user-friendly features in evaluating and positioning cartographic products. Such a comparative study would likely offer insights into the most effective software for this specific application, optimizing the evaluation and restructuring process of the asphalt within the BRT system.

It is worth noting that, in December 2023, Rio City Hall delivered works to revitalize 59 kilometers of runway in the Transoeste corridor, with 31 kilometers of gutter rebuilt in concrete, corroborating the preliminary results presented in this work in terms of the necessary replacement of the asphalt pavement in the analyzed section.

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6 References

AGISOFT. 2020. Agisoft Metashape 1.5.3—Professional edition: Agisoft LLC software. Viewed 1 Oct. 2022, <https://www.agisoft.com/downloads/installer/>.

ANAC. 2017, *Orientações para usuários de Drones*, Assessoria de Comunicação Social – ASCOM, 1ª Edição. Viewed 3 Nov. 2023, <https://www.gov.br/anac/pt-br/assuntos/drones/orientacoes_para_usuarios.pdf>.

ASPHALT INSTITUTE. 2007, *The Asphalt Handbook*, 7th Edition, MS-4, Lexington, Kentucky.

Barbosa, E.D.M., Monico, J.F.G., Alves, D.B.M. & Oliveira, L.C. 2010, 'Integridade no posicionamento RTK e RTK em rede', *Boletim De Ciências Geodésicas*, vol. 16, no. 4, pp. 589–605, DOI:10.1590/S1982-21702010000400007.

Brito, J. L. N. S. 2007, *Fotogrametria digital*. EdUERJ, Rio de Janeiro, 196 p.

Castelo Branco, L. H. 2016. MANIAC: uma metodologia para o monitoramento automatizado das condições dos pavimentos utilizando VANTs. Phd These, Escola de Engenharia de São Carlos da Universidade de São Paulo, Brazil.

CHC. 2023, GNSS equipement and receivers. Viewed 3 Nov. 2023, <https://www.chcnav.com/>.

Ciriquian, P.M. & Medina, A.M. 2018, 'Contextos Urbanos, Intermodalidad y Gestión', in R.O.S. Romero (eds), *Movilidad Urbana y Espacio Público: Reflexiones, Métodos y Contextos*, 1. ed., DGP Editores, SAS, Bogotá, Colômbia.

Costa, L.G. & Amorim, A.L. 2009, Geração de Ortofotos para Produção de Mapas de Danos. 13th Congress of the Iberoamerican Society of Digital Graphics.

Dai, L., Wang, J., Rizos, C. & Han, S. 2003, 'Predicting atmospheric biases for real-time ambiguity resolution in GPS/GLONASS reference station networks', *Journal of Geodesy*, v. 76, nº11/12, p. 617-628.

DNIT (Departamento Nacional de Infraestrutura de Transportes). 2003, *DNIT 005-TER: defeitos nos pavimentos flexíveis e semirrígidos: terminologia*. Rio de Janeiro.

Drost, L. 2021, 'A transport equity analysis of a 2016 Olympic Games Legacy Project: Bus Rapid Transit in the city of Rio de Janeiro, Brazil', Bachelor Thesis, University of Groningen, Portugal.

Fernandes Jr., J.L., Oda, S. & Zerbini, L.F. 2022, 'Defeitos e atividades de manutenção e reabilitação em pavimentos asfálticos', Apostila Didática. Departamento de Transportes da Escola de Engenharia de São Carlos - Universidade de São Paulo, São Carlos, São Paulo, Brazil.

Ferreira., A.M.R., Roig, H.L., Marotta, G.S. & Menezes, P.H.B.J. 2013, 'Utilização de aeronaves remotamente pilotadas para extração de mosaico georreferenciado multiespectral e modelo digital de elevação de altíssima resolução espacial'. Simpósio Brasileiro de Sensoriamento Remoto (SBSR), p. 9308-9315.

Haala, N. 2011, 'Multiray photogrammetry and dense image matching', *Photogrammetric week*, vol. 11, pp. 185-195.

Hernández, D. 2017, 'Transporte público, bienestar y desigualdad: cobertura y capacidad de pago en la ciudad de Montevideo', *Revista de la CEPAL*, v. 166-184, n. 122.

Herold, M. & Roberts, D. 2005, 'Spectral characteristics of asphalt road aging and deterioration: implications for remote-sensing applications', *Applied Optics*, v. 44, n. 20, p. 4327–4334.

Herold, M., Roberts, D., Noronha, V., & Smadi, O. 2008, 'Imaging spectrometry and asphalt road surveys', *Transportation Research Part C: Emerging Technologies*, v. 16, n. 2, pp. 153–166.

INCRA (Instituto Nacional de Colonização e Reforma Agrária). 2013, Manual Técnico de Posicionamento: Georreferenciamento de Imóveis Rurais, 1 ed., Brasília.

SHRP. 1993, 'Distress Identification Manual for the Long-Term Pavement Performance Studies', The Strategic Highway Research Program, National Academy of Science, Washington, D.C.

Silva, J.E.C.F. & Botelho, M.F. 2017, 'Cadastro Ambiental Rural utilizando imagem de drone aerofotogramétrico', *Revista Agrogeoambiental*, vol. 9, no. 2.

TechReview. 2023, 'DJI Phantom 4 review'. Viewed 3 Nov 2023, <https://www.techadvisor.com/article/716844/dji-phantom-4-review.html>.

Tejada, J. M. 2002, 'El Transporte Colectivo Urbano: Aplicación del Enfoque de Sistemas para un mejor Servicio Fermentum', *Revista Venezolana de Sociología y Antropología*, vol. 12, n. 34, p. 285-302.

Tomasiello, D.B. 2016, *Modelos de Rede de Transporte Público e Individual para estudos de acessibilidade em São Paulo*, Master dissertation, Escola Politécnica da Universidade de São Paulo. São Paulo, Brazil.

Universidad Del Cuyo. 2017, 'Medios de Transporte Urbano', Facultad de Ingeniería, Universidad Nacional del Cuyo. Argentina, 40 p., versión 01/2017. Viewed 3 Nov. 2023. <https://ingenieria.uncuyo.edu.ar/catedras/u1-medios-de-transporte-urbano.pdf>.

Van Sickle, J. 2015. *GPS for land surveyors*, CRC press.

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