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Contact information:

Web page: www.itegam-jetia.org
Email: editor@itegam-jetia.org
Galileo Institute of Technology and Education of the Amazon (ITEGAM).

Joaquim Nabuco Avenue, No. 1950. Center. Manaus, Amazonas. Brazil.
Zip Code: 69020-031. Phone: (92) 3584-6145.

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SUMMARY

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INFLUENCE OF CUTTING PARAMETERS ON SURFACE INTEGRITY AND MACHINING FORCES IN TOP MILLING OF METALLIC SPRAYING METAL COATINGS

Carlos Jorge Leão de Oliveira*[1], Rafael da Cunha Hamano[2], Tatiane de Campos Chuvas[3] and Hector Reynaldo Meneses Costa[4]

[1, 2, 3, 4] Postgraduate Program in Mechanical Engineering and Materials Technology, Federal Center for Technological Education Celso Suckow da Fonseca – CEFET-RJ, Rio de Janeiro, Brazil.

[1] http://orcid.org/0000-0002-2554-9775, [2] http://orcid.org/0000-0002-6811-5328, [3] http://orcid.org/0000-0002-7512-4193, [4] http://orcid.org/0000-0002-0887-6838

Email: *cjleao216430@gmail.com, rafaelhamano@gmail.com, chuvas.tatiane@gmail.com, hectorey@gmail.com

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ABSTRACT

This work aims to evaluate the behavior of coatings applied by electric arc thermal spraying on a low carbon steel substrate when subjected to a milling process under different cutting conditions (cutting speed and tool tip radius). It was observed how these cutting conditions influenced the surface integrity of the machined part (roughness) and the machining forces generated during the process. An evaluation of the types and levels of tool wear in the milling operations was carried out. To obtain the results, samples of ASTM-A36 steel sheets thermally sprayed with and without sealant were milled with cutting speeds of 50 m/min and 84 m/min, and inserts with tip radius of 0.4 mm and 0.8 mm. The cutting parameters used were based on previous work and information from the cutting tool manufacturer. The present work identifies that cutting speed set to 50m/min led to lower machining forces and better tool wear performance. The results obtained indicated that the tool with the smallest tip radius provided better cutting conditions, in the coating without application of sealant. The tool with the largest tip radius presented lower machining forces for the application of sealant. There were no expressive differences in the finish of the machined surfaces, but the experimental values obtained for the average roughness (1µm to 1,79 µm) remained in accordance with the limits indicated in the literature. The predominant tool wear was the plastic deformation in the tip of the inserts and crater wear located on rake face.

I. INTRODUCTION

In the search for solutions to increase the useful life of machinery and equipment components, with regard to minimizing (or even inhibiting) the action of agents in environments with aggressive atmospheres, the technological advance in the area of metallurgy with the development of new surface treatment techniques, as described [1].

There are many metallic coating techniques used in the industry. The increase in the number and importance of surface treatment process applications allows replacing traditional applications such as nickel plating, galvanizing, chrome plating, etc. by thermal spraying [2]. Among the metallization processes, thermal spraying stands out for guaranteeing the protection of the base material without impacting the environment, compared to other coating techniques.

Many thermal spray coatings will certainly undergo machining processes, either to improve surface finish and/or to meet dimensional tolerance requirements for certain projects. Thus, the most accurate decision of machining technology applied to the coating is directly linked to the functionality of the parts for which the coating was defined.

There are several elements present in the structure of sprayed coatings that affect the machining process, such as partially fused or unfused particles, pores, oxidized particles, and different hard and brittle phases (carbides and oxides). During the machining process, these elements are the cause of intermittent cutting, which leads to rapid wear of the cutting tool, which can affect the desired quality of the thermal coating surface finish that could be achieved. It is also known that other factors that influence the selection of technology and machining parameters concern the set of phenomena that occur because of the cutting process in the surface layers: changes in mechanical properties, structural changes, defects, hardening and residual stresses. However, there are no studies on the behavior of materials sprayed in machining and how the cutting parameters can influence the process [3]. However, machining thermal sprayed coatings is a process for cutting materials that are difficult to machine. In the work performed by [4], the machining by end milling of samples of superalloy Inconel 718 showed, among results, a surface finish ranging from 1.5 µm and approximately 2.5 µm, with cutting speed (Vc) 60 m/min. Comparing this result with the variable surface roughness obtained in milling the coatings sprayed in this work (1 µm to 1.79 µm), with cutting speed (Vc) 50 m/min, it is possible to observe the existence of proximity in the experimental values found. Thus, similarities in the behavior of these materials are assumed when machining with a tool with defined geometry.

The purpose of this work is to evaluate the influence of cutting parameters (cutting speed and feed per tooth), together with different cutting tool tip radius, on tool wear, machining forces and surface finish by the milling process in metallic coatings based on iron-nickel, iron-chromium, and cobalt-chromium alloys. The coating deposition process was performed by electric arc thermal spraying, which compared to other spraying techniques has advantages such as high deposition rate and lower cost.

II. THEORETICAL REFERENCE

II.1 THERMAL SPRAY

Of the methods of applying metallic coatings, thermal spraying (ts) is a method of great industrial acceptance for bringing together low cost and certain advantages compared to other techniques. This process guarantees a wide range of chemically different materials that can be sprayed, and has a high coating deposition rate, which allows for greater thicknesses of sprayed material, in addition to the portability of the equipment used [5].

The coating structure is formed from the continuous deposition of molten particles that will accumulate a coating characterized by flattened particles and lamellar microstructure [6]. Among the various existing processes, thermal spraying is the one with the most numerous configurations, both in terms of energy sources (plasma, flame, electric arc) and materials used (metals, ceramics, polymers, composites, etc.) [7].

Electric arc thermal spray technology has become popular compared to other spray technologies mainly due to its high thermal efficiency, high spraying efficiency and low processing cost [8].

The coatings produced by thermal spraying have high roughness, which can have undesirable effects on the mechanical set in operation, resulting in greater friction and wear of components, causing changes in the adjustments provided for in the project. To meet these mechanical elements and guarantee them pre-established dimensions, they must be subjected to a precision finishing operation. As a result, coatings are often turned, milled, or ground [9].

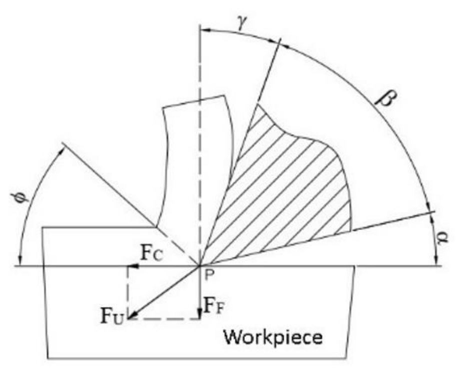
II.2 MILLING THERMAL SPRAYED MATERIALS

According to [9], some care must be taken when milling thermally sprayed flat surfaces: priority should be given to removing raised areas or irregularities and making very light cuts; in crosscut tangential milling, care must be taken to avoid lifting the coating from the substrate; cutting speeds should be in the range of 20 to 30 m/min, however, they can be higher when milling some materials, such as copper alloys; the feed is usually 0.2 – 0.5 mm/revolution for roughing and should be reduced according to the finishing required.

II.3 MACHINING FORCES ANALYSIS

In machining operations where there are interruptions in the cut and variations in the thickness of the cut, as in milling, the analysis of the efforts involved is essential for understanding the mechanical behavior of the tool. According to [10] the main factors that can affect the machining forces are the cutting parameters (mainly the feed), workpiece hardness, shear strength of the machined material, tool geometry and the stability of the machine and the cutting device fixation. In this study, for the simplification and understanding of the machining force analysis, the orthogonal cut hypothesis is adopted. That is, the material to be removed undergoes plane deformation, as it does not deform in the direction of the length of the cutting edge. The deformation of the material occurs on the surface of the tool, in the plane orthogonal to the cutting edge, the work plane [11]. However, it is necessary to understand the theories of orthogonal and oblique cutting for the application in current projects of cutting tools with complex geometries. Because the basic mechanisms for material removal and chip formation remain the same as in classical processes [12].

Having as reference the hypothesis of the orthogonal cut, [11] considers that in the work plane there will be three pairs of components, perpendicular to each other. These pairs will be arranged in three different directions: in the cutting direction, where the cutting force (F_C) is located, forming an orthogonal pair with the advance force (F_F), as shown in figure 1a; towards the tool rake face, placing the friction force (F_T) and perpendicular to the force normal to the rake face (F_N), indicated in figure 1b; in the direction of the shear plane, which contains the shear force (F_Z) followed by the force normal to the shear plane (F_{NZ}), illustrated in Figure 1c.



(a)

Figure 1a: Machining force components in the work plan: a) cutting force (F_C) and feeding force (F_F).
Source: Adaptation by [11].

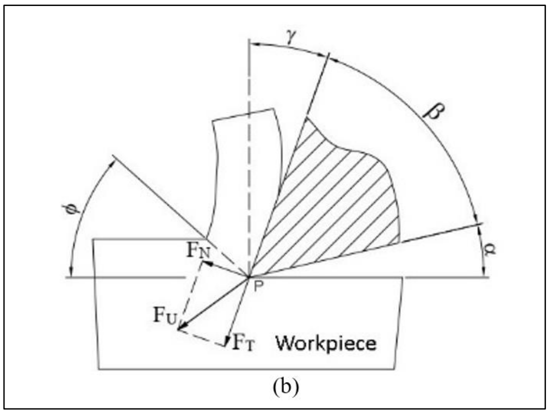


Figure 1b: Machining force components in the work plan: b) frictional force (F_T) and normal force to the output surface (F_N).
Source: Adaptation by [11].

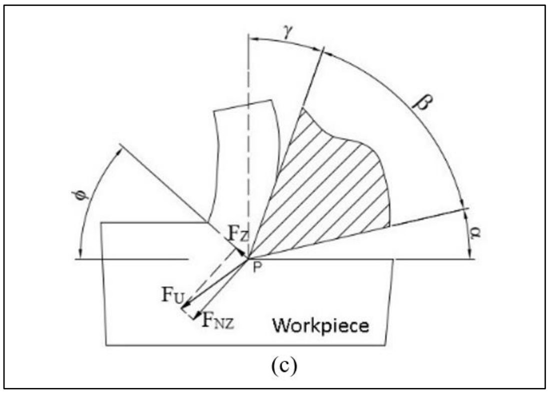


Figure 1c: Machining force components in the work plan: c) shear force (F_Z) and normal shear force (F_{NZ}).
Source: Adaptation by [11].

II.4 TOOL WEAR EVALUATION

In the cutting tool, the evaluation of the cutting edge is a vitally important factor in defining the tool life in the machine and has a direct influence on the surface quality of the part, its dimensional accuracy and the cost of the final product. In general, wear is mainly influenced by the state of stress and temperature variation in the cutting region and propagates according to several different mechanisms. The presence of Ni favors the increase of resistance to heat and oxidation in materials. Researchers, such as [13], describe that the traditional machining processes of Ni-based materials are challenging, as these alloys usually have low thermal conductivity. For this reason, heat will advance into the tool material, and this causes the tool to wear out.

In the cutting edge, there are three main wears that can occur on cutting tools: flank wear, crater wear, and notch wear.

Flank wear is the most frequent among the wear. It is located on the tool clearance surface and is attributed to the heat generated by friction between the tool flank face and the newly machined surface of the part. For [14], high temperatures on the tool and chip surfaces increase the heat transfer to the tool and accelerate its wear.

Notch wear occurs when machining a hardened (hardened) surface. The notch tends to be a region of stress concentration due to its steep depth, which can lead to rapid and sudden tool failure.

Crater wear occurs on the tool rake surface, where the chip flows, in the secondary shear zone. This wear takes place at high levels of cutting speed and temperature and results from the combination of abrasion and diffusion wear mechanisms. Crater formation is the result of stress distribution on the tool rake surface.

III. MATERIALS AND METHODS

III.1 SUBSTRATE MATERIAL

For the samples, ASTM A36 carbon steel was used as a substrate and they were made in the form of a ¼” thick plate and chemical composition, according to standard [15], which is shown in Table 1.

Table 1: Chemical composition of carbon steel (% weight).

C	Mn	P_{max}	S_{max}	Si_{max}
0,26	0,85	0,04	0,05	0,40

Source: [15].

III.2 METHODS

III.2.1 Thermal Spraying Process

To obtain the coating, the electric arc thermal spraying process was used. The main characteristics of the process, from blasting to the formation of texturing to the application of the metallic coating, are described in Table 2.

Table 2: Coating process characteristics.

Characteristics	
Process	Thermal spraying
Form of heating	Electrical energy (electric arc)
Application mode	Manual
Sample dimensions	Plate with 100 mm x 150 mm x ¼”
Number of samples	06
Sample preparation	Sandblasting with aluminum abrasive grains
Sample roughness	130 to 150 μm
Aplication distance	100 mm
Electrode	AISI 420 martensitic stainless steel wire
Electrical characteristics	Voltage: 30 V Amperage: 100 A
Air pressure	7 kgf/cm^2
Coating thickness	1,2 to 1,5 mm
Coating hardness	35 to 400 HRc
Sealant	3 Coats of epoxy resin (on 3 samples)

Source: Authors, (2022).

In the electric arc thermal spraying process, in this research, the wires used (ER420) have a chemical composition, as shown in Table 3.

Table 3: Chemical composition of wires in the thermal spraying process.

C	P	S	Mn	Mo	Cr	Si	Cu	Ni
0,25 to 0,40	0,03	0,03	0,6	0,6	12 to 14	0,5	0,75	0,6

Source: [16].

The samples obtained were divided into two groups: samples sprayed and sprayed with sealant application. In this research, the sealant resin copolymer WFT 1532 was used, which has the characteristic of promoting active capillary sealing of the porosity of the coating. Figure 2 represents the dimensions and surface characteristics of the samples.

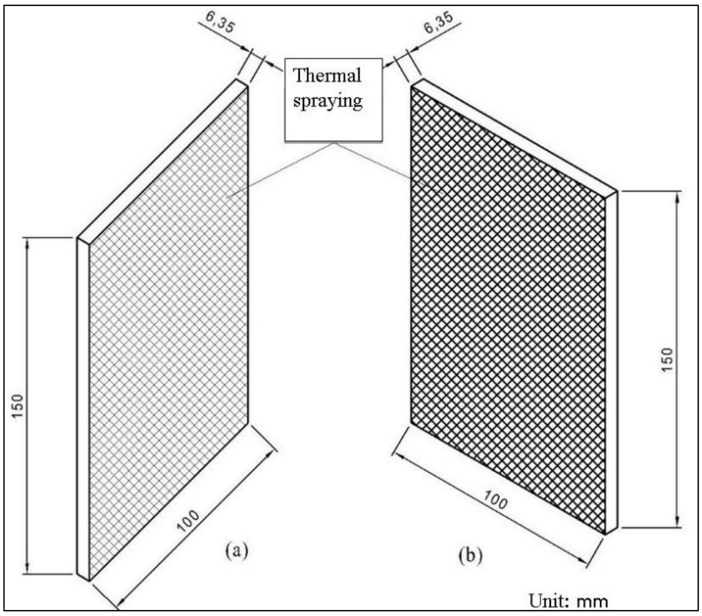


Figure 2: Dimensions and surface characteristics of samples: (a) sample without sealant, (b) sample with sealant
Source: Authors, (2022).

Ill.2.2 Machining, Machining Forces and Roughness of Samples Thermal Spraying Process

The machining of the samples was carried out in a Diplomat 3001 milling machine, model FVF-2000, at the Machining Research Laboratory (LABUS) at CEFET/RJ. To evaluate the surface treatment applied to the samples and to investigate the mechanical properties of the resulting material, the surface finish (roughness) and the machining force after milling the coating were adopted as evaluation criteria. The milling operation was performed using cutter R390-020 A 20L -11L with Ø20 mm, with two cutting edges and inserts R390-11T3 08M-PM1130 with 0.8 mm of nose radius and R390-11T3 04M-PM1130 with 0, 4 mm nose radius, both from the manufacturer Sandvik. These pellets had AlTiCrN coatings obtained by the physical vapor deposition (PVD) process.

To perform the machining of the samples, channels were milled with a length covering the entire width of the part and a depth of 0.50 mm. The cutting parameters used are shown in Table 4. In all conditions, abundant cutting fluid was used (approximate flow rate of 3.8 l/min). In each condition, a new pair of cutting edges was used, so that the wear did not influence the results obtained.

Table 4: Sample machining conditions.

Parameters	Values
Cutting depth (a_p)	0,50 mm
Cutting speed (V_c)	50m/min and 84m/mmin
Rotation (n)	795RPM and 1337RPM
Forward speed (V_f)	175mm/min and 294mm/min
Feed per tooth (F_z)	0,11mm

Source: Authors, (2022).

In the initial evaluation by machining, a tool with a radius of 0.8 mm was used and the samples were submitted to two levels of cutting speed: 50 m/min and 84 m/min. The initial results, totaled in four conditions, refer to samples without sealant and with sealant, as shown in Table 5.

Table 5: Sample machining initial conditions.

Condition	Sealant	Vc (m/min)
1	Without	50
2	Without	84
3	With	50
4	With	84

Source: Authors, (2022).

The sprayed metallic coating started to be analyzed through milling, where the influence of the cutting parameters on the useful life of the tools, on the machining forces acting on the cut and on the surface finish resulting from the machining process was evaluated.

For the acquisition of machining force data, a piezoelectric dynamometer brand Kistler, model 9257 BA, acquisition in 3 working ranges in Fx, Fy and Fz from 0.5 kN to 10 kN, acquisition rate of 2 kHz (Fx , Fy) and 3.5 kHz (Fz) and a 3-channel charge amplifier, Kistler, model 5233A. A National Instruments AD data acquisition board, model NI-USB-6221 was used for the conversion and transmission of analog to digital signals. Figure 3 represents the assembly of samples for acquisition of machining force data, during the milling process.

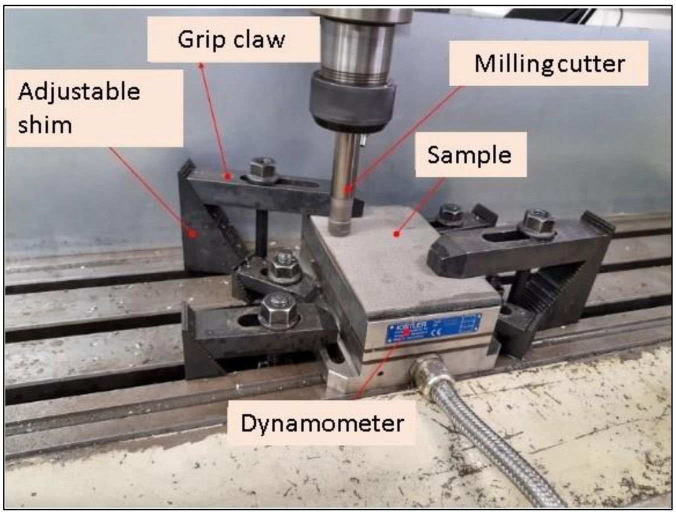


Figure 3: Assembly of samples.
Source: Authors, (2022).

For the acquisition of roughness data, a Mitutoyo rugosimeter, model SJ-210, was used, with a probe of 5 µm/s, cut off 0.8 mm and resolution of 0.01 µm. In each milled slot, 3 measurements were taken.

The preparation of the machined surface for evaluation of the surface finish was carried out by two passes with a depth of 0.5 mm in each groove. The experimental values measured were considered after the execution of the 2nd pass (denoted new tool) and 6th pass (denoted worn tool) of machining. In the evaluation of the surface finish attributed to the samples, the parameters Ra (with corresponding mean values and standard deviation), Rz and Rt (with their maximum values) were considered.

It is important to highlight that, in the samples with and without sealant machined with a cutting speed of 84 m/min, there was a strong vibration in the process, which was more intense in the sample with sealant.

IV. RESULTS AND DISCUSSIONS

IV.1 WITH VARIATION OF CUTTING SPEED

In the evaluation of the coating, considering the variation of cutting speed with 50 m/min and 84 m/min, it was observed how these speeds influenced the machining force, the surface finish and tool wear. The best results were obtained with a cutting speed of 50 m/min based on machining forces and tool wear analysis, although the presence of the sealant did not impact the surface quality, given the variation in cutting speed.

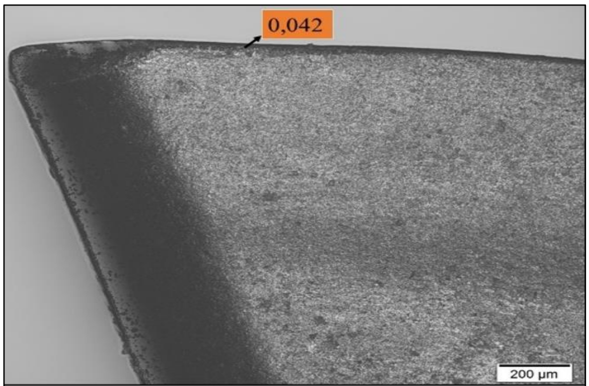
It can be highlighted, in the machining of samples with and without sealant with a speed of 84 m/min, the presence of strong vibration in the process. Though vibration has been more intense in the sample with sealant. This fact resulted in expressive tool wear, as well as an increase in the machining force.

IV.2 WITH CONSTANT CUTTING SPEED

Cutting speed was set to 50m/min because it demonstrated better performance in terms of machining forces and tool wear. Having defined the best cutting parameters, the following tests were carried out with tools with radius of 0.4 mm and 0.8 mm, using a cutting speed of 50 m/min.

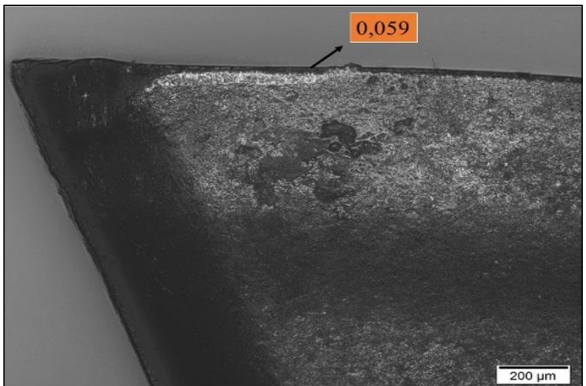
IV.2.1 CUTTING TOOL WEAR

Nose flank wear is notably evident on the main flank, as shown in Figures 4 and 5.



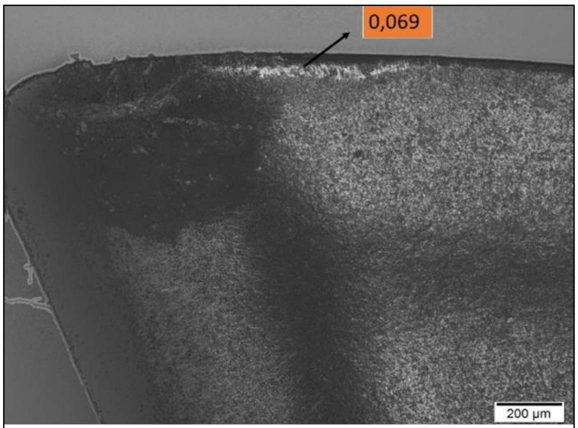
(a)

Figure 4a: Wear on the main flank with insert 0,4 mm: (a) Without sealant.
Source: Authors, (2022).



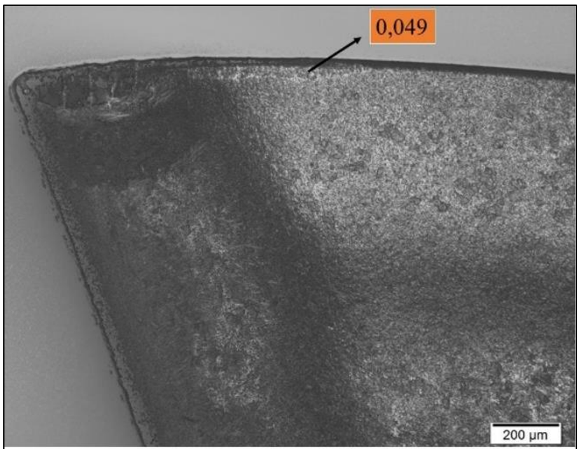
(b)

Figure 4b: Wear on the main flank with insert 0,4 mm: (b) With sealant.
Source: Authors, (2022).



(a)

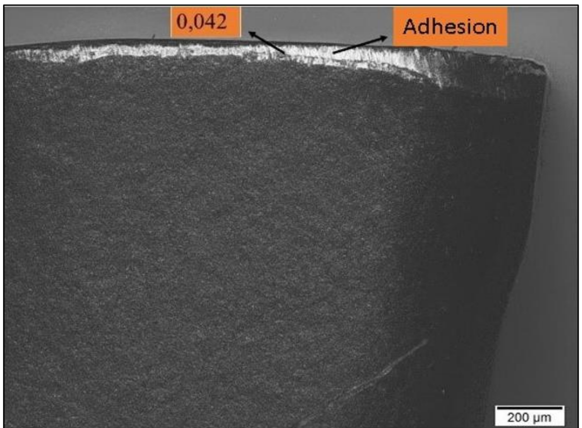
Figure 5a: Wear on the main flank with insert 0,8 mm: (a) Without sealant.
Source: Authors, (2022).



(b)

Figure 5b: Wear on the main flank with insert 0,8 mm: (b) With sealant.
Source: Authors, (2022).

Figures 6 and 7 show the predominant wear characteristic located at the tool tip, in the secondary flank region. The phenomenon of adhesion is present, mainly on the flank of the tool with a radius of 0.4mm, when milling the material without sealant, illustrated in Figure 6a.



(a)

Figure 6a: Wear on the secondary flank with insert 0,4 mm: (a) Without sealant.
Source: Authors, (2022).

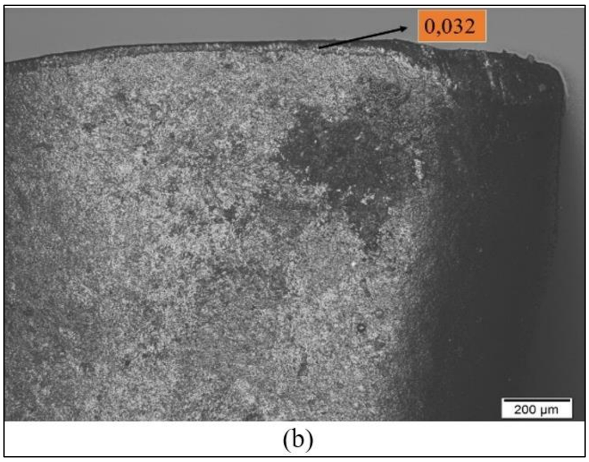


Figure 6b: Wear on the secondary flank with insert 0,4 mm: (b) With sealant.
Source: Authors, (2022).

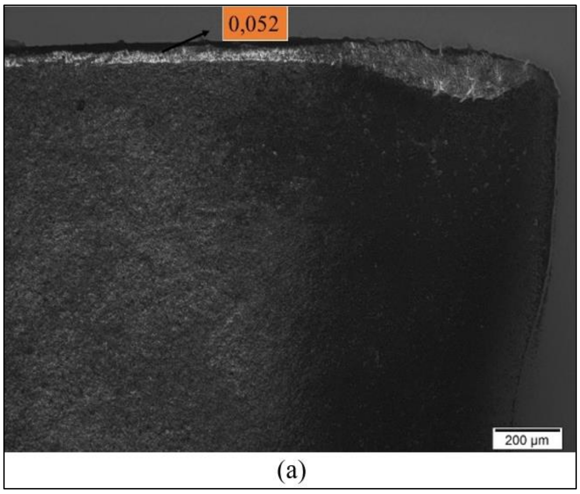


Figure 7a: Wear on the secondary flank with insert 0,8 mm: (a) Without sealant.
Source: Authors, (2022).

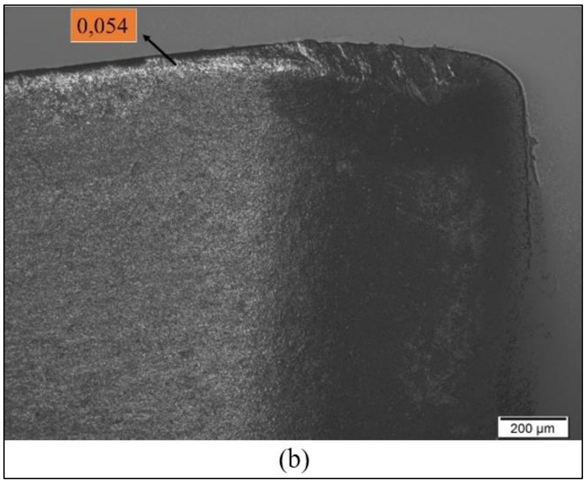


Figure 7b: Wear on the secondary flank with insert 0,8 mm: b) With sealant.
Source: Authors, (2022).

Crater wear caused by plastic deformation on the rake face can be seen in Figures 8 and 9. The wear is more pronounced on inserts with a 0.8mm radius, as seen in Figures 9a and 9b.

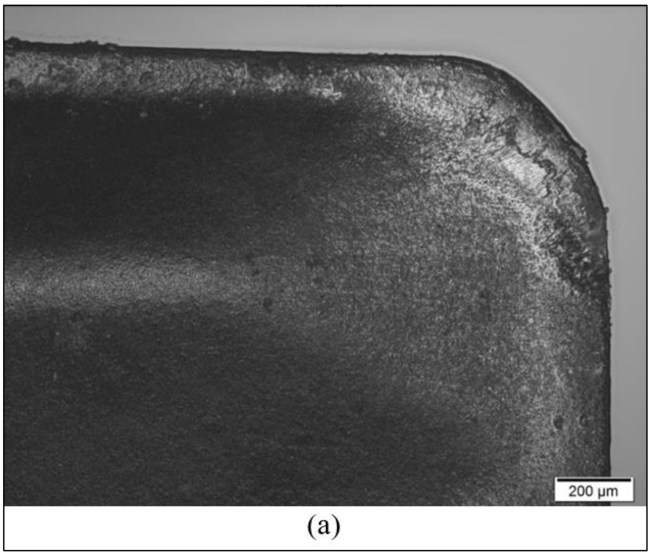


Figure 8a: Wear on the cutting tool rake face with insert 0,4 mm: (a) Without sealant.
Source: Authors, (2022).

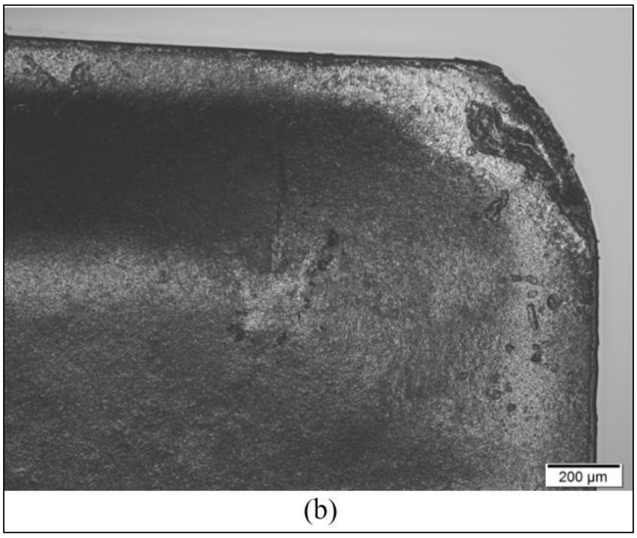


Figure 8b: Wear on the cutting tool rake face with insert 0,4 mm: (b) With sealant.
Source: Authors, (2022).

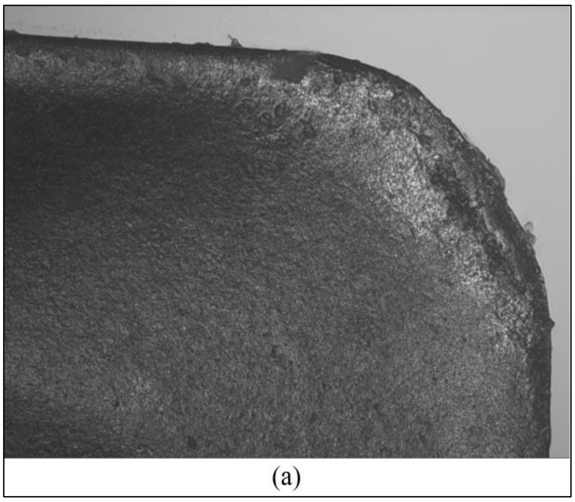
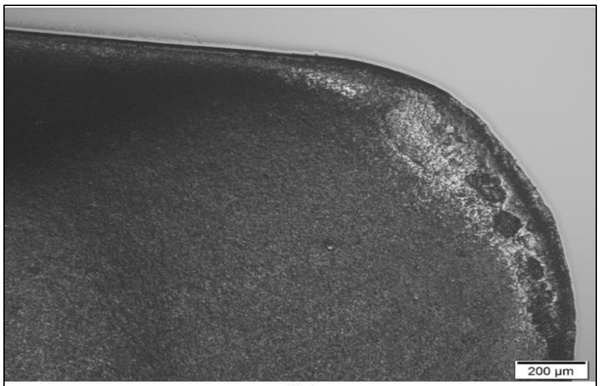


Figure 9a: Wear on the cutting tool rake surface with insert 0,8 mm: (a) Without sealant.
Source: Authors, (2022).



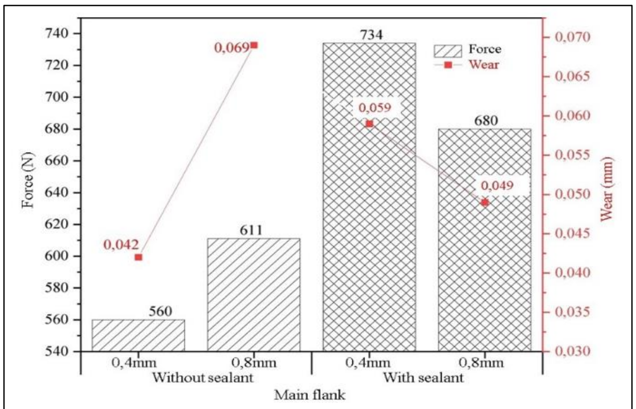
(b)

Figure 9b: Wear on the cutting tool rake surface with insert 0,8 mm: (b) With sealant.
Source: Authors, (2022).

IV.2.2 *Machining Force and Wear on Cutting* Tools

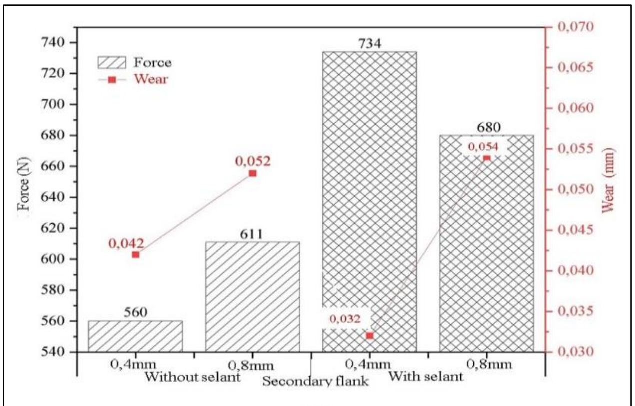
Figures 10a and 10b represent the values corresponding to the machining forces and wear on the inserts, at the end of the milling process, where the inserts are in the worn condition. Analyzing the machining forces acting, it is noted the predominance of the highest values in the samples with sealant. The effect of machining in these samples can be attributed to the typical behavior of the cutting mechanism in fiber-reinforced composites, where hard polymer particles are formed during tool sliding. Studying the effect of milling carbon fiber-reinforced polymer composites, [17] admitted the possibility of the milling process inducing delamination during machining. The shear forces act by pushing the unsupported fibers, resulting in delamination of the composite material. The presence of protruding fibers on the machined surface prevents the tool edge from passing through, thus increasing the friction force.

With reference to the insert with 0.4mm radius, there was less machining force with less wear, when milling the samples without sealant. However, with the application of the sealant, the machining force and wear were higher (mainly on the main flank) compared to the insert with a radius of 0.8 mm, as shown in Figures 10a and 10b. [18] performed a check on the behavior of the cutting force through the ratio r/h (insert tip radius / depth of cut) greater and less than unity. Uncoated carbide inserts were used for milling glass fiber reinforced polymer (GFRP) sheets. The r/h parameter was investigated for different tool nose radius. The researchers found that there was a disproportionate increase in shear forces in the r/h < 1 condition, a fact repeated in this work, as reported above.



(a)

Figure 10a: Machining forces x wear: (a) Main flank.
Source: Authors, (2022).

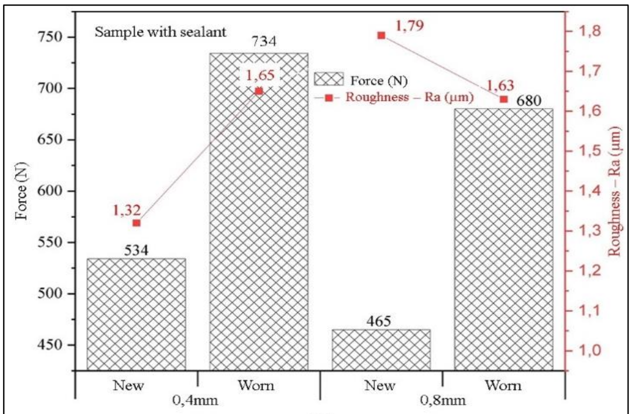


(b)

Figure 10b: Machining forces x wear: (b) Secondary flank.
Source: Authors, (2022).

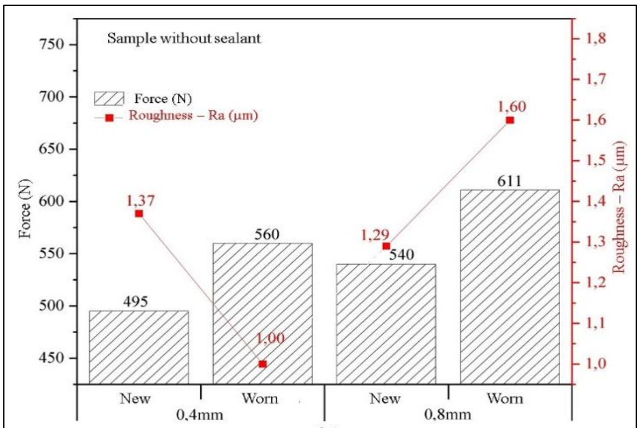
IV.2.3 Machining Force and Surface Finish

As can be seen in figures 11a and 11b, there was a tendency towards higher average roughness values in the samples coated with sealant. However, there are no significant differences in the values presented. The experimental values obtained remained satisfactory, according to the limits proposed in the literature. It is also noted that the tool with a radius of 0.4 mm on the sample without sealant produced a better final finish, with less machining effort.



(a)

Figure 11a: Machining force x surface finish: (a) Samples with sealant.
Source: Authors, (2022).

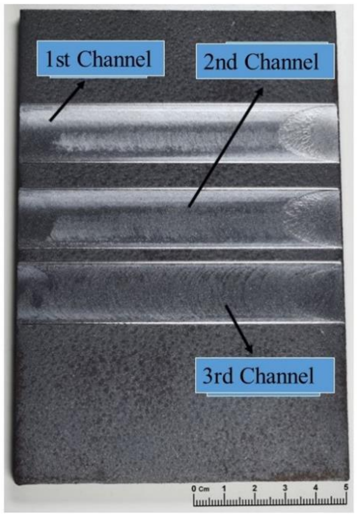


(b)

Figure 11b: Machining force x surface finish: b) Samples without sealant.
Source: Authors, (2022).

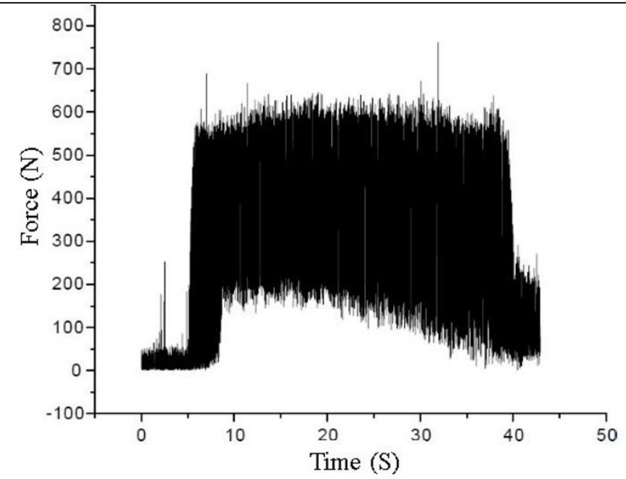
IV.3 ANALYSIS OF MACHINED SURFACES

With reference to the surfaces of the sample without sealant machined with inserts with a radius of 0.8 mm (Figure 12a), visible tool marks are noted on the machined surface in the 3rd groove. This fact is probably due to the wear on the flanks and the plastic deformation that occurred at the tips of the inserts, as can be seen in Figures 14a and 16a. The highest value of machining force used is observed with the insert with a radius of 0.8 mm, in comparison with the insert with a radius of 0.4 mm, as shown in Figure 10a. According to [19], plastic deformation originates from the action of cutting forces and stresses on the cutting edge at high temperatures, which reduces the mechanical properties of the tool, making it vulnerable to wear. The spectrum of the machining force at the end of the milling process can be seen in Figure 12b.



(a)

Figure 12a: Sample without sealant (nose radius 0,8 mm): (a) Machined surfaces.
Source: Authors, (2022).



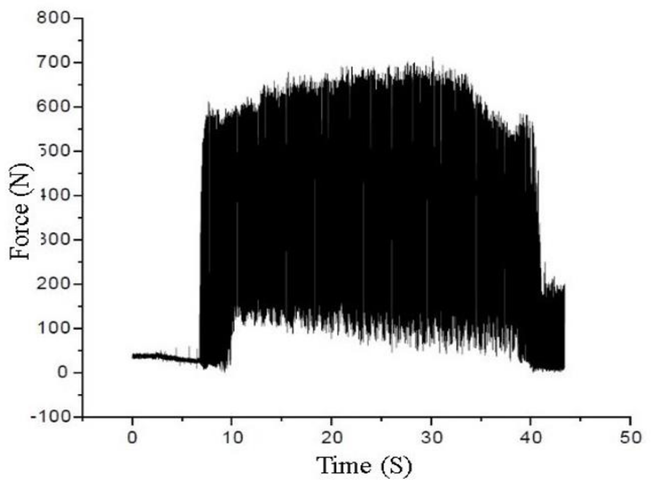
(b)

Figure 12b: Sample without sealant (nose radius 0,8 mm): (b) Force spectrum (3rd channel).
Source: Authors, (2022).

In the case of the sample with sealant milled with a radius of 0.8 mm (Figure 13a), the machined channels also have tool marks on their surfaces due to the same reason attributed to the samples without sealant, previously described. Less wear is observed on the main flank, in relation to the sample with sealant machined with a radius of 0.4 mm, as shown in Figure 10a. The behavior of the machining forces acting on the cutting edge can be described in the spectrum indicated in Figure 13b.

(a)

Figure 13a: Sample with sealant (nose radius 0,8 mm): (a) Machined surfaces.
Source: Authors, (2022).



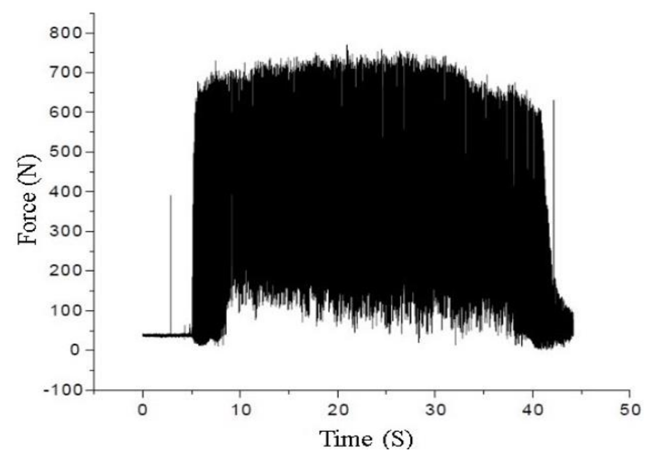
(b)

Figure 13b: Sample with sealant (nose radius 0,8 mm): (b) Force spectrum (3rd channel).
Source: Authors, (2022).

When milling the sample with a sealant machined with an insert with a radius of 0.4 mm expressed in Figure 14a, the deep marks of the cutting tool on the machined surface can be seen in the 2nd groove, which must have increased the wear on the flanks and on the tip of the wafer, as shown in Figures 4b and 6b. According to [20], grooves on the machined surface are attributed to the bearing of hard particles between the tool-workpiece interface. These particles penetrate the grooves and cavities of the worn surface of the tool, acting on the machined surface. This fact resulted in an increase in the machining force and greater wear on the main flank, compared to the wear and machining force acting on the 0.8mm radius insert, as shown in Figure 10a. At the end of the milling process, the machining forces were maintained according to the spectrum in Figure 14b.

(a)

Figure 14a: Sample with sealant (nose radius 0,4 mm): (a) Machined surfaces.
Source: Authors, (2022).

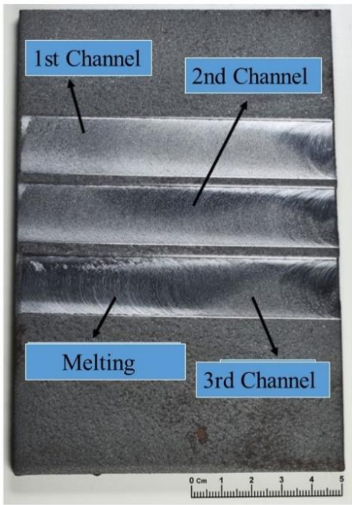


(b)

Figure 14b: Sample with sealant (nose radius 0,4 mm): (b) Force spectrum (3rd channel).
Source: Authors, (2022).

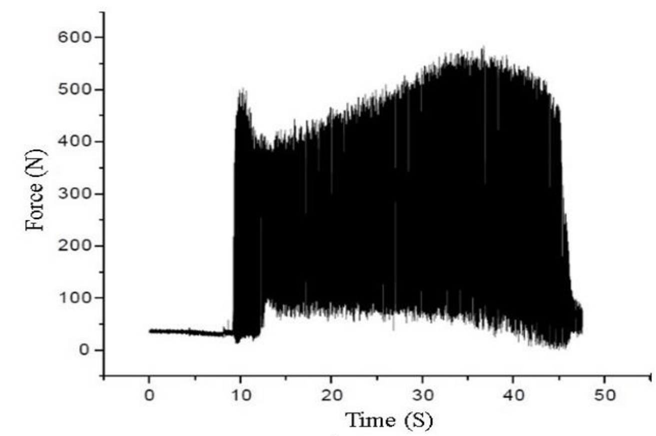
Observing Figure 15a, which depicts the milling on the sample without sealant machined with an insert with a radius of 0.4 mm, one can see, in the machining of the 3rd groove, a surface finish with gloss, tool marks and a roughness value below the found, as discussed in Figure 11b. What may have occurred in the machining of this groove, due to the loss of coating, was the adhesion of the material to the edge of the cutting insert, as shown in Figure 6a. There was no shear in the action of the cutting edge on the material, but the plasticization of the coating sprayed on the machined surface. This phenomenon is called melting. According to [21], the melting is related to the adhesion of the sample material on the cutting edge of the tool, causing an increase in temperature at the interface of the tool and the surface of the sample, due to friction. Consequently, there is a reduction in the mechanical strength and plasticity of the sample material. However, [22] indicate that, to the coating of carbide tools, the characteristic of increasing the adhesion resistance is attributed, facilitating the flow and removal of the chip.

The force spectrum shown in Figure 15b, indicates the presence of melting on the surface of the sample without sealant machined with a tool with a radius of 0.4 mm, at the end of the milling process.



(a)

Figure 15a: Sample without sealant (nose radius 0,4 mm): (a) Machined surfaces.
Source: Authors, (2022).



(b)

Figure 15b: Sample without sealant (nose radius 0,4 mm): (b) Force spectrum (3rd channel)
Source: Authors, (2022).

V. CONCLUSIONS

Due to the results obtained, it is possible to conclude that:

1. The current thermal sprayed demonstrated high surface roughness and high porosity, which are intrinsic from the arc spray process, resulting intermittent cutting;
2. The presence of sealant on the coating provided an increase in the machining force. Due to the sealant being an epoxy resin, the typical behavior of the cutting mechanism may have occurred in composite materials in which hard polymer particles are formed during milling, increasing the machining force;
3. In the machining process of the coating with the highest cutting speed (84 m/min), and with an insert with a radius of 0.8 mm, there was strong vibration, and the highest values of machining force were recorded, especially in the sample with sealant application;

4. The wear on the tip, which occurred as a result of the friction between the insert tip and the part, and the crater wear, as a result of the friction between the tool and the chip, were the most expressive in cutting tools;
5. The quality of the machined surface did not show relevant differences, where the average roughness remained within the standard of the literature in tools with or without sealant;
6. In machining with cutting speed of 50 m/min and spray coating without application of sealant, the insert with 0.4 mm radius showed more favorable results such as lower machining force, less wear and better finish on the machined surface;
7. The 0.8 mm radius insert showed better performance when machining the specimen with sealant with lower machining force, less tool wear on the main flank and slightly lower surface roughness.

VI. AUTHOR'S CONTRIBUTION

Conceptualization: Carlos Jorge Leão de Oliveira, Hector Reynaldo Meneses Costa, Tatiane de Campos Chuvas and Rafael da Cunha Hamano.
Methodology: Carlos Jorge Leão de Oliveira and Tatiane de Campos Chuvas.
Investigation: Carlos Jorge Leão de Oliveira and Rafael da Cunha Hamano.
Discussion of results: Carlos Jorge Leão de Oliveira and Tatiane de Campos Chuvas.
Writing – Original Draft: Carlos Jorge Leão de Oliveira.
Writing – Review and Editing: Carlos Jorge Leão de Oliveira, Rafael da Cunha Hamano and Tatiane de Campos Chuvas.
Resources: Carlos Jorge Leão de Oliveia and Hector Reynaldo Meneses Costa.
Supervision: Hector Reynaldo Meneses Costa and Tatiane de Campos Chuvas.
Approval of the final text: Carlos Jorge Leão de Oliveira, Hector Reynaldo Meneses Costa, Tatiane de Campos Chuvas and Rafael da Cunha Hamano.

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VIII. REFERENCES

[1] R. Varavallo, M. D. Manfrinato, L. S. Rossino, F. Camargo, e S. D. de Souza, "Ensaio de adesão em revestimentos metálicos obtidos por HVOF", p. 1–6, jul. 2008.

[2] J. Řehoř et al., "Prediction Of The Influence Of Cutting Conditions On Surface Morphology After Its Thermal Spraying With Stellite 6 Alloy", In Review, preprint, fev. 2022. doi: 10.21203/rs.3.rs-1336218/v1.

[3] T. Zlámal, J. Petrů, M. Pagáč, e P. Krajkovič, "Influence of Machining Process on Surface Integrity of Plasma Coating", vol. 11, no 12, p. 5, 2017.

[4] M. Gueli, J. Ma, N. Cococcetta, D. Pearl, e M. P. Jahan, "Experimental investigation into tool wear, cutting forces, and resulting surface finish during dry and flood coolant slot milling of Inconel 718", Procedia Manuf., vol. 53, p. 236–245, 2021, doi: 10.1016/j.promfg.2021.06.026.

[5] P. Das, S. Paul, e P. P. Bandyopadhyay, "Plasma sprayed diamond reinforced molybdenum coatings", J. Alloys Compd., vol. 767, p. 448–455, 2018, doi: 10.1016/j.jallcom.2018.07.088.

[6] J.-K. Xiao, Y.-Q. Wu, W. Zhang, J. Chen, X.-L. Wei, e C. Zhang, "Microstructure, wear and corrosion behaviors of plasma sprayed NiCrBSi-Zr coating", Surf. Coat. Technol., vol. 360, p. 172–180, fev. 2019, doi: 10.1016/j.surfcoat.2018.12.114.

[7] G. Darut et al., "State of the art of particle emissions in thermal spraying and other high energy processes based on metal powders", J. Clean. Prod., vol. 303, p. 126952, jun. 2021, doi: 10.1016/j.jclepro.2021.126952.

[8] W. Chen et al., "Friction and anti-corrosion characteristics of arc sprayed Al+Zn coatings on steel structures prepared in atmospheric environment", J. Mater. Res. Technol., vol. 15, p. 6562–6573, nov. 2021, doi: 10.1016/j.jmrt.2021.11.084.

[9] M. M. Verdian, "3.13 Finishing and Post-Treatment of Thermal Spray Coatings", em Comprehensive Materials Finishing, Elsevier, 2017, p. 191–206. doi: 10.1016/B978-0-12-803581-8.09200-6.

[10] M. Vijaya Ganesa Velan, M. Subha Shree, e P. Muthuswamy, "Effect of cutting parameters and high-pressure coolant on forces, surface roughness and tool life in turning AISI 1045 steel", Mater. Today Proc., vol. 43, p. 482–489, 2021, doi: 10.1016/j.matpr.2020.12.020.

[11] Araújo, Anna Carla (último), Mougo, Adriane Lopes, e Campos, Fábio de Oliveira, Usinagem para Engenharia - Um Curso de Mecânica do Corte, 1a. Rio de janeiro - BR, 2020.

[12] Y. Chen, J. Wang, e Q. An, "Mechanisms and predictive force models for machining with rake face textured cutting tools under orthogonal cutting conditions", Int. J. Mech. Sci., vol. 195, p. 106246, abr. 2021, doi: 10.1016/j.ijmecsci.2020.106246.

[13] G. Jangali Satish, V. N. Gaitonde, e V. N. Kulkarni, "Traditional and non-traditional machining of nickel-based superalloys: A brief review", Mater. Today Proc., vol. 44, p. 1448–1454, 2021, doi: 10.1016/j.matpr.2020.11.632.

[14] Z. Barzegar e E. Ozlu, "Analytical prediction of cutting tool temperature distribution in orthogonal cutting including third deformation zone", J. Manuf. Process., vol. 67, p. 325–344, jul. 2021, doi: 10.1016/j.jmapro.2021.05.003.

[15] ASTM, "ASTM A36: Standard Specification for Carbon Structural Steel", p. 6, 1977.

[16] Norma ASME, "ASME SECTION II - Materials - ASME Boiler and Pressure Vessel code an International code", no 2021, p. 1019, 2021.

[17] F. Romeo Martins, "Caracterização do fresamento de chapas de compósito polímero reforçado com fibras de carbono (PRFC)", Doutor em Engenharia Mecânica, Universidade Estadual de Campinas, Campinas, 2014. doi: 10.47749/T/UNICAMP.2014.931949.

[18] V. Schulze, C. Becke, e R. Pabst, "Specific machining forces and resultant force vectors for machining of reinforced plastics", CIRP Ann., vol. 60, no 1, p. 69–72, 2011, doi: 10.1016/j.cirp.2011.03.085.

[19] W. Akhtar, J. Sun, P. Sun, W. Chen, e Z. Saleem, "Tool wear mechanisms in the machining of Nickel based super-alloys: A review", Front. Mech. Eng., vol. 9, no 2, p. 106–119, jun. 2014, doi: 10.1007/s11465-014-0301-2.

[20] M. Sarıkaya et al., "A state-of-the-art review on tool wear and surface integrity characteristics in machining of superalloys", CIRP J. Manuf. Sci. Technol., vol. 35, p. 624–658, nov. 2021, doi: 10.1016/j.cirpj.2021.08.005.

[21] J. M. Zhou, V. Bushlya, e J. E. Stahl, "An investigation of surface damage in the high speed turning of Inconel 718 with use of whisker reinforced ceramic tools", J. Mater. Process. Technol., vol. 212, no 2, p. 372–384, fev. 2012, doi: 10.1016/j.jmatprotec.2011.09.022.

[22] B. C. M. Reis et al., "Influência do material da ferramenta de corte sobre a usinabilidade do aço ABNT 4340 no torneamento", Matér. Rio Jan., vol. 24, no 3, p. e12449, 2019, doi: 10.1590/s1517-707620190003.0765.

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RESEARCH ARTICLE OPEN ACCESS

LOCALIZED FEATURES IN SUBSOIL INVESTIGATION AND IMPLICATIONS FOR FOUNDATION WORKS: CASE STUDY FROM ILORA, SOUTHWESTERN NIGERIA

Akintunde Akinola Oyedele*[1], Joshua T. Akinwamide[2] and Segun N. Ogunyebi[3]

[1] Department of Physics, Ekiti State University, Ado – Ekiti, Nigeria.
[2] Department of Civil Engineering, The Federal Polytechnic, Ado – Ekiti, Nigeria.
[3] Department of Mathematics, Ekiti State University, Ado – Ekiti, Nigeria.

[1] http://orcid.org/0000-0003-0428-7566, [2] http://orcid.org/0000-0001-5057-0173, [3] http://orcid.org/0000-0002-4452-3693

Email: *akinakin02@yahoo.com, akinwamide_Joshua@yahoo.com, segunogunyebi@yahoo.com

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ABSTRACT

Subsoil investigations involving geoelectric depth sounding, boring and sampling with *in situ* and laboratory tests were carried out at an interchange location in a typical basement complex terrain of Ilora, Southwestern Nigeria with the objective of detailing the subsurface characteristics and appropriate foundation. The geotechnical investigations utilized 2 Numbers exploratory boreholes while geoelectric depth soundings were carried out at seven (7) points along the traverse using the Schlumberger array. An allowable bearing capacity of $>$800 kN/m^2 was observed for the bedrock revealed at 4.00 and 6.95 m, respectively. The geoelectric depth sounding delineated the bedrock (of resistivity $>$3000 Ωm) occurring at varying depths of 4.00 to 12.00 m with structural features diagnostic of faulting (resistivity of 1082 / 1282 Ωm) and clayey saprolite of significant thickness (resistivity of 58 / 66 Ωm; thickness of 12 m) localized within about 45 m span. Integration of the data sets indicated that the drilling programme could not decipher the localized features which could be hazardous to the stability of the structure despite the good correlation observed at the points of investigation. This study underlines the need to complement traditional geotechnical testing with geophysical exploration methods for optimal results in subsoil investigation.

I. INTRODUCTION

Subsoil investigation, consisting of *in situ* tests either independently or in combination with laboratory tests, has become a prerequisite for civil engineering projects. It provides geotechnical information which would inform the safe design of the substructure elements. Amongst the main challenges of the procedure is the determination of exploratory borehole (BH) locations. The borehole locations for collection of subsoil samples are often picked by the rule of thumb. It has been identified that one common cause of structural failures is inadequate subsoil investigation resulting in poor foundation design [1, 2, 3].

In geotechnical site investigation, it is often difficult to determine the spacing of borings before an investigation begins in any drilling programme without any specific pre-drilling guide such as the geophysical investigation methods. The subsurface geology of the proposed site remains the primary determinant.

The thrust of this study is to consider mapping localized features that could heighten post construction failure of built structures amidst the borehole spacing constraint, with a view to forestalling the attendant consequences on foundation works.

II. THEORETICAL REFERENCE

The stability of a structure depends greatly on the nature of the foundation which is anchored on the geologic conditions of the underlying geomaterials. The spacing adequate enough for reliable results demands requisite attention. Otherwise, some inherent features might be inevitably missed out as exploratory boreholes provide information only at discrete locations [3, 4, 5].

The crystalline basement rocks exhibit structural features (joints, fissures and fractures/faults) which are produced by weathering and tectonic processes. The features are associated with enhanced secondary porosity and permeability. Most often, occurrence of these water-bearing features in this terrain is localized and confined to weathered/fractured zones. These features must be avoided in foundation works as the watered joints and faults are more likely to be problematic in engineering construction works. Most embankment problems occur from low compressive strength subsoil, high void ratios and unfavorable water content in the soil [1, 3, 6].

An efficient location of boring and *in situ* test points is required to furnish adequate subsoil information. It is essential that borings should penetrate all strata that could shear or consolidate materially under the load of the structure. However, it is almost impracticable to drill boreholes at very close intervals. Foundation failures are often traceable to concealed geologic features within the subsurface which may precipitate differential settlement leading to failure or collapse of structures [7, 8, 9].

II.1 SITE DESCRIPTION AND GEOLOGY

The area of study is located on the Ilora - Oyo road (Figure 1). It is underlain by undifferentiated basement complex rocks of the Southwest, Nigeria. The crystalline basement complex is highly fractured and jointed. Minor folds, lineations, shearing, bondinage and axial plane foliation are among the most prominent structural elements in these rocks.

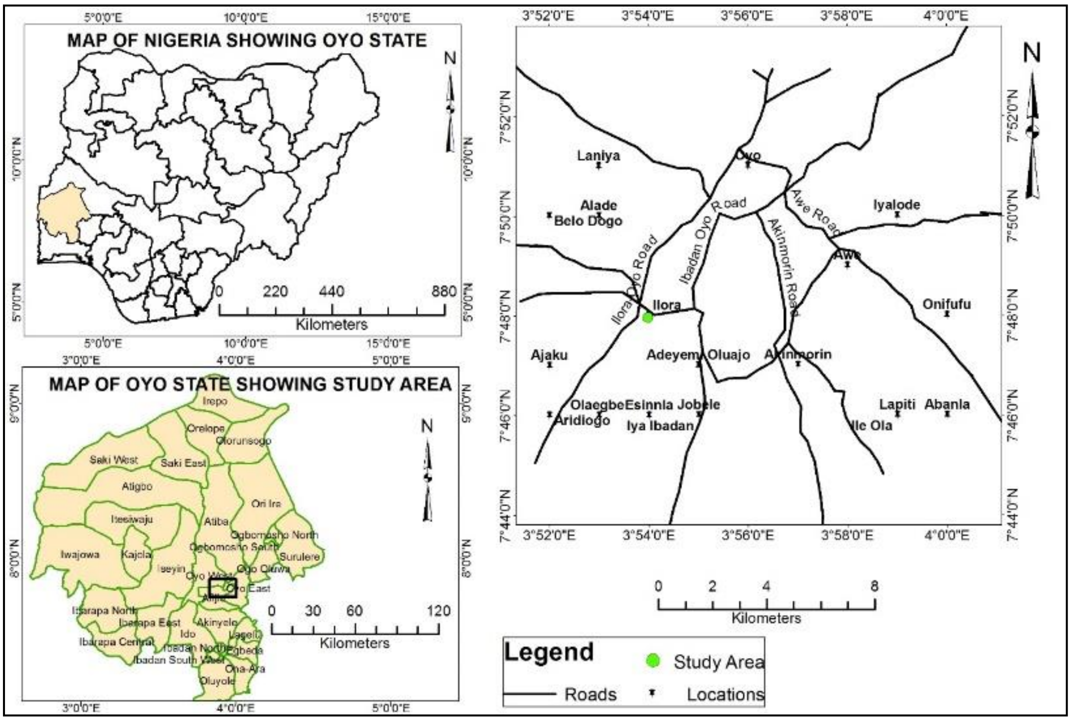


Figure 1: Location map of Ilora.
Source: Authors, (2022).

The dominant rock types in the area include migmatite, undifferentiated schist and gneiss, silicified sheared rocks and quartz veins (Figure 2). The region is characterized by faulting and jointing, showing a general trend of North – South with subsidiaries along NW – SE, E –W and NE – SW orientations. The depth of weathering depends to a large extent on the nature of the rocks, climate, topography and structural elements such as faults and joints [10, 11, 12].

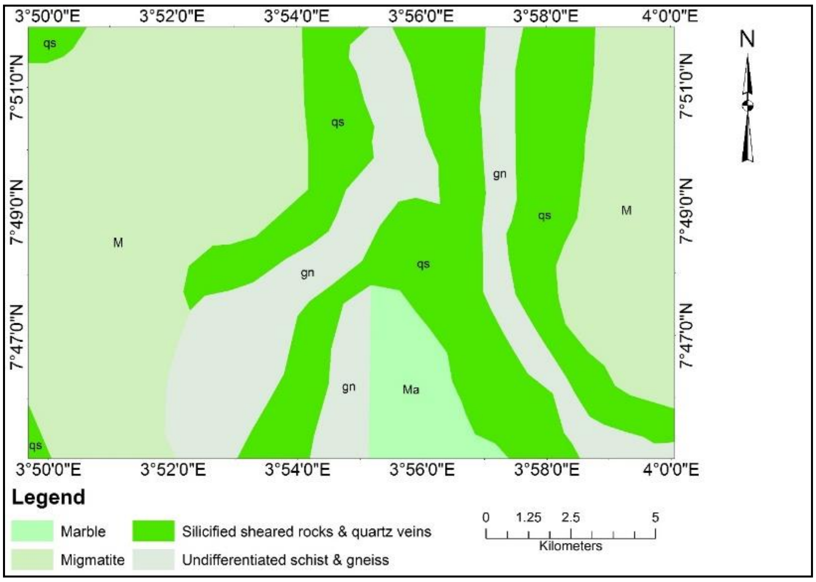


Figure 2: Geological map of Ilora.
Source: Authors, (2022).

III. MATERIALS AND METHODS

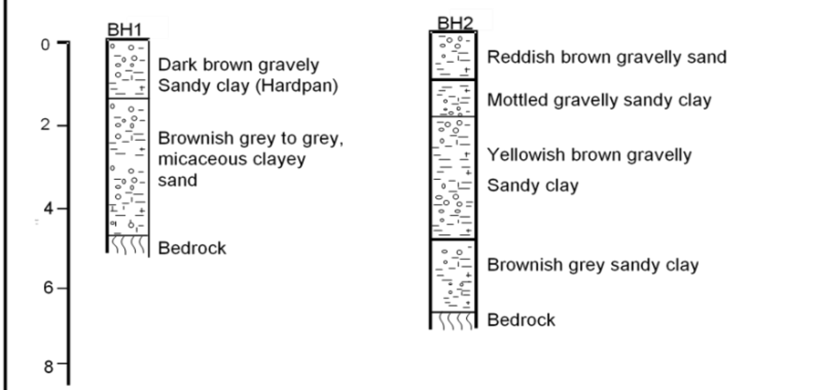
The investigation consisted of geotechnical fieldwork followed by geoelectric surveying essentially run to provide for an appraisal of the drilling results and eventual foundation recommendations. The geotechnical fieldwork comprising of two (2 Nos.) shell and auger boring was carried out using the light cable percussion rig of the Pilcon Wayfarer type. Sampling and *in suit* tests were carried out where necessary during the boring operations. Standard Penetration Test (SPT) was carried out at intervals to determine penetration resistance. The tests involve obtaining the number of blows (N-values) producing the last 300mm of penetration, in connection with an overall 450 mm penetration test, by a 63.4 kg hammer having a free fall through 760 mm. The penetration resistance is an indication of the density of cohesionless soils and of the strength of cohesive soils. SPT is thus an in – place dynamic shear test. The allowable bearing pressure based on the 'N' value has been estimated for the borehole locations [13, 14].

The geophysical investigation was carried out using vertical electrical sounding (VES) technique with the Schlumberger array. Half current electrode spacing (AB/2) has been varied from 1 to 100m. The instrument used for resistance measurement was the ABEM Tetrameter SAS 300B with ABEM 2000 Booster. VES stations were located along the traverse such that at least one of the stations was very close to an exploratory borehole. Seven VES stations were occupied to generate the geoelectric sequence of the study area, delineate zones of weakness and evaluate the structural competence of the sub-soil/bedrock [3, 15, 16]. The apparent resistivity values obtained from the vertical electrical sounding were plotted against electrode spacing on a bi-log paper. Visual inspection of these curves gave qualitative interpretation of the subsurface resistivity variations. Quantitatively the sounding curves were interpreted by partial curve matching technique using a 2-layer master curve and the corresponding auxiliary curves. Geoelectric parameters from this manual interpretation were improved upon through the use of computer iteration technique using the computer algorithm RESIST Version 1.0 [17]. These results were then presented as geoelectric sections [3, 15, 18]. In this study the exploratory boreholes provided controls to avoid interpretation ambiguity.

IV. RESULTS AND DISCUSSIONS

The results of the drilling exercise showed a considerable variation in the subsoil conditions at the two points investigated. Bedrock was encountered at 4.0 m depth at BH 1 and 6.95 m depth at BH 2. The soil stratifications with the corresponding lithological sections are presented in Figure 3. The results of the SPT, the estimated allowable pressure and the proposed foundation recommendation based on the 2 Nos. exploratory boreholes drilled at the site are presented in Table 1. The SPT gave >800 kN/m^2 as allowable pressure at BH 1 and BH 2 respectively.

The geoelectric investigation is presented as a geoelectric section with the BH lithological section in place (Figure 4).



BH 1

0.00 - 1.45m	Dar brown gravelly sandy clay (Hard pan)
1.45 - 4.00m	Brownish grey to grey micaceous clayey sand
4.00m	Bedrock

BH 2

0.00 - 1.20m	Reddish brown gravelly sand
1.20 - 2.10m	Motted gravelly sandy clay
2.10 - 5.00m	Yellowish brown gravelly sandy clay
5.00 - 6.95m	Brownish gray sandy clay
6.95m	Bedrock

Figure 3: Lithological Section of the Bridge Site.
Source: Authors, (2022).

Table 1: SPT Results and Foundation Recommendation (based on 2Nos. Exploratory boreholes drilled at the site).

Bh	Depth (m)	Value of "N"	Pressure (kN/m^2)	Proposed Foundation Depth and Type
BH 1	0.45	40	530	Spread foundation at depth 4.0m below existing ground level (elev. +282.26). Proposed road level +284.20
	1.95	28	440	
	3.45	21	330	
	4.00	50	>800	
BH 2	0.4	12	230	Spread foundation at depth 6.0m below existing ground level (elev. +280.26). Proposed road level +284.20
	1.95	27	480	
	3.45	12	250	
	5.25	23	300	
	6.95	50	>800	

Source: Authors, (2022).

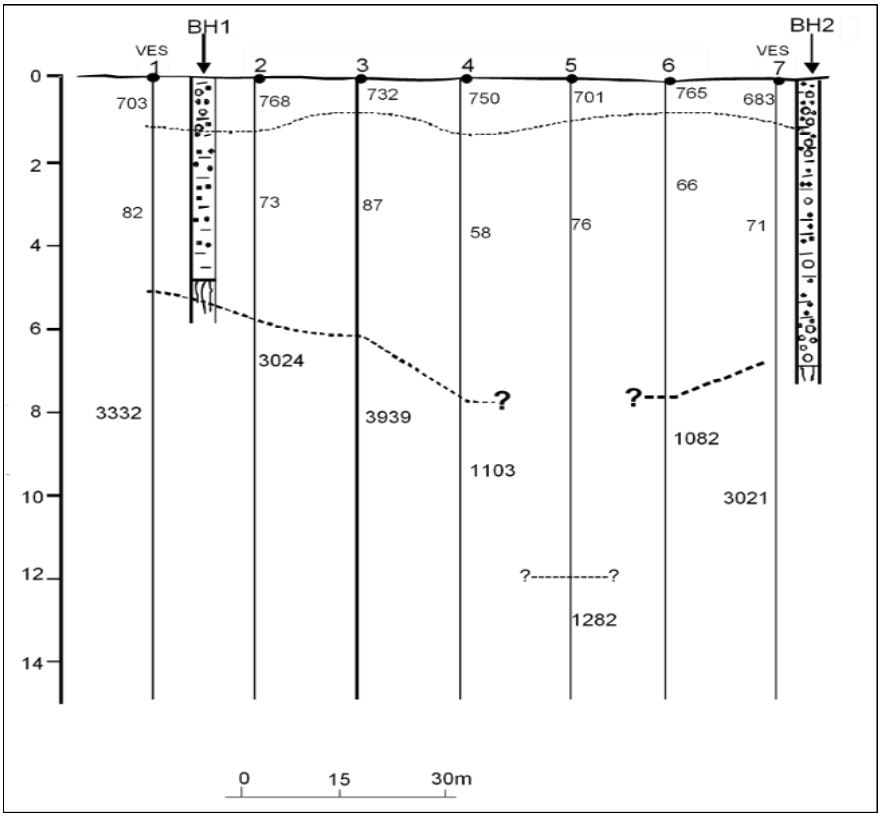


Figure 4: Correlation between Geoelectric Section and Lithological Section.
Source: Authors, (2022).

Three subsurface geologic layers were delineated (the topsoil, lateritic/clay substratum and partly weathered/fractured basement/fresh basement with resistivity ranging from 623 – 768 ohm-m, 58 – 87 ohm-m and 1082 – 3939 ohm-m, respectively). The thickness under VES 5 could be attributed to local fracturing of the bedrock. The third layer constitutes the bedrock with varying degree of freshness indicated by resistivity values ranging from 1082 to 3939 Ωm. The faulting/fracturing under VES 5 could be a consequence of a minor tectonic event emanating from the major faulting between Ilora and Oyo [10, 11, 15].

Despite the good correlations shown in Figure 3 (BH 1 / VES 1; BH 2 / VES 7) the localized structural defects (fracturing/faulting) occurring between VES 4 and VES 6 could not be deciphered from the borehole data. This is consistent with the fact that results from conventional geotechnical investigation methods are discrete. The marked variability and unpredictability of the nature of crystalline basement rocks suggests that precision is essential as the prolonged *in situ* weathering under tropical conditions has produced a lithologic sequence of unconsolidated material whose thickness and lateral extent vary extensively. The geology of the subsurface thus needs to be investigated in considerable details [12, 15, 16].

The thickness of the clayey horizon overlying the faulted bedrock is also significant. Substrata characterized by low resistivity (~ 1000 ohm-m) within the bedrock and low average resistivity (<100 ohm-m) within the overburden are considered geotechnically incompetent to bear significant engineering structures (Figure 5). Loading the near surface soil will result in consolidation settlement of the clayey layer overlying the bedrock [3, 18]. The existence of such tectonic features is inimical to the performance of the project if not addressed in the selection and design of the foundation. An effective site characterization is required in order to detect zones with poor geotechnical materials [2, 13, 19].

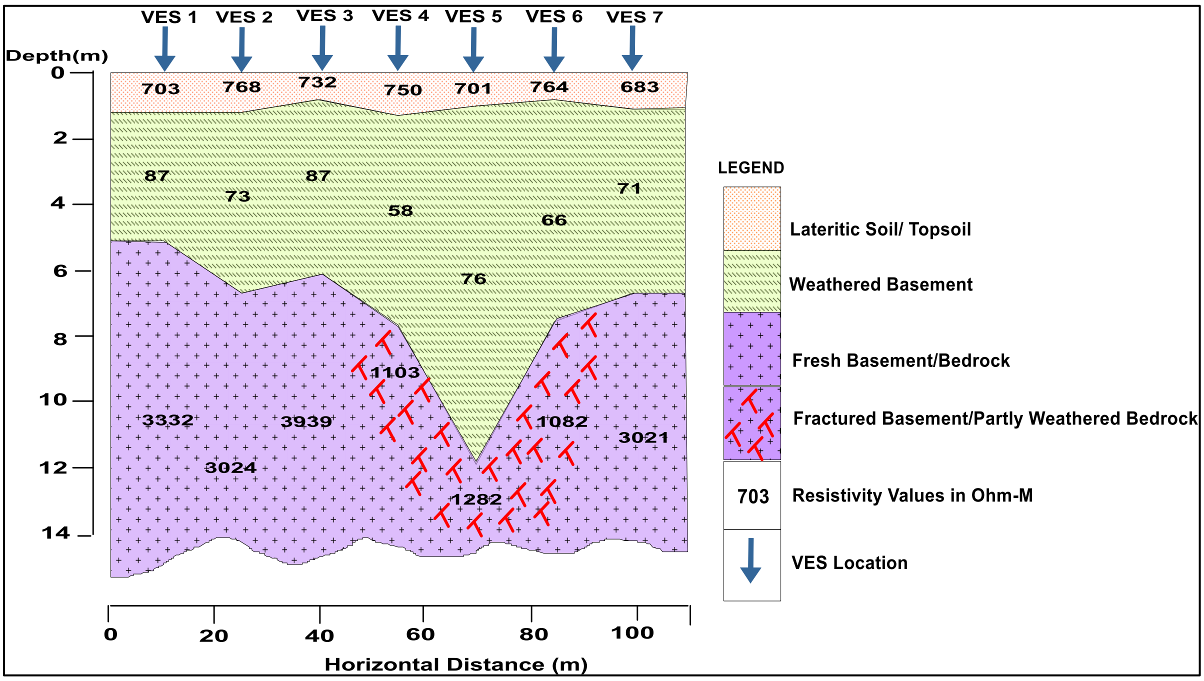


Figure 5: 2-D Geoelectric Section along the traverse.
Source: Authors, (2022).

The proposal of placing a spread foundation at a depth of 4.0m below the existing ground level at BH 1 (Elevation +282.26) and similarly at depth of 6.0 m at BH 2 (Elevation +280.26) informed by the results of the 2Nos. exploratory boreholes (Table 1) would have been considered adequate but for the risk of founding the piers and abutments within the problematic region around VES 5 spanning about 45.0 m of the 100 m right of way. The presence of these localized features would have adverse effects on the stability of the interchange if the spread foundation is adopted.

Although the bedrock with allowable bearing pressure of >800 kN/m^2 and resistivity of >3000 Ωm indicates a substratum of appreciable geotechnical competence, the uniformity of sound and competent unit cannot be assumed for the span (of about 45.0 m) through the degradation evidenced by the localized features. The region delineated as geotechnically incompetent requires engineering workings to be determined by the proposed load in order to improve the bearing capacity of the geomaterial. The application of jet grouting technique, as a soil stabilization method would enhance the competence of the affected region. Jet grouted piles become a suitable choice under these conditions [20, 21, 22].

V. CONCLUSIONS

The study revealed that geophysical exploration methods should be run to complement boring exercise for optimal results. Appropriate geophysical investigations should precede the application of traditional geotechnical investigation methods in order to guide the positioning of exploratory test points for optimum information on subsoil investigation. A simple spread foundation would be inadequate for the interchange despite the coherent results of the carefully executed drilling exercise due to the localized faulted region with the clayey saprolite of significant thickness delineated by the geoelectric survey. The 2Nos. borings at a separation of about 90.0m could not detect the problematic region. These results agree with the submission that exploratory boreholes provide information only at discrete locations while geophysical studies provide a relatively rapid and cost – effective means of deriving aerially distributed information on subsurface geology.

To accommodate the varying depths to competent bedrock and the localized features indicative of lesser geotechnical integrity, friction bearing piles or jet grouted piles should be adopted for the foundation works of the structure. An integration of geophysics and conventional geotechnical investigation methods will enhance the efficiency and reliability of subsoil investigation thereby promoting stability of built structures.

VI. AUTHOR'S CONTRIBUTION

Conceptualization: Oyedele, Akinwamide and Ogunyebi.
Methodology: Oyedele and Akinwamide.
Investigation: Oyedele and Ogunyebi.
Discussion of results: Oyedele, Akinwamide and Ogunyebi.
Writing – Original Draft: Oyedele.
Writing– Review and Editing: Akinwamide and Ogunyebi.
Resources: Oyedele and Ogunyebi.
Supervision: Oyedele and Akinwamide.
Approval of the final text: Oyedele, Akinwamide and Ogunyebi.

VII. ACKNOWLEDGMENTS

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VIII. REFERENCES

[1] Olayanju, G.M., Mogaji, A.K., Lim, H.S., Ojo, T.S., "Foundation integrity assessment using integrated geophysical and geotechnical techniques: Case study in crystalline basement complex, southwestern Nigeria." J. Geophys. Eng., vol. 14, pp. 675–690, 2017.

[2] Rehman, Z., Akbar, A., Clarke. B.G., “Characterization of an Artificially Prepared Cohesive Soil Bed.” Pak. J. Eng. & Appl. Sci., vol. 6, pp. 26-41, 2010.

[3] Coker, J.O., “Integration of Geophysical and Geotechnical Methods to Site Characterization for Construction Work at the School of Management Area, Lagos State Polytechnic, Ikorodu, Lagos, Nigeria.” Int. J Energy Sc & Eng, vol. 1, no. 2, pp. 40-48, 2015.

[4] Kearey, P., Brooks, M., Hil, I., “An Introduction to Geophysical Exploration. 3rd Edition, Blackwell Science Limited.” 2002.

[5] Abu Zeid N., “3D Electrical Resistivity Tomography for Noninvasive Characterization of Historical Walls.” In: D'Amico S., Venuti V. (eds) Handbook of Cultural Heritage Analysis. Springer, Cham., 2022. https://doi.org/10.1007/978-3-030-60016-7_28.

[6] Ayodele, M. O., Omoirabor, O., Adiela, U.P., “An Investigation of the Relationship between Electrical Resistivity (Wenner and Schlumberger Arrays) and Geotechnical Parameters in Foundation Investigation in Basement Complex Area of Iloko, Osun State, Nigeria.” Int. J. Sci Eng. Sci., vol. 1, no. 5, pp. 18-23, 2017.

[7] Adelusi, A.O., Adiat, K.A.N., Amigun, J.O., “Integration of surface electrical prospecting methods for fracture detection in precambrian basement rocks of Iwaraja area, southwestern Nigeria.” Ozean J. Appl Sci., vol. 2, no. 3, pp. 265-280, 2009.

[8] Fatoba, J.O., Salami, B.M., Adesida, A., “Structural failure investigation using electrical resistivity method: A case study of Amafor Ihuokpala, Enugu, Southeastern Nigeria.” J. Geol Mining Res., vol. 5, no. 8, pp. 208-215, 2013.

[9] Oyeyemi, K.D., Olofinnade, O. M., “Geoelectrical-Geotechnical Studies for Near Surface Characterization, Case History: Lagos, SW Nigeria.” Electro J. Geotech Eng., vol. 21, no. 10, pp. 3735 – 3750, 2016.

[10] Faniran, A., “Depth and Pattern of Weathering in the Nigerian Precambrian Basement Complex Rock Areas: A Preliminary Report. African Geology.” pp. 379-394, 1988.

[11] Rahaman, M.A., “Recent Advances in the study of the Basement Complex of Nigeria in the Precambrian Geology of Nigeria.” pp. 11 – 43, 1988.

[12] Omowumi, O., “Electrical Resistivity Imaging Survey For Shallow Site Investigation At University of Ibadan Campus Southwestern Nigeria.” J. Eng & Appl Sci, vol. 7, no. 2, pp. 187-196, 2012.

[13] Gutiérrez-Martín, A., Yenes, J.I., Fernández-Hernández, M., Castedo, R., Stabilization Methodology in Foundation Soils by ERT-3D Application in Estepona, South Spain. Appl. Sci. 11, 4455, 2021. https://doi.org/10.3390/app11104455.

[14] Akbar, A., Arshad, M., Clarke, B. G., “Site Characterization Using CPT, DMT, SPT and Laboratory Test Results.” Proceedings, International Conference on Geotechnical and Geophysical Site Characterization, Taipei, Taiwan, pp. 251-256, 2008.

[15] Olorunfemi, M.O., Idonigie, A.I., Coker, A.T., Babadiya, G.E., “On the application of the electrical resistivity method in foundation failure investigation: A Case Study.” Global J. Geol. Sci., vol. 2, pp. 139-151, 2004.

[16] Adelekan, A., Igbasan, A., Oladunjoye, M., “Integration of Electrical Resistivity and Ground Penetrating Radar Methods for Site Characterization: a Case study of Ajibode Area, Ibadan, Southwestern Nigeria.” Int. J. of Environ Sci Nat Res., vol.1, no. 3, pp. 555 – 564, 2017.

[17] Vander Velpen, B.P.A., “Resist Version 1.0.” M.Sc Research Project, ITC, Delft, Netherlands, 1988.

[18] Ofomola, M.O., Adiat, K.A.N., Olayanju, G.M., Ako, B.D., “Integrated Geophysical Methods for Post Foundation Studies, Obanla Staff Quarters of the Federal University of Technology, Akure, Nigeria”. The Pacific J. Sci & Tech., vol. 10, no. 2, pp. 93 – 111, 2009.

[19] Adesida, A., Omosuyi, G.O., “Geoelectric Investigation of Bedrock Structures in the Mini-Campus of the Federal University of Technology, Akure, Southwestern Nigeria and the Geotechnical Significance.” Nig. J. Pure Appl Phys. pp. 4:32-40, 2005.

[20] Bouassida, M., Manigniavy, S. A., Azaiez, D., Bouassida, Y. “New Approach for Characterization and Mitigation of the Swelling Phenomenon.” Front. Built Environ., vol. 8, no. 836277, 2022. doi: 10.3389/fbuil.2022.836277.

[21] Argal, E.S. “Modern Technologies and Problems of Ground Stabilization by Injection.” Soil Mech. Found. Eng., vol. 57, pp. 219–226, 2020.

[22] Shao, P.; Shang, Y.; Hasan, M.; Yi, X.; Meng, H. “Integration of ERT, IP and SP Methods in Hard Rock Engineering.” Appl. Sci., 11, 10752, 2021 https://doi.org/10.3390/app112210752

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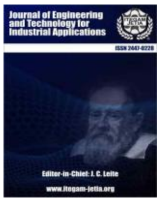

RESEARCH ARTICLE OPEN ACCESS

APPLICATION OF METHODS-TIME MEASUREMENT AS A TOOL TO IMPROVE PRODUCTIVITY IN A BEAUTY SALON

Eliana de Jesus Lopes*[1], Antonia Bruna Vieira de Souza[2], José Ítalo da Silva Pierre[3], Raimundo Alberto Rêgo Júnior[4] and Flávio Albuquerque Ferreira da Ponte[5]

[1, 2, 3, 4, 5] University Center INTA – UNINTA, Sobral, Ceará, Brazil.

[1] http://orcid.org/0000-0003-0496-1661, [2] http://orcid.org/0000-0002-5313-0015, [3] http://orcid.org/0000-0003-1740-9876, [4] http://orcid.org/0000-0003-2885-6647, [5] http://orcid.org/0000-0003-4631-5828,

Email: *prof.eng.eliana@gmail.com, brunna1006@hotmail.com, italopierre.eng@gmail.com, albertojuniorpdf@hotmail.com, flaviodaponte@hotmail.com

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ABSTRACT

The Methods-Time Measurement (MTM) tool has been gaining ground for offering cost-effective solutions for products/services, focusing on time reduction and wastage elimination. Aiming at the optimization of operations, this research aimed to evaluate the operational results from the MTM tool in a medium-sized beauty salon in the Tianguá-CE city. To carry out the study, the services provided by the salon were evaluated to verify the one that was most relevant, highlighting the services of manicure and pedicure. In these services, a diagnosis of the current scenario was carried out, and MTM were applied to identify opportunities for their optimization. After obtaining the results and analyzing them, it was possible to reduce unnecessary activities by 54.61% in the pedicure service and 62.57% in the manicure service, resulting in more agile, efficient, and low-cost services. In addition to reducing unnecessary activities, this improvement was possible through the standardization of the other activities that make up the service and the reorganization of the layout. Therefore, it is concluded that the application of the MTM provided gains in productivity and in the quality of the service provided, as there was a reduction in waste and greater agility in the service.

I. INTRODUCTION

The rapid technological evolution of the last decades has been one of the main driving factors for organizations to be able to constantly outline new strategies and thus remain competitive in the market [1]. These constant changes bring the need for adjustments in processes and operational procedures to seek increased productivity while maintaining the quality of products/services [2, 3].

In this context, the application of standardized operational methods, as well as the management of activities so that they could generate more value to production processes, have become indispensable for current organizations to remain competitive and one of the tools that allow identifying opportunities for this standardization is the Methods-Time Measurement (MTM) [4].

MTM increases the competitiveness of the business, making it possible to identify its productive capacity and correct its weaknesses in relation to competitors [5]. As we are experiencing a critical moment in the Brazilian economy, mainly because of the Covid-19 pandemic, it is necessary for organizations to be able to streamline their processes and this tool is a great opportunity for that.

Widely used in industry [4, 5, 6], however, there are already studies with its application in service providers, allowing an effective solution for product/service costs, with a focus on reducing time and eliminating waste [7].

The services segment has been greatly affected in recent years, mainly because of the current economic-sanitary crisis, with the stoppage of trade due to the expansion of the Covid-19 contagion. This situation has led companies to reinvent themselves and seek alternatives to better manage their processes and thus increase their efficiency and competitiveness [8].

Another factor that can improve performance is the use of new technologies, which allows for greater flow of information and materials, providing a more solid and concise basis for decision-making [9]. Thus, organizations have been betting on new technologies for better process and product management, as well as identifying opportunities for continuous improvement.

In the quest to guarantee competitiveness, the application of the MTM allows maintaining the quality of services, reducing the idle time of some activities, and seeking continuous improvement of the processes [10, 11]. Banks are examples of service providers that, with the customer as the center of attention, their differential is in maintaining a service with quality, efficiency, and low operating cost [8]. In the same way, it is possible to perceive this situation in organizations that provide services of the most different segments, such as, for example, in a beauty salon.

In this context, according to the Brazilian Association of the Personal Hygiene and Cosmetic Industry [12], Brazil has been gaining ground in the beauty sector, being among the three countries that most invested and invests in this sector, behind only China and the United States, in relation to the global market.

In this type of enterprise, there is a high demand for services that has been growing every year, especially in Brazil, which, even in the face of an economic crisis due to the covid-19 pandemic, has been recording continuous increases according to the Brazilian Institute of Geography and Statistics, known by the acronym IBGE, and the Brazilian Association of the Personal Hygiene, Perfumery and Cosmetics Industry, known by the acronym ABIHPEC [12].

This high demand implies operational overloads that can result in customer dissatisfaction if the establishment does not plan and adapt its activities. Thus, operations management tools such as MTM emerge as an opportunity to optimize the processes and resources employed.

Faced with a scenario conducive to the growth of this type of enterprise and the opportunities for improvement through MTM, this study aims to evaluate the operational results obtained from the application of the MTM tool in a medium-sized beauty salon in the Brazilian Northeast, to improve the productivity of your operations.

II. THEORETICAL REFERENCE

II.1 METHOD ENGINEERING: FROM TIME AND MOTION STUDY TO CHRONOANALYSIS

One of the pioneering areas of production engineering is methods engineering, which studies and analyzes the work system with the purpose of developing the best methods and procedures for people or a group of people to perform tasks in the production system without difficulties [13, 14].

Method engineering has the purpose of developing the best methods and procedures for people or a group of people to perform tasks in the production system without difficulties [15], that is, this concept can be understood as the evolution of time, motion and chronoanalysis studies [16].

The study of time began in the first half of the 20th century through studies carried out by Frederick Winslow Taylor (1856-1915) whose purpose was to determine the standard times of processes, but it was applied only in industries [2, 17, 18].

However, it was with the studies of the Gilbreth couple that work encompassing various topics began to be developed, with emphasis on improvements achieved on fatigue and monotony. In addition to these, they also developed studies on micro motions, chronocyclographs and the process flow chart [19].

The objectives of the study of movements are to determine the appropriate methods for performing a task, through a detailed analysis of the movements performed during the execution of the task, seeking to eliminate unnecessary movements and actions that increase the time to perform the activity [17].

The study by the Gilbreth couple, due to the proven cost reduction, was disseminated in the routine of the industries since their studies of movements focused on three specific objectives: preventing unnecessary movements in a task, optimizing movements that do not add value, but that are necessary for the process and define the best sequence of movements [20, 18]. These studies presented a more scientific methodology than the one used by Taylor, with the use of filming equipment, photographs, among others, and thus, it was possible to determine the characteristics of the fundamental movements.

To design increasingly efficient work methods, planning and standardizing their procedures are essential for enterprises to increase their productivity [20]. Thus, the Gilbreth couple proposed the concept of "Therbligs", in which they classify into 18 elements and their respective symbologies, the elementary movements of human work, which are those precise movements that cannot be fragmented (Table 1).

Table 1: Elementary movements of human work.

Acronym	Movement	Acronym	Movement
SH	Search	**PE**	Position
F	Find	I	Inspect
ST	Select	A	Assemble
G	Grab	DA	Disassemble
ET	Empty Transport	U	Use
TL	Loaded Transport	UD	Unavoidable Delay
H	Hold	AD	Avoidable Delay
RL	Release Load	Pn	Plan
PP	Pre-Positioning	RL	Rest for Recovery

Source: Adapted by Yen [20].

This division of movements allows for a better detailing of operations, providing deeper analysis regarding unnecessary movements that do not add value to the product [21].

Chronoanalysis is one of the methods of time and motion evaluation, which is used to measure the time required for an operator to perform a task in production [22, 23]. Considering the physiological needs and fatigue of the operator, machines subject to breakage among other unforeseen events and, in view of the unforeseen events that may occur, a tolerance is considered over the proposed time [23].

With the updates carried out over time, the term study of movements and times started to have broader purposes, starting to emphasize the ideal method of process [2, 20]. So, the term methods engineering was suggested to be used in place of the term motion and time study [24].

Method engineering seeks to optimize workstations, establishing the handling and movement of materials, layout, tools to be used in the process and specific devices, through time measurements and rationalization of movements [25]. Complementing, [26], state that installing the best working method guarantees quality in the service, making the process more productive, agile, and more economical.

The increase in performance cannot be attributed to the physical effort of the operator, but to the increase in productivity resulting from the better use of movements. The improvement of methods can be divided into three stages, namely: planning, preproduction, and production, where a new work situation is created [16].

The study of methods listed in the rationalization, idealizes efficient and productive methods maintaining the standardization of the processes, in which once implanted, and the performer properly trained allows the establishment of the method and the workplace [27, 28].

II.2 METHODS-TIME MEASUREMENT

Methods-Time Measurement (MTM) is considered a method that uses the evaluation of times and motions, initially implemented in the 1940s at the Westinghouse company, located in the city of Pittsburgh in the United States, by engineers Harold Bright Maynard, John Lenhard Schwab, and Gustave James Stegemerten [29, 30].

MTM consists of analyzing the basic movements of manual operations or existing methods, where a predetermined standard time is associated with each movement that is established according to the nature of the movements and the conditions imposed [31, 32].

For this, the main elements and their respective times are determined by filming the operations at a constant speed of 16 frames per second, facilitating the identification of the beginning and end. Operators must be properly trained to obtain better data, in addition to reducing operations times and improving existing methods [5, 31].

According to [30], it is not necessary to measure the time of the man as the operator, as there are corresponding times for each movement to be performed, that is, the chronometer becomes obsolete for the evaluation of time and movement. In parallel with the advance in the use of MTM in organizations, the MTM Association was created, developing some ramifications such as [30, 32]:

Table 2: Ramifications of MTM organizations.

MTM – GPD	American MTM Association
MTM – 2	Swedish MTM Association
MTM – SD	German MTM Association
MTM – UAS	Universal Analysis System
MTM – MEK	For production of individual parts and small series

Source: Adapted by Hengstebeck et al. [30] and Schröter et al. [32].

The basic movements considered by the MTM consist of five elements, reaching (R), grasping (G), moving (M), positioning (P) and releasing (RL), which constitute 80% to 85% of the human movements necessary for the performing a task or manual operation [30].

A standard time is assigned to each movement, represented by the Time Measurement Unit (TMU), where 1 TMU corresponds to 0.00001 hour and 1 second corresponds to 27.8 TMU's. [5, 32]. Thus, its implementation allows the uniformity of information, concept, applications and uses a single language that facilitates understanding and helps in the control of applications [29, 33].

III. MATERIALS AND METHODS

This research is characterized as a case study carried out in a beauty salon applying MTM in operational processes and procedures. For this, technical visits were carried out to observe the processes of the enterprise and seek to understand the services provided.

For data collection, a checklist was used that allowed the identification of services and their characteristics such as weekly demand, number of people involved in the process, the level of return to the salon by customers and the evaluation of the service (Figure 1).

Check List																	
Responsible for Checklist														Date	/ /		
	Services	Service per week				Number of people involved in the service					Degree of return to the company			Customer evaluation			
		1	5	9	or +	1	2	3	4	or +	High	Medium	Low	Great	Good	Regular	Bad
1																	
2																	
3																	
4																	
5																	
6																	
7																	
8																	
9																	
10																	
11																	
12																	
13																	
14																	

Figure 1: Checklist of mapped activities.
Source: Authors, (2020).

After collecting these data over a period of one-week, electronic spreadsheets were used to analyze the information and identify the service that has the greatest demand. This service was monitored through video recordings and, to provide greater accuracy in the information, the same operator was recorded in each service he performed.

Then, the stratification and identification of the movements performed in the operation were carried out, through the Kinovea program (specific software for this type of study), which allows the capture of the exact moments of each movement and its timing in milliseconds.

The video was attached to the software, reducing the speed of the movements for layering and timing. To analyze the movements and standard times established by the MTM, Table 3 was used as a basis.

Table 3: Standard fills for MTM moves.

OPERATION DESCRIPTION						
Description	**Left hand**	**Frequency**	**TMU**	**Right hand**	**Frequency**	**TMU**
Total Time						
Description	**Left foot**	**Frequency**	**TMU**	**Right foot**	**Frequency**	**TMU**
Total time						

Source: Authors, (2022).

Each movement was treated in a table with its respective data, and, at the end, we sought to identify the standard times of each movement. These standard times were applied together with the others that were not transformed into MTM. Finally, the sequencing of the movements of the entire operation was standardized and the reduction of times was observed as a function of the standardization of the movements, analyzing the results obtained.

IV. RESULTS AND DISCUSSIONS

The company in the study operates in the segment of beauty services in a city in the Brazilian Northeast and has a team of employees composed of 13 people working in different activities such as: manicure, pedicure, hair hydration, hair bleaching, brushing, straightening, depilation, moon bath, among other services. It is considered as a medium-sized beauty salon, serving 78 customers weekly.

The physical structure includes a built area of approximately 91 m², however, because of the amount and arrangement of equipment, furniture, as well as the flow of people and materials, there are reports that some days productivity is impaired. The project's layout and activities are illustrated in Figure 2.

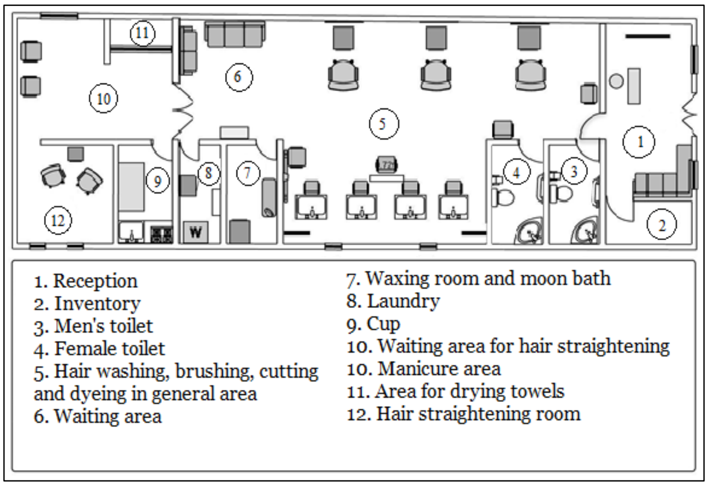

Figure 2: Beauty salon layout and its operations.
Source: Authors, (2021).

When analyzing the layout of the establishment (Figure 2), it was observed some points that hindered the fluidity of operations such as the bad dimensioning of the installed capacity, disorganization of equipment and tools, high level of movement and, in addition, the services of manicure and pedicures do not have a fixed location.

After collecting data through the checklist (Figure 1), the results presented in Figure 3 were obtained, where it was possible to verify 11 main services, the weekly demand of each one, as well as the evaluation of customers regarding the return of their return. to the place and its perception of quality, totaling 122 services performed that week.

This week, 78 customers were served, as mentioned above. Regarding the services provided at the enterprise during this period, 43.59% (34 customers) of the customers used manicure and pedicure services and 56.41% (44 customers) used the other services provided by the beauty salon. It is noticed that there are customers who consume several services in the same week.

Check List																	
Responsible for Checklist		Antonia Bruna Vieira de Souza												Date		08/08/2021	
Services		Service per week				Number of people involved in the service					Degree of return to the company			Customer evaluation			
		1	5	9	or +	1	2	3	4	or +	High	Medium	Low	Great	Good	Regular	Bad
1	Manicure and pedicure				34	x							x			x	
2	Hair highlights				20		x				x					x	
3	Blow-dry				15	x					x					x	
4	Discoloration Hair				12		x					x				x	
5	Eyebrow design				10	x					x					x	
6	Hair hydration				9	x						x				x	
7	Hair straightened (Intelligent)				6			x				x				x	
8	Progressive blow-dry				3			x				x				x	
9	Moon bath				3	x					x					x	

Figure 3: List of services, demand, and customer evaluation.
Source: Authors, (2021).

As the manicure and pedicure service presented greater demand, an in-depth evaluation was carried out, verifying the operator's movement, and recording of the 3 different services: only manicure; pedicure only; and manicure and pedicure.

The manicure service is one of the services of the establishment that most requires movement, where through the Flowchart map (Figure 4) it was possible to observe the number of movements performed by the employee in a service. The lines in blue show the amount of travel for the manicurist and the lines in red the amount of travel for the customer.

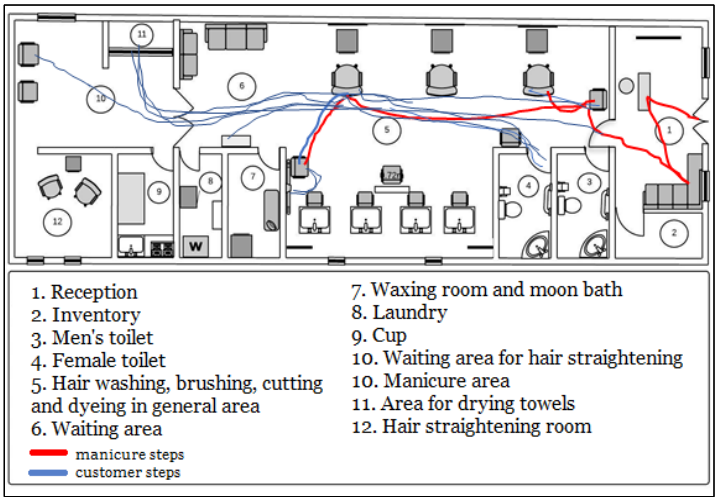

Figure 4: Flowchart map of the service provided.
Source: Authors, (2022).

The evaluated manicurist has no control over its operations and performs the activities according to the progress of the other services, not presenting a standardized service. Due to this, in a service she changes location more than once.

For daily care, the manicurist makes an average of 15 trips, with an average of 46 steps each, considering a standard of 0.5 meters per step. At the end of the service, she has performed 690 steps, which in meters she has walked 345 meters per day, the equivalent of 2070 meters per week of service (6 days worked each week). Table 4 presents these data in detail.

With the recording of this operator's process, her movements were stratified, making it possible to perceive that the clients who wanted to do the procedure only with the foot, it has an average duration of 44 and a half minutes, for the clients who want to do the service only with the hand, has an average duration of 50 minutes and those who requested both procedures, on the feet and hands, the average duration was 1 hour and 30 minutes.

Table 4: Service x Operator's Movement.

	weekly service	*monthly service*
number of trips	90	360
number of steps	4,140 steps	16,560 steps
Average distance walked (meter)	2,070 m	8,280 m
Total number of clients served by the service	34 customers	136 customers
% of customers served by the service	43,59%	

Source: Authors, (2022).

The first aggravating factor that enhances the long duration of the activity is linked to the attention that the manicurist needs to give to the client, because at times there are conversations that make it impossible to carry out the activity and handle the tools. The second aggravating factor is the management of your activity from one place to another, due to having another person also performing different procedures (which may be brushing, cutting, eyebrows, among other services).

With the stratification of the movements, it was observed that this service is divided into six movements, where they are subdivided into more movements between them. Among these movements, four of them tend to add value to the service and demand more from the manicure to perform, namely: sawing nails, enameling nails, removing cuticles, and exfoliating feet (Figure 5).

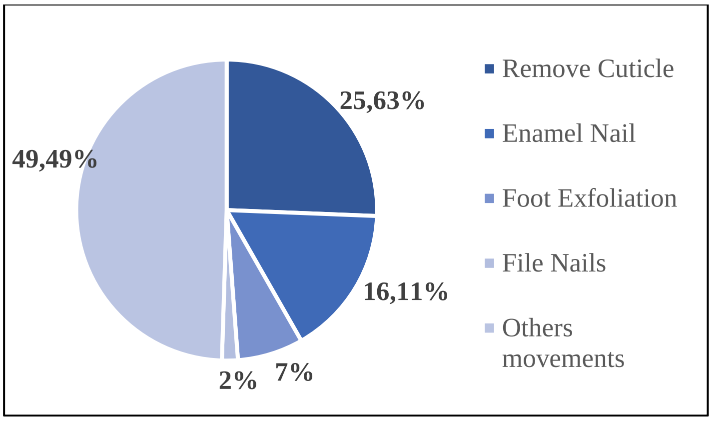

Figure 5: Graphic of the activities that add value to manicure and pedicure services.
Source: Authors, (2022).

It can be seen in Figure 5 that the movements that add the most value are the removal of cuticles and nail enameled, as customers see it as a product within the service provided.

Linked to the objectives of optimizing and standardizing the movements, it was decided to map and analyze these movements through the MTM tool, where it was possible to describe each operation through coding and a standard time established by the tool (Table 3).

Table 3: MTM analysis of pedicure and manicure services.

	Pedicure Service			***Manicure Service***		
movements	**Length of time**		**Reduction**	**Length of time**		**Reduction**
	Current (Second)	MTM (Second)	(%)	Current (Second)	MTM (Second)	(%)
File nails	48	11,05	77,00%	78	11,05	85,83%
Remove cuticle	188,48	49,11	74,00%	922,66	320,22	65,00%
Enamel Nails	606,51	320,22	47,00%	849,06	194,84	78,00%
Foot exfoliation	755,59	205,85	72,75%	-	-	-

Source: Authors, (2022).

All these analyzes resulted in the reduction of the total time of the manicure to perform its function, with a reduction of 54.61% in the total time to do the foot, passing to a duration of 20 minutes and 62.57% to do the hand, passing to have a duration of 20 and a half minutes.

V. CONCLUSIONS

During the pandemic period, the company suffered from the new health rules and had to adapt. This further required the organization to identify its weaknesses and eliminate waste to overcome these obstacles. Observing the results obtained, it was possible to perceive that the manicure and pedicure operation presents the greatest demand, and that the operator makes many movements that do not add value to the service and can be considered as a waste.

Applying Methods-Time Measurement (MTM) in the manicure and pedicure operation allowed us to better understand their activities and identify points for improvement. By optimizing this activity, we were able to achieve the objectives of this study, which was to evaluate the operational results obtained from the application of MTM in a medium-sized beauty salon in the Brazilian Northeast, to improve the productivity of its operations.

With the results obtained, it was possible to point out opportunities for improvement to the organization, with the perspective of making it more competitive in the market, better use of resources and with a focus on productivity, as it was possible to analyze its movements and reduce them, making it more agile. In addition, a reorganization of the company's layout was proposed, resulting in ergonomic improvements, reduced fatigue, and reduced physical effort by the operator.

In view of the above, it is concluded that this study can be extended to other operations of the establishment, as well as it can serve as a basis for other studies that use the MTM as a process evaluation tool aimed at optimizing operations.

VI. AUTHOR'S CONTRIBUTION

Conceptualization: A. B. V. de Souza, J. I. da S. Pierre and R. A. Rêgo Júnior.
Methodology: A. B. V. de Souza, R. A. Rêgo Júnior and E. de J. Lopes.
Investigation: A. B. V. de Souza, J. I. da S. Pierre and R. A. Rêgo Júnior.
Discussion of results: A. B. V. de Souza, J. I. da S. Pierre, R. A. Rêgo Júnior and E. de J. Lopes.
Writing – Original Draft: A. B. V. de Souza, J. I. da S. Pierre and R. A. Rêgo Júnior.
Writing – Review and Editing: R. A. Rêgo Júnior, E. de J. Lopes and F. A. F. da Ponte.
Resources: A. B. V. de Souza, J. I. da S. Pierre, R. A. Rêgo Júnior and E. de J. Lopes, F. A. F. da Ponte.
Supervision: R. A. Rêgo Júnior, E. de J. Lopes and F. A. F. da Ponte.
Approval of the final text: A. B. V. de Souza, J. I. da S. Pierre, R. A. Rêgo Júnior and E. de J. Lopes, F. A. F. da Ponte.

VII. DISCLOSURE STATEMENT AND ACKNOWLEDGMENTS

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VIII. REFERENCES

[1] Machado, R. H. C., Pelissari, R., Gennaro, C. K., and Oliveira, E. D. 2018. "Panorama bibliográfico de Methods Time Measurement aplicado a engenharia". Espacios 39(4): 2–12. Accessed June 10, 2021. https://www.revistaespacios.com/a18v39n04/a18v39n04p02.pdf

[2] Barnes, R. M. 1977. "Estudo de movimentos e de tempos: projeto e medida do trabalho". 6th ed. 15th reprint 2017. São Paulo: Blucher.

[3] Sousa, S. R. O., Lacerda, M. S., Lameira, I. W. A., Campos, E. M. R., Oliveira, R. D. 2017. "O estudo de tempos e movimentos na eliminação de desperdícios: uma aplicação prática na área de limpeza industrial mecanizada". Exacta 15(3): 407–420. doi: https://doi.org/10.5585/ExactaEP.v15n3.6892

[4] Gorobets, V., Holzwarth, V., Hirt, C., Jufer, N., and Kunz, A. 2021. "A VR-based approach in conducting MTM for manual workplaces". The International Journal of Advanced Manufacturing Technology 117: 2501–2510 June 29. doi: https://doi.org/10.1007/s00170-021-07260-7

[5] Ribeiro Junior, L. C. de A., and Chaves, C. A. 2012. "Análise de posto de trabalho com aplicação do MTM como ferramenta para padronização de tempo". Exacta 10(2): 167-179. doi: https://doi.org/10.5585/Exacta.v10n2.3881

[6] Machado, R. H. C., Helleno, A. L., Oliveira, M. C., Santos, M. S. C., and Dias, R. M. C. 2019. "Analysis of the Influence of Standard Time Variability on the Reliability of the Simulation of Assembly Operations in Manufacturing Systems". Human Factors: The Journal of the Human Factors and Ergonomics Society 61(4): 627–641, June 5. doi: https://doi.org/10.1177/0018720819829596

[7] Martins, V. W. B., Lima, I. D. A.; Silva, J. C. K., Piol, K. D. B., and Diniz, M. F. S. 2015. "Utilização do estudo de tempos cronometrados para determinação da capacidade produtiva de um salão de beleza". Produção em Foco 5(1): 123–144. doi: https://doi.org/10.14521/P2237-5163201500070007

[8] Bernardo, S. M., Rampasso, I. S., Quelhas, O. L.G., Leal Filho, W., Anholon, R. 2022. "Method to integrate management tools aiming organizational excellence". Production, 32, e20210101: 1-14. doi: https://doi.org/10.1590/0103-6513.20210101

[9] Vagnoni, E., and Khoddami, S. 2016. "Designing competitivity activity model through the strategic agility approach in a turbulent environment". Foresight 18(6): 625-648. Doi: https://doi.org/10.1108/FS-03-2016-0012

[10] Sugai, M. 2003. Avaliação do uso do MTM (Methods-Time Measurement) em uma empresa de Metal-Mecânica. [s.l.] UNIVERSIDADE ESTADUAL DE CAMPINAS. Disponível em: <http://repositorio.unicamp.br/jspui/handle/REPOSIP/264278> Acesso em: 20 fev. 2021.

[11] Adil, M., Ghaswyneh, O. F. M. and Albkour, A. M. SERVQUAL and SERVPERF: A Reivew of Measures in Services Marketing Research. Global Journal of Management and Business Research Marketing, v. 13, n. 6, p. 64–76, 2013. Disponível em: < https://www.tirocon.de/wp-content/uploads/SERVQUAL-and-SERVPERF.pdf> Acesso em: 20 fev. 2022.

[12] ABRAS. 2021. "Mercado de beleza cresce no Brasil durante a pandemia". 27 January 2021. Accessed July 19, 2021. https://www.abras.com.br/clipping/geral/72323/mercado-de-beleza-cresce-no-brasil-durante-a-pandemia

[13] Beňo, R., Hrdinová, G., Sakál, P., and Šmida, L. 2013. The Time Analysis of Material Flow with Methods Time Measurement Contribution to CSR Implementation at the Level of Industrial Production I. Applied Mechanics and Materials 309: 302-308. doi: https://doi.org/10.4028/www.scientific.net/AMM.309.309

[14] Christmansson, M., Falck, A. C., Amprazis, J., Forsman, M., Rasmusson, L., and Kadefors, R. (2000). Modified method time measurements for ergonomic planning of production systems in the manufacturing industry. International Journal of Production Research 38(17): 4051-4059. doi: https://doi.org/10.1080/00207540050204911

[15] Baumgart, A., and Neuhauser, D. 2009. Frank and Lillian Gilbreth: scientific management in the operating room. Qual Saf Health Care 18: 413–415. doi: https://doi.org/10.1136/qshc.2009.032409

[16] Ferreira, L. A. F., Santos, A. C. de S. G. dos, Dias, J. de O., and Pessanha, L. P. M. 2018. "Engenharia de métodos: uma revisão de literatura sobre o estudo de tempos e movimentos". Revista Fatec Zona Sul – REFAS 4 (3), p. 31-46. Accessed November 13, 2021. http://www.revistarefas.com.br/index.php/RevFATECZS/article/view/174>.

[17] Gibson, J. W., Clayton, R. W., Deem, J., Einstein, J. E., and Henry, E. L. 2015. "Viewing the work of Lillian M. Gilbreth through the lens of critical biography". Journal of Management History 21 (3): 288–308, June 8. doi: https://doi.org/10.1108/JMH-01-2014-0014

[18] Gibson, J. W., Deem, J., Einstein, J. E., and Humphreys, J. H. 2016. "Applying a critical biography perspective to the work of Frank Gilbreth". Journal of Management History 22 (4): 413–436. doi: https://doi.org/10.1108/JMH-03-2016-0017

[19] Mousa, F. T., and Lemak, D. J. 2009. "The Gilbreths' quality system stands the test of time". Journal of Management History 15(2): 198–215. doi: https://doi.org/10.1108/17511340910943822

[20] Yen, Y. R. 2011. "A study of developing the procedural logic learning system using the concept of Therbligs," *2011 IEEE International Conference on Multimedia and Expo*, 2011, pp. 1-6, doi: https://10.1109/ICME.2011.6012140.

[21] Tajini, R., and Elhaq, S. L. 2014. "Methodology for work measurement of the human factor in industry". Int. J. Industrial and Systems Engineering 16(4): 472-492. doi: https://doi.org/10.1504/IJISE.2014.060655

[22] Kuroda, B. D., Gasques, A. C. F., Gomes, P. F. O., and Cotrim, S. L. 2018. "Study of times and documentation of the patterns of a production process of ratios". Revista Gestão Industrial 14(3): 173-190. doi: https://doi.org/10.3895/gi.v14n3.7463

[23] Coelho, W. L. V., Matos, I. S., Gauto, R. F., and B. A. F. 2021. "Chrono-analysis: Study applied to a processing unit of swine in Brazil". Revista Zeiki Barra do Bugres 2(1): 4-28. doi: https://doi.org/10.30681/zeiki.v2i1.5046

[24] Bedny, G. Z., Karwowski, W., and Voskoboynikov, F. 2015. "Application of Standardized Motions in Temporal Analysis of Work Activity". Human Factors and Ergonomics in Manufacturing & Service Industries 25(4): 469-483. doi: https://doi.org/10.1002/hfm.20562

[25] Goshime, Y., Kitaw, D., and Jilcha, K. 2019. "Lean manufacturing as a vehicle for improving productivity and customer satisfaction: A literature review on metals and engineering industries". International Journal of Lean Six Sigma 10(2): 691-714. doi: https://doi.org/10.1108/IJLSS-06-2017-0063

[26] Rocha Junior, A. H. 2021. "Estudo de Tempos e Movimentos como Ferramenta Para a Melhoria da Produtividade nas Obras". Universidade Federal do Rio de Janeiro Escola Politécnica, 2014. Accessed July 19, 2021. http://monografias.poli.ufrj.br/monografias/monopoli10009237.pdf

[27] Parmar, K., Parth, D., and Shingala, N. 2016. "An optimization of process parameter in crankshaft using with time study method". International Journal of Engineering Development and Research 4(2): 2321–9939. Accessed June 10, 2021. https://www.ijedr.org/papers/IJEDR1602188.pdf

[28] Vijayan, R., Karthikeyan, P., Bharanichandar, J., Palanisamy, R., and Geetha, T. T. 2017. “Patrol inspection and time study to improve quality”. International Journal on Smart and Intelligent Systems 10(5): 459–470. doi: https://doi.org/10.21307/ijssis-2017-263

[29] Kunz, A., Zank, M., Nescher, T., Wegener, K. 2016. “Virtual reality based time and motion study with support for real walking”. In: Procedia CIRP 57, pp. 303-308. doi: https://10.1016/j.procir.2016.11.053

[30] Hengstebeck, A., Weisnera, K., Klöckner, M., Deuse, J., Kötter, B. K., Roßmannac, J. 2016. “Formal Modelling of Manual Work Processes for the Application of Industrial Service Robotics”. Procedia CIRP 41: 364-369. doi: https://doi.org/10.1016/j.procir.2015.12.013

[31] Kuhlang, P., Erohin, O., Krebs, M., Deuse, J., and Sihn, W. 2014. "Morphology of time data management – systematic design of time data management processes as fundamental challenge in industrial engineering". Int. J. Industrial and Systems Engineering 16(4): 415-432. doi: https://doi.org/10.1504/IJISE.2014.060652

[32] Schröter, D., Kuhlang, P., Finsterbusch, T., Kuhrke, B., and Verl, A. 2016. “Introducing Process Building Blocks for Designing Human Robot Interaction Work Systems and Calculating Accurate Cycle Times”. Procedia CIRP 44: 216-221. doi: https://doi.org/10.1016/j.procir.2016.02.038

[33] Seifermann, S., Böllhoff, J., Metternich, J., Bellaghnach, A. 2014. “Evaluation of Work Measurement Concepts for a Cellular Manufacturing Reference Line to Enable Low Cost Automation for Lean Machining”. In: Procedia CIRP, v. 17: 588-593. doi: https://doi.org/10.1016/j.procir.2014.01.065

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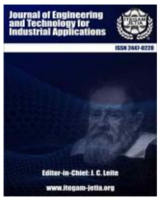

RESEARCH ARTICLE OPEN ACCESS

PROPOSAL FOR INSERTION OF ELECTRIC VEHICLES IN THE TRANSPORT OF LOADS FROM A DISTRIBUTION CENTER

Douglas Vieira Barboza[1], Marcelo Jasmin Meiriño[2], Marcio Zamboti Fortes*[3] and Carlos Diego dos Santos Tavares[4]

[1, 2, 3, 4] Federal University of Fluminense - UFF. Niterói, Rio de Janeiro, Brazil.

[1] http://orcid.org/0000-0002-2653-8541, [2] http://orcid.org/0000-0001-9165-2300, [3] http://orcid.org/0000-0003-4040-8126, [4] http://orcid.org/0000-0002-0886-9742

Email: douglasbarboza@id.uff.br, marcelojm@id.uff.br, *mzamboti@id.uff.br, diee.tavares@gmail.com

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ABSTRACT

This article deals with the sustainable question about electric vehicles in front of the fossil fuels paradigm, as well as possibilities of self-management of its energy matrix. The economic feasibility of changing these vehicles is necessary for the reduction of polluting gases in the atmosphere and considering the challenges that the greenhouse effect imposes, a cultural transition is necessary for a sustainable planet. The methodology used in this research was bibliographic and documentary research, besides data collection of diesel vehicles which belong to the Central of Distribution of goods located in São Gonçalo, Rio de Janeiro, Brazil. In order for the purchase of large electric vehicles to be viable, it is necessary to adopt fiscal incentives to offset the high cost of acquisition, but these incentives are still insufficient in Brazil.

I. INTRODUCTION

With the expected scarcity of fossil fuels and the need to reduce greenhouse gases, the adhesion of electric vehicles becomes considerable to meet the demands of distribution in the transportation of goods along with the Brazilian road network. In this way, the present article aims through the case study of a Distribution Center of food products located in São Gonçalo, RJ, to analyze the feasibility of the use of the prototype electric vehicle "TESLA Semi" as a possible sustainable action of the organization that other shipping companies could employ.

It is important to emphasize that the study proposed to be developed requires the application of the interdisciplinary premises since it depends on the use of knowledge from the areas of engineering, environmental sciences, and applied social sciences to integrate technical, environmental, and economic characteristics in order to develop a sustainable strategy for the supply chain management.

According to [1], the demand for the use of electric vehicles is directly linked to fuel economy and reduction of carbon dioxide emissions to the atmosphere. As well as to innovate a whole technological market, but that demands the capture and generation of energy electricity from vehicles from renewable sources since if electric vehicles are recharged from electricity produced from conventional technology plants like oil or coal-fired power plants, they can produce greenhouse gas emissions equal to or sometimes larger than conventional gasoline vehicles. The use of electric vehicle timeshare is another optimal solution that can be explored as reported by [2].

The importance of the electric vehicle in the sustainability is the main theme in several research as the discussion about the battery electric vehicle contributing to the sustainable urban logistic in [3], a comparison with hydrogen fuel vehicles [4], the use of personal carbon dioxide trade [5] and the experience of Netherlands with the electric vehicle adoption [6].

In Brazil the theme of electric vehicles and sustainability are discussed on different topics as hybrid vehicles [7], purchase intentions compared with other countries [8], and subsidies to accelerate the integration of the electric vehicle [9], impact of the electric vehicle connection in the distribution network [10-11] and the electric vehicles used in postal deliveries [12].

In the case of this study, we can observe that the use of the electric vehicle for the case studied, even though it brings environmental and social gains, is still economically infeasible, due to the acquisition and maintenance costs, which, even when disregarding fiscal charges, can reach on average three times the cost of the diesel model.

II. METHODOLOGY

As reported by [13] the mobility limits are imposed by geography and the speed, energy, and ergonomic constraints of travel models. In order to answer if the use of electric powered vehicles in Brazil is viable, the methodological procedures were based on data collection of the electric vehicle through two information systems: The Tesla Motors website (https://www.tesla.com/semi) for the data collection on the "Semi" prototype, and the McKinsey & Company website (https://www.mckinseyenergyinsights.com/insights/new-reality-electric-trucks-and-their-implications-on-energy-demand/), as well as searches on other informative platforms and videos, to better understand the features of the model. To conduct research on the diesel vehicle, model CRM6X2, manufactured by Volkswagen, data collection was realized out at the place of use of the same, where it was possible to diagnose the costs related to the acquisition and use of the vehicle from the ERP system CiSS Poder, which has the database of the company used in this case study.

Load acceleration tests and fuel consumption tests were carried out from data collection with drivers, with the mechanical workshop that handles the fleet for more than 10 years, and cost reports were made available by the other tracking software (OpenSat). Regarding the value of fuel consumption, a calculation was made as to the total kilometers travelled by these vehicles linked to the total fuel, considering the initial tank as zero, thus obtaining the average of all vehicles of the same model that travel in different urban areas of the Rio de Janeiro state. It should be noted that the data corresponding to the load capacity was obtained through the vehicle manual itself, as well as, the information obtained in the trucks themselves, which are authorized by ANTT (Agência Nacional de Transportes Terrestres – Brazilian National Road Transport Agency) to operate, and the data sources and methods defined are adequate to answer the question of research.

III. RESULTS

Table 1 presents information that was collected in the field and data obtained through the Tesla Motors tests and made available on its website (https://www.tesla.com/semi). Information based on the Dollar price referring to R$ 3.74 and Diesel price at R$ 3.48 (Liter). In this way, performing the direct conversion, without adding any other financial charges. The base date for 06/06/2018.

Table 1: Data of the searched vehicles.

	Volkswagen (CRM 6x2)	**TESLA Semi (300 mile range)**
Vehicle cost (R$)	231,000.00	635,800.00
Consume	1.68 km/l	2 km/kWh
Fuel Cost (Base 2019)	R$ 3.48	R$ 0.81
Fuel value/km	R$ 2.07	R$ 0.41
Lifespan (years)	10	15
Acceleration	40 seconds with 24 tons	20 seconds with 36 tons
Maximum speed	100 km/h	96 km/l
Capacity (load)	24 tons	36 tons

Source: Authors, (2022).

Based on the data obtained and making a direct comparison between the two proposed vehicles, we noticed initially a large difference in the stipulated value of the cost of each truck. Therefore, more accurate analysis of the values to maintain this type of vehicle is necessary for the best choice according to the location of the road network of each location. Tesla Motors' vehicle proposal is directly linked to sustainability and environmental viability, see that there is a drastic reduction in the emission of polluting gases from the burning of fossil fuels and the emission of CO^2 generated by diesel vehicles. In addition to these environmental factors, one factor that makes the feasibility of electric vehicles effective is the issue of fuel economy, according to Tesla Motors Website (https://www.tesla.com/semi) there will be a substantial reduction in the value of fuels. Thus, a reduction of more than US $ 200,000.00 (R$ 740,000.00 + in direct conversion with the dollar price used in this research) over two years. In this way, the vehicle is paid in that period. Official note from Tesla's website: "Electric energy costs are half those of diesel. With fewer systems to maintain, the Tesla Semi provides $200,000+ in fuel savings and a two-year payback period."[14]. In Liu and Meng [15] there is an interesting comparative study considering innovation, ecological environment, market positioning and, business model with Tesla, Toyota, and BYD electric vehicles.

One of the factors disregarded in this research was the vehicle maintenance, where it is not yet possible to predict some incidents that may occur during the vehicle usage, as well as little information on periodic maintenance related to the Tesla model, has still not been released officially.

According to [16], the race for electric vehicles, whether small, medium, or large, will be subdivided into three main regions: United States, Europe, and China. Thus, with the rise of this type of vehicle throughout the world, it is believed that by 2030 electric vehicles are widely exploited. However, it should be noted that there has been researched in this area since the 2000s, in addition to the idea of electric vehicles was started more than 100 years ago, said that we can consider that this estimate changes and that in the coming years there are positive surprises in this follow-up of vehicle development, sustainability, and economic and social integration.

Figure 1 depicts the future possibility of electric vehicle racing across the globe.

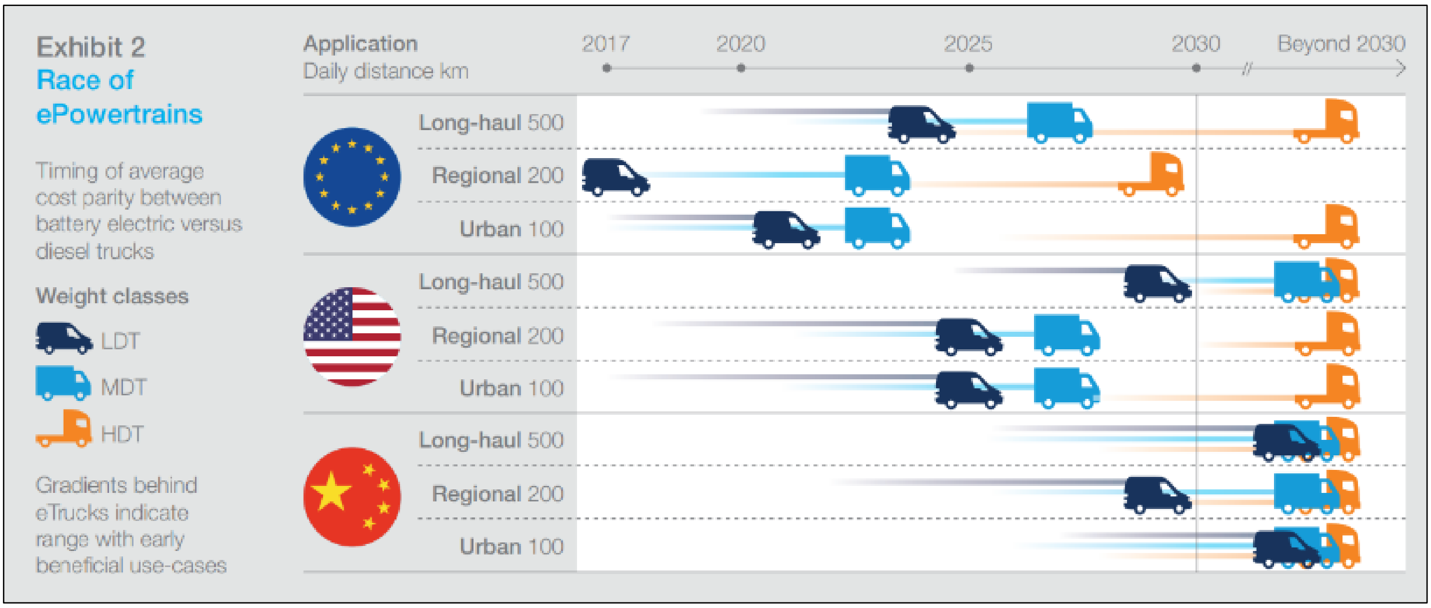

Figure 1: Race of ePowertrains.
Source: [17].

Still, according to [16], it is possible to understand that the replacement of diesel vehicles will generate a great change in the economy in the years following the transition of fleet change. With electric power costing less than half of diesel as a form of fuel, different ways to self-sufficiency can be created to make this type of vehicle viable. Thinking strategically at a Distribution Center, we envisage a series of methods that can aid in this process of electric vehicle deployment, as well as meet the sustainability requirements proposed by the vehicle change. Among the proposed methods, we have:

• Implementation of power plants from solar panels coupled throughout the Distribution Center;

• Implementation of solar panels in the vehicles themselves, optimizing the use of the battery;

• Regenerative load serving as an extra battery, where it would be implanted in the vehicles themselves, recharging through the truck's brakes, in this way, the kinetic energy recharges the auxiliary battery. (This method may damage the battery lifespan)

In addition to the modes presented, others can be developed over the years, considering that the technology tends to evolve more and more, we have great possibilities of sustainable viability on this type of vehicle. As one of these modes, induction recharging, refers to a new technology presented by Qualcomm (an American multinational semiconductor and telecommunications equipment company)[18] where the battery of the vehicle would be recharged without the need for contact between the vehicle and the charger, thus providing the vehicle can be recharged in motion. Although it is a great innovation in this sector, we are still far from achieving it due to the many reasons inherent to the road network. Thus, the trend of acquiring this type of vehicle tends to be greater over the periods, and, perhaps, becoming more used than diesel vehicles.

Table II (Appendix) shows a complete analysis of the fleet studied in this proposal, where the consumption discrepancy between vehicles can be seen more clearly.

Considering the data obtained through the analysis and field tests carried out on the vehicles of the distribution center, we can consider a series of factors that contribute to the diffusion of the thought of the fleet exchange of vehicles driven by combustion engines for vehicles with electric motors. From the environmental bias, we must consider the amount of gases emitted by these vehicles and think of methods to mitigate them. From the economic point of view, we have the question of average daily fuel consumption ranging from 21 liters to the most economical up to 86 liters per day. These values directly impact the company's revenue as its operating costs, since, depending on the vehicle and its use, there may be a daily fuel cost of approximately R$ 301.00, on the other hand, if the vehicle depended on an electric motor, that figure could have been reduced by 67% of the cost, and if there were clean and sustainable production of electricity (wind and solar are more prone in the region), this could become self-sufficient, reducing fuel costs by 100%(From data obtained by OpenSat). As proposed by [19], other renewable energy sources can be considered and analyzed so that sustainable bias can be achieved in full.

According to [20], with the increasing urban expansion in the transport sector, the burning of fossil fuels from these vehicles increases gradually and implies a series of environmental and social factors. Much is said about electric vehicles and their viability within urban centers as a mitigating agent for the emission of gases that contribute to the greenhouse effect. However, in addition to tax incentives to replace the diesel fleet, other assumptions must be studied, analyzed, understood, and designed for the efficient reduction of the polluting gases, as well as to structure in an intelligent and technological way that pole for reference in sustainability. Within this assembly line of electric vehicles, the battery is the main component of this automobile and, consequently, the item with the highest value in its production and acquisition of it. Considering this fact, since the assembly line must pay special attention to the production of this item and after its useful life, a more relevant factor is its discard. Certainly, this issue of battery disposal will be the industry's biggest challenge globally. There are specific studies about the re-use of the electric vehicle batteries in stationary applications as discussed in [21].

IV. CONCLUSION

According to the objective, it is possible to conclude that in the current scenario, Brazil is very distant from the implantation of large electric vehicles, so that this new step towards the sustainable future it is necessary that there be fiscal incentives not only for the acquisition of imported vehicles, but also that it allows the implantation of assemblers along the federative units of the national territory, as well as the incentive to the installation of workshops specialized in the sector because with such prerequisites being met, success in the future has its probability increased. Such a thought change has a greater social and environmental potential than previously used diesel vehicles, but still, under current conditions, it is not yet economically attractive.

V. AUTHOR'S CONTRIBUTION

Conceptualization: Barboza, Meiriño
Methodology: Barboza, Tavares
Investigation: Barboza, Tavares
Discussion of results: Meiriño, Fortes
Writing – Original Draft: Meiriño, Barboza
Writing – Review and Editing: Meiriño, Fortes
Resources: Tavares, Barboza
Supervision: Fortes.
Approval of the final text: Meiriño, Fortes.

Data Availability Statement

Some or all data, models, or codes that support the findings of this study are available from the corresponding author upon reasonable request.

VI. REFERENCES

[1] Poullikkas A (2015) Sustainable options for electric vehicle technologies. Renewable and Sustainable Energy Reviews. 41: 1277-1287. doi:10.1016/j.rser.2014.09.016.

[2] Wei Luo, Sun L, Shi M, Yao L, Rong J (2020) An investigation into electric vehicle timeshare rental schemes in Beijing, China. Proceedings of the Institution of Civil Engineers - Engineering Sustainability 173(2):73-83. doi: 10.1680/jensu.18.00025.

[3] Duarte G, Rolim C, Baptista P (2016) How battery electric vehicle can contribute to sustainable urban logistics: A real-world application in Lisbon, Portugal. Sustainable Energy Technologies and Assessments 15: 71-78. doi: 10.1016/j.seta.2016.03.006.

[4] Shin, J, Hwang, W_S, Choi H (2019) Can hydrogen fuel vehicles be a sustainable alternative on vehicle market? : Comparison of electric and hydrogen fuel cell vehicles. Technological Forecasting and Social Change 143: 239-248. doi: 10.1016/j.techfore.2019.02.001.

[5] Li Y, Li W, Wei Y, Bao L, Deng H (2017) Using personal carbon dioxide trading to promote cleaner cars. Proceedings of the Institution of Civil Engineers – Transport 170(2): 86-98. doi: 10.1680/jtran.15.00117.

[6] Peters A M, van der Werff E, Steg L (2018) Beyond purchasing: Electric vehicle adoption motivation and consistent sustainable energy behaviour in The Netherlands. Energy Research & Social Science 39: 234-247. doi: 10.1016/j.erss.2017.10.008.

[7] Souza L L P, Lora E E S, Palacio J C E, Rocha M H, Renó M L G, Venturini O J (2018) Comparative environmental life cycle assessment of conventional vehicle with fuel options, plug-in hybrid and electric vehicles for a sustainable transportation system in Brazil. Journal of Cleaner Production 203:444-468. doi: 10.1016/j.clepro.2018.08.236.

[8] Habich-Sobiegalla S, Kostka G, Anzinger N (2018) Electric vehicle purchase intentions of Chinese, Russian and Brazilian citizens: An international comparative study. Journal of Cleaner Production 205: 188-200. doi: 10.1016/j.clepro.2018.08.318.

[9] Silva R E, Sobrinho P M, Souza T M (2018) How can energy prices and subsidies accelerate the integration of electric vehicle in Brazil? An economic analysis. The Electricity Journal 31(3):16-22. doi: 10.1016/j.tej.2018.03.007.

[10] Silva G I M, Guaracy P A, Dias B H, Oliveira L W, Fortes M Z, Borges T T (2018) A probabilistic analysis of the impact of electrical vehicles in a shopping center phase unbalance. In Proceedings of 2018 Simpósio Brasileiro de Sistemas Elétricos (SBSE). doi: 10.1109/SBSE.2018.8395660.

[11] Fortes M Z, Silva D F, Abud T P, Machado P P, Maciel R S, Dias D N H (2016) Impact Analysis of plug-in Electric Vehicle connected in a Real Distribution Network, IEEE Transactions on Latin America 14(5):2239-2245. doi: 10.1109/TLA.2016.7530419.

[12] Bandeira R A M, Goes G V, Gonçalves D N S, D'Agosto M A, Oliveira C M (2019) Electric vehicles in the last miles of urban freight transportation: A sustainability assessment of postal deliveries in Rio de Janeiro, Brazil. Transportation Research Part D 67: 491-502. doi: 10.1016/j.trd.2018.12.017.

[13] Taylor N B (2019) Comparative analysis of transport modes for regional mobility: a case study. Proceedings of the Institution of Civil Engineers – Transport. doi: 10.1680/jtran.18.00150.

[14] Tesla Motors (2017) Tesla Semi. See https://www.tesla.com/semi. (accessed 05/05/2017)

[15] Liu J-H, Meng Z (2017) Innovation model analysis of new energy vehicles: taking Toyota, Tesla and BYD as an example. Procedia Engineering 174: 965-972. doi: 10.1016/j.proeng.2017.01.248.

[16] Tryggestad C, Sharma N, van de Staaij J, Keizer A (2018) New reality: Electric trucks and their implications on energy demand, Energy Insights, See https://www.mckinseyenergyinsights.com/insights/new-reality-electric-trucks-and-their-implications-on-energy-demand/. (accessed 03/03/2018)

[17] https://www.mckinseyenergyinsights.com/insights/new-reality-electric-trucks-and-their-implications-on-energy-demand/. (accessed 03/03/2018).

[18] Qualcomm (2017) Qualcomm Demonstrates Dynamic Electric Vehicle Charging. See https://www.qualcomm.com/news/releases/2017/05/18/qualcomm-demonstrates-dynamic-electric-vehicle-charging. (accessed 01/12/2017).

[19] Ruiz B J, Rodríguez-Padilla V (2016) Renewable energy sources in the Colombian energy policy, analysis and perspectives. Energy Policy 34(18): 3684-3690. https://doi.org/10.1016/j.enpol.2005.08.007.

[20] Teixeira I G R, Calia R C (2013) Gestão da Inovação, Desenvolvimento e Difusão de Veículos Híbridos e Elétricos Mitigadores da Poluição Urbana: Um Estudo de Caso Múltiplo. RAI – Revista de Administração e Inovação 10 (2). doi:10.5773/rai.v10i2.881.

[21] Ahmadi L, Yip A, Fowler M, Young S B, Fraser R A (2014) Environmental feasibility of re-use of electric vehicle batteries. Sustainable Energy Technologies and Assessments 6: 64-74. doi: 10.1016/j.seta.2014.01.006.

VII. APPENDIX

This appendix shows Table II cited in item III.

Table II – Analysis of diesel vehicles

Model	Year	Vehicle Weight (tons)	Traction Capacity (tone)	Gross Weight (tons)	Top Speed (km/h)	Consumption (km/l)	Total Distance Travelled (km)	Average Distance Travelled (km/day)	Operational Days (days)
M.Benz ATEGO 1719	2018	4.91	11.09	16	117	3.7	7,873	106.39	74
M.Benz L1318	2010	4.89	9.01	13.9	117	2.91	5,742	92.61	62
M.Benz ATEGO 3026	2017	7.58	21.42	29	120	2.6	6,761	169.03	40
VW 13.180	2008	4.87	8.35	13.2	113	3.56	6,977	93.03	75
M.Benz L1318	2010	4.89	9.01	13.9	117	1.08	5,711	93.62	61
VW 24.280	2015	6.64	16.36	23	116	2.8	6,417	87.9	73
M.Benz ATEGO 3026	2017	7.58	21.42	29	120	2.67	5,719	129.98	44
M.Benz ATEGO 3026	2017	7.58	21.42	29	120	2.75	6,732	192.34	35
VW 17.190	2012	4.97	11.03	16	113	1.94	8,204	110.86	74
M.Benz L1318	2010	4.89	9.01	13.9	117	3.96	6,224	91.53	68
VW 24.250	2012	7.12	17.58	24.7	114	5.31	8,266	116.42	71
VW 17.230	2017	6.27	10.83	17.1	110	1.49	6,461	88.51	73
VW 17.230	2017	6.27	10.83	17.1	110	3.18	9,126	125.01	73