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Advanced and Sustainable Technologies for Automotive Industry Innovation

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Prefácio

Rodrigo Leite[1]

Alexandre Machado[2]

A inovação como força motriz do conhecimento e do avanço tecnológico sempre permeou a história da indústria automotiva, e a Ford Motor Company sempre esteve presente nesta trajetória de transformação e de grandes desafios. Em um dos seus primeiros anúncios, Henry Ford declarou que queria abrir as estradas para toda a humanidade. Essa ideia aliada a criação da linha de montagem e da produção em massa permitiu uma nova e extraordinária liberdade – viajar grandes distâncias e circular pela cidade de forma sem precedentes. Assim iniciava-se um ciclo de inovações que revolucionariam a maneira como as pessoas percebiam questões como distância, tempo, amplitude do comércio e seu próprio cotidiano. Se no século passado o desafio de acessibilidade era a distância física, hoje temos a transformação digital, além de outros aspectos de acessibilidade e conectividade como alguns dos objetivos a serem perseguidos durante o desenvolvimento do veículo.

Grande parte da indústria automotiva tem como primeira etapa de criação de um produto a fase de planejamento, na qual se realizam extensas pesquisas para identificar o perfil do futuro cliente, suas demandas e dores mais significativas, bem como mapear novas tecnologias e materiais que possam ser utilizados para criar veículos mais eficientes, modernos e sustentáveis. Diversas ferramentas digitais como inteligência artificial, big data, óculos de imersão 3D, dentre outras colaboram para a obtenção de respostas mais objetivas. Todas estas informações capturadas culminarão em um proposito bem definido para o projeto.

A fase de desenvolvimento compreende a criação da estratégia e especificações para o novo veículo, levando em consideração fatores como tamanho, peso, aerodinâmica, segurança, desempenho, custos etc. Os testes e validações envolvem submeter protótipos a uma variedade de avaliações, tanto em ambiente virtual, físico em laboratório e em pistas de teste, de forma

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a garantir a performance esperada em diferentes condições e atenda a todos os padrões de segurança e emissões.

Por fim, na fase de produção e comercialização, o veículo é produzido em massa e disponibilizado para compra pelos consumidores. Assim como o processo de criação do veículo, todas as etapas que compõem a experiencia do usuário, da expectativa de compra ao relacionamento de manutenção precisam ser mapeadas, entendidas e desenvolvidas de forma a criar uma experiência integrada que surpreenda positivamente o cliente.

O grande número de marcas disponíveis, a alta variedade de produtos no mercado e a cada vez mais rápida obsolescência tecnológica gera uma alta competição pela busca de inovação através de novas aplicações tecnológicas, principalmente às ligadas a transformação digital. Espera-se que a transformação digital tenha um impacto significativo na indústria automotiva de várias maneiras:

- Experiências personalizadas ao usuário: as tecnologias digitais ajudarão as empresas automotivas a coletar e analisar dados sobre as preferências, comportamentos e experiências dos usuários, permitindo a criação de experiências para os clientes altamente personalizadas.
- Veículos conectados e autônomos: espera-se que tecnologias digitais como conectividade 5G, inteligência artificial (IA) e Internet das Coisas (IoT) desempenhem um papel crucial no desenvolvimento de veículos conectados e autônomos. Isso proporcionará aos motoristas novos níveis de conveniência, segurança e eficiência e ajudará a reduzir o número de acidentes causados por erro humano.
- Otimização da cadeia de suprimentos: o uso de tecnologias digitais como blockchain e aprendizado de máquina ajudará a otimizar a cadeia de suprimentos, reduzindo custos, melhorando a eficiência e reduzindo o desperdício.
- Inovação na fabricação: O uso de tecnologias da Indústria 4.0, como impressão 3D, robótica e realidade aumentada, ajudará a transformar o processo de fabricação, reduzindo custos, melhorando a eficiência e aumentando a personalização.

- Novos modelos de negócios: espera-se que o surgimento de serviços de mobilidade elétrica e compartilhada interrompa os modelos de negócios automotivos tradicionais e leve a novas oportunidades para as empresas monetizarem seus conhecimentos em áreas como software, serviços e dados.

Assim como a experiencia do usuário, espera-se que a transformação digital desempenhe um papel significativo na formação do futuro da indústria automotiva, impulsionando a inovação e permitindo que as empresas criem veículos mais avançados, atraentes e convenientes. Assim, o Programa de Master in Technology and Innovation - MTI, parceria entre o SENAI CIMATEC e a Ford Motor Company, busca gerar valor a indústria automobilística brasileira através de conhecimentos avançados para os seus profissionais, proporcionando uma formação aprofundada e especializada em disciplinas específicas, permitindo aos profissionais adquirir conhecimentos e competências em áreas avançadas como a engenharia, produção e gestão.

O programa envolve a realização de projetos de pesquisa independentes, permitindo que os profissionais ganhem experiência prática na resolução de problemas do mundo real e no desenvolvimento de novas tecnologias e soluções. Ao realizar pesquisas e trabalhar em projetos do mundo real, os profissionais desenvolvem habilidades de pensamento crítico e resolução de problemas que são altamente valorizados pelos empregadores da indústria automotiva.

O MTI oferece oportunidades para os profissionais fazerem networking e construir relacionamentos com os principais atores do ambiente automotivo, gerando um diferencial competitivo na hora de seguir na carreira, através do compromisso com o aprendizado contínuo e o desenvolvimento profissional. No geral, o programa MTI fornece aos profissionais uma educação abrangente através dos conhecimentos, habilidades e da experiência prática a possibilidade de se obter sucesso no mercado automotivo de alta competitividade e mudanças tecnológicas.

Esperamos que os projetos aqui apresentados inspirem outros profissionais a abraçarem a inovação e utilizá-la como um dos principais impulsionadores do crescimento e da competitividade em seus respectivos setores. É uma prova do poder da inovação e de sua capacidade de transformar negócios e criar um futuro melhor para a sociedade.

Preface

Rodrigo Leite[3]

Alexandre Machado[4]

Innovation as a driving force for knowledge and technological advancement has always permeated the history of the automotive industry, and Ford Motor Company has always been present in this trajectory of transformation and great challenges. In one of its earliest announcements, Henry Ford declared that he wanted to open the roads to all of humanity. This idea, combined with the creation of the assembly line and mass production, allowed for a new and extraordinary freedom – traveling long distances and moving around the city in unprecedented ways. Thus began a cycle of innovations that would revolutionize the way people perceived issues such as distance, time, the scope of commerce, and their own daily lives. If in the last century the challenge of accessibility was physical distance, today we have digital transformation, as well as other aspects of accessibility and connectivity, as some of the goals to be pursued during the development of the vehicle.

Much of the automotive industry has as its first step in creating a product the planning phase, in which extensive research is conducted to identify the profile of the future customer, their most significant demands and pains, as well as mapping new technologies and materials that can be used to create more efficient, modern, and sustainable vehicles. Various digital tools such as artificial intelligence, big data, 3D immersion glasses, among others, collaborate to obtain more objective answers. All this captured information will culminate in a well-defined purpose for the project.

The development phase involves the creation of the strategy and specifications for the new vehicle, taking into account factors such as size, weight, aerodynamics, safety, performance, costs, etc. Tests and validations involve subjecting prototypes to a variety of evaluations, both in a virtual environment,

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physical laboratory, and test tracks, in order to ensure the expected performance in different conditions and meet all safety and emissions standards.

Finally, in the production and commercialization phase, the vehicle is mass-produced and made available for purchase by consumers. Just as the process of creating the vehicle, all stages that make up the user experience, from the expectation of purchase to maintenance relationship, need to be mapped, understood, and developed in order to create an integrated experience that positively surprises the customer.

The large number of available brands, the high variety of products on the market, and the increasingly rapid technological obsolescence generate high competition for the search for innovation through new technological applications, mainly related to digital transformation. It is expected that digital transformation will have a significant impact on the automotive industry in several ways:

- Personalized user experiences: Digital technologies will help automotive companies collect and analyze data about user preferences, behaviors, and experiences, allowing for highly personalized experiences for customers.
- Connected and autonomous vehicles: It is expected that digital technologies such as 5G connectivity, artificial intelligence (AI), and the Internet of Things (IoT) will play a crucial role in the development of connected and autonomous vehicles. This will provide drivers with new levels of convenience, safety, and efficiency and help reduce the number of accidents caused by human error.
- Supply chain optimization: The use of digital technologies such as blockchain and machine learning will help optimize the supply chain, reducing costs, improving efficiency, and reducing waste.
- Innovation in manufacturing: The use of Industry 4.0 technologies, such as 3D printing, robotics, and augmented reality, will help transform the manufacturing process, reducing costs, improving efficiency, and increasing personalization.
- New business models: The emergence of electric and shared mobility services is expected to disrupt traditional automotive business models

and lead to new opportunities for companies to monetize their knowledge in areas such as software, services, and data.

Just like user experience, digital transformation is expected to play a significant role in shaping the future of the automotive industry, driving innovation and enabling companies to create more advanced, attractive, and convenient vehicles. Therefore, the Master's Program in Technology and Innovation - MTI, a partnership between SENAI CIMATEC and Ford Motor Company, aims to generate value for the Brazilian automotive industry through advanced knowledge for its professionals, providing in-depth and specialized training in specific disciplines, allowing professionals to acquire knowledge and skills in advanced areas such as engineering, production, and management.

The program involves the completion of independent research projects, allowing professionals to gain practical experience in solving real-world problems and developing new technologies and solutions. By conducting research and working on real-world projects, professionals develop critical thinking and problem-solving skills that are highly valued by employers in the automotive industry.

The MTI offers opportunities for professionals to network and build relationships with key players in the automotive environment, generating a competitive advantage when pursuing their careers through a commitment to continuous learning and professional development. Overall, the MTI program provides professionals with comprehensive education through knowledge, skills, and practical experience, providing the possibility of success in the highly competitive and technologically changing automotive market.

We hope that the projects presented here inspire other professionals to embrace innovation and use it as one of the main drivers of growth and competitiveness in their respective sectors. It is proof of the power of innovation and its ability to transform businesses and create a better future for society.

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Dataset creation for traffic sign detection

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contents

ABSTRACT

Damage assessment for traffic signs is an expensive process for the government and road developers around the world since it requires the displacement of an employee to the desired area with some regularity. This process can be improved by applying artificial intelligence to the images captured by vehicular cameras. However, to implement such a solution, modern AI's image detection and classification require massive batches of pictures for training and validation, called datasets. Acquiring images to compose the desired dataset is no trivial task. Unless the desired images are physically captured and manually edited, there is the need to apply annotation and automatic digital augmentation to the pictures. This chapter shall propose improvements to the concepts of computing vision for Artificial Intelligence and the techniques applied to augment image datasets, reaching the conclusion that datasets can gain much from the application of augmentation techniques, making them more suited for AI and autonomous vehicles usage.

Keywords: traffic sign detection, dataset, challenge.

1 INTRODUCTION

Technology is evolving towards IOT (Internet of Things), Smart Cities, and products that explore artificial intelligence, such as autonomous vehicles. The presence of vehicular cameras and embedded computers with connectivity can present a revolution for how cars are used commercially. One of these possible usages is road maintenance. Artificial intelligence can be used to identify points of interest for the owners of these roads. A strategic usage of this technology might identify damaged traffic signs, for example, a current issue for the government and road developers. The current model of operation establishes that an employee must personally check, from time to time, the placards placed along the road. This process is tiresome and expensive, so artificial intelligence can be applied to reduce the human and monetary costs.

Modern AIs can detect and classify images according to the amount of training and validation materials at their disposal. Because of that, the consistency and accuracy measured in these systems can vary greatly. For AIs to create reliable models, there is the need of specialized datasets.

Computer Vision AI is usually represented by Convolutional Neural Networks (CNNs) to recognize image patterns through the use of image filters and many neuron layers. For CNNs to give reliable results, it is necessary to feed the system with huge batches of images. The variety of images influences how many classes the system might recognize, but the number of different images affects the overall accuracy of the model.

Capturing Images of different placards using a camera might be effective, but this method takes a very long time to build a dataset. Traffic signs are not fully standardized throughout different countries, so the amount of public available pictures might be scarce depending on area of interest. South America, for instance, presents significantly less image datasets of traffic signs in comparison to United States or Europe. Road signs are unevenly distributed through urban areas, countryside, and highways. To create an effective dataset, it is important to assure the variety of images, so all three areas can contribute to build the dataset, however, the distance between each placard can be very long, increasing the time and difficulty to acquire these images. It is common sense in the AI development community that Image Augmentation is a powerful resource to increase the size of datasets and enhance the performance of CNNs.

By combining images acquired using specialized apps, real image capturing and data augmentation it is possible to produce an effective dataset. It is important to pinpoint that image augmentation consists of a variety of techniques. Some are singular and can only be achieved by using certain algorithms. It is crucial to determine which augmentations are relevant for the project and how these techs can be improved, when appliable.

Creating custom datasets is a challenging process that involves image capturing, research in public databases and data augmentation.

The initial acquisition of different images for the dataset can be made in different forms:

- Direct Image Capture.
- Capturing free images in mapping applications.
- Annotation of pre-recorded footage of streets and roads.
- Expand the dataset with images captured by cameras of interconnected vehicles.

Aside from regular image filtering, creating a dataset might involve different image augmentation techniques to simulate the different conditions in which the placards might be in the real world, since damaged traffic signs can present variation in color and shape.

Finally, it is necessary to show the results obtained by the implementation of these techniques in order to build a dataset for traffic signs and how they act upon the effectiveness of CNNs, that is, if the systems show improvement in detection and classification of traffic signs.

This work proposes the discussion of a different approach to building image datasets for AI systems. Section 2 contains information regarding AI systems and the importance of datasets especially for systems based on neural networks. Section 3 discusses the methods applied to obtain images applicable for the desired dataset, and the technologies used for image capture and image augmentation. Section 4 of this chapter presents some of the obtained results. Finally, Section 5 presents the conclusions by asserting the viability of the dataset creation system built by using the pre-mentioned techniques.

2 CONCEPTS AND APPROACHES

This section presents important definitions and methods regarding the traffic sign detection problem.

2.1 Neural Network

According to Alpayadin (2010), Artificial Neural Networks (ANN) or *Multilayer Perceptrons* are parallel distributed systems composed of processing units (nodes), that apply mathematical functions to a given signal. Usually, nodes are associated to different processing levels, connected by a great number of links. The standard model presents weights to these connections, representing the acquired knowledge. The operation of these structures is inspired by the human brain. The nodes of an artificial neural network abstract biological neurons, which are the data processing cells of the brain. Natural neurons are normally divided into dendrites, the body of the cell, and the axon. An axon is connected to the dendrite of the next neuron, therefore building a network, this connection is called a synapse.

Natural neuron communication happens through electrical signals. Neurons are able to generate an electric tension by controlling the ion concentration of sodium and potassium inside the cell. The generated tension can either excite the neuron or put it at rest. Multilayer Perceptrons utilize artificial neurons, however. According to Braga (2000), the most used model is the MacCulloch and Pitts neuron, which uses the following structure: inputs, representing the dendrites; weights, that represent the chemical alteration inside the body of the cell; and a threshold, that represents the electrical trigger of the neuron. This threshold is represented by the activation function.

2.2 Traffic Sign Detection problem

The objective of the traffic sign detection is to use computer vision (CV) techniques to detect and classify traffic signs in images obtained by vehicular cameras. The classification must be carried out according to the type of the sign: stop, speed bump, maximum speed allowed, pedestrian crossing ahead etc.

CV applications have improved a lot with the evolution of Convolutional Neural Networks and hardware. The creation of the dataset proposed in this paper follow guidelines that are applicable for CNN based architectures for object detection.

CNNs, image classification and object detection are discussed in the following subsection.

2.3 Convolutional Neural Networks (CNNs)

A basic structure of CNNs is composed of convolutional, pooling, flattening and fully connected layers.

Convolutional layers are responsible for extracting and grouping features such as horizontal and vertical traces of the image. This is done by applying convolution filters on the input image. Convolution filters are matrices that represent these characteristics and whose elements constitute the weights that are adjusted during the training of the network. Several of these filters are applied in a convolutional layer such that their output is a set of matrices where each matrix consists of a feature map.

In the pooling layers, the output dimension provided by the convolutional layer is reduced to condense the feature maps extracted from the image. There are no weights associated with neurons in this layer, only the maximum value or the average of the elements of a submatrix of the input is computed. The output of this layer is also a set of matrices.

The flattening layer transforms the set of matrices provided by the pooling into a vector representation. This is necessary so that the data extracted by the previous layers can be provided as input to a traditional Artificial Neural

Network with fully connected neurons, which is responsible for applying weights and providing output probabilities associated with each object class.

The CNN architecture described above can perform image classification tasks, which consists in defining a single class for an input image, which must have a single instance (or a featured instance) to be classified. The localization of the object in the image is not performed.

However, simply classifying images does not fit the purpose of the project because the images obtained by vehicular cameras may contain more than one license plate. Therefore, it was necessary to investigate the current methodologies aimed at this type of situation, which can be solved by the detection and segmentation tasks presented below.

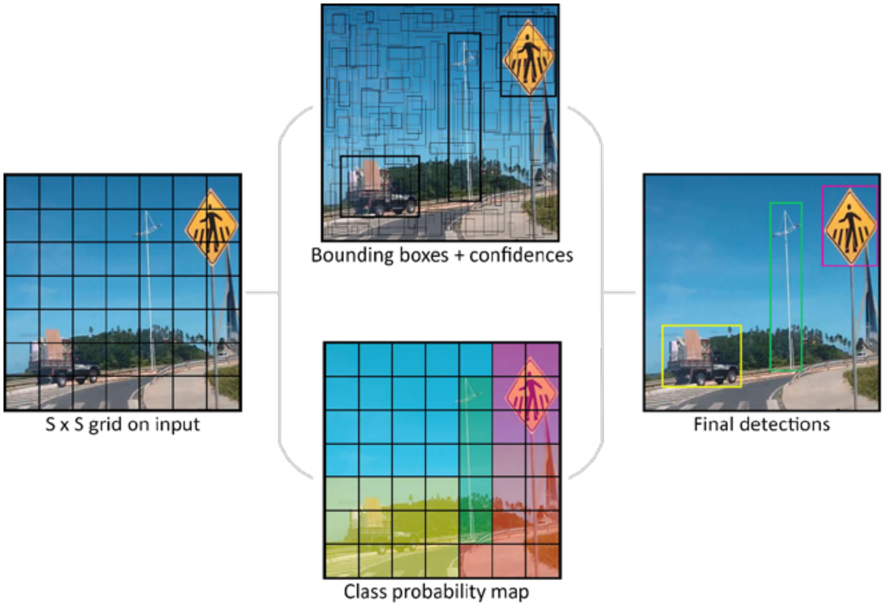
2.4 Object detection

The object detection task consists of locating and classifying one or more object in an image. As a result, rectangular bounding boxes are added around the detected object (location), and next to these boxes, the object's class (classification) and the associated degree of precision are indicated.

YOLO, acronym for You Only Look Once, is a modern neural network architecture that performs object detection tasks. Different from other architectures like Faster R-CNN, YOLO is a single-stage detector that predicts all the bounding boxes and classifies them in one step (REDMON *et al.,* 2016). Thus, YOLO can be used in real-time applications like traffic sign detection.

YOLO approaches object detection as a regression problem. As shown in Figure 1, it works by dividing the input image into an SxS grid and predicting B bounding boxes with confidence scores and C class probabilities for each grid cell. This confidence score represents how sure the algorithm is that the box contains an object. Higher scores regions have boxes with thicker lines in Figure 1. So, by crossing the predicted bounding boxes and confidence information with the predicted class probability map, YOLO produces the outputs: one bounding box and one class probability for each detection.

Figure 1 – Yolo detection example

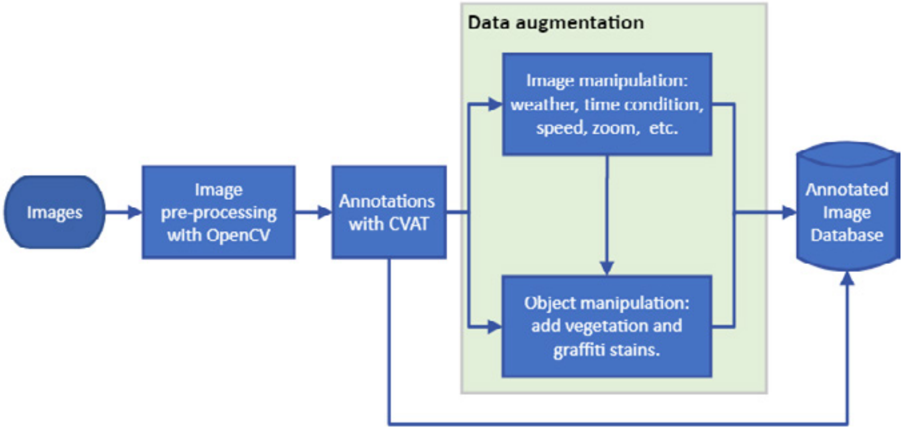


Source: Redmon *et al*., 2016.

3 MATERIALS AND METHODS

This section presents the materials and methods used to create the traffic sign detection dataset. The flowchart in Figure 2 shows the steps taken to obtain the dataset. First, the input images are pre-processed with Open-source Computer Vision Library (OpenCV) to remove some unnecessary content from the images. Then, the traffic signs of the processed images are annotated with the Computer Vision Annotation Tool (CVAT) software. After that, the annotations and images are stored in the database and go through a process called data augmentation, needed to increase the dataset with circumstances that aren't found in the input images, like different weather conditions or vegetation occlusion. All these steps are detailed in the following figure.

Figure 2 – Flowchart for dataset creation



Source: Elaborated by the authors.

3.1 Image acquisition

All images used for AI training were acquired using proprietary equipment, images obtained through Youtube and KartaView. We emphasize that all image use rights were met and that the footage was treated so as not to recognize any individual.

3.2 OpenCV

OpenCV is a programming library functions aimed at real-time visual computing. Originally developed by Intel, it is a cross-platform library that operates under an open-source Apache 2 license. Since 2011, OpenCV has supported real-time operations processed using GPUs. OpenCV has a wide range of applications, from image pre-processing to application in artificial intelligence (OPENCV, 2022).

In the creation of the traffic sign detection dataset, OpenCV is used to crop images and simulate weather conditions, brightness variations and speed effects on the camera.

3.3 Image pre-processing

A first step of image pre-processing is to delete images and videos with bad quality or irrelevant content for the model training.

Also, the recorded videos for a traffic sign detection dataset may come from cameras located inside of a vehicle, and some irrelevant objects for this detection purpose, like dashes or hoods, can persistently appear in the bottom of these captures. In this case, since OpenCV easily reads and converts video frames to numerical matrix representation, it is possible to crop bulk images by removing rows in the end of each matrix and, consequently, the hood and dash from the images. Figure 3 illustrates this pre-processing task.

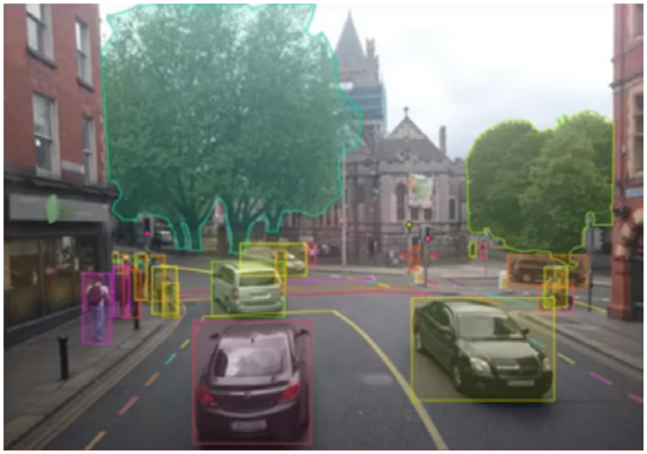
Figure 3 – Pre-processing task

Source: Elaborated by the authors.

3.4 CVAT Study

Training deep networks for computer vision requires large image datasets. And for object detection or image segmentation, AI frameworks needs information about the coordinates of each object of interest in each image to train the model. Usually, obtaining this information is a manual work with computer--assisted help from specialized annotation software, which provides, at least, graphical tools to delimit and label regions in an image, as shown in Figure 4.

Figure 4 – Annotation process



Source: Objects Annotation, 2020.

Considering that there are a great number of classes for traffic sign detection purposes and that YOLOv5 architecture recommends 10,000 or more instances per class (JOCHER *et al*., 2022), this annotation process can take a long time. Also, annotation mistakes (e.g., space between an object and its delimiter, wrong labeling, and objects missing labels) must be avoided, which requires attention and reviews.

One of the most used software for the preparation of computer vision datasets is CVAT, a free software provided by Intel for video and image annotation (SEKACHEV *et al*., 2020). It supports annotations for image classification, object detection, and segmentation by drawing boxes, polygons, polylines, and/or points shapes on loaded images. CVAT has an easy-to-use interface with integrated features, for example, shortcuts, zoom, automatic object trackers and detectors, and image manipulation, to accelerate the process and ensure good annotations. Furthermore, CVAT allows collaborative work, and the number of images to be annotated or reviewed can be distributed into a team of annotators to speed up the entire process and make it possible to carry out large-scale projects.

CVAT exports the annotations in various formats often used with computer vision: PASCAL VOC, YOLO, COCO, TFRecord etc., so that the same dataset can be used with different computer vision architectures for comparation purposes.

If the dataset is being created from scratch, a useful CVAT workflow is create a primary dataset by annotating some images, use data augmentation methods, train this augmented dataset with a computer vision architecture, and load the resulting trained model into CVAT to help with automatic annotations of new images to increase the dataset. This workflow can be repeated until the model is under the required accuracy.

3.5 Data Augmentation

The process of training an artificial intelligence system involves the usage of a robust set of data to identify or classify it. The accuracy of this system largely depends on two variables: the amount of data used for training and the quality of the information. Performance improves with the inclusion of low-quality data, if the data has useful information for classification (WANG *et al*., 2017). For example, text-based templates performed better when Google provided a trillion-word database, even though the pages were not filtered and had a lot of errors (HALEVY; NORVIG; PEREIRA, 2009). When the amount of information is too small or when the information passed is presented in a limited context that does not cover the different scenarios in which the network will be used, the so-called overfitting occurs.

Overfitting is the inability of an AI system to generalize the data used in training to classify data not yet seen. This occurrence is easily visualized by the high accuracy in the training data and the low number of hits in the test data (YING, 2019). An example of this is a trained network with images of traffic signs collected in a rural area but is unable to recognize the same signs in an urban area. A possible reason for this is because all training traffic signals have vegetation in the background, the network considers that vegetation contains information and have a poor performance when applied to images with buildings in the background.

Several methods have been proposed to reduce the impact of overfitting (WANG; KLABJAN, 2017). For example, transfer learning uses a convolutional network that has been previously trained on data with similar values or structures to the problem data that will be used in the training step. In this way, some network parameters are calibrated to solve the specific problem and less data is needed to achieve a high hit rate.

Another way to ensure the accuracy of this set is to have a lot of information collected in all possible circumstances. For the system that will identify defective traffic signals, that means having pictures of all types of traffic signals it can find collected in different lighting conditions (night, day, twilight, etc.), different weather conditions (sun, rain, fog, etc.), different photo qualities (high resolution, distorted by speed, blurred by camera shake, etc.) and different qualities of plate (perfect condition, pixelated, broken, rusty, obstructed by vegetation, etc.).

Due to time and resource limitations, it is impractical to capture photos in all these conditions. The main dataset available, which is Google Maps, has images captured under controlled conditions. Likewise, capture using maps, web scraping methods or video capture by the researchers themselves would lead to many traffic signals plates captured per day, with good quality, in clear time and with good resolution. This would lead to a biased system for recognizing "good" traffic signals plates, when the main objective of building the database is to create a base capable of recognizing defective traffic signs. To achieve this goal, it is important that there is a balance in the data, with an amount of defective traffic signals plates in the same order of magnitude as the amount of traffic signals plates in good condition.

Failures due to scarcity of data are quite common. Normally, as the problem becomes more and more specialized, the difficulty of obtaining a reasonable amount of data to solve it increases (WANG *et al*., 2017). For example, in the medical industry the lack of data makes it difficult to classify different types of cancer (VASCONCELOS; VASCONCELOS, 2017). In addition, small players in the AI industry often do not have the resources to capture this data or even buy it (WANG *et al*., 2017).

Overcoming data scarcity is the goal of data augmentation techniques, a field of study of ways you can increase the amount of data that is used in training. This is not a new field of study, its first successful application can be considered the introduction of defects within the MNIST dataset (BAIRD, 1992), that shown positive results in several problems such as: use of expert knowledge

(VASCONCELOS; VASCONCELOS, 2017), relationship classification (XU *et al*., 2016) and, more usually, images classification (WONG *et al*., 2016). The accuracy in image classification increased, even with the use of traditional transformations only, in all tasks that were evaluated (WANG *et al*., 2017).

Currently, existing methods for image augmentation can be broadly separated into two categories: black box methods, in which deep neural networks are used to generate new data, and more traditional white box methods, in which transformations over collected data are described explicitly (MIKOŁAJCZYK; GROCHOWSKI, 2018).

White box methods are the most popular and have been tested the most in the literature (MIKOŁAJCZYK; GROCHOWSKI, 2018). In these methods, a copy of the input image is subjected to a combination of transformations to change the information in the input image (BJERRUM, 2017). This information is usually related to the geometry and colors of the image (WANG *et al*., 2017). For example, geometric changes in the image are obtained through affine transformations and can be reflection, shifting, rotation, zooming, scaling or shear. Also, changes related to image color palettes are distortion, sharpening, blurring, color balance, contrast, brightness and hue changes or image combination (GALDRAN, 2017; WANG *et al*., 2017).

Traditional data augmentation methods should be enough to start building a robust traffic sign image dataset because they can generate significant variations in the elements that make it difficult to detect traffic signs: road conditions and traffic sign conditions. The solution chosen to increase the data obtained from information captured by researchers and taken from the internet was to use a white box data increase process. Operations are performed on the available data to generate artificial images that will be used during training. These operations, also called masks, can be applied over the entire image (as in the case of changing lighting or weather) or just over the area of the image where a plate is identified (as in rust or obstruction by vegetation). When only the traffic signal plate area is changed, it is necessary to identify the pixels that belong to it. This is done by importing the annotations already made on the original image into the enlargement program and passing the mask only on the sub-image limited by the annotation.

The filters were developed using the OpenCV library in the Python language. This library was created by Intel and is complete both in software packages and in hardware integration for computer vision. Eight ways to enlarge the entire image were developed: adding rain, lightening and darkening, adding solar flare, adding haze, adding velocity distortion, and adding horizontal and vertical flips. Four ways of increasing the area of the plate were also developed: addition of graphite, erasure of colors, obstruction by vegetation and bending of the traffic signal plate. These shapes are exemplified in Figure 5.

Figure 5 – Examples of change methods in the plate region. From left to right: original image, graffiti sign, sign obstructed by vegetation

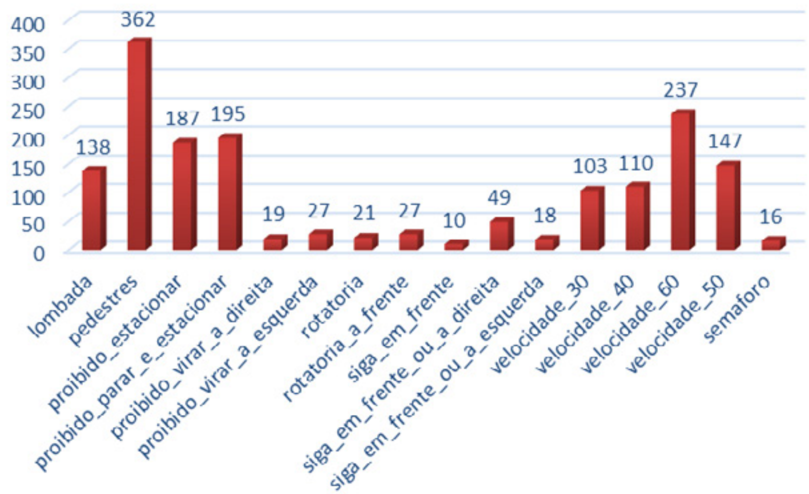
Source: Elaborated by the authors.

4 RESULTS AND DISCUSSION

This section presents some of the results obtained with the new traffic sign detection dataset and YOLOv5 object detection architecture (JOCHER *et al*., 2022).

The total number of real objects annotated with CVAT software is 1666. The distribution over the classes can be observed in the histogram of Figure 6. It is not close to the YOLOv5 recommendations mentioned before, but the authors are still increasing the dataset.

Figure 6 – Total results objects annotated



Source: Elaborated by the authors.

Two experiments were performed with the obtained dataset and YOLOv5 object detection architecture. The first experiment was carried out with only built-in YOLOv5 data augmentation policies: scaling, color space adjustments and mosaic augmentation (JOCHER *et al*., 2022). In the second one, besides the YOLOv5 built-in augmentation, "random_brightness", "add_rain", and "add_speed" filters from Automold library are applied to the original dataset, increasing by three times the number of annotations per class. Image rotations or flips are not applied because some directional signs can become mislabeled with these kinds of augmentations. Both obtained models were trained over 50 epochs with the dataset split into 80% for training, 10% for validation and 10% for test.

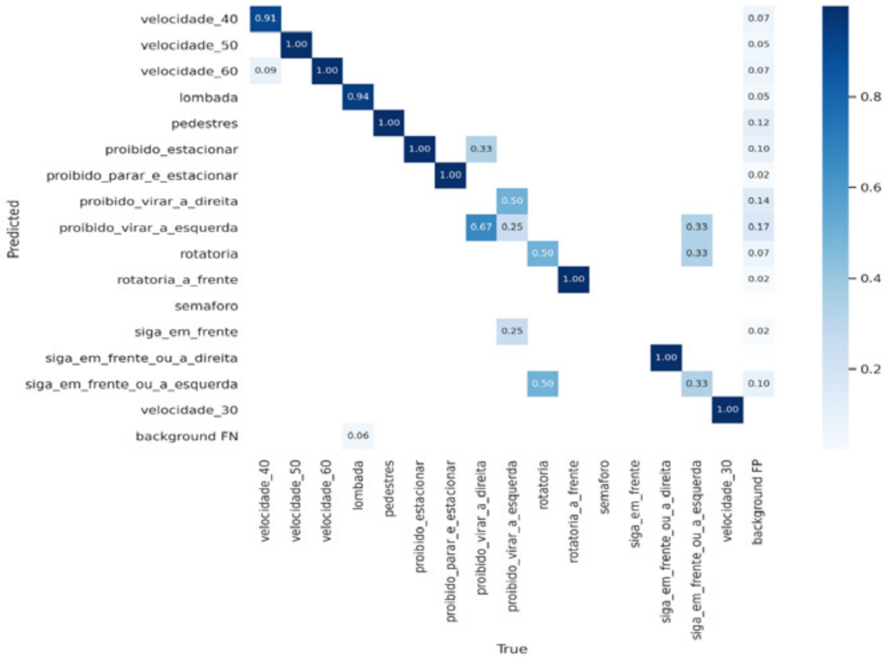
By applying the model obtained from the first experiment in the test set returned the precision, recall, mAP@0.5, and mAP@0.5:0.95 presented in Table 1. Figure 7 shows the confusion matrix obtained with the test set. These results indicates that the obtained model for the first case detects and classifies with good precision the classes that have great number of annotations in Figure 6. On the other hand, the model is not good for classes with few annotations. This behavior is expected because neural network models are generally not as good when the number of information (annotations in this case) used during the training process is not large enough.

Table 1 – Model obtained from the first experiment

Precision	Recall	mAP@0.5	mAP@0.5:0.95
0.782	0.972	0.928	0.778

Source: Elaborated by the authors.

Figure 7 – Confusion Matrix for First Model



Source: Elaborated by the authors.

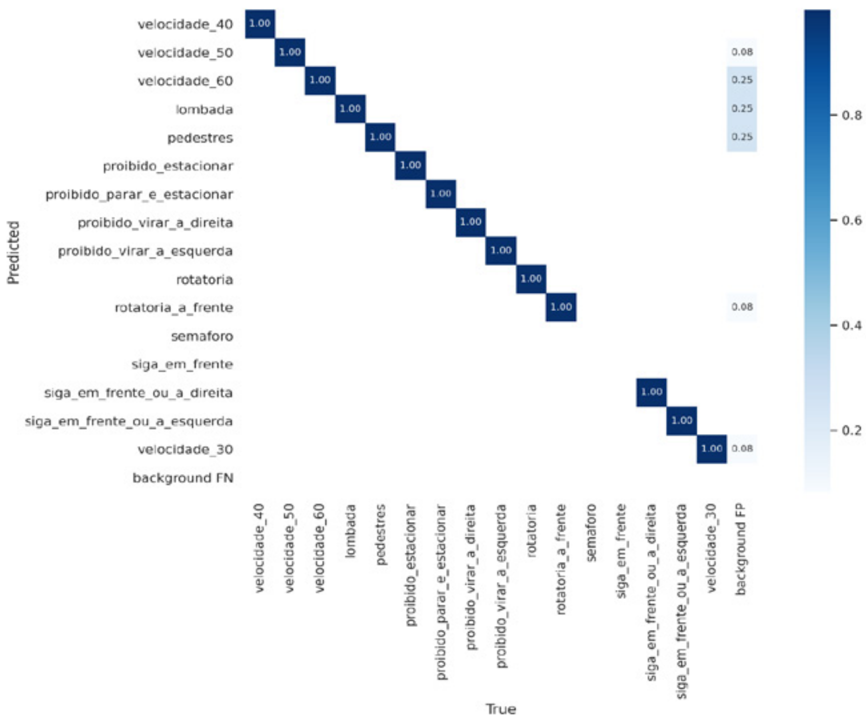
For the second model, the test results are presented in Table 2 and in Figure 8. These results were obtained by applying this model to the same test set used with the first model. Note that the obtained model has a good validation score to detect those types of signs. The main reason for this behavior is the use of data augmentation provided by Automold library.

Table 2 - Model obtained from the second experiment

Precision	Recall	mAP@0.5	mAP@0.5:0.95
0.989	0.983	0.994	0.881

Source: Elaborated by the authors.

Figure 8 – Confusion Matrix for second Model



Source: Elaborated by the authors.

5 CONCLUSIONS

Creating a dataset of this magnitude requires the usage of different techniques to obtain the desired results, the same picture can be reused many times once different editing is applied to it. The main object of study of the dataset is traffic signs, so it is necessary to obtain these pictures in various conditions, in which the plate can be broken, bent, rotated, rusty, tainted, with graffiti stains etc. Nonetheless, weather and time conditions applied to the camera can also influence the results: rain, clouds, ice, sand, light conditions etc.

Meeting all these different conditions in real life, while capturing the photographs would be ideal, but it would take a very long time to obtain such images combining all those factors while considering the variety of signs and how far they are placed in each area. To build this database, image editing, and autonomous image augmentation are being used.

The proposed process uses a combination of filters, digital brushes, and geometric operations as augmentation techniques. Digital brushes are tools used in digital image editing to apply certain effects over a picture, they can create specific effects, like dirt and rust, with ease. Using these assets, it's possible to expand about three to eight times the number of images in each dataset and obtain more accurate results as show the results topic.

The challenge of this model is increasing the dataset automatically, detecting, classifying and segmenting the traffic signals as good or damaged. Computer Vision AIs normally use Convolutional Neural Networks (CNNs) to identify a said pattern in a set of given images. To achieve the desired goal, CNNs must be trained by a big collection of images.

Vehicles' cameras continued to provide new images after the initial version was released, so the network will continue to be trained continuously with new situations. The authors believe that the training must be supervised, at least until it is possible to improve the results of the confusion matrix. Another point is that these results can be used by the government to achieve efficient road maintenance, creating tags to show the location of each problem found and confirmed, as well as the type of problem. For example: in a place where the slab is covered by vegetation, a tree pruning service is requested, reducing the chance of sending a slab change team and thus wasting resources (time and fuel for the dislocation). The second team would not solve the problem.

Modern AIs are still not fully capable of consistently detecting and classifying damaged traffic signs. Especially due to the lack of training material at their disposal. The creation of this dataset allows AI training detection and damage assessment for traffic signs, and is an can be a relevant process for the government, for road developers and for autonomous vehicles and smart cities.

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2

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Technological roadmap of types of battery thermal management system and their applications in the Brazilian electrified passenger vehicles automarket

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ABSTRACT

In the last years, the use of lithium-ion batteries (LIBs) has been growing with the migration of automakers to manufacturing electric and hybrid vehicles. So far, LIB has been shown to be the most suitable battery technology for application in electric vehicles due to their energy storage capacity and life cycle. However, these features and safety are directly linked to temperature control. Due to the sensitivity of LIB to temperatures below 15 °C and above 50 °C, this research aims to evaluate the thermal management systems of batteries found in the literature and their applications in electrified passenger vehicles commercialized in the the Brazilian market. This was done through the research and classification of data available in the literature, identification of the types of battery management systems adopted in these vehicles and, finally, a comparison between the literature and what is applied in the field. It was possible to identify that despite the various proposals for thermal management systems available in the literature, only two models are implemented for commercial purpose: air-cooled and liquid-cooled. Therefore, it is concluded that many of the improvement proposals are not mature enough for a scalable and marketable proposal.

Keywords: Battery Thermal Management, Battery Cooling, Thermal Management.

1 INTRODUCTION

Humanity's constant race to reduce the impacts of greenhouse gases (GHGs) has turned the attention of governments and companies to the levels of CO_2 emission generated by the transport sector, as it is one of the main polluters, among other (COSTA *et al*., 2020). This race against time to contain the advance of global warming has made automotive companies focus their resources on the development of electrified vehicles (EVs), as a solution to the emission of pollutants during vehicle use.

Currently, the number of EVs is still small when compared to internal combustion engine vehicles. However, this proportion has been changing rapidly year after year (GLOBAL EV OUTLOOK, 2019). In 2020, sales figures reached 4.6% of total vehicle sales globally, with significant growth prospects for the coming years, estimating to reach 88% of the global light vehicle market by the year 2035 (BOSTON CONSULTING GROUP, 2020).

Coupled with the rapid growth in the number of EVs is the increasing demand for traction batteries with high energy density, which is the main source of energy for EVs. To date, Li-Ion (LIB) batteries are preferred by EV manufacturers due to their low self-discharge rate, long lifespan, high power and energy densities. Research carried out by Ziegler and Trancik (2021) and Duffner *et al*. (2020) indicate that lithium-ion batteries will continue to improve in cost, safety, energy, and power capacity in the coming years due to research investments. However, the degradation and thermal safety of LIB are still the main challenges for the development of LIB and EVs. Studies have shown that the capacity, life cycle and safety of LIBs are highly temperature-dependent (KIM *et al*. 2019; JAGUEMONT *et al*. 2020; LIN *et al*. 2021; TETE *et al*. 2021). The performance and stability of LIBs rapidly decrease in the temperature range above 50°C and below 15°C, which can compromise the safety of the conductors in cases of temperatures below 0°C or above 80°C (LIN *et al*. 2021).

The temperature control of LIBs in EVs is done by the battery thermal management system (BTMS), which is the focus of the study of this work. With the high sensitivity of LIBs to temperature, this work aims to identify the types of BTMS available in the literature and compare them with the BTMS that are commercialized in EVs in Brazil in order to identify the challenges and opportunities in the commercialization of each BTMS presented in the literature and thus help in the propagation and acceptance of EVs.

contents

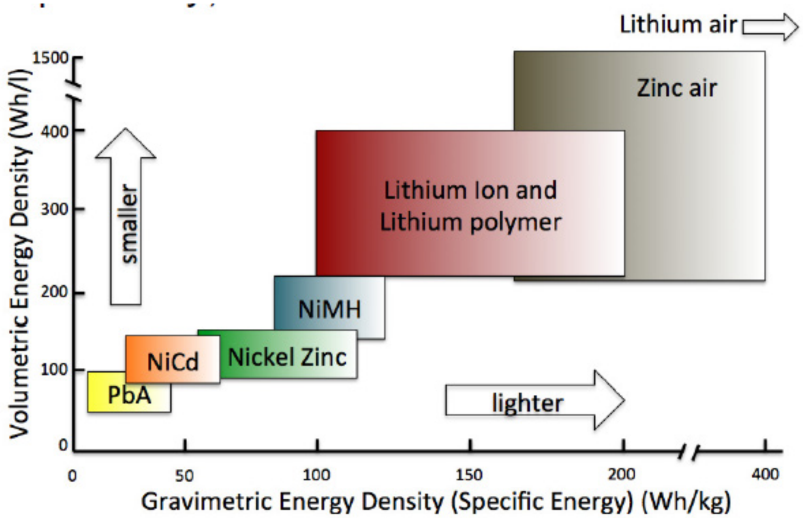
1.1 Lithium-Ion Battery

Currently, lithium-ion batteries are widely used in applications such as telecommunications, appliances and tools, automotive and aerospace industries. Among the several types of energy storage devices, lithium-ion is the preferred choice due to its high energy capacity, power density, voltage, cycle life, and low self-discharge rate (LIN *et al*. 2021). Thus, these batteries are receiving considerable attention from the automobile and electronics industries.

One of the main components of electric vehicles are traction batteries. As mentioned by Bernhart (2019), depending on the energy capacity of the battery, it can correspond to 27% of the total cost of the vehicle.

As highlighted by Kim *et al*. (2021), the fundamental challenge for EVs is to find an appropriate energy storage system that can travel high mileage, has fast charging and high performance. At the time of the present study, rechargeable lithium-ion batteries are considered the most suitable energy storage device for EVs due to their higher energy density, higher specific power, lower weight, lower self-discharge rates, higher recyclability, and cycle time. It has a longer life than other rechargeable batteries such as lead-acid, nickel-cadmium (Ni-Cd), nickel-metal hydride (Ni-MH) batteries, as shown in Figure 1.

Figure 1 – Comparative chart between the types of components used in the manufacture of batteries



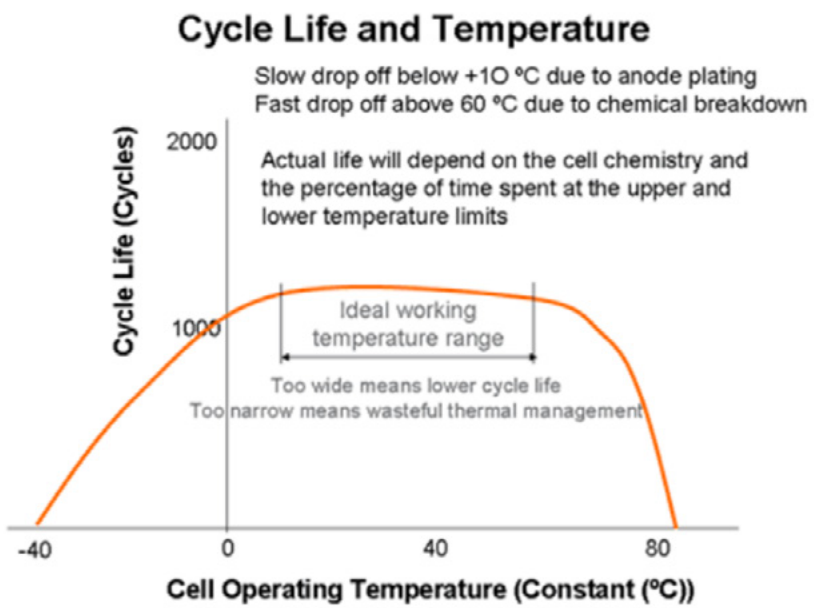
Source: Adapted from Plett (2015).

1.2 Battery Thermal Behavior

Lithium-ion batteries play a key role in the acceptance and diffusion of electric vehicles globally. However, the degradation and thermal safety of lithium-ion batteries are still the main challenges for their development and application in electric vehicles (LIN *et al*., 2021). The reviews carried out by Lin *et al*. (2021), Choudhari *et al*. (2021) and Tete *et al*. (2021) show that battery capacity, life cycle and safety are significantly temperature dependent: high (>50 °C) or low (<15 °C).

In the literature, it is possible to find several recommended temperature ranges for the use of lithium-ion batteries, with the temperature range from 15°C to 35°C being considered as desired, as shown in Figure 5 (PESARAN *et al*., 2013). Some battery vendors mandate four temperature ranges: (0–10°C) decrease in battery capacity and pulse performance, (20–30°C) optimal range, (30–40°C) faster self-discharge, and (40-60°C) irreversible reactions, with 60°C being the upper safety limit under normal operating conditions. Another important point is the temperature uniformity between the cells in which the temperature difference must be less than 5°C (TETE *et al*., 2021) Figure 2.

Figure 2 – Temperature effect on battery life cycle



Source: Tete *et al*. (2021).

Tete *et al*. (2021) revealed that lithium-ion battery cells lost more than 60% of their initial energy after 800 cycles at 50°C and lost 70% after 500 cycles at 55°C. In another example, the authors report that the life cycle of a lithium-ion battery at 45°C is approximately 3323 cycles, and that this value is significantly reduced to 1037 cycles at a temperature of 60°C.

1.3 Battery Thermal Management System (BTMS)

As discussed in previous chapters, Li-Ion batteries have an optimal operating temperature range that needs to be maintained to ensure the safety, life, and proper performance of the system. Currently, the temperature control of batteries in electric vehicles is done using the battery thermal management system (BTMS). This system is responsible for ensuring that the battery operates in the proper temperature range and maintains the smallest possible temperature difference between the cells.

According to Pesaran (2013), every BTMS must have the following essential functions: cooling to remove heat from the battery, heating for very low temperature environments, insulation to avoid sudden changes in battery temperature and ventilation to exhaust potentially dangerous gases from the battery. In addition to these four functions, the most modern BTMS must have additional features such as taking up little space, being light, having low cost, high reliability, easy maintenance, low energy consumption and easy assembly.

In the literature, there are several ways of classifying the BTMS. Some authors such as Zhao *et al*. (2020) classify it by the energy consumption of the system (passive and active), while Lin *et al*. (2021) classify it by functionality (preheating, cooling and emergency). The classification method adopted in this study is based on the medium used for heat transfer, focusing on battery cooling: air, liquid, phase change material, thermoelectric modules, heat pipe and hybrid models, Figure 3.

Figure 3 – List of BTMS under study in literature

BTMS-Battery Thermal Management System			
Air	Natural	Modified air-flow channel	
		Different cell configuration	
	Forced	Modified air-flow channel	
		Different cell configuration	
Liquid	Direct contact	Phase change	
		Fluid Flow	
	indirect contact	Cold Plate	
		Discret tubes	
PCM-Phase Chance Material	Organic	Paraffins	
		Non-Paraffins	
	Inorganic	Salt Hydrates	
		Molten Salts	
		Metals	
	Eutectic	Inoganic-Inorganic	
		Organic-Inoganic	
		Organic-Organic	
HP-Heat Pipe	Flat		
	Flat plate loop		
	Ultra thin		
	Pulsating		
	Oscilating		
Hybrid	PCM+Air		
	PCM+Liquid		
	TEC+Air		
	TEC+Liquid		
	HP+Air		
	HP+Liquid		
TEC - Thermoelectric Cooling			

Source: Elaborated by the authors.

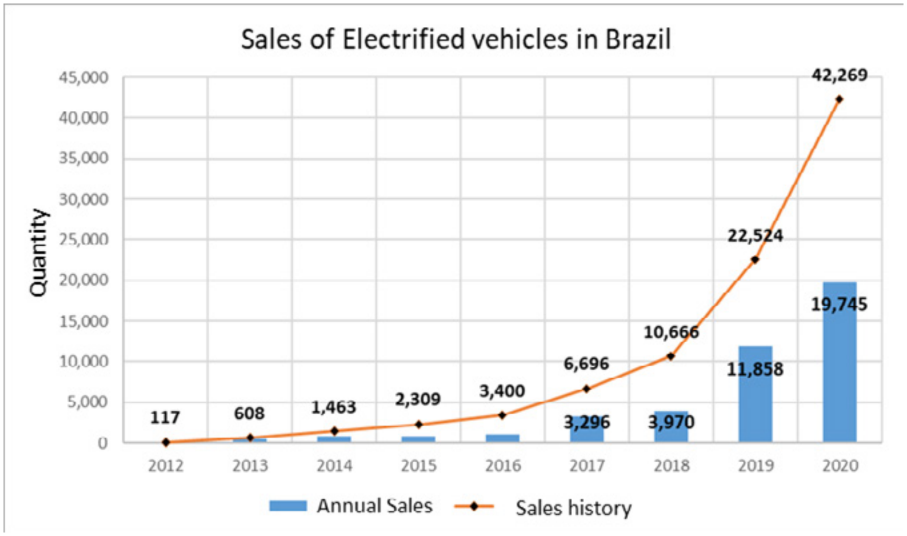
1.4 Battery Thermal Management System (BTMS)

Vehicle sales in Brazil have been growing year after year, although the number of electrified passenger vehicles in Brazil is still considerably small when compared to internal combustion engine vehicles. However, the trend towards the adoption of electric vehicles that has been seen in the United States, Europe and China is also taking place in Brazil, but at a slower pace.

According to the Brazilian Electric Vehicle Association (ABVE), in 2020, electric and hybrid vehicles reached 1% of total sales in Brazil for the first time and in April 2021 they reached 1.6%, when compared to the global volume of electrical vehicles.

According to the latest Global EV Outlook 2021 report and the International Energy Agency (IEA), worldwide sales of electric vehicles in 2020 (auto and light commercial vehicles) reached 4.6% of total sales. Figure 4 represents the number of electric vehicles licensed in Brazil from 2012 to 2020, where it is possible to identify a growth of 60% in 2020 compared to 2019.

Figure 4 – History of Sales/Licensing of Electrified Vehicles in Brazil 2012 to 2020



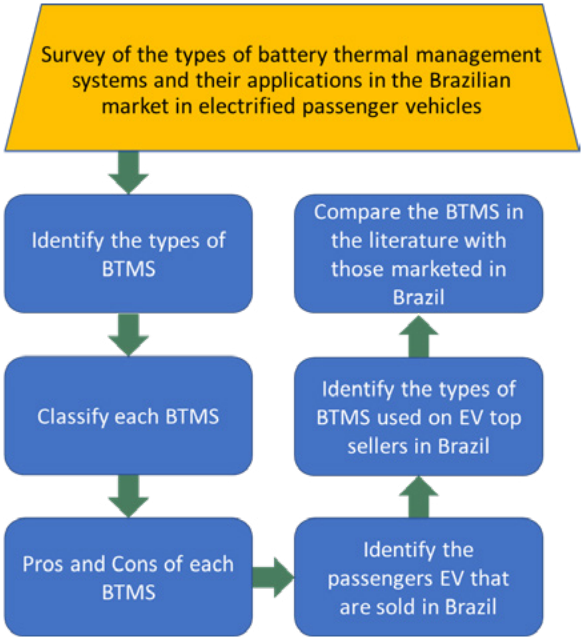
Source: Elaborated by the authors.

It is possible to see that the growth trend of the electric vehicle market has been materializing at an accelerated pace. This growth makes the battery thermal management system increasingly important, as it is one of the critical items in vehicles, as presented in previous chapters.

2 MATERIALS AND METHODS

The steps for the construction of this research can be seen in a summarized way in the block diagram from Figure 5.

Figure 5 – Schematic flowchart of the research methodology developed



Source: Elaborated by the authors.

The process of identifying the types of BTMS took place through bibliographic research, using the keywords "battery thermal management" and "battery cooling and thermal management" in databases such as Science Direct, MDPI, SAE and Google Scholar. For this work, a range of publications were considered, such as reviews, research and technical articles, and congress presentations, with the main objective of identifying all types of BTMS under study in the literature.

Following the identification of BTMS types, a method of grouping/classifying BTMS types was defined. For this definition, the technical aspect, means of heat transfer and primary characteristic of the form of cooling, were considered according to the ease in delimiting the group presented by this criterion. Some methods such as dividing by energy consumption end up causing mixed classifications of BTMS.

After the grouping process was done, the positive and negative points of each type of BTMS were tabulated using as criteria key points of a BTMS such as low energy consumption, simplicity, etc. This tabulation is intended to facilitate the comparison between the types of BTMS.

The next step was to identify which electric vehicles are sold in Brazil, through research in specific data sources such as ANFVEA (National Association of Automotive Vehicle Manufacturers), ABVE (Brazilian Association of Electric Vehicles), FENABRAVE (National Federation of Automotive Vehicle Distribution) and NeoCharge, filtering the data considering only electrified vehicles — in this case hybrid vehicles and electric vehicles that are the focus of the study.

Having identified the electrified vehicles sold in Brazil, the next step was to understand and list the types of BTMS used by most commercialized models for each vehicle classification – Hybrid, Plugin Hybrid and Electric. This survey was carried out through specialized magazine websites and YouTube channels focused on the automotive sector.

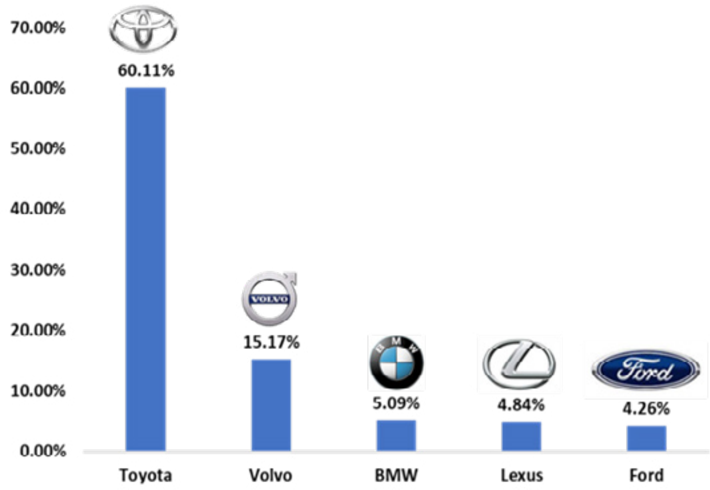
With the information of positive and negative points of each type of BTMS available in the literature and the data of the types of BTMS commercialized in electrified vehicles, a comparison was carried out and notes were made on the opportunities and challenges for the types of BTMS under study.

In patent research, the methodology applied was like that used with BTMS. The keywords “battery thermal management” and “battery cooling” were used in the INPI (National Industrial Property Institute) database and in the Google Patents website.

3 RESULTS AND DISCUSSION

Brazilian market has been gradually adopting the use of electrified vehicles (hybrid [HEV], plug-in hybrids [PHEV] and battery powered vehicles [BEV]), following the global trend of the automotive market. The electrified vehicle market in Brazil is composed mostly of HEV vehicles with 71.8% of electrified vehicles licensed, followed by PHEV vehicles with 23% and completed of BEV vehicles with 5.2%. There is a range of electrified vehicles in Brazil, from various manufacturers. Today, the top 5 automakers in terms of cumulative number of electrified vehicle sales can be seen in Figure 6.

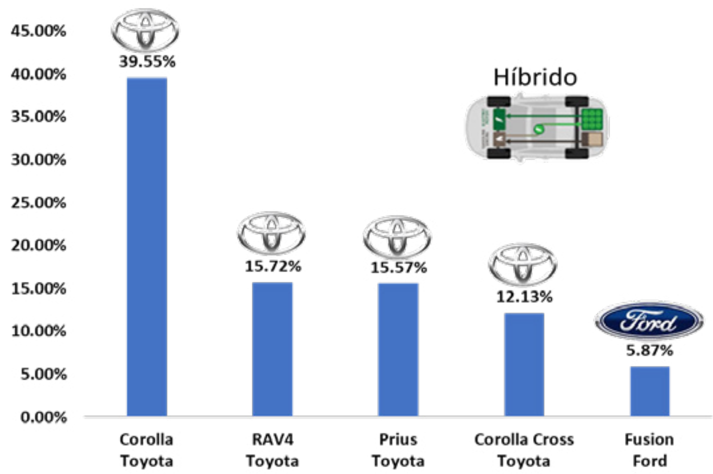
Figure 6 – Top 5 automakers in terms of cumulative number of electrified vehicles sales in Brazil from 2015 to Oct. 2021



Source: Elaborated by the authors.

Toyota leads the cumulative number of sales of the electrified vehicle market in Brazil, however, looking at the top 5 of each of the three classifications of electrified vehicles by vehicle model, its participation is limited to HEV vehicles, in which Toyota leads the number of vehicle sales, occupying the first four places of the sales rank, with Ford in fifth place completing the top 5 as can be seen in Figure 7.

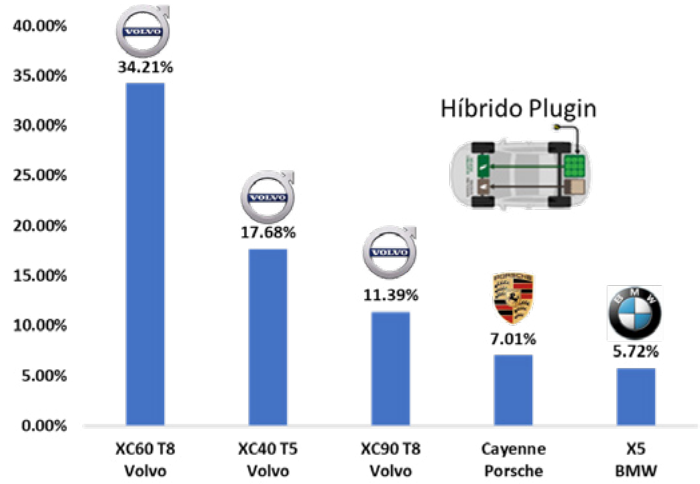
Figure 7 – Top 5 of HEV in accumulated sales in Brazil from 2015 to Oct 2021



Source: Elaborated by the authors.

The PHEV category has the sales leadership from Volvo, occupying the top three places in the ranking, followed by Porsche with the fourth place and BMW with the fifth, as seen in Figure 8.

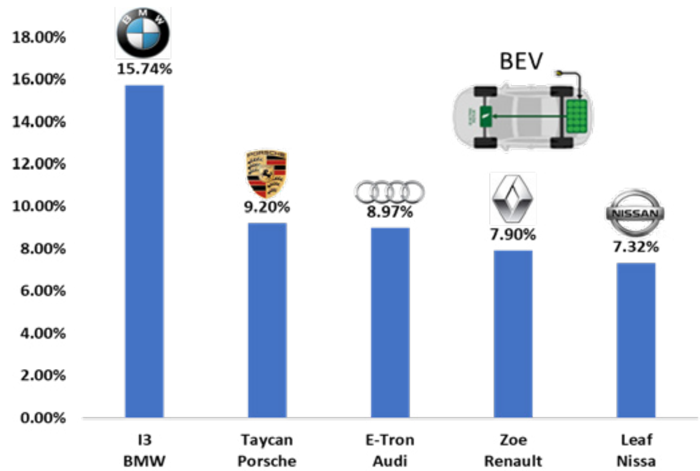
Figure 8 – Top 5 PHEV in accumulated sales in Brazil from 2015 to Oct. 2021



Source: Elaborated by the authors.

Finishing the ranking of electrified vehicles by model, BMW leads the accumulated number of sales of BEV vehicles, followed by Porsche, Audi, Renault and Nissan, as seen in Figure 9.

Figure 9 – Top 5 of BEV vehicles in accumulated sales in Brazil from 2015 to Oct. 2021



Source: Elaborated by the authors.

It is possible to identify a preference of Brazilian consumers of HEV vehicles for vehicles manufactured by Toyota as well as a preference for PHEV vehicles manufactured by Volvo. In the BEV ranking, although BMW is leading the cumulative sales rank with more than double the second place in this category, a mix of vehicle manufacturers can be seen in the composition of the top 5 rank.

It is worth mentioning that among these three categories of electrified vehicles, HEV vehicles are usually the cheapest vehicles, followed by PHEVs and finally BEVs Depending on the model chosen, the positions can change, but generally this is the cost sequence. Of the models presented in the three ranks, only the Toyota Corolla, Prius and Corolla Cross models are manufactured in Brazil, the other vehicles are imported.

Looking to the BTMS of each vehicle that leads each rank, we have the following result on Table 1:

Table 1 – Battery capacity summary of the best-selling vehicle models in Brazil by category and BTMS

Electrification	Battery Capacity			BTMS Used
	Kilowatts H (kWh)	Ampere-H (Ah)	Voltage (V)	
Toyota Corolla - HEV	1,3	6,4	201,1	Air cooling – Active
Volvo XC60 T8 - PHEV	10,4	26	400	Liquid Cooling – Indirect
BMW i3 - BEV	37,9	120	352	Liquid Cooling – Indirect with phase change

Source: Elaborated by the authors.

The way of using the energy and power of the battery is different between HEV, PHEV and BEV vehicles. HEV-type vehicle batteries focus on greater power density for use during situations in which the combustion engine has low efficiency, which are usually low rotation situations, resumes and vehicle starts. Vehicles of the PHEV type are an intermediate point where the power/energy – P/E ratio of the batteries starts to have a more balanced relationship, however as they still have a combustion engine, the batteries usually still have a direction for power. BEV vehicles have the battery as the only source of energy for the vehicle, the batteries focus on a greater energy density.

Table 2 presents four classifications of the main attributes of BTMS based on information found in the literature, enabling the identification of strengths and weaknesses of BTMS.

Table 2 – BTMS classification based on attributes

BTMS		Attributes							
		Weight	Price	Energy Consump.	Noise	Electric Safety	Thermal Capacity	Complex	Maintan
Air		★★★★	★★★★	★★★	★	★★★★	★	★★★	★★★★
Liquid		★★	★	★	★★★	★★★	★★★★	★★	★
Hybrid	PCM	★	★★	★★★	★★★	★★	★	★	★
	HP	★★	★★	★★★	★★★	★★★	★★★	★★	★
	TEC	★★★	★	★★	★★★★	★★★★	★	★★	★★★

Subtitle: Bad★ / Regular★★ / Good★★★ / Excellent★★★★
Source: Elaborated by the authors.

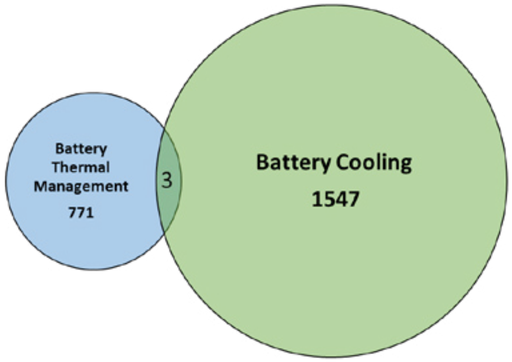
The attributes presented in the previous table have different degrees of importance, however, electrical safety is a non-negotiable characteristic, the BTMS system chosen cannot endanger the life of the driver, especially in critical situations such as automotive accidents. The choice of other features may vary depending on the level of electrification that BTMS will under (HEV, PHEV or BEV).

The patent research carried out in the INPI and Google Patents database resulted in more than 37 thousand patents, with the INPI having an inexpressive number of two patents. Due to this, the refinement of the data was made only with the patents found in Google Patents.

From these more than 37 thousand results, it was identified that even using the keywords "battery thermal management" and "battery cooling", many results had a different focus from the purpose of this research, such as thermal management related to fuel cells and other components. Due to this, the search method was improved with a specific focus on the sentences "battery thermal management" and "battery cooling", in quotes, which made it possible to reduce the search results to 2321 patents.

In this panorama of 2321 patents, they are divided into 1061 assignees who benefit from these patents. It was also noticed that there are patents with rights shared with more than one assignee. From this number of patents, 771 have the sentence “battery thermal management” in the title and 1547 have the sentence “battery cooling” in the title. Three of the results have the two sentences in the title as can be seen in Figure 10.

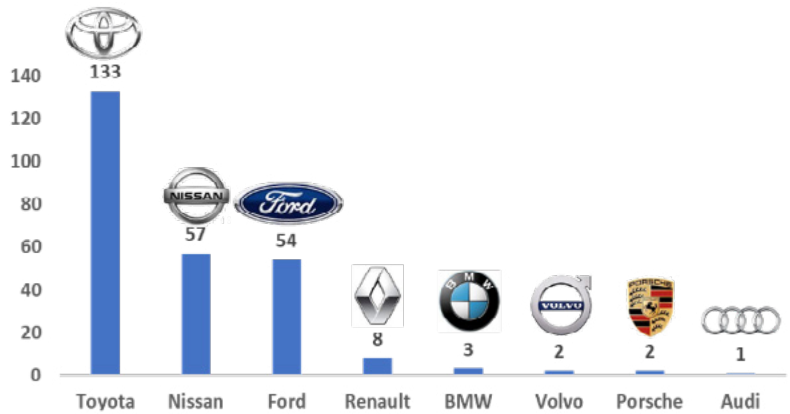
Figure 10 – Venn graph of the distribution of the number of patents related to the search keywords



Source: Elaborated by the authors.

Looking at the automakers presented in the previous topic, the following patent numbers were found, see Figure 11. Toyota also leads in number of patents when compared to the automakers in the survey of the previous topic.

Figure 11 – Number of patents related to the keywords mentioned above

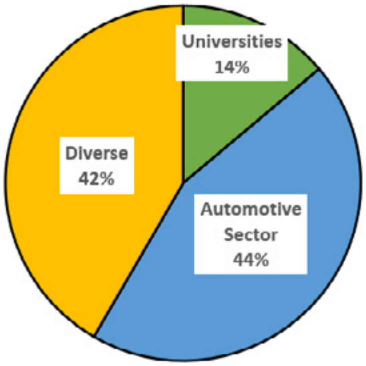


Source: Elaborated by the authors.

Dividing the 2321 patents into three affinity groups, we have the graphic in Figure 12:

- Automotive Sector: Automotive manufacturers.
- Universities: Universities, college and research institutes;
- Diverse: Telecommunications, aviation, industry manufacturers in general.

Figure 12 – Division of patents into 3 groups of affinities



Source: Elaborated by the authors.

A relevant point regarding the list of patent owners is that in a sample of 2321 patents, 322 or 14% of the total volume of patents have the University as an assignee.

4 CONCLUSIONS

This Paper presented a review of the types of traction batteries and demonstrated the reason for the lithium battery to heat up and the ideal working temperature range as well as the damage caused to LIBs to the be used at temperatures below 15°C and above 50°C. The importance of BTMS and the types available in the literature and the variations found for each one was presented, such as liquid BTMS with cooling by direct contact and by indirect contact and the other classifications. A specific overview of patents related to battery thermal management and battery cooling was presented, demonstrating the volume of patents and possible groupings and relevance.

The growth in the commercialization of electrified vehicles globally was presented, as well as in Brazil. It is an indication that this type of vehicle is being well accepted by consumers and a forecasts that indicate that the automotive market will be dominated by electrified vehicles in the next 15 years, reinforcing the reason for investments of automakers in the technological development of traction batteries and their peripherals that help in their proper functioning and guarantee the extension of battery life.

This article also identifies the most commercialized vehicles by electrification levels in the last 7 years, identifying the sales leader by type of electrification, with Toyota as the automaker that most commercialized electrified passenger vehicles, and also the sales leader in HEV with Corolla in first place, followed by Volvo in second in the sales rank of electrified vehicles and leader in sales of PHEVs with the XC60 T8, and BMW in third place in the sales rank of electrified vehicles and leader in sales of BEVs with the i3.

With the data on the types of BTMS used in the sales-leading vehicles of the HEV, PHEV and BEV segments, a comparison was made resulting in Table 3, which helped to understand the reasons why only the air and liquid-based BTMS are the only ones commercialized so far, leading to the conclusion that the tests and simulations carried out with BTMS based on PCM, HP and TEC simple or hybrids still do not bring results that lead them to replace BTMS with Air or liquid, since in more critical use, these same BTMS PCM, HP and TEC, rely on BTMS Air or liquid to improve their ability to remove heat, generating even more complexity.

Finally, the information presented by this work is significant to support new researchers on the topic and in understanding BTMS, and it can be used as a source of information for academics as well as for those active in the electrified vehicle market. The guidelines on the types of BTMS found in the literature and their variations are one of the factors for a full understanding of this topic.

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3

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A NEW APPROACH TO USE EMOTIONS RECOGNITION FOR VEHICLE SECURITY

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ABSTRACT

Express kidnapping is unfortunately growing in Brazil, mainly when people are getting into their cars. In this type of crime, in most of the cases the victims are completely vulnerable, and they do not have any chance to ask for help due to the fact they are under the kidnapper custody. However, technology evolved in the last decades in a way that can mitigating such problems. There was huge progress on artificial intelligence (AI) and computer vision usages. The evolution on emotion's studies allowed to characterize the basic emotions and confirmed that the facial expressions for each emotion are common for all human being. It made possible the development of affective computing, which utilizes the computer vision to create a better interaction between AI and humans. AI and computer vision are already being used on the automotive industry in several areas, but its usage for the personal security in vehicles is very limited or nil. This work proposes a new approach using computer vision, affective computing and artificial intelligence to recognize the emotions through facial expressions in order to identify an express kidnapping situation and allow the vehicle to ask for help and bring the possibility to the driver to have support during this moment of vulnerability. To validate the proposal, a system capable to capture and process images from the interior of the vehicle to recognize the occupant's emotions was integrated to the vehicle using AI developed in Python. Once the express kidnapping condition is identified, the system sends a help message without requiring any action from the victim. A MVP (Minimum Viable Prototype) methodology was used to select the *python* models and to speed up the concept validation. Initial tests result for facial recognition achieved 99% accuracy and 53% on the emotions recognition using facial expressions. These results during the tests triggered the alert message indicating a risky situation in the vehicle without any human intervention, as it was designed to do. The proposed system increases vehicle security, add value to the product, create new business opportunities and contribute for public safety.

Keywords: Facial emotions recognition, Vehicle security, Computer Vision, Artificial intelligence, Express kidnapping.

contents

1 INTRODUCTION

All human beings have needs, motivations and aspirations which affect their daily activities and decisions. According to Abraham Maslow, who developed a concept about the hierarchy of the human needs (Maslow's Pyramid), safety and security are the most important thing to an individual after meets his physiological needs.

The definition of security according to the Oxford American Dictionary is: 1. secure condition or feeling; and Secure means: 2. Untroubled by danger or fear.

Considering these definitions, individuals in Brazil are getting their "secure condition" and the "untroubled by danger or fear" feeling reduced year over year due to the reality in the country caused by grown urban violence indicators. The situation is alarming to the point that Brazil reached in 2014 a metric of 1 vehicle stolen per minute (AMÂNCIO, 2017). Also, according to the Social Progress Imperative (2020), the country was ranked in 2018 as the 11th least safe country in the world. Another increasing indicator is the number of express kidnappings. The number of express kidnappings in Pernambuco, between 2017 and 2018, increased 41% from 122 to 171 cases (GUERRA, 2019). In São Paulo, from January 2017 to April 2017, 129 caseswere registered, which represents a 30% increase compared to the same period in the previous year (G1, 2017), reaching 1 registered case per day in 2018 (FALA BRASIL, 2020).

In this context, considering the importance of security for the human, following Maslow's pyramid theory, and the safety issue in Brazil, individuals will always be looking for alternatives and any solution in this field will be relevant for human well-being.

At the same time, the studies on Human Machine Interaction (HMI) have progressed in the last decades making these interactions easier and faster. It also increased alternatives to provide input to machines beyond the traditional keyboard and mouse, like touch screen, microphone, camera etc. HMI moved to the next level and supported machine learning development. A good example is

Computer Vision (CV), in which the machine can get the dada from the camera, interpret it, make a decision and improve the HMI (DOMINGOS, 2017).

CV has already been studied and applied in the security area through facial recognition and has become an important tool for public safety (SILVA JÚNIOR, 2010). It is also being applied in cities in Brazil to locate fugitives, by associating the databases of arrest warrants with the infrastructure of video monitoring centers (ALVES, 2020).

Human emotions have also been studied since the 19^{th} century, when Darwin made the first observations on the anatomy of emotions. These studies supported the development, in recent decades, of a coding system for human facial expressions. The system allows the identification of basic emotions through facial muscle movements regardless of race, gender and age of the person (EKMAN *et al*., 1987). The encoding of basic emotions opens up new possibilities for their use in different areas of knowledge.

Affective Computing (AC) is a sub-area of AI that addresses the ability of computers to understand the emotions to improve interaction with people and mainly increase their decision-making capacity (PICARD, 2000). AC also uses CV for the emotions recognition and has already been applied in several areas, such as in health, to identify levels of pain in patients (VIRREY *et al*., 2019), in vehicles to assess safety risks, according to the driver's driving conditions (KOWALCZUK, 2015), among others.

Vehicles are designed to be safe for their occupants as well as pedestrians in the event of a collision. More and more vehicles are equipped with devices that help to avoid these collisions or reduce their effects. This evolution in vehicle safety levels has called attention from drivers and it already affects decision to purchase a vehicle. However, there are still not many advances to help vehicle occupants and users in the face of risks related to security. Considering the arrival of 5G and smart and connected cars, the use of a Vehicle Digital Security Platform brings a proposal to close this gap (OLIVEIRA, LEPIKSON, 2020).

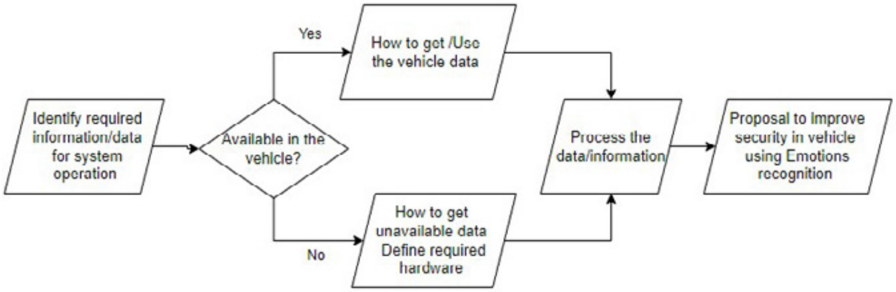
Given this scenario, the need to find solutions to improve individual security in Brazil is evident. Thus, meeting one of these basic needs, the Vehicle Digital Security Platform proposes that the vehicle uses data from smart cities and from the internet of things to improve security of its users (OLIVEIRA, 2021). The platform aims to act in situations of express kidnapping, vehicle theft (including helping in the recovery of stolen vehicles), fleet control and identification of the criminals. Recognition of faces, emotions, objects and voices are used to identify the risk of a situation. This work addresses one of the elements of the platform that uses emotion recognition, through facial expressions, in an express kidnapping situation to give the vehicle an active role in decision-making and in helping victims who are unable to act at the time of the occurrence.

2 THE CONCEPT

The concept for the vehicle security platform combines existing technologies into the automotive environment. MVP (Minimum Viable Product) was selected to have a continuous progress in development, optimized project costs and time without losing sight of the main objective. The hardware selected for this project were defined only by their functions to validate the concept and do not necessarily represent the hardware that will eventually be used in vehicle production. In this way, it was possible to assemble several MVPs according to the function being evaluated.

An important premise to achieve the expected objective is that the vehicle is connected to an internet network, so that the vehicle sends alerts in case of detection of an express kidnapping situation. As a new approach to the use of emotion recognition to improve security for vehicle users, it is important to identify the required information for the proposal feasibility, which of them are already available in the vehicle, which will need to be generated, how they will be processed and if any additional hardware is needed (Figure 1).

Figure 1 – Required Data Flowchart



Source: Elaborated by the authors.

2.1 Digital Systems Embedded in Vehicles

Vehicle technologies are evolving, and more and more sensors are added to them, which generates much more data during their regular operation. This data travels on the vehicle's CAN network (Controller Area Network) so that each module can access the information it needs for its operation. The CAN network will be the way to integrate the proposed system with the vehicle and take advantage of the data already available on the network for its operation. Three pieces of information available on the CAN network will be essential for the system: door opening indication, vehicle speed and cellphone pairing. The first piece of information will be the trigger for the system to start working. The second will indicate whether the vehicle is stationary or moving. The third will allow the sending of risk alerts through the cellphone. Table 1 below, indicates the data that will be used by the system and its availability on the vehicle's CAN network.

Table 1 – Data Available on the CAN Network Required by the System

Input/ output Data	Hardware	Available	Where
Vehicle Speed	Speed Sensor	Yes	CAN Network
Unlock / Open the doors	Door Open Sensor	Yes	CAN Network
Vehicle interior images (Users)	Camera	No	
Faces Recognition	Data Process Unit	No	
Emotions Recognition	Data Process Unit	No	
Internet connection	Vehicle Moden/ Celphone (Bluetooth / Cable)	Yes	CAN Network

Source: Elaborated by the authors.

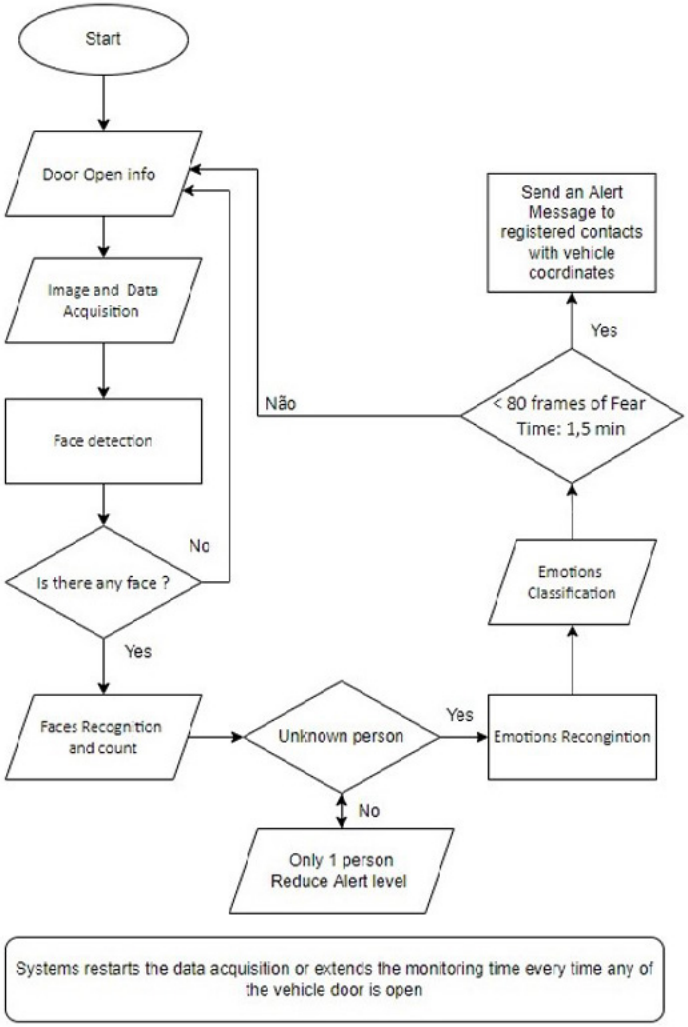
2.2 Emotion Recognition for Vehicle Users Security

To use emotions recognition for vehicles users' security it is important to identify the information and data that will be used in its development, therefore, it is necessary to understand the conditions of the vehicle at the time of the express kidnapping. According to the *modus operandi* used as a reference, 94% of the occurrences. happen with the vehicle stopped (AZEVEDO, 2015), which means, vehicle speed is zero. It is also noted that soon after the approaches, one or more doors are unlocked and/or opened, for the entrance of the driver/users and, also of the kidnappers. Opening and unlocking the doors is also information available in the vehicle. This information can be used as input to start a routine using Computer Vision.

Once the routine has started (Figure 2), a camera located inside the vehicle starts the detection of faces, analyzes the expressions and consequently identifies who is in the car, if there is an unknown person, if the users are afraid, using as a reference the models of facial expressions of the basic emotions and Affective Computing. With the processing of this information and the confirmation of an express kidnapping situation, or risk situation for the user, the vehicle, without any interference of the user/driver, issues an alert of the situation in almost real time to contacts indicated by the user and/or to the authorities.

For the proposed algorithm development, the language adopted was *Python*, a high-level, object-oriented and open-source language, being chosen due to its easy integration and fast development. Also, there are already several proposals and studies using artificial intelligence models to execute these tasks. Some pre-trained models were evaluated during the different MVPs to assess the model's performance and define which one will be used in the project.

Figure 2 – Emotions Recognition Algorithm Flowchart



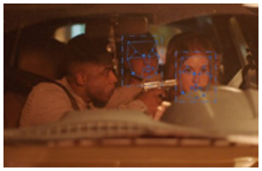
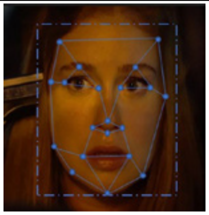
Source: Elaborated by the authors.

The film *Sequestro Relâmpago* (Express Kidnapping, 2018) was used to illustrate a risky situation and demonstrate how the proposal would work according to the sequence of facts referenced above.

The operational stages of the project are indicated in Table 2, with the input data for each stage and the hardware needed. In events 1 and 2, the necessary information is the vehicle speed and the indication of unlocking or opening the doors.

For events 3 and 4, the area of vision computing and affective computing comes into scene, in which image capture is necessary, that is, a camera is needed inside the vehicle (not yet part of the standard accessories of most production vehicles). Still in event 4, the image processing will take place and therefore a processor is necessary to identify the faces inside the vehicle, recognize the user and the emotions of the occupants. The fifth and final event consists of two activities: deciding, based on learning from the analysis of previous events, whether the user is in a risky situation, or express kidnapping. In case of confirmation, the system connects to the network and issues alerts to the authorities or contacts pre-registered by the user.

Table 2 – Illustration of Express Kidnapping identification using Emotions Recognition

		User approached by the criminal when arriving or picking up the vehicle. Vehicle stopped
		Unlocking or Opening the Door.
		
	!!! Panic !!!	Emotions Identification using facial expressions (Fear, tension and panic).
 	Security Risk Confirmed	Sending alerts to the Police and/or people previously registered in the system

Source: Elaborated by the authors. The images depicted are from the movie *Express Kidnapping* (2018).

3 RESULTS AND DISCUSSION

Once the concepts and architecture of the system were defined, the development of the experimental part of the project evolved in three stages, called MVPs, which are described below.

3.1 MVP1

MVP1 was designed for a quick validation of the face detection algorithms, without considering the implications of the positioning of the internal camera. The proposal hardware used was a SAMSUNG laptop, with an Intel Core i5 processor, 9300H, 4.2GHz clock, 4GB NVIDIA GeForce GTX1650 dedicated GPU, 240GB SATA SSD, 8GB of RAM and an integrated 1MP Webcam with 720p resolution in a Ford Ka vehicle. As the objectives of MVP1 was the initial analysis of the algorithms and selection of AI models for the system, it was not connected to the vehicle CAN. An Arduino UNO was integrated into the hardware to emulate the vehicle information that would obtain from the CAN network, like the opening door signal. This first prototype was also not intended to send alert messages. This strategy allowed the start of software tests without having to wait for the system to be integrated with the vehicle's CAN network. Based on the tests results, Mediapipe was the model selected to be used for face recognition, because it could process more frames per second when compared to the FER model (Table 3).

Table 3 – MVP1 Face Detection Model Validation Test Data

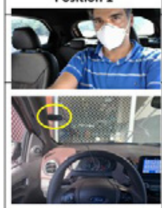
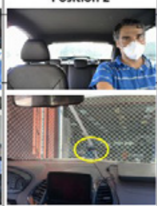
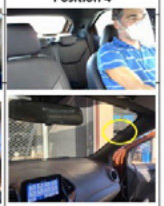
	Accuracy (%)	Proccessing Time (Fps)
Mediapipe	100	29,17
FER	100	4,44

Source: Elaborated by the authors.

3.2 MVP2

MVP2's objective was to confirm the face recognition model, define the model to be used on the emotion's recognition and define a position for the internal camera inside the vehicle. The hardware was the same used in the MVP1 just changing the camera. It used an external camera Logitech C270 instead of the laptop one. The first set of tests were designed to define the internal camera position. Four camera positions have been evaluated (Figure 3). The camera positioning must be set to have a wide field of view of the vehicle interior, to increase the system's ability to detect people in all vehicle positions. It must also be observed that the movements derived from driving the vehicle should not obstruct the camera's field of view.

Figure 3 – Internal Camera Position Evaluation

	Position 1	Position 2	Position 3	Position 4
				
Clear View - Driver face Recognition	✓	✓	×	✓
Clear View – Passengers - front & Rear seat	×	✓	×	×

Source: Elaborated by the authors.

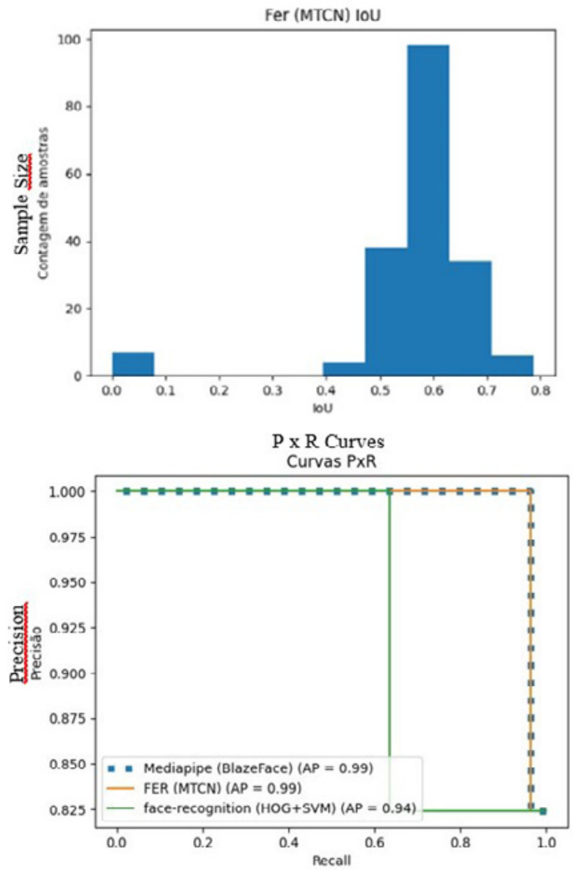
Based on the test results (Table 4 and Figure 4), locating the camera in position 2 meets the established criteria. On the Face recognition, after the tests, the Mediapipe confirmed to have the best performance comparing to other tested models. The criteria to select the model was accuracy, IoU (intersection of Union) and curve PxR (Precision vs Recall).

Table 4 – MVP 2 – Face Recognition Test Results

	Accuracy (%)	Proccessing Time (Fps)
Mediapipe	99	28,9
Fer	99	6,3
Face-recognition	99	4,8

Source: Elaborated by the authors.

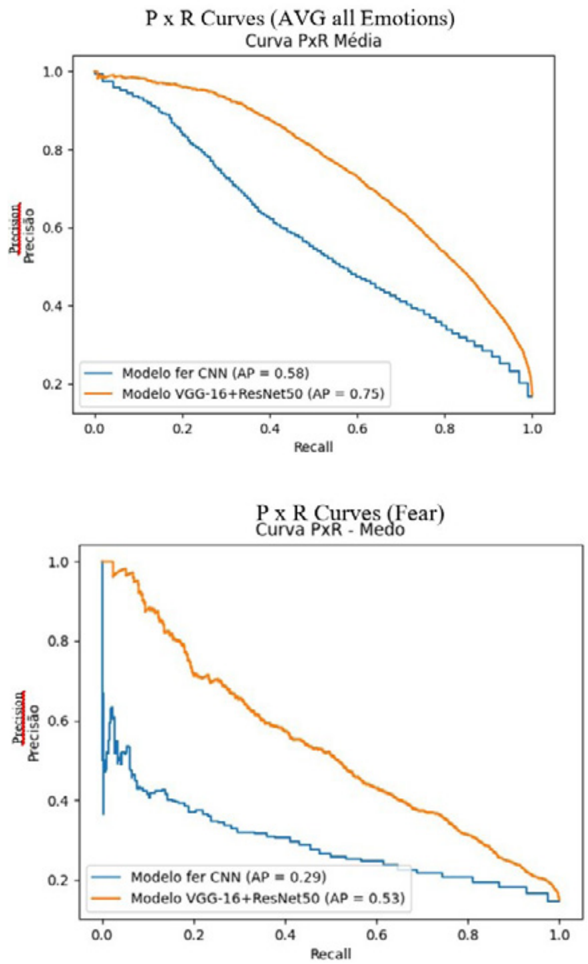
Figure 4 – MVP 2 – Face Recognition Test Results



Source: Elaborated by the authors.

The criteria used to select the emotion's detection model were the accuracy, Recall, Precision, F1 Score, PxR curve and the confusion matrix (Figure 5 and Table 5).

Figure 5 – Emotions' Recognition PxR curves



Source: Elaborated by the authors.

Table 5 – Emotions Recognition Model VGG-16+ResNet50 Performance Results

Basic Emotions	Confusion Matrix (%)					
	Anger	Fear	Happy	Sad	Surprise	Neutral
Anger	69	11	2	8	3	5
Fear	5	53	1	9	7	3
Happy	3	3	88	3	3	6
Sad	10	16	1	63	2	11
Surprise	2	8	3	2	83	1
Neutral	11	9	5	15	2	74

Basic Emotions	Acuracy	*Recall*	Precision	F1-*Score*
Anger	68	59	62	60
Fear	53	54	41	47
Happy	87	86	85	85
Sad	62	53	54	53
Surprise	83	78	80	79
Neutral	74	59	68	63

Source: Elaborated by the authors.

Based on the results, the model *VGG-16+ResNet50*[3] presented a better performance compared to the other models. Even though it presented a 53% accuracy for fear, there are models that when trained with good datasets already reach an accuracy of 82.58% to detect fear (YANG, 2018).

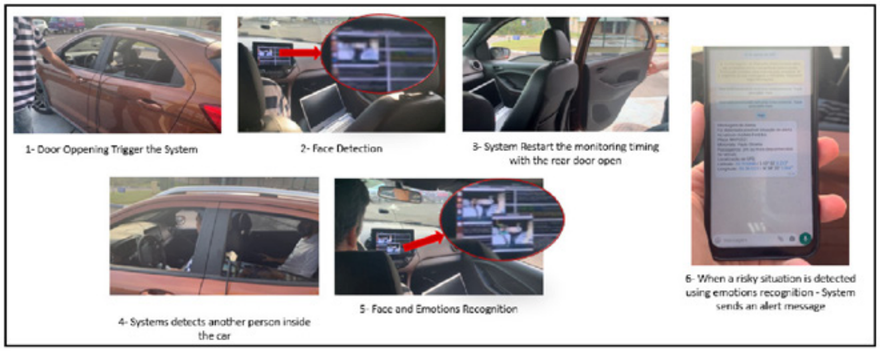
3.2 MVP3 or Concept Proof Test

The MVP3 or proof of concept test was designed to represent an express kidnapping approach situation where the victim is accosted shortly after entering the vehicle (Figure 6). The approach is made by opening another vehi-

3 Available at https://github.com/BishalLakha/Facial-Expression-Recognition-with-Keras

cle door to force the system to restart the internal monitoring, detection and identification of the vehicle occupants and recognition of driver emotions. The hardware utilized in this test was the same used in the MVP2.

Figure 6 – MVP3 Test Summary



Source: Elaborated by the authors.

The system works offline during the entire time when is identifying people, capturing emotions. It only works online to send the alert messages.

As already indicated, in the reference used on the express kidnapping *modus operandi*, 94% of the situations start with the vehicle still, which makes the doors opening an excellent signal to the trigger the system. However this brings a limitation for cases in which the express kidnapping is announced after a while with the vehicle in motion. In these cases, the driver will not express fear in the moment in which the system will be monitoring the emotions. These cases mostly occur with taxi drivers and/or app drivers, since the crime can be announced after a ride has started.

4 CONCLUSIONS

The new approach proposed to support drivers in cases of express kidnapping using emotions recognition for smart vehicles makes decisions,asks for help, is technologically feasible and, as already mentioned, closes a gap in vehicle security studies. The proposed system was able to use the data available on the vehicle's CAN network, together with the images acquired from the vehicle occupants. It could detect the presence of people inside the vehicle through facial identification with 99% accuracy. As for the detection of emotions, the system identified fear with 53% accuracy and triggered an alert message about the risky situation for the driver. Fear detection should be explored to improve accuracy in future works, since other research already reached 82.58% of accuracy for the detection of fear.

This proposal is very relevant for people, since safety is one of their fundamental needs, and for bringing help for drivers in a vulnerability moment. The proposal also values the automotive sector and automakers, by bringing more features to the product and a differentiated experience to the vehicle user through technology. It also opens the door to new business models, such as partnerships with public security agencies, security companies and insurance companies, generating new opportunities. Finally, a potential improvement in public security by inhibiting the practice of express kidnappings and/or increasing the number of cases with a positive outcome benefiting society.

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4

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Enhancement of mechanical properties of polypropylene nanocomposites with the incorporation of graphene in lightweight automotive parts

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ABSTRACT

The automotive industry is approaching a transformation into electrified vehicles. In this scenario, weight reduction through novel nanocomposites materials is one of the most promising solutions to improve energy efficiency of cars and trucks. Graphene is at the center of an ever-growing academic and industrial interest because it can produce substantial improvement in mechanical properties at low filler content, making it a potential candidate for nanocomposites polymeric materials. However, many challenges remain on the functionalization and the ability to synthesize graphene nanoparticles. This review presents the state of art involved between graphene and the polypropylene matrix. The significant improvement provided by this nanomaterial to polymer and hybrid compounds shall be evaluated due to its intrinsically high mechanical properties. Nonetheless, there is still a gap in the scientific research of properties that have not yet been achieved in terms of tensile strength and modulus, that are currently met by the polypropylene-glass fiber (PP/GF) nanocomposites, which are commonly used by automotive industry. The major challenge identified as the border of knowledge is how to avoid the significant weight drawback, due to the different GF density. Finally, the results were gathered to demonstrate this gap, the existing formulations and the technological challenges faced by the scientific community.

Keywords: graphene, graphene oxide, nanocomposites, polypropylene.

1 INTRODUCTION

The automotive industry is on the verge of a transformation into electrified vehicles and amongst many solutions to improve energy efficiency of cars and trucks, the lightweight materials offer great potential for increasing vehicle efficiency, as it requires less energy to accelerate a lighter object than a heavier one (ELMARAKBI; AZOTI, 2018). The application of traditional materials, like steel, is migrating to lighter metallic alternatives like Aluminum and the same transition is also happening to polymer composites (GONÇALVES *et al*., 2022). In this context, the polymer nanocomposites are of special interest as it enhances the performance of the base material, once the nano-sized inclusions in polymer matrices improve the structural and functional properties which lead to the design of novel materials (POTTS *et al*., 2011).

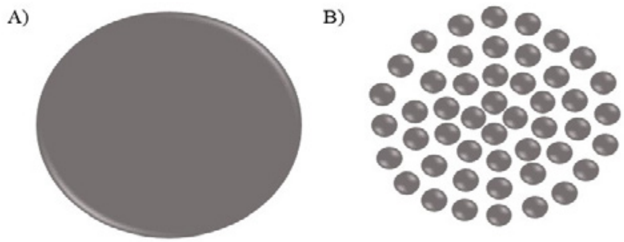
To be classified as nanomaterial, the material should present nanofillers with at least one dimension in the size ranging from 1nm to 100nm, according to the International Organization for Standardization (ISO) definition (ISO, 2010). Depending on their morphology, nanofillers can be classified as i) isodimensional (3D, nanoparticles with a characteristic dimension less than 100 nm), ii) bi-dimensional (2D, nanofibers or nanotubes with a diameter less than 100 nm), or iii) mono-dimensional (1D, lamellar nanoplatelets with a thickness less than 1 nm) (PEGORETTI *et al*., 2016).

Nanosized particles have a large surface area that enables more contact with surrounding materials and thus more reactivity leading to a stronger material with lighter weight (Figure 1). This dispersed phase is responsible for the enhancement of properties in the polymers, which in turn is directly dependent on the homogeneity of inclusion in the matrix, due to the molecular interactions that influence the final properties of the material (ABBASI *et al*., 2020).

Among the polymer matrices most used in the automotive sector, polypropylene (PP) is extensively used in the plastic and polymer industry due to its low manufacturing cost, full recyclability, and low weight. When PP is used at room temperature, it exhibits particularly good mechanical, thermal, and physical properties. However, it also has certain weaknesses, such as low modulus and strength, limiting its applications, making it a promising candidate for nanoreinforcement studies (DANESHPAYEH *et al*., 2021).

Thermoplastic polymers, such as PP, are reinforced by physically ordered domains, which are not chemically cross-linked so that they can be processed, molded, melted, and recycled. It is of special interest for the automotive industry to improve the mechanical properties of PP to use this polymer in structural applications. The nanometric inclusions of particles will play a role of heterogeneous nucleation in this matrix, increasing the degree of crystallinity or generating a change in the structure of the crystal type, improving the rigidity of the material (LIANG *et al*., 2016; PEGORETTI *et al*., 2016; TARANI *et al*., 2019; ZHANG *et al*., 2017). The filler particles are dispersed in the matrix. The more uniformly/homogeneously it is dispersed, the more the stiffness tendency is increased, making it directly proportional to the number of inclusions (LIANG *et al*., 2016).

Figure 1 – (A) Conventional macroparticle and (B) nanoparticle with increased surface area



Source: Adapted from ABBASI *et al*., 2020.

Amongst the various existing nanomaterials available for use, there are numerous studies using carbon nanomaterials, as they have demonstrated a significant increase in the properties of pure polymers (DANESHPAYEH *et al*., 2021). Graphene is a kind of nanoparticle that has attracted enormous attention in polymer nanocomposites, due to its high Young's modulus, high fracture strength, making it a promise candidate to act as filler for the PP (WANG *et al*., 2022).

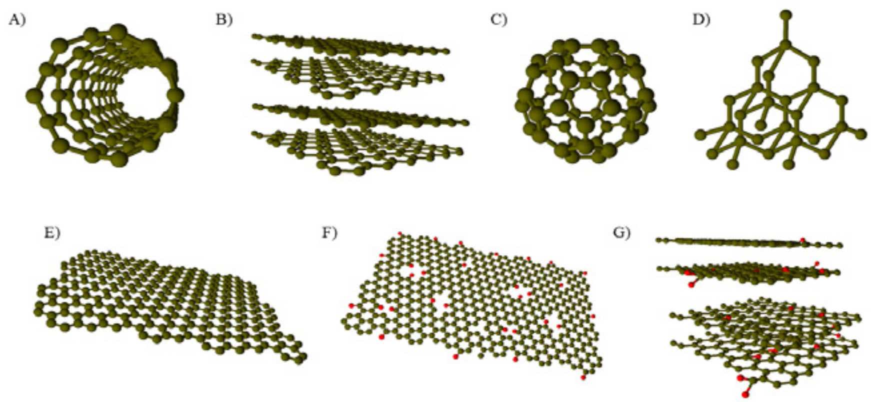
1.1 The Graphene

Graphene is one of the allotropes of carbon that include graphite, carbon black, carbon nanotubes, carbon fibers, activated carbons, porous carbons, diamond, and fullerenes. It is a flat monolayer of carbon atoms compacted in a two-dimensional grid with a thickness of only one atom, joined in a crystal structure with its atoms arranged hexagonally forming a lattice in a two-dimensional (2D) plane, where each carbon atom represents a carbon-carbon bond length of 0.142 nm (COOPER *et al*., 2012; KAULING *et al*., 2018; SINGH *et al*., 2011).

Graphene is one of the strongest materials ever discovered, presenting a set of exceptional properties such as its ultimate strength, 100 times greater than a steel film at the same thickness, Young's modulus of 1TPa, tensile strength of 130 GPa, thermal conductivity of 3,000 Wm-1 K-1 (GEIM; NOVOSELOV, 2009) and a surface area of 2,630 m 2 g -1 (theoretical limit) considered extremely high (SINGH *et al*., 2011).

Figure 2 presents some allotropes of carbon, such as nanoreinforcement ranging from diamond and graphite, carbon nanotubes (1D), single-layer graphene (2D), thin-layer graphene, and graphene nanoplates (GNP) along with functionalized graphene (FG) and edge-functionalized graphene nanoplates (MFG) (BURK; GLIEM; MÜLHAUPT, 2019).

Figure 2 – Carbon allotropes as nanoreinforcement. a) carbon nanotubes b) graphite c) fullerene d) diamond e) single-layer graphene f) functionalized graphene g) edge-functionalized graphene nanoplates



Source: Elaborated by the authors.

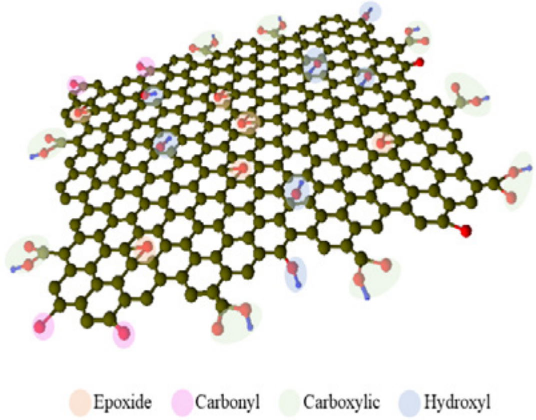
Graphene has several classifications in the literature, the most popular being: Very few layers graphene (vFLG), one to three layers; Few layers graphene (FLG), two to five layers; Multilayer graphene (MLG), two to ten layers; Graphene Nanoplates (GNP), more than ten layers. Furthermore, graphene can assume different forms: Graphene oxide (GO) and reduced graphene oxide (rGO), both with multilayer structure but with differences in degree oxidation (KAULING *et al*., 2018).

Graphene with few layers of thickness ends up offering greater potential for adding properties and consequently a greater scope for applications, due to reducing agglomerates in the mixing process with the substrate (polymer matrix). The greater the number of graphene layers, the greater the difficulty of a homogeneous dispersion, but even with few layers in polar polymer matrices the difficulty exists, as the hexagonal rings of graphene have strong bonds between them, due to the attraction caused by the Van der Waals forces. The layers tend to pile up, thus favoring agglomeration, making it difficult to achieve homogeneity in the matrices (MD SAID *et al*., 2021). Graphene oxide (GO) is unlike pure graphene, as it contains functional groups with oxygen that functionalize its structure, facilitating this interaction in several applications, making it favorable due to its modified surface form (DANESHPAYEH *et al*., 2021; MD SAID *et al*., 2021). Thus, graphene oxide can be easily inserted into the polymer matrix, due to the presence of functional groups that help in the dispersion.

1.2 Graphene oxide

Graphene Oxide (GO) and pure graphene do not differ structurally, both are composed of non-oxidized aromatic regions randomly distributed in six-member aliphatic regions, the difference is in the oxidation, which assigns a 3:1 carbon-oxygen ratio in GO. This distribution of functional groups makes it have a structural configuration formed by layers of parallel two-dimensional pseudo lamellae, causing the binding of polar groups to its surface such as: hydroxyl, epoxide, ether, and carboxylate, functional groups that have a high affinity for water molecules, making GO hydrophilic and allowing its dissolution in water and other solvents (YANG *et al*., 2013). Thus, GO undergoes chemical modifications resulting in a material with different chemical and physical properties, but also capable of generating significant property improvements in various applications (BOTAS *et al*., 2012; EDA; CHHOWALLA, 2010). Figure 3 depicts the structure of the GO and how different functional groups are distributed along its structure.

Figure 3 – Structure of Graphene Oxide



Source: Elaborated by the authors.

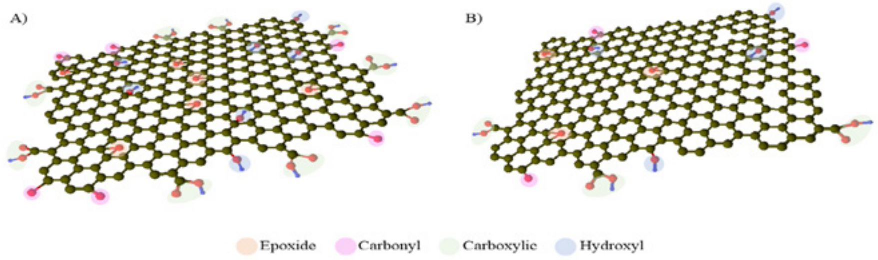
Graphene oxide can be easily inserted into hydrophilic polymers to obtain intercalated nanocomposites, as it is used as a compatibilizer for mixtures of immiscible polymers (YANG *et al*., 2013).

Several oxygenated functional groups are added to the material structure, commonly performed by the Hummers and Offeman method, which involves a mixture of sodium nitrate, potassium permanganate and concentrated sulfuric acid (EDA; CHHOWALLA, 2010). Resulting in a lower electrical conductivity and to restore its electrical conductivity, OG can be partially reduced by a reaction with reducing agents to synthesize reduced graphene oxide (rGO) and extract oxygen functional groups (ARADHANA; MOHANTY; NAYAK, 2018).

1.3 Reduced graphene oxide

The reduced graphene oxide (rGO) is another form of GO with a lower oxygen content. It will not have all the characteristics of pure graphene, as the reduction performed will not completely reduce the oxygenated functional groups, presenting substantially different properties (EDA; CHHOWALLA, 2010; KOL; KENIG; NAVEH, 2020). The two are often confused, but the structural differences can be significant. Figure 4 demonstrates the functional groups dispersed in the structures, exemplifying the structural difference between GO and rGO.

Figure 4 – Structural difference between A) GO and B) rGO



Source: Elaborated by the authors.

The reduction process can be achieved through three pathways: chemical, thermal, or electrochemical reduction. Most strong reductants have a mild to strong reactivity with water, whereas hydrazine monohydrate reductants do not, making it an attractive option for reducing aqueous dispersions of graphene oxide (GAO *et al*., 2009). Chemical exfoliation of graphite via oxidation leads to covalent functionalization, which drastically alters the structure of graphene, therefore, it is inappropriate to refer to GO or reduced GO simply as graphene, as their properties are different (EDA; CHHOWALLA, 2010).

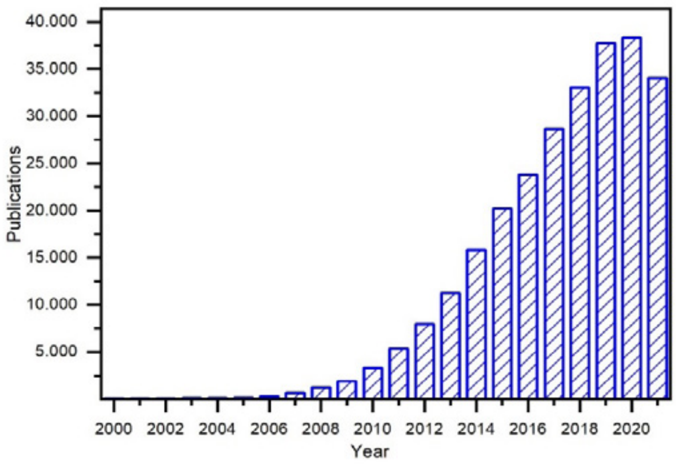
Although GNP and GO share the same excellent characteristics as graphene, they differ in chemical structure, with GO composed of sp3 and sp2 hybridized carbon (C) atoms, covalently bonded with hydroxyl, epoxy, carbonyl, and carboxyl groups, while GNP is dominated by sp2 hybridized carbon, characterized by strong π–π stacking (EZENKWA; HASSAN; SAMSUDIN, 2022).

Even though the term graphene is already widely used, it is known that to develop polymeric composites, it is necessary to have a good dispersion of graphene, which is one of the critical factors in the production of composites. When added to the matrix, nanofillers tend to agglomerate, negatively affecting the final properties of the composite. Thus, it is worth mentioning that graphene must be functionalized to be incorporated into a polymer matrix, especially when dealing with large volume production. In the next section, we will present how we found the theoretical basis of recent technological developments discussed below for the different forms of graphene, concepts and theories addressed for a better understanding.

2 METHODOLOGY

The methodology of the present study was based on research on the platforms Science Direct, Scopus and Web of Science, realizing that the number of publications has grown exponentially since January 2000. Checking the data collection of the Web of Science, between January 2000 and December 2021, a total of 264,405 publications were made globally. When we use the keyword "graphene", the results drop 1.60%, between 2020 and 2021. These data are presented in Figure 5.

Figure 5 – Publication trend from 2000 to 2021 according to Web Of Science



Source: Elaborated by the authors.

In addition, the percentage of publications drops sharply when the keyword "polypropylene" is added. It represents 0.5% of the total, that is a drop of 95%, totaling 1,361 thousand articles. These data demonstrate that the area of nanocomposites with graphene and polypropylene as a matrix is a field for exploration and development of new technologies. The results were further refined to assess the main areas of research in which these studies are being published, namely: Polymer Science (486), Materials Science Multidisciplinary (390), Chemistry Physical (191), Materials Science Composites (189), Chemistry Multidisciplinary (188), Engineering Chemical (141), Nanoscience Nanotechnology (139), among others, considering that the articles serve more than a specific area. Even so, as it is a thermoplastic commodity, 60% of these developments address mechanical properties.

The screening and labeling tool for large collection of textual data was the library AS Review LAB in Python, an open-source machine learning based, generating the following data: 50% of these studies used graphene nanoplates, 40% graphene oxide and 10% used reduced graphene oxide in their scientific research.

3 RESULTS AND DISCUSSION

The addition of reinforcing fillers improves the mechanical properties, influenced by the homogeneous dispersion and strong interaction between layers of the filler and the matrix (MD SAID *et al*., 2021). The study by Jun *et al*. (2018) addressed the influence of the type of graphene nanoplates (GNPs) on the mechanical properties of nanocomposites with PP, with different number of layers. Tensile Strength and Young`s module improved as the fraction of GNPs in the matrix increased, except when the nanoreinforcement with a diameter greater than 150 μm. This can be attributed to the interface between the polymer matrix and the nanofiller, since the morphological analysis showed an agglomeration, with the particles changed from plates to spheres when filled with a larger diameter. Therefore, the smaller the filler diameter, the greater the reinforcement efficiency obtained in the matrix (JUN *et al*., 2018).

Table 1 – Representation of the study Jun *et al*. (2018)

<table>
<tr><th>Thickness (nm) | Surface area (m2/g)</th><th>Graphene (vol%)</th><th>Method of preparation</th><th>Melt Flow Index PP (g/ 10 min)</th><th>Tensile modulus (Mpa)</th><th>Tensile strength (Mpa)</th><th>Straub at break</th></tr>
<tr><td>PP</td><td>0</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="3">~15 | 50-80</td><td>1,3</td><td rowspan="12">Melt</td><td rowspan="12">19,4</td><td>540</td><td>34,4</td><td>17</td></tr>
<tr><td>4,4</td><td>610</td><td>34,5</td><td>12</td></tr>
<tr><td>9,3</td><td>660</td><td>34,3</td><td>7</td></tr>
<tr><td rowspan="3">~6-8 | 120-150</td><td>2,1</td><td>574</td><td>35,7</td><td>13</td></tr>
<tr><td>4,4</td><td>563</td><td>35,3</td><td>10</td></tr>
<tr><td>9,3</td><td>785</td><td>41,6</td><td>7</td></tr>
<tr><td rowspan="3">~6-8 | 120-150</td><td>2,1</td><td>615</td><td>37,5</td><td>18</td></tr>
<tr><td>4,4</td><td>698</td><td>39,6</td><td>10</td></tr>
<tr><td>9,3</td><td>817</td><td>43,6</td><td>8</td></tr>
<tr><td rowspan="3">~5 | ~300</td><td>2,1</td><td>659</td><td>40.9</td><td>21</td></tr>
<tr><td>4,4</td><td>727</td><td>43.8</td><td>14</td></tr>
<tr><td>9,3</td><td>775</td><td>46.3</td><td>8</td></tr>
</table>

Source: Adapted from Jun *et al*. (2018).

In the evaluation of some of the formulations of this study, presented in Table 1, the GNPs of smaller diameter and with addition 2.1% vol obtained a tensile strength superior to 40 MPa, about 17.5% above the pure PP used (34.8 MPa) and a 28.2% increase in traction modulus. We can see that as the reinforcement content in the matrix increases, the elongation at break is lower, which may be related to the degree of dispersion and agglomeration of GNPs within the matrix, due to the crosslinking caused by the reinforcement, since the affinity between PP and GNPs does not change with their size (JUN *et al*., 2018).

The data correlates with the properties increase as the surface area grows, compared to different areas with the same addition of graphene, as shown in the study by Jun *et al*. (2018), because of greater interfacial adhesion between the filler and the matrix. The addition of 4.4% of GNP showed a difference in Young's modulus with an increase of approximately 19.2%, while the yield strength and fracture showed a slight increase and the elongation at break decreased with increasing fractions of GNPs. This happens because the addition of GNP increased the crystallinity of the polymer, significantly improving the yield strength and Young's modulus of the virgin polymer (ASHENAI GHASEMI; GHORBANI; GHASEMI, 2021). These data corroborate the studies by Liang *et al*. (2016), who also obtained this behavior in their experiments, as shown in Table 2.

Table 2 – Results by Liang *et al*. (2016)

Thickness (nm) | Surface area (m2/g)	Graphene (wt%)	Method of preparation	Melt Flow Index PP (g/ 10 min)	Tensile modulus (Gpa)	Tensile strength (Mpa)	Tensile elongation at break
PP	0			1.25	26	25
	0,1			1.6	27	24
5-25 | 40-60	0,3			2.1	28	17
	0,5			2.3	26	12
	0,1			1.4	28	21
3.4-7 | 150-200	0,3	Melt	10	1.75	30	16
	0,5			1.9	30	12
	0,1			1.8	29	24
< 5 | > 200	0,3			2.2	30	17
	0,5			2.5	30	14

Source: Adapted from Liang *et al*. (2016).

The results of the study by Liang *et al*. (2016) corroborate the results of Jun *et al*. (2018), that shows the improvement of Young's modulus, yield strength and tensile fracture and indicates that the stiffening effect that GNPs apply to the PP matrix is significant. Furthermore, they demonstrated that the tensile modulus of pure PP, with 1.25 GPa, reached up to 100% increase (2.5 GPa), with the use of 0.5% of thinner GNP (5 nm and > 200 m2/g) and thicker GNP reached a tensile modulus close to 2.3 GPa, but there was no increase in tension at rupture. It's noticed that the stress at break did not change significantly, and the elongation decreases with increasing weight fraction of GNP.

As demonstrated by the studies above, the addition of GNP improves a range of properties of the polymer matrix. This performance is dependent on the size of the GNP particle. The study by Liang *et al*. (2016) shows that small-sized GNPs should be incorporated when lightweight reinforced composites are considered for automotive parts.

A good dispersion of graphene in any polymeric matrix is a challenge, as it can influence the properties of the nanocomposites produced. Poor dispersion is caused by re-stacking of weak bonds at the interface and incompatibility between graphene and polymer matrices (AUMNATE *et al*., 2021).

The tensile strength results exhibited by GO-PP and RGO-PP are shown in Table 3. Both samples show a similar pattern of increase in tensile strength. However, rGO-PP samples showed higher tensile strength compared to GO-PP and pure PP, of approximately 88.5% and 72.5% respectively. This improvement in tensile strength was attributed to the increase in crystallinity, since in the RGO-PP and GO-PP samples with 2.5% increment, the degree of crystallinity was 13% and 10%, respectively, higher than PP pure (MD SAID *et al*., 2016). The crystallization and crystalline geometry of semi-crystallized polymers positively influence the mechanical and thermal properties of the polymeric nanocomposite, where the incorporation of inorganic fillers in semi-crystalline polymers acts as nucleating agents (TONG *et al*., 2015).

Table 3 – Results of mechanical properties, according to MD Said *et al*. (2016)

Loading (wt%)	Tensile Strength (MPa)		Young´s Modulus (MPa)		Elongation at Break (%)	
	GO-PP	RGO-PP	GO-PP	RGO-PP	GO-PP	RGO-PP
Neat PP	23.20		159.63		13.50	
0.5	24.48	23.84	238.48	378.81	7.76	6.84
1.0	29.92	30.26	306.23	403.88	7.46	6.72
1.5	32.70	40.01	317.46	414.16	5.50	5.47
2.0	35.51	42.57	375.13	428.01	5.10	4.04
2.5	40.02	43.74	400.42	461.45	4.24	3.46

Source: Adapted from MD Said *et al*. (2016).

The Young's Modulus increased with the insertion of rGO and GO, and the reduced graphene oxide presented higher values compared to the graphene oxide and pure PP. The highest Young's modulus of 461.45 and 400.42 MPa were obtained by rGO-PP and GO-PP, with an increase of 2.5%, resulting in an improvement of 189% and 150%, respectively, in relation to PP pure. Furthermore, the improvement in the Young's modulus value in both nanocomposites also pointed to the fact that both became more rigid, due to the increase in the degree of crystallinity with increasing loads in both nanocomposites. The elongation at break was reduced when compared to pure PP, for example, in the case of 0.5% non-reinforcements, the elongation was drastically reduced from the pure PP value to 42.5% and 49.3% for GO-PP and rGO-PP, respectively. These reduction patterns indicate that GO and rGO cause PP to lose toughness and become brittle.

The study by Castilho *et al*. (2020) addresses the influence of distinct types of embedded graphene nanofillers (GNP, GO and rGO) in terms of mechanical properties of nanocomposites with PP and the same number of layers. The addition of rGO to the polymer matrix increased the stiffness, as can be seen in Table 4. The Young's Modulus of rGO 0.75 increased by 51%, also increasing its elongation at break by 15% when compared to the pure polymer. In the tensile strength with incorporation of GO, it is noticed that there were no significant changes. The most promising results are with the incorporation of GNP and rGO, being associated with the degree of exfoliation of the graphene nanoplates, as mentioned above. Polymers reinforced with fillers, the elongation at break is reduced even at low concentrations of nanofillers, however we had an increase in rGO samples and in GO 0.75 (disregarded by the author).

Table 4 – Representation of the study Castilho *et al*. (2020)

Thickness (nm) | Surface area (m2/g)	Graphene (wt%)	Method of preparation	Melt Flow Index PP (g/ 10 min)	Tensile modulus (Gpa)	Tensile strength (Mpa)	Tensile elongation at break
PP	0			1,50	28.0	1524
	0,25			1,40	29,8	1516
GNP 3-12 nm | *	0,5			1,46	28.7	1327
	0,75			1,41	27.4	923
	0,25			1,39	28.7	1484
GO 3-12 nm | *	0,5	Melt	3	1,36	29.7	1224
	0,75			1,32	28.6	1606
	0,25			1,87	32.0	1430
rGO 3-12 nm | *	0,5			1,81	32.3	1537
	0,75			2,26	34.7	1755

Source: Adapted from Castilho *et al*. (2020).

The study demonstrated that rGO presented better mechanical properties due to its better dispersion and interfacial adhesion and presented a higher percentage of crystal linearity when compared to other applied nanofillers, since the reduction of GO was incomplete, with a 1% difference between groups, oxygenates between rGO and GO (CASTILHO *et al*., 2020).

4 CONCLUSIONS

The effect of the nanoreinforcement loading such as GNP, GO and rGO on tensile strength and Young's modulus as a function of the added graphene content demonstrates how far the literature has come in terms of values of mechanical properties.

This review showed a great potential to be explored. Especially the challenges in the polymeric composites synthesis, from the preparation to analysis focused on the physical-chemical characteristics of the structure. However, it is important to mention that decreasing the sheet thickness increases the efficiency of the reinforcement, the mechanical property being inversely proportional to the filler size. The result of this study is significant in the search for a better understanding of composites, as the processing methods and how the type of graphene affects the mechanical properties of the new material.

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Development of polypropylene composites reinforced with piassava fiber

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ABSTRACT

The technique of incorporating natural elements to develop engineering materials is increasingly in evidence, since specific properties can be potentialized. Natural fibers have attracted great attention from industries and researchers for the development of polymeric composites because they are ecologically correct, and consequently contribute to sustainable practices. Natural fibers, due to their abundance in nature, biodegradability and low cost not only expand the use of these materials, but also reduce dependence on petroleum-based products. Several industries have implemented sustainable technologies in their processes, in order to improve the balance between the environment and sustainable economic development. Natural fiber-based polymer composites have been widely used in automotive applications. This is due to its low weight, which leads to lower fuel consumption and reduced greenhouse gas (GHG) emissions. In addition to its corrosion resistance, design versatility and recycling. In this sense, one of the natural fibers that can be widely used in the production of polymeric composites is piassava fiber, which has 90% of its national production concentrated in the State of Bahia, and which today is used only for low to medium added value applications. Aiming to reach new applications for piassava fibers, this study has as an objective develop polypropylene (PP) polymer matrix composites reinforced with piassava fibers, using two types of additives. Being a compatibilizing agent, the maleic anhydride (MA) functionalized in polypropylene and the flow agent of commercial name Protack, in order to increase the degree of interaction/bonding between the polymer and the fiber. In this study, composites were prepared with a fixed percentage of 10% of piassava fibers and five different formulations (% w/w) of MA/Protack, they are, 3 / 0 (F1), 1.5 / 1.5 (F2), 3 / 3 (F3), 0 / 3 (F4), 0 / 0 (F5) and 1.5 / 1.5 (F6). The materials were processed by extrusion and molded in a hydraulic press to making the specimens. The composites were submitted to morphological analysis (Scanning Electron Microscopy – SEM), mechanical tests (tensile and flexural strength), physical tests (impact resistance and flow rate) and thermal analysis (thermogravimetry – TGA). The results showed that formulation 1 (F1), with the highest concentration of MA (3%), has the most promising results. Unlike formulation 4 (F4), with the highest concentration of Protack, which presented the lowest values of mechanical and impact resistance. From this study, it is concluded that composites reinforced with piassava fibers have properties with great potential for application in industry, in addition to the evident environmental and economic advantages.

Keywords: composites, polypropylene, piassava fiber, compatibilizing agent, flow agent.

1 INTRODUCTION

Currently, Brazil is the 4th largest producer of plastic waste in the world and recycles only 1% of the total of what is produced (BISPO, 2021). Therefore, it is of great interest to develop new alternatives to reduce the consumption of petroleum-based materials, preserving the environment and encouraging sustainability. As the world gets more concerned about environment preservation grows, the interest in the utilization of recycled and/or renewable raw material grows concurrently, with special highlight to natural fibers (DA SILVA *et al*., 2021).

With the technological advances of the last decades, use of composite materials is a reality in most diverse sectors of manufacture and industry, from the high-performance composites used by space and aeronautical sectors, to even the commonest ones, used in interior design of automobiles (DE OLIVEIRA FILHO *et al*., 2019; NETO *et al*., 2022). The automotive industry is under a growing volume of regulations, related to safety, emissions, recyclability and other aspects (DELGADO-AGUILAR *et al*., 2019). That is why, the use of natural fiber-reinforced polymers has caught the attention of automotive industry (CIPRIANO *et al*., 2019). Mainly due to their lower weight, which leads to lower fuel consumption and reduced greenhouse gas (GHG) emissions, in addition to its corrosion resistance, versatility and recycling properties.

The relevance of natural fibers (NFs) composites is usually associated with sustainable issues in which the recyclability and renewability are essential features. However, several other advantages support the use of NFs such as relatively high strength and high toughness as well as low density and lower cost of production when compared to synthetic fibers (BISPO *et al*., 2022; COSTA *et al*., 2020; DA FONSECA *et al*., 2021).

The piassava fiber (Attalea funifera Mart) is a natural lignocellulosic fiber extracted from several palm trees. This rigid fiber is extracted from a palm tree naturally grown in the Brazilian Atlantic rain forest (DA COSTA GARCIA FILHO et al., 2020). Piassava fibers have several traditional applications such as brooms, brushes, marine cordage and ropes, and roof for modest housing (CASTRO et al., 2020; CORREIA et al., 2019). The main advantages of piassava fibers include low specific gravity, easy handling, biodegradability, availability, thermal insulation, non-toxicity, among others (BORGES et al., 2017).

The mechanical properties of natural fiber reinforced polymer composite are the result of the chemical properties of the materials that form the composite and the interface properties at the fiber surface. The propagation of stress from matrix to fiber takes place at that interface and it is of much importance to identify these interfacial properties to better understand the composite behavior (DE OLIVEIRA FILHO *et al*., 2019).

One of the main problems that can occur in the production of composites with natural fibers is the deficiency in the fiber/matrix interface, which ends up reducing the mechanical properties of the material, due to the hydrophilic characteristics of the fibers and their incompatibility with the hydrophobic polymeric matrix (NETO *et al*., 2022). In many cases, chemical bonding occurs by the addition of coupling agents which are able to link with compatible groups present in both reinforcement and the matrix (FERREIRA *et al*., 2019). As for example, the maleic anhydride (MA), which is widely used as coupling agent to improve the interaction between the polymeric matrix and the lignocellulosic fiber in composites. This coupling agent provides a better interfacial bond between the phases of the composite, increasing the mechanical properties of the material and acting on the connection between the natural fibers (polar) and the polypropylene (PP) matrix (nonpolar) (BORSOI *et al*., 2021). Therefore, understanding the properties and potential of using reinforcement's materials to develop composites is of great interest.

For this reason, this study has as an objective to develop and evaluate PP polymer matrix composites reinforced with piassava fibers, using two types of additives, being a compatibilizing agent the maleic anhydride (MA) functionalized in polypropylene and the flow agent polyester-glycol based, of low molecular weight and high glycol content, of commercial name Protack, in order to increase the degree of interaction/bonding between the polymer and the fiber.

2 MATERIALS AND METHODS

2.1 Materials

The piassava fibers used to reinforce the polymer matrix were supplied by the fiber processing unit in Itaberoê, municipality of Ituberá, Bahia, Brazil. The polypropylene (EP 440 L, heterophasic copolymer) supplied by Braskem

S.A. (Brazil) was used as a matrix. Polypropylene (PP) (OREVAC® CA 100) was used as a compatibilizing agent, chemically functionalized with high content maleic anhydride (MA) and Protack (RA-C70) was used as a flow agent, which is a thermoplastic polymer-based polyester-glycol of low molecular weight and high glycol content, supplied by Inoquímica Ltda. (Brazil).

2.2 Preparation of the composites

The piassava fibers were previously cut using a paper guillotine and crushed in a knife mill. Then the fibers were dried in an air circulation oven at 90 ± 5°C for 24 hours. The fiber content of piassava was fixed at 10% (wt%) of the composite. This content was fixed to avoid problems during processing, as it is a high stiffness fiber. Six compositions were studied, as described in Table 1. The selected materials were manually mixed and processed in a Krauss Maffei twin screw co-rotating extruder model Berstoff 30:40 IF, with a screw diameter of 30 mm, speed of 200 rpm, L/D ratio of 40 and temperature zones within 160-190 ºC, a usual range for the processing of PP with natural fibers. After extrusion, the pellets were dried in an oven with air circulation at a temperature of 110 ºC for 8 h to remove any moisture absorbed after processing. The pellets were later processed in a ROMI 100T, 100R Model Promax plastic injection machine (temperature zones within 170-200ºC) to obtain specimens for testing.

Table 1 – Nomenclature of the formulations

Formulation	PP (wt%)	Fiber (wt%)	MA (wt%)	Protack (wt%)
F0	100	0	0	0
F1	87	10	3	0
F2	87	10	1.5	1.5
F3	84	10	3	3
F4	87	10	0	3
F5	90	10	0	0
F6	87	10	1.5	1.5

Source: Elaborated by the authors.

2.3 Characterization

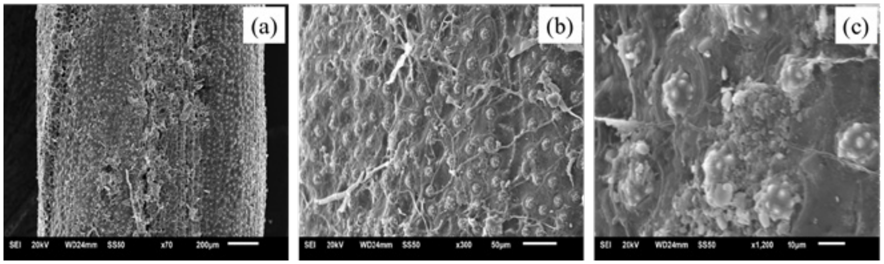
A morphological analysis of the samples was performed using a Jeol Model Never (JSM) 6510lv scanning electron microscope (SEM) at 20 kV. All samples were gold-sputtered prior to the analysis. The statistical distribution of fiber diameter was performed on 80 fibers using a digital pachymeter. Tensile testing was performed according to ASTM D638 in ten samples of each formulation, using a universal mechanical testing machine EMIC DL 2000, with a load cell of 500 N, with a speed of 5 mm/min, using an extensometer. Flexural tests were performed according to ASTM D790 in ten samples of each formulation, using the same machine, with a load cell of 5 kN, and speed of 2 mm/min. Izod impact tests were performed according to ASTM D256 in seven notched samples of each formulation, using an EMIC brand machine, with a 2.7 J pendulum. The melt flow index (MFI) was measured in accordance with ASTM D1238 in five samples of each formulation, using a Kayeness Plastomer (Dynisco), using 230 ^{o}C, preheating time of 30 seconds, and load of 2.16 kg. Thermal stability of the samples was determined in accordance with ASTM E1131. The thermogravimetric analysis (TGA) was performed under nitrogen atmosphere with a heating rate of 10^{o}C/min, from 25 to 950^{o}C in a TGA Shimadzu model Q50.

3 RESULTS AND DISCUSSION

3.1 Fibers Characterization

The SEM micrographs of the piassava fibers are shown in Figure 1. It is possible to observe the presence of microparticles distributed randomly throughout the fiber surface (Figure 1 [a] and [b]). Analyzing in more detail the fiber surface (Figure 1 [c]), it is noted that the microparticles have a thorny characteristic and strong adhesion to the fiber, also known as protrusions. According to Da Costa Garcia Filho *et al*., (2020), the presence of these microparticles can be beneficial in the adhesion of the piassava fiber to PP, for providing anchoring points in contact with the polymer matrix.

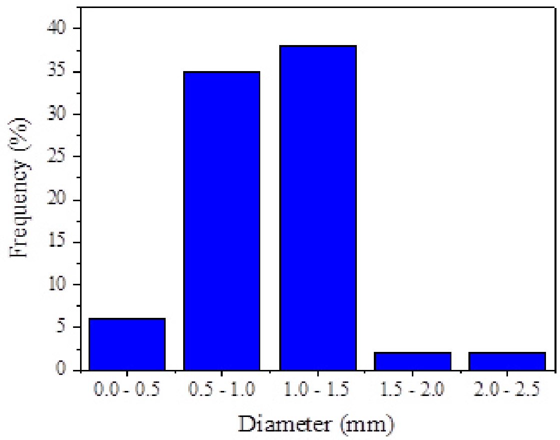
Figure 1 – SEM micrographs of piassava fiber. (a) 70x, (b) 300x and (c) 1200x



Source: Elaborated by the authors.

Figure 2 presents the results regarding the evaluation of the diameter of the piassava fiber. Around 75 % of the analyzed fibers had a diameter varying between 0.5 and 1.5 mm. Because it is a natural fiber (non-uniform), it is common for it to have a diameter variation between fibers of the same species. This diameter variation has a direct influence on the mechanical strength results (KORONIS *et al*., 2013). The piassava fibers presented tensile strength varying between 43.4 ± 256 MPa (standard deviation of 46.9), and average value of 113.4 MPa. Similar result to that found by Ferreira *et al.,* (2018), who statistically analyzed the tensile strength of piassava fibers using the Weibull methodology. In their studies they recorded an average tensile strength of 125 MPa for fibers with a diameter of 1.5 mm.

Figure 2 – Statistical distribution of diameter of the piassava fibers

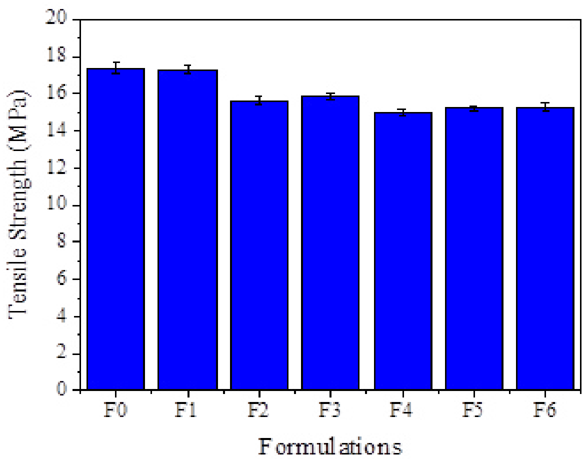


Source: Elaborated by the authors.

3.2 Composites Characterization

The results of the tensile strength test of the formulations are shown in Figure 3. Formulation F1 presented the highest tensile strength among the composites, with an average stress of 17.3 MPa. This is due to the higher concentration of maleic anhydride, which acted more efficiently in the interfacial adhesion between the matrix and the reinforcement (BEN AMOR *et al*., 2014). Unlike the F4 formulation with a higher concentration of Protack (3% wt), which presented the lowest tensile strength, 14.9 MPa. According to Nunes *et al.*, (2017), the lower the concentration of compatibilizing agent, the weaker the adhesion between the PP (matrix) and the fiber (reinforcement). For this reason, the fiber acted with discontinuity in the matrix, behaving as stress concentrators, weakening the composite. It is also possible to observe that F1 presented a value similar to F0, which shows that there was no gain or loss of strength of composite with the incorporation of the fibers, maintaining the same mechanical behavior.

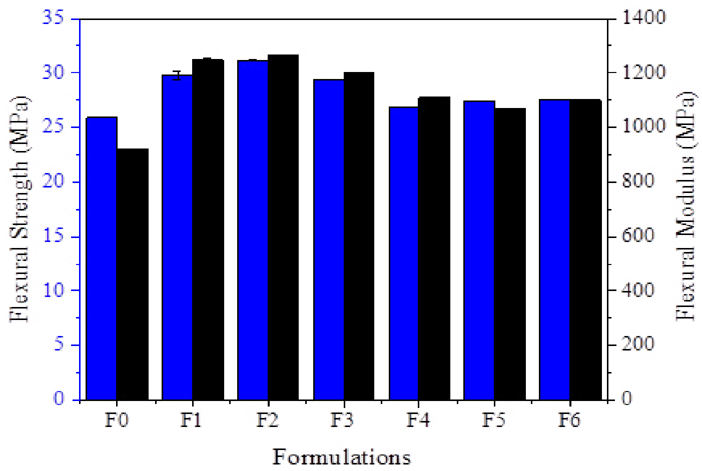
Figure 3 – Tensile strength of the formulations



Source: Elaborated by the authors.

The results of the flexural strength and elastic modulus of the formulations are shown in Figure 4. Analyzing the composites, it is noted that the formulation F2 presented higher flexural strength, as well as higher flexural modulus, 31.1 and 12.6 MPa, respectively. The smallest elastic modulus among the composites was recorded for the F5 formulation, 1071 MPa. Another interesting result is observed for the F0 formulation, among all the formulations, it was the one that presented the smallest value of flexural strength and flexural modulus, 25.9 and 923.4 MPa, respectively. This confirms that the incorporation of the fibers improved the flexural properties of the polymer matrix. As well, the incorporation of MA and Protack increased the strength and flexural modulus of the composites, as it is possible to observe for the formulations F1, F2, F3 and F6. Soleimani *et al*., (2008) reported the same behavior when incorporating a compatibilizing agent into natural fiber reinforced PP matrix composites.

Figure 4 – Flexural strength and flexural modulus of the formulations

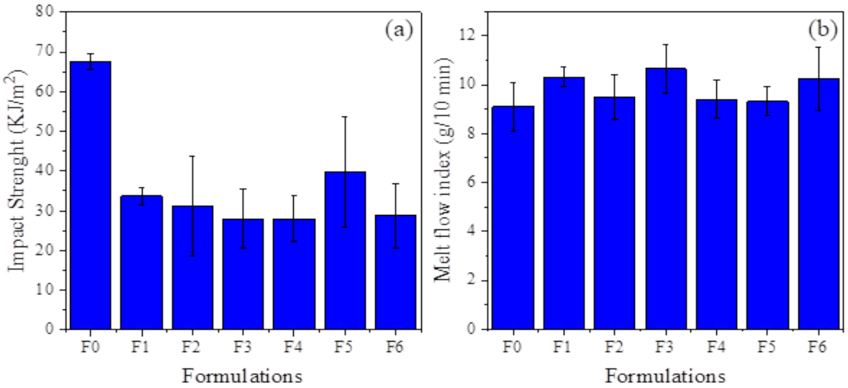


Source: Elaborated by the authors.

Figure 5 presents the impact resistance results (Figure 5 [a]) and melt flow index (Figure 5 [b]) of the formulations. The composites showed lower impact strength when compared to F0 (67.5 KJ/m^2) (Figure 5 [a]). According to Mahesh *et al*., (2020), the incorporation of fibers into the PP matrix increases the formation of "crack", leading to a decrease in impact force. Another factor that causes the decrease in impact force is the hardening of the polymer chains due to the bond between fibers and PP, which makes the composite more rigid.

Analyzing the melt flow index (Figure 5 [b]), composites have a higher flow index compared to F0 (PP matrix). We can highlight the composites F1 and F3 that presented the highest flow index, 10.3 and 10.6 g/10 min, respectively. This is mainly due to the higher concentration of MA (3 %), which provided a plasticizing effect in the composites (NUNES *et al*., 2017).

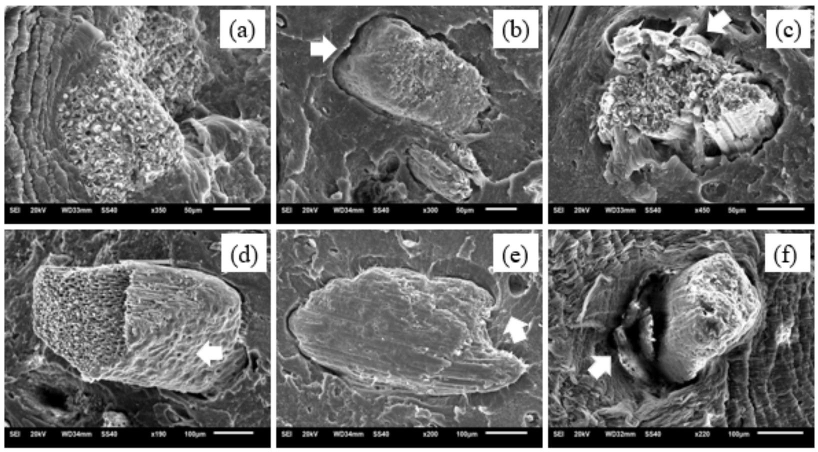
Figure 5 – (a) Impact strength and (b) Melt flow index of the formulations



Source: Elaborated by the authors.

Figure 6 presents micrographs of the fracture surface of the composites. It is possible to observe a strong adhesion between the fiber and the polymer matrix for the composite F1 (Figure 6 [a]). This same behavior was not observed for the other formulations (F2-F6) (Figure 44 [b – f]), where there is a low interfacial adhesion characterized by the formation of voids around the fibers (Figure 6 [b] e [c]), in addition to completely clean fibers (Figure 6 [d]) and fiber extraction, presence of cavities originated by fibers completely extracted (Figure 6 [e] e [f]). These results corroborate with the tensile strength tests, where the F1 composite showed higher tensile strength.

Figure 6 – Micrographs of the fracture surface of the composites. (a) F1, (b) F2, (c) F3, (d) F4, (e) F5 and (f) F6

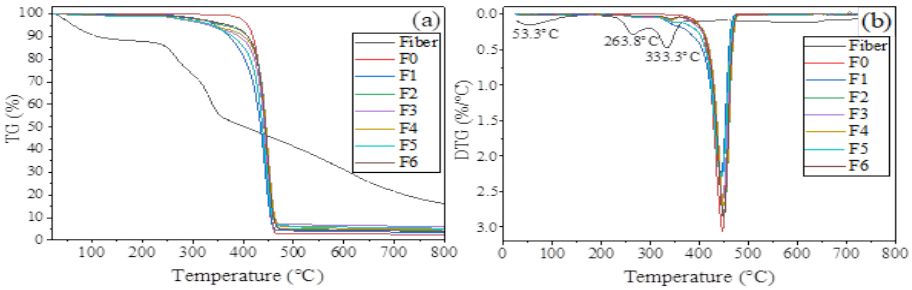


Source: Elaborated by the authors.

Figure 7 shows the TGA and DTG curves (derived from the TGA curve) for fiber, matrix (F0) and composites (F1 to F6). Analyzing the derivatives of thermogravimetric curves (Figure 7 [b]), the thermal decomposition of the piassava fiber occurred in three events. The first mass loss event occurs at 53.3°C, relatively low temperature. This first loss can be attributed to the presence of absorbed humidity and volatile substances present in the fiber. The second event occurs between 204–296°C, with a maximum rate of 263.8°C, and is associated with the decomposition of hemicellulose and lignin. Finally, the third event occurs between 296-379.1°C, with a maximum rate at 333.3°C, related to cellulose decomposition (ELZUBAIR; MIGUEZ SUAREZ, 2012).

The composites (F1 to F6) showed a thermogravimetric profile similar to the PP matrix (F0), with thermal stability up to 245°C and this did not change with the variation of the composition of the compatibilizing agents. The thermal degradation of the F0 formulation happened in a single step, between 340 and 480°C, with maximum rate at 446°C and generation of 2.5% waste. Formulations F1 to F6 showed two thermal decomposition events (Figure 7 [b]). The first occurred with a slight loss of mass between 314 and 358°C and maximum rate of 341°C, related to the decomposition of the cellulose present in the fibers (DA COSTA GARCIA FILHO *et al*., 2020)in some cases, may require exposure to temperatures above ambient. In the present work a promising fiber extracted from a Brazilian palm tree, the piassava fiber both neat as well as graphene oxide (GO. The most pronounced mass loss occurred between 365-480°C, with maximum rate in 466°C, due to degradation of the PP polymer matrix, with generation of approximately 6% of waste.

Figure 7 – TGA/DTG curves for fiber and formulations. (a) TG and (b) DTG



Source: Elaborated by the authors.

4 CONCLUSIONS

The tensile tests showed that composite F1 with the incorporation of 3 % wt of MA obtained a value similar to F0. However, there was a reduction in resistance with the variation of concentrations of MA and Protack. Composite formulations (F1 to F6) showed higher flexural strength and modulus of elasticity, compared to F0. Confirming that the incorporation of the compatibilizing and flow agent potentiated the flexural properties of the composites. The impact strength of the composites showed significant reductions for all formulations. The addition of piassava fiber did not significantly alter the fluidity of the material. The morphological analysis found a strong adhesion between the fiber and the matrix for the F1 formulation, corroborating the results obtained in the tensile test. The thermogravimetric analysis showed that the incorporation of the fibers provided a greater thermal stability of the material. The incorporation of piassava fiber as a reinforcement of the PP polymer matrix showed interesting results, since the composites obtained can be applied in the most diverse areas, such as the automotive industry.

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DETERMINANTS OF THE SPREAD OF VEHICLE ELECTRIFICATION AND DIRECTIONS FOR THE BRAZILIAN MARKET

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ABSTRACT

Society's demand for more sustainable transport alternatives is growing, with vehicular electrification being a modality with a strong tendency to be adopted by consumers. Considering the still scarce number of publications on the theme "Electric Vehicles" (EVs) in Brazil, this exploratory research aims to identify the major thematic areas of the global literature on EVs, analyze the determining factors for the dissemination of electrification dissemination at a global level and discuss the limits and possibilities of the Brazilian market in this scenario of technological change. Aiming to achieve the three objectives mentioned above, the systematic literature review approach was elected as the main research strategy, supported by complementary documentary analysis. At first, eight keywords were chosen to compose the search for publications. Those were: "Recharge Infrastructure", "Tax Incentives", "Greenhouse Gas Emissions", "Commercial Fleet", "Brazil", "Consumer Behavior", "Electricity Generation", "Technology". The ninth keyword, "Electric Vehicle" (EV), was combined with each of the eight keywords aforementioned. The inclusion of "Electric Vehicle" in all keywords matched pairs ensured the search convergence for publications associated with this central theme. The search for keywords in the Science Direct database resulted in a sample of 36 articles, published between 2016 and 2020, related to the topic of vehicle electrification. Seeking to mitigate bias, an analysis table was created, displaying the information compiled from each of the mentioned publications, such as: title, authorship, year of publication, country of origin, methods, among others. Seeking to enrich the analysis of Brazil, documentary research was carried out on the Google Scholar platform, considering the same period from 2016 to 2020, which resulted in eleven publications specifically associated with the Brazilian context. This work fulfilled the three proposed objectives as it identified eight major thematic areas of research on the subject (greenhouse gas emissions, EVs – market data and diagnostics, electricity generation, incentives for vehicular electrification, EVs – commercial fleet applications, EV consumer behavior, charging station infrastructure – market data and diagnostics, charging station infrastructure – technologies, costs and trends). It analyzed the determinant factors for the dissemination of vehicular electrification at a global level, the major ones pointed out by the literature were: availability of charging infrastructure, battery capacity, tax incentives, electric energy availability and attractive, and the increase in social demand for transport alternatives with less environmental impact. Finally, it discussed the limits and possibilities of the Brazilian market. While the Brazilian electricity generation has proven to be environmentally favorable, its capacity was insufficient for the adoption of EVs on a large scale, the same can be said about the practically non-existent charging infrastructure. These two factors emerge as critical paths for the successful adoption of EVs in the country, and they add up to a decentralized policy of incentives, being these critical and strategic factors that demand urgent attention from stakeholders.

Keywords: Automotive Industry, Electric Vehicles, Systematic Review, Technology Management, Brazil.

1 INTRODUCTION

The study of emissions of harmful gases to the ozone layer, or greenhouse gases (GHG), and their undesired effects, have been gaining more relevance in the academic community. In 2017, the transport sector was responsible for 23% of carbon dioxide emissions on the planet (LEMME *et al.*, 2019). In this context, vehicular electrification emerges as a high-impact alternative for reducing GHG emissions.

Currently, electrified vehicles (EVs) can be subdivided into two major categories: hybrid vehicles and purely electric vehicles. This market has been gaining scale and in 2035 the expectation is that there will be around one hundred million EVs circulating on the streets globally (DAS *et al.,* 2020).

In this context, Brazil emerges as a practically unexplored market in terms of vehicular electrification. EVs accounted for 0.1% of sales in the country in 2019, or less than two thousand vehicles, adding up to an accumulated fleet of approximately three thousand vehicles in 2019 (IEA, 2020). It is a consensus among authors that the acceleration of vehicular electrification in Brazil involves government initiatives, among tax exemptions (PROMOB-e, 2018; LEMME *et al*., 2019).

This study aims to identify the major thematic areas of the global literature on EVs, also analyzing the determining factors for the dissemination of vehicular electrification at a global level, and finally discussing the limits and possibilities of the Brazilian market in this scenario of technological change.

2 METHODS

Aiming to achieve the research objective, it is necessary to contextualize vehicular electrification and consequently the technologies and infrastructure necessary for charging EV batteries. In this sense, this exploratory research proposes a systematic review of the literature, through the collection, processing and presentation of comprehensive data, taking into account the specific context of the transport sector and also the reality of the Brazilian market.

At first, 8 keywords were elected to compose the search for publications: “Recharge Infrastructure”, “Tax Incentives”, “Greenhouse Gas Emissions”, “Commercial Fleet”, “Brazil”, “Consumer Behavior”, “Electricity Generation”, “Technology”. The ninth keyword, “Electric Vehicle”, was combined with each of the eight keywords mentioned in this paragraph, and eight separate searches were then performed, with individual pairs of keywords. The inclusion of “Electric Vehicle” in all matched pairs of keywords ensured the convergence of the search for publications associated with this central theme.

Subsequently, the *Science Direct* database was used for publications carried out between the years 2016 to 2020, adding a total of 36 articles, which are relevant to the central themes of this work: identification of the major thematic areas of the global literature on EVs, analyze the determinant factors for the dissemination of vehicular electrification at a global level, discuss the limits and possibilities of the Brazilian market in this scenario of technological change. These papers were published by 14 different international journals, which addressed the themes raised in the aforementioned period. For the 36 works cited, careful reading was performed.

Seeking to mitigate bias, an analysis table was created, extracting information considered essential from each of the 36 mentioned articles. Information regarding the authorship of the work, publication title, topics covered, applied methods, year of publication and country of origin of the research were collected. The result of this analysis will be shared throughout this work.

The results of the search on the *Science Direct* platform have shown a gap, both quantitative and qualitative, in publications related to vehicle electrification associated with the Brazilian context. As Brazil is one of the pillars of this research, it was necessary to complement the search using *Google Scholar* platform, applying the same process already described for the *Science Direct* platform. There were eleven documents found, specifically approaching the Brazilian context. A careful reading was carried out in each of the 11 documents cited, and individual summaries focused on each of the publications were prepared.

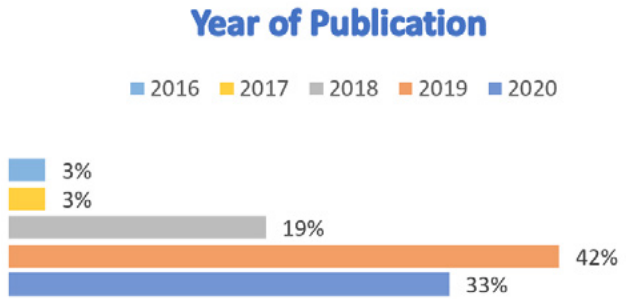
3 RESULTS AND DISCUSSION

3.1 Results

Through analysis of the sample of 36 articles published between the years 2016 and 2020, quantitative and qualitative data were raised and a temporal, thematic, methodological and geographical analysis will be presented.

It was found an increase, over time, in the number of publications focused on vehicular electrification. Papers published between the years 2019 and 2020 accounted for 75% of the total surveyed. This demonstrates the growing relevance of electric vehicles (EV), and its consequent impact on society. Figure 1 shows the number of publications in the sample.

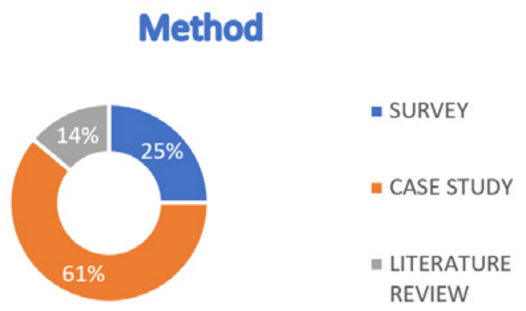
Figure 1 – Quantitative temporal analysis of the sample publications



Source: Elaborated by the authors.

Analyzing the methods applied in the sample, it is possible to observe that three different strategies were adopted: Survey, Case Study and Systematic Literature Review. The sum of Survey and Systematic Literature Review methodologies corresponded to almost 40% of the publications. With this, the Case Study category was preponderant, accounting for 61% of the articles in the sample. There then emerges the gap related to the preparation of Systematic Literature Reviews concerning vehicular electrification and also the Brazilian position in this scenario.

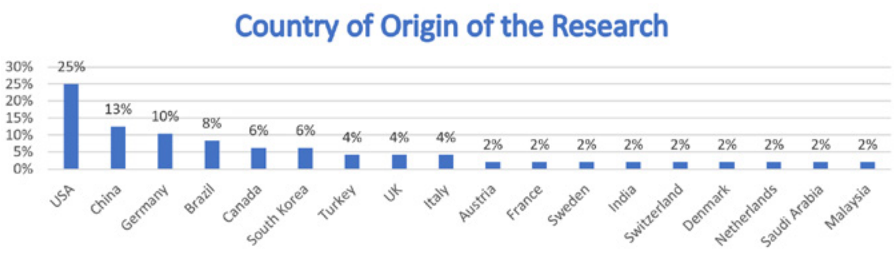
Figure 2 – Methodological analysis of the publications in the sample



Source: Elaborated by the authors.

In the sample, three nations can be considered protagonists: United States, China, and Germany. These countries, combined, accounted for approximately half of the papers. Canada and South Korea are also in a prominent position, with each originating 6% of the total number of publications. It is also worth noting that there were papers published with more than one geographical origin in their list of associated institutions; in these cases, two or more geographical origins were accounted for.

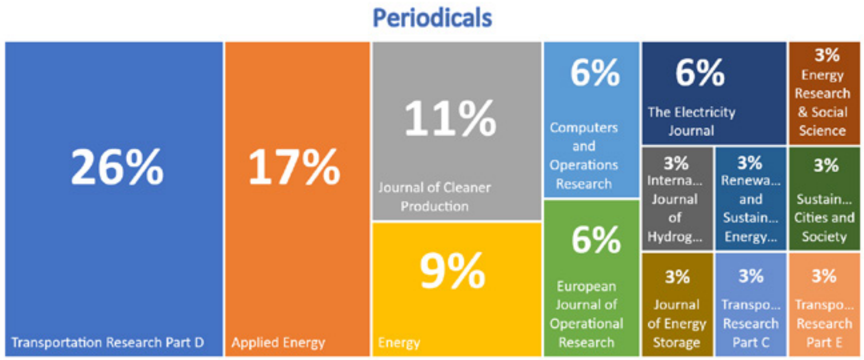
Figure 3 – Countries of origin of the survey in the sample



Source: Elaborated by the authors.

Within the sample, it can be observed that the publications occurred in 14 different journals. There is a relevant concentration, of 63%, in four journals: Transportation Research Part D, Applied Energy, Journal of Cleaner Production, and Energy.

Figure 4 – Journals in the sample



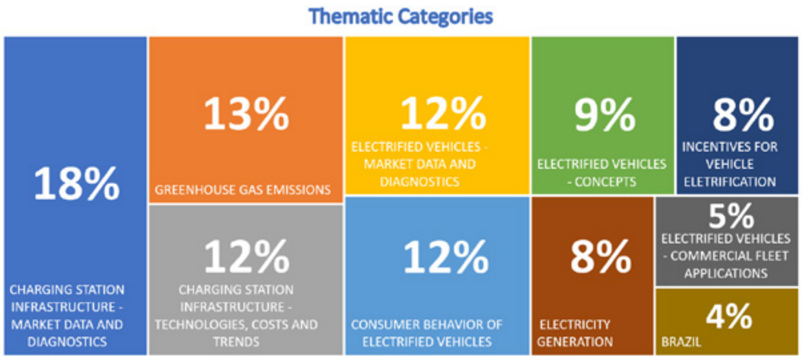
Source: Elaborated by the authors.

Based on an analysis of the papers, it was possible to subdivide and classify them into nine distinct and complementary themes, as follows: Infrastructure of recharging stations — data and market diagnostics; Infrastructure of recharging stations — technologies, costs and trends; Greenhouse gas emissions; Electrified vehicles — concepts; Electrified vehicles — data and market diagnostics; Consumer behavior; Electric power generation; incentives for vehicular electrification; Electrified vehicles — applications to commercial fleets. Due to very nature of the work and data collection, it is also possible to observe the presence of an additional theme: Brazil.

Among the aforementioned themes, it was possible to observe that the one related to charging station infrastructure (market data and diagnostics) prevailed, having appeared in 18% of the sample. The topic Infrastructure of recharging stations (technologies, costs and trends) also had an important contribution, being observed in 12% of the articles. Among the other themes, two stood out. The first is that of greenhouse gas emissions, with a 13% presence, and the second was the one that addresses Consumer Behavior related to EVs, appearing in 12% of the sample.

Figure 5 shows the thematic distribution of the sample of publications. It is important to emphasize that it was possible to observe the occurrence of more than one theme in each of the articles. Also in Figure 5, it is possible to observe that the Brazilian reality, which represent only 4% of the publications, is a relatively unexplored theme in the academic world concerning vehicular electrification. Due to the aforementioned scarcity, a complementary documentary search was performed on the Google Scholar platform, which returned 11 publications specifically related to Brazil.

Figure 5 – Thematic categories addressed in the sample



Source: Elaborated by the authors.

3.2 Discussion

The objective of this subsection is to deepen the qualitative analysis on eight of the themes associated with vehicular electrification on Figure 5. Due to the very nature of this study, “Electrified Vehicles – Concepts”, “EV – Commercial Fleet Applications” and “Brazil” themes will not have a dedicated subsection, but will be contextualized along every subsection of this work when necessary. Each theme will be presented in a specific subsection, and the first will address GHG emissions.

3.2.1 Greenhouse Gas Emissions

According to Woo *et al.* (2017), the transportation sector consumed 27.6% of all energy produced on the planet in the year 2013. Specifically in terms of carbon dioxide emissions, one of the GHGs, the transportation sector has been contributing a relevant share of global emissions. In the year 2016, according to Rupp *et al.* (2019), transportation sector accounted for 25.5% of the total GHG emissions.

According to Li *et al.* (2019), hybrid electric vehicles (HEV), plug-in hybrid electric vehicles (PHEV) and battery electric vehicles (BEV) are emerging as more energy-efficient alternatives for the transportation sector. According to Teixeira and Sodré (2018), for a fleet application with battery electric vehicles (BEV), emissions can be 10 to 26 times lower when compared to a fleet of internal combustion engine vehicles (ICEV).

3.2.2 Electrified Vehicles – Market Data and Diagnostics

PHEVs are at a more advanced commercial stage when compared to BEVs. According to Li *et al.* (2019), PHEVs are found to be a more energy-efficient transportation alternative compared to ICEVs, but are still considered an intermediate step towards the adoption of BEVs.

According to Funke *et al.* (2019), in the year 2017 the sales of plug-in electric vehicles (PEV) represented more than 1% of total sales in important markets, such as: China, USA, France, Germany, Japan and the UK. Norway is also noteworthy, which in 2017 had a 39% share of BEVs in total vehicle sales in the country. Being BEVs part of the PEV market, in all these nations its share was over 50% of total PEV sales in 2017.

According to Napoli *et al.* (2019), the commercial relevance of EVs had an upward trend in 2018, corresponding to 4.5% of total global vehicle sales, with a growth of approximately 100% compared to the previous year. By the year 2035 a fleet of one hundred million EVs is expected to be circulating around the planet (DAS *et al.,* 2020).

The Brazilian market of EVs also shows a growth trend, but with smaller numbers than those found in the more mature countries. The Brazilian fleet of PEVs went from only around 100 vehicles in the year 2014 to 1,100 vehicles in 2018, reaching 3,000 vehicles in 2019 (IEA, 2020). In the case of Brazil, PEVs accounted for only 0.1% of sales in 2019 (IEA, 2021). Thus, it is clear that there is a long way to a relevant penetration of PEVs in Brazil.

3.3.3 Electricity Generation

The adoption of EVs relates directly to electricity generation, because they are dependent on a robust, reliable and clean matrix in order to be increased. Although these vehicles do not directly emit GHGs, BEVs, depending on the composition of the energy matrix, can have a level of emissions at similar or even higher levels than ICEV (WOO *et al.,* 2017).

In terms of coal burning, countries like China, India, Australia, and South Africa have more than 65% of their energy matrices tied to this specific source of energy. With still high levels of coal burning, above 35%, countries such as Indonesia, Germany, South Korea and the USA can be enumerated. Another relevant mode of electricity generation related to fossil fuels is the burning of natural gas. Countries such as Russia, Japan, Mexico, the UK, and the US stand out - with a share of over 30% of electricity generation (WOO *et al.,* 2017).

Among the main sources of electricity that are considered less polluting to the ozone layer there are hydroelectric, wind, biomass, solar and nuclear energies. Countries such as Norway, Brazil, and Canada stand out in the generation of hydroelectric power, with a share of over 55% of their energy matrices. Regarding wind power generation, Germany and the United Kingdom play a leading role, with over 8% of their matrices supplied by this means. In terms of Biomass electricity generation, Brazil, Germany, and the United Kingdom have production levels above 7%. It is also worth mentioning photovoltaic plants, powered by sunlight, which are an important source in countries such as Germany, with a 6% share (WOO *et al.,* 2017).

The increase in the adoption of EVs brings with it a relevant demand increase for the electricity grid, besides the aforementioned environmental impact. Pagani *et al.* (2019) mention that the recharges of EVs occur mostly at the users' homes, during the night, and the increase in demand for electricity, in their simulated models, can reach 78% at peak times.

During 2020, in the context of the Covid-19 pandemic in Brazil, due to the circulation restrictions, an industrial and commercial consumption decrease was imposed. In 2021, the resumption of economic growth had a direct impact on electricity consumption, and by the end of June, the yearly consumption growth was 4.4%. Still in 2021, hydroelectric generation accounted for 63% of the national energy matrix. By July, the yearly rainfall reached only 67% of the historical average (DE CASTRO *et al.,* 2021). It's clear that there is a strategic need for electricity generation alternatives and growth to support Brazilian electricity demand.

Still in the Brazilian context, FGV Energia (2017) suggests a hypothetical and extreme scenario associated to the electrification of the national fleet.

If all 36 million vehicles in the Brazilian fleet in 2016 were BEVs, traveling on average 20,000 kilometers per year, with an average yield of 4.37km/kWh, approximately 163TWh of energy would be needed to charge these vehicles, representing 31% of the total electricity consumption in 2016. This scenario would demand dramatic investments in the Brazilian energy matrix. In a more realistic scenario brought out by the Ten-Year Energy Plan (PDE) 2026, prepared by the Energy Research Company (EPE), the Brazilian demand for electricity from PEVs in the year 2026 would correspond to only 0.3% of the total production. (FGV ENERGIA, 2017)

3.3.4 Incentives for Vehicle Electrification

Tax incentives are a strategic tool widely used by governments to promote vehicular electrification. According to Anjos *et al.* (2020), these are given directly to the final consumer through discounts on fees and prices related to EVs. In the other hand, Fang *et al.* (2020) points out that government interventions in plug-in electric vehicle charging infrastructure (PEVCI) help mitigate fluctuations in the transportation market by maintaining a stable supply of charging points. Furthermore, through subsidies, the operation of PEVCIs is shielded from fluctuations in the price of electricity, another determining factor in this EV scenario.

According to Wang *et al.* (2019), there are four main categories of government taxations on vehicles, electrified or not. These are: VAT (Value Added Tax), Vehicle Registration Tax (at the time of purchase), Annual Road Tax, and Sales Tax (paid by the company that sold the vehicle). Partial exemptions to the mentioned taxes are mainly based on the emissions level of the vehicle. Lower emissions receive greater governmental incentives.

The purchase costs, much higher for EVs, are still considered as the main barrier for the growth of this market (Wang *et al.,* 2019). As a practical example of tax incentives for EVs, Moon *et al.* (2018) mentions the South Korean government, highlighting the USD 21,900 in subsidies per purchase offered in 2016, an amount four times higher than that provided by France, the UK and Germany in the same period.

In the case of Brazil, the actions related to tax incentives can be subdivided between federal and state/town. Among the federal actions, it is worth mentioning resolution number 97 of the Chamber of Foreign Trade (CAMEX), which in 2015 zeroed the import tariffs for BEVs with autonomy greater than 80 km (PROMOB-e, 2018). In the case of PHEVs, the import tax rate went from 35% to between 2% and 7%, depending on the energy efficiency of the vehicles. In the town sphere, monetary incentives were associated with the Motor Vehicle Ownership Tax, with discounts of up to 40% on the annual collection. The observed initiatives presented themselves as occasional and isolated, thus governmental actions do not present the robustness needed by the EV market, lacking well-defined objectives and continuity.

3.3.5 Consumer Behavior of Electrified Vehicles

The motivation of the consumers to purchase EVs and their habits before and after acquiring EVs will be addressed in this section. One of the major challenges for the adoption of vehicular electrification, according to Zhang *et al.* (2020), is its suitability to the users' daily activities, given the perception of lower autonomy and longer recharging time in EVs compared to ICEVs.

Users inclined to join EVs take into account both macro factors (e.g., environmental impacts), and micro factors, based on their interpersonal relationships. Habich-Sobiegalla *et al.* (2018) demonstrate, based on a survey conducted in parallel in China, Russia and Brazil, that micro factors, such as knowing someone who already uses EVs, are preponderant in the decision to purchase. Regarding the macro factors, Brazilian consumers were concerned with GHG emissions and the availability of charging stations. Moon *et al.* (2018) highlights that consumer preferences regarding battery charging of their EVs can be subdivided into: charging schedule, charging station location, and charging station type. Author's method was survey, held in 2016, with a South Korea pool of respondents.

In terms of where to charge the batteries of their PEVs, Chakraborty *et al.* (2019) and Lee *et al.* (2020) indicated that users prefer to perform home charging. Those who rely only on home recharging accounted for more than half of the occurrences in both studies. Also, it was found that the workplace is the second preferred place for PEVs battery recharging events, with approximately 15% of preference. In third and last place were public charging stations.

Another relevant factor to consumers is the timing of recharging events. Approximately 60% of users prefer to charge the battery of their PEVs at night, between 6 PM and 6 AM, while the rest opt for recharging during the day, between 6 AM and 6 PM. (Moon *et al.,* 2018)

The availability of battery charging stations at the destination, and also during a given route, plays an important role in the choice of a given route by the user of PEVs. Zhang *et al.* (2020) found that charging stations in parking lots are also critical infrastructures for the mass adoption of PEVs. No studies were found focusing on consumer behavior related to EVs in Brazil, and it is reasonable to assume that this is due to its incipient penetration in the country.

3.3.6 Charging Station Infrastructure – Market Data and Diagnostics

As an enabler of PEV consumers daily itineraries completion, there must be charging stations available, both along roadways and in parking lots. Funke *et al.* (2019) discuss the ratio of PEVs per available charging infrastructure quite comprehensively, mentioning Norway and the United States as leaders, with 19 and 17 charging stations per PEV. Sweden and the United Kingdom also appear prominently, with 12 and 10 ratios. Globally, the average number of charging points per PEV is 7, a proportion seen in France, China, and Germany.

In the European continent, Napoli *et al.* (2019) mentions the existence of approximately 120 thousand PEVCS, mostly distributed, in absolute numbers, among the United Kingdom, France, Germany and the Netherlands. In 2020, PEVCIs should reach 440,000 units in the continent, reaching 2 million units in 2025, supporting an expected 7% share of EV vehicles.

Funke *et al.* (2019) show that for Norway and the United States there are 1400 and 1600 ICEVs for each refueling station, respectively, a number far higher than the 19 and 17 PEVs per PEVCS in the same period. A similar scenario occurs in other countries considered more mature in relation to vehicular electrification. Fang *et al.* (2020) addresses the case of China, where in 2018 there was a ratio of less than 20% between PEVCSs and PEVs in circulation. Also, the Chinese government planned to deliver 12,000 additional charging stations by 2020.

For the PEVCS market further develop globally, an increase in the circulating fleet of PEVs is expected, since the associated investments, which will be discussed in the next section, are still high compared to the current demand. Fang *et al.* (2020) also addresses the feasibility of charging stations, pointing out urban areas and large centers as preferable for their installation.

In the Brazilian context, according to IEA (2020), PEVCS available went from 476 in 2017 to 1,930 by the end of 2019, corresponding to a growth ratio close to 300%. Among the 1,930 PEVCSs distributed across the country in 2019, 908 were slow recharging stations, with power ratings below 22kW. Despite its growth ratio, absolute numbers in Brazil show the relevant gap of charging stations to support PEV consumer daily itinerary.

3.3.6 Charging Station Infrastructure – Technologies, Costs and Trends

Das *et al*. (2020) performs a detailed technological study regarding technical factors such as: Current Source, Voltage and Maximum Current. Depending on the set of these characteristics, a station fits into a certain Level or Mode. In terms of Current Source, stations can be of Alternating Current (AC) or Direct Current (DC). In the other hand, Voltage can range from 120V to 600V, as well as currents, Alternating or Continuous, varying between 16A and 400A. Charging hardware can also be subdivided into Slow-Recharge (Levels 1 and 2) and Fast-Recharge (Levels 3 and 4).

The charging technologies for PEVs follow standards from Regulatory Bodies. Organizations such as IEC (International Electro-Technical Commission), SAE (Society of Automotive Engineers), JEVA (Japan Electric Vehicle Association) and SAC (Standardization Administration of China), are concerned with the standardization of Components, the ISO (International Organization of Standardization) aims to standardize EVs as a whole.

The Brazilian market uses IEC as the main source for establishing standards and regulations (PROMOB-e, 2018). The body responsible for standards and regulations in the country is the Brazilian Association of Technical Standards (ABNT). In the following table it is possible to observe the Brazilian standards directly related to EVs.

Table 1 – Brazilian Technical Standards related to EVs

Standard	Description
ABNT NBR IEC 61851-1	Conductive charging system for EVs - General requirements;
ABNT NBR IEC 61851-21	Conductive charging system for EVs - Requirements;
ABNT NBR IEC 61851-22	Conductive charging system for EVs - Station;
ABNT NBR IEC 62196-1	Plugs, Sockets, Mobile EV Sockets and Plugs;
ABNT NBR IEC 62196-2	Plugs, Sockets, Mobile EV Sockets and Plugs;
ABNT IEC/TR 60783	Wiring and connectors of road EVs;
ABNT NBR IEC 62660-1	Secondary lithium-ion cells for vehicle propulsion;
ABNT NBR IEC 62660-2	Secondary lithium-ion cells for vehicle propulsion;
ABNT NBR IEC 61434	Secondary cells and batteries containing alkaline electrolytes.

Source: Elaborated by the authors.

The national standards are often different from each other, including the design of doors and connectors. While China uses Guobiao (GB/T) for its vehicles, Japan uses CHAdeMO, Europe generally uses IEC, and the United States uses SAE-J1772 standards and also the proprietary Tesla design (DAS *et al.,* 2020). Vehicle manufacturers and regulators are still trying to agree on a proposed global standard, thus avoiding the current conflicts among existing standards.

In terms of implementation costs related to ERVEPs, while Huang and Kockelman (2020) chose to add land acquisition costs for the installation of stations, mentioning costs, per charging point, of approximately USD 20,000. Pagani *et al.* (2019) focused on the costs directly linked to the technologies, mentioning costs ranging between USD 22,000 and USD 122,000.

In the case of PEVs, the trends related to public PEVCSs go in favor of direct current sources for fast charging, allowing the use of these vehicles for longer routes. The ratio of fast charging stations to all available public charging stations, according to Funke *et al.* (2019) ranged from 10% to 40% in mature markets, such as Germany, Norway, USA and China. In Brazil, it was not possible to define the ratio of fast charging stations, when compared to all PEVCS available in the country.

4 CONCLUSIONS

This study presented and analyzed the main trends in the recent literature on the subject of EVs in the global and Brazilian contexts, bringing reflections for the development of strategies for this emerging scenario of technological change. The systematic analysis of the literature undertaken had confirmed an increasing global trend in the number of publications on the subject, as well as the acceleration of the adoption of EVs by society. Eight major thematic areas of research on the topic were identified: greenhouse gas emissions; EVs – market data and diagnostics; electricity generation; incentives for vehicular electrification; EVs – commercial fleet applications; EV consumer behavior; charging station infrastructure – market data and diagnostics; charging station infrastructure – technologies, costs and trends.

Then, the EV adoption impacts related to GHG emissions were addressed, as well as the challenges related to electricity generation and EV charging infrastructure availability, emphasizing the relevance of tax incentives in promoting vehicular electrification globally. Finally, the determining factors for the dissemination of vehicular electrification were listed: adequate infrastructure for EV charging, battery capacity that allows autonomy in terms of distance traveled, tax incentives for the purchase, maintenance and charging of the EV, availability and cost attractiveness of electric energy and increased social demand for transport alternatives with less environmental impact.

In the context of Brazil, the literature proven to be quite scarce, as finding robust data on this topic was one of the main difficulties faced in the period of searches using the Science Direct tool. In Brazil, while the energy matrix is environmentally favorable, its dependency on hydroelectric sources and consequently rainfall proved to be a strategic downside, requiring electricity generation alternatives to increase its mix robustness. Still on this topic, electricity generation capacity is also a roadblock to EVs dissemination in the country, currently being uncapable to support a relevant increase of demand coming from transportation.

Brazilian EV charging infrastructure has also shown to be incipient, or practically null, while the tax incentives associated to EVs were found to be punctual, clearly lacking a centralized strategy. It’s no surprise that Brazil is a large automotive market practically unexplored with regard to the electrification of its fleet. A larger and more diversified electricity generation matrix is required, as well as a centralized strategy on EV charging infrastructure and tax incentives. Those are critical topics of attention to unleash EV market potential in Brazil, following global best practices on the subject.

Finally, the present study fulfilled its main objective by providing contributions to the advancement of the literature on the subject and presenting the strategic aspects for the acceleration of vehicular electrification in Brazil, which is still in its inception today. Strategies related to electricity generation, infrastructure and recharge technologies, and tax incentives appear as topics to be explored in more depth by academy, government entities and also by Brazilian society itself.

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7

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THE OPINION OF CUSTOMERS CONTRIBUTING TO IMPROVEMENTS IN PRODUCTS AND PROCESSES OF THE COMPANY:

a study of case in the automotive industry

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ABSTRACT

Companies are continually striving for opportunities to achieve high levels of customer satisfaction. For this reason, evaluating the opinions of the company's customers has become an accessible, practical and direct research alternative to identify possible opportunities for improvement in processes or products, allowing us to understand which items are the best and the worst evaluated by customers. The objective of this study is to show how the information, from customers and made available to the company, could help in the development and improvement of its vehicles, and thereby characterize which categories of opinions contribute most effectively to the improvement of the quality of its products and process. The methodology of this work comes from an investigation through secondary and qualitative data of a descriptive nature, whose base was obtained from documents applied to a sample of buyers of the investigated company. Through the research findings, we sought to identify information about automobiles and their vehicle systems, thus examining those that had the highest number of negative comments, in addition to demonstrating the consequences of these opinions in improvements of the company's product and process to characterize the most relevant improvements in the corporation. Thus, it is evident that this type of study approach can be used to understand the voice of consumers and transform this information into an opportunity for customer loyalty with the company.

Keywords: Customer opinion, Quality improvement, Automobilist industry, Marketing.

1 INTRODUCTION

Vehicle manufacturers, with a focus on ensuring the level of competitiveness and sustainability in the market, seek alternatives to differentiate themselves in the development and manufacture of their products. In addition, they seek to attract and retain customers through initiatives that guarantee a high standard of quality, reduction of production costs, competitive delivery times and robust processes aligned with corporate strategy and meeting customer expectations (COPETTI; CECCONELLO, 2020).

Based on that, the present work is embedded in this scenario, since it used a specific sample of product buyers from an automotive company, with the objective of understanding the voice of these customers and, from that, using all the lessons learned to improve the development of products that will be produced and launched in the future.

2 BIBLIOGRAPHIC REVIEW

Initially, this work addresses a general perspective on the importance of customer opinion, in which this topic is presented to understand the principles of relationship marketing and customer satisfaction. In addition, practices for managing the voice of consumers are presented, as well as some methodologies used in this sense. Finally, we present a section on possible improvement methods and tools for taking advantage of the voice of the customer, used to support product and process evolutions of the studied company.

2.1 Importance of Customer Opinion

Due to the current advance of globalization and the accelerated development of innovative technologies, consumers have a wide and varied set of purchase possibilities when compared to previous periods (DEMO; ROSETI, 2013; KOTLER; KELLER, 2018).

Based on this explanation, Bueno *et al*. (2016) highlight the Marketing relations as a business philosophy that promotes the interaction of internal employees, partners (suppliers) and customers, aiming at commitment to the company and generation of value for all involved. However, it is common to question what the real advantages of MR for the company are. According to the authors Evans and Laskin (1994), the following positive effects are described: (A) higher quality of products and services, (B) Greater customer satisfaction, (C) customer loyalty and (D) Greater profitability, as illustrated. in Figure 1, with the benefits generated for companies.

Figure 1 – Advantages of relationship marketing

Source: Adapted from Zeithaml and Bitner (2003).

2.2 Customer "Voice" Management.

According to Oliveira *et al.* (2016), the Net Promoter Score (NPS) is a tool model that is used to guide companies by measuring the level of customer satisfaction in an easy and robust way. The NPS survey works by applying questions to which customers answer through ratings, following a scale from 1 to 10, which represents how much they would recommend the brand or service to someone they don't know.

Based on the results of the questions, customers are classified as promoters (grades 9 and 10), neutral (grades 7 and 8) or detractors (1 to 6) of the brand or product. According to Silva *et al*. (2010), customers classified as detractors are those who did not have a good relationship with the company and are unlikely to be brand ambassadors, probably making negative advertising. According to Duarte and Mascena (2021), NPS proves to be a relevant support resource for managing customer relationships in corporations, in addition to being a robust alternative for solidifying customer loyalty and providing information about opinions and preferences of these consumers for a better view of the company in the market.

2.3 Possible Improvement Tools Used from the Customer's Opinion

According to Amaro (2020), it is through quality improvement initiatives that companies are able to differentiate themselves from competitors to the point of being able to reach the level of quality required by customers through robust products and services. Authors who defend these ideas claim that this should be treated as a priority, given that effective quality management makes it possible to value products and services. Furthermore, it is difficult to imitate from the perspective of consumers, maximizing the potential gains of the company.

As a result, some methodologies and tools are applied in the industry to mitigate potential problems arising from internal indicators or customer opinion through external data indicators, resulting from satisfaction surveys.

2.3.1 FMEA for failure reduction

The objective of this method is to prevent potential failures and analyze risks in a systemic way by identifying their causes and effects, resulting in the elimination of nonconformities that can affect products or processes. According to Wang *et al*. (2018), it is possible to identify the criticality of failures through the FMEA, as well as to assess how they are likely to happen, as well as it is possible to detect how failure modes occur before affecting the operation of the product and, therefore, consumer satisfaction.

In this way, the tool is supported by three basic assumptions:

1. Detection: Check the failure before the product reaches the customer.
2. Severity: possibility in which the client recognizes and is affected by the failure.

3. Occurrence: possibility that there is a cause, and a failure occurs.

Failure modes that have the greatest risk to consumers are considered by the FMEA during the prioritization process.

2.3.2 Six-Sigma/DMAIC for Variability Reduction

Another example of a tool applied in the automotive industry and also by the Alpha company, is the combined methodology Six-Sigma/DMAIC (Define, Measure Analyze, Improve, Control), adopted with the purpose of improving the quality of the processes, products and services of the corporation through the application of quantitative investigations and statistical studies, which reduce the variability of characteristics of a product or process. The correct use of the Six-Sigma/DMAIC methodology provides greater results than the resources used for its implementation.

Applied in this context, Santos and Martins (2005) report that a Six-Sigma project aims to eliminate variation and increase process efficiency. Its application is conditioned to the use of statistical methods that aim to enable the interpretation of cause and effect analyzes that directly affect the company's significant processes. The effects of applying the tool result in significant and measurable gains on various dimensions or performance categories in the company's measurement system.

2.3.3 Design for Six Sigma

Another example of a methodology applied in the automotive industry and adopted by the Alpha company is DFSS (Design for Six Sigma). According to El-Haik and Yang (2003), it is a method applied to the product development process, using projects guided by the voice of the customer with the objective of improving or optimizing products that assertively translate consumer requirements, responding to growing demand regarding the need to improve project performance.

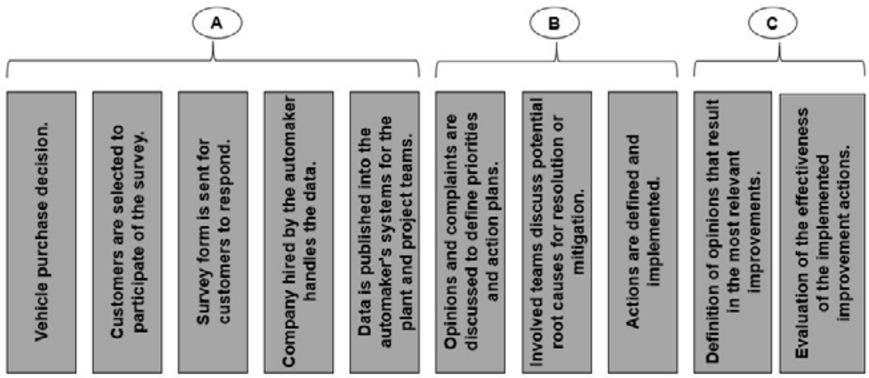
According to Curione and Correa (2012), DFSS is a method of improving the product development process present in the automobile company. In this sense, companies supply the development demand and DFSS promotes the techniques and resources for the application.

Therefore, the improvement has to be developed efficiently.

3 METHODS

According to the specificities of this work, it is a qualitative research, of a descriptive nature, in which the method used is characterized as a case study, based on data collected in company documents. Furthermore, the methodological procedure is divided into three phases, which are detailed in Figure 2.

Figure 2 – Phases of the methodological process



Source: Elaborated by the authors.

3.1 A – Capture of negative opinions from the NPS

The process begins from the moment consumers buy a vehicle from the Alpha company. Next, customers are selected to participate in the Net Promoter Score (NPS) satisfaction survey and answer the questionnaire.

Consumers receive an email with the survey instructions, in addition to the guidance that the questions need to be answered by the main driver of the vehicle, so that there is greater representation in the information and perceptions exposed. After obtaining the answers from the customers interviewed through the NPS survey questionnaire, the company hired by the automaker Alpha processes this data and discloses the results, directing this information to the responsible teams.

3.2 B – Deployment of opinions on improvements using the DMAIC and FMEA tools

To promote the deployment of negative opinions into improvement actions, the information collected and prioritized will be treated and discussed by the work teams. Thus, the investigation of the causes of the problems and identification of critical failure modes begins, to transform these dissatisfactions into effective quality improvements. To implement these actions, the Six-Sigma/ DMAIC and/or DFSS tools will be used. In this context, all phases of DMAIC actions are followed, both for improvements to existing products/processes (Six-Sigma) and for eventual improvements in the design of new products (DFSS).

3.3 C – Characterization of the opinions that resulted in the most relevant improvements – criteria

In this phase, it is demonstrated which characteristics should be evaluated by the Alpha company and, therefore, prioritized to ensure: (a) increased customer satisfaction and/or (b) sales expansion for the company.

Therefore, the following criteria will be established to classify the relevance of the improvements. Below are listed which of them will be used in this final stage of the study to characterize the opinions that resulted in the most relevant improvements for the Alpha company: 1) Vehicle model; 2) Country surveyed; 3) Sales volume by vehicle model; 4) Motorization; 5) Sales volume by motorization type; and 6) Transmission type.

3.4 Sample analyzed for the study

From the model selected for this study, data from 1,233 customers interviewed by the company were used, out of a total of 45,966 vehicles sold. This model was chosen for study due to its representativeness in the company's sales volume and the slightly higher amount of directed complaints

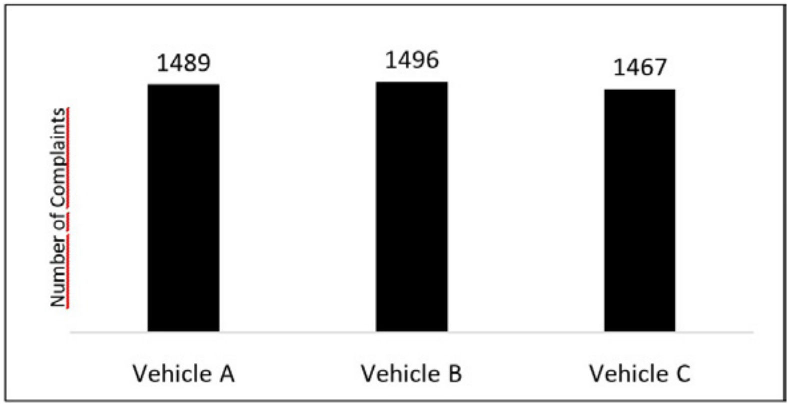
RESULTS AND DISCUSSION

4.1 A – Capture of negative opinions, from the NPS

In order to respond one of the objectives of the study, that is, to verify how after-sales customer opinions were captured to identify and prioritize their complaints, it was necessary to access the result of the 2020 NPS survey of the Alpha company, through corporate documents. Based on this data, it is demonstrated in an adequate way how the company captures the customer's opinions, in addition to exposing the process of evaluating dissatisfaction and defining the key issues that must be addressed by the responsible teams.

In the year of the research used in this study, Alpha produced three car models, named, for the preservation of confidentiality, as vehicles A, B and C. In Figure 3, the amounts of negative customer opinions (complaints) for each car. In the same questionnaire answered by the customers, they were able to give their opinions more than once about each vehicle system according to their perception of the product.

Figure 3 – Complaints related to vehicles.

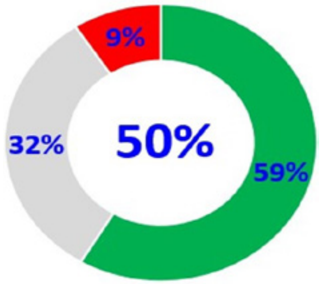


Source: Elaborated by the authors.

The investigation had as its object of study the vehicle model B (Hatch/ Sedan), as it is the vehicle with the highest representation in the number of sales for the Alpha company in the region and has a slightly higher number of complaints (Figure 3) compared to the A (SUV) and C (Med Pickup) models.

In consequence, the number of promoter customers was evaluated respectively with the neutrals and detractors of the NPS survey. In the case of vehicle B, object of this study, 59% of customers are promoters, that is, they recommend the brand and assigned scores between 9 and 10 on the NPS scale. In the other hand, 32% of them are classified as neutral, this means that they provide scores between 7 and 8. The last part of the customers, 9%, were classified as detractors, as they applied scores below 6. Figure 4 represents an overview of these evaluations.

Figure 4 – NPS result of vehicle B for 2020



Source: Elaborated by the authors.

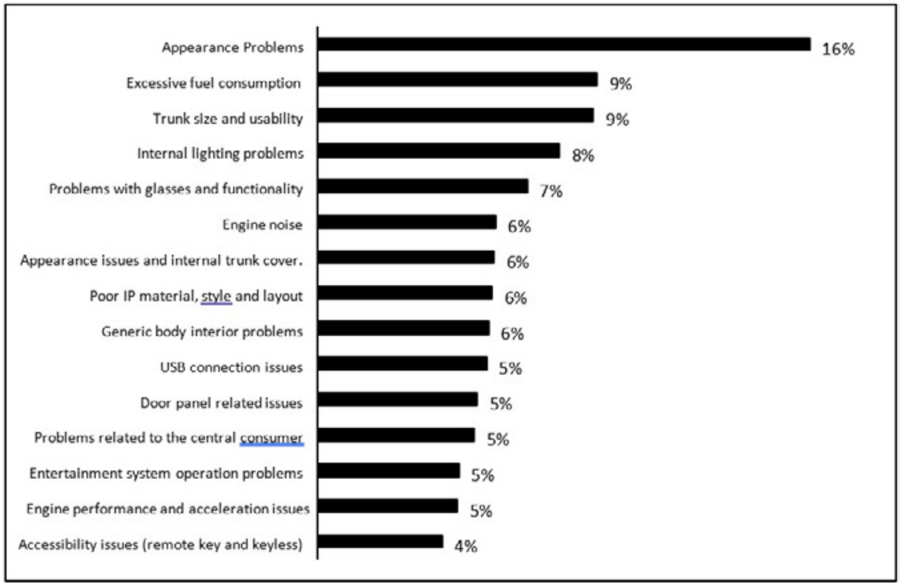
The 50% value represented in the center of Figure 8 is calculated by the number of promoter customers (shown in the green area), minus the number of detractor customers in the red area.

The formula, NPS = 59% (Promoters) – 9% (Detractors) = 50%, brings the Net Promoter Score result to vehicle B. Neutrals are not considered in this equation, as they are not "loyal" customers. In other words, they hardly make recommendations and, when they do, they are without observation or enthusiasm, according to the concepts covered in the bibliographic review.

The next step was to pay attention to the vehicular functions. As the vehicle is divided into specific functions, the objective is to guarantee the prioritization of work teams and, therefore, allow the specialists of the functions to direct their efforts in understanding the problem and eventual solutions. At Alpha, there are teams of professionals from the engineering, quality, and manufacturing areas responsible for each function. These teams work together to understand and prioritize the issues to be addressed.

In Figure 5, it was possible to verify that 16% of the complaints are related to appearance problems, and this complaint is the one that most degrades the vehicle studied.

Figure 5 – Most frequent complaints for vehicle B



Source: Elaborated by the authors.

In order to reach this level of stratification and ordering, a detailing was made considering all the systems of vehicle B. In this way, it enabled the Alpha company to prioritize resources to meet the expectations of its customers.

4.2 B — The application of DMAIC and FMEA to improve the problems indicated in the negative reviews

Through the most negative opinions captured in the previous section, it was found that there are potential areas to be evaluated so that the opinions can be deployed into improvements.

During the investigation process, the first step was to build the “Define” phase of the DMAIC clearly in order to understand the real state of the problem.

In the next step, already in the “Measure” phase of the DMAIC methodology, after clearly defining the problem, it was necessary to align with the entire team responsible and brainstorming sessions to understand which are the most relevant factors of the problem in question.

After all these evaluations, it was recommended to verify that the glove box and the cross-car beam (structural part of the instrument panel attachment to the car body) are meeting the specifications for which they were designed. Furthermore, the storage of the cross-car beam was another variable raised by the team involved as a possible contributor, as it is known that this part is transported by the supplier in large quantities and, depending on the way it is organized inside the rack (storage), it is possible that it will suffer some damage.

During “Analyze” phase of the DMAIC, the product, process, logistics and quality engineering teams worked together to define proposals to implement improvement actions. From the discussions, the main contributors to the failure modes were defined.

After defining the three “Xs”, classified as priorities in the Ishikawa Diagram, the responsible team evaluated that the main contributors to the problem cited by customers would be the variation of the cross-car beam (CCB) and its storage.

Among the main “Xs” defined, one of the main contributors to the problem cited by customers was the CCB. The part supplier’s manufacturing process was evaluated by the responsible team, and it was found that the welding device had wear on the locator pins, which causes misalignment between the CCB and the instrument panel, leaving the assembly out of the specified position, generating gap and imperfections in the position of the glove box, as collected in the NPS survey.

In the “Improve” phase of the DMAIC, after completing the analysis of the “Xs” contributors, action plans were defined to solve the gap problems between the instrument panel and the glove compartment. For the problem of decentralization of the locator hole between the CCB and the instrument panel, a replacement of the locator pins, addition of inspection in 100% of the CCB and retraining of the operators were made. A review of the supplier’s manufacturing process maintenance plan was also organized, increasing inspection frequency.

The lessons learned were added to the FMEA documentation to ensure that the actions taken were considered effective in the future production and respective processes of vehicle B. After all the investigation and implementation of the improvement actions and plan to avoid recurrence, the project was concluded with leadership approval.

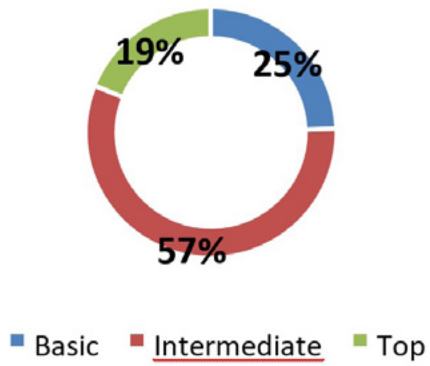
4.3 C — Types of negative opinions that resulted in the most relevant improvements

In this section, the opinions that enabled the most relevant improvements for the vehicle and for the company are selected.

Although the NPS survey is highly disseminated and used in the most diverse fields as an indicator to measure customer satisfaction, the questionnaire applied by the Alpha company cannot collect information such as gender, age, or socioeconomic class of customers. This limits a deeper stratification of the buyer's profile, and this limitation is based on data protection law.

On the other hand, the NPS survey tool offers data such as versions, model (in this study, the model was 2020), engine, country of origin and the type of fuel of the vehicles (in the case of vehicle B, all models are "flex", that is, they use alcohol or gasoline). Figure 6 represents the versions of vehicle model B and their respective percentages of complaints.

Figure 6 – Vehicle B versions and corresponding percentage of complaints



Source: Elaborated by the authors.

By weighting sales volume by versions of vehicle B, Figure 6 shows that most detractor customers own intermediate versions (57%). The hypothesis is that these consumers have high expectations regarding the vehicle, given that in their view the product should have accessories that are only available for a higher model, such as a multimedia center, leather seats or more robust acoustic insulation.

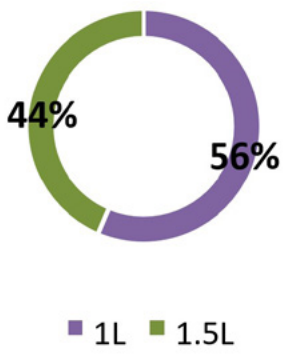
It is noteworthy that the decisions to include accessories, in the top versions, are supported and directed by the marketing and product development teams to guarantee competitive prices and correct positioning in the market. Another information evaluated was the origin of the consumers who made the complaints, as shown, in the case of vehicle B, 82% of the complaints originated in Brazil and 18% in Argentina.

Due to the volume of complaints, the Brazilian customer would naturally be a priority. On the other hand, only 7% of model B sales are to Argentina and 18% of complaints come from that country, indicating that the ratio between complaints and sales volume is significantly higher in Argentina.

It should be noted that although the Alpha company sells cars in several countries in South America, the research for vehicle B was carried out only in Brazil and Argentina. This is due to strategic issues based on the representativeness of the sales volume.

Regarding the type of vehicle engine, the distribution of complaints is shown in Figure 7.

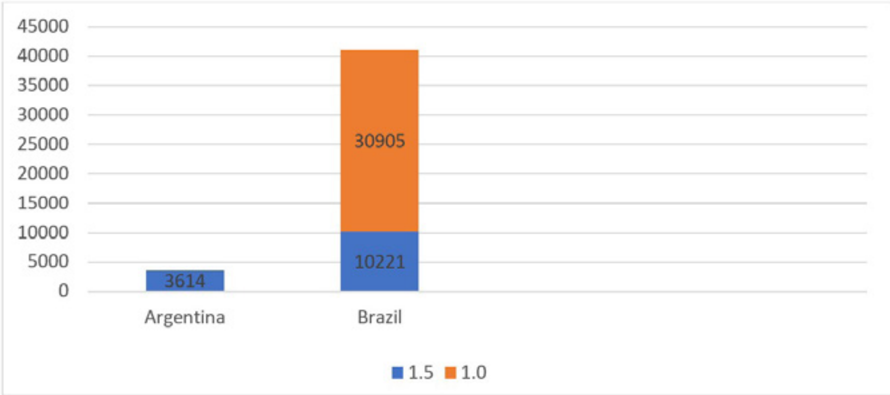
Figure 7 – Complaints classified by engine



Source: Elaborated by the authors.

In this case, it is possible to observe that there are differences in the number of complaints between the types of engines, that is, the complaints of the 1.0 engines are 4% higher than the 1.5 version. It is noteworthy that regarding the models analyzed in the study, version 1.0 is sold only in the Brazilian market. As exemplified in Figure 8, with the distribution of sales volume by version for vehicle B.

Figure 8 – Sales volume by engine



Source: Elaborated by the authors.

Figure 8 shows the representation of complaints from model 1.5, because, despite not being the most sold model, it has a high representation in the general percentage of complaints when analyzing Brazil and Argentina. This stratification is fundamental and can help to understand customer expectations by market, considering the sales volume, version available in each market.

In summary, from the information obtained in the research, it was possible to observe that the Argentine market should receive special attention, given that it is the market that has the lowest number of vehicles sold, but proportionally complains more. In the same sense, it was also found that the vehicles of intermediate versions are the ones that obtained the greatest number of negative opinions, which endorses the need to pay special attention to this audience and vehicle model.

5 CONCLUSIONS — LESSONS LEARNED FROM THE OPINION OF DISSATISFIED CUSTOMERS

Through the study applied in the Alpha company, the use of the dissatisfied customers' opinion to improve the quality of products and processes proved to be a robust alternative for the development of this work. In this sense, the NPS questionnaire consisted of a reduced number of questions. And, through the questionnaire, it was possible to verify the main factors of customer dissatisfaction to focus and prioritize the problems.

Then, the work addressed the steps for defining improvement actions, the use of the agile project methodology, be it DMAIC (for the production stage), or DFSS (for the design stage), as well as the use of the FMEA tool. This allowed us to clearly understand all the steps that make up the investigation process, definition of critical failure modes, application of improvement actions to mitigate or solve problems and to monitor the effectiveness of actions.

As a result, the following points are made by stratifying the markets that receive the most complaints, sales volume by country, vehicle version, engine and vehicle transmission models:

- Vehicle B is the vehicle with the highest number of complaints in the investigated period (1,496) and has the highest sales volume of the company covered in this study;
- From this contingent of consumers, the opinions of the so-called detractor customers were evaluated (9% of the total interviewed);
- Complaints from detractor customers classified in this study referred to 15 different aspects of vehicle B, with 10 of these aspects being presented, corresponding to 78% of classified complaints;
- The versions of vehicle B with the most complaints are the basic and the intermediate;
- Related to the markets by vehicle studied, it appears that the Brazilian market has a greater number of detractors than the Argentinian one, due

to its larger size. On the other hand, the ratio of detractor customers by sales volume is significantly higher in Argentina;

- Related to the engine of vehicle B, despite the number of complaints of the 1.0 vehicle being 4% higher than the number for the 1.5 version, when considering the volume of sales per engine, the complaints of the 1.5 vehicle are more representative, since the percentage difference is very low, with a lower sale volume.

Some limitations were identified in this study, among them the fact that vehicle B is a specific model, so that the representativeness of the exposed data is limited to just this category (Hatch/Sedan). On the other hand, although the conclusions of the study are focused on a particular type of vehicle, this approach of using the voice of the customer to improve products and processes can be applied to other models and industry segments.

Beyond that, due to the limited number of questions in the company's survey questionnaire, it was not possible to achieve a deeper stratification of the customer profile and failure characteristics. The finding in this study gives rise to a suggestion to improve the questionnaire used by the company Alpha.

Furthermore, with the growth of the Internet of Things and the use of vehicles connected to the world wide web, it is feasible to collect data from cars in real time, and this possibility allows acquiring information about the category of customer use, driving alert, diagnosis of potential problems and communication with the automaker through servers and data processing.

Finally, it is concluded that the understanding of customer opinions brings learning to support the development and improvement of more robust vehicles, both from a quality point of view, and in terms of meeting technical and design requirements, according to concepts addressed in the reference theoretical of this work.

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8

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Towards an immersive product development process:

opportunities and challenges for the automotive industry

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ABSTRACT

With the emergence of low-cost virtual reality devices, there is an increasing number of immersive applications in the automotive product development. However, certain constraints must be overcome before the technology's possibilities can be fully harnessed. This study gathers the opportunities and challenges highlighted in patents and literature reviews on virtual reality-based market research, ergonomics assessment, and usability testing in the automotive industry. The patent filings have boomed since 2016, in a technology space that is rapidly evolving, offering opportunities to enter an area while it is still young. Virtual reality benefits the development process by saving costs and time, closing customers, improving interactions, avoiding prototype transportation, optimizing the assembly line, improving the performance and well-being of the user, mitigating hidden dangers, stimulating novel insights and increasing team collaboration, and feeling of engagement, among others. The challenges faced by VR-based processes are the lack of realism due to unnatural tactile and visual interactions, latency and registration issues, communication difficulties between teams, unpleasant symptoms, issues on depth, haptic, motion and movement perceptions, cybersecurity, cybersickness, lack of intuitiveness, and partial control over the user's moving around, among others. While these constraints prevent virtual reality from fully replacing conventional automotive product development in the near future, it is a valuable contribution to the process. These outcomes may provide a reference for decision-makers and researchers to develop innovative immersive solutions in the product development in the automotive industry.

Keywords: virtual reality, product development, ergonomics assessment, market research, usability testing, automotive industry.

1 INTRODUCTION

In the product development, the success of a manufacturing strategy is achieved by specifying a manufacturing process that can be produced with minimal impact. In the automotive industry, to detect late, i.e., already during manufacturing phase, issues on customers preferences on new vehicles, physical ergonomic issues, or problems on usability of a product has a high cost of correction and long the time to launch a new product.

With the emergence of low-cost virtual reality devices, an increasing number of solutions are employing immersive technology in automotive product development process. Not only is the global virtual reality market projected to grow from USD 6.30 billion in 2021 to USD 84.09 billion in 2028 (FORTUNE BUSINESS INSIGHT, 2021), but this rise may be much greater, given that the COVID-19 pandemic boosted the use of virtual reality (CCS INSIGHT, 2021).

In this context, this study gathers the opportunities and challenges highlighted by patents and literature reviews on virtual reality-based market research, ergonomics assessment, and usability testing in the automotive industry.

This document is organized as follows: Section 2 describes the methods utilized, Section 3 analyzes the results, and Section 4 provides our conclusions and future research suggestions.

2 MATERIALS AND METHODS

This study compiles the opportunities and challenges highlighted by three patents and literature systematic reviews. Henriques *et al*. (2021) identified and characterized into attributes the challenges and opportunities for the application of Virtual Reality in car clinics. Gonçalves da Silva (2021) analyzed the application of virtual reality and digital human modeling for physical ergonomics assessment during product development in the industry, and De Freitas *et al*. (2022) identified the benefits and challenges of virtual-reality-based usability testing and design reviews in industry. These are reference studies since no previous works on the topic examined scientific and technological knowledge.

We analyzed the three studies in order to answer two research questions:

Q1: How are patents related to industrial VR-based market research, physical ergonomics assessment, and usability testing in the product development characterized?

Q2: What are the opportunities and challenges of VR-based automotive market research, ergonomics assessments and usability testing in automotive industry?

3 RESULTS AND DISCUSSION

Table 1 compiles the search strategy followed by Henriques *et al*. (2021), Gonçalves da Silva (2021) and De Freitas *et al*. (2022).

Table 1 – Search strategy

Step	VR-based market research	VR-based ergonomics assessment	VR-based usability testing
Knowledge bases explored	PatentScout; ScienceDirect; Springer; IEEEXplore	Derwent; Scopus; Web of Science	Derwent; Scopus; Web of Science
Search phrases defined	"virtual reality", "virtual environment", "artificial environment", automotive, auto, car, "virtual reality", "marketing research", "market research", "human research", "people research"	"virtual reality", "extended reality", "immers*", "digital human modeling", "dhm", "human factors", "ergo*", "product development", "product design"	"usability evaluation", "usability testing", "usability assessment", "usability engineering", "design review", "mixed reality", "virtual reality", "immers*", "virtual prototyp*", industr*, "product development", "product design"
Exclusion criteria applied	**E1** – Documents not written in the English language; **E2** – Published before 2016; **E3** – Publications not related to the industrial domains (such Medicine, Social Sciences, Physics, and Environmental Science; **E4** – Patent applications that are no longer alive.		
Search dates	Jul, 20	Dec, 21	Jan, 22
Included items	72 patents, 13 articles	250 patents, 18 articles	7 patents, 20 articles

Source: Elaborated by the authors.

The research questions Q1 and Q2 are addressed in the sections that follow.

3.1 How are patents related to industrial VR-based market research, physical ergonomics assessment, and usability testing in the product development characterized?

In terms of VR-based market research, in relation to yearly patent publishing, 2018 had the largest number of patents filled. The patent origin locations are highly concentrated on only four countries: United States (with significantly higher number of patents than the other countries), Japan, India, and Chinese Taipei. The patent assignees are also highly concentrated since a small group of only six inventors correspond to 54% of the patents, with five groups from the United States. The identification of the assignees may help the discovery of industry leaders, the evaluation of possible rivals, and the identification of niche players. A large portfolio held by a few companies indicates an active competitive market with strong investments by multiple companies, suggesting that the market is difficult to enter. Concerning the applications, the patents are grouped into four categories: (1) automatic feedback, i.e., apparatus to automatically analyze the VR users' reactions such as gestures, body positions, facial reactions, brainwaves, and eye movements, has biggest average filings and has been growing among the years; (2) using of virtual reality to understanding the customer profile and their intents of purchasing, which is the most spread and stable application over the years; (3) VR-based advertisement, and (4) VR-based stores, with the latter two also stable and spread over the years, but less frequently than customer profiles.

In terms of VR-based ergonomics assessment, the yearly patent publication has increased significantly since 2016, when there were nearly no patent applications, with a notable rise in 2019. The year 2016 was a technological breakthrough in the virtual reality domain (ZENG *et al*., 2018). Before that, commercial virtual reality systems required users to connect a headset, controllers, and sensors to an external high-end computer, which was an expensive, bulky, and inconvenient setup. Thus, the current all-in-one virtual reality systems are a big step forward, occurring only a few years ago

(KUGLER, 2021). The upward trend in patent publications slowed in 2020, with the probable explanation being the 18-month patent legal secrecy restriction. Patent origin locations are highly concentrated, similar to VR-based market research, with the United States and China having equal equivalent proportions of patent filings (44% and 41%, respectively). Again, the high concentration of patent applications among a few assignees is intriguing: the top ten assignees filed 24% of all patents, with Microsoft having 20% of the top ten assignees' patent filings. Of the top ten assignees, six are major players of technology (Microsoft, Apple, Intel, Facebook, IBM, and Bytedance) and two are in industrial automation (Rockwell and Siemens). Regarding technologies that are currently being developed and patented, there were found 30 different technology classifications, with the top three groups being (1) augmented reality, three-dimensional, processing, rendering, model, and storage medium; (2) computing, transitory, touch, information processing, user, virtual, and management; (3) holographic and hologram. The high number of technologies reflects recent innovations and provides an overview of the "state of the market" and market segmentation. Since 2020, there has been a substantial increase in the pace of innovation in the sector: with over 83% of all technologies represented, 2021 had the largest technical diversity.

In terms of VR-based usability testing, following a period of no patent registrations in 2016 and 2017, this trend shifted in 2018, followed by increase in 2019 and 2020, reinforcing that 2016 marked a technological breakthrough in the domain of virtual reality. The upward trend slowed in 2020, although one likely explanation is the 18-month patent legal secrecy restriction. Unlike patents on VR-based market research and ergonomic assessments, patent applications are widely dispersed across many assignees: only one assignee submitted two patents, whilst the remain patents were filed by different assignees. Three of the six assignees are major financial institutions. This large number of assignees, each with a small number of records, indicates a developing technology space, indicating an opportunity to enter a domain while it is still young, either by licensing existing technology, purchasing one of the players, or developing new technology that is not already patented.

3.2 What are the opportunities and challenges of VR-based automotive market research, ergonomics assessments and usability testing in automotive industry?

Table 2 summarizes the opportunities and challenges in each topic.

Table 2 – Summary of opportunities and challenges identified

	Opportunities	Challenges
VR-based market research	• Cost and time savings • Proximity to customers • Flexibility in interactions • Avoidance of prototype transportation	• visual spatial • graphic quality • depth perception • haptic perception • motion perception • physical collision/ movement perception • color and texture definition • sound feedback • interaction/ manipulation • intuitiveness • cybersecurity • cybersickness
VR-based ergonomics assessment	• Cost and time savings • Optimization of the assembly line • Human–machine interactions • Improvement of the overall performance and well-being of the user • Mitigation of hidden dangers	• sense of touch and the expectation of physical resistance cannot be adequately simulated • partial control over the user's moving around • inconsistency between the user's actual movement and the virtual animation • high setup, implementation, and maintenance costs • lack of peripheral visual inputs • little information on the return on investment • reduced sense of immersion • facial tracking jeopardized by motion sickness
VR-based usability testing	• Redesign cost and time savings • Stimulation of Novel Insights • Increased Team Collaboration and Feeling of Engagement • More Intuitive and Natural Interactions • Increased Safety	• Lack of Realism as a Result of Unnatural Tactile and Visual Senses • Latency and Registration Issues • Teams Communication Difficulties • Motion Sickness/ Unpleasant Symptoms

Source: Elaborated by the authors.

3.2.1 Opportunities and benefits

In terms of opportunities for market research, virtual reality is acknowledged as a method to improve costs, timing, and physical prototype relocation required for the research (LAWSON *et al*., 2016). Cost saving is one of the broadest benefits, since virtual prototypes are less expensive to build, demand no storage space, lowers the costs of delivering physical prototypes and avoid user travel (HENRIQUES *et al*., 2021). Virtual also prototypes decrease rework and boost productivity and survey performance. The time to develop a virtual prototype is minimal and can enhance the overall review process; virtual prototypes can be generated earlier than physical property, improving development schedule. A study on Malaysian automobile sector found that the main advantages of using VR were reduced rework and improved manufacturing quality (MOUSAVI *et al*., 2012). Besides, physical prototypes are challenging to handle and move (HENRIQUES *et al*., 2021; MOUSAVI *et al*., 2021). Virtual reality also enables trials that is challenging and costly to do in physical car clinics, such as research with large numbers of participants or in multiple surroundings, such as alternative store setups(LOMBART *et al*., 2020). Thus, immersive clinics might be carried out in more appealing atmosphere than is afforded by physical survey, with VR providing the buyer the impression that they are in a friendlier location, such as a vast showroom or open atmosphere.

In terms of usability testing and design review, virtual reality benefits the conventional design reviews and usability testing processes in two key aspects: over conventional CAD models on screens and over physical prototypes.

The most frequently cited benefit over CAD on screens is that the visualization of products from different viewpoints and on a true scale stimulated novel insights. A conventional review is carried out on a computer with CAD tools on a flat screen, that not always satisfy all the criteria for functional and ergonomic validations of complicated 3D models. Virtual reality allows more novel modes of visualization and interaction to enhance engineering design reviews in this situation (WOLFARTSBERGER, 2019). The opportunity to observe a product from different angles and with more detail might generate innovative discoveries (CHEN *et al*., 2021). Berg and Vance (2017) observed that visualizing planes in a virtual reality environment gave participants a better understanding of the spatial relationships between product components, as well as the interaction space around the assembly line, allowing the design team to understand the operating clearances in real size.

Brandt *et al*. (2017) found that relevant information about transport routes or kinematic properties, which is either not modeled in the CAD data or is lost during conversion processes, played an important role in reviews and provided an observation of machine mechanics. Also, to interact with the geometry of the product (a pump) and the surroundings (an assembly line) on a true scale benefited the understanding of important viewability problems during a subassembly engagement (BERG; VANCE, 2017).

The possibility of new visualization facilitated overall mistake detection. When compared to a standard CAD software approach on a flat screen, participants are more likely to spot faults in a 3D model inside an immersive virtual reality environment (WOLFARTSBERGER, 2019). In Berg and Vance (2017), the team uncovered design flaws and possible solutions that could not be detected or verified using conventional computer tools. VR-based design review enables users to detect significantly more flaws in a 3D model than a CAD-software-based approach on a PC screen (WOLFARTSBERGER, 2019).

The benefits of combining fully digital CAD models with physical components of hybrid prototypes, such as the cockpit gear utilized in the automotive industry, are also emphasized. With the addition of the physical model, designers can evaluate their designs both visually and tactilely. This adds a further physical dimension, allowing designers to not only "see" their designs, but also "touch" them, providing designers with simulated interaction solutions in the early stages of design (MA; HAN, 2019). Virtual reality's benefits might contribute to the Industry 4.0 and cyberphysical system issue of linking the physical and digital worlds (ADWERNAT; WOLF; GERHARD, 2020).

The advantages of improved collaboration and engagement were also frequently cited. Industrial design reviews and usability testing are complex processes involving a variety of stakeholders, including designers, engineers, and end users. In conventional review process, CAD is a communication tool to transmit design ideas and enable a better common understanding among diverging perspectives (WOLFARTSBERGER *et al*., 2018). Virtual reality decreases the possibility of exclusion of some groups from the review process, fostering collaboration among stakeholders (WOLFARTSBERGER, 2019).

The high focus provided by VR-based reviews increases a feeling of team engagement (PETTERSSON *et al*., 2019). In the conventional process, design teams cluster around conference tables with laptops, mobile phones, and paper notes while one person manipulates the design on a 2D screen. Maintaining team engagement and attention becomes more challenging when battling with device distractions. The virtual environment allowed the team to move away from the traditional conference room and into a creative area with fewer distractions. So, the design discussions in the immersive environment increased team engagement, resulting in better interactions and fuller participation from team members in decision-making (BERG; VANCE, 2017).

VR-based design evaluations and usability tests might be more natural, friendly and intuitive for non-CAD specialists. While CAD software does not allow the intuitive manipulation of 3D models by users without a CAD or computer science background (WOLFARTSBERGER *et al*., 2018), interaction in VR environments is generally simple (WOLFARTSBERGER, 2019; ADWERNAT *et al*., 2020). Because of the high level of immersion provided, design reviews and interactions with 3D models are regarded as more intuitive and "natural" for non-CAD specialists, enabling a considerably faster entry into the design review (WOLFARTSBERGER, 2019).

In terms of advantages of virtual reality when compared to the conventional review process of physical prototypes, the most frequently noted advantages are cost and time savings for redesign. Industries may employ virtual prototypes to save money (DE CLERK *et al*., 2017; BOLDER *et al*., 2018; MA; HAN, 2019)., minimize redesign time, and expedite time-to-market. Prototyping is an essential step in the product development process, but after building a product model, testing its design and functionality requires time and money. A VR-based prototyping system can overcome these shortcomings. Because physical prototypes and mock-ups may be replaced by their virtual counterparts, virtual reality improves design verifications and the review process, which might contribute to cost savings for manufacturers (LAWSON *et al*., 2016; MA; HAN, 2019; ADWERNAT *et al*., 2020; GRANDI *et al*., 2020). The principle of "simultaneous engineering", in which elements are designed and tested virtually concurrently with vehicle development, might be achievable with, and potentially strengthened by, the use of virtual reality (BOLDER *et al*., 2018). As an example, in automotive industry, a type of control could be created early and parallel to the development of a new car model and tested within a virtual car model worldwide. So, the cost of redesigning a model can be reduced if the type of control can be changed in the course of development, enabling the creative departments to produce and test novel concepts without disrupting the conventional flow of product development. Virtual reality allows therefore a novel, concrete, and resource-saving design evaluation method with significant application potential, since designers only need to produce the models that need to be tested, which greatly reduces time and costs (DE FREITAS *et al*., 2022). Furthermore, since VR allows to replace physical review meetings for immersive technical discussions, the reduced travel frequencies might save costs (CHEN *et al*., 2021).

For dynamic usability testing, such as driving a car, virtual testing increases the participants safety, that are not subjected to actual risks since a vehicle collision while driving, or a car accident involving passengers, would not occur in the virtual environment (PETTERSSON *et al*., 2019; CARLSSON; SONESSON, 2017; BARBIERI *et al*., 2013).

3.2.2 Challenges and constraints

Concerning VR-based market research challenges, visual–spatial and graphic quality are the most significant issues in a virtual clinic. Since the market research's goal is to determine style acceptability for customers and the external design and vehicle size are important factors in consumer decisions in the automotive business, the prototypes must visually be as realistic to a production vehicle as possible. The graphic quality must be defined so that consumers do not lose fluidity. If this challenge is not addressed, respondents may have the feeling that they are watching a 1930s movie, with visual motions that are slower that the brain requires to give the user the impression that they are in a real world. So, the virtual prototypes must have a sufficient quality to customers provide relevant input in immersive car clinics. A strategy might be to select suitable VR devices, as well as relevant skills on the crew that develops the virtual prototypes and to conduct a pre-event technical team evaluation to anticipate and fix difficulties within an appropriate time frame.

Cybersecurity, product manipulation/interaction, depth perception, and color and texture have the potential to cause significant effects on immersive car clinic applications. Due to product confidentiality, car clinics are held in a secure setting; the virtual clinic likewise demands limiting access, so cybersecurity must be carefully considered. Now there is software that can minimize the threat of illegal access during survey.

In relation to manipulation and interaction in a virtual car clinic, customers should be able to roam around the item on their own, achieving the higher perceived amount of information required between product and customer. This would reduce any adverse effects on virtual product manipulation and engagement. A hybrid reality, which give some level of physical manipulation and interactions connected with a virtual process, could remedy this challenge. Environments that allow customers to wander around the virtual asset, which simulates the same experience as a conventional car clinic with a physical asset, should strengthen the association. To decide how realistic this experience should be, a balancing between the needs of a larger VR area and the advantage of more immersed clinic customers should be undertaken.

Many simulation opportunities, such as opening a door or manipulating mirrors, may be accomplished virtually, but these do necessitate refined virtual prototype and potentially more robust equipment to process such data without losing customers' feeling of movement.

Customers prefer not to approach the car too closely when depth perception difficulties are most apparent; so, market research for exterior design testing experiment may not be an issue. Customers may be bothered by vehicle interior feedback because most customer interfaces and verifications are performed at close proximity to the stimuli. The specification of the Head-Mounted Display (HMD) may also lessen depth perception concerns, so it is critical to determine the best hardware depending on the intended survey outcome.

In physical stimuli, different textures and colors are presented with small samples or 2D images, rather than in a vehicle environment, because this would considerably increase the complexity of stimuli to be done. Virtual reality enhances the opportunity to test various colors and textures in the vehicle surroundings. Through sensors, current VR technology may provide visual texture and basic haptic experience. This difficulty may be readily overcome by combining virtual and actual surroundings. Small physical samples of color and texture taken outside of the virtual environment can be used in the same manner as physical clinics are now operated without the need for several pricey physical stimuli. This can be utilized if VR gear is not available or to lower the expense of virtual vehicle clinics.

Difficulties that have a significant impact on immersive car clinics are the VR equipment intuitiveness, cybersickness, haptic, and physical collisions. Concerns about intuitiveness can be alleviated by selecting appropriate VR devices and delivering consumer instruction prior to the survey. Respondents can experience cybersickness, which is most seen after lengthy periods of use. Car clinics are normally accomplished in a couple hours with some interruptions, such as coffee breaks. These pauses can be timed in a way that minimizes cybersickness; similarly, paying attention to participants' well-being allows for schedule changes. Customers' immersion in the event would be enhanced via haptic feedback and physical collision. Most interactions with prototypes at car clinics are directed by hand–eye coordination, allowing a customer's eyesight to complement hand movement and touch; haptic sensor gloves might support this perception in a virtual environment. Another option is to utilize a hybrid technology, also known as mixed reality, in some parts of the automotive industry, which combines virtual reality with a simple physical asset that customers can touch.

In car clinics, motion perception, sound feedback, and the physical environment needed by VR hardware are irrelevant. Clinics are held in workshops that require space for four to eight vehicles, which is far greater than what VR hardware requires. Since physical prototypes seldom give sound feedback, it is usual in physical car clinics to instruct participants not to evaluate particular prototype performance, such as door shutting sound or similar, due to material limitations. However, if sound is a characteristic to be assessed, having hand gloves with multisensorial and audio connections might improve the survey.

In terms of ergonomics assessment, Gonçalves da Silva *et al*. (2021) observed a contradiction. Despite the consensus on the benefits of carrying out the assessments early – cost and time savings, optimization of the assembly line, and improvement of human–machine interactions – the overall performance and well-being of the user, and mitigating hidden dangers, only a few cases use virtual reality and digital human modeling for physical ergonomics analysis during early product development. The majority of cases oriented to pre-designed production processes, when all resources (devices, facilities, equipment etc.) are fully installed.

Another relevant contradiction relates to the integration of virtual reality and digital human modeling. Digital human modeling has limitations to evaluating physical ergonomics, such as fidelity issues (AHMED *et al*., 2019); failure to properly simulate human perceptions and emotions (WOLFARTSBERGER *et al*., 2018); the need for manual selection of manikin viewpoint, which can be both time consuming and difficult; the need for significant engineering training (GEIGER *et al*., 2020); and an assessment mostly limited to static evaluations of reachability and posture (GLÄSER *et al*., 2016). Studies show that combining virtual reality and digital human modeling include benefits such as more realistic replication of workers' actions into the virtual scene due to motion capture; a higher level of immersion for users; greater simplicity for simulation creation; the lack of direct observation of workers on the shop floor or involvement of production engineers to generate reliable simulations; the ability to conduct interviews with users during task execution, providing of a cost-effective and safe environment for testing various concepts and hypotheses before they are deployed in the real world. In fact, Oyekan *et al*. (2019) estimates that, because of virtual reality's potential to optimize factory layouts before construction, well-designed layouts may save up to 50% of operating costs.

However, still few virtual simulations combine virtual reality and digital human modeling in the same analysis. Hansson *et al*. (2022) suggest as possible explanations the slow integration of virtual reality features into digital human modeling the additional technical expertise required to run such a system and the relative newness of most consumer virtual reality solutions. There is a gap between the researchers' and practitioners' expectations: although academics perceive a clear benefit, further development is required to persuade the digital human modeling community to use the technologies.

Another reason is that virtual reality imposes additional challenges that restrict its widespread adoption. The heavy emphasis on the sense of touch during assembly processes and the expectation of a physical resistance when interacting with virtual structures can often not be adequately simulated (REINHARD *et al*., 2020). De la Cruz and Dajac (2021) addressed the following issues: having only partial control over the user's approach to moving around in the virtual reality environment; inconsistency between the user's actual movement and the virtual animation; high setup, implementation, and maintenance costs; a lack of peripheral visual inputs while wearing head-mounted displays; little information on the return on investment for virtual reality usage. Additionally, rather than improving the sense of immersion, virtual reality can reduce it. Reinhard *et al*. (2020) observed that some individuals may feel less present in a virtual environment or may even respond negatively to virtual reality use by having motion sickness-like symptoms, which can impair work performance. As a result, the facial validity of motions tracked in virtual reality may not be as well established as it is in real-world tests on prototypes.

In terms of usability testing, virtual reality might impose additional constraints on conventional process limiting its wide-spread adoption (WOLFARTSBERGER, 2019). The literature frequently refers to the lack of realism resulting of unnatural tactile and visual senses, that difficulties interactions between individuals and virtual prototypes. The complicated interactions in virtual reality have proven to be major drawbacks in industrial settings. Haptic feedback and multimodal interactions are still problematic, and a lack of visualization and interaction techniques harness the virtual reality's potential (WOLFARTSBERGER *et al*., 2018). The movement of participants' hands could not be well simulated and positioning offset occurs frequently (BERG; VANCE, 2017). Berg and Vance (2017) found that the collision detection experience was insufficiently robust to be helpful in their study. Users reported issues with virtual object feedback when compared to external device motions, such as steering-wheel twisting. Another issue is that the sense of reach and the dimensions of virtual items do not correspond to physical interaction features, such as buttons or flat surfaces that mimic multimedia screens (BOLDER *et al*., 2018; PETTERSSON *et al*., 2019). Given the significance of natural human connection with a virtual interface, haptic devices such as gloves, suits, and others may strengthen the sensation of immersion. Including haptic technology to allow human interaction modeling of natural human senses and motion would result in a significant improvement in usability testing. Replacing the handle with data gloves could simulate hand movement (MA; HAN, 2019). As a result, the effectiveness of incorporating haptic devices to improve usability testing is connected to the purpose of the testing, the complexity of the interaction, and the maturity of the virtual item under consideration. Therefore, haptic devices should be avoided for usability testing on products that are still in the early stages of development and do not have accurate hand-and-finger interaction.

Besides the touch sense, the lack of realism is caused also by visual sense issues. The readability and representation in a virtual prototype system can be troublesome due to the head-mounted display's low display resolution. Some tests participants complained that they could not view the virtual environment clearly because the virtual environment image was not fine enough, requiring more dynamic movement behavior and improved graphics resolution from the virtual prototype (BOLDER *et al*., 2018).

Due to complex interaction systems with a substantial amount of visual information, high graphical representativeness is essential. Otherwise, only systems with a limited number of interactions may effectively correlate with conventional usability testing (BARBIERI *et al*., 2013).

A major issue is that employing virtual-reality technology without an auxiliary device, such as hand-tracking sensors, may influence user perceptions and, as a result, test findings. A strategy for providing tactile feedback to a user engaged in a virtual environment is the adoption of physical tools, such as a flat wood table emulating the screen of a multimedia system (CARLSSON; SONESSON, 2017).

In usability testing with physical prototypes, each participant's perception of a product's depth, reach, and dimensions is spontaneous. In virtual reality, however, the user desires touch with physical devices to handle objects in the virtual world; thus, visual calibration and positioning algorithms are needed to provide an accurate user experience (DE FREITAS *et al*., 2022).

When human interaction beyond visual verification is desired, virtual prototypes present an industrial challenge. When creating functional virtual prototypes that are designed to offer visual, tactile, and aural feedback, the difficulty is to produce a high-fidelity virtual prototype that has the same features as a physical prototype. Geometric component qualities, such as high-fidelity colors and textures or part structure animations (such as when a vehicle's door opens), require powerful hardware to process data within the virtual reality to ensure a reliable experience for the immersed individual.

Since it is critical to assess the participant's emotional reaction while designing the qualitative metrics of a usability test, occlusion is also challenging. Virtual surroundings might diminish some sensations throughout an activity, such as user happiness or dissatisfaction (PETTERSSON *et al*., 2019). While engaged in the virtual environment, the attention of participants became predominately focused on the need to accomplish tasks. Due to the inability to watch the participants' facial behavior, which the head-mounted display was partially hiding, the moderator did not fully observe the participants' emotions. As a result, physical prototypes are advised for tests in which participant behavior must be assessed by face observation (BOLDER *et al*., 2018).

Another difficulty is the time between head movements and viewing the scene, i.e., latency and Registration Issues. Bolder *et al*. (2018) identified registration issues between virtual and physical elements of the environment, which they linked to hand and finger optical tracking controller calibration or tracking errors. The authors sought to improve tracking by instructing participants on how to adjust the head-mounted display before beginning the trial; however, the adjustment cannot be controlled from the outside by the experimenter. The resolution of the HMD might play a role in this scenario. When interacting with mixed physical-virtual prototypes, study participants mentioned a dimensional discrepancy between the virtual and physical aspects of the prototypes (for example, the cockpit's physical wheel and the virtual air conditioning control). So, the need to calibrating the position and visibility of virtual objects with physical prototypes was identified as a barrier. The difficulty is the time it takes to calibrate the system, given that calibration modifications are dependent on the user's participation.

VR-based design reviews of complex CAD data often suffer from communication issues between virtual reality users and team members who observe the virtual scene from an outside perspective (e.g., a TV screen). Therefore, spoken descriptions are often insufficient to express a specific detail about a machinery component. In the virtual environment, participants voiced less (PETTERSSON *et al*., 2019), and Bolder *et al*. (2018) found that the social exclusion of virtual reality users sharing the same physical space as colleagues during a design review session has a negative impact on team communication and cooperation.

While immersed in virtual-reality environments, several people reported motion sickness and unpleasant symptoms, such as nausea or headache. The source of these symptoms, according to the participants, was the lack of shadows and reflections of objects, as well as a delay in the virtual environment related to body movements and gaze (PETTERSSON *et al*., 2019; DE CLERK *et al*., 2017). So, VR-based usability testing needs careful consideration of the method carried out.

A frequent worry when using virtual-reality-based prototypes is whether the correlation with conventional review and testing methods is maintained, as well as the degree of accuracy for usability testing. Literature indicates that virtual prototypes do not compromise correlation, i.e., VR-based usability testing applies to the same degree and may provide results equal to conventional testing with physical prototypes. Ma and Han (2019), Carlsson and Sonesson (2017) and Nam *et al*. (2019) reported that virtual reality usability testing has a significant connection with physical testing in terms of the metrics collected. The variance of quantitative data, such as operation errors and the time spent completing tasks, was statistically analyzed, and their correlations were validated and reported with sufficient correlational data between physical and virtual prototype testing outcomes. There were no significant differences in UX questionnaire data between virtual reality and the physical prototypes, but there were correlations between rated presence in the virtual reality system and UX ratings, particularly for reported stimulation (PETTERSSON *et al*., 2019). The data and experience from a mixed-reality prototype vehicle were equivalent to those from a fully physical prototype vehicle (MA; HAN, 2019) as well as physical prototype and a mixed-reality prototype automobile have comparable rated usability, with no significant difference between the metrics collected (BOLDER *et al*., 2018).

4 CONCLUSIONS

The automobile sector has been under pressure to reduce time to market and increase product definition accuracy. Virtual Reality is a powerful tool to engage with customers from the early stages of product development through after-sales support, as well as might be a cost-saving measure and shorten cycle time in the automotive industry.

The devices remain relatively expensive and technical constraints exist, but the price of virtual reality equipment decreased year on year, technological constraints have been reduced, and new features have been developed, resulting in the increased development of VR applications.

In this context, our findings may provide as a reference for decision-makers and researchers as they continue to develop novel solutions for the industrial product development process.

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ASSISTIVE TECHNOLOGY IN AUTOMOBILES:

a project methodology proposal for product development teams

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ABSTRACT

One billion people, or 15% of the world population, live with some type of disability and in Brazil this rate is almost 24% (50 million people). In addition to people with disabilities (PwD), there are those with reduced mobility, and there is an increasing demand for the adaptation of passenger vehicles for drivers with special needs. Many assistive technology (AT) products are designed to serve these people, but not all are affordable for the low-income population. Therefore, this work aims to contribute with a low-cost AT project methodology for product development teams in the automotive area. The Design Science Research (DSR) method was used, in three stages: 1 – Survey of articles, with a search on the CAPES portal; 2 – Technological prospection for patents, searching the Espacenet database; 3 – Proposed AT project methodology, based on V model. The results show that the demand for AT resources tends to grow in Brazil as well as worldwide, and that most AT projects are developed for people with physical disabilities, showing the need for further research to include other disabilities. Users are not involved in all stages of the AT product development when they should be central. There is a need for investment increases by the government and private sectors for technological advances in the AT area. The number of articles and patents related to this theme is limited and it is assumed that it is related to confidentiality and industrial privacy issues. The solutions developed in educational institutions are not always industrialized and incorporated into the market. This study aims to bring benefits to the academic community and the automotive industry, with a possible increase in market share and competitiveness, in addition to contributing to society and sustainability. The application of V model as a basis for the proposal was very adequate. As a continuation of this research, it is suggested to verify the applicability of the proposed project methodology.

Keywords: People with disability, Drivers with special needs, Assistive technology, Automobiles.

1 INTRODUCTION

About 15% of the world's population, or 1 billion people, live with some type of disability (WHO, 2022). Brazil has around 50 million people with disabilities (PwD), which corresponds to almost 24% of its population, most of them being located in the Northeast, the lowest income region of Brazil, whilst also having the lowest HDI (human development index) (IBGE, 2010; BRASIL, 2020). Most people are visually impaired, representing 18.8% of the Brazilian population. Then comes the physical disability, representing 6.95%. The largest contingent occurs in elderly group, around half of PwD population (STOPA *et al*., 2020).

These numbers tend to increase even more, in view of the expected increased life expectancy, and an aging population in the coming decades (OPAS, 2016). In addition to PwD, anyone can have temporary reduced mobility (BRASIL, 2015). Between 2000 and 2015, life expectancy increased by 5 years globally and Brazil recorded an expectation of 75 years, with an estimated increase to 77 years in 2020 (OPAS, 2016). However, there was a decline of 1.94 years in 2020 due to the COVID-19 pandemic (CASTRO, 2021).

There are laws to promote inclusion, equality, mobility and accessibility for all people. But in everyday life, people with special needs face a harsh reality to live in society, facing obstacles that hinder their autonomy and quality of life (CGEE, 2012; BARBOSA, 2016). There is an increasing need to adapt transportation to meet their needs, since having the right to transport means having access to the social, cultural, economic and political activities of society (MARSHALL, 1967). A huge arsenal of equipment, services and special strategies, called assistive technology (AT) have been developed to minimize or eliminate the functional problems encountered by these people, however, they are not accessible to everyone (BRASIL, 2015). In many low and middle-income countries, only 5 to 15% of people who need AT devices have access to them (WHO, 2022).

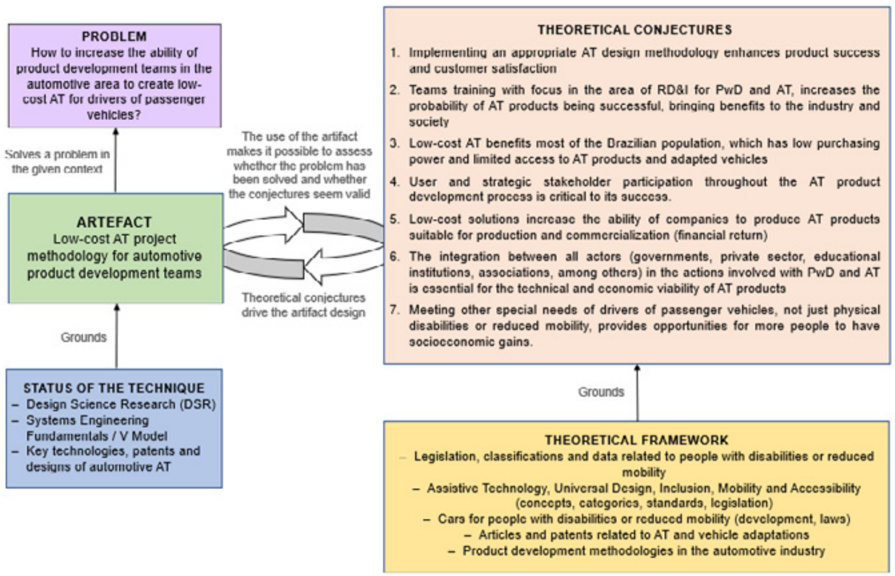
AT can be divided into 12 categories: 1- Aid for daily life and practical life; 2- Augmentative and/or Alternative communication; 3- Computer accessibility features; 4- Environmental control systems; 5- Architectural projects for accessibility; 6- Orthoses and prostheses; 7- Postural adequacy; 8- Mobility aids; 9- Aid for the qualification of visual ability and resources that increase information to people with low vision or blindness; 10- Aid for the expansion of hearing ability and for autonomy in communication to people with hearing loss, deafness and deaf blindness; 11- Adaptations in vehicles and in vehicle access environments; 12- Sports and leisure (BRASIL, 2012).

Automotive AT can be produced in factory by the OEM (Original Equipment Manufacturer) otherwise the vehicle can be adapted by specialized companies (BRASIL, 2012; BARBOSA, 2018). Public participation, including people with disabilities or reduced mobility, during the planning and development stages of transport projects is essential to provide a safe, accessible and reliable transport system for all (DOT, 2020).

In view of the scenarios of an increasing trend of PwD over the years, increased interest in purchasing vehicles, little availability of national and affordable AT, low income and limited access to AT products by the majority of the Brazilian population, it has been verified that there is a need to make more low-cost automotive AT resources available to promote accessibility and mobility. As a solution, this study proposes the creation of a low-cost automotive AT project methodology for product development teams, aiming to meet the main needs of drivers of passenger vehicles, with special needs.

For the development of this research, an epistemological-methodological approach called Design Science Research (DSR) was used, which makes it possible to carry out scientific research linked to the development of artifacts. Figure 1 shows the map of the main elements of this DSR.

Figure 1 – Mapping of the DSR elements of this research

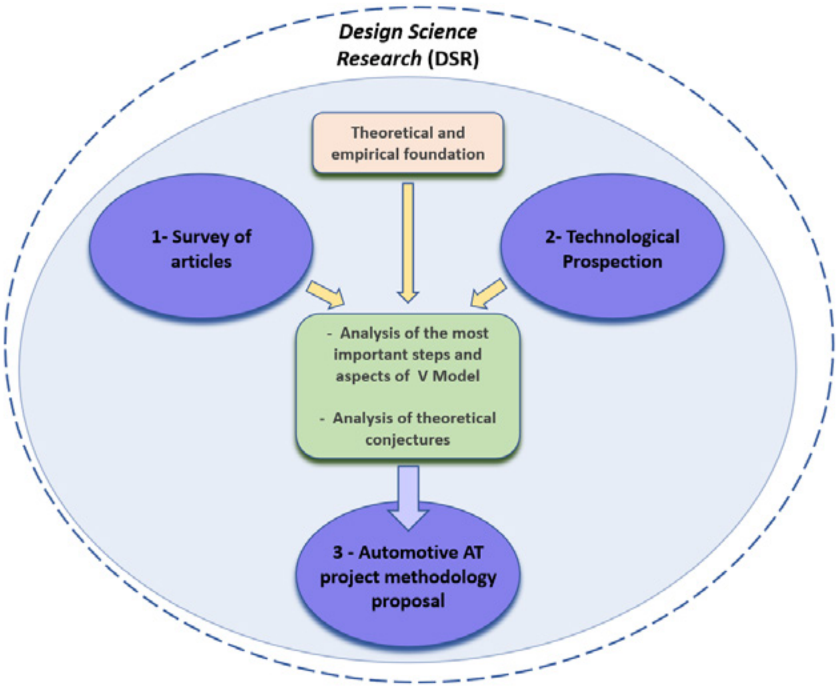


Source: Adapted from Pimentel *et al*. (2019).

2 METHODOLOGY

The fundamental principle of this DSR is that through the definition of the problem and study of the theoretical framework items, it is possible to define the theoretical conjectures, which support and direct the construction of an artifact to solve the problem (HEVNER; CHATTERJEE, 2010). An artifact can be anything designed to achieve a goal: a construct, a model, a framework, a method or an instantiation (PEFFERS *et al*., 2007; HEVNER; CHATTERJEE, 2010). This DSR is divided into 3 stages showed in Figure 2: Survey of articles; Technological prospection; Automotive AT project methodology proposal.

Figure 2 – Main steps of this DSR



Source: Adapted from Peffers *et al*. (2017) and Hevner and Chatterjee (2010).

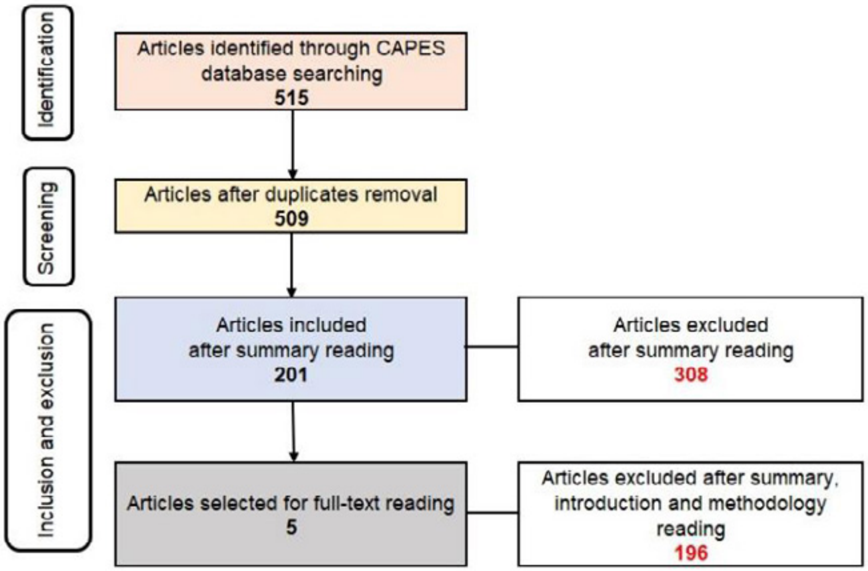
The theoretical and empirical foundation, and surveys of articles and technological prospects, serve as a source for the elaboration of theoretical conjectures, which guide the design of the artifact based on the V model.

2.1 Survey of articles

A survey of articles has been carried out with the objective of characterizing the current knowledge on the topic related to AT in vehicles for PwD, with a search for peer-reviewed articles produced worldwide (all languages), in the CAPES journal database, corresponding to the period from August 2015 to August 2020, using the keywords and boolean operators: *Tecnologia Assistiva*; Assistive Technology and Automotive; Assistive Technology and PwD; Assistive Technology for vehicles and PwD. 515 articles were identified, 6 of which were repeated.

By reading the abstracts, those with a thematic approach related to automotive AT for people with disabilities or reduced mobility were identified, totalling 201 studies. Then, the abstracts were read, as well as the introduction and methodologies, in order to classify them according to type of disability, age group, year of publication and study type, country of publication, AT category. The studies that fitted AT No. 11 (Adaptations in vehicles and in vehicle access environments) were selected for full reading, totalling 5 articles, according to the flow in Figure 3.

Figure 3 – Articles selection according to inclusion and exclusion criteria



Source: Elaborated by the authors.

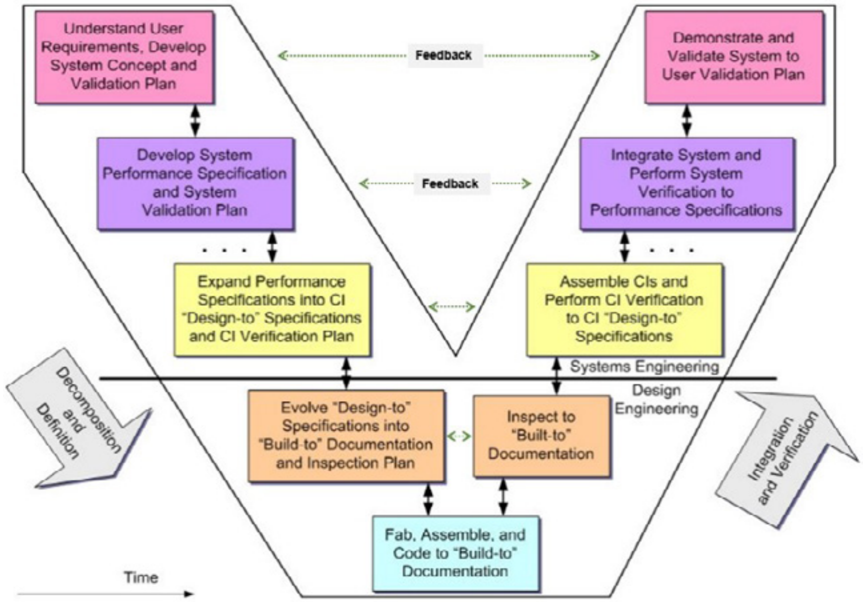
2.2 Technological Prospection

A patent search has been carried out on Espacenet (a database of the EPO – European Patent Office), together with the survey of articles, to characterize the current knowledge and technological maturity on the subject related to AT in vehicles for people with disabilities or reduced mobility. The objective was to understand the main project types that generated patents over time, and for which type of disability, and whether Brazil was among the main applicants. This data supported the development of the theoretical conjectures for the DSR.

2.3 Automotive AT project methodology proposal

In this study, the artifact is a project methodology, being the V model from Figure 4 the basis for its development, based on author's previous experience in automotive industry, also for the fact that it has been widely applied in systems engineering and development (ESTEFAN *et al*., 2007).

Figure 4 – Original V Model



Source: Estefan *et al*. (2007) and Ruparelia (2010).

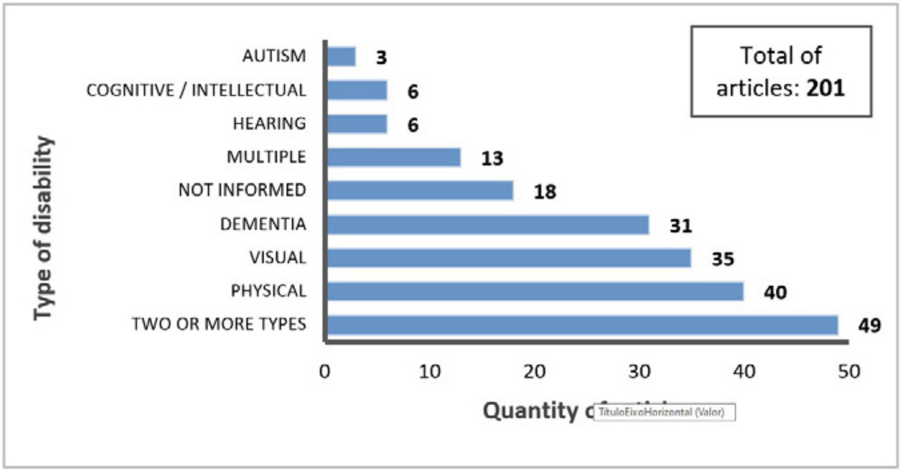
The model is primarily requirements-driven and starts with identifying user requirements. It has two sides, which are directly correlated, so that the validation and quality assurance procedures are defined on the right side, during the development of the corresponding stages on the left side (RUPARELIA, 2010). The V Model was adapted to include the important steps determined by this study, becoming a specific model for the development of low-cost automotive AT for drivers of passenger vehicles.

3 RESULTS AND DISCUSSION

3.1 Survey of articles

The 201 selected articles were analyzed to extract the most relevant data, which are presented in graphs prepared in the Excel format. Figure 5 shows the number of articles by type of disability.

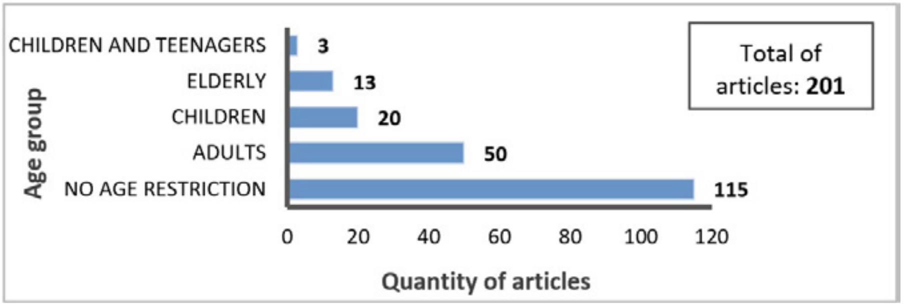
Figure 5 – Number of publications (articles) directed to each type of disability



Source: Elaborated by the authors.

Most of the articles deal with AT for people with physical disabilities, with 40 articles. After which comes the AT for people with visual impairments, with 35 articles. In general, most of all studies were directed to people with physical disabilities. Figure 6 shows the distribution of articles by age group.

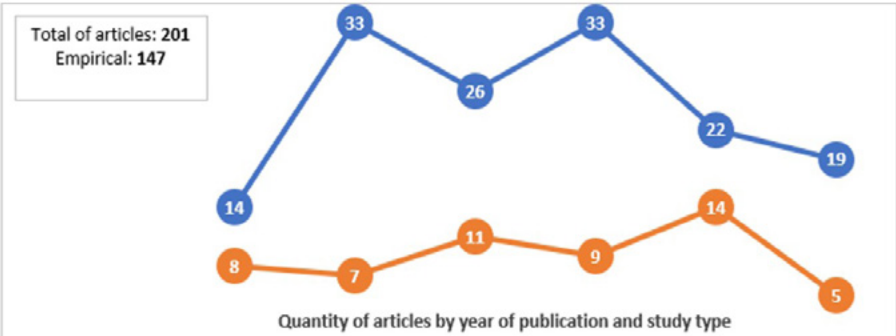
Figure 6 – Number of publications (articles) directed to each age group



Source: Elaborated by the authors.

Most articles did not restrict the application of AT by age. Those who specified age were mostly aimed at adults, with 50 articles, followed by children, with 20 articles. Figure 7 shows the number of articles by year of publication and study type.

Figure 7 – Number of articles by year of publication and



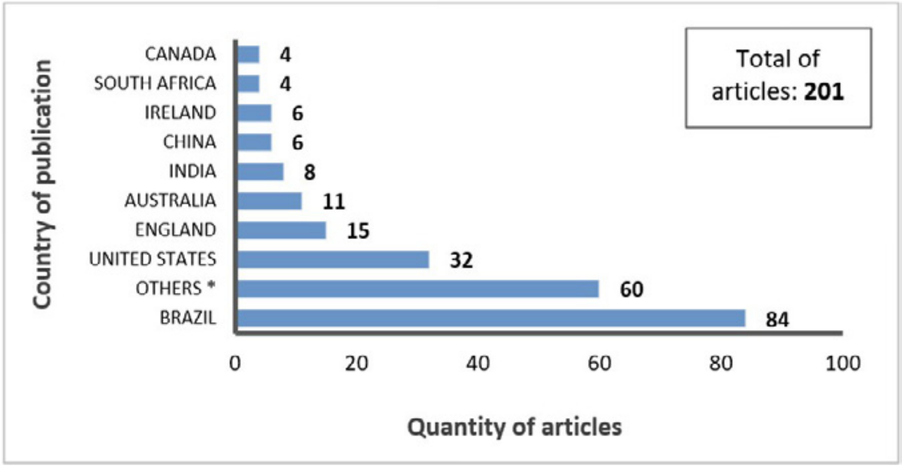
Type/ Year	2015	2016	2017	2018	2019	2020
Empirical	14	33	26	33	22	19
Theoretical	8	7	11	9	14	5

study typeSource: Elaborated by the authors.

The number of publications did not change significantly between 2015 and 2020. The greater number of empirical studies can be attributed to the fact that is the research area in question is very recent, for-which academic and institutional recognition is still in the process of being built to provide the basis for new theories (GARCIA *et al*., 2017).

Figure 8 shows the articles by country of publication, and considering only those with 4 articles or more, resulted in 9 countries. Another 30 countries had published 3 times or less and appear in the chart as Others*.

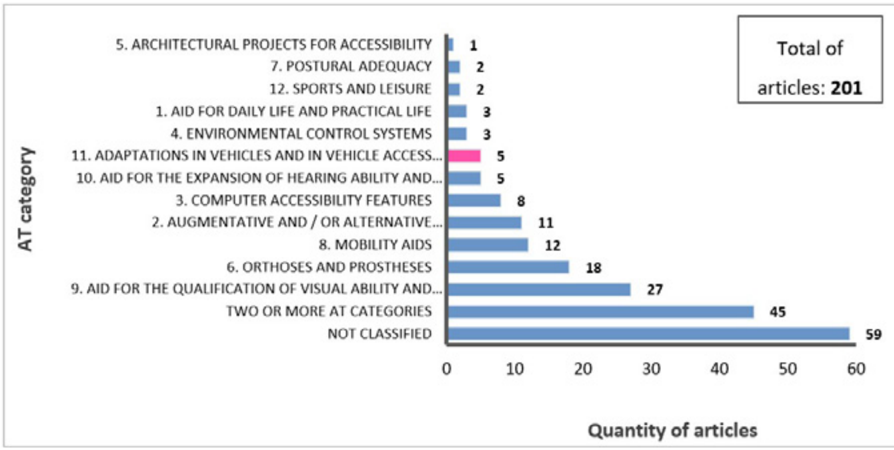
Figure 8 – Number of articles by country of publication



Others *: Saudi Arabia, Italy, Mexico, Israel, Denmark, Spain, Germany, Korea, Switzerland, Malaysia, Scotland, Pakistan, France, Japan, Hong Kong, Austria, Ghana, Portugal, South Korea, Finland, Vietnam, Romania, Taiwan, Qatar, Croatia, Greece, Colombia, Canada, Sweden, Bangladesh. Cited 3 times or less.
Source: Elaborated by the authors.

Brazil has a predominance of articles, with 84 articles, which is explained by the use of the Portuguese keywords "*Tecnologia Assistiva*" in searches in the CAPES journal. Following Brazil is the United States with 32 articles, England with 15 and Australia with 11. Figure 9 shows the articles by AT category.

Figure 9 – Number of publications (articles) directed to each AT category



Source: Elaborated by the authors.

45 articles covered two or more AT categories and the majority had focused on people with visual or physical disabilities. Among the 97 articles that specified only one AT category, AT number 9 predominated, with 27 articles, followed by AT number 6, with 18. The focus of this research is on AT number 11, which presented only 5 studies. It can be deduced that this may be related to the confidentiality issues of the work developed together with the companies, limiting their publications. A complete reading of the 5 articles was made and none of them addressed the development of low-cost automotive AT, or AT project methodology for product development teams in the automotive area. They are really innovative, but mostly explored high-cost AT, like brain-actuated car or expression facial detection.

3.2 Technological Prospection

The selected patents have been analyzed to extract the data of interest for this research. The results show that the total number of patents filed in this area is minor and with limited increase over the years, which might be attributed to industrial privacy. 28 countries registered patents, with China and the Republic of Korea being the main depositors, while Brazil has registered only 1 patent. The reason might be associated to lack of resources and privacy issues. All of them have the focus on people with physical disability. This data supported the strategies for the elaboration of the project methodology proposal, through the understanding of the necessary investments in RD&I and in specific projects to assist drivers with special needs.

3.3 Automotive AT project methodology proposal

Using the results from previous steps to develop the theorical conjectures, the following systematic steps were created to be applied to V model, becoming a specific project methodology for low-cost automotive AT:

I. Definition and preparation of internal areas.

a. Definition of the internal areas of the company / b. Preparation of the internal areas of the company: Specific training.

II. Definition of individuals or external groups (stakeholders).

a. Users definition: Engagement of drivers with disabilities or reduced mobility / b. Definition of professionals from different areas / c. Partnerships with

Research Institutes / d. Partnerships with other AT developer companies / e. Partnerships with groups related to AT and PwD themes / f. Partnerships with federal and state governments.

III. Verification of user needs and problem definition, using Design Thinking.

a. Use of techniques applied by Engineering, Marketing and User Experience (UX) / b. Evaluation of competitors and products already on the market / c. Free face-to-face Occupational Therapy Professional assessment for users.

IV. Generation and selection of AT product ideas.

a. Use of techniques applied by the Engineering, Marketing and UX Teams / b. Company investment to create favourable environments for creativity and innovation / c. Assessment of automotive AT solutions already on the market.

V. Definition of technical and project requirements.

a. Transforming user needs (voice of the customer) into technical design requirements.

VI. Design and development of AT products.

a. Search for lower cost alternative resources and materials / b. Strengthening data and intellectual property protection: patent registration / c. Systematization for higher quality at all stages: Standardization and normalization / d. Application of tools for the elaboration of new projects / e. Focus on sustainability and concern for environmental impact: 17 Sustainable Development Goals (SDGs) and ESG (Environmental, Social and Governance) / f. Project feasibility analysis: EVTEC (Technical, Economic and Commercial Feasibility Study) / g. Definition of AT product validation plans.

VII. Prototype construction of AT products.

a. Use of virtual prototyping to reduce the number of physical prototypes / b. Use of partner resources.

VIII. Evaluation and validation of AT products.

a. Tests (Virtual and Physical) for validation of requirements, standards and legislation / b. Experimentation in the real situation of use / c. Certification and evaluation by users and external stakeholders.

IX. AT products manufacturing and validation of the production process.

a. Search for alternative and cost-effective production methods / b. Partnerships with other AT development companies for larger scale production / c. Use of existing business centers and tax incentives from public bodies / d. Validation of the production process according to company requirements.

X. Launch of AT products on the market.

a. Advertising campaigns by Marketing Teams / b. Financial incentives and awards for technological innovations and patents filed / c. Implementation and dissemination of support and incentive programs so that PwD can acquire the special driver's license and buy vehicles with tax incentives.

XI. Monitoring sales and use of AT products - field validation.

a. Sales database creation / b. Customer satisfaction survey (feedback) / c. Verification of adaptation or adjustment needs in the product / d. Proper documentation process (Lessons learned, publication of works).

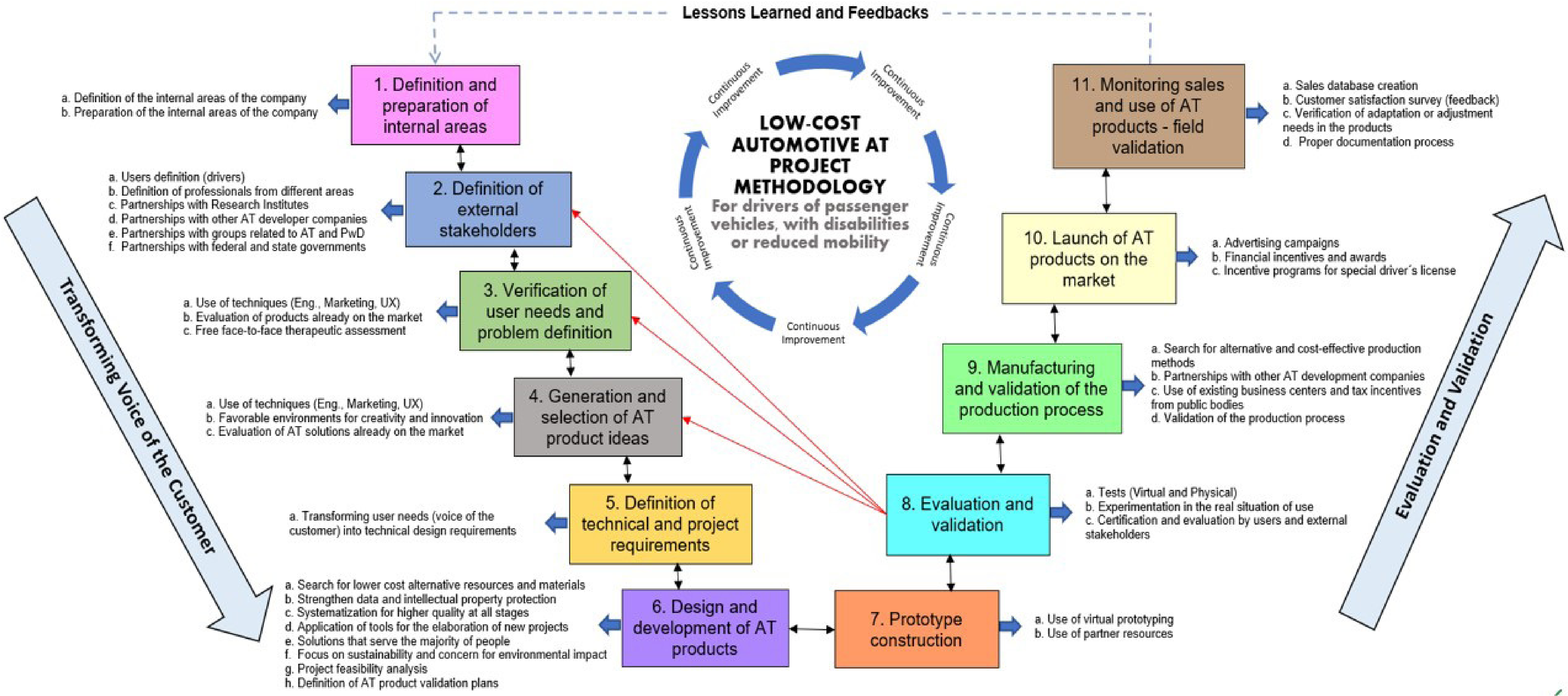
The main benefits of these steps are described below, and it is assumed that they led to a reduction of time and/or cost, as well as a greater probability of product success and customer satisfaction:

More assertive projects aimed at a wide range of people, an increase in national projects, with reduced dependence on raw materials or imported products. Improvement in communication between society, companies, researchers, institutions and public bodies. Effective involvement of users from the beginning of the project, with a deeper understanding of their needs. More assertive definition of the project requirements and validation plan (lower cost, sustainability, more security for the company's investment). Increased product quality and possible increase in sales and revenue, with less after-sales costs. More possibilities of re-design before the final investment. Partnerships with other companies. Maximum use of operational capacity. Social action, with more information and culture dissemination, making all people aware of PwD and their needs. Whilst demonstrating to drivers with disabilities or reduced mobility, the existing AT products which meets their needs, would generate more interest and more customers.

All stages of the methodology, including the identification of external stakeholders, rely on the participation of users, who must be considered protagonists throughout the development process of AT products. They can create strong and lasting relationships, which translate into profitability and growth.

Based on the steps described above, the methodology of Figure 10 was elaborated:

Figure 10 – AT project methodology proposal based on V Model



4 CONCLUSIONS

With the growth of the number of people with disabilities or reduced mobility, the demand for AT tends to grow in the same proportion. Low-income people do not have access to AT resources, which are expensive and do not always provide the financial return intended by companies, limiting investments in production and innovation in this area. There is a need to increase investments from Governments and the private sector for technological advances in RD&I in this area. The number of publications available in the literature is low, being mostly composed by articles and patents directed to people with physical disabilities, pointing out the need to explore other types of disabilities. Only 5 articles addressed AT number 11, and it is assumed that this is due to confidentiality issues. No article addressed low-cost automotive AT or AT design methodology to assist product development teams in the automotive area, reinforcing the relevance of this study. It is also noted that solutions developed in educational institutions do not always reach the level of maturity to be industrialized and incorporated in the market.

It is assumed that the proposed methodology will help product development teams in the automotive area to create low-cost AT for drivers of passenger vehicles, focusing on UD (Universal Design) and empathic human-centered methodologies. The use of the V model proved to be very suitable, as: it has the voice of the customer and the stakeholders as a premise for the products development; automotive engineering teams are familiar with this tool; it was possible to introduce all the theoretical conjectures raised in the research. The ideal would be to have as many adaptations as possible approved and carried out in factory by OEMs or partner adaptation companies, guaranteeing the quality of the products. It's a matter of health and safety and not just inclusion in the vehicle domain. The active participation of all affected groups is necessary at all stages of AT development, giving credibility to processes and products. It is suggested that alliances between educational institutions and companies are strengthened, enabling the connection between scientific innovation and technological innovation. It is recommended the creation of specific and trained teams for exclusive dedication to AT development. This study brings ideas that will allow reflection and deepening of this subject and brings benefits such as the qualification of scientific and technological knowledge for the academic community and for the industry, with a possible increase in market share and competitiveness. In addition, it contributes to society, as the aim is to improve the quality of life of people with special needs and their families, providing greater opportunities for independence and active participation in society. As a continuation of this research, it is suggested to verify the applicability of the proposed methodology. Although it does not invalidate the study, the results found here should be viewed with caution, considering that the search for articles occurred only in one database. It is suggested that new studies expand the literature review considering other databases.

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10

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A PROPOSED LIST OF REQUIREMENTS RELATED TO THE IMPLEMENTATION OF SHARED AUTONOMOUS VEHICLES IN URBAN AREAS

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ABSTRACT

It is predicted that 60 percent of the global population will be living in urban areas by 2030. In order to provide a sustainable growth, the United Nations, which has Brazil as an associate, has set ambitious targets to be met by the end of this decade, which call for valuable transport systems for everyone. Systems that will have to be affordable, accessible, safe, and sustainable. Elderlies and people with disabilities will have to be assisted as well. Big constructions, such as overpasses, ring roads, and subways take long to be delivered, what makes it necessary to search for other alternatives such as the ones based on technological innovations. This work suggests the implementation of shared autonomous vehicles (SAV) as an option to help out on urban mobility challenges. This way, this study has as its main objective to elaborate the requirements related to the implementation of SAVs in big Brazilian cities, and so, to detect the benefits for the population, the barriers, the needs, and strengths related to our big urban centers. In order to achieve that, the study will be based on the V-Model of Systems Engineering methodology, which will consist in identifying the stakeholders, evaluating the relations among them, and lastly defining the requirements. It's expected this work will collaborate in supporting the decision-making process related to SAVs.

Keywords: Shared Autonomous Vehicle, Traffic Legislation, Urban Mobility, Stakeholder.

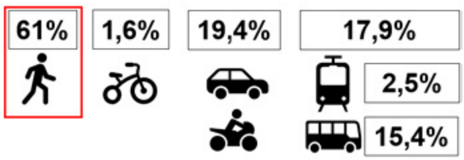
1 INTRODUCTION

It is predicted at least 60% of the world population will be concentrated in urban areas by 2030 (UN, 2021). Today, only half of the urban population has convenient access to public transportation (PT), between 500m to 1000m to the nearest pickup point. In developing countries that can be worsened, where most people rely on the PT, and use to live in the suburbs. In 2013, a manifestation called *Passe Livre* claimed for free of charge mobility for everybody (MARICATO, 2017) in Brazil. During an economic growth in Brazil, from 2003 to 2013 (LUCE, 2013), more people could afford to choose comfortable private transportation means, what resulted in traffic congestion, lack of productivity, and caused a shortening on the PT services and an increment on the PT fares (GOMIDE, 2003). Economic and environmental costs associated with traffic congestion are very high (ECONOMICS; RESEARCH., 2014), and are related to the global warming (UN, 2021).

The Covid-19 pandemic, caused by the virus SARS-CoV-2 (VELAVAN; MEYER, 2020), has highlighted the negative factors related to the big urban centers, mainly for people in absolute poverty (TAVARES; BETTI, 2021). The pandemic has defied the governments to find ways to overcome the pandemic related economic crises (WERNECK; CARVALHO, 2020) and has also caused an impoverishment of the population (MATTEI; HEINEN, 2020), what may force more people to be dependent on PT, which is a social right according to the Brazilian Constitution (BRASIL, 2015).

The percentages of transport modes mostly used in the Brazilian urban centers (SIMOB/ANTP, 2020) are shown in Figure 1:

Figure 1 – Categories of Transportation



Source: Elaborated by the authors.

The Brazilian population is aging (IBGE, 2010). With that in mind, the population will require more assessable sorts of transportation, which can come closer to the origin and final destination (first and last miles).

Urban transportation is on the verge of being electrified and automated and become shared (on-demand) (FULTON, 2018). Smart cities are arising and demanding solutions to address efficiency and sustainability issues, with the aid of technology innovations (ANGELIDOU, 2015). That may allow a leapfrogging (AMUOMO, 2017) on the transport systems of urban centers in developing countries. SAVs have the potential to improve safety on the roads, reduce traffic and help the environment (FAGNANT; KOCKELMAN, 2015).

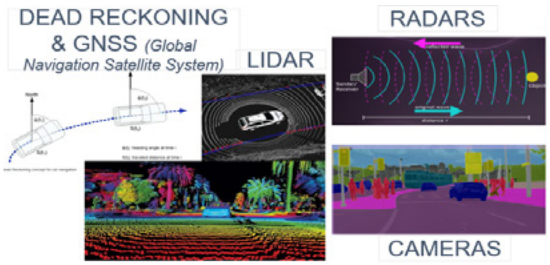
Research question: What are the requirements for the implementation of an urban road SAV in an emerging country like Brazil?

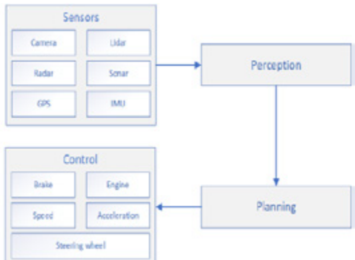
Objective: Propose requirements for the implementation of SAV in urban areas, by identifying the affected stakeholders, their expectations, and evaluate the relations among them.

2 LITERATURE REVIEW

There are six levels of vehicle automation, being level 5 used to designate a vehicle in which all the occupants are just passengers, and, therefore, it is driven without human intervention (SAE, 2021). SAVs can self-locate and gather information from the vicinity thorough the usage of sensors distributed around the vehicle, such as radars, cameras, lidar (Figure 2). The gathered information is dealt in a sensor fusion basis by algorithms which translate this data into meaningful information, and then decide what action to be performed by the control module: steer, accelerate, brake (KOČIĆ; JOVIČIĆ; DRNDAREVIĆ, 2018) (Figure 3).

Figure 2 – Sensors **Figure 3 – Block diagram of the AV system**





Source: Adapted from Vozar and Wyglinkski (2019).

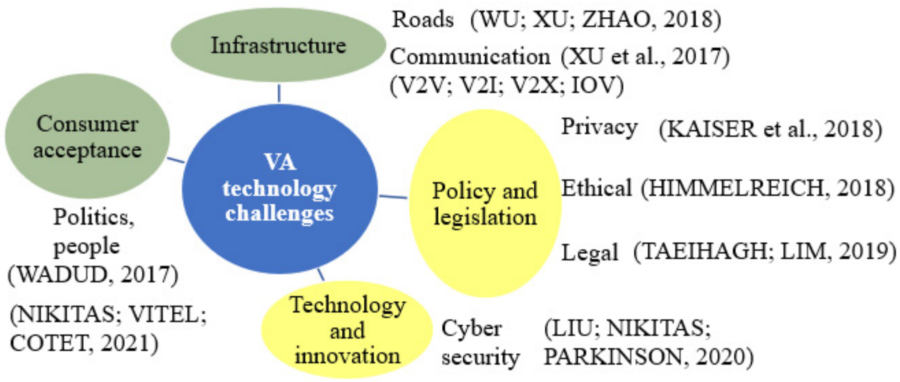
SAV market penetration forecasted for 2030 is still small, despite the expected increment on shared transport modes (MISKOLCZI *et al*., 2021). Shared mobility may facilitate the economic viability of AVs (STOCKER; SHAHEEN, 2017) and compensate the raise on the vehicle miles traveled (VMT) (ROSS; GUHATHAKURTA, 2017). Improvements on congestion and emissions levels will be more satisfactory in case of massive autonomous vehicles (AV) implementation (LIU *et al*., 2019).

The lockdown strategy imposed to the population during the Covid-19 pandemic forced people to stay home (BORKOWSKI; JAZDZEWSKA-GUTTA; SZMELTER-JAROSZ, 2021) People have learned how to study and work at distance, using the internet (BRIDI *et al*., 2020). E-commerce was enhanced in the same period, what overstretched the freight transport system, worsening the emissions caused by these services (NOGUEIRA; RANGEL; SHIMODA, 2021). On the other hand, people transport services faced a drop on revenues (JUNIOR *et al*., 2021). This scenario suggests vehicles and transport systems to attend a mix of people and cargo, allowing a more efficient usage of the fleets, as investigated in Singapore (SUN *et al*., 2020).

PT users demand for solutions more flexible, trusting, and comfortable, what fosters the development of new technologies (MACHADO *et al*., 2018). A concept called mobility as a service (MaaS) refers to the ability of searching, booking, and paying for the ride in only one system (HEIKKILÄ *et al*., 2014). MaaS promotes the integration of several transport modes to fulfill the user itinerary, being them public or private, and also including the first and the last miles, or targeted public (AMBROSINO *et al*., 2016).

KPMG has published the “Autonomous Vehicles Readiness Index” (AVRI) annually (KPMG, 2020), which measures the level of preparedness for AVs across 30 selected countries by applying a questionnaire based in four pillars, whose answers come from publicly Available atformation, including media reports, press releases, and others (Figure 4).

Figure 4 – AV technology challenges



Source: Elaborated by the authors.

Brazil did not rank well in the last editions of the AVRI, similarly to countries like India, Mexico, Chile, and Russia. Nevertheless, the good news is that Brazil has recently disclosed the *Estratégia Brasileira de Inteligência Artificial-E-BIA*, the Brazilian Artificial Intelligence Strategy (BRASIL, 2021), giving emphasis on the need of investments in the field of artificial intelligence, and updates on the Constitution to support the implementation of AVs. Another document, called *Plano Nacional de Redução de Mortes e Lesões no Trânsito* (PNATRANS), National Plan for the Reduction of Deaths and Injuries in the Traffic (BRASIL, 2018), imposes goals to reduce the number of deaths on the roads by 50% until 2028, targeting updates on the traffic laws by 2028, in support of the AVs implementation, and by 2025 to support AV tests.

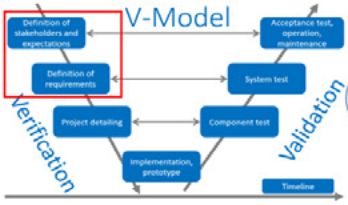
Developed countries such as United States, Sweden, Germany, United Kingdom, and France have already started AV tests on public roads and initiated the processes to update the laws in terms of liability for the upcoming accidents with AVs (NHTSA, 2021; TRANSPORTSTYRELSEN, 2021; LEXOLOGY, 2021).

European Union (EU) is moving towards a target of zero deaths caused by traffic accidents (COMMISSION, 2019). Germany is responsible for more than half of the patents related to AVs (DFKI, 2021). China is also on the race to update the laws to facilitate the spread of AVs, and so has recently issued the "Draft Proposed Amendments of the Road Traffic Safety Law", mentioning road tests and liability matters (LEXOLOGY, 2021).

3 METHODOLOGY

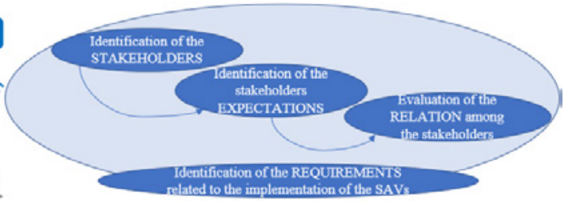
The implementation of the SAV will imply on the development of many other technologies, what directed this study to follow the Systems Engineering methodology, which can administer design, realization, technical management, operations, and retirement of a system (HIRSHORN, 2016). The methodology steps can be understood with the aid of the letter V, known as V-Model (Figure 5). The steps on the left are related to the product development, and the ones on the right are related to the test and validation phases. This study is limited to the initial V-Model steps (Figure 6).

Figure 5 – V-Model



Source: Elaborated by the authors.

Figure 6 – Methodology steps



Source: Elaborated by the authors.

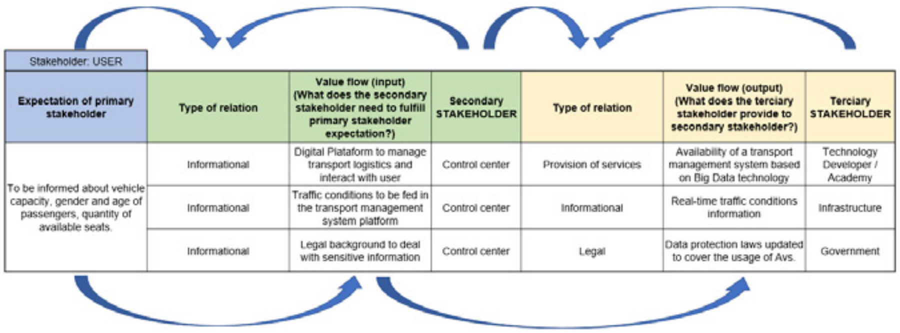
The steps regarding the identification of the stakeholders and their expectations, and evaluation of the relations among stakeholders followed the "Stakeholder Value Network" (SVN) techniques, which consists of collecting data to identify the stakeholders, evaluating the direct and indirect relations among the stakeholders (qualitative model), and evaluating the value flow of the most important stakeholders (quantitative model) (SUTHERLAND, 2009).

The identification of the stakeholders and their expectations were based in the bibliographic review of publications related to SAV, which were selected from the database Banco de Periódicos CAPES (BRASIL, 2021b), by filtering publications revised by pairs and published from 2018 to 2021 and applying the keywords and Boolean operators: Stakeholder and "Shared Autonomous Vehicle" or "Veículo Autônomo Compartilhado" or "Shared Self-Driven Vehicle" or "Shared Automated Vehicle".

The bibliographic search resulted in 56 articles, for which only 41 articles were relevant to the SAV on wheels subject. The remaining ones were reviewed, and the stakeholders mentioned in each one of them were computed. Only the first ten stakeholders with the bigger recurrence were selected, once this limited quantity is necessary in order to make the work more doable and grouping the stakeholders with the same primary function is a good practice too (SUTHERLAND, 2009).

By following the SVN process, it was time to search for the expectations of the stakeholders, then the same database was used to identify them. In this step, only the two stakeholders with higher recurrence on the reviewed publications were picked, in order to have their expectations studied. Depending on each expectation, and stakeholders affected, a different value flow can be observed. These flows were classified in six categories, being them: Financial, Informational, Legal, Social, Politic, and Provision of services. Figure 7 exemplifies a value flow, in which an expectation of the primary stakeholder generates a need from the secondary stakeholder, which generates a task to the tertiary stakeholder:

Figure 7 – Value flows



Stakeholder: USER

Expectation of primary stakeholder	Type of relation	Value flow (input) (What does the secondary stakeholder need to fulfill primary stakeholder expectation?)	Secondary STAKEHOLDER	Type of relation	Value flow (output) (What does the terciary stakeholder provide to secondary stakeholder?)	Terciary STAKEHOLDER
To be informed about vehicle capacity, gender and age of passengers, quantity of available seats.	Informational	Digital Plataform to manage transport logistics and interact with user	Control center	Provision of services	Availability of a transport management system based on Big Data technology	Technology Developer / Academy
	Informational	Traffic conditions to be fed in the transport management system platform	Control center	Informational	Real-time traffic conditions information	Infrastructure
	Informational	Legal background to deal with sensitive information	Control center	Legal	Data protection laws updated to cover the usage of Avs.	Government

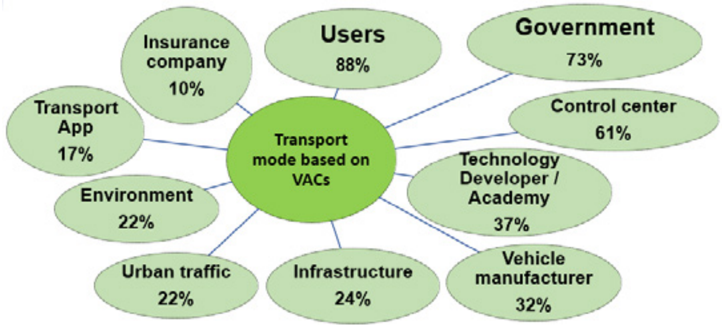
Source: Elaborated by the authors.

The next step was to define the requirements, which can be understood as being the translation of the expectations of the stakeholders and have to be taken as guidance for the successful implementation of the SAV.

4 RESULTS AND DISCUSSIONS

Figure 8 shows the ten stakeholders originated according to the selection criteria applied to the bibliographic review:

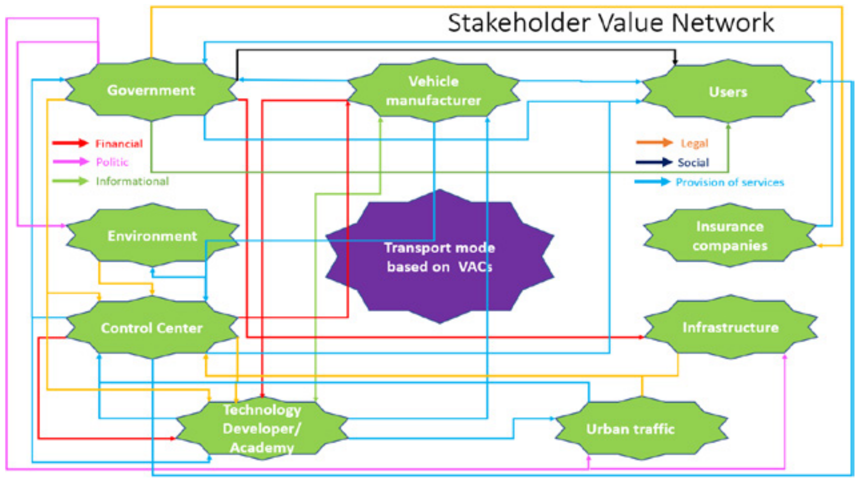
Figure 8 – Stakeholders



Source: Elaborated by the authors.

The expectations for the two stakeholders with the highest recurrence, USERS and GOVERNMENT, were analyzed. The expectations about the stakeholder Government are concentrated in subjects related to updates on the legislation, diminishing of deaths caused by accidents (CARVALHO, 2020), emission matters, and technological innovations applied to urban mobility (YE; YAMAMOTO, 2019). On the other hand, the stakeholder Users is more concerned about sharing a vehicle with strangers, clarity on the chosen route and timing, entertainment and amenities on board, safety and surveillance, and decease contamination (SCHUSS; WINTERSBERGER; RIENER, 2021). Figure 9 shows a SVN graphic representation of the relations among stakeholders:

Figure 9 – SVN



Source: Elaborated by the authors.

Table 1 shows the requirements, which were generated from the value flows:

Table 1 – Requirements

Requirements	Stakeholder
Brazilian General Data Protection Law (LGPD) to be updated to attend the needs from SAV transport mode.	Government
Brazilian Traffic Code to be updated to cover SAV tests, commercialization, and usage.	Government
Civil and Criminal liability for the usage of SAV to be foreseen by Brazilian Constitution.	Government
Incentivize research and development of new transportation technologies.	Government
Availability of 5G mobile internet, or superior technology.	Government ; Technology Developer / Academy
In case of malfunction of critical equipment, the VAC has to run in safe mode.	Technology Developer / Academy
The SAV must inform the User and the Central control in case of malfunction.	Technology Developer / Academy
The SAV must not cause accidents.	Technology Developer / Academy
Smart technology to be implemented on the traffic signs.	Government
The SAV must meet the safety requirements required by the National Traffic Code (CONTRAN).	Technology Developer / Academy; Vehicle manufacturer
The SAV must respect the traffic regulation.	Technology Developer / Academy; Vehicle manufacturer
The pavement of the roads has to be kept in good conditions, and the lane markings have to be visible.	Government
Availability of a technology that allows the SAV to detect the lane markings, despite of the climate conditions.	Technology Developer / Academy
Legislation to foreseen and inhibit cyber-crimes related to SAVs	Government
Data cloud infrastructure to support the SAV data collection demand.	Government; Technology Developer / Academy
Availability of real-time updated digital maps.	Government; Technology Developer / Academy
Control center must be connected to the SAV all the time during usage.	Control center

Requirements	**Stakeholder**
Control center has to be ready to take SAV control in case of emergency.	Control center
The vehicle must inform its location within millimeters of precision.	Technology Developer / Academy
The SAV must communicate to the road infrastructure and traffic signs.	Technology Developer / Academy
The SAV must communicate and exchange information to the other vehicles.	Technology Developer / Academy
SAV, infrastructure and Central code must communicate themselves fast and clearly.	Government; Technology Developer / Academy
Infrastructure must provide information about road, weather, and traffic conditions to SAV and Control center.	Government; Technology Developer / Academy
Road works must be signaled with the aid of smart and connected signals.	Government; Technology Developer / Academy
In case of an emergency, the SAV must issue a safety warning to other vehicles, infrastructure, control center, police, and rescue team.	Government; Technology Developer / Academy
Availability of technology to inhibit cyber-attacks.	Technology Developer / Academy
There have to be promotional campaigns to incentivize people to choose shared transportation, and inform how to use.	Government; Control central
Critical components have to attend failing rates probability lower than one fail per one billion samples.	Technology Developer / Academy; Vehicle manufacturer
Brazil has to attend Paris Agreement goals.	Government
SAV must meet emissions targets imposed by the CONSELHO NACIONAL DO MEIO AMBIENTE - CONAMA.	Technology Developer / Academy; Vehicle manufacturer
Maximize the fleet usage by alternating or combining cargo and passenger transportation.	Control center
Public transport social right compliance to be met.	Government
SAV to be equipped with wheelchair tie-down and occupant restraint system.	Vehicle manufacturer
SAV to be equipped with ramp, or motorized lift, or other accessibility feature to embark occupant wheelchair.	Vehicle manufacturer
SAV to be equipped with audio-visual system or another necessary feature to help PWD to embark and disembark.	Vehicle manufacturer
Brazil has to meet UN goals for 2030.	Government
SAV to be equipped with automated door opening and closing.	Vehicle manufacturer
SAV fare not to exceed ride-hauling service fare.	Government; Control center

Requirements	Stakeholder
User to be informed about waiting time, that cannot exceed 15 minutes.	Control center
Availability of a transport management system based on Big Data technology	Control center
Availability of a digital platform to interact with the user.	Control center; Technology Developer / Academy
Digital platform to inform at real-time about vehicle capacity, gender and age of passengers, quantity of available seats.	Control center
Digital platform to inform at real-time about the route, travel time, number of stops.	Control center
SUV to announce the proximity of the User selected stop.	Control center; Vehicle manufacturer
SAV to be equipped with Wi-Fi and cell phone charge port for all passengers.	Control center; Vehicle manufacturer
SAV to be equipped with emergency stop button.	Control center; Vehicle manufacturer
SAV to be equipped with surveillance system connected to the Police department.	Control center; Vehicle manufacturer
SAV to be equipped with air cleaner capable to neutralize viruses and bacteria.	Technology Developer / Academy; Vehicle manufacturer
SAV interior and exterior parts that have contact to the user to be produced with materials which properties are replant to fungus, bacteria, viruses.	Technology Developer / Academy; Vehicle manufacturer
SAV to be equipped with fixtures which are capable to disinfect the interior of the vehicle.	Technology Developer / Academy; Vehicle manufacturer
SAV to be equipped with fixture to detect dirt and odor.	Technology Developer / Academy; Vehicle manufacturer

Source: Elaborated by the authors.

5 CONCLUSIONS

The SAV has potential to bring benefits to the population of the urban centers, but, besides the necessary technology development, its implementation also depends on updates on the whole infrastructure, such as roads, traffic signs; and updates on the juridic and transportation fields.

From the population side there may be some resistance (HABOUCHA; ISHAQ; SHIFTAN, 2017) to swap from the ownership pattern to a sharing pattern. Ownership reminds the present Fordism mindset (JESSOP, 2005), in which the personality and social status of the owner are personified on the vehicle (HEFFNER; TURRENTINE; KURANI, 2006). People who are concerned about sustainability, more educated, technologically savvy, and current PT users, are likely to adopt the SAV earlier (LAVIERI *et al*., 2017; PAKUSCH *et al*., 2018).

In developing countries most of the population relies on PT, what is a green light for the SAV. Either being managed by private or public sectors, the SAV will fit to the first and last mile transportation service. The best scenario would be to have it incorporated to a MaaS mode.

This paper is meant to help stakeholders by providing helpful information in regarding the implementation of the SAV, what is expected to be translated in diminishing congestion, improvements on safety rates, and a growth on accessibility and customer satisfaction.

Different regions or countries may require unique requirements due to specific geographic characteristics, social factors, energy matrix. As most of the publications used were international, some adjustments may be necessary.

A new player on the transportation system is the Covid-19 pandemic, which has raised question about the real need of moving around. Those are times when people are concerned about getting infected outside home. Changes on the population habits and consequently urban transportation strategies will be noticed and discussed after the pandemic.

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11

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AUGMENTED REALITY HEAD-UP DISPLAY INTERFACES FOR ADVANCED DRIVER ASSISTANCE SYSTEMS:

a reference architecture

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ABSTRACT

The growing volume of data from driver assistance systems exhibited in Augmented Reality Head-Up Displays (AR-HUD) requires safer interfaces for conveying diverse sorts of information. Reference architectures help with development by lowering costs, giving quality and continuous improvement requirements, and providing syntax and structural representation. This work defines a reference architecture for designing augmented reality-based driving assistance systems. We selected relevant studies on augmented reality and heads-up displays and examined reference architectures and their applications in driving assistance systems. In this examination, we noticed an expanding debate as well as a scarcity of reference designs to standardize and aid developers in designing and developing concrete instances. We concluded that reference architectures serve a number of tasks in the application of augmented reality to the driving assistance system production chain, bringing expert knowledge and standards together to generate concrete instances.

Keywords: Augmented Reality Head-Up Display, AR-HUD, Advanced Driver Assistance Systems, Reference Architecture, Automotive Industry

1 INTRODUCTION

Bad weather conditions such as light reflection, rain, fog, and smoke reduce visibility and cause dangerous driving situations. In this context, Advanced Driver Assistance Systems (ADAS) devices alert and instruct the driver about obstacles on the roadways that could compromise the safety of people and other vehicles (ABDI; MEDDEB, 2017).

Augmented reality (AR) complements the real world with virtual (computer-generated) objects that appear to coexist in the same space as the viewer (AZUMA, 2017). Augmented Reality Head-Up Display (AR-HUD) devices consist of a transparent screen on which information is superimposed in the driver's line of sight, so that the driver does not shift his focus from the road to the vehicle's dashboard or have any interference of his view of the road (ABDI *et al*., 2015; KNOLL, 2017; CHOUKSEY; SIRSIKAR, 2016; HAEUSLSCHMID *et al*., 2016; WIENTAPPER *et al*., 2013). According to Abdi and Meddeb (2017a), there is a demand for cars to present more information and for AR-HUD to contribute to increasing driving safety (SÁNCHEZ *et al*., 2017; QIN *et al*., 2017) and to enable a more comfortable experience for drivers (PARK; PARK, 2019; HAJISEYEDJAVADI *et al*., 2018).

However, overlaying the real-world view with a vast amount of virtual elements is still challenging and the increasing volume of information presented makes the driving environment more complex. Paradoxically, instead of supporting the driver and providing safer driving, information overload can overwhelm the driver, affecting the driver's concentration and cognitive abilities and hindering their response time (ABDI; MEDDEB, 2017a; BETANCUR *et al*., 2018; CHARISSIS, 2014). AR-HUD systems have limitations to be solved, such as projecting bright images with saturated colors that have sufficient legibility and luminance to combat sunlight (QIN *et al*., 2017). There is also a risk of occlusion of traffic relevant objects and phenomena such as tunneling for perception and cognitive capture (PAUZIE, 2015). Current interfaces communicate ambiguous alerts and elements that can distract drivers, creating danger with information overload (CHARISSIS, 2014). Thus, there are still open questions about HUDs interface design, such as: How should HUDs display content? In which ways can they best serve the driver? How effective are they as representation methods in unfavorable environments? (YOON *et al*., 2014; WINKLER; KAZAZI;

VOLLRATH, 2015; LANGNER *et al*., 2016.) Visual organization rules can interfere with interface design and information elements that are important in the scenario surrounding the driver (JIN; YOU; WANG, 2016).

The increasing demand for information requires new types of displays and safer interfaces to convey various types of information (HAEUSLSCHMID *et al*., 2016; WIENTAPPER *et al*., 2013; PARK; PARK, 2019). Park and Park (2019) noted that knowledge on the topic is disjointed and poorly integrated and propose improving the design of automotive HUDs. As research into the development of ADAS systems continues, questions about the hardware and software elements that can comprise a standard platform, end solutions, or high-level abstractions to assist developers emerge arise.

The automotive industry has a tight and well-modularized set of guidelines, but there is a knowledge gap about reference architectures to standardize and support developers in building driving assistance systems and interfaces for AR-HUD, given the vast amount of information that can be displayed to drivers (PARK; PARK, 2019; CHENG *et al*., 2019).

A reference architecture is a model that brings a group of related objects that collaborate by exchanging messages, providing resources, or connecting other components. Reference architectures bring advantages such as abstraction, encapsulation, and reuse for the components. Reference architectures also guide the specification and benefit the quality of design, future evolutions of concrete architectures, and the resulting systems. Integrated concrete instances can be developed incrementally and evolutionarily based on the architecture.

Although the literature discusses information modeling and interface design methods, comprehensive reference architectures are not offered. The works include simple flowcharts and architecture diagrams for isolated core modules, providing a superficial overview of AR-HUD systems and design (ABDI; MEDDEB, 2017a; ABDI; MEDDEB, 2017b; LANGNER *et al*., 2016; BILA *et al*., 2017; KIM; HWANG, 2016).

Reference architectures are utilized in a variety of fields, including the automotive industry. Because of their modularity, such reference architectures have been adopted by many industries and are used in product development as well as in production configuration. The automobile industry benefits from standardization and modularity since it has strict standardization for functional requirements as well as architectural standards specified by international authorities for all components, regardless of automation degree (SERBAN *et al*., 2018).

This work defines a reference architecture for designing augmented reality-based driving assistance systems. This document is organized as follows: Section 2 describes the materials and methods utilized, Section 3 presents and analyzes the results, and Section 4 provides our conclusions and suggestions for further research.

2 MATERIALS AND METHODS

The method was organized into two phases. The first phase was to identify requirements, which related to the technical and functional assumptions to be addressed for AR-HUD interfaces in assistive systems and were based on the research of Park and Park (2019) and Betancur *et al*. (2018). The second phase was to specify the reference architecture, which included elements, characteristics, behavior, and contextual relationships, as well as a graphical representation of them. The standards and the Architecture Description Language were used to create the diagrams (ADL).

3 RESULTS AND DISCUSSION

3.1 Requirements for reference architectures for steering assistance systems

From a high level, we organized the technical requirements into three major groupings, which we will refer to as “domain”, that are connected in a continuous or control cycle. According to Bila *et al*. (2017), the elements consider the behavioral cycle necessary in autonomous vehicles.

The requirements definition also considers the sequence of operations associated with the input data, according to the continuous cycle, to describe the complete behavior of a given module. Such systems are focused on moving objects. It is necessary to distinguish such objects and monitor their movements continuously predicting future actions (BILA *et al*., 2017; KIM; HWANG, 2016; PARK; KIM, 2013). The model is RTOS, which validates cycle for these groups (BILA *et al*., 2017):

- **Measurements or acquisition** refers to the hardware components, with the function of capturing data. Sensory information is the basis of analysis and critical for decision-making, and contemplates sensors such as radar, sonar, video sensors and lasers.
- **Analysis** is a model for situation awareness, or the group called "perception," which handles the data coming from measurement. Activities include advanced data and image processing methods such as tracking, filtering, and object recognition. This group covers various technologies, techniques, and algorithms.
- **Execution** is the control fed by the outputs resulting from the analysis level. They consider that every action is executed in the third part of the cycle, through the decision layer. Action is calculated based on warning signals and possible scenarios, requiring appropriate alarms to perform maneuvers and trigger brakes.

The reference model demands requirements also listed in the software engineering context for the proper instantiation of the concrete architecture (DUARTE FILHO, 2016), such as **Interoperability** (the environment must allow the exchange of information with other systems or modules); **Component-Based** (the set of services to be provided, capable of incorporation or combination, with the goal of forming other services; it should be possible to integrate other services or environments through reutilization); **Layers** (allowing the visualization in stages and facilitating modifications and evolution throughout the life cycle); **Communication** (covering both data models and services in the environment, restricting protocols and technologies to security directives) and **Scalability** (the model's ability to upgrade, meeting constant technological advances by continuously including new elements or devices).

Human-Computer Interaction (HCI) is the last layer of the group contemplating the functionalities for the final user, in addition to allowing to configure and control all the available systems. The layer that composes the interactions between the users and the hardware and software elements is detached or independent from the cycle presented. The cycle considers the autonomy of the systems, so the interface module can be used in the context of assistance and presentation.

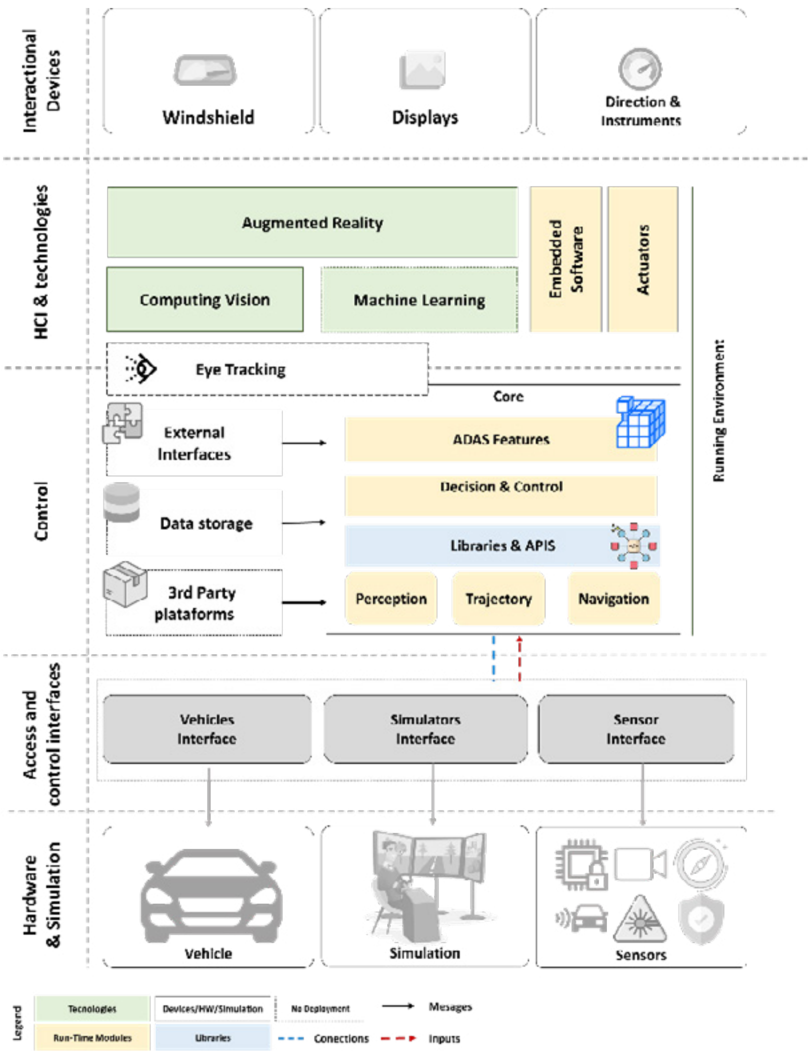
In the HCI context, the interaction devices are interfaces enabling the manipulation of systems or devices in a simple, safe and comfortable way. Windshields, LCD screens, analog and mechanical panel displays, such as the speedometer, are examples of devices on which augmented reality may be used to offer visual interfaces to enhance the usage of computer systems and sophisticated hardware equipment.

Technology independence is a desired feature in the reference architecture and required in the layered architecture because it allows you to create applications on different platforms and languages. The following technologies are worth noting: **Computational Vision** encompasses recognition techniques and technologies based on large sets of multidimensional information and data; **Machine Learning** is a set of statistical techniques and models that, by means of algorithms, enable computerized systems to perform tasks under specific and explicit conditions based on patterns, to enable machines and systems to learn; **Embedded Software** are systems that perform only a given function and combines processor or microprocessor, memory, and input and output peripherals with functions dedicated to mechanical and electrical systems; **Actuators** produce motion by manual, hydraulic, or mechanical commands and **Eye Tracking** measures the viewpoint or movement of the eyes relative to the head while a head--tracking technology uses a fixed camera to observe a subject (e.g., a driver).

3.2. Modeling the reference architecture

Reference architecture is a conceptual solution that serves different scopes to build concrete instances. Thus, the architecture was designed to operate independently of layers or modules. Figure 1 illustrates the architectural views module overview and Figure 2 shows the structural view or architectural model. In the module overview, we present the main components and technological resources used to support developers in the implementation and development of Heads-up Display interfaces using AR, in the domain of Driving Assistance Systems. The proposal for functional architectures is based on Serban *et al*. (2018), Ulbrich *et al*. (2017) and Curiel-Ramirez *et al*. (2018), and the set of technical requirements seen in Bila *et al*. (2017), Kim and Hwang (2016), and Park and Kim (2013), in addition to the works of Langner *et al*. (2016), Park and Park (2019), Aeberhard *et al*. (2015), Abdi and Meddeb (2017c), Fisher and Lee (2017) and Grabe *et al*. (2013).

Figure 1 – High-level overview of the components of the proposed reference architecture



Source: the author.

The design for the artifact is defined at a high level of abstraction. In this scenario, it presents the layers in a hierarchical way for functional separation, allowing modifications and refinements and addressing open problems, similarly to the models presented by Park and Kim (2013) and Ulbrich *et al*. (2017).

Among the items are the Interaction Devices, the forms of Human Computer Interaction, and the Technologies used. These technologies are crucial as they figure in the main role of AR adoption and use (RIENER *et al*., 2019). The Control center, as well as the Access and Control Interfaces, make up the center and allow access to the Hardware, the Computer Simulation models and the Sensors spread throughout the vehicle body. The artifact contemplates the defined requirements and the technologies provide support for third party applications, defined as "3rd party". The following sections describe the modules, layers, and foundation components.

Regarding **HCI and Interaction Devices and Technologies**, Interaction Devices encompass hardware items such as windshields, LCD screens (displays), analog displays, and mechanical panels (e.g., speedometer). AR technology uses cameras, displays, and motion sensors to integrate virtual elements into real world visualization and is combined with the computer vision, machine learning, and eye tracking technologies.

The **Control & Core** block are the central element of the architecture, which contains the execution environment and standardized modules (Figure 1). The Core modules reflect the mandatory requirements for assembling ADAS systems and autonomous cars (SERBAN *et al*., 2018; ULBRICH *et al*., 2017; CURIEL-RAMIREZ *et al*., 2018). We highlight the following modules:

- **ADAS Features**, or Advanced Driver Assistance Systems Features: A set of individual technologies or autonomous system modules that support drivers. Due to regulation, they are considered passive systems, providing only information.

- **Decision & control**: Generalist models that merge and analyze data. It is typical to feed such modules with already integrated data to be examined by decision algorithms.

- **Libraries & APIS**: They enable interaction between the modules and allow independent application development, such as features in ADAS systems, and third-party applications for entertainment.
- **Perception:** It is powered by fusing environmental and complementary data (communications, driver behavior analysis, vehicle data) from the various sensors such as cameras, lidars, radars. The combination of these data generates a model of vehicle perception and location in environment (CURIEL-RAMIREZ, 2018).
- **Trajectory & Navigation**: They plan and determine each maneuver to be executed, in addition to using the data and worldview are processed by the perception module to generate the maps and positioning of the vehicle.
- **External Control Interfaces**: It modules and access ports made available for improvements or adding new functionality.
- **Data Storage**: Resources to temporarily persist the collected data or information in the file system or as objects in a database.
- **3rd Party Platforms**: Components developed by third parties, according to industry regulations, that can be added to the system (e.g., electronic equipment for entertainment and devices that increase security).

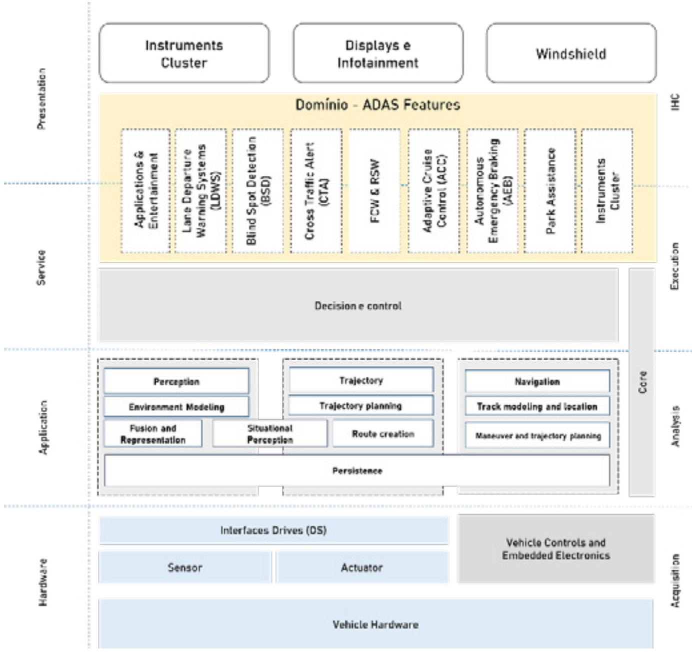
The **Access and Control Interfaces** module consists of drives, physical ports or electronic and mechanical devices that connect the system modules, sensors, actuators and the vehicle hardware.

The **Hardware & Simulation** encompass the vehicle itself and the sensor suite, which vary in quantity and types depending on manufacturers and purposes. Simulation is important for system development, for driver training, and for research and interface development.

3.3 Architectural Vision

Figure 2 illustrates the proposed reference architecture and its relationships, such as context, goals, and design.

Figure 2 – Vision for the architectural model



Source: the author.

Since this is a vehicle, the layout of the modules mentioned in the previous section plays a crucial role in the operation. It needs to be robust and reliable, both for ADAS systems and for automated and autonomous vehicles.

The architectural view is presented in layers, following the multilayer pattern. The componentization design is scalable, describing the logic in the software and hardware systems that encompass the sensors and embedded modules.

The **Presentation Layer** represents the forms of interaction with the user, from the control elements to the passive elements, whose function is to display information and alerts. In this layer reside specialized components both for interacting with users and with other applications and processes of the layer below. Human Machine Interface (HMI) is a definition for user interaction with any type of machine/hardware. These are software applications or interfaces on a screen or physical items such as buttons and analog displays that make communication between people and machines easier and more efficient.

The **Service Layer** consists of services that are generally protected against unauthorized or direct access. Access to components is only allowed securely through validation processes that can be present in this layer or in the logical layer. Decision making for specific issues can also be implemented in service modules, such as daemon or algorithm. The service layer also enables decoupling between the application, presentation, and other systems.

The **Application Layer**, also called the logical or business layer, concentrates the components that are defined as logical for the computer system. This layer concentrates most of the processes, components and business rules. It can access the processes of the lower layer. It generally manages its own transactions and is accessed by the services layer.

The **Hardware Layer** or physical layer describes the operational model and encompasses the sensors, actuators, or equipment needed to operate the above computing system. This layer embeds the systems and physical data processors that can operate autonomously or on demand.

The **Instrument Cluster** or dashboard provides relevant information to the driver and is usually located at the lower edge of the driver's main field of view. It is a passive HMI module, as it only displays information.

The **Display & Infotainment** are used to help the driver understand the surrounding situation, using various sensors to display warnings and providing comfort to drivers and passengers through informational and entertainment content.

The **Windshield** is used for information relevant to the driver since it is in the main field of view. It is used to present information without the driver needing to take his eyes off the road and without the need for visual accommodation.

Navigation consists in controlling the movement of the vehicle from an initial position to another destination or position. The module has the responsibility of following a path where the directives come from the decision and control module. The groups for display are characterized by different requirements regarding the performance of the relevant display medium.

The modules elicited earlier are distributed among the layers, as shown in Table 1.

Table 1 – Required Components in the Acquisition Layer

Module	Feature (Macro Requirement)
Measurement or Acquisition	(A) Instrumentation (B) Interfaces with Devices and Processors
Analysis or Perception	(A) Environment Modeling (B) Data Fusion and Representation (C) Situational Interpretation (D) Data Persistence
Execution or Decision and Control	(A) Navigation (B) Route modeling and location (C) Maneuver and trajectory planning (D) Interfaces for vehicle control (E) Connectivity

Source: Elaborated by the authors.

Communication between the layers must be done through exposed protocols and APIs to simplify communication and reduce coupling. The communication protocols for the hardware devices are also relevant since the sensors and processors communicate differently. These protocols are anticipated in the hardware architecture requirements and connect to the physical layer of the architecture, but they will not be addressed in this element of the artifact.

There is a diverse range of information available for display and related to the mechanical controls when it comes to a vehicle (KNOLL, 2017). Considering the appropriate and necessary information for the driver, the presentation layer can be divided into groups, as demonstrated.

The presented structure makes it possible to build and add new modules, by which the experience of both drivers and passengers can be enhanced, in terms of safety and navigation, providing route instructions and entertainment.

4 CONCLUSIONS

This work established a reference architecture to support developers in deploying and building concrete architectures and developing Heads-up Display Interfaces. The architecture contributes to improve component reuse, system structuring and artifacts documentation. Also, the modular strategy that complements the methodology adopted by the automotive industry to significantly include technological and managerial advances. We sought to contribute to the communities of engineers, software architects, and developers, through the overview and distribution of the artifacts and source codes produced under free licensing, with the goal of stimulating developments to the reference architecture and the artifacts.

As future research, there are opportunities to develop the architecture in applying design patterns, building a UX framework to incorporate the reference architecture to facilitate interface development, and including metrics and tools to improve drivers' experience and quality assessment of the proposed reference architecture.

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