BRAZILIAN GUIDE FOR PERFORMANCE MONITORING OF HS-WIM SYSTEM

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Abstract

High Speed Weigh-in-Motion (HS-WIM) technology has evolved in Brazil as a monitoring and inspection tool, in addition to automatically identifying and classifying vehicles. The first HS-WIM installation in Brazil took place in 2009 and, since that time, the eccentricities of the highway and the constant need for restoration have been observed. Due to this, the motivation for a specific pavement catalog for the HS-WIM system with structures with greater resistance and durability is presented, proposing the reconstruction of the pavement of these areas to satisfy the structural requirements. In order to concentrate information from national experiences and subsequent repeatability of processes, the development of the Brazilian guide for performance monitoring of HS-WIM systems began. The focus of the document is to gather information about the different legislations, such as the new ordinance of INMETRO (*Instituto Nacional de Metrologia, Qualidade e Tecnologia* - National Institute of Metrology, Quality and Technology); the equipment; the operation; and the different performances obtained due to the sensors and the infrastructure. This research presents all the variables used for the development of the Brazilian guide from the characterization, demands and eccentricities of the Brazilian situation.

Keywords: HS-WIM System, Brazilian Inspection Guide, Sensors, WIM Pavement.

1. Introduction

The importance of weighing vehicles on highways is due to the preservation of infrastructure, the reduction of maintenance costs, fair competition between transporters, in addition to reducing the risk of accidents on the highway. The High Speed Weigh-in-Motion (HS-WIM) technology has evolved as an important monitoring and inspection tool, in addition to automatically identifying and classifying, at the guideline speed of the road. With a focus on replacing the traditional Vehicle Weighing Stations in Brazil, they have been the main idea for monitoring overweight. Currently, there are Integrated Automated Inspection Posts and Mobile Operational Units that are already in the process of being implemented by the Brazilian Federal Government.

Over the years, Brazil improved the technique with investments in research and Weigh-in-Motion (WIM) sites. The first installation of HS-WIM sensors of this project took place in 2009 in Araranguá city, south of Brazil. As of 2012, the National Department of Transport Infrastructure (DNIT) began the road inspection process, combining WIM and automation of weight inspection supervision, through the remote action of the traffic authority agent. In the country, large loads of food and inputs are mostly transported by road. This action occasionally leads to overloading of the road system and early damage to the pavement. Due to the empirical dimensioning method used for many years in the country, created in 1970 (BRASIL, 2006), these impacts were aggravated, leading to an early reduction in the useful life of structures. This is a simple method that does not present any analytical characteristics, being based on previous experiences and projects and on the observation of the behavior of existing pavements. However, this is outdated so that the load capacity and Brazilian road traffic has grown a lot in recent decades, in disagreement with the updating of standards and manuals that date from the 1970s, in general.

Thus, the fragility of the structures is evidenced by the implementation of HS-WIM systems in sections of conventional highways. Even if there is installation, the resistance of the structure is incompatible with the extreme demands of traffic and the constant need for restoration makes it impossible to collect reliable data. As a form of improvement, the empirical-mechanistic dimensioning method, called MeDiNa, is being implemented, which proposes structures with greater resistance and durability over the years. In addition, the method analyzes the resilience of all materials used in the structure and the incident traffic, being able to provide layers with greater application efficiency. Thus, in areas of HS-WIM systems, the structure is dimensioned so that, in addition to the cladding, the other layers bear the traffic overload. This change in the dimensioning method, over the years, will provide changes in the construction and management of pavements in Brazil, corresponding to that used in developed countries.

Thus, as an immediate response, the methodology for adapting specific stretches is defined, where sensors and HS-WIM systems can be installed. Adaptation takes place through the exclusive reconstruction of the area intended for weighing systems, in accordance with normative structural requirements. In 2015, LabTrans carried out the reconstruction of a section of the BR-101 highway, to adapt it to the HS-WIM system with solutions in asphalt pavement and concrete pavement. Restructuring in these areas is capable of reconciling the adaptation of the highway to the HS-WIM systems in the section of interest, without the need for intervention on the entire highway, in order to reduce the economic impact.

A catalog of pavement solution is being developed aiming at the dissemination of new methods for pavement design and improving Brazilian highways to the needs of traffic and HS-WIM systems. This catalog presents structural reconstruction alternatives aiming at the installation of WIM sensors and satisfactory mechanical performance for the highway.

As a way of compiling information about HS-WIM and the constant updates, LabTrans began the development of the Brazilian Guide for performance monitoring of HS-WIM systems. The basis of the document comes from the results of research and installations at weighing sites, since the first implementation on conventional highways, carried out in 2009. Updates to structures, such as the reconstruction of the section, were recorded and now make up the Brazilian Guide, as a way of to standardize repeatability. For the development of the guide, priority was also given to the theoretical basis covering different legislation, equipment, operation, performance of the HS-WIM system and other related subjects. Among the worldwide recommendations consulted, there are COST 323 (2002), ASTM E1318-09 (2017), OIML R 134-1 (2006), FHWA (2018), LTPP (FHWA, 2012), WIM Data Analyst's Manual (FHWA, 2010) and, mainly, the Guide for Users of WIM (ISWIM, 2019).

Acting jointly, the Brazilian guide and the solutions catalog aim for Brazil to adapt as quickly as possible to the HS-WIM structures implemented around the world. The focus of both deals with the sensors and equipment most used in Brazil and that perform the function at the lowest possible cost. Making the information and characterization of the equipment accessible to companies and also to the competent federal and state agencies. Two types of pavement are described and characterized (asphalt and concrete). Pavement selection depends on the projected traffic volume and available materials. This work presents all the envelopes used for the development of the Brazilian guide for inspection of HS-WIM systems, based on the characterization of the Brazilian situation, its demands and eccentricities.

2. Bibliography

Overloading of heavy vehicles causes negative impacts on the road system, with regard to road users, pavement infrastructure and the market competitiveness. As a consequence of overloading vehicles, they are capable of impairing defensive maneuvers in emergency situations, as well as increasing the likelihood of overturning. Overloaded vehicles move more slowly and cause traffic jam, so other drivers may want to overtake them, which sometimes do not provide the necessary safety, causing accidents.

The road infrastructure is damaged by vehicle overloading, as this causes greater surface wear, in addition to increasing the cost of repairs and maintenance. This wear intensifies the formation rutting, which lead to the accumulation of water on the road, causing damage. For effective overload control in heavy vehicles, inspection of the Gross Vehicle Weight (GVW) and weight per axle is essential. This control can be carried out by the Weigh-in-Motion (WIM) system, which is capable of collecting vehicle data at the guideline speed of the road.

HS-WIM monitors all traffic passing through the instrumented area, without the need for stoppages in the flow of vehicles on the lanes (LEDUC, 2008; BRITO et al., 2013), together with cameras, scanners, inductive loops, among others, which allow the collection of various information from each vehicle that passes over the weighing area (DETRAN, 2018). The installation project for this system varies according to the type of sensor and the complementary equipment that compose it. When integrated with other Intelligent Transportation System (ITS) equipment, Figure 1, this system allows for the pre-selection of potential offending vehicles, enabling the automation of the process of collecting weights and dimensions, for the verification of legal limits, and guidance for drivers to go to the inspection area.

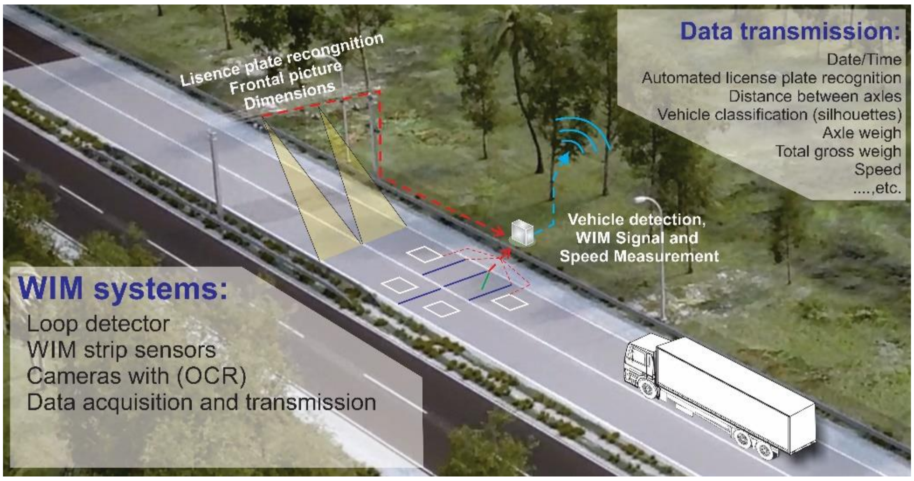

Figure 1 – WIM system and additional technologies

Eliminating the obligation to stop vehicles reflects positively on the level of service on the highway and on the efficiency of overload control, as shown by the comparison between the conventional weighing method and the WIM system in Figure 2 (BRASIL, 2008). If the vehicle is not overloaded, it will pass the pre-selection at the road's guideline speed without having to face a traffic jam at the entrances to the inspection station and will be able to continue their journey.

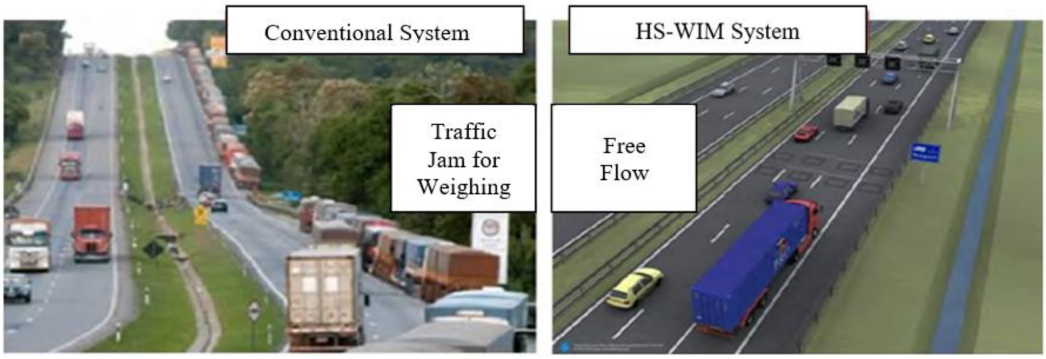

Figure 2 - Comparison between the conventional weighing and the WIM system

For both systems it is worth mentioning that if the vehicle is overloaded, there is a need to stop it at a inspection station for precision weighing and writing of the fine, if applicable. In some situations, there is a need to transfer or relocate loads so that the vehicle can continue its journey.

The automated HS-WIM system can provide several improvements to the movement of loads and users on Brazilian roads. In this way, research and means of adequacy with the least possible impact on the existing network are emerging, as a way of minimizing budgetary and design obstacles. Thus, the central focus of the HS-WIM system in Brazil is the adequacy of the existing mesh in the areas intended for weighing.

It is recommended that the WIM system be installed on road segments with characteristics that do not affect data collection during weighing activities and that guarantee, together with the equipment, the accuracy of the results. Given the concern to inspect vehicles more efficiently and preserve heritage, Brazil is currently studying and developing technologies for WIM systems. However, the implementation of these systems cannot be carried out without the complete foundation of the components involved. Thus, since Brazil does not yet have its own installation and monitoring methodology for weigh-in-motion, efforts have been made to better understand global specifications and their constant adaptations. Initially, these regulations have been implemented in the country and their monitoring and results, responsible for the delimitation of the analyzed criteria.

2.1. Evolution of HS-WIM Systems in Brazil

Research and implementation of WIM sites have gained greater prominence in Brazil over the years, in line with the world scenario (Figure 3). In the 90s, the first WIM standard (ASTM-1318) was published in north America, and the COST323 action provided European specifications of WIM as well as pan-European tests of WIM systems. In the following years, as the technology spread, researchers gathered at the 1st ICWIM, organized by the International Society for WIM. From then on, the event took shape and countries began to implement the technologies presented there, as a way to spread WIM worldwide and modernize the process. In Brazil, the first cooperation term was signed in 2007 between the Transport and Logistics Laboratory (LabTrans) of the Federal University of Santa Catarina (UFSC) and the National Department of Transport Infrastructure (DNIT). In the same year, Brazil took another important step towards the automation of the weighing system, with the creation of the National Weighing Plan, which included in its studies the implementation of 148 fixed weighing stations and 72 stations operating mobile equipment.

From the beginning of this WIM implementation in Brazil, there was the first installation of weighing sensors on an existing highway, in 2009 in the Ararangua city, in southern Brazil. Over the years, the runway was monitored and the installed technologies observed. Brazil was then gaining more prominence worldwide in WIM systems and in 2011 the 2nd International Seminar on WIM (RSWIM2) was held in the Florianopolis city. In 2012, the federal government (DNIT) launched the project of integrated automated inspection posts, further engaging research with WIM.

The highway where the sensors were installed in 2009 underwent several restorations due to traffic and the adaptation of the system to conventional pavements. Thus, in 2015, specific pavements were designed and built in this same area for the use and installation of the WIM system, concrete and asphalt pavement. With the most developed technology and research innovations, Brazil hosted the 7th International Conference on WIM, in Foz do Iguaçu, in 2016. In 2021, the project for the implementation of mixed weighing stations with operation and inspection of operational mobile units equipped with the WIM system began. The next steps of technological innovation in Brazil with respect to the WIM system are due to the application of direct inspection of the weight of vehicles, that is, without a human agent.

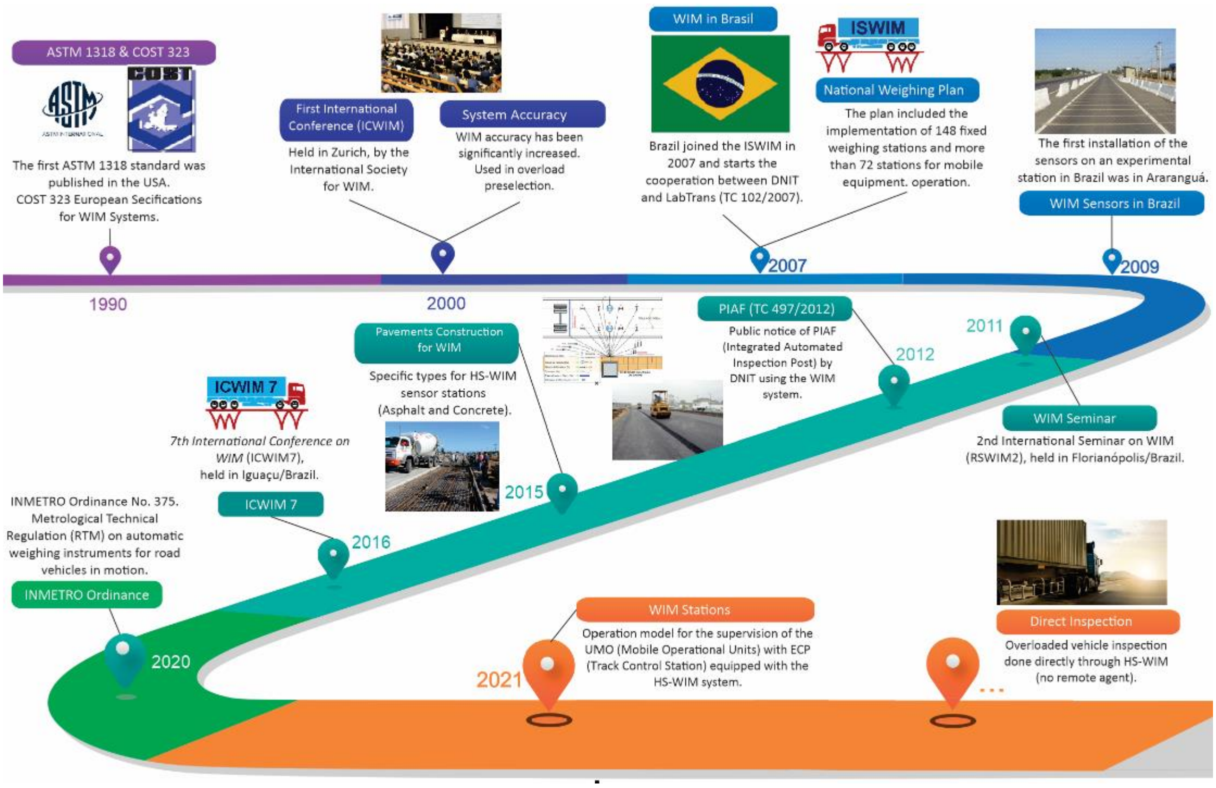

Figure 3 – Timeline of evolution of WIM systems

Based on these advances, Brazil began to technically regulate the accuracy class of automatic instruments for road vehicles in motion. The National Institute of Metrology, Quality and Technology (*Instituto Nacional de Metrologia, Qualidade e Tecnologia* – INMETRO) published the Ordinance nº 019 (INMETRO, 2022) of applies to the instruments that are used to determine the GVW, loads per axle and per set of axles of road vehicles in motion when used in vehicle inspection. An example of the application of INMETRO Ordinance nº 19 on a WIM road, using quartz sensors, was carried out by the company Fiscaltech, which resulted in a general classification of 2B, that is, 3.50% for GVW and 6.00% for axles and groups of axles. Considering the accuracy levels of class 2B, the equipment can be related to class A(5) of COST 323 (2002), indicated for weight inspection. Thus, Brazil takes a big step related to WIM to improve techniques and technological advances.

The automation process of conventional weighing systems for HS-WIM is dependent on several factors, in addition to investments in technologies. The initial impact of this alteration is perceived by the pavement, which must present specific characteristics of mechanical structure so that the implementation of HS-WIM systems is possible. For the implementation of these systems, a survey is carried out of the mechanical and structural conditions of the highway, associated with incident traffic and other classification factors. Due to the dimensioning method used in Brazil, for many years, being exclusively empirical, the presented structure no longer matches the requirements of the HS-WIM system. Unlike the structures executed in Europe, which are mechanistically dimensioned and result in robust structures with greater resistance in all layers. The implementation of the HS-WIM system becomes trivial, since the requirements of the ISWIM guide are met immediately and maintained throughout the useful life. This is an eccentricity faced by Brazil, which, based on the Brazilian Guide, aims to help adapt pavements to the demands of HS-WIM systems at the lowest cost of the necessary intervention. The objective is to disseminate this knowledge and techniques with methodology and equipment already used in the country, so that gradually there is equivalence with pavements from other countries.

2.2. HS-WIM Systems Installation in Brazil roads

The Brazilian road network is extensive and therefore its maintenance becomes expensive given the size of the country. Thus, so that the automation of the systems would not depend exclusively on the construction of new highways, the initial objective was to implement them on existing highways. The verification of the functionality and condition of the pavement started with the classification of suitable highways, from the geometric point of view and the average daily volume of vehicles.

An asphalt pavement road was selected considering the delimitations which followed the world recommendations for WIM areas. The highway is located in the southern region of Brazil and in an area with a high volume of daily traffic. The existing pavement has a similar configuration to that of several Brazilian highways and was dimensioned by the empirical method, consisting of a coating layer in an asphalt mixture using a 50/70 binder, a base layer in graded gravel, a layer of dry macadam subbase and subgrade layer partially reconstituted with sand.

The pavement behavior was evaluated after the installation of four groups of 16 sensors (quartz, ceramic, polymer and optical), totaling 64 sensors, including information transmission systems (Figure 4a). One of the main aspects of the experiment was the evaluation of the ability of such systems to provide consistent information on the loading caused by traffic and pavement degradation according to the technology used, in addition to using the data in strategic planning and legal enforcement. The road was kept in operation and over the five years, several fissures, cracks and other defects were observed (Figure 4b). Considering that the performance of HS-WIM systems is dependent on the behavior of the structures in which they are integrated, it was found that this type of pavement is not capable of supporting these systems.

(a) after installing the HS-WIM sensors (b) after 5 years of installing the sensors

Figure 4 - HS-WIM test area on conventional highway in Brazil

In this way, it is concluded that conventional highways do not perform well when targeted for the installation of weighing systems, making the restructuring of the pavement inevitable, or even a new construction being considered. After experience with conventional roads, there was a need to restructure a section of the road to install the HS-WIM system and its components. The new pavement met the demands regarding the necessary strength and performance of the

HS-WIM systems. The reconstruction project relied on the French design method through the *Catalog des Structures Types by Chaussées Neuves* (LCPC, 1998) and the Concrete Pavements Manual - IPR 714 (DNIT, 2005). On the test road, quartz, polymer and ceramic sensors were installed (Figure 5).

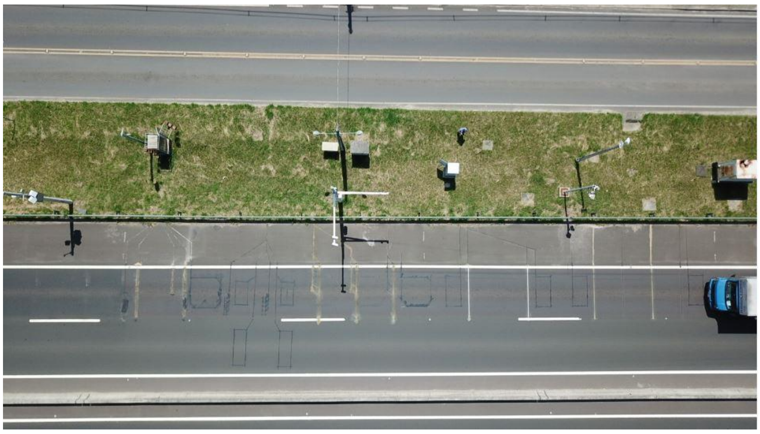

Figure 5 – HS-WIM system test road in Brazil

These two types of pavements, asphalt and concrete, were dimensioned, with structural variations according to the regulations consulted at the time of construction. Some adaptations were made so that the structures were compatible with the Brazilian reality and with the demands of the country. The main adaptations were due to the materials used, thickness of the layers and types of sensors, which highlighted the demands of the market. In this way, data and information began to be stored to integrate the database of Brazilian studies, which originated the Technical Guide.

3. Development of the Brazilian Guide

As already mentioned, for several years in Brazil, the pavement dimensioning method did not follow the development of freight vehicles, their capacity and composition. Thus, as the vehicles underwent upgrades, the highways continued to consider exceeded loads, which quickly imposed restorations and interventions on the stretch. The pavement and its condition directly influence the quality of the signal recorded by the WIM sensors. Longitudinal unevenness and deterioration (caused by fatigue, deformation, etc.) limit measurement accuracy, while surface cracks can reduce measurement capability or affect your responses. High deflections and lack of transverse uniformity can also affect the reliability and durability of sensors.

The expenditure of public and private money in these restorations ends up making the process difficult, and in a certain way conditions the road to a poor state of conservation. This finding was presented after the implementation of weighing sensors on a conventional highway and its monitoring. From the results obtained by the road test, it was noticed that the reconstruction of the area destined to the HS-WIM system satisfies the conditions. Thus, Brazil began a search for technical and reference improvements so that it could prepare its own technical guide. Obviously, great world guides and references in the HS-WIM system were used, however, the purpose of the guide is to present and focus on Brazilian eccentricities so that technologies are implemented in the country.

3.1. Recommendations used as a Reference

For the development of the Brazilian Guide for HS-WIM systems, an advanced research was initially carried out in the technologies already present worldwide. This collection of information is necessary for understanding the methodologies already used and that may be the basis for Brazil. Regulations, recommendations, standards and indicatives were consulted. The recommendations underlie the installation, monitoring and follow-up procedures for WIM systems under the eyes of different countries and departments worldwide.

The Guide for Users of WIM - ISWIM, was one of the materials consulted as it presents information on the different aspects related to the use of WIM systems, specification, purchase, installation, testing, operation and maintenance and data generated. The guide uses simplified language on all aspects, and also provides references for further insight into the subject.

COST publications 323 (2002) and ASTM E1318-09 (2017) are specifications used worldwide, being references for the other guides presented. While the first is widely used by European agencies, covering aspects such as geometric and pavement characteristics for site selection, installation procedures, calibration and classification according to the accuracy classes of the WIM system, the second is more used by agencies. American companies, also with their own accuracy classification criteria, installation requirements, traffic data collection and WIM system performance testing methods.

In addition to these regulations, OIML R 134-1 (OIML, 2006), WIM Pocket Guide (FHWA, 2018), Long-Term Pavement Performance (FHWA, 2012), WIM Data Analyst's Manual (FHWA, 2010) was also consulted. Figure 7 brings together the main topics addressed by each of the analyzed documents.

Documents	Site			Accuracy Rating	Calibration	Performance Evaluation	Data Quality	Metrological Tests
	Geometry	Pavement	Others					
COST 323 (2002)	X	X	X	X	X	X		
ASTM E1318-09 (2017)	X	X	X	X	X	X		
OIML R 134-1 (2006)						X	X	X
WIM Pocket Guide (FHWA, 2018a)	X	X	X	X	X	X	X	
LTPP *Field Operations Guide* (FHWA, 2012)		X	X		X	X	X	
WIM *Data Analyst's Manual* (FHWA, 2010)						X	X	
Guide for Users of WIM (ISWIM, 2019) (ISWIM, 2019)			X		X	X	X	

Figure 7 – Summary the WIM recommendations items

3.2. Sensors

During the development of the Brazilian Guide, several types of sensors were evaluated, as a way to compose the HS-WIM system. However, the focus was on those that are usually traded and have a lower financial impact. The idea at this time was that the guide represented the instrumentations already carried out in Brazil and that these could be associated with the HS-WIM systems. Thus, sensor technology consists of piezoelectric sensors (quartz, polymers, ceramics), optical fiber and Bragg fiber, as shown in Figure 6.

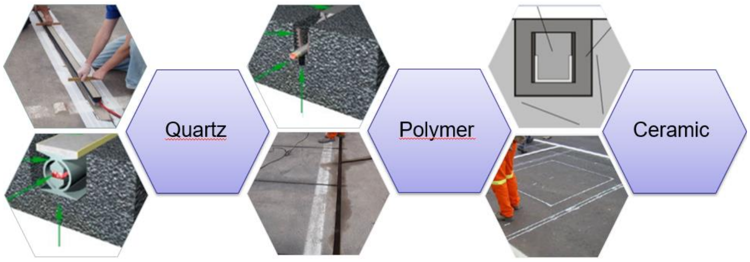

Figure 6 – Sensor technology for HS-WIM systems

One of the most used types of sensors for HS-WIM weighing is piezoelectric. In these, the operation takes place when a pressure, or force, or acceleration, through the generation of an electric current, is applied to the crystal, being transformed into the weight of the vehicle (BRASIL, 2020). Even though there are other types of sensors for HS-WIM systems, such as optical fiber and Bragg fiber, the Brazilian Guide has a greater focus on the quartz sensor.

3.3. HS-WIM Pavement

It is recommended that the WIM system be installed on road segments with characteristics that do not impair data collection during weighing activities and that guarantee, together with the equipment, the accuracy of results. There are several methods for designing road pavements, with asphalt and concrete pavements being the two main structures used worldwide. WIM sensors can also be installed on rigid floors, as in European countries. However, considering that, in Brazil, asphalt pavements correspond to 95% of the types of pavement (ARAÚJO et al., 2016), this will be the focus of the Guide. In order for this type of floor to have greater detail, the development of the solutions catalog was also linked. Thus, both documents can be used jointly.

The main objective of the catalogs is to make the dimensioning of pavement structures practical, provide alternatives in different scenarios, standardize, in addition to establishing quality levels for construction in the same region. The traffic characteristics, the properties of the available materials, the analysis of the mechanical performance of the pavement layers, the technical and economic viability, the geotechnical studies, among others, can be highlighted. Catalog solutions are usually organized based on categories, such as subgrade type or expected traffic volume.

The implementation of the Brazilian Guide for HS-WIM inspection becomes an important tool as this technology has gained great prominence in the country. In addition, greater reliability is sought in the data obtained by monitoring systems and even direct inspection. It is understood that for this, the highways must present an excellent structural and visual condition and the diffusion of these techniques is capable of providing this standardization.

4. Final Considerations

This article presented the motivation for the elaboration of the Brazilian technical Guide for HS-WIM systems. For its development, the consequences of vehicle overloading on existing pavements in the country and the need for new pavement design methods to compose the weighing systems were exemplified. To base the construction of the Guide, the main world recommendations were consulted (COST 323 (2002); ASTM E1318-09 (2017); etc) that cite the installation, maintenance, infrastructure and analysis of WIM data, in addition to the Guide for Users of WIM (ISWIM, 2019).

The development of the Brazilian technical Guide became essential after the installation of the HS-WIM system on conventional pavements of Brazilian highways and the presentation of unsatisfactory results on the road test. From this dissatisfaction, sections destined to the installation of the HS-WIM sensors were restructured through the use of pavement construction methodologies from other countries (French and north American), in which the necessary requirements for the systems were met. In this way, it is concluded that the elaboration and implementation of a technical Guide considering the Brazilian conditions can contribute to a better understanding of the inspection of heavy vehicles through the use HS-WIM, contributing to the reduction of accidents and extending the service life of the pavement.

5. Acknowledgment

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