NEW PROCEDURE BASED ON OBTAINING THE AVERAGE DECELERATION FOR IMPROVING THE SPANISH NATIONAL INSPECTION OF TRACTOR SERVICE BRAKES

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ABSTRACT:

This study addresses the status and proposes key aspects relevant to refining of the procedure for the Spanish National Inspection of Vehicles relative to tractor service brakes, specifically focusing on obtaining the average deceleration. The current inspection method lacks a clear definition of the calculation process for average deceleration in the Spanish Official Manual of Procedures of Inspection of Vehicles. This lack of clarity results in varying outcomes and potential acceptance or rejection of the inspection based on the selected equipment and procedure. To address this issue, a comprehensive series of tests were conducted on different vehicles, using various equipment and calculation methods. The objective was to derive meaningful conclusions regarding the calculation method, measuring equipment, and other relevant factors. This study reveals the inadequacy of the current average deceleration calculation method as outlined in the official inspection manual. The findings highlight the crucial role of accurate equipment selection, appropriate calculation methods, and skilled personnel experience in ensuring reliable and consistent results. To address this, a new standardized procedure is proposed to streamline the process of obtaining the average deceleration in the inspection of tractor service brakes. The recommended procedure encompasses the use of a secure, well-defined track, clearly marked acceleration and braking points, a GPS decelerometer, a portable or on-track speedometer, and data processing that excludes the initial and final sections of the deceleration curve. Furthermore, this study highlights the need to update the acceptance thresholds for the inspection, as the current thresholds may no longer align with the proposed procedure. A revision of these thresholds is suggested to establish new criteria that are more appropriate and in line with the proposed method and for tractors manufactured after 01/01/2016.

Keywords: *Tractors, brake testing, vehicle inspection, road safety.*

1.INTRODUCTION

The Technical Inspection of Vehicles (TIV, referred in Spanish as ITV) in Spain is regulated by Royal Decree 920/2017 [1]. Article 8 of this decree designates the "Manual of Inspection Procedures for TIV Stations" (referred to as "MIP-TIV") as the comprehensive document that outlines the inspection methods, aiming to establish a harmonized inspection procedure nationwide. The MIP-TIV undergoes periodic revisions, with the latest version being 7.7.0 dated 25 May 2023.The primary objective of the MIP-TIV is to establish a set of rules and procedures to be followed during the inspection process, promoting uniformity in criteria and approaches across different TIV stations.

This study focuses on tractors (T-vehicles) covered in Sections III and IV of the MIP-TIV. Particularly in Section "6.1 Service brake."

However, due to specific circumstances related to these vehicles, many of them are incompatible with the roller bench brake test. Consequently, a deceleration test on the track is conducted instead. In such cases, the MIP-TIV states that the effectiveness of the braking system should be assessed using the mean deceleration measurement parameter (dm). The current method is regulatory-based but does not replicate the test. This is unnecessary because TIV stations do not need to re-homologate the vehicles. The TIV stations simply verify if the brake system function is significantly efficient. Per other hand, the manual does not provide clear definitions or guidelines regarding the test conditions, execution, required equipment, and result analysis. As a result, significant discrepancies can arise depending on the interpretation of the test procedure. Furthermore, the procedure for obtaining dm is described in a generic manner in the manual.

1.1. BACKGROUND

In a previous study [2], several issues related to vehicle brakes were identified, along with the relevant regulations governing these aspects (Table 1, see section: supplementary material). Two primary problems were identified: the lack of clear inspection procedures for on-track testing and the commercially available equipment does not readily provide compatible solutions that account for the unique geometry and dynamic behaviour of these vehicles. In Table 1, also present a summary of the procedures and efficacy limits extracted from the analysed regulations, which will serve as the basis for comparison with the current procedure defined in MIP-TIV.

Deceleration average can be measured in different ways. As we can see in some of the sources consulted, the most common and used in this study are: indirect measurement through the reading of speed and position over time using GPS technology [3] and direct measurement with accelerometer-type sensors [4].

1.2. OBJECTIVE

The study aims to evaluate the adequacy of existing procedures and equipment for assessing the functionality of the brake system in TIV. In accordance with current regulations, it proposes a refined procedure for TIV, addressing identified issues and specifying track conditions, initial test speed, data recording requirements, and data processing methods to derive a valid average deceleration value.

2. MATERIALS AND METHODS

2.1. TEST EQUIPMENT[1]

The study utilized four different calibrates portable track-tests equipment:

- A: Refers to the MAHA® VZM 300 tri-axial decelerometer. It records deceleration data during the entire braking period, performs internal processing to obtain the measured deceleration and provides complete recording data.
- B: Refers to the RYME® Brake Check decelerometer and provide direct result of the average braking deceleration, with limited access to the complete test data.
- C: Refers to the decelerometer self-performed by an TIV station and also provides direct result outputs only.
- D (Reference): Refers to RACELOGIC® VBOXII GPS and records speed data over time in the horizontal plane.

2.2. DEFINITION OF THE TEST PLAN[2]

For the tests, a sample of 6 vehicles was utilized, and deceleration tests were conducted on two different test tracks (Tracks A and B, as shown in Figure 1a to 1d) at speeds of 15, 25, 35, and the maximum achievable speed, utilizing four distinct measuring devices and assessing using six different processing methods. The test plan consisted of three main phases:

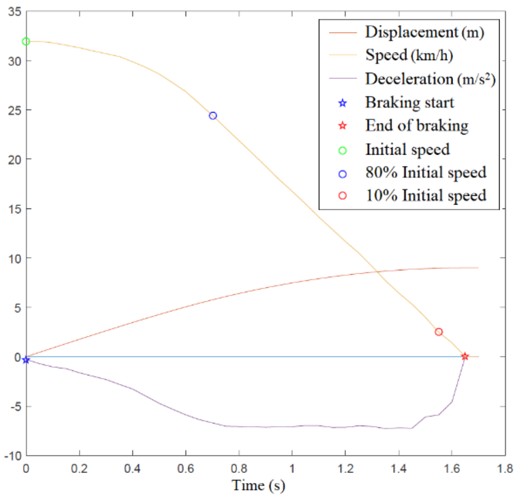
[1] For further equipment details, please refer to Section 2.1 of the supplementary material.
[2] For further vehicles details, please refer to Table 2 of Section 2.2 of the supplementary material.

(a) Track A

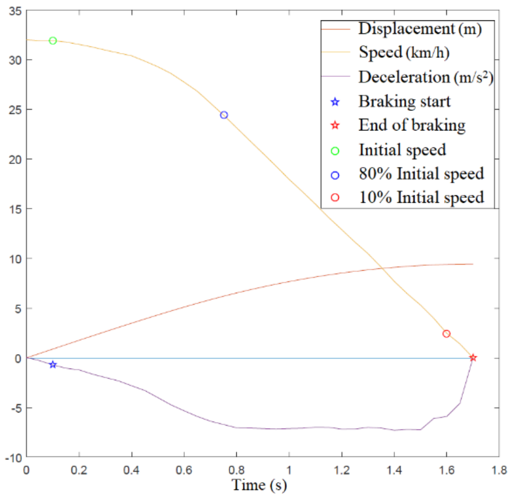
(b) Track B

(c) Truck test in track A

(d) Truck test in track B



(e) Programmatically braked start



(f) Brake sensor braking initiation

Figure 1. *Example of test tracks at TIV stations and graphical representation of processed data.*

Initial Phase: This phase involved collecting characteristic data for each vehicle, checking and adjusting tyre pressure, weighing each axle on scales, and properly anchoring the measuring instrumentation.

Testing Phase: This phase comprised the following steps: 1) Positioning the vehicle at the starting point of the track; 2) Accelerating the vehicle until the desired test speed was attained; 3) Stabilizing the vehicle at this speed for 1 to 3 seconds; 4) Applying force to the brake pedal until the vehicle came to a complete stop.

Data Processing Phase: Finally, all the data collected were processed, and the following variables were obtained for each vehicle, test speed, and measuring equipment: initial speed in m/s, average deceleration in m/s², acceleration length in meters, and braking distance in meters. Due to the specific characteristics of each equipment, these variables were obtained using different methods, designated by the following references:

- MM_A: Manual method using equipment A. The calculation interval was manually entered in seconds, and the result was obtained through internal processing of the equipment immediately.
- DM_B and DM_C: Direct Method using equipment B and C, respectively. The result was directly obtained from the equipment.
- MOM_A and MOM_D: Post-processing method based on the M.O. 11/06/1984 procedure (current on TIV an used as a reference method on this study) using equipment A and D, respectively. The start of braking was determined by programming, following the formulation defined in Table 1 (see section: supplementary material), with data records from the equipment.
- DRM_A and DRM_D: Same as the previous method but based on the D.R. (EU) 2015/68 procedure. Note that this procedure uses a mean fully development deceleration (MFDD) as a d_m, and it is foreseeable that this method yields more realistic results. Refer to Figure 1e for example.

- MOM_D_PF and DRM_D_PF: Same as the two previous methods but instead of determining the braking by programming, using equipment D along with a trigger force sensor in the brake pedal. Refer to Figure 1f for example.

3. RESULTS AND DISCUSSION

Following data processing, a statistical analysis was conducted on various categories and speeds in relation to the average d_m achieved. In order to compare equipment and data processing methods and not the type of vehicle used, each average d_m processed has been used as a single data item regardless of the equipment or processing method used. Therefore, when considering the vehicles tested, test speeds, number of repetitions, equipment variations and data processing techniques, the sample size exceeds 350 results.[3]

Refer to Figure 2 to view the diverse average of d_m grouping results. Figure 2a illustrates the diverse average of d_m obtained with each equipment and calculation procedure used, categorized according to the aforementioned speed groups. Figure 2b presents equal values but obtained for each speed group using different equipment or calculation processes.

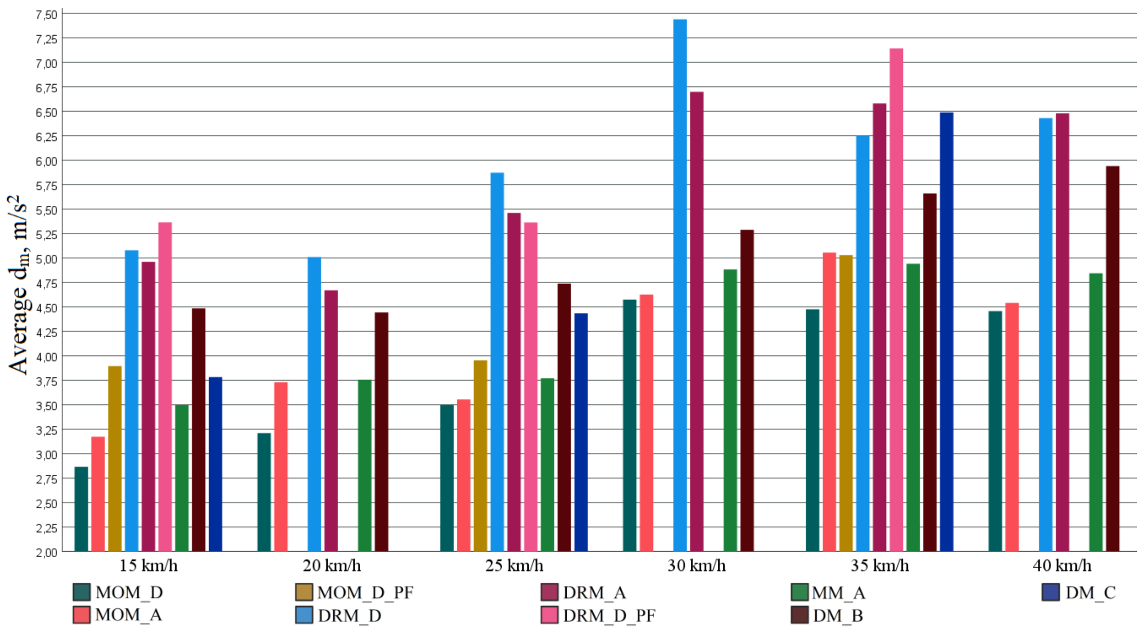
Nevertheless, for a more visual data analysis, the results were grouped based on the initial speed recorded by laboratory equipment D, which is the only equipment that records all speed data over time, within a range of determined values of ±2 km/h. The speed groups were as follows: 15, 20, 25, 30, 35 and 40 in km/h.

The primary categories examined included the initial test velocity categorized by equipment D, as well as the equipment and data processing methods employed. Subsequently, the collected data concerning initial speed acceleration length and braking distances, along with safety margin recommendations and vehicle actual mass, will be utilized to ascertain the dimensions of the test track based on the initial test velocity from equipment D.

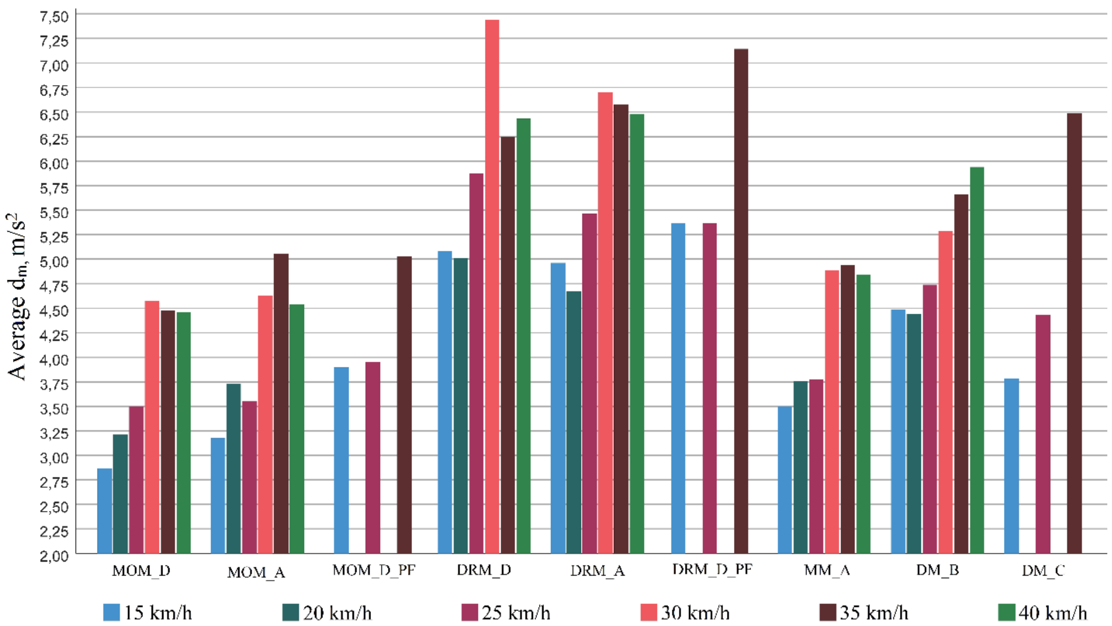
3.1. INFLUENCE OF INITIAL TEST SPEED

One of the primary objectives was to evaluate the impact of the initial target speed on the d_m values obtained during the test. A notable aspect to highlight was the challenge encountered in attaining the desired initial test speed. In this vehicle category, it was found that speedometers were either absent or unreliable, if available. Furthermore, the speed display provided by the equipment used was inconvenient or difficult to observe while driving. Additionally, to record the initial braking speed, a dependable recording system was necessary for test verification and validation. Hence, it is imperative to ensure the driver has a reliable and easily recordable vehicle speed during the test. A post-hoc Scheffé counter test (referred to as post-hoc ANOVA) between the average of mean deceleration of equipment groups was performed for each target speed. Bar graphs in Figure 3a demonstrate that the speed ranges of 15÷25 km/h and 30÷40 km/h exhibited similar average d_m. The analysis conducted on these ranges are presented in Table 3 (see section: supplementary material), which confirms the observed clustering. In conclusion, two distinct groups can be identified: one for medium speeds and another for high speeds.

[3] For analysis justification details, please refer to Section 3 of the supplementary material.



(a) Groupings per equipment and subsets per initial speed

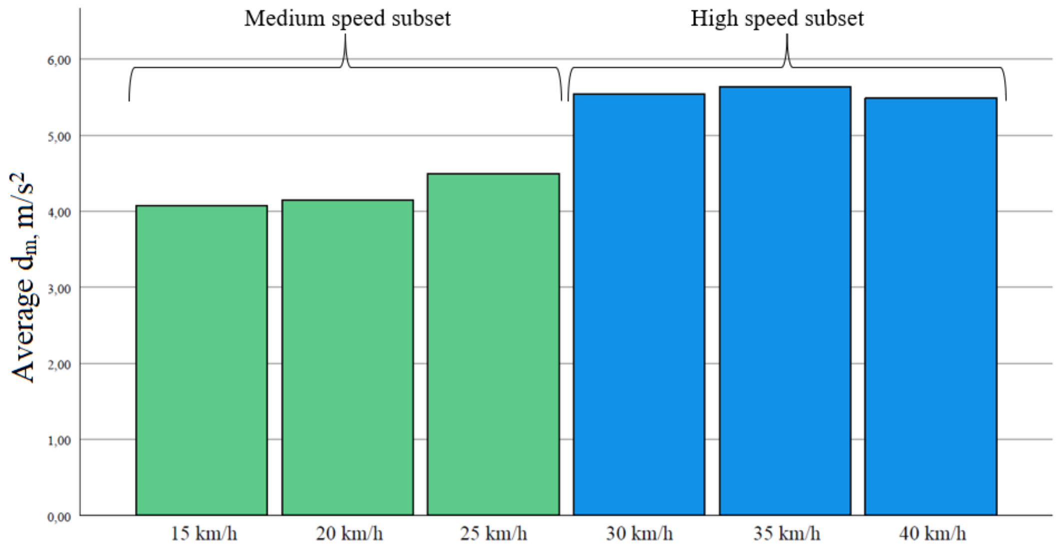


(b) Groupings per initial speed and subsets per equipment

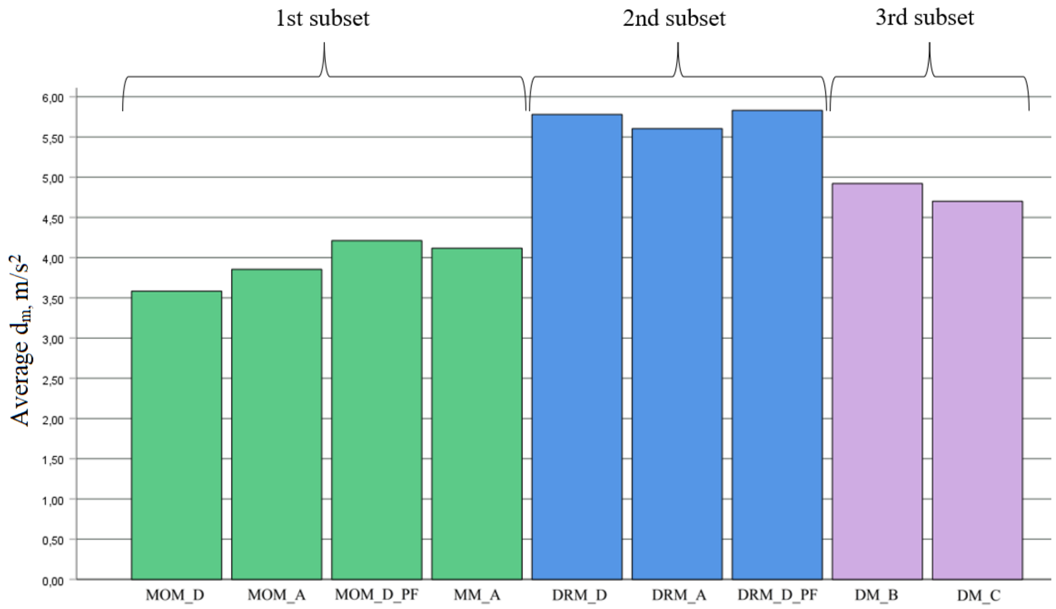
Figure 2. *Average d_m results.*

(Figure note: Speed grouping or subsets based on speed from reference equipment D)

Therefore, the test can be considered valid within the medium-speed group of 15 to 25 km/h. Reliable results can be obtained within this speed range, provided the appropriate rejection threshold is applied to maximum speed range of vehicle set by the MIP-TIV (Table 1, see section supplementary material for view rejection threshold). This offers significant advantages during the test, including improved safety, reduced track size requirements, and simplified vehicle handling.



(a) Groupings per initial speed



(b) Groupings per each method

Figure 3. *Average d_m comparisons.*

3.2. INFLUENCE OF TEST EQUIPMENT AND DATA PROCESSING

Another key aspect to evaluate was the influence of the equipment used and the different data processing methods on the d_m values obtained. The positioning of the decelerometer within the vehicle during the test is an important consideration. Naturally, there is no designated or prepared location, and it can be challenging to secure and position the decelerometer. The sensitivity to the device's placement can have a significant impact.

Several noteworthy observations have been made regarding the equipment. Unit A, when operating in manual mode (MM_A), adequately collects the data for processing. However, the time interval for calculating the average d_m is manually defined in the process, an aspect that has not been implemented. This influences the final result, making it necessary to determine how to choose this interval.

It has been noted that equipment B frequently malfunctions, detecting tests that were not performed due to actions such as gear changes, clutch usage, or inherent vibrations in the vehicles. The equipment's sensitivity contributes to these failures. When initiating the test, the corresponding function is set and activated. As configured, the equipment is designed to identify the end of the test.

However, a sudden gear change can be misidentified as a test run, resulting in a failure. The equipment does not ascertain whether the initial test speed has been achieved. Certainly, it is important to note that these results were not included in all the analyses conducted.

In terms of data processing method, the difference between MOM and DRM lies in the section of the deceleration curve used for calculating the d_m. DRM processing excludes the initial and final sections of the deceleration curve, which encompass the start-of-braking and end-of-trial transients. It is reasonable to omit these sections since the evaluation focuses on the braking system's performance under maximum capacity. The initial braking time and the bouncing suspension at the end of the test do not provide relevant information. Consequently, the d_m values obtained through DRM processing are higher.

To assess equipment performance, equipment D, a laboratory device based on GPS technology rather than accelerometers, was used as a reference. It is unaffected by suspension pitching and ensures accurate longitudinal orientation, which can provide more reliable deceleration values.

To better visualize and distinguish between the equipment, average of d_m were calculated for each equipment across all speeds, resulting in bar diagram shown in Figure 3b.

Depending on the data processing method employed by each, three distinct subsets can be identified. The first one comprises units that calculate the d_m by processing data using the MOM method and the A unit in manual processing mode (1st subset members: MM_A, MOM_A, MOM_D, and MOM_D_PF). The second one follows the same approach but utilizes the DRM method for data processing (2nd subset members: DRM_A, DRM_D, and DRM_D_PF). The third consists of teams B and C, which directly measure the d_m value and appear to lie between the other two methods (3rd subset members: DM_B and DM_C).

It is noteworthy that the results obtained by DM_C exhibit a confidence interval that significantly overlaps with the other groups, making it challenging to differentiate its application. However, it should be acknowledged that there is less available data for this equipment. Conversely, the results obtained by DM_B align centrally and overlap with the other devices. Nevertheless, this decelerometer shows poorer performance in terms of failures and unrecorded tests. Clear disparities can be observed in the processed results of units A and D compared to the rest. The processed results that consider only the central part of the curve yield higher values, as anticipated. Unit A demonstrates the most similar results to the reference unit D.

Based on these findings, it can be considered that processing the entire curve, encompassing the initial speed decrease and ending at zero speed, yields valid results for TIV station. These results exhibit lower but consistent mean values. However, in such conditions, the algorithms for determining the test's end are affected by transients caused by the final pitches. On the other hand, processing solely the central part of the curve yields cleaner data with fewer processing errors and higher result values. Therefore, considering this general trend across all tested vehicles, the data processing method should be linked to the rejection threshold to be applied. Both methodologies are initially valid, but they yield results with significant differences exceeding 2 m/s².

To further support this assertion, a post-hoc ANOVA processing was conducted (Table 4, see section: supplementary material).

In conclusion, significant differences have been observed between devices that measure the mean deceleration using the MOM method and those that employ the DRM method. It cannot be concluded that devices B and C adhere to a specific internal calculation process, as it was not possible to determine the precise calculation process used for determining the mean deceleration. However, with known and controlled calculation processes, satisfactory repeatability and valid results have been achieved.

The market offers equipment that, with appropriate configuration, can provide consistent and reproducible results. In this work two different technologies have been used, GPS and tri-axial decelerometer. Both can detect the orientation of the equipment, determine the direction of travel, and calculate longitudinal deceleration, thus mitigating issues related to positioning and orientation. It has been demonstrated, and is therefore used in the current braking homologation regulations, that DRM can provide more realistic results. Although the technology is available, specific commercial equipment capable of quickly and easily implementing this configuration has not yet been defined.

3.3. KEY ISSUES IDENTIFIED IN THIS STUDY

As highlighted in various publications [6:9], the importance of maintaining the braking systems in good condition cannot be overstated, particularly for ensuring safety on public roads. Therefore, it is crucial to establish a comprehensive procedure that clearly outlines the steps required to determine the average deceleration of tractors. Studies, such as [9, 10], indicate a direct influence on the results based on the driver's performance during each test repetition. In addition to the knowledge acquired during the study and the experience gained from conducting tests, it is evident that there is a need to refine the procedure for obtaining d_m at TIV stations.

From the experience gained, a compilation of key points has been made to develop an inspection procedure, which includes determining the dimensions of the test track. In conclusion to this and as reference values for determining the track length, the recommended values for test track lengths are presented in Table 5. It should be noted, for example, that testing at 35 km/h requires 81,7 meters, approximately twice the track length compared to 20 km/h.[4]

Test speed (km/h)	Acceleration distance (m)	Distance from braking (m)	Safety margin (m)	Track length (m)
15	28.7	2.1	2.3	33.0
20	35.9	4.5	4.0	44.4
25	43.2	6.9	6.3	56.3
30	50.5	9.3	9.0	68.8
35	57.8	11.7	12.3	81.7
40	65.1	14.1	16.0	95.2

Table 5: *Track lengths as a function of test speed (±0,1 m)*

By other hand, when examining the minimum mean deceleration thresholds values set by the MIP-TIV, an interesting aspect becomes apparent. In the example shown in Figure 6, all the obtained values are above the current acceptability threshold. However, it is possible that for vehicles with values close to these thresholds, the suitability or unsuitability of the service braking check may vary depending on the equipment used and the calculation method selected. In accordance with this conclusion, we have made an honest proposal for new acceptance thresholds (Table 7, see section: supplementary material).[5]

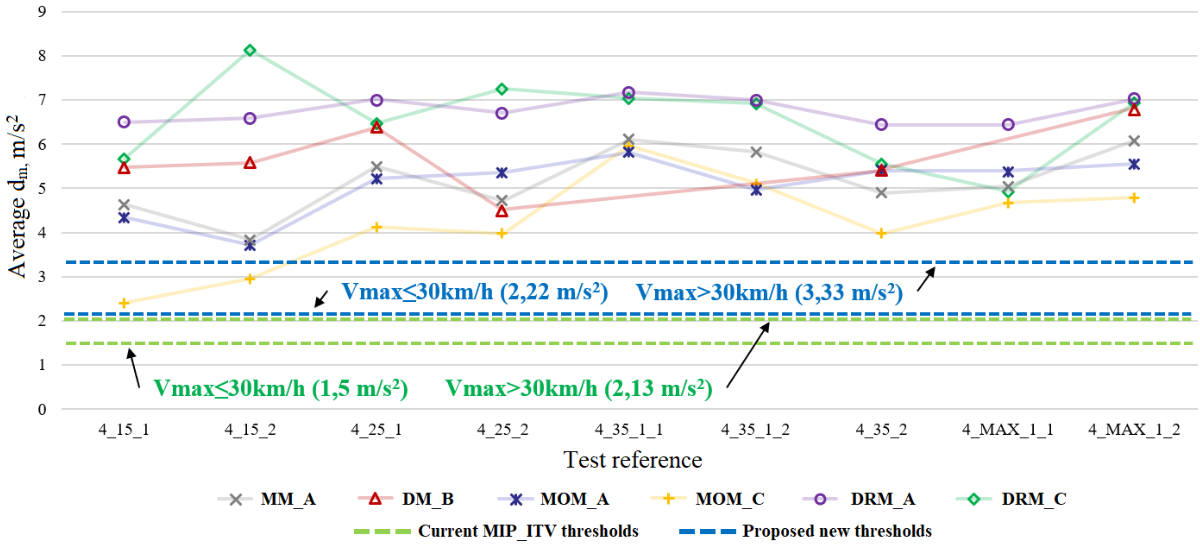


Figure 4. *Average d_m by equipment at different speeds and comparison of thresholds.*

(Figure note: The labels on the horizontal axis indicate the test reference, for example: Vehicle tests 4_Speed in km/h_Test number. MAX was the maximum speed by construction, approx. 40 km/h.)

[4] Consult the Section 4 of supplementary material to see recompilation of keys to developing an inspection procedure.
[5] Consult the Section 5 of supplementary material to see an honest proposal for new acceptance thresholds.

4. CONCLUSIONS

A total of 45 track tests were conducted on six agricultural vehicles, utilizing four measuring devices and assessing using six processing methods. These tests generated over 350 data points, facilitating analysis of critical factors like test speed, equipment selection, and test track dimensions.

Testing at low initial speeds (15 to 25 km/h) emerged as a viable option for evaluating braking systems in all tractors, necessitating shorter, safer tracks ranging from 33 to 56.3 meters.

The post-hoc ANOVA revealed significant differences between devices and calculation methods, influencing the fit or unfit determination of a vehicle's brake testing. Focusing on the central part of the braking curve yielded better, more robust data.

While ensuring uniformity and comparability of results across all TIV stations, specifying the calculation method in the MIP-TIV is crucial. Qualified personnel should execute tests, ensuring safety and quality by precisely defining the test track and delineating acceleration and braking zones.

These findings led to the development of guidelines for a new test procedure and revised acceptance limits for service brakes (2.22 m/s^2 for $\leq$ 30 km/h and 3.33 m/s^2 for > 30 km/h). While expanding the sample size is necessary for comprehensive analysis, the proposed test procedure and acceptance limits offer a solid starting point for redefining the MIP-TIV inspection procedure.

Future work involves developing automated dm measurement equipment using cost-effective technologies like Arduino or Raspberry Pi, aiming for easier, quicker, and more cost-effective service brake inspections.

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SUPPLEMENTARY MATERIALS

https://www.revistadyna.com/documentos/pdfs/_adic/11154-1_en.pdf