MEASUREMENT OF NON-ELECTRIC QUANTITIES

METROLOGICAL REQUIREMENTS OF WEIGH-IN-MOTION SYSTEMS FOR VEHICLES

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Abstract. The article analyzes and proposes solutions for metrological support of weight information systems of road vehicles in motion, including the method of classification of WIM systems by purpose and accuracy classes, metrological requirements for them and control methods for testing and verification, as well as the main metrological risks for Weigh-in-motion systems for road vehicles and requirements for determining and calculating reliability.

Key words: Weigh-in-Motion; Weight monitoring; Classification; Automatic monitoring of weight parameters; Axial load.

1. Introduction

The issue of weighing road vehicles while driving is very important, both in Ukraine and in other countries. In Dec. 2018, the State Agency of Roads of Ukraine signed a contract for the implementation of a pilot project for weighing cars in motion (hereinafter WiM). At the first stage, it is planned to build six platforms for automatic weighing while driving at the entrances to Kyiv on roads M-01, 03, 05-07. In general, the project envisages organizing up to 200-250 such points across the country in two or three years.

For today, 6 WiM systems operate in the test mode of preselection in Ukraine. They separate from the general flow of those vehicles that move over the permitted parameters. After this, the Ukrtransbezpeka inspectors stop such a vehicle to carry out additional weighing and impose sanctions. Currently, the system allows the pre-selection of vehicles. With the WiM systems, the state becomes able to manage the traffic effectively and reliably aiming the direct collection of fines for exceeding the Weighing norms and the protection of the roads from destruction by overloaded vehicles.

The WiM systems should become part of the general intelligent transport system, which Ukravtodor plans to implement on the country's roads. It combines the following components: Traffic Control, Automatic Speeding Control, Tolling, WIM.

The Weigh-in-Motion system is a modern, intelligent system for comprehensively collecting information about vehicles traveling on highways. It automatically monitors traffic on the roads in real-time, guarantees accurate measurements with minimal error, collects the necessary data on vehicles. WiM system’s implementation means round-the-clock traffic monitoring; an automatic fixation of violations; the minimal human impact.

As part of the Pilot Project for the implementation of WiM systems while driving, the WiM portals were installed at busy entrances to Kyiv: WiM 1 (highway M-06 Kyiv – Chop, km 24 + 130); WiM 2 (highway M-06 Kyiv – Chop, km 54 + 336); WiM 3 (highway M-03 Kyiv – Kharkiv – Dovzhansky, km 80 + 939); WiM 4 (highway R-03 Northeast bypass of Boryspil, km 19 + 543); WiM 5 (highway M-05 Kyiv – Odessa, km 36 + 304); WiM 6 (highway M-07 Kyiv – Kovel – Yagodyn, km 62 + 879). In the coming years, the WiM system is planned to be extended to the entire road network of Ukraine, using the experience gained during the implementation of the Pilot Project.

2. Formulation of the problem

The WiM systems have spread in the United States and the European Union since the end of the last century. In Ukraine, the impetus for the introduction of automatic dimensional and Weigh monitoring was the Order of the Ministry of Infrastructure of Ukraine [1].

In world practice, three documents are often applied as technical and metrological requirements for automatic weighing of road vehicles while driving: ASTM-1318 [2], OIML R134 [3], COST-323 [4], demonstrating different approaches to classification, test methods, and areas of use of weighing trucks in motion. However, these international documents for weighing trucks while driving [2–4] and national standards of Ukraine are incompatible. The specific nature of weighing during movement requires a certain classification of weighing systems, metrological requirements for them, identification and risk assessment in the application of these systems during weight control, and the development of stable statistics and experience, which is currently absent in our country.

3. The Goal of the Paper

Determination of metrological and technical requirements for weighing-in-movement systems as well as the methods of their monitoring, testing, and verification, assessment of metrological risks, which is necessary for the creation of a national regulatory document.

4. Classification of Weighing-in-Motion Systems

The system of high-speed dynamic weighing performs the functions of measurement, processing, storage, and transmission of data related to the following tasks:

– Measurement of axle load, total Weigh and overall parameters of vehicles.

– Vehicle identification by photo-fixation and license plate recognition.

– Aggregation of data on vehicles with simultaneous classification by dimensional and weight parameters.

– Providing the ability to view data on each point of dynamic weighting in real-time by on-site or remote access.

4.1. Classification by Functional Purpose

WiM systems should be classified into at least three functional groups, according to the degree of increase in accuracy requirements.

Group 1 is for collecting the statistical data for economic and technical research of freight transport, assessment of the total traffic flow. Group 2 goals the automatic control of weight parameters of vehicles for preselection of accidents and state regulation; detailed analysis of traffic; better maintenance of bridges, overpasses, and other important sections of roads. Group 3 is for control weighing to ensure the uniformity of measurements (adjustment, calibration, verification, testing), as well as for checking the weight of vehicles after loading preceding the departure on the public roads. Classification by functional purpose is given in Table 1.

Table 1

Classification by functional purpose

Criteria	Scope	Group 1	Group 2	Group 3
Functional purpose	Collection of statistical data	MA	VA	VA
	Automatic control of weight parameters	–	MA	VA
	Control weighing	–	–	MA
Location		On the road	On the road	On a separate lane
Speed range		20–130 km/h	5–90 km/h	0–5 km/h
Lock-on uneven speed (acceleration)		VA	MA	MA
"MA"– mandatory application; "VA" – voluntary application; "–" – not applicable				

The most widespread in terms of scope is the WiM system, belonging to Group 3. They are characterized by high accuracy in determining the weight characteristics. However, increased requirements for weighing accuracy impose restrictions on the speed and acceleration of the measured vehicles. For these systems, it is necessary to install a separate lane location of which has to be determined with a speed limit of 5 km/h.

Group 2 WiM systems are the most universal and can be installed on flat sections of roads, bridges, etc. Their accuracy does not contribute to the control weighing but must be sufficient to manage the automatic determination and monitoring of the vehicle dimensional and weight characteristics. It is the Group 2 WiM systems that are urgently needed today. Such systems have to be located directly on roads and highways; their operation can be carried out at a uniform speed, up to 90 km/h velocity.

Group 1 WiM systems put forward the lowest requirements for accuracy. Their scope involves assessing the traffic intensity and setting of freight statistics. These systems facilitate the preliminary assessment and modeling of the situation for a particular district or region as well as the determination of the number and location of the considered systems.

4.2. Classification by the accuracy

Let's consider the classification of WiM systems by the weighing accuracy. Accuracy is a generalized characteristic of the measuring equipment, expressed within the permissible main and additional errors, as well as other characteristics that affect the accuracy. The high-mentioned systems are characterized by several different errors for the monitored mass, the axial loads or their groups, for different vehicles and their types, operating speed ranges, and some other factors.

According to the functional purpose, the systems should be classified by the level of confidence to the limits of permissible weighing error. For the collection of statistics or pre-weighing (Group 1) the confidence level p has to be ≥ 95 %, and for the implementation of the state regulation (Group 2 and Group 3) – not less than 99 %.

Accuracy classes with a confidence level of permissible error $p = 99$ % are basic, with a confidence level $p = 95$ % belong to the additional. WiM systems may have different accuracy classes for different operating speed ranges. A certain class of accuracy can be chosen according to the functional purpose of the particular system. While changing the operating conditions or functional purpose, the WiM system can be transferred to another class of accuracy, according to their calibration results in the considered operating conditions.

Basing on the proposed, the following metrological requirements for WiM systems are set by the following factors:

– the limits of the permissible errors;
– the price of division;
– the minimum load;
– the operation speed;
– the permissible acceleration.

The main accuracy classes are given in Table 2, and additional accuracy classes – Table 3.

4.3. Classification by the permissible errors

While testing and calibrating the systems, 95 % of the load measurements results from the single axle and, at the necessity, the load measurements results from the axles group, have not exceeded the greater of the following values: a) the estimated absolute error (following Table 1) rounded to the nearest larger value of the division price; b) $1d \times N$, $2d \times N$, where d is the division price, N is the number of monitored vehicle's axles.

Table 2

The main accuracy classes of WiM systems at the confidence level 99 %

Criteria	Monitored vehicle	Group 2		Group 3	
		10F	**5E**	**2D**	**1B**
Confidence limits of permissible error, %	Weight	±10	±5	±2	±1
	Load of the axles group	±16	±8	±4	±2
	Axial load	±16	±8	±4	±2
Static weighing mode	–	**VA**	**VA**	**MA**	**MA**
Name of the normative document	–	OIML R 134-1			
"MA"– mandatory application; "VA" – voluntary application					

Table 3

The additional accuracy classes of WiM systems at the confidence level of 95 %

Criteria	Monitored vehicle	Group 1			
		Type I	**Type II**	**Type III**	**Type IV**
Confidence limits of permissible error, %	Weight	±10	±15	±6	±5
	Load of the axles group	±15	±20	±10	±8
	Axial load	±20	±30	±15	±8
Static weighing mode	–	**VA**	**VA**	**MA**	**MA**
Name of the normative document	–	ASTME – 1318			OIML R 134-1
"MA"– mandatory application; "VA" – voluntary application					

Table 4

Limits of permissible errors at static loadings on the load-receiving device

Accuracy class	Limits of permissible error while calibrating, % of the reference value		
	Vehicle weight	Vehicle's axles load	A load of an axle
1B	±0,5	±1	±1
2D	±1	±2	±2
5E	±2,5	±4	±4
10F	±5	±8	±8
Type I	±10	±15	±20
Type II	±15	±20	±30
Type III	±6	±10	±15
Type IV	±5	±8	±8

The values of the limits of permissible measurement error during calibration are given in Table 4. These requirements can only be applied to WiM systems that were calibrated with the static reference loads placed entirely on the load-receiving device. In the mode of measuring static loads, these systems must meet the requirements for Weighs of non-automatic action according to OIML R 76-1: 2014 [5] and EN 45501: 2017 [6].

The limits of permissible errors under static loads on the runway shall correspond to the values given in Table 5.

4.3.1. The price of the division

For each weighting method (in static weighing mode or moving weighing mode) the division price may be different. Then for a particular method of weighting and the established accuracy class, every indicating and printing device of scales must have the same division price. The readouts of the vehicle weight and its axial loads must also be characterized by the same division price. The relationship between the accuracy class, the value of the division price, and the number of divisions at the maximum load of the WiM system is shown in Table 6.

Table 5

Limits of permissible errors at static loadings

Load m, expressed in units of the division price at statistical weighing, d	Limits of permissible errors	
	When calibrating	In operation
$0 \le m \le 500$	±0,5 · d	± 1 · d
$500 < m \le 2000$	±1 · d	±2 · d
$2000 < m \le 5000$	±1,5 · d	±3 · d

Table 6

The relationship between the accuracy class, the value of the division price, and the number of divisions at the maximum load of WiM systems while weighting vehicle in parts

<table>
<tr><th>The accuracy class</th><th>d, kg</th><th>Minimal number of the divisions</th><th>Maximal number of the divisions</th></tr>
<tr><td>1B</td><td>≤ 20</td><td>500</td><td>5000</td></tr>
<tr><td>2D</td><td>≤ 50</td><td rowspan="4">50</td><td rowspan="4">1000</td></tr>
<tr><td>Type IV, Type III, 5E</td><td>≤ 100</td></tr>
<tr><td>Type I, 10F</td><td rowspan="2">≤ 200</td></tr>
<tr><td>Type II</td></tr>
<tr><td colspan="4">The division price of the indicating and printing devices would be chosen from the range of 1 … 10 k or 5 … 10 k, where k is a positive or negative number, or zero</td></tr>
</table>

The WiM system can store information about weighting in one direction of movement more than 10,000 cars with the Weigh higher than 3.5 tons. The accuracy of weighing is also impressive: during movement, it fluctuates within 2 %, in statics fluctuations are lower than 0.05 %. The systems can operate within the temperature from – 30 °C to + 40 °C, being protected from possible overvoltages. Currently, the main tasks of WiM systems are traffic monitoring, preliminary selection for identification of the company. Soon, it is planned to carry out the tolls based on weight parameters. The dimensions of the active site are 700×450×58 cm. That is, it is impossible to bypass the considered system blocking the road across its width. Reliability data is confirmed by measurements of each axle load of at least three consecutive trajectory points [7].

To increase the efficiency of freight traffic, more data is available. Some of them are collected in an infrastructure, equipped with smart sensors networks. This data may be related to that coming from vehicle documents and other available sources: 1) to assess the interaction of vehicles and infrastructure; 2) to facilitate the operation of them, the provision of certain services and/or improve their safety; 3) to estimate the impact of the vehicle on the infrastructure, possible damage to the road surface and its service life; 4) to ensure monitoring of traffic and infrastructure. Therefore, the collection of the WiM system's data can prevent the highway's resources without violating the operating conditions.

4.4. Classification by the minimum load

The minimum load of the load-receiving device should not be less than the load, expressed in units of the division price and specified in Table 7.

Today, regulations provide for the carriage of goods with a total weight (including the weight of the vehicle) of less than 40 tons. In addition, the weight parameters are monitored by the load on a single axel, not more than 11 tons, on a double axel, not more than 16 tons, on the triple one – 22 tons [6, 7].

Table 7

The minimum load of the load-receiving device

Accuracy classes for the weight measurements	The minimum load in the units of division price
1B	50
2D, 5E, 10F, Type I – Type IV	10

4.5. Classification by operating speed and permissible acceleration

WiM system must meet the metrological and technical requirements for the movement of the monitored vehicle at a speed not exceeding the operating speed specified in the system's documentation or determined while system's testing. The operating speed must be shown and/or printed only after weighing at the movement. Its range can be divided into subranges, in each of which different accuracy classes can be set, as well as different methods of estimating metrological characteristics can be applied. Systems designed to monitor the changes in the speed (to estimate an acceleration) must be able to determine that the monitored vehicle passed through the runway at a non-uniform speed and its acceleration exceeds the specified limit. The results of measurements of such vehicle's weight must be marked with the appropriate violation code with a warning that the obtained results are unreliable.

5. Metrological risks of the WiM system application

To ensure the required quality of measuring processes, their metrological support is carried out. Modern approaches to the measurements and large-scale implementation of smart measuring instruments significantly increase the requirements for the organization of metrological activity. This determines the improvement of the quality and efficiency of measurement and integration them into the regulatory support of the weight monitoring.

In modern conditions, any company in its activities is faced with uncertainty and risk. Particularly relevant is the issue of metrological risk management as the main risk that determines the controllability of technology, the control of measurement processes, and hence the provision costs [8].

The importance of the metrological risk reduction stage is the need for a formalized justification of the decision-making process and planning of effective actions to minimize the metrological risk of the managed process. It is also necessary to organize a process of the permanent monitoring of metrological risk to respond in-situ to its change and timely correct the impacts.

The amount of loss caused by an adverse event is called the risk which is defined as the mathematical expectation of the loss function. In the risk assessment, the latter can be considered as the dependence of road holder or carrier losses on the measurement uncertainty of WiM systems, processing and computing the results. So, the metrological risk can be defined as the probability of the measurement data impact on the result of the compliance the monitored vehicle parameters with the established norms; and the measure of the considered risk can be losses caused by the uncertainty of measurements.

With the introduction of quality management and measurement management, there arise the conditions for effective risk management, including metrological risk management. For the latter, it needs to classify them by important features, the choice of which should be reflected by most of their characteristics and the influence of impact-factor on the outcome of the process to which it relates. The importance of correct identification and risk assessment is determined by the need for objective and reliable information on the applied WiM system. A classification of the mentioned risks in the WiM systems is given in Table 8.

Table 8

Classification of the metrological risks in the WiM systems

	Classification features of the metrological risks	Types of the metrological risks
1	By the ability to influence the level of risk	Risks that can be managed Risks that cannot be controlled
2	By the ability to predict the consequences that may lead to the risk	Risks, the consequences of which can be predicted Risks, the consequences of which are impossible to predict
3	By the ability to correct the consequences that can lead to risk emerging	Risks, the consequences of which can be corrected Risks, the consequences of which cannot be corrected
4	By the sphere of influence upon the risk	The impact on the measurement process The influence on the processing of measurement results
5	For the significance of the risk	Basic risks Minor risks
6	According to the source of the risk	Structural risks Operational risks
7	According to the level of the risk	Permissible risks Critical risks Catastrophic risks

An important condition for effective risk management in the WiM system is the development of a regulatory document where it is necessary to systematize the possible sources of the metrological risks according to the proposed classification and to develop a methodology for assessing the risk level. This forms the foundation of creating the identification model of risk estimation and proposing effective methods for lowering its impact. Since it is quite rare to define the permanent correlation between the metrological risks and losses caused by them, we advise assessing such losses by expert evaluation according to the accepted scale of points. It is possible to offer such a scale for the WiM system based on the metrological risks, aiming for in-place monitoring of the road holder loss while vehicle weighing. Depending on the available information on losses, this scale can be constructed considering the following loss indicators.

Table 9

Score scale for assessing losses from the level of metrological risk in WiM system

The average losses from metrological risk, %	B_M, points
0… 20	1
20 … 40	2
40 … 60	3
60 … 80	4
80 …100	5

Losses of the road holder V_M from the metrological risks during the weight monitoring of the vehicle can be estimated by:

$$V_M = B_M I_M ,$$

where B_M is the point assessment of losses, I_M is an index of metrological risk, determined by the particular method and indicated the effectiveness of metrological support of WiM system.

The main advantages of the risk management approach to estimating the losses of the WiM system from the metrological risks are the fast identification of possible metrological failures of measuring equipment; the quantitative assessments of metrological risks over time, which can help reasonably in the choice of appropriate measures; identification of factors that determine the certain risk and the weak links in the metrological support; identification and comparison of risks of relevant processes from the uncertainty of measurements; creation of databases for the optimal management and quality assurance of the WiM system operation [9].

6. Conclusion

By studying various Weigh-in-Motion systems and methods of their testing and verification, the metrological concept is proposed as a basis for the development of a National standard of Ukraine.

7. Conflict of interest

The authors state that there are no financial or other conflicts regarding the work.

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