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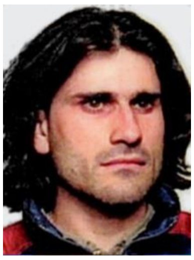
DEVELOPMENT AND TECHNOLOGY TRANSFER OF A WEIGH IN MOTION SYSTEM IN ARGENTINA





J. JORGE **I. MORETTI** **J. AMADO** **D. PUNTILLO** **C. CANIGLIA**
National Institute of Industrial Technology,
Argentina

Abstract
With a transportation system centered on the roads, and a very deficient railway infrastructure, it is increasingly important to do proper planning and design of Highways of our country and more specifically of our province. In this context, the Department of Roads of the Province of Córdoba and the National Institute of Industrial Technology (INTI) initiated a joint project for the development and construction of an inexpensive, adaptable to the conditions of the region, and with local support prototype of a high-speed weigh in motion system that it could be produced in our country. This paper presents the process of design, implementation, calibration, testing and technology transfer of a WIM system for statistical purpose, developed entirely in an institution of the national state and transferred to the productive sector. The current status of WIM in Argentina and future prospects are also mentioned.

Keywords: Weigh In Motion, high-speed WIM, WIM development kit.

Resumen
El sistema de transporte argentino está centrado en las carreteras por lo que cada vez es más fuerte la necesidad de realizar una correcta planificación y diseño de las rutas de nuestro país, y puntualmente de nuestra provincia. En este contexto, la Dirección de Vialidad de la Provincia de Córdoba y el Instituto Nacional de Tecnología Industrial (INTI) inician un proyecto conjunto para el desarrollo y construcción de un sistema de pesaje dinámico de bajo costo, adaptable a las condiciones de la región, con soporte local, y que pueda ser producido en nuestro país. En esta publicación se describe el proceso de diseño, desarrollo, implementación, verificación, calibración, pruebas, y transferencia tecnológica de este sistema, completamente desarrollado en una institución del estado y transferido al sector productivo. Se muestra el estado actual del área en Argentina y se mencionan las perspectivas futuras.

Palabras Claves: Pesaje en movimiento, WIM de alta velocidad, prototipo WIM.

1. Introduction

Argentinian transportation system is centered on the roads; we have a very deficient railway infrastructure. Road transport in Argentina has a decisive weight in the total cargo movement (which includes exports, imports and domestic cargo). Currently more than 90% of the total load is delivered by road transport (Barbero, J. 2013). In contrast, the railway carries only a little more than 5% of the loads and water transport 1.5%, Figure 1 depicts this distribution and exports distribution.

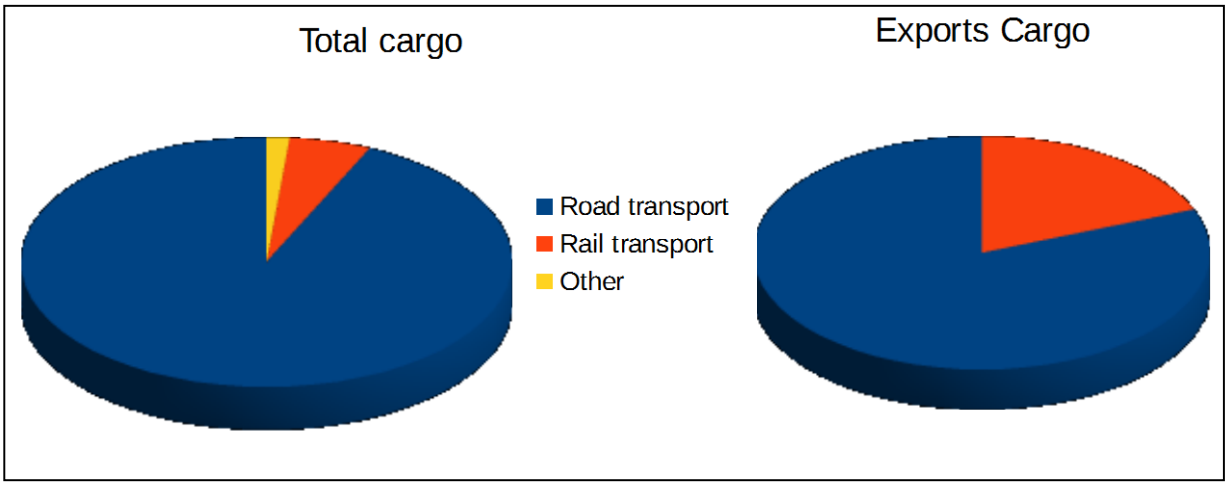


Figure 1 – Transport type participation for total cargo and export only cargo.

Argentinian export cargo volume is expected to increase by about 25% in the next decade. It is increasingly important to do proper planning and design of Highways of our country and more specifically of our province. To accomplish this objective it is essential to have characterization of current traffic volumes on the road network. In addition, it is also necessary to avoid the circulation of overloaded vehicles. Current controls are not being effective because Argentina only has static weighing stations and a very small number of operators. There are some groups of operators with portable static scales but permanent stations are essential. It is very important to have a more effective load control and new road enforcement systems to avoid premature deterioration of the highways.

This scenario serves as an indispensable starting point in the implementation and design of traffic monitoring and control plan that includes WIM systems as data providers. In this context, in 2009 the Department of Roads of the Province of Córdoba and the National Institute of Industrial Technology initiated a joint project for the development and construction of an inexpensive, adaptable to the conditions the region, and with local support prototype of a high-speed weigh in motion system that it could be produced in our country.

The paper presents the process of design, development, implementation, calibration, validation, and technology transfer of a WIM system for statistical purpose, developed entirely in an institution of the national state and transferred to the productive sector. The most important aspects of the development process, verification and calibration of the system, methodologies, current applications, its scope and limitations are also summarized.

Given the incipient progress in this area in our country, it has also begun to outline a draft of metrological and technical requirements as well as the methods of certification for high-speed weighing equipment that allows direct enforcement, which currently cannot be performed due to the absence of corresponding legislation. The current status of WIM in Argentina and future prospects are also mentioned.

2. Development Process

A prototype driven development (PDD) approach was adopted. Each prototype was used to test different components of the system. The reason why PDD was adopted by this project was that specific knowledge of the whole system and specific requirements were not available at the beginning of the project. By continuously creating, improving, and interacting with prototypes devices can be launched faster, with higher quality and with a stronger focus on the customer's needs.

In this context, a prototype is a good tool to learn form a technology. Each prototype was developed using a reduced version of the V model (Turner, R. 2013). The main advantage of V model is that test plan and test design is conducted as soon as the design process is done. Then once an artifact has been implemented, the testing stage can take place.

Initial planning for the first prototype took lot of time. INTI development group members had already had an experience with WIM sensors back in 1998, but by the time the development started the technology had evolved a lot. After the initial planning a sketch of the initial requirements and an architecture design was made. With that in mind each group started a detailed design and implementation of the components. Meanwhile in parallel the team started the building of the WIM site and performed the sensors installation. Once the sensors where in place, the team proceeded with the capture of real signals to aid the development process in the lab.

The first prototype "P0" was just a charge amplifier, and a small system capable of integrate the signal and measure the time between axles. With this device integration capabilities and weight calculation algorithms were designed. By that time the weight calculation was done after the each field measurements back in the lab. The next prototype "P1" added a control module that gives it full weigh-in-motion capabilities. This new device was able to measure speed, weight and classify the vehicles. This new capabilities where tested and the need of axle inconsistency detection arises. The last prototype included a printed circuit board (PCB) redesign (noise reduction), system calibration and performance evaluations, and major software upgrades (Figure 2).

3. The final Prototype

The system is designed to work in a distributed fashion. This means several data acquisition equipment are spread in different roads and transmit collected data to a predefined statistical data center (Figure 2). This allows remote monitoring of traffic flow of different places. Data acquisition devices can also operate autonomously, as a measurement station, and data can be extracted locally.

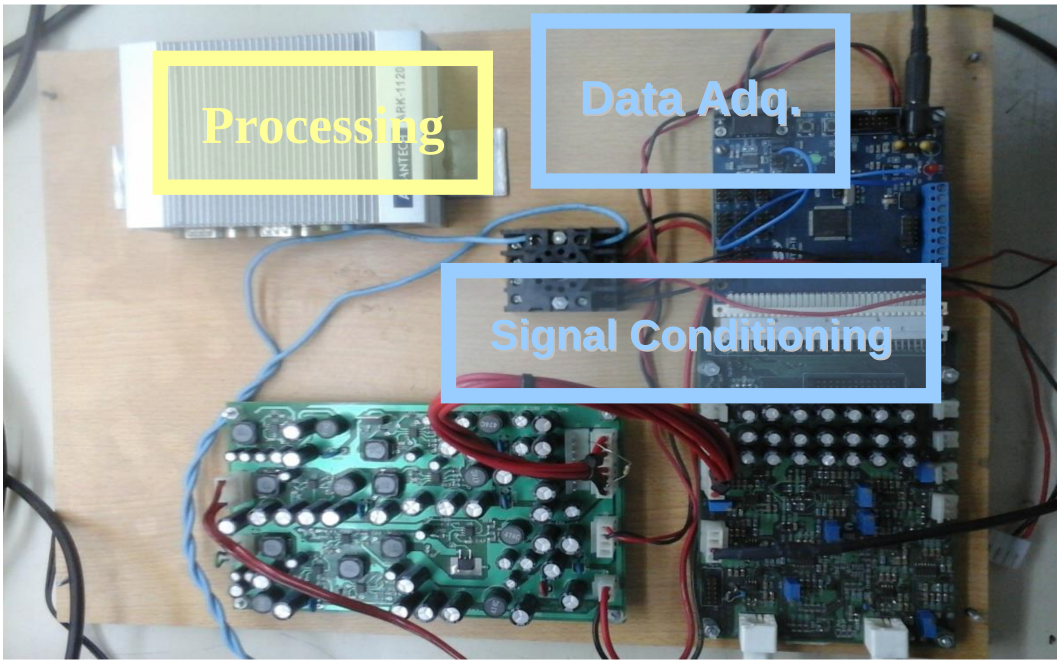


Figure 2 – Photograph of the final PCBs

3.1 Block Diagram

This block diagram (Figure 3) depicts the main sections of the final prototype and its interactions. Vehicles interact with sensors, Signal conditioning block transmits voltage signal to the acquisition block. This last block preprocesses the signal and re transmits the most important information to the processing unit. Once the weight, speed and type of vehicle are calculated, all this information is packed into a register that is sent to a concentrator.

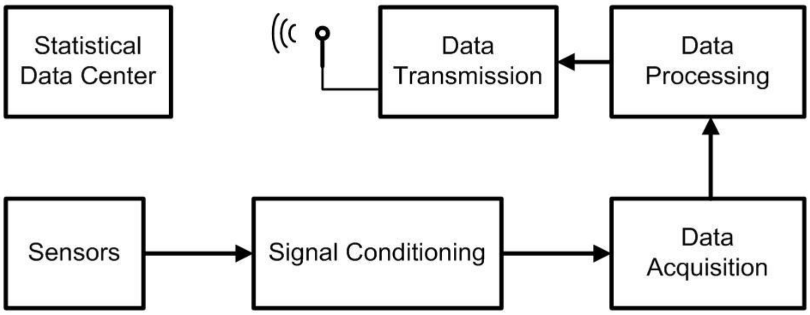


Figure 3 – Simplified block diagram

3.1.1 Sensors

This prototype has five sensors, two inductive loops, two 6' (1.82m) Class I (WIM) RoadTrax BL Piezo Sensors and one temperature sensor.

3.1.2 Signal Conditioning

The idea of this block is to transform charge signal into voltage, extract some indicators and reduce the dynamic range of the signals at the input of the ADC.

3.1.3 Data Acquisition

This block contains a 100 MIPS 8 bit microcontroller that converts the analog data into digital and preprocesses the signal. It acquires raw data and transmits this data to the processing block.

3.1.4 Data Processing

This block is based on an x86 32bit system, capable of receiving real time raw data and post process this data in order to produce relevant information such as weight, speed, classification etc. This block also performs surveillance over the performance of the whole system.

3.1.5 Data Transmission

Data transmission is performed over a network of computers and it is independent of the hardware, it can be throw an Ethernet connection, a GPRS modem or a WIFI connection depending on the available infrastructure.

3.1.6 Statistical Data Center

This is a software application that concentrates information from different devices and processes it in order to give statistical information of each device. The software was programmed to meet the needs of local road authorities

3.2 Piezo electric sensor characterization

At the beginning of development only nominal transfer function of the sensor (pC / Nt) and the maximum error along it where known. In order to acquire a detailed knowledge of the sensor's response, and especially its variation with respect to temperature, extensive measurements were performed on the sensors installed on the road in the experimental site. Measurements were performed at different speeds, different weights and different temperatures; this helped us to characterize the variation of the sensor gain against these parameters. Then algorithms that compensate for these variations were developed. Obtained results are similar to that of Kwon (2016).

3.3 Test site description

Field measurements where done in an experimental test site. This site was chosen in order to help the development and the serve as a permanent WIM site and real time traffic monitoring station. The site was constructed with the aid of the national direction of the Department of Roads of the Province of Córdoba. The chosen place corresponds to road C45, at 40km from Cordoba city (Figure 4). This road is often used for legume and cereal transport from the farms to the nearest silo. This road was also chosen because it has some conditions similar to most Argentinean roads; it’s made of asphalt and has some deformations.
The site corresponds with criteria for the choice of WIM sites according to the literature and the European WIM specification (1999), Chapter 5, and was evaluated as Acceptable.
All the electronic was located in a bunker at approximately 15 m from the road, to achieve a distance that is safe enough to avoid accidents and give more comfortable measurement conditions and not so far to use shorter cables.

Figure 4 – sensors and test truck

4. Prototype Validation

The system validation included a complex set of tests, unit tests integration tests and system tests. This section will summarize some of the most important tests and its results

4.1 Weigh validation

The weighing process includes the measurement of vehicle speed and the sensor signal integral calculation. Each block was first individually validated, and then integrated. The system speed measurements were first validated in laboratory. Using a digitalized signal obtained from a real vehicle. The signals were replicated using an arbitrary signal generator. The speed measurement error was within the 0.2% for all measurements. Some integration tests where done in software. Some integration tests and functional tests were done in order to check that the results obtained in the unit tests against simulated values reach the data base and the frontend. Then the system was validated in field against INTI national speed reference device. All measurements errors where less than 1.5% Integral calculations were also validated separately using a laboratory signal generation pattern. This pattern is also validated against international signal generator patterns. Integral measurements revealed that errors was allays less than 0.8%. The temperature sensor was also calibrated against INTI temperature patterns.

4.1.1 Calibration

The calibration method implemented was the “Pre-Weighed Calibration Lorries” according with COST 323. The main task was to estimates the variation of the thermal sensibility of the two piezo electric sensors. The estimation function was a lineal approximation according to passing some test pre-weighed vehicles over the WIM system. This test plan calibration consisted in 30 events of different vehicles, weights and speed levels. The class of vehicle was type 2, the weights were between 8t and 16t and the speed levels were between 30km/h to 90km/h. This process consisted of three consecutive days of measurements over six months.

According to Principles of Weigh-in-Motion using Piezoelectric Axle Sensors (Brown, R. H. 2001), the weight of the vehicle is calculated by integration of the axle-crossing waveform. The integral *I* must then be scaled (multiplied) by the vehicle speed *V*. This quantity (time integral of charge or voltage, multiplied by speed) is then proportional to the total load applied during the axle crossing. Then, the weight *P* is calculated as Equation 1:

$$P = I \,.\, V .\, k \qquad (1)$$

where *k* is the sensibility of the sensor and depends on the temperature. The calibration process goal is to estimate this function. This approximation result for the first sensor is given in Figure 5.

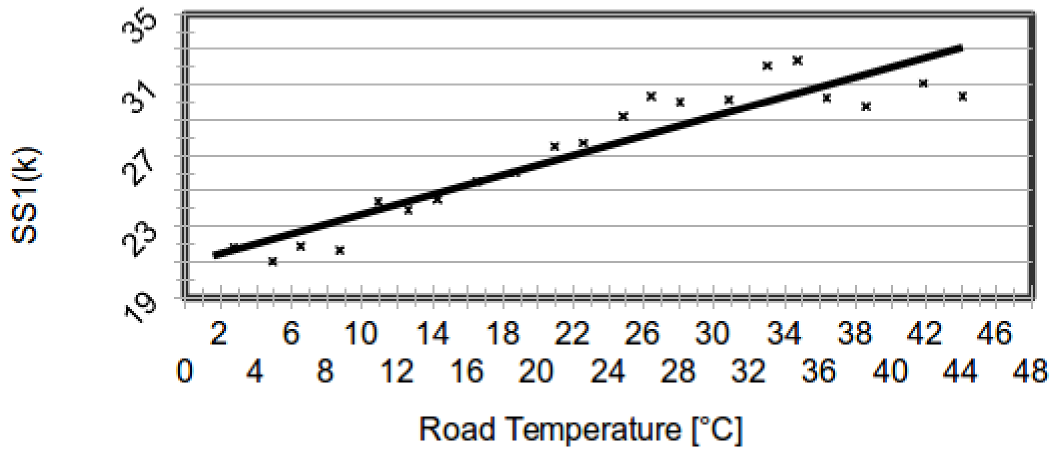


Figure 5 – Thermal Sensibility estimation of sensor 1

4.1.2 Accuracy verification

According to the European WIM specification (COST 323, 1998) the site was evaluated as “III Acceptable”. The site was chosen because it represents the most common route condition in Argentina. For the calibration of the prototype we used Pre-Weighed Calibration Lorries. According to the test plan the environmental repeatability and reproducibility was ***(II) limited environmental reproducibility*** and ***(R2) extended repeatability conditions***. The test for the accuracy verification was at different days, vehicles and weights. In total there were 196 independent events. The results were measured with 5 (five) accurately weighed calibration vehicles, possessing two axles with a gross and axles weight distributed according to Table 1. The vehicles speed varied between 29 and 86 km/h during the measurements. The vehicles were ford cargo 1722, the first (front) axle has rigid axle suspension and second (rear) axle has full floating suspension.

Due to budget restrictions the test site only had two half lane sensors installed consecutively. The system calculates the right wheel weight; the calculated weight is the average of the estimation of both sensors. Dynamic wheel weight calculation error was within 25% for the 95% of the measures, so the prototype cloud is classified as Type I in accordance with ASTM 1318 2009.

The axle weight information was estimated by multiplying the weight of the wheel by two in order to obtain a COST 323 classification. This is merely illustrative because sensor configuration does not allow obtaining a full axle dynamic weigh.

Table 1 – Static loads/weights Ws (kg) calculated in concordance to COST323 procedures

Vehicle	GW	A1	A2
A	8000	4041	3959
B	12240	5039	7201
C	13090	4391	8699
D	15640	4858	10782
E	16240	5059	11181

Table 2 describes some event and the relative error of the measurements.

Table 2 – Some events and its relative error

Nº	T(ºC)	V(km-h)	Type	WD(kg)			WS(kg)			Relative errors(%)		
				GW	A1	A2	GW	A1	A2	GW	A1	A2
1	14,3	40	2	8067	4095	3972	8000	4041	3959	0,84	1,34	0,33
35	8,7	36	2	12283	5086	7196	12240	5039	7201	0,35	0,93	-0,07
77	10,4	41	2	13144	4339	8805	13090	4391	8699	0,41	-1,18	1,22
113	10,9	49	2	15708	4924	10784	15640	4858	10782	0,43	1,36	0,02
162	16,5	58	2	16444	4946	11498	16240	5059	11181	1,26	-2,23	2,84

After that we calculated the mean and standard deviation of relative error of GW and SA the results are described in Table 3.

Table 3 - Relative errors (%) statistics

	GW	SAL
number	196	392
mean	0,64	1,35
st.dev	10,88	13,67

Table 4 summarizes experiments with the vehicles mentioned in Table 1 in the chosen site. The COST 323 European WIM specification accuracy calculated result is E(30).

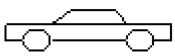
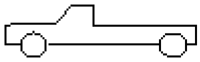
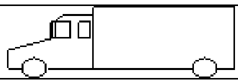
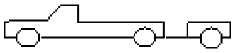
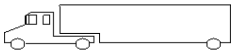
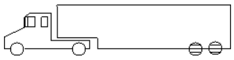
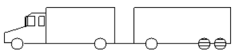
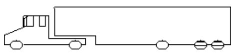
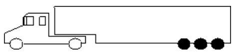
Table 4 – Accuracy calculated results

Conditions (1)	Test plan		Env^t		Initial verification (Yes=1, No=0):					0
	R2		II							
SYSTEM	Number	Identified	Mean	Std deviat	π_o	Class	δ	δ_{min}	δ_c	π
Entity		(%)	(%)	(%)	(%)		(%)	(%)	(%)	(%)
gross weight	196	100,0	0,64	10,88	96,5	D(25)	25	24,7	24,7	96,7
single axle	392	100,0	1,35	13,67	96,8	E(30)	36	31,0	26,0	98,8

4.2 Classification algorithm and validation

The classification is performed according to the requirements of the National Roads Authority as published in Dirección Nacional de Vialidad (2003), which is based on the separation of the vehicles axles. The classification algorithm was performed by a key-value structure, where vehicles are grouped by type. Each element of the structure contains a list of all vehicles with the same number of axles, whenever it presents a new vehicle it is only necessary compare it against all vehicles having the same number of axes. Besides, it was implemented an automatic sort system that permits to locate the last vehicles identified at the beginning of the list. This classification algorithm was tested in the WIM site and the results are displayed in Table 5.

Table 5 – Classification results

Vehicle type	Outline	Categ. No.	No. of axles	No. of vehicles	No. of classified vehicles	Percentage (%)
Car		2	2	30	28	93,33
Pickup truck		3	2	9	9	100
Truck 11		6	2	34	34	100
Pickup + trailer		3	3	4	2	50
Semi truck 111		10	3	1	1	100
Semi truck 112		11	4	7	7	100
Truck 11 12		9	5	15	14	93,33
Semi 11 (1) 2		12	5	3	3	100
Semi 113		12	5	2	2	100

5. Technology transfer

The developed technology is being transferred to national enterprises for production stages. The main idea is that these enterprises take the development and could make improvements and evolutions of the system to get new commercial products. The transfer process includes training about system development, operation, calibration, use and regulations. And it also provides technical assistance for installation of the measuring station and start up the system.

6. WIM in Argentina

The use of WIM system in Argentina is very poor, there is only a few sites in the whole country, but the need of monitoring the traffic weight is more and more important. In general, the organisms that manage the roads don't have automatic systems to monitor their state. Even the current legislation does not allow overload punishment with dynamic weighing systems. So, the control of load traffic is made using expensive and inefficient static weighing systems. The main important objectives of this project were develop a more inexpensive system that could be produced by national industry, and to produce knowledge in the area of weigh-in-motion of vehicles.

7. Conclusion

A prototype of high-speed weigh-in-motion system has been developed, according to the conditions of the road network in this country. The system is adaptable, flexible, versatile and inexpensive. It has been proven correct operation of the equipment and characterized his error under various conditions of use. Several experiments have been performed, both by simulation and field measurement, verifying the accuracy of the prototype and its high degree of reliability. The next step is to bring the system to a commercial product, working with several companies. The main idea is that Argentinian enterprises be able to evolve this technology and produce commercial devices. In this work we develop the most important parts of a WIM system: characterization of pavement-resin-sensor response, temperature compensation system, analog signal conditioning, digitalization, data processing, storage and data transfer, etc. Besides, very special and refined algorithms had been designed for vehicle classification and calculation of weight, even correcting some common phenomena such as removing spurious axles. Now, all this technology can be produced in Argentina, which is an important innovation and a great advance for the national industry. It has been presented errors study and statistical processing of the results of field measurements, which show adequate accuracy and precision for the development model. It is expected that in production stage the performance of the system can be improved considerably. For example, due to various problems in our project (mainly related to budget restrictions), we had to develop the prototype using two half lane sensors, with the measurement problem that this represents. Now, we are working together with enterprises, so we can implement new measurement sites detecting the whole lane and to achieve a significantly reduction of the errors. Besides, this project also reached the important goal of research and produce knowledge in the area of WIM systems of vehicles, which will allow us to initiate more complex projects, such as the drafting of a technical regulation for dynamic weighing. Given importance which traffic monitoring is taking today in Argentina, we have begun to write a technical regulation draft, in order to normalize the use of these equipment in our country.

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