

**WEIGH-IN-MOTION RESEARCH AND DEVELOPMENT ACTIVITIES AT
THE OAK RIDGE NATIONAL LABORATORY**

				
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Abstract

The Oak Ridge National Laboratory (ORNL) has been involved in Weigh-in-Motion (WIM) Research with both government agencies and private companies since 1989. The discussion here will focus on the United States Army's need for an automated system to weigh and determine the center-of-balance for military wheeled vehicles as it relates to deployments for both military and humanitarian activities. A demonstration test at Fort Bragg/Pope AFB of ORNL's first generation portable Weigh-in-Motion (WIM Gen I) will be discussed as well as the development and fielding activities for a WIM Gen II system.

Keywords: Weigh-in-Motion, WIM, center-of-balance, defense deployments, aircraft load planning

Résumé

Le laboratoire national d'Oak Ridge (ORNL) a été impliqué dans la recherche de Peser-dans-Mouvement (WIM) des organismes gouvernementaux et des entreprises privés anonymes depuis 1989. La discussion ici se concentrera sur le besoin de l'armée des Etats-Unis d'un système automatisé de peser et déterminer le centre de l'équilibre pour les véhicules roulés militaires pendant qu'elle se relie aux déploiements pour des activités militaires et humanitaires. Un essai de démonstration au fort Bragg/Pope AFB du Peser-dans-Mouvement portatif de la génération d'ORNL (la GEN de WIM I) sera discutée comme le développement et les activités fielding pour un système de GEN II de WIM.

Mots-clés: Peser-dans-Mouvement, WIM, centre-de-équilibre, déploiements de la défense, planification de charge d'avion

1. Introduction and Background

The United States Department of Defense must maintain the capability to rapidly project massive combat power anywhere in the world with minimum preparation time. Currently, personnel use portable individual wheel weight or fixed in-ground static scales, tape measures and calculators to determine vehicle axle weights, total vehicle weight and center-of-balance for vehicles and palletized cargo to be shipped via railcar, sealift, or airlift in support of military and humanitarian operations. The process of manually weighing and measuring all vehicles and cargo subject to these transshipment operations is time-consuming, labor-intensive, and most importantly is prone to human errors that can result in safety hazards and inaccurate data.

Errors can result from inaccurate or incomplete identification of vehicles and equipment; misreading a scale or tape measure, manually recording data incorrectly; manually miscalculating the axle weight, total vehicle weight or center-of-balance; and transferring data from manually prepared work sheets into an electronic database via keyboard entry personnel. Many of these errors can greatly increase during stressful deployment times and adverse weather conditions.

Errors in determining weighs and balances in military deployments as well as commercial air transport can be fatal. In June 2002, a special operations combat supply plane crashed in Afghanistan, killing several of the crew. U.S. Air Force accident investigators concluded that the crash was caused by “imprecise information” about cargo weight combined with a “get the job done” attitude. The aircraft crashed not because it was overloaded but because it was overweight for the location, 7,200 feet above sea level. *Army Times* reported that weighing cargo at such isolated airstrips was not practicable —the Air Force special operations crews were relying instead on weight estimates (Rolfsen, 2002).

A Weigh-in-Motion (WIM) system may also have applicability in response to the National Transportation Safety Board’s February 2004 recommendation that federal regulators and the airlines develop methods to weigh passengers and baggage to prevent overloading of airplanes (Levin, 2004). The safety board had concluded that the crash of Air Midwest Flight 5481 on January 8, 2003, was caused by too much weight in the rear of the aircraft combined with a maintenance mistake. The United States military has recognized and documented a need for WIM technology (Keane, 1996) and further documented the requirement (Coats, et al., 2004a) and a recommended WIM technology solution for military applications in 2004 (Coats, et al., 2004b).

In this paper, we will concentrate on the military applications of WIM. We will discuss specific aspects of the United States Army/Oak Ridge National Laboratory WIM program which will include the discussions of: 1) a Fort Bragg/Pope Air Force Base (AFB) demonstration test where a first generation WIM prototype system WIM Gen I was compared to existing techniques for determining weighs and balance using fixed in-ground scales, single wheel weigh scales, tape measures, and calculators, 2) the present WIM-GEN II development program, as well as 3) testing and future plans.

The lack of a standardized airlift-weighing system for joint service use also creates redundant weighing requirements at the cost of scarce resources and time. The process of determining the vehicle weight, center-of-balance, and individual axle weights for load planning and assets visibility consists of: staging and identifying the vehicle; determining the individual

wheel weights; determining the axle spacing; calculating the total weight, center-of-balance and individual axle weights; marking the vehicle with its total weight and center-of-balance; accumulating the vehicle data for a group of vehicles; and finally entering the data into an electronic database to enhance military planning and visibility capabilities. Presently, the entire process is performed manually using a large static truck scale or multiple individual portable wheel weight scales, tape measures, calculators, and clipboards. The process is very time consuming, manpower intensive and prone to human errors. The WIM system can greatly reduce the time required to perform this operation and eliminate the human errors resulting from the manual nature of these measurements, calculations, and data input.

2. Field Prototype Demonstration

The demonstration of the WIM was conducted at Fort Bragg/Pope AFB, NC in May 2003.

2.1 Purpose

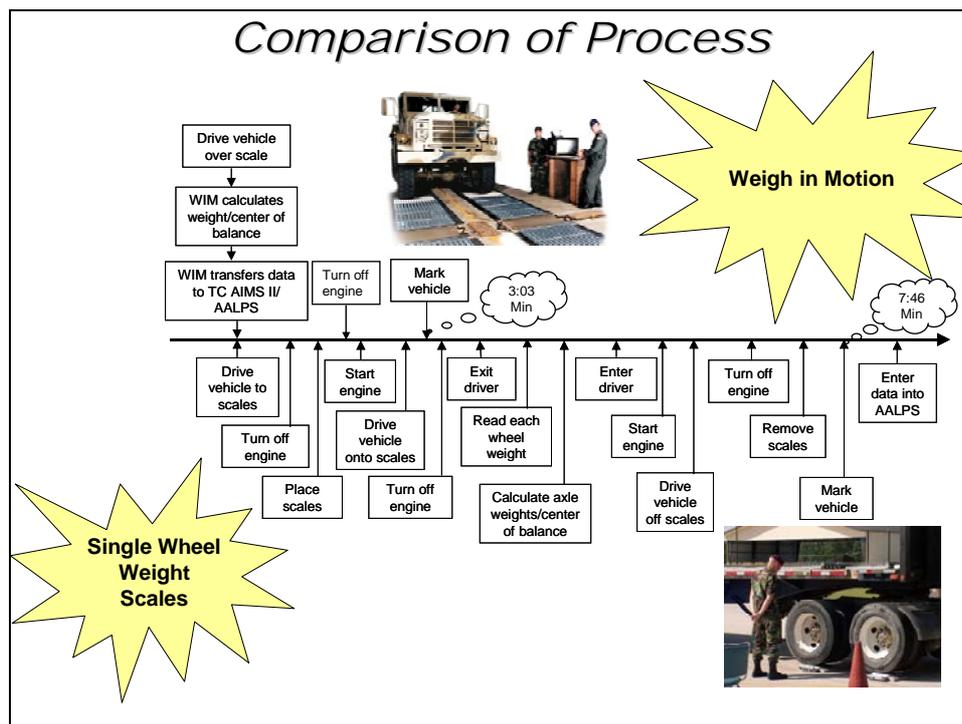
The purpose of the WIM Field Demonstration was to provide analytical data that allowed the comparison of two existing weigh/center-of-balance determination techniques of weighing and determining the center-of-balance of military vehicles to a portable WIM Gen I system. The portable WIM Gen I system used during the comparison test was developed by the Oak Ridge National Laboratory for the United States Air Force Productivity, Availability, Reliability, and Maintainability (PRAM) office. The WIM Gen I was developed as a prototype WIM system to demonstrate the feasibility of the WIM concept in 1996. The WIM Gen I prototype system, funded by the PRAM office, was completed, calibrated and tested some years ago. At that time, additional funding was not provided to move the WIM Gen I forward from its prototype status to an improved hardened commercially available WIM system to meet the needs of today's military. The results provided analytical data to show: 1) how the WIM Gen I system automatically determines the total vehicle weight, center-of-balance measured from the front axle, and the individual axle weights for military conventional single and dual wheeled vehicles as they move across the transducers at low speeds in real-time; 2) how automated processing significantly reduces the time needed to determine total weight, balance, and axle weights of unit vehicles; 3) how WIM avoids the class of errors (transcription and calculation) introduced through the current manual process; 4) how WIM reduces the required manpower to setup and operate the process, and 5) what enhancements were required to fully satisfy Army's WIM requirements.

2.2 Description of Deployment Weighing Comparison Techniques

Three techniques for weighing and determining the center of balance for military vehicles were compared: 1) Large in-ground static truck scale (available at large power projection facilities), 2) Six to eight portable single wheel weight scales and 3) WIM Gen I system. Twenty-three vehicles and one container were used to test each technique. The data presented will focus only on the weighing process. Figure 1 illustrates temporally the procedure as it applies to the WIM and single wheel weight techniques. The static scale procedure is not included in the figure due to sheer simplicity (and immobility). The static scales are the most accurate and are as labor intensive in terms of the manual calculations (average total time - 4mins 48secs) as the single wheel weight scales (average total time - 4min 52 secs). Each weighing technique is explained in detail below:

A. In-ground Static Scales

1. Obtain and record the vehicle identification,
2. Pull the vehicle front axle onto the static scale, have the driver exit the vehicle, and manually record the front axle weight on the standard data sheet,
3. Pull the first and second axle onto the static scale, have the driver exit the vehicle, and determine the total weight of axle 1 and axle 2 combined; subtract the weight of axle 1 from the total weight of axles 1 and 2 to determine the weight of axle 2 and manually record the calculated weight,
4. Pull the third axle onto the scale and determine the total weight of the three axles; subtract the weight of axles 1 and 2 and record the resultant weight of axle 3,
5. Repeat step 3 until all the axle weights have been determined,



6. Use a tape measure to measure and record the distance from the front forward edge of the vehicle to the center of axle 1,
7. Repeat step 6 for each of the axles,
8. Calculate the moment for each axle by multiplying the individual axle weight times the distance from the front forward edge to the individual axle,
9. Repeat step 8 for each axle,
10. Determine the total moment about the front forward edge by summing the individual moments for the individual axles.
11. Divide the total moment about the front forward edge by the total vehicle weight to determine the vehicle center of balance for the total vehicle, and finally
12. Transfer all weight and center of balance data for all the vehicles in the group manually to a hand written spreadsheet.

B. Portable Individual Wheel Weight Scales

1. Obtain and record the vehicle identification,
2. Pull vehicle into weighing position,
3. Position scales in front of the individual tire sets,

4. Pull the vehicle forward to position it in the center of each of the individual scales, set the brake, turn off the vehicle, and have the driver exit the vehicle,
5. Manually record the individual wheel weights,
6. Manually calculate and record the individual axle weights,
7. Measure and manually record the distance from the front bumper to axle 1,
8. Measure and manually record the distance from the front bumper to axle 2,
9. Repeat step 8 for each of the remaining axles,
10. Calculate and manually record the center of balance,
11. Transfer all weight and center of balance data for all the vehicles in the group manually to a hand written spreadsheet.

C. WIM GEN I System

1. Obtain and enter the vehicle identification into the WIM computer,
2. Instruct the driver to pull forward over the WIM system at a constant speed of 3-10 mph,
3. WIM system will automatically determine the individual wheel weights, individual axle weights, total vehicle weight, vehicle center of balance from the front axle and add the data to the group's data base,
4. Once weight and center of balance for all the vehicles in the group have been determined, the WIM system automatically accumulates and compiles the database,
5. Save the unit's database on appropriate storage media for input into electronic database.

The demonstration test photos in Figures 2-4 illustrate each of the three techniques. The military vehicles used in the test included a HMMWV, a 5-ton wrecker, a tractor with a flatbed trailer, a 5-ton vehicle with a trailer, and a forklift as well as a containerized load. The group of vehicles were prepared for deployment three times: first using an in-ground static scale, tape measure, a standard data sheet, and a calculator following standard military procedures; second using individual wheel weight scales, tape measure, a standard data sheet, and a calculator following standard military procedures, and; finally using the WIM Gen I prototype system.



Figure 2 - In-Ground Static Scale



Figure 3 - Individual Single Wheel Weight Scales



Figure 4 - WIM Gen I System

2.3 Results and Conclusions from the Current Deployment Weighing Comparison

The static scale and tape measure technique used three operating personnel; the individual wheel-weigh scales and tape measure technique used seven; and the WIM system used three. Figure 5 shows a plot of the average times for processing vehicles with varying number of axles as well as the overall scatter in the data.

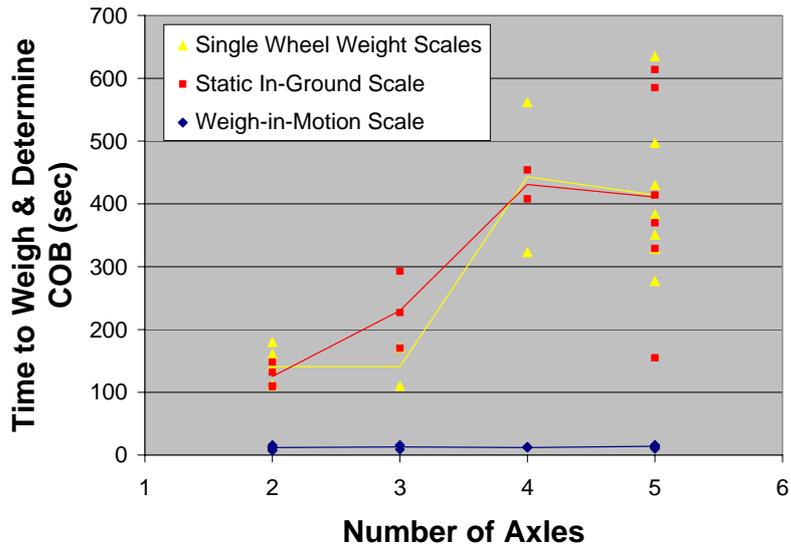


Figure 5 - Individual and average time required to weigh and determine the center-of-balance

Because of the manual nature of the weighing process (using both the static in-ground scale and the single wheel weight scales), the time required to complete the task tend to increase as the number of axles increase. Additionally, the variability in the task completion time increases as the number of axles increase. The WIM system consistently registered the same times, regardless of the number of axles.

The results from the static scale and tape measure technique were erroneous in 9% of the cases (due to human errors in the calculations); 14% for the individual wheel-weigh scales and tape measure technique; and 0% for the WIM system. The tests were performed in excellent weather conditions, but in rain, snow, high winds or other stressful environments, the human error rate would be expected to increase when using the two manual techniques.

The main advantage of the portable WIM is the reduction of potential errors along with a reduction in the level of effort. The individual wheel-weigh scales and the static scales require the transfer of data from a manually created data sheet to an electronic military planning system, as well as the manual calculation of individual axle weights, total vehicle weight and center of balance. The WIM system eliminates the need for manual calculations and feeds the data directly into other systems for the automated management of deployment and load planning. WIM also frees up military personnel to perform other deployment tasks.

3. Weigh-In-Motion Generation II Development Program

The accuracy demonstrated with the WIM Gen I prototype system was +/- 3%, based on 500+ vehicle passes of the standard weight-range of military vehicles. There were a number of advanced programs, technology improvements and lessons learned considered as a precursor to the development of WIM Gen II (e.g., Federal Highway Administration High Speed WIM and Air Mobility Battle Laboratory In-ground Static Scale Conversion to WIM projects). These experiences, along with the after action report from the comparison tests, influenced the technical path forward and resulted in a 66% accuracy improvement. Furthermore, ORNL's experiences identifying and monitoring vehicle asset movements (Coats, et al., 2004b) were factored into the technical path forward strategy.

3.1 Overview

The WIM Gen II development focused on improving accuracy, automatic vehicle and cargo identification and providing an interface to load planning/deployment databases. Specific enhancements included improved weight and center-of-balance determination algorithms, on-board processing, modifications to simplify field operation, incorporation of state-of-the-art load cell transducers and electronics as well as optimal transducer spacing. Moreover, the WIM Gen II provides an enhanced field-ruggedized system that can go anywhere to automatically identify vehicle, cargo, weight/center-of-balance parameters safer and faster to all authorized systems and users, and be transportable in the back of the last vehicle to be loaded.

3.2 Weigh-in-Motion Generation II Design Features

The automated nature of the WIM Gen II system avoids the introduction of human errors caused by manual computations/data entry and minimizes the effect of adverse weather conditions and stress. Individual vehicles can be weighed continuously at low speeds (approximately 3-10 mph), at intervals of less than one minute and requires only two men to operate. Figure 6 shows the WIM Gen II system both assembled and disassembled. The system is comprised of 1, 2, 3 or 4 sets of transducers each with its own on-board processor, a power supply/host computer box, a wireless handheld tag reader/system display, wireless printer and a single cable (with links to daisy chain the transducer pads together). The system is designed to simplify setup by allowing the transducer pads to be positioned in any order while the host computer will determine their locations transparently. These enhancements allow vehicles to pass over the WIM system in either direction while the host computer provides all pertinent vehicle characteristics. The system operates in either the dynamic mode or static mode (i.e., individual wheel and axle weights are measured statically) in areas where WIM surface conditions are not available.

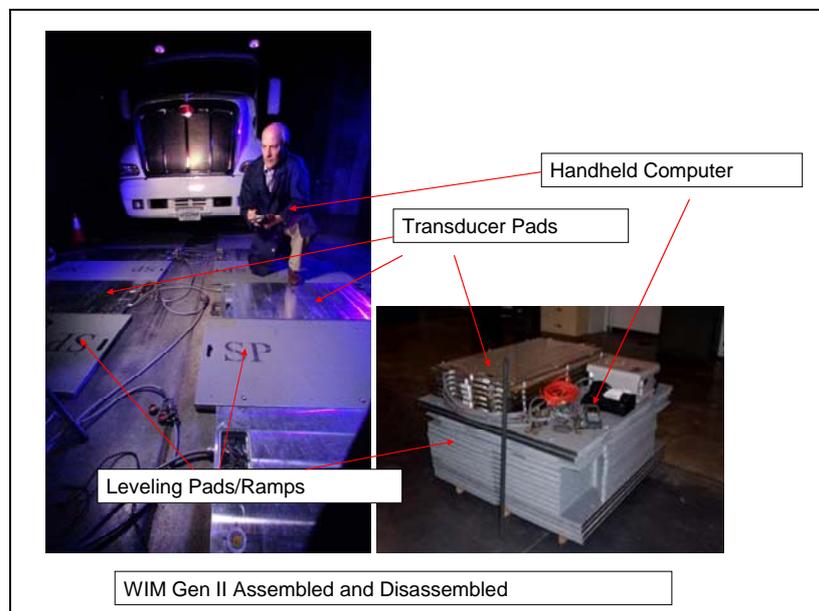


Figure 6 - WIM Gen II System Assembled and Disassembled

The WIM Gen II system's portability combined with the capability to rapidly weigh vehicles and determine their center-of-balance fully supports the rapid and safe deployment of equipment. For example, deploying and supporting units can set up their portable WIM Gen II systems at home stations, ports of embarkation, intermediate staging bases, ports of

debarkation, theater staging bases, and austere airfields in accordance with the combat, combat support and combat service support requirements of the geographic combatant commander. Moreover, WIM Gen II enables timely distribution of real-world “actual” data electronically into external systems such as the Automated Air Load Planning System (AALPS). AALPS provides for load planning and manifesting purposes which feeds into the Transportation Coordinators’ Automated Information for Movement System II (TC-AIMS II) for in-transit visibility to support operational planning, deployment and execution purposes.

3.3 Testing

Initial testing of the system has been undertaken. All the features outlined above have been verified and preliminary data indicate that the accuracy requirement of +/- 1% is feasible. Efforts in FY-05 are concentrating on rigorous testing of the system with a wide variety of private, commercial and military vehicles. Statistical design of experiments will be performed under a variety of surface conditions to determine the effect of the surface on system accuracy. Testing is being performed using all four sets of pads to determine how the accuracy varies with the number of pads in the system. Our goal will be to meet the accuracy requirement with a minimum number of pads thus reducing the system cost, physical size, weight and total number of components. This effort also includes integration of currently available commercial technology (e.g. Radio Frequency Identification (RFID) vehicle identification tags, bar codes, bar code readers).

3.4 Additional WIM Gen II Activities

Additional FY-05 activities include a limited production of systems to be delivered to sponsors for test and evaluation. The systems will be used in operational scenarios to emulate actual deployments prior to conveyance loading in a variety of physically diverse environments. Operating units will provide feedback on ease of use, ease of setup and tear down, any operating or maintenance problems encountered, as well as recommendations for improvements. As feedback is received, modifications to both hardware and software will be incorporated into the system where possible.

A cubic measuring system is being developed and incorporated into the WIM Gen II system to profile the vehicle and determine its height, width and length for loading and planning purposes (so-called cubic measuring technologies). ORNL is prototyping available cubic measuring technology and leveraging its own version of cubic measurement using digital technology. The goal is to determine if either of these technologies can be a potential solution for incorporating cubic measurement into a WIM system in an austere environment scenario. To achieve this goal it will be necessary to determine the technical developments necessary to provide a man-portable measuring system and provide this information electronically to downstream load planning systems such as AALPS and TC-AIMS II.

ORNL will upgrade fixed-site scales to dual use (static and dynamic) WIM scales at multiple selected sites and modify interface software to static weight scales for collection and processing of data. These systems would provide a user interface identical to the portable WIM Gen II system and utilize the same wireless handheld tag reader/system display.

4. Conclusions

The technologies described herein leverage COTS hardware components and custom developed software that has been demonstrated to: track and locate vehicles and cargo on a

worldwide basis, provide the source data for In-transit Visibility and Total Asset Visibility in real-time, extract total vehicle and cargo weight, weigh individual surface contact for each tire, weigh individual axle, locate axle position, and calculate center-of-balance. The outputs of the WIM system are provided seamlessly to appropriate logistics planning systems and are subsequently made available to the global transportation network(s). An important and direct tangible benefit of WIM is the result of improved safety and labor savings.

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