The Potential and Beneficial Use of Weigh-In-Motion (WIM) Systems Integrated with Radio Frequency Identification (RFID) Systems for Characterizing Disposal of Waste Debris to Optimize the Waste Shipping Process

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ABSTRACT

The Oak Ridge National Laboratory (ORNL) Weigh-In-Motion (WIM) system provides a portable and/or semi-portable means of accurately weighing vehicles and its cargo as each vehicle crosses the scales (while in motion), and determining (1) axle weights and (2) axle spacing for vehicles (for determination of Bridge Formula compliance), (3) total vehicle/cargo weight and (4) longitudinal center of gravity (for safety considerations). The WIM system can also weigh the above statically. Because of the automated nature of the WIM system, it eliminates the introduction of human errors caused by manual computations and data entry, adverse weather conditions, and stress. Individual vehicles can be weighed continuously at low speeds (approximately 3-10 mph) and at intervals of less than one minute.

The ORNL WIM system operates and is integrated into the Bethel Jacobs Company Transportation Management and Information System (TMIS, a Radio-Frequency Identification [RFID] enabled information system). The integrated process is as follows: Truck Identification Number and Tare Weight are programmed into a RFID Tag. Handheld RFID devices interact with the RFID Tag, and Electronic Shipping Document is written to the RFID Tag. The RFID tag "read" by an RFID tower identifies the vehicle and its associated cargo, the specific manifest of radioactive debris for the uniquely identified vehicle. The weight of the cargo (in this case waste debris) is calculated from total vehicle weight information supplied from WIM to TMIS and is further processed into the Information System and kept for historical and archival purposes. The assembled data is the further process in downstream information systems where waste coordination activities at the Y-12 Environmental Management Waste Management Facility (EMWMF) are written to RFID Tag. All cycle time information is monitored by Transportation Operations and Security personnel.

INTRODUCTION - INSTITUTIONAL

Based in Oak Ridge, Tennessee, the Department of Energy's Oak Ridge Office is rich in history, dating back to World War II when the organization played a major role in the production of enriched uranium for the Manhattan Project. Since then, Oak Ridge Office (ORO) has expanded far beyond that first mission and today is responsible for major Department of Energy (DOE) programs in science, environmental management, energy efficiency, nuclear fuel supply, reindustrialization, and national security and support is provided to science laboratories and facilities operated by DOE throughout the United States. ORO also provides support to national

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security activities managed by the National Nuclear Security Administration (NNSA). The FY 2008 budget for all DOE programs in Oak Ridge is $2.9 billion. 12 percent of the overall DOE budget comes to Oak Ridge.

The majority of ORO programs are performed at facilities located on the 33,699-acre Oak Ridge Reservation located in Anderson and Roane Counties in East Tennessee. The Oak Ridge facilities include the Oak Ridge National Laboratory (ORNL); the Y-12 National Security Complex; and the East Tennessee Technology Park (ETTP) [1].

Science Programs within ORO are performed at ORNL. At ORNL, researchers focus on basic and applied research to advance the nation's energy resources, environmental quality, scientific knowledge, and contribute to science education and national economic competitiveness. The Laboratory also performs work for non-DOE sponsors when such activities complement DOE missions and address important national or international issues. ORNL is operated by UT-Battelle LLC [2].

The East Tennessee Technology Park (ETTP) is a compilation of resource-rich industrial facilities which have their beginnings in the Manhattan Project during World War II. The site's original mission was to enrich uranium in the uranium 235 isotope for use in atomic weapons and subsequently for use in the commercial nuclear power industry. The plant was permanently shut down in 1987 and in 1996, reindustrialization went into effect with efforts focusing on restoration of the environment, decontamination and decommissioning of the facilities, and management of legacy wastes. Bechtel Jacobs Company LLC is the environmental management contractor for the ORO that is performing this cleanup work at ETTP [3]. The company is responsible for environmental cleanup and waste management on DOE’s Oak Ridge Reservation [4, 5]. Bechtel Jacobs Company LLC also supports DOE in a reindustrialization program to find commercial uses for many Oak Ridge facilities that no longer have a mission [6]. The goal is to create a brown fields industrial park known as Heritage Center under coordination of the Community Reuse Organization of East Tennessee. Also, near the ETTP site is Horizon Center, which includes more than 1,000 acres of pristine Greenfield land that is available for private industrial use.

To reindustrialize the site, work is underway to complete cleanup of some of the largest buildings in the Department of Energy complex. Included are the K-33, K-31, and K-29 former gaseous diffusion plant building along with the “U”-shaped K-25 Building. At its time of construction, the K-25 Building was the largest building in the world, with over 1.6 million square feet. These facilities played an important role in enriching uranium for use in nuclear power plants and to support national defense needs. The ETTP site also serves as the test location of the next-generation enrichment technology under the U.S. Enrichment Corporation's American Centrifuge Program. This technology will allow the United States to maintain energy security through use of state-of-the-art materials, control systems and manufacturing processes to enrich uranium. Centrifuges are presently tested at the site for eventual use in a full-scale American Centrifuge Plant by the end of the decade.

WEIGH-IN-MOTION (WIM) BASELINE

The current non-integrated portable, low-speed WIM system automatically acquires various data from a moving vehicle and its cargo: weight on each tire and axle; total weight; axle spacing; longitudinal and transverse center of balance (Figure 1). The system estimates vehicle volume (length, width, and height) from two digital camera images. The system identifies the vehicle via radio-frequency Identification (RFID) tags, barcodes, via manual entry off a pre-determined list. Data is managed via a Pocket PC/WiFi-enabled Personal Digital Assistant (PDA) or cell phone and/or Windows XP ruggedized PC/tablet with a secure infrastructure and data repository. The system works ideally on smooth asphalt or concrete with no more than 2 degrees of longitudinal or transverse slope. The system's total weight is 2200 pounds (1000 kg) crated in a ruggedized box. The physical, electrical and software interfaces tolerate severe weather and human error.

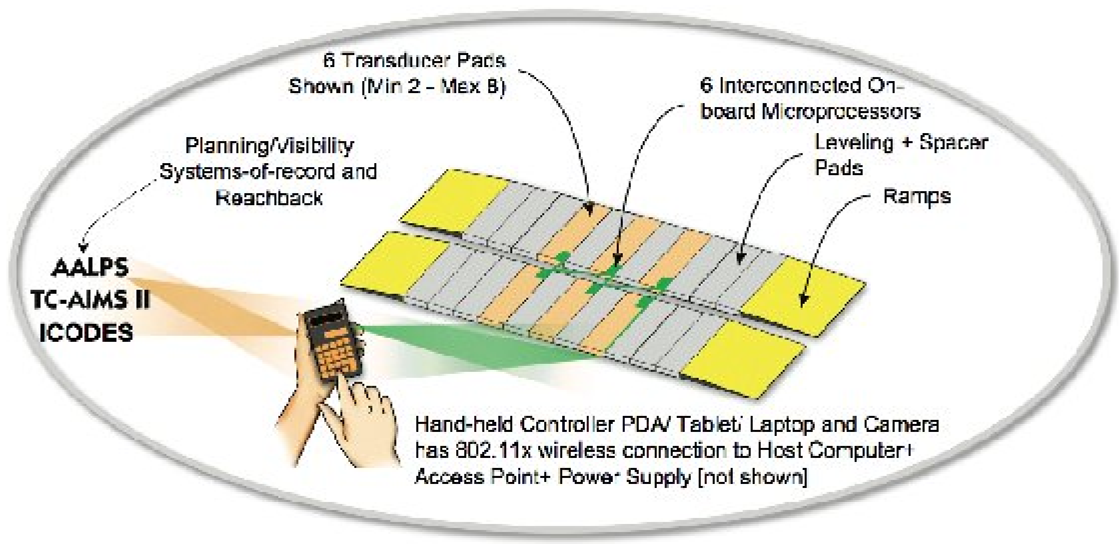

Figure 1. Baseline Weigh-In-Motion (WIM) System illustrating Human controlled variant.

INHERENT DESIGN FEATURES OF WIM BASELINE

The automated nature of the current WIM 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 2 shows the original military version of the WIM 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 characteristics of the vehicle. The system can operate in either the dynamic mode or static mode (i.e., individual wheel and axle weights are measured statically) in areas where acceptable WIM surface conditions are not available.

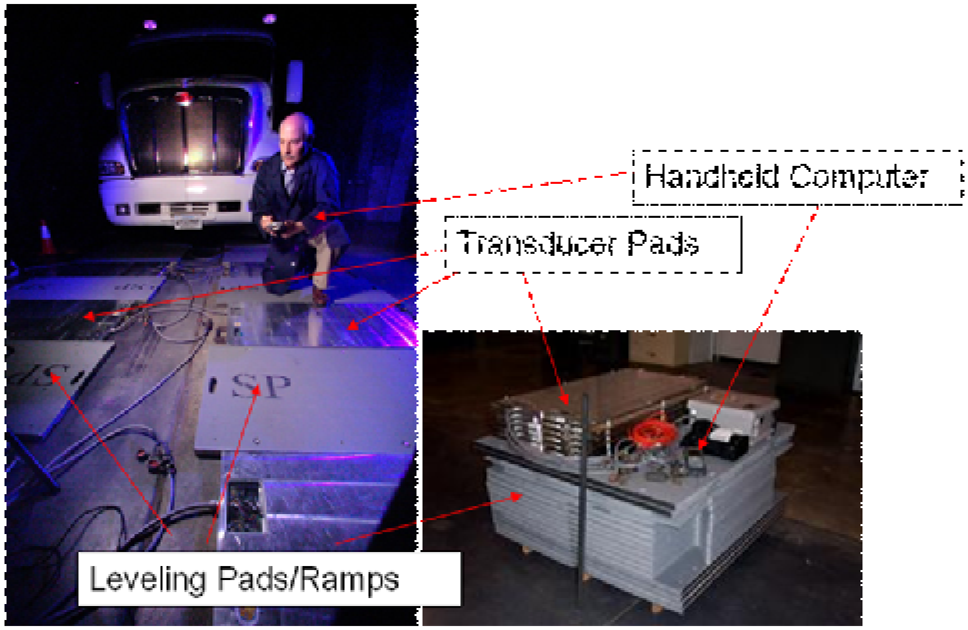

Figure 2. Composite of two pictures illustrating the current military version of WIM assembled and disassembled.

The military version of the WIM system illustrates its portability combined with the capability to rapidly weigh vehicles and determine their center-of-balance. These features fully support the rapid and safe deployment of equipment. For example, deploying and supporting units can set up their portable WIM 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, the current WIM baseline system (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 [7].

DURABILITY

The system durability has previously been shown over a 2-year period. Transducer pads are warranted for 10 years (not including electronics). Load cells (embedded in the transducer pads) are warranted for 5 years (including electronics). Leveling, spacing and ramp pads are warranted for 10 years. Data/power cables are warranted for 5 years. The host computer with power supplies and access point has a 1-year warranty. We subsequently used a commercially-hardened computer with a 3-year warranty. Three pads (out of eighty-eight) exhibited problems on arrival at field sites, two of which were returned and retested as OK. One crated system at a site was flooded and stored outside for 3 months in standing water, causing one inoperable pad. The system requires the same number of interconnecting cables as transducer pads, plus the host computer connection. Only one out of 100 cables failed. No other failures occurred [8, 9].

TIME AND MOTION EFFICIENCY

Vehicles can be weighed continuously at low speeds (approximately 3-5 mph) and at intervals of less than one minute. The current WIM baseline system requires two individuals to assemble and minimally, one to operate (two are recommended). Table 1 gives a performance comparison of different weighing methods [7]. The exact step-by-step procedure has been documented for the three techniques and is available [7].

Table 1 – Time and Motion Study Efficiencies of Military Weighing/Measuring Process

Weighing and Measuring Techniques	**Min : Sec** (w/ marking)	**Min : Sec** (no marking)	**Personnel Required**	**% of Data** w/ human err
Static Scale/ Tape Measure	7:38	4:48	3	9%
Wheel-Weight Scales/ Tape Meas.	7:46	4:52	7	14%
WIM Gen II System	3:03	0:13	2	None found

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) an earlier version of ORNL's current WIM system. Twenty-three vehicles and one container were used to test each technique. In the synopsis we focused on the weighing and Center-of-Balance (COB) calculation process (not the physical marking on the vehicle of the COB data). For weighing and determining the COB, a time and motion assessment differentiates the respective efficiencies of the techniques. The single wheel weight scales' technique (average total time – 4min 52secs) is the most labor intensive in terms of the manual calculations and the static scale technique (average total time – 4mins 48secs) is almost as labor intensive, when compared to the WIM technique.

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.

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.

RADIO FREQUENCY IDENTIFICATION TRANSPORT SYSTEM (RFITS) BASELINE

Bechtel Jacobs Company LLC has implemented a fully integrated electronic waste shipping system to facilitate a paperless on-site shipping process. This process meets the equivalent level of safety requirements of DOE Order 460.1B [10] using Passive RFID technology to reduce or eliminate the paperwork associated with on-site waste shipments to the Environmental Management Waste Management Facility (EMWMF) [11].

The Bechtel Jacobs Company LLC Radio Frequency Identification Transport System (RFITS) uses a combination of Motorola 9090G RFID handhelds to write shipping data to passive RFID tags mounted to trucks and ruggedized Figure 3 illustrates the NEMA-4 compliant towers which automatically identify vehicles at designated checkpoints along a pre-defined route, thus giving Bechtel Jacobs Company LLC visibility into real-time material tracking in locations where infrastructures may be non-existent. Encrypted tag data is captured by the RFID towers and transferred to a centralized RFID middleware system. The RFID middleware system applies filtering, formatting and logic so the data can be processed by the Waste Transportation Management System. RFITS provides enhanced transportation logistics through advanced shipping notices and estimated times of arrival for shipments entering EMWMF.

Figure 3. Baseline Portable RFITS.

As reported in a separate paper, the system was installed and implemented in February 2009 on the K-25 D&D Project [11]. The system has eliminated errors associated with manual data entry, and improved cycle time by 25 minutes per truck shipment. In addition, cost savings have been achieved by improving performance of vehicle searches at truck inspection stations exiting limited areas, and centralized logistics of all current and future shipments at the EMWMF. The technology is scalable to assist new projects and American Recovery and Reinvestment Act initiatives at the ETTP, ORNL, Y-12 National Security Complex and other DOE installations.

Environmental benefits include the elimination of 25 minutes of idling time per shipping cycle resulting in the avoidance of 10,332 gallons of diesel use, 4,000 lbs of NO_x emissions and 228,448 lbs of CO_2 emissions. Additional benefits of paperless shipping include the use avoidance of 250,000 sheets of paper, natural resources preserved and pollution prevention resulting from the paper use avoidance includes 30 trees (40 ft high and 6 to 8 inch diameter), 8,750 gallons of water, 5,125 kilowatt-hours of electricity, and 75 lbs of air pollution.

These environmental and cost savings reflect only one of five projects at Bechtel Jacobs Company LLC currently using the RFITS.

In the five month period since installation the project has shipped over 6,000 shipments to the EMWMF using the RFITS. Currently the system is being expanded to include ORNL and Y-12 waste shipments to EMWMF.

SYSTEM INTEGRATION OF WIM AND RFITS

The current RFITS is uniquely designed to facilitate the waste shipping process. The WIM baseline system has been designed for unique military and commercial purposes, and is suitable for adaptation in this environment. The current baseline WIM system was designed for use with the military. ORNL has been experimenting with and developing portable WIM systems for more nearly 20 years [12]. ORNL developed its first system for the verification program of the U.D.-Soviet missile disarmament agreement, to identify and verify the weights of missiles moved from production facilities, assembly plants, and deployment bases, or 10 destruction sites. WIM Systems have highway applications for commercial vehicles at low and high speeds. In the early 1990's, the Air Force Productivity, Reliability, Availability, and Maintainability Office commissioned ORNL to develop a portable WIM system for military deployment. The military needed a tool that could weigh and determine the center of balance for wheeled vehicles and cargo, providing data electronically for deployment, redeployment, and other inter- and intra-theater activities. ORNL developed a system to register individual wheel weights, axle weights, axle spacing, total vehicle weight, and center of balance, regardless of the total number of axles. The current WIM system offers portability, reduces labor, increases productivity, and eliminates human errors in transferring data and making calculations. In addition, portable WIM enhances speed of operations (e.g. deployability) and reduces the logistics footprint with fewer items of equipment, so that the military can react quickly and effectively to any need.

Figure 4. Dump truck approaching portable WIM (testing at ETTP).

The WIM system has commercial applications as well. State enforcement agencies use portable units for random weight checks of commercial vehicles on highways and state roads where static weighing scales are not available. Figures 4 and 5 illustrate the industrial portable application of weighing trucks at an ad-hoc temporary facility to assure proper weight distribution for safe travel, while characterizing the waste (weight of demolition debris) for further processing at the EMWMF. An added benefit is the processing of the collected data into the RFITS and Waste Tracking System.

Figure 5. Dump truck crossing portable WIM (testing at ETTP).

The following modifications are necessary to enhance smooth and efficient operations. Hardware System modifications to the baseline WIM and RFITS systems include:

- **Wired Configuration** – The current military version makes extensive use of wireless communications. Since the current version is intended for continuous autonomous use, modifications eliminating the human interaction are required and the wireless configuration will be replaced with a wired configuration.
- **Electronic Circuit Board Modification** – Currently the WIM system is self-contained, i.e., it only needs line power to run. Since the RFITS tower can provide conditioned line power, the electronics of the WIM Supervisory host system and its circuitry can be housed in the RFITS Tower proper. This will allow simplification of the electronic circuitry for both the WIM and the RFITS system. It also allows elimination of components for regulated conditioned line power in the WIM proper. Added benefit includes that the RFITS Tower is equipped with battery backup and is completely self-sufficient via solar panels that recharge the battery backup.
- **WIM Pad Placement Requirement** – Actual WIM weigh pads (with approach) are 15 feet long plus an approach of 1.5 times maximum vehicle length and exit of 1.5 times maximum vehicle length. Width is standard road lane width plus appropriate safety margin. Normal road is acceptable. No enhancements are necessary to standard road that truck travel on.

The following Software System modifications to the baseline WIM and RFITS systems include:

- **Continuous Autonomous Operations** – The original WIM baseline is designed for operators to control the flow of traffic. In this configuration, it is the intent that the trucks are already loaded and no operators will be at the integrated WIM and RFITS site. This necessitated a modification for the WIM system to run continuously and autonomously without operator intervention. This will be accomplished by:
    a. **Time out via Axle Count Spacing re-activated –** reinstituting the feature that is currently is deactivated in the human controlled system version since the conveyances are matched with a list of known vehicles. A time out condition will be reinstituted to allow vehicles with varying number of axles to be counted to accommodate continuous operation.
- **Stop Light Change –** The current Stop light will be enhanced to mimic a standard roadside Stop Light and be modified to trigger to Indicate Overweight Condition.
- **Process Weight Answer to RFITS Tower Middleware –** The entire logical process is explain via the Use case allowing weight and characterization data to be processed and transmitted to RFITS automatically.

PROCESSING INTEGRATION OF WIM AND RFITS

The information processing integration of the WIM system with the RFITS will be explained via a series of use cases. These use cases describe the data feed process of the RFID Tag middleware processing software of the RFITS to the WIM system proper, the actual weighing and characterization process, information processing, forwarding the collected data to the RFID Tag middleware processing software of the RFITS, and its subsequent forwarding for ultimate use by the Waste Transportation Management System. The modification of the original hardware design of both systems has been described in the previous section.

This use case begins when the RFID tag is or is not present. If present it identifies itself to and is authorized for connection to the RFITS data repository via the WIM system.

Initialization:

Shipping data has been loaded into the RFID tag (in this case a passive tag) at the demolition site by the portable Motorola 9090G (a standard part of the RFITS system). This information is also contained in the Waste Management System and will be updated via checkpoint along the route from the demolition site to the EMWMF. The entire system for this use case consists of an integrated WIM and RFITS system with RFID tags that are fixed on dump trucks loaded with debris. The following use case identifies the basic flow on the transportation route once the basic information has been loaded on the RFID tag as described in a separate paper [11].

Data Flow processing (Routine Initialization and Maintenance Status):

- Initially and routinely, the RFITS tower middleware interrogates the WIM Supervisory host system, which in turns keeps the WIM system weighing components in an active mode ready to weigh conveyances dynamically.
    - If the active "ready to weigh dynamically" status is successful, the WIM Supervisory host system is ready to weigh conveyances, go to the Basic Information Flow Step and proceed.
    - If the active "ready to weigh dynamically" status is unsuccessful,
        - The WIM Supervisory host system sends a "GOTO Dynamic Mode" message to the WIM host system which puts WIM system weighing components in an active mode ready to weigh conveyances dynamically.
        - If the active "ready to weigh dynamically" status is still not successful,
            - The WIM Supervisory host system sends a "Reboot" message to the WIM host system, which upon reboot goes through the standard maintenance checks of the entire WIM system.
            - Once rebooted,
                - The WIM Supervisory host system sends a "GOTO Dynamic Mode" to the WIM host system to put WIM system weighing components in an active mode ready to weigh conveyances dynamically.
                - If the active "ready to weigh" status is successful, the WIM Supervisory host system is ready to weigh, go to the Basic Information Flow Step and proceed.
                    - If active "ready to weigh dynamically" status is still unsuccessful, a "failure" message is sent to the Waste Management System and maintenance personnel are dispatched to diagnose and correct any problems with the integrated WIM and RFITS system.

Basic Information Flow during normal operations:

- The loaded dump truck (or any conveyance) approaches the integrated WIM and RFITS system.
- The RFITS tower middleware interrogates the RFID tag.
- If a RFID tag is present and if the RFID tag responds with its unique ID.
  - The RFITS tower middleware creates a unique time stamped entry and places the information in the WIM Supervisory host system Inbox directory.
  - The RFITS tower middleware stores the unique ID for further processing.
- If the RFITS tower middleware times out during the interrogation.
  - A RFID tag "failure" message is sent to Waste Management System for further processing and reconciliation.
  - The RFITS tower middleware assumes no RFID is present and processing is continued under the "No RFID Tag Present Alternative Flow".
- The RFITS tower middleware checks the status from the WIM Supervisory host system to ensure that the WIM system is in the Dynamic Mode ("ready to weigh dynamically" status) and ready to weigh conveyances dynamically.
  - If the WIM system is not in Dynamic Mode ("ready to weigh dynamically" mode), go to the Data Flow processing (Routine Initialization and Maintenance Status) section.
  - Upon successful return from the Routine Initialization and Maintenance Status section, normal processing continues.
- The WIM Supervisory host system establishes a communication path to the directory where the RFID tag time stamped information is to be retrieved from (WIM Supervisory host WIM inbox).
- The WIM Supervisory host system establishes a communication path to the directory where the weight and characteristics data are to be stored (WIM Supervisory RFITS tower middleware Interface Outbox).
- The WIM Supervisory host system retrieves the RFID tag information from the RFITS tower middleware (time stamped data entry in the WIM Supervisory host WIM inbox).
- WIM system device weighs conveyance and its cargo and performs appropriate calculations as the conveyance passes dynamically over the weigh pads scales of the WIM system device proper.
- WIM system device transmits cargo "actual" weights and measurement data to WIM Supervisory host system.
- WIM Supervisory host system processes the time stamped weight and characteristics conveyance data by linking the time stamped RFID tag identifier, if present or a WIM generated RFID tag identifier (if not present) with it.
- The WIM Supervisory host system stores this time stamped entry in the WIM Supervisory RFITS tower middleware Interface Outbox.
- The WIM Supervisory host system also forwards this time stamped entry to the RFITS tower middleware.
- The RFITS tower middleware acknowledges receipt.
- The WIM Supervisory host system records this receipt in a time stamped entry in the WIM Supervisory RFITS tower middleware Interface Outbox.

- If the WIM Supervisory host system times out waiting for the receipt, a time stamped entry of this event is recorded in the WIM Supervisory RFITS tower middleware Interface Outbox.
- The WIM Supervisory host system enters into the "Routine Initialization and Maintenance Status" mode awaiting dialog from the RFITS tower middleware.

Alternative Flows – No RFID Tag Present Alternative Flow (Basic Information Flow during normal operations):

- The RFITS tower middleware checks the status from the WIM Supervisory host system to ensure that the WIM system is in the Dynamic Mode ("ready to weigh dynamically" status) and ready to weigh conveyances dynamically.
    - If the WIM system is not in Dynamic Mode ("ready to weigh dynamically" mode), go to the Data Flow processing (Routine Initialization and Maintenance Status) section.
    - Upon successful return from the Routine Initialization and Maintenance Status section, normal processing continues.
- The WIM Supervisory host system establishes a communication path to the directory where the RFID tag time stamped information is to be retrieved from (WIM Supervisory host WIM inbox).
- The WIM Supervisory host system creates a pseudo-RFID tag time stamped information and places the entry into WIM Supervisory host WIM inbox.
- The WIM Supervisory host system establishes a communication path to the directory where the weight and characteristics data is to be stored (WIM Supervisory RFITS tower middleware Interface Outbox).
- The WIM Supervisory host system retrieves the pseudo-RFID tag information from the RFITS tower middleware (time stamped data entry in the WIM Supervisory host WIM inbox).
- This process now re-enters the normal processing at the weighing step.

CONCLUSIONS

Fixed in-ground WIM systems have been available in the commercial vehicle industry and enforcement services for more than a decade, with wider applications in Europe and South America. The integration of the current portable WIM system and the RFITS eliminates human errors in data entry and in calculations, increases speed and productivity, eliminates the need for a static weigh scale, enables operational flexibility and reduces costs. The system is portable, can be set up, and be operation in a few minutes. With portable WIM system integrated with RFITS, along with processing the Waste Transportation Management System, DOE operations can be optimized, more efficiently, more accurately, and with greater safety.

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