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Feasibility Study of Portable Weigh-in-Motion Systems for Highway Speed

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Minnesota Department of Transportation (Mn/DOT) needs improved traffic monitoring tools to optimally allocate road maintenance and improvement resources. In particular, the department needs a method of including vehicle and axle weights with portable traffic logging equipment. The cost of existing Weigh-in-Motion (WIM) equipment prevents widespread use in locations where only temporary monitoring is needed. This project was a survey of the suppliers of portable WIM systems, allowing a few systems to be moved between locations of interest. There were four candidate systems found and studied, of which two are recommended for further evaluation. Both systems appear to meet the needs Mn/DOT established and local testing will allow a final decision on their suitability.

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Feasibility Study of Portable Weigh-in-Motion Systems for Highway Speed

Final Report

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Executive Summary

Road planning and maintenance requires an understanding of existing traffic patterns and loads. Vehicle load information is particularly difficult to obtain. There are a number of WIM systems being used by the Minnesota Department of Transportation (Mn/DOT) to measure traffic volume and weight on selected routes. The cost and maintenance of these systems has limited their use to a few high-volume roads. A need exists to measure this information on smaller roads. The requirements do not normally require data logging for more than a few weeks and are often seasonal, such as harvest season on rural highways. Using a portable system would allow Mn/DOT to cover data logging needs over a large number of roads with minimal investment.

A survey of Mn/DOT engineers was made for the type of data needed. This provided a number of system requirements to make a usable system. Requirements are for a system that can be quickly set up to monitor normal traffic traveling at highway speeds and provide the same vehicle data as the existing permanent systems. Preferences for the system include an easily portable system that can be installed with one or two workpeople with lane closures of 30 minutes or less, and be capable of autonomous operation for up to two weeks.

Four candidate systems were found for consideration. The electrical and computer components of all four systems met the requirements and were relatively similar. Sensors were the limiting factor. The system manufactured by Truvelo uses a capacitance mat providing the low profile and durability necessary for this application. The piezoelectric sensors manufactured by Electronique Control Measure (ECM) also meet the Mn/DOT needs. The system by International Road Dynamics (IRD) does not have the durability and ability to remain as placed over several days when mounted on the surface. Transportation Data Systems has a metal carrier that must be mounted into the road in a similar manner to permanent WIM systems. While the sensor itself can be moved between carriers, the system does not meet the portability requirements.

As a result of these findings, it is suggested that Mn/DOT consider the ECM and Truvelo systems. The specifications for both meet the needs of Mn/DOT and have the potential to provide the benefits that will justify their purchase. Current users, however, report the need for elaborate correlation procedures using these sensors with surface mounting. Any evaluation of these systems should be done in an extended period beyond the original scope of this project. In addition, periodic reviews of equipment manufactures should be continued. Sensors are continually being improved and new offerings should be expected. The improvements to the sensors are primarily in the packaging and do not require new technologies for better systems.

Chapter 1: Introduction

The Minnesota Department of Transportation (Mn/DOT) needs an accurate picture of road use for planning new roads and maintenance of existing roads. Most major roads such as interstate highways have traffic monitoring equipment in place to provide vehicle counts as well as classifying the vehicle types and providing the weight per axle. The weights are the hardest to measure.

The current generation of Weigh in Motion (WIM) systems placed on highways consist of two piezoelectric sensors embedded in the roadway. These are mounted to two associated induction loops also embedded in the roadway. As a system, these can determine the vehicle speed, number of axles, axle grouping, type, and weight. These allow vehicles to pass with no restriction on speed and can store data at the onsite computer or transmit the information through a modem. Minnesota already has several of these WIM systems in use. A brief discussion of recent progress in WIM systems was written by Kent (1).

These systems have the advantages over the truck weigh station scales in a greatly reduced cost, lack of speed restriction, and reduced installation time. The tradeoff is reduced accuracy. Accuracy of these systems is not adequate for weight enforcement, but is acceptable for monitoring. Even with the cost and installation advantages, these systems can cost over $100,000 for equipment, installation, and calibration. Installation can require closing each lane for a day (2). This limits broader use of the system.

Most road study projects only require monitoring for a limited time, so a portable system is more practical. A portable system will allow the department to study specific needs such as a roads planned, bridges being studied for update or replacement, or rural highways during harvest season. These represent some of the opportunities where traffic load monitoring is needed for only a limited period of time. This is the benefit of the project to find a portable WIM system; more accurate monitoring roads without the expense of permanent systems.

Chapter 2: Project Objectives

The objective of this project was to perform a market study of portable WIM systems and find any that fit the needs of Mn/DOT. If any viable systems were found, then a road test and evaluation would be done. An analytical study will be made as part of project to quantify the effects of reduced gage sizes necessary for a portable system.

Ultimately, the final outcome of this project will be a list of any applicable WIM systems for use by the Mn/DOT. Another result of this research will be an assessment of the market status for portable WIM systems. This is still a very active area of research and several new types of systems are in development.

Chapter 3: WIM System Background

WIM systems are broken into four types, as described in the ASTM standard (3) for these systems. Type I systems are the primary focus of the project. They are normally used for data collection and have a 15% tolerance on axle group load (
Table **1**). This type is designed for use in normal traffic lanes with traffic moving up to 80 MPH. Type II systems are less expensive versions also used for data gathering. The elimination of the wheel load requirement and more generous tolerances reduces the cost of these systems. All of these tolerances require measurement of the vehicle speed to within 1 MPH.

Table 1 - Performance Requirements for WIM Systems at 95% Confidence

Function	Type I	Type II	Type III
Wheel Load	±25%		±20%
Axle Load	±20%	±30%	±15%
Axle-Group Load	±15%	±20%	±10%
Gross-Vehicle Weight	±10%	±15%	±6%

Type III and IV sensors are used primarily for enforcement and are beyond the requirements of this application. Type III systems are typically placed in traffic lanes and are used for screening vehicles. Type IV (not shown in Table 1) has tighter tolerances given in weight instead of percent of weight. Type IV scales require lower speeds and so are usually removed from normal traffic lanes. Types III and IV also require acceleration measurements to reject bad measurements from vehicles undergoing large acceleration or deceleration.

Bending plate sensors are almost universally used for weigh-station (Type IV) scales. These sensors use a metal plate mounted to the frame by steel supports. Strain gages on these supports are used to measure the load on the plate. The advantages of this type sensor include accuracy, since the entire contact patch of the tire fits on the plate, temperature compensation from proper strain gage mounting, and maturity.

The cost of bending plate sensors are the major limiting factor. They require a large cutout in the road, and require lifting equipment for installation and maintenance. This results in equipment, installation, and maintenance costs much higher than the newer types and limits its use for data collection. Their ability to handle higher speeds is limited by the large moving mass of the plate and beam.

Piezoelectric sensors have gained significantly in the last few years primarily due to cost. The sensors are encased in a long polymer carrier for installation in the roadway. The current generation of sensors require a cutout approximately 2 inches deep and 3 inches long. The sensors can be easily handled by two or three people depending on lane width and installed in four to six hours. Material and installation costs are much lower than bending plate applications. There are no moving parts, which reduces maintenance to grinding the top surface to match road wear and patching the grout and pavement surrounding the sensor. Sensors are generally considered to be non-repairable and are replaced on failure.

The main drawback of piezoelectric sensors is accuracy. Due to their small size, their gage length is shorter than the contact patch of most trucks. There are a number of methods used to approximate the total load of the tire, but this remains a limiting factor in the accuracy of the sensor. There is no intrinsic temperature compensation equivalent to a balanced strain gage bridge setup, so some type of temperature sensing and compensation mechanism is required. Piezoelectric sensors must also be packaged to prevent shear loads.

Capacitance mats are a new method that has not yet achieved significant market penetration. These sensors use parallel foil sheets that can be sealed and laid flat on the roadway. Load is sensed by the capacitance change of the two sheets. They have the potential of being packaged into very thin sensors that are large enough for the full contact patch of a truck tire. Their primary shortcomings are accuracy and temperature sensitivity.

One issue with all sensor types is road condition. Vehicle behavior over irregular surfaces varies dramatically with vehicle type, weight, and condition. Settling time for some vehicles will exceed the time differential between the first and second sensor. No viable compensation mechanisms have proven themselves so far. For this reason, all permanent WIM sensors are buried into the road and the tops are ground to match the road surface.

In addition to the load sensor, WIM sites require additional sensors for speed and classification information. Vehicle speed is necessary for calculating the vehicle load from sensor input. Piezoelectric sensors are usually mounted in pairs to allow speed calculation from the signal timing. Pairs of induction loops can be used in the same manner, or radar sensors are added to the system. Induction loops are also used for vehicle classification.

A permanent WIM system was installed near East Grand Forks during this project. This system used piezoelectric sensors which are the most common option for portable WIM system. This installation used two sensors per lane plus two induction loops. A roadside electronics cabinet with power was already available at the site which simplified the installation. A representative from the sensor supplier (Kistler) was on site to use this installation for training Mn/DOT employees. For this reason, the number of people and installation time were greater than a normal installation.

The sensors for one lane required about 6 hours to install, including induction loops and most of the wiring. Sensors for this installation were $9,000 per lane and the electronics were $15,000. The installation was ground and lane reopened less than an hour after the sensor was placed. Per the manufacturer's recommendations, the installation must sit for the grout to completely cure for at least two weeks before calibration. Calibration requires about 30 passes of the reference vehicle. These steps follow the Kistler installation instructions (4) and ASTM E2415-05 standard (2).

Chapter 4: Mn/DOT Requirements for Portable WIM Systems

Discussions and interviews with Mn/DOT engineers were used to determine the requirements and preferences of a portable WIM system. It is important to note that this work focused entirely on data logging. Enforcement is not a consideration for this project.

The requirements for the system were fairly common across the group of engineers. There were differences in some of the preferences. The following lists detail the requirements (minimum specification) and preferences.

<u>Minimum Specifications</u>

1. Setup – complete system setup at a new site must require no more than four hours.

2. Capacity – the system must be capable of

   a. loads to at least 20% over the state axle limit of 20,000 lbs.

   b. speeds from 10 to 80 MPH.

3. Accuracy – axle load measurements must be within 20% at a 95% confidence level.

4. Output – output needs to be available on a per car basis, be compatible with the formats from existing systems and must include (at the minimum):

   a. axle loads

   b. axle group load

   c. vehicle classification

   d. vehicle speed

   e. gross-vehicle weight

5. Operation – the system must be capable of autonomous operation with battery and memory capacity for at least 7 days of unattended operation.

Note that most of these specifications also follow the ASTM standard (2) for type I WIM installations, with the exception that tire load was not requested.

<u>Preferences</u>

1. Portability – Ideally, the system should disassemble to a size that will fit into a van. A larger system should fit into the bed of a highway maintenance vehicle. No consensus exists on electronic packaging, but it must include weather tight packaging for installations without an electronic cabinet.

2. Setup – the maximum required setup time must be no more than four hours, but shorter times are better. Ideally, the lane closures should be less than 30 minutes. Setup should require no more than two workers (not including flagmen).

3. Calibration – this is primarily a cost issue, so shorter the calibration cycles after each move are desirable. A continuously self calibrating system is ideal.

4. Tolerance – improvements to the 20% axle loads are desirable. Ideally, the system should fit the 15% tolerance suggested for type III systems. Accuracy also needs to be independent of temperature.

5. Recording – data recording output in a format compatible with existing WIM installations in Minnesota is preferable. Ideally, the output can be customized by the user and formatted for import to Excel spreadsheets.

6. Operation – extended operation without service of 14 days is ideal. Preference is for a system capable of data download via modem or wireless transmission.

7. Cost – due to the portability of the system, initial cost is not as serious as for permanent systems. As the only item expected to wear significantly, the cost of replacement sensors is important.

This is a summary of the needs, preferences, and concerns expressed by the MnDOT personnel I have met with during this study. In some cases, there are conflicting sentiments, and these have been included.

Opinions of the maximum acceptable setup time for a portable system varied, but all the engineers agreed that it should be no more than 4 hours. There was no consensus on the maximum size (portability), but ideally a complete system could be transported in the back of a van.

An option that can improve the portability and setup time concerns is reducing sensor length. Installations are expected to occur in conditions where putting sensors in a single wheel path is acceptable. Reducing sensor length to four feet may reduce sensor cost and will greatly improve portability of rigid sensors.

Calibration (item 3) was a particular concern. The time and accessibility for reference trucks can be a particular problem on remote sites. An abbreviated calibration procedure is needed to keep the cost of use in control.

Opinions on item 4 – tolerance, were quite varied. For traffic monitoring, 10% was desirable. Using ASTM standard (2), axle loads must be within 20% for type I (data collection) systems. Type III (weigh station screening) systems have a tighter 15% axle load tolerance. All tolerances specified are for a 95% confidence (probability of conformity) level.

Maximum speed capability of the system needs to match the current maximum speed limit of 70 MPH in Minnesota. A capacity of 80 MPH to realistically handle actual vehicle speeds is preferred, and this is supported by the 80 MPH speed specified for WIM types I and III .

One of the major questions remaining on the system concerns autonomous operation. Battery operation for at least one week was an expressed preference, but there were no requirements or specific preferences given for packaging the electronics. This may become a significant issue due to concerns over system security. The concern for packaging is that the portable WIM systems may be perceived as enforcement devices and provoke criminal mischief when they are perceived as such. There have been instances of existing WIM sites suffering vandalism and other attempts to disable the equipment.

Chapter 5: Analytical Study of Portable WIM Accuracy

One of the major concerns with portable WIM systems is the possible reduction in accuracy resulting from the shorter gage length. While bending plate systems are large enough to support the entire contact patch of a truck tire, piezoelectric sensors are shorter. The permanent installation in East Grand Forks used sensors with a 1.97 inch (50 mm) gage length and one of the portable systems studied has a gage length estimated at 0.59 inch (15 mm). The shorter gage length corresponds to the estimated active sensing length of the smaller portable WIM sensors.

There are two methods for calculating the tire weight from the load profile. One uses the peak load (5-6) on the sensor and the other integrates the load for the duration of the load cycle. In this study, a time domain simulation of a load cycle was made using various sensor lengths and load profiles. As seen in previous studies (7-9), vehicle suspension is very unpredictable. For this study, those effects are neglected. A perfectly smooth road is assumed. Further, any error in speed measurement is neglected.

This model is a time domain calculation of the load on the WIM sensor. The model was run using several different tire load profiles reflecting different states of inflation. Three of the profiles are shown in Figure 1. For each profile, the load was calculated using both the peak and integral methods on sensors of length 0.25, 0.6, 2.0, and 12.0 inches at speeds of 20 to 80 MPH in 10 MPH increments. In each case, a contact patch length of 3.94 inches (100 mm) was used.

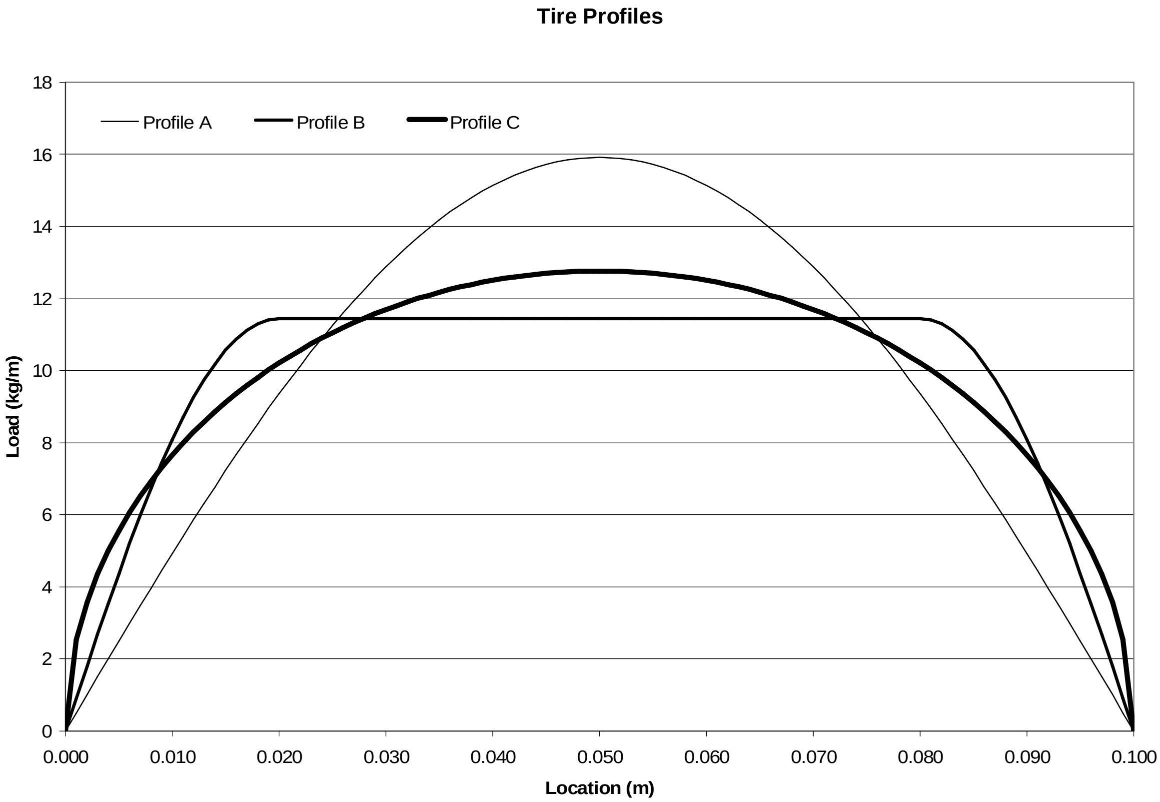

Figure 1 - Tire Load Profiles

The calculations showed very little error. There was no error found in the peak load measurements, as expected. Using the integral method, the error was below 0.1% in all cases. These values are well below the error due to electrical noise and filtering and vehicle dynamics. The worst case seen was for a bimodal load profile which should only be seen with a misaligned sensor (not perpendicular to the direction of travel). From these results, it can be expected that any error related to the gage length will be negligible in relation to the errors from the transition between road surface and sensor thickness.

Chapter 6: Existing Applicable Portable WIM Systems

A review of vendors found only four responding that can currently supply a portable system capable of the speeds specified in the project proposal. These are International Road Dynamics (IRD) of Saskatoon Saskatchewan, Transport Data Systems (TDS) of San Diego California, AVIAR Inc. of Austin Texas, and ECM Inc. of Buda Texas. The system by IRD uses encased piezoelectric sensors approximately ¾ inch square in cross section and twelve feet long. These can be taped to the road surface or mounted in grooves. The system by Transport Data Systems (TDS) uses a Kistler sensor mounted in a metal channel. AVIAR is the U.S. distributor for a capacitance mat manufactured by Truvelo of South Africa. ECM Inc. is the U.S. distributor for Electronic Control Measure of France. The ECM system is similar to the TDS system with a different casing for the sensor.

The IRD sensors are in production and used in several U.S. state and one Canadian province. Both locations used the sensors permanently mounted in grooves. One of them also used them taped to the road, primarily in enforcement applications. In portable use, they are normally used in pairs to provide speed sensing. Most permanent installations combine them with inductive loops for vehicle classification.

The IRD sensors can be operated with a portable control box and are compatible with their existing IRD boxes of the type currently used by MnDOT. Accuracy is listed at 20% by the manufacturer. The representative said they should be capable of better accuracy when mounted in grooves, but there is no specific accuracy claimed. They are capable of speeds up to 75 MPH (120 KPH).

The TDS system described is a prototype. It was developed through discussions with Margaret Chalkline of Mn/DOT and the vendor has offered to allow use of the unit for evaluation without charge. The system uses the same type Kistler sensors and electronics as one of their permanent WIM systems. It is supplied with a metal channel that is permanently mounted in the roadway using the same methods as permanent WIMs. The piezoelectric sensor slides into the tray and connections are made through an integrated junction box. The sensor can be removed for use at other sites and replaced with a blank insert. The manufacturer claims that sensors can be removed and replaced in less than one hour for a pre-wired channel. This uses Kistler 9195C sensors and is mounted flush with the road surface, so the accuracy claim of 5% is similar to permanent WIM installations. The proposed system uses one sensor and a radar gun 20 feet away, but can be operated using sensor pairs.

Kistler 9195C sensors used by TDS are functionally identical to the 9195E type used in existing Mn/DOT installations. According to Aaron Schumacher or Kistler, the 9195E is a replacement for the now discontinued 9195C series. The differences are limited to lead lengths and sensor packaging to simply handling and installation.

The Truvelo system marketed by AVIAR is a large mat using change in capacitance for sensing load. It is designed to cover a single wheel path and matches the Type II sensor specifications. The sensor is mounted using an aluminum wedge nailed to the road on the leading edge and tape around the remaining edges. The portable mat is their series 8 sensor and works with their model

TDL 500 traffic data logger. The system requires two inductive loops for speed and classification information. The data is stored in ASCII format on the logger for processing into reports. Temperature compensation is from an internal sensor and compensation algorithm.

The ECM system is a piezoelectric strip to place on the road surface, similar to the IRD system. A BL series sensor from Measurement Specialties, Inc. (MSI) is used with the ECM electronics. This sensor is very common and is also compatible with IRD and PEEK electronics for WIM. The sensor is 0.26 inch wide, 0.0625 inch thick, and available numerous lengths. The sensor can be held down with pocket tape or a holder developed by Ronald Wuertly, currently of the Montana Department of Transportation. Pocket tape has been found unsuitable for the 7 to 14 day durations desired for this study. The holder is a fabric sheet with a pocket for the sensor and is held down by nails. Other forms of this holder have been built by others, including Dan Inabnitt of Southern Traffic Services, as part of his consulting work.

The primary concern with these surface-mount setups is accuracy. None of the vendors were anxious to provide this information for surface mount applications. Ronald Wuertly discussed the accuracy findings in Montana, where there is extensive use of six portable systems. They use their system to study candidate locations for weight enforcement. His findings were that vehicle dynamics severely restricted the accuracy of the system. When the system was calibrated for a particular load, such as 80,000 pound class 9 trucks, the results were good for trucks in that range. Outside the range, smaller vehicles appeared heavier and heavier trucks weighed lighter. More important, the good results for that range were for GVW and not axle groups. On a class 9 truck, the front axle was typically 15% light, the drive axles 8% heavy, and trailer tandem was unpredictable. The system was also very sensitive to axle groups. If it was calibrated for class 9, tridem axle groups or single axles gave unpredictable results. In his opinion, the system would be a poor choice for determining Equivalent Single Axle Load (ESAL) values used in road planning. Similar results were found in testing 10 years ago using the AVIAR capacitance mats.

A comparison of the various systems is given in Table 2.

Table 2 - Summary of System Capabilities

Criterion	IRD	TDS	AVIAR	ECM
Specifications				
1. Setup time (hours)	1.0	2.0[1]	1.0	1.0
2. Capacity (MPH)	75[2]	100	80	80
2. Accuracy (at 95% confidence, GVW)	20%	5%	15%	15%[8]
3. Output (matches requirements)	Yes	Yes	Yes	Yes
4. Unattended Operation (days)	14	7	7	7
Configuration	2 sensors 1 loop	1 sensor radar	1 sensor 2 loops	2 sensors
Features				

Criterion	IRD	TDS	AVIAR	ECM
1. Portability (sensor)	Flexible single piece	2 pieces – 3 feet long	2 pieces	Flexible single piece
1. Portability (electronic box, dimensions in inches)	15 lb 11″ x 14″ x 7″	20″x26″x10″	17 lb 9.5”x11.8”x7.5”	16 lb 14”x8.5”x10”
2. Setup				
3. Calibration	GVW or Front axle	GVW	GVW or Front axle	GVW or Front axle
4. Tolerance	20% accuracy Axle calibration[6]	5% accuracy -0.011% / °F	20% accuracy Axle calibration[6]	20% accuracy Axle calibration[6]
5. Recording	Existing (to MnDOT) report format	Preformatted reports	Preformatted reports or ASCII data	Preformatted reports
6. Operation (output capabilities)	RS-232 or Modem	RS-232 or Modem	RS-232 or Modem	RS-232 or Modem
7. Cost[3] – sensors (US$)	2,000	12,100[4] 3,100[5]	$9,000[7]	5,000
7. Cost[3] – electronics (US$)	12,000	8,700	$6,750	10,000

[1] does not include initial installation of carrier
[2] the proposed specification is for 80 MPH, this may need consideration
[3] sensor configure is for a two sensors to cover a single lane. Electronics packages are for at least two lanes, or four sensors. Training, installation supervision, and other support costs are not included.
[4] cost is for sensors and carrier. Extra carriers alone are $600.
[5] this is the cost of the radar for the standard configuration
[6] IRD and Truvelo systems can use front axles for calibration update to compensate for temperature changes
[7] Installation requires a $140 installation kit that lasts about 5 installations
[8] the accuracy quoted is for imbedded, not surface mount, applications

Notes on the systems

International Road Dynamics

- The system is in production and used in several states and provinces. Many of the users mount the sensors permanently in a groove and treat the sensor as a consumable supply when moving between sites.
- The system is design to qualify as a type I sensor by ASTM and USDOT standards.
- The sensor is flexible and has a 20 mm x 20 mm cross section.
- Sensors are 12 feet long and the price quoted includes a 250 foot lead.
- Standard configuration uses two sensors and can be configured with induction loops.
- Mounting in ¾” deep grooves is expected to improve accuracy, but no data is available.

- Installations with the sensor taped to the surface generally need to be monitored and re-taped within 72 hours. For longer installations, it has been found more efficient to permanently mount the sensor. This requires a ¾″ deep, ¾″ wide (20 mm x 20 mm) groove. There is a quick setting grout ($99 per installation) to hold the assembly. The grout sets in 45 minutes and can set in conditions as low as 25°F. These installations are ready as soon as the grout sets (NYDOT, Saskatoon). IRD suggests using the BL sensors with pocket tape for above ground installations.
- According to NYDOT, the permanently sensors typically last from 3 to 5 years (IRD claims 1 to 2). Their sensors are installed and maintained by vendors. Installation of a single sensor in one lane requires the lane to be shut down for one hour. This is time to cut the ¾ inch groove, clean it out, install sensor with grout, and grind the surface. IRD recommends waiting 45 minutes for the grout to set, but NYDOT will grind the surface and open the lane after 20. Their typical installation uses two sensors with an induction loop between.
- Sensors using in the above ground (taped) mode typically last about 6 weeks, with periodic re-attachment. Sensors mounted in grooves typically last about 2 years (Saskatoon).

Transport Data Systems

- This is a prototype system. It uses the sensor and electronics from an existing WIM system, with a prototype carrier for permanent mounting. The Kistler sensors are similar to the ones already used in Minnesota for permanent WIM stations.
- One concern with this approach is leveling. Depending on how it is set up, only the roadway to carrier or carrier to sensor transition can be leveled. Unlike a permanent installation, there will likely be at least one step exciting vehicle suspension. The result is still much closer to smooth than the 20 mm step for the IRD sensor, but it does raise concern on how valid the 5% accuracy claim will be.
- The prototype system available for evaluation is configured with a single sensor strip and a radar for speed detection.
- The standard configuration is a single sensor with radar for speed measurement. It is available in two sensor configuration, and can use induction loops.
- TDS offers a license capture system that will work with their WIMs, including portable. The cost of the system is $4,600 for an interface board, interface card, card, light, and cables.
- Reports are pre-formatted for printing or file export. The vendor can supply a format more easily imported into Excel.

AVIAR (Truvelo)

- This system is currently being used in Kansas, Alabama, Rhode Island, and Massachusetts.
- The sensor is “weatherproof” in case of rain, but immersion or standing water will cause permanent damage.
- Suspension interactions should be much smaller than the IRD sensor because it is much thinner at 8 mm (0.315 inch). This is still much thicker than the BL sensors suggested by ECM.
- The pad size 1.8m x 0.5 m (71 in x 20 in) for coverage of one tire path.
- Truvelo also market a series 9 sensor that can be placed in a permanent tray similar to the TDS system.
- The TDL-500 can handle data from up to four lanes.

ECM Inc.

- The HESTIA data logger comes in two portable models, P2 for two lanes or P4 for 4 lanes
- There is an optional solar collector to extend unattended operation.
- The sensors share the advantage of Truvelo with very thin sensors. The cross-section of the sensors should produce lower shear and twisting forces than the IRD design.
- The standard sensor lead wires are 10 m (33 feet) long.

Chapter 7: Conclusions on Existing WIM Systems

A review of the systems evaluated presents two candidates for consideration. The AVIAR capacitance mats and MSI BL series sensors meet the criterion for size, ease of installation, and capability for re-use. They have the advantage of being the shortest at 7 and 8 mm. At this height, both still have problems with suspension interactions which will limit their accuracy. Even with the mounting systems proposed, the BL sensors also have the problem of shifting and sensitivity to shear forces from wheel torque. The attachment methods for both are secure enough to last for the three week target of this study. The only permanent effects on the road would be nail holes. All of the sensors meet the specifications for accuracy in flush (permanent) mounting, but data on surface mount is limited and should be questioned.

The IRD system with their own sensors does meet the requirements of a truly portable system that can be quickly installed and removed. Continuous calibration through front axle weight is also an advantage. Unfortunately, the sensor lifetime when mounted on the surface (not in a groove) is not adequate. The shape and thickness of the sensor allow significant shear loads on the sensor, which limits durability, accuracy and increases the risk of damage and shifting. In addition, using tape as the primary attachment method is more prone to failure than the adhesives and nails used by the other sensors.

The TDS system is not truly portable. The installation cost is the same or higher than a permanent installation. The sensor and electronics costs are reduced if it is rotated between existing monitoring locations. This would work well if our application involved several sites that are revisited rather than completely new sites. The system also presents the problem in grinding to match the road profile. Matching would require grinding a metal carrier rather than pavement and a polymer sensor casing. This can be a significant issue on softer asphalt roads.

All of the vendors have electronics packages that match the needs of this project. Traffic logging equipment has become very common over the years and the cost of adding additional input capability is small. Another vendor, Peek, supplies some data logging equipment used by Mn/DOT. While they do not offer a suitable sensor for this project, they do have portable data logging electronics packages capable of working with piezoelectric weight sensors. If the BL sensors used with the ECM package are selected, they have the advantage of working with ECM electronics, or IRD and PEEK where Mn/DOT already has working knowledge. The sensors are the limiting factor with portable WIM systems.

Chapter 8: Recommendations

The limiting factor for these systems is the sensors. The ECM system and capacitance mats from AVIAR both have the potential of meeting the needs of this project. In view of the experience from Montana and other users, a long term study is more appropriate than a two or three week evaluation. Vehicle dynamics still play a significant role with these small sensors and evaluation would need to see a full range of loads, axle configurations, speeds, and weather. The key issue to watch will be the accuracy for axle groups to determine if useable ESAL values can be calculated.

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