IATSS Research 34 (2010) 9–15

Contents lists available at ScienceDirect

IATSS Research

journal homepage: www.elsevier.com/wps/locate/iatssr

Improving truck safety: Potential of weigh-in-motion technology

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ARTICLE INFO

Available online 30 July 2010

Keywords:
Weigh-in-motion (WIM)
Truck
Safety
Road
Bridge

ABSTRACT

Trucks exceeding the legal mass limits increase the risk of traffic accidents and damage to the infrastructure. They also result in unfair competition between transport modes and companies. It is therefore important to ensure truck compliance to weight regulation. New technologies are being developed for more efficient overload screening and enforcement. Weigh-in-Motion (WIM) technologies allow trucks to be weighed in the traffic flow, without any disruption to operations. Much progress has been made recently to improve and implement WIM systems, which can contribute to safer and more efficient operation of trucks.

1. The issues with overloaded trucks

Overloaded trucks pose serious threats to road transport operations, with increased risks for road users, deterioration of road safety, severe impacts on the durability of infrastructure (pavements and bridges), and on fair competition between transport modes and operators.

1.1. Accident risk and accident severity

An overloaded truck is more likely to be involved in an accident, and have more severe consequences, than a legally loaded truck. The heavier the vehicle, the higher its kinetic energy, resulting in greater impact forces and damage – to other vehicles or to the infrastructure – in the event of a crash. However, the absolute weight is not an issue in itself and heavy loads can safely be carried by trucks designed for that purpose, such as the so-called "high capacity vehicles". However, when the current load exceeds the maximum permitted limit of a truck, several adverse consequences may occur:

- *Truck instability*: an overloaded vehicle is less stable because of the increased height at the centre of gravity and more inertia of the vehicle bodies (*e.g.* trailer or semi-trailer.). Because the on-board stability tools (ESP, anti-rollover system, etc.) may be overstrained, the risk of rollover, lane departure or knife-jacking is increased (Fig. 1).
- *Braking default*: the braking system of any truck is designed for the maximum allowable weight indicated on the vehicle documents. The breaking capacity depends on the brakes themselves, but also on the tire and suspension performances designed for the maximum allowable weight of the truck. Any weight in excess reduces the braking capacity of a truck, and may even damage the braking system.
- *Loss of motivity and maneuverability*: an overloaded vehicle becomes under-powered; this results in lower speeds on up-hill slopes as well as the risk of congestion, inefficient engine braking and over speeding on down-hill slopes. Overtaking also takes longer, and thus incurs additional risks for the other road users.
- Overloads can induce tire overheat, with a higher risk of tire blow-outs.
- When flammable goods are transported, overloads increase both the *risk* and *severity* of a fire, due to accident or loss of control of a truck.

Statistics on the load and overload of trucks involved in road accidents are very scarce because of frequent loss of freight during an accident, and because weight data are not collected by the police. A few studies document the increased severity of crashes [8]. In addition, during weight controls, overloaded trucks are frequently in default for other violations, *e.g.* exceeding the driving time, faulty speed limitation device, etc.

1.2. Damage to the infrastructure

Overloaded trucks present a threat to road safety, but also to infrastructure, as they increase pavement wear, cracking and rutting, and thus can contribute to premature pavement failure Heavy trucks also contribute to bridge fatigue damage. When trucks are overloaded their aggressiveness may be significantly increased. Extreme bridge loading cases are also governed by very heavy trucks, either carrying abnormal loads (*e.g.* cranes) or illegal overloads. Some weak (old) bridges with reduced capacity may be severely damaged, or even destroyed, by overloaded trucks.

In January 1986, during a very cold period (−15 °C), a log truck skidded on an icy section of road entering the suspended bridge on the Loire river in France, hitting the parapet and cable anchorage on the bridge deck. The shock resulted in the collapse of the bridge

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0386-1112/$ – see front matter
doi:10.1016/j.iatssr.2010.06.003

Fig. 1. Truck rollover and knife-jacking.

following the failure of a cable anchorage with low-resilience steel at the top of a pylon (Fig. 2).

1.3. Economic impact

There are also economical consequences of overloaded trucks. Overloading leads to large distortions in freight transport competition, between transport modes (*e.g.* rail, waterborne and road), and between road transport companies and operators. In France, it was estimated that a 5-axle articulated truck, operated at 20% overload all year round, generated an additional 25 000 € benefit per year. Overloading also means violation of the taxation rules, such as vehicle registration fees, axle taxes, and toll infrastructure fees (Figs. 3 and 4).

It is therefore necessary to enforce vehicle weight and dimension regulations to minimize the number of overloaded and oversized trucks. The development of advanced truck load monitoring systems, either on-board or on the road, as part of intelligent transport systems (ITS), offers important potential and alternative solutions to traditional roadside enforcement by compliance officers.

2. Traditional enforcement practices: static weighing

Traditional weight limit enforcement procedures are static weighing. This was the only method approved by the legal metrology up until the mid 1990s.

Weighbridges, and wheel and axle scales, are used to measure gross vehicle weight and wheel or axle loads. If axle scales are used, the gross vehicle weight is obtained by summing the individual axle loads. If wheel scales are used, an axle load is obtained by summing the wheel loads of the same axle. There are three types of static weighing devices:

- The fixed systems, which are permanently mounted in the pavement, generally in concrete frames or platforms. This is the case for all weighbridges and some wheel and axle scales.
- Semi-portable systems, which use permanent grooves and road installations (electricity supply, connection to the weight recorder, etc.), but with portable scales which are installed only during the weighing operations.
- Portable systems, using either wheel or axle scales which are laid on the pavement surface (*e.g.* on a parking lot or any weighing area), and complemented with leveling plates or ramps, in order to get all the weighed wheels at the same level and in the same plane.

3. Limitations of static weighing

Static weighing suffers from a number of limitations. It requires staff and time to perform static weighing. Staff is needed to select and intercept trucks in the traffic flow, to perform the weighing operation on the static control area, and to fine the violators and apply other penalties as needed.

It is difficult to safely perform checks on heavily trafficked highways and motorways. With high traffic volume, and the increase on roads of heavy vehicles, static weighing becomes ineffective and acts as a limited deterrent. In Europe, it was estimated that the mean time between two checks of a given truck operated every day was almost 30 years! With such a low probability of being weighed – and the rather low level of penalties for weight limit violation – the benefit of overloading was becoming much too high.

Fig. 2. Bridge collapse in Sully-sur-Loire (January 1986) due to a truck accident.

Fig. 3. Portable static wheel scales and leveling wood plates.

Fig. 4. Low Speed WIM using load cell wheel scales in a concrete platform (Châlon s/ Saône, France).

Because of the long time required for static weighing, when several trucks are selected for checking, the weighing area becomes saturated and thus other overloaded trucks are able to by-pass the check point. Moreover, static weighing implies delays of 10 to 30 min (sometimes more), which penalizes truck operators, including the majority of them who comply with the regulations.

4. Development of weigh-in-motion (WIM)

4.1. Low speed WIM (LS-WIM)

For the reasons described above, and in order to increase the efficiency of the controls by partially automated weighing, the low speed WIM concept was developed and implemented. LS-WIM consists of using wheel or axle scales, mainly equipped with load cells – the most accurate technology – and installed in concrete or strong asphalt platforms of at least 30 to 40 m in length. The software of the data acquisition and processing system is designed to analyze the signal of the load cells, taking into account the speed, and to accurately calculate the wheel or axle loads. Such systems are installed either outside the traffic lanes, on weighing areas, or in toll gates or any other controlled area. The operating speed is generally in the range of 5 to 15 km/h.

The International Organization for Legal Metrology [7] published an international recommendation to perform model type approval tests, and to certify automatic weighing instruments for road vehicles, which applies to LS-WIM systems. LS-WIM has been legally implemented for enforcement in the UK since 1978, as well as in several North American States and Canadian and Australian provinces. In the late 1990s and early 2000s, several European countries (Germany, France, Belgium, etc.) and Japan authorized LS-WIM for enforcement. The accuracy of LS-WIM systems can be 3 to 5%.

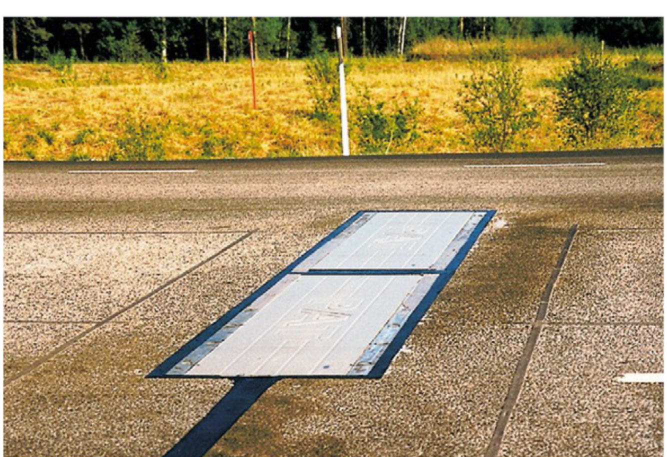

Fig. 5. HS-WIM bending plates installed in a road section.

4.2. High speed WIM (HS-WIM)

High speed WIM means that sensors, installed in one or more traffic lanes, measure axle and vehicle loads while these vehicles are traveling at normal speed in the traffic flow. HS-WIM allows the weighing of almost all trucks crossing a road section, and either individual measurements or statistics to be recorded.

The main advantages of HS-WIM are:

- it is a fully automated weighing system;
- it can record all vehicles — whatever their speed, number of axles, or time of the day;
- no additional infrastructure is required, and it can be installed on good pavements and road sections according to the European specifications of WIM [4];
- it is a reasonable cost system.

HS-WIM systems have some limitations however. The main issue is the accuracy, which depends highly on the road surface evenness and pavement characteristics – as well as truck suspension performances – because of the dynamic interaction between road and trucks. In addition, as road sensors are exposed to whole traffic loads and are mounted on the pavement surface, they may have a limited lifetime if the pavement failed. A difficult issue is the calibration and accuracy assessment of HS-WIM systems [1,3]. The accuracy of HS-WIM systems varies from B(10) to D(25), according to the COST323 European specifications ([4], *i.e.* 10 to 25% for approximately 95% of the gross weights. The full range of accuracy classes is A(5) to E(30).

HS-WIM technology can be used [4] for:

- Pavement and bridge engineering, *i.e.* to record traffic load patterns which are used for: (i) design code and conventional load models calibration, (ii) infrastructure monitoring and assessment, in fatigue or against extreme loads, and (iii) inspection and reinforcement strategies.
- Traffic data collection, statistics on freight transport, economical surveys, and sometime road pricing based on real traffic loads and volume, *e.g.* the "shadow toll"[1];
- Screening overloaded trucks prior to a checking area equipped with static weighing or LS-WIM devices; an accurate pre-selection in the traffic flow widely increases the efficiency of the controls and avoids stopping legally loaded, or empty, vehicles.

5. WIM technologies

WIM systems were introduced in the United States in the mid 1950s. Since then, many developments and progresses have taken place, while various sensors and techniques have been introduced and implemented.

5.1. Road sensors WIM systems

5.1.1. Bending and load cell plates

The first WIM sensors were instrumented plates (scales) fixed in a frame mounted on the road. They were developed and implemented in the mid 1950s until the late 1970s (Fig. 5). Depending on the plate

[1] Shadow toll: an operator is contracted to (build), finance, operate and maintain a road infrastructure, and is paid at a predefined rate, based on some traffic assumptions. If the traffic is higher or lower than expected, the contract payment is adjusted to reflect the real use of the infrastructure.

width, they can be wheel or axle scales. The advantage of these sensors is that they get the full tire imprint on the scale at once, because their extent is longer than the tire imprint length (*i.e.* at least 40 cm). Thus they are able to measure directly the wheel/axle load. Moreover, they may be calibrated with standard masses on site, and thus comply with the traditional metrological requirements for legal approval [7]. To date, these are the only sensors approved for enforcement at low speed. At high speed, the accuracy may be B(10) to C(15) on a smooth pavement.

These plates present major disadvantages, however, such as requiring extensive civil engineering work for their installation. This causes some damage to the pavements (large holes or grooves), and they may be dangerous on heavily trafficked highways if the plate comes loose. These sensors are forbidden on motorways and main highways in some areas.

For operational and economical reasons, the current trend is to abandon progressively the use of plates, and to adopt instead the use of strip sensors.

5.1.2. Strip sensors

WIM strip sensors were introduced in the early 80s. A strip sensor consists of a narrow bar, a strip or wire with a section of a few mm^2 or cm^2, and a length equal to a traffic lane width (or half of it), mounted in a groove transversally to the lane (Fig. 6). These sensors measure the pressure, strain or force variation when a wheel or axle passes over it. A signal processing algorithm calculates the loads with respect to the vehicle speed and estimated tire characteristics. There are piezo-ceramic, piezo-quarz and piezo-polymer strip sensors, and some fiber optics strips. In the 80s and early 90s, capacitive strips were also used.

The main advantage of these sensors is that they are cheaper than the plates — particularly when taking into account the installation cost. They also require less civil engineering work and thus cause less traffic disturbance and pavement damage. However these sensors do not measure directly the wheel or axle loads, as the tire imprint exceeds the size of the sensor surface, and they require an integration process. Moreover, their behavior and response depends on the pavement characteristics (above all its modulus). Therefore they are more sensitive to their environment and conditions of use, and they cannot be calibrated under a metrological procedure (standard masses). The accuracy varies from B(10) to D(25).

5.2. New WIM technologies

5.2.1. Multiple sensor (MS-)WIM

If HS-WIM is used for vehicle mass or static axle load estimation, errors result from the difference between the static wheel or axle loads and the impact forces applied to the pavement – and thus to the road sensors – while the vehicle is in motion.

This dynamic effect was studied in detail in the OECD/DIVINE project [6], and it was shown that, on a good (even or smooth) pavement, the ratio between the dynamic load and the static load may reach 1.1 to 1.15 for axle load and gross weight respectively, and up to 1.2 and 1.25 or more on average or rough pavements. Therefore, even the best WIM sensor cannot accurately measure wheel or axle load – and thus gross vehicle weight – with accuracy better than this difference.

For overload detection and enforcement such a tolerance would be much too high. To cope with this issue, in the late 80s the UK's Transport Research Laboratory (TRL) suggested the concept of multiple sensor WIM (MS-WIM), which consists of installing several road sensors at uniform or non-uniform spacing along a road section of 10 to 50 m approximately (*i.e.* a MS-WIM array, Fig. 7). For a given axle, each sensor will measure the axle load (or force), which varies with time and distance. The axle is bouncing along the road slightly — although lift-off only rarely occurs on very rough roads. The sensor array allows for the multiple measurement of the wheel load.

However, the sensors cannot be installed randomly along the pavement. Their spacing (if uniformly distributed) needs to take into account the mean vehicle speed and eigen frequencies to avoid a sampling frequency (in space) close to the signal frequency. Extensive works were carried out to calculate optimal sensor spacing (and numbers) with respect to the vehicle, traffic and road characteristics and to develop more powerful algorithms for static weight estimation [2].

There are some design and implementation issues with MS-WIM systems. The individual sensor accuracy for axle force measurement and calibration is best established using true axle dynamic loads rather than static loads — as is usually the case with the traditional WIM systems. In addition, the sensor response needs to be stable and independent of the environment, etc. A compromise needs to be struck between the costs of the MS-WIM array — largely related to the number of sensors and the accuracy of the system. The accuracy of a MS-WIM system depends on the quality and number of sensors, the pavement profile, the algorithm and data processing, and other parameters. It varies from B+(7) to B(10), and the objective is to reach the class A(5) for enforcement purpose.

A few MS-WIM arrays were installed, mainly for research and development works, in the UK, the USA, France and the Netherlands. Some users are considering using them for accurate pre-selection, and perhaps in the future for automatic enforcement. However, the issue of getting a legal metrological type approval for enforcement is not yet solved for such a system.

Fig. 6. HS-WIM with piezo-ceramic strip sensors (RN4, eastern of France).

Fig. 7. MS-WIM (multiple sensor) array on the A31 motorway (East of France).

Fig. 8. B-WIM: culway in Australia (left), instrumentation (center) and measurement (right) on an integral bridge in Nogent-sur-Seine, France.

5.2.2. Bridge (B-)WIM

The concept of bridge (B-)WIM was introduced [5]. It uses instrumented bridge parts (*e.g.* deck, slab or beam) to measure the strains induced by the moving vehicle loads crossing the bridge. It then calculates the axle and vehicle loads, using the calculated or measured transfer function (load to strain) called an influence line (1-D) or influence surface (2-D). In a B-WIM system, the bridge is used as a large scale calibrated to weigh axles and vehicles (Fig. 8).

In the early stage (1979–1996), the B-WIM systems required additional axle detectors mounted in the road pavement or on the road surface to count the axles, and measure axle spacing and vehicle speed. The Australian Road Research Board (ARRB) developed the Culway system, which used box culverts (very short span bridges — less than 5 m) with excellent damping as a result of having pavement material over them. Conventional bridges tend to vibrate — creating an additional strain response that needs to be filtered out to establish the strain induced by the truck on the bridge. In the WAVE project [2], it was shown that strain sensors may be sensitive enough to work without axle detectors, which led to the concept of Free of Axle Detector (FAD) B-WIM. It improved greatly the interest in this technology, which avoids any road closure for installation and maintenance, thus reducing traffic disturbance and increasing safety. The system is also fully undetectable by drivers; an advantage for enforcement.

The accuracy of the B-WIM system was initially rather poor for gross weights, and more so for axles, if detected, and only working on concrete girder bridges. The accuracy of Culway systems was better and axles were well detected and rather well weighed. In the WAVE project, the types of suitable bridges significantly increased with short span slab integral bridges; short and medium span simply supported slab and beam bridges, orthotropic steel deck bridges and a few others. However, the bridge instrumentation needs to be done properly and requires well trained staff, as well as the calibration of the system. A Slovenian company developed a marketed B-WIM system (SiWIM).

Another advantage of the B-WIM (SiWIM) is the portability. Transducers are simply attached, and may be quickly removed and reinstalled on another bridge. This is also the case with the electronics. For example, the Swedish Road Administration manages more than 30 bridges with less than 10 systems for non-permanent overload survey. The technology is valuable in harsh climates, where de-icing machines may damage any road sensor; or on busy highways and motorways, where lane closures are difficult and dangerous.

For overload pre-selection and enforcement it is a discrete system; not visible, and difficult for truck drivers to avoid. However it requires the presence of a suitable bridge and the technology still requires a high level of expertise for the installation and operation.

5.2.3. Video-WIM and automatic vehicle identification (AVI)

The concept of video-WIM was developed in North America and the Netherlands. It involves coupling a WIM system to a video camera with OCR — automatic license plate number recognition (Fig. 9). The video-WIM system is installed a few kilometers upstream to a weighing area. If a vehicle passes with an overloaded axle, an overload on the gross weight, or is even over speeding, pictures of the whole vehicle – including number plate – are sent to the compliance officers at the weighing area. The vehicle is then stopped on the weighing area (*e.g.* if located after a toll barrier) or is directed to the weighing area.

A new preventive concept was introduced in the Netherlands in the early 2000s, which consists of recording the pictures of all suspicious vehicles and storing them in a database managed by the Ministry of Transport. Even when there is no policing at the weighing area, the suspected violators are recorded; the Ministry of Transport then sends warnings to the companies which are most frequently cited.

6. Data management issues

The use of high speed WIM systems for pre-selection require telecommunication tools to transmit the data (loads, vehicle characteristics such as speed, lane used, type of truck, license plate, etc.) and the pictures, either to the compliance officers or to a database, for later analysis and use. This requires a high level of security to protect personal data and road users' privacy, as well as prevent mistakes which could lead to court challenges. In several countries, careful legal procedures are being prepared to implement such a system. Only authorized officers will be able to access the data, which generally cannot be stored for too long. However, some anonymous data (vehicle loads and characteristics without license plate number, statistics) are often sent to traffic management centres for operational purposes; and to the policing organization to help plan enforcement programmes.

Moreover, if there is a static or low speed WIM system adjacent to a high speed WIM system, it is recommended to use these more accurate systems to continuously calibrate or check the calibration of the high speed WIM system in a "closed loop" process.

7. Application of WIM: best practices and implementation

There are various practices around the world in using WIM for enforcement. In very few countries, such as Taiwan, high speed WIM systems are used for direct enforcement, with large tolerances to account for inaccuracies in the system. Tolerances of up to 30% were reported, but this may be acceptable if there are very large and frequent overloads (*e.g.* 20 to 50% of the trucks overloaded, with a significant amount by more than 50%).

In some countries, portable high speed WIM systems are used over short time periods to detect overloads, and then to perform static controls with portable scales. However, the accuracy of portable WIM systems is not very good, and thus the efficiency or pre-selection is low.

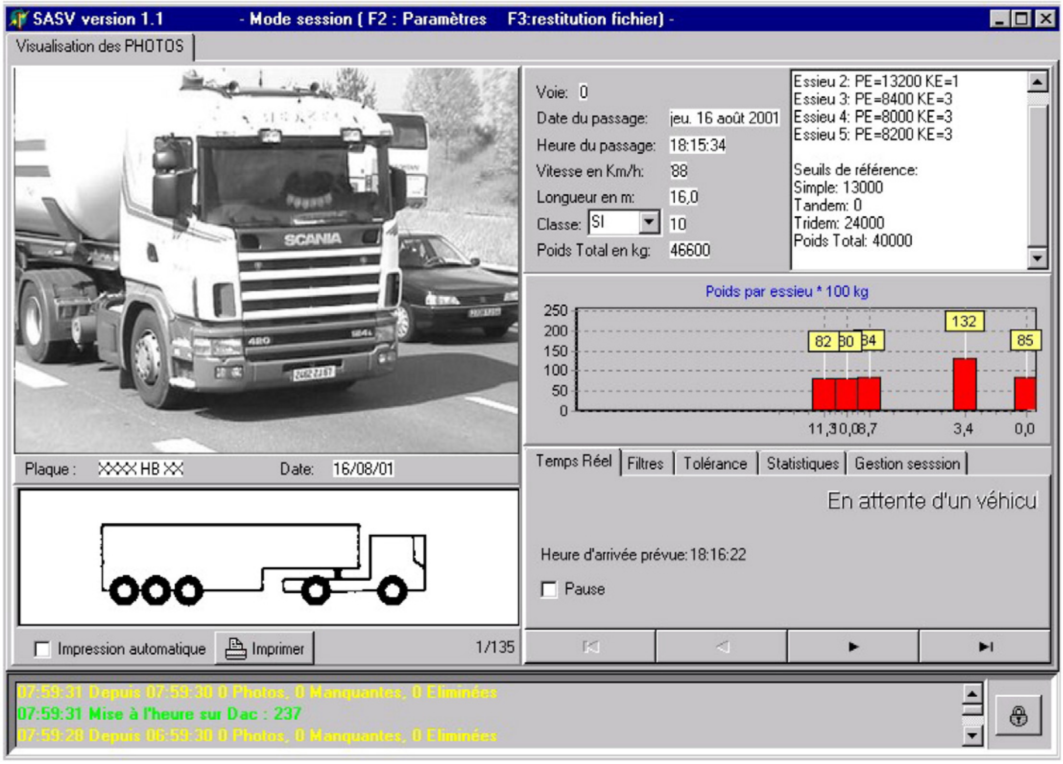

Fig. 9. Video-WIM: coupling a HS-WIM and a video camera on a French motorway.

In North America and other countries around the world, high quality high speed WIM systems are installed in pavements upstream of large weighing stations (Fig. 10). These weighing stations – along motorways and highways — are equipped with low speed or static weighing systems as well as parking lots for enforcement. Many of these high speed WIM systems weigh very accurately, due to the effort put into ensuring the weigh pads are absolutely planar with the road surface to minimize vehicle dynamics — or bounce. The WIM system is generally used to identify potentially overloaded trucks and divert them to the weighing area. Depending on the traffic density and the local organization, the suspicious vehicles are chosen one by one; some sequences of vehicles are picked when one of them is detected by the WIM system. If the weigh station is not permanently manned, the WIM system only records statistics outside the enforcement sessions.

In the Netherlands, France, Sweden, Japan, and some other countries, the video-WIM was implemented for pre-selection, and for continuously monitoring overloads and sending warnings to the transport companies. This procedure has been very efficient in reducing overloading. Since 2007 a reduction of up to 50% of the overloads has been observed in some countries; however the economic crisis and its impact of road freight transport volume has certainly also contributed to this reduction.

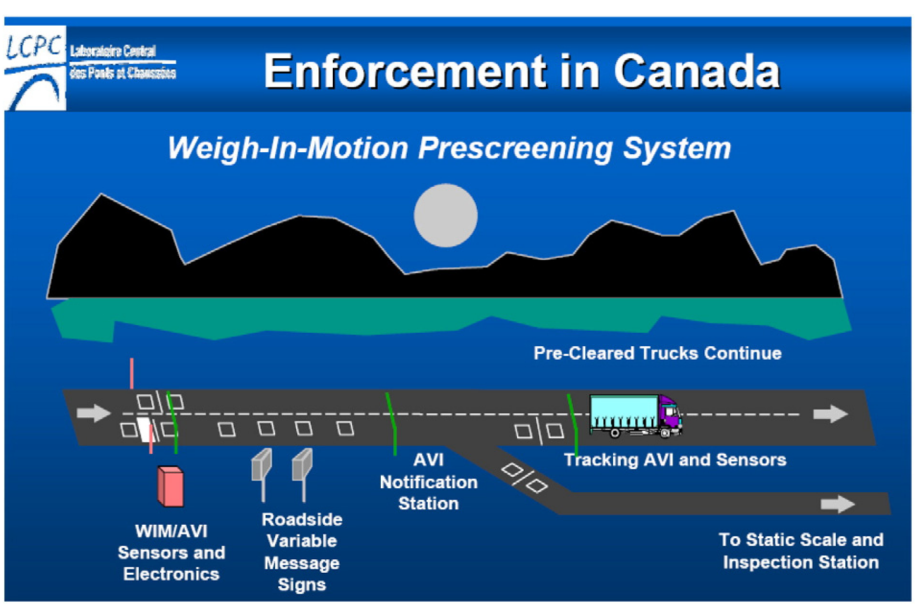

Fig. 10. Overload screening using a HS-WIM and a video camera in Canada.

7.1. Coupling of high-speed and low-speed WIM for pre-selection and enforcement

Coupling high speed WIM for pre-selection and low speed WIM for enforcement is already implemented in several countries. The process could be automated to become more efficient and to require less staff. That is also the challenge in countries where bribery is an issue. The automatic self calibration of the HS-WIM system using the low speed data could also be improved and more automated.

8. Future perspectives

New applications of WIM systems are expected, both for traffic and heavy vehicle regulation enforcement, and as part of new ITS solutions. The main objectives of the newly-founded International Society for WIM (ISWIM: http://iswim.free.fr) are to support these goals.

8.1. Automatic enforcement in the traffic flow

A great challenge is to use HS-WIM systems for automated (direct) enforcement in the traffic flow, as is the case for speed enforcement. In most countries, the requirements are to get WIM systems in accuracy class A(5) for more than 95% of the vehicles, and even closer to 99%. However, it is impossible to guarantee 100% of the measurements in any given tolerance for a large population of trucks traveling at speed because of the dynamic interaction with the pavement. Therefore the OIML recommendation does not apply, and legal metrology approval will be difficult to obtain. However, with the progresses of MS-WIM and B-WIM, automated enforcement may become a reality. Besides the technological issues, legal issues will also need to be solved.

8.2. Dynamic load regulation and on board WIM

Weighing trucks in static and in motion, using on board equipment, was done in the 1980s and '90s with instrumented vehicles. Continuous measurements of wheel and axle impact forces were carried out for research purposes in a few countries, such as Canada, Finland, and the UK [6], for pavement and vehicle engineering applications. Most of these systems used accelerometers and strain gauges mounted on the vehicle body (suspended masses) and/or on the axles or wheels (unsuspended masses). The impact forces were calculated using calibrated vehicle dynamic models. However, this required rather long calculations, which were often done *a posteriori*. The instrumentation was costly, and the dynamic calibration of the systems required sophisticated testing platforms, trained staff, and a long time.

In the OECD/DIVINE project, on-board axle load measurements and road WIM sensor data collection were synchronized. This opened a new approach to WIM system calibration, using true dynamic forces applied on the road sensor. A calibration vehicle was then developed in the Netherlands for this purpose. Recently, the Australian Road Research Board (ARRB) tested a system using a laser mounted to the wheel hub to measure tire deflections and hence wheel loads. This low cost portable tool is designed to improve the knowledge of the coupling between dynamic loads and suspension characteristics. The results are very promising. The availability of accurate lasers, very high speed data acquisition and processing technology was the key to this success.

On-board static weighing systems have been used in the trucking industry for many years. They were developed by truck or tire manufacturers, and by metrological companies. A number of technologies and patents are reported which correspond to a market for hauliers and fleet managers (*e.g.* garbage trucks in cities and logging trucks). The main objective is to optimize truck fleet management and routing with respect to their capacity and load limits.

Recently, road operators and enforcement bodies have expressed the need for on-board weighing systems, which could be installed on all trucks in the future to monitor and enforce load limits, as done with the chronotachygraphe (a device which measures and records the driving time all along the journey). Coupled with a GPS, an on-board weighing system could meet the needs of hauliers, fleet managers, road managers and enforcement bodies. The current marketed systems weigh the vehicle when it is stationary — such as at traffic lights, in queues, in gas stations, or parking lots during rest periods. They weigh only the mass above the sensors, and their accuracy is pretty much dependent on the operator and their calibration.

Significant investments are being made in Australia to have on-board mass measurement equipment which is tamper proof and of an evidentiary standard. A recent review found a viable and experienced on-board mass monitoring industry in Australia, where the current systems were built as an aid to the driver. The systems use both load cells and air pressure transducers. In recent times, telematics service providers have entered the industry, bringing the on-board mass product to a wider industry base. The review concluded that there were many areas that needed to be addressed in order to ensure accuracy and to prevent tampering with the mass parameters.

On board WIM systems seem to be a promising alternative, both to cover the same needs and to address new challenges. On-board WIM systems may be part of an advanced driving assistance (ADAS) to prevent large dynamic amplifications on rough or deteriorated pavements by a variable speed adaptation (to the road profile and the vehicle dynamic characteristics). This would improve road safety and vehicle comfort, as well as reduce road wear because of the dynamic load factors.

In a longer term future, if the trucks can be equipped with reliable on-board WIM systems the driving law could be modified to not only limit the (static) masses of the vehicles, but also their impact on the roads (*i.e.* the dynamic impact forces). In a first stage, that could be done on a voluntary basis with incentives such as tax reduction, or an increase in the static load limits. A main advantage would be to monitor and record continuously the loads, and to allow after the event checks and fines if needed. Real time overload monitoring could also be possible using a data transmission system and a GPS; necessary to stop the highest overloaded trucks.

9. Conclusions

WIM is a useful tool to contribute towards more compliance with mass regulation. It has been used most successfully for nearly two decades. WIM has helped to reduce the number of overloaded trucks, and contributed to the more efficient and effective use of police officers' time. A reduction in overloaded trucks is also conducive to a reduction in crashes. There are still issues and challenges for WIM technology and application which require more research and development work. It is also essential to better disseminate knowledge and best practices, to exchange experiences, and carry out large scale common tests of WIM sensors and systems.

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