COMPARISON OF WIM, NOISE, VIBRATION DATA FROM HEAVY VEHICLES

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Abstract
A European cooperative project aims to develop an innovative and cost effective method to identify road and rail vehicles by means of their environmental "footprint" as characterized by dynamic load, noise, ground borne vibration and gaseous emissions induced by the vehicle. This characterization can produce a method for a 'true' bottom up allocation of effects of vehicles on infrastructure and environment. An important part of this project is the installation of road and rail Footprint Monitoring Sites (FMS) throughout Europe. This paper presents the results from the Swiss FMS where the environmental Footprints of heavy vehicles are systematically collected and compared.

Keywords: Environmental footprint, Heavy vehicles, Weigh-in-Motion, WIM, Noise, vibration.

Résumé
Un projet de coopération européen se propose de développer une méthode innovante et économique d'identification des véhicules routiers et ferroviaires par leur « impact environnemental », caractérisé par la charge dynamique, le bruit, les vibrations engendrées dans le sol et les émissions gazeuses. Ceci passe par le développement d'une méthode de détection ascendante des effets des véhicules sur l'infrastructure et sur l'environnement. Une partie importante de ce projet est consacrée à l'installation de sites de surveillance « Footprint » (FMS) sur des routes et des voies ferroviaires en Europe. Cet article présente les résultats du site FMS suisse sur lequel les impacts environnementaux des poids lourds sont systématiquement enregistrés et comparés entre eux.

1. Introduction

The European cooperative project Eureka Logchain Footprint E!2486 hereafter referred to as Footprint is an ongoing project that begun in 2001 and has been extended until 2009. The Footprint project has developed an innovative and cost effective method to identify road and rail vehicles by means of their environmental "footprint" as characterized by dynamic load, noise, ground borne vibrations and gaseous emissions induced by the vehicle. This characterization can produce a method for a 'true' bottom up allocation of effects of vehicles on infrastructure and environment. An important part of this project is the installation of road and rail Footprint Monitoring Stations (FMS) throughout Europe. The Footprint project proposes methods to measure the dynamic impact of heavy vehicles on the environment. To this end, the input from the monitoring sites in Europe has been used to propose methods to identify the environmental impact of vehicles (Mayer et al, 2007).

2. Footprint Monitoring Station (FMS)

The first road FMS in Europe was built in June 2005 on the A1 motorway in Switzerland on a flexible asphalt pavement. Dynamic load using weigh in motion sensors, noise and vibration of individual vehicles have been monitored and compared. This paper presents the results of monitoring from this FMS. This site is also used for long term pavement performance monitoring and as shows in Figure 1 in addition to the footprint parameters of WIM, vibration and noise, deformation, temperature, humidity and contact stresses using stress in motion sensors are measured. Gaseous emissions are not measured in situ, however various modeling techniques for the integration of gaseous emissions as a Footprint parameter are being explored within the project.

![Figure 1 – Schema of the Footprint Monitoring Site in Switzerland.](image)

2.1 WIM Monitoring

Dynamic loads are monitored using piezo quartz weigh in motion (WIM) sensors. At the FMS both lanes are covered with each containing two rows of three sensors (Figure 1). In addition,
the same set up is used for the traffic in the opposite direction (Bern to Zürich). A wheel rolling over the WIM sensor applies vertical forces to the quartz crystals in the sensor, with virtually no deformation. The piezoelectric quartz discs yield an electrical charge proportional to the forces applied. The piezoelectric sensitivity is virtually independent of temperature, time and speed. The electric charge signals are converted by a charge amplifier into exactly proportional voltages that can be further processed as required. The accuracy of the measured wheel load is not influenced by tire type, tire quantity or tire pressure. In the case of dual tires, the sensor measures one signal and expresses it as one wheel load, which is equal to the sum of both wheel loads (www.kistler.com).

The WIM sensors at this site record on the average 3700 heavy goods vehicles (HGV) per day and deliver axle load, gross vehicle weight (GVW), speed, axle distance and vehicle length with very good accuracy at this particular site. The sensors are calibrated once a year normally in the fall as reported by Mastrangelo (2005, 2006). The accuracy class as defined by COST 323 (1999) for the FMS location in 2005 was B(10) and in 2006 A(5).

To gain more insight into the range of axle loads and gross vehicle weights passing through this site a sample of the data for the month of September 2005 was examined in detail. The results are shown in Figure 2 and Figure 3 respectively.

The results of the WIM monitoring show that the vast majority of the vehicles recorded on the A1 are considered to have pavement friendly axles in accordance to existing criteria in Switzerland i.e. < 10 t. The number of axles exceeding the 10 t limit is less than 6% of the total number of axles recorded by the WIM during the period under investigation.
In Switzerland the maximum allowable Gross Vehicle Weight (GVW) is 40t. Figure 2 presents the maximum GVW per day of all trucks passed at the FMS each day. It can be seen that every day the limit of 40 t has been surpassed. This is possible as overweight vehicles are allowed under special circumstances with permits. The heaviest vehicles recorded in September 2005 passed by on the 8th, 13th, and 19th with GVW of 90.06 t, 91.16 t and 90.55 t respectively. Keeping in mind the goals of the project, a closer look at the large vehicles revealed that for example the vehicle on the 8th was a 9 axle, class 8 truck with maximum axle load of 13.42 t. The vehicle on the 19th was a 6 axle, class 10 and axle load of 16.33 t. Figure 3 shows the maximum axle loads per day for the same period. Maximum axle loads range from 12.48 t to a maximum for the month of 20.14 t. This latter maximum for the month was for a class 7 truck with four axles and a GVW of 45.45 t which is considerably lower than the maximums seen for GVW.

2.2 Noise Monitoring

The acoustical footprint of a vehicle passing by is determined by evaluating the maximum sound pressure level received at a microphone in a distance of 7.5 m from the center of the traffic lane in accordance to the ISO standard (ISO 11819-1: 1997). A measurement is considered valid (without distortion by neighboring vehicles) if the level time history falls more than 6 dB before and after the maximum. If this criterion is not fulfilled the interference stemming from neighboring vehicles is estimated and compensated for based on the level time history. A maximum correction of 6 dB(A) is allowed and if a higher correction is deemed necessary from the calculations, the measurement is categorized as invalid. Current data from the FMS indicates that this procedure led to an increase of the percentage of pass-by events that could be evaluated successfully in the order of 95%. This result is for roads with dense traffic and an improvement can be expected for traffic that is less dense.
A sample of the results is shown in Figure 4. The figure shows an overview of the noisiest vehicles per day during the period under investigation. The highest emissions per vehicle per day range from \(90.8\) dB(A) to \(97.4\) dB(A). The latter from a four axle truck with GVW of \(36\) t and highest axle load of \(11\) t. The values shown in the figure are the actual measured values and have not been normalized for reference speed (80 km/h). It is difficult to identify the noisiest vehicles in absolute terms as the site and weather conditions play a role in the noise emissions. In addition, noise is more of a nuisance at night than during the day, all factors that should be considered when criteria for environmental friendliness are set.

![Figure 4 - Maximum Noise Emission Per Day for a Single Vehicle, GVW=Gross Vehicle Weight, AL=Axle Load.](image)

**Figure 4** – Maximum Noise Emission Per Day for a Single Vehicle, GVW=Gross Vehicle Weight, AL=Axle Load.

### 2.3 Ground Born Vibrations Monitoring

Another Footprint parameter considered is ground borne vibrations produced by individual vehicles, as they may affect persons and buildings standing near the traffic corridors.

Traffic vibrations are caused by dynamic tire forces on the pavement surface. The amount of energy transmitted into the structure is strongly dependent on the induced impact forces. These are a function of the characteristics of the vehicle (gross vehicle weight, axle load, speed, type of suspension, etc.) and also depend on the roughness of the road surface as well as the presence of potholes, pavement joints, etc. This energy propagates and dissipates in the structure, sub structure and sub-grade. The characteristics of the propagation are strongly influenced by factors such as type of soil and its compaction, humidity condition, temperature, where and how the sensor is installed, topography, etc. Therefore, vibration is highly dependent on the measurement location and conditions.

The objective of performing vibration measurements is to evaluate vibration levels produced by road traffic and to determinate what types of vehicles (identified using the information
registered by the Weigh in Motion (WIM) sensor are the most disturbing ones. The vibration measuring system consists basically of an electromagnetic velocity sensor positioned outside the road (Figure 1). To avoid potential problems due to human discomfort or building damage, there are various guidelines that establish maximum values to be measured at the receiver location. These reference levels of “acceptable vibration” are usually established in terms of Particle Peak Velocity (PPV) or acceleration and sometimes the frequency content of the signal is also considered. In addition, either the type of activity of the disturbed person or the type of building that is affected is taken into account. For example, researchers of the UK Transport Research Laboratory (TRL) developed guidelines to assess traffic induced vibration based on a substantial number of tests. The proposed values published by Whiffen A. C. (1971) indicate that the threshold of human perception is 0.15 mm/s PPV. Maximum PPV measured at the FMS is compared with this threshold.

Ground borne vibration levels obtained during the measuring campaign at the FMS are not absolute as they depend on variables such as the road roughness, soil type, environmental conditions, etc. It is possible to make comparisons between vibrations produced by vehicles at this site as long as measurements are taken under the same conditions. Nevertheless, a simple comparison to reference values show that the measured vibration is low compared to the human perception threshold (Figure 5).

![Graph showing vibration levels](image)

**Figure 5** – Maximum Vibration Per Day for a Single Vehicle Presented as Peak Particle Velocity (PPV), GVW=Gross Vehicle Weight.

### 2.4 Data Acquisition

The sensor outputs for measuring parameters like axle and wheel load, pavement deformation, vibration, noise, temperature and humidity need to be recorded and synchronized. The data acquisition system has been a challenge as analogue and digital signals with quite different dynamics and sample rates had to be processed. They range from quasi static signals like temperature and humidity to the highly dynamic signals of wheel load distribution, which
requires a sample rate of 8192 Hz to obtain reliable data at speeds up to 100 km/h. To gain readout speed, load measurement data were stored in binary form and analyzed offline.

3. Comparison of Various Parameters

According to the project guidelines it is important to measure the effect of single vehicles regardless of frequency of occurrence. I.e. the 90 t vehicle should pay a higher road access charge even if it comes once through Switzerland.

In identifying which vehicles contribute most to pavement damage it is important to take into account maximum axle loads as shown earlier. Therefore the axle load data is matched with the Stress in Motion (SIM) data and is fed into the finite element pavement model in order to determine the effect on the pavement. A sample of the SIM results analyzed using the vehicle infrastructure interaction model is presented elsewhere (Morgan et al 2007). It was shown that for all but the heaviest tires, the shape of the contact stress distribution had a significant effect on the stresses and strains in the pavement.

An overview of the ground borne vibration measurements so far at this monitoring site, including the September 2005 monitoring, indicate that all measurements are below values for human perception. It is therefore concluded that with current soil and traffic conditions, ground borne vibrations are not an environmental nuisance at this site. Monitoring will be continued and the development of ground borne vibrations at this site will be reported.

An overview of the noise emissions of single vehicles per day during this period shows that the noisiest vehicles are not necessarily the heaviest ones. It is important to note that it is difficult to identify the noisiest vehicles in absolute terms as the site and weather conditions play a role in the noise emissions. In addition, noise is more of a nuisance at night than during the day; factors that should be considered in any charging scheme.

4. Summary and Conclusions

It is clear from analysis of the data that the heavy vehicles are not necessarily the ones with the highest axle loads causing the most damage to the pavement nor are they the noisiest or the ones causing the most vibrations. It is imperative that each vehicle is assessed separately for the various parameters that it causes and compared to an established criteria. Environmental friendliness criteria are under discussion within the project and have to be established. In addition a method of normalizing the footprint parameters with respect to the sites should be established so that the various sites could be compared with one another.

A ‘true’ bottom up allocation of effects of vehicles on infrastructure and environment is only possible through a consistent charging scheme between the various modes of transport and between the various countries in Europe. In order to disaggregate costs so that they can be attributed, countries will need to collect detailed records of maintenance and renewal expenditure, and costs due to accidents, congestion and pollution. Further research is required on the impact transport has on the wear and tear of infrastructure and on society and the environment. To this end the current operating Footprint Monitoring Sites on the road and rail provide vital data.
5. Acknowledgements

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6. References

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