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Footprint II- Long Term Pavement Performance and Environmental Monitoring on A1

Footprint II- Langzeit Belag Performance und Umwelt Monitoring an der A1

Footprint II- Long terme performance des chaussées et à la surveillance de l'environnement A1

Empa, Swiss Federal Laboratories for Materials Science and Technology, Dübendorf

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Bezug: Schweizerischer Verband der Strassen- und Verkehrsfachleute (VSS)

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Zusammenfassung

In der 2. Phase des Projekts „Footprint“ wurde das Monitoring des Umweltfussabdruckes der Fahrzeuge, welcher durch die dynamische Last (WIM), Lärm, Vibrationen und Abgase definiert ist, auf der A1 gemäss Kriterien des europäischen Projekts „Eureka Logchain Footprint“ weitergeführt.

WIM Messungen haben gezeigt, dass an Werktagen ca. 6000 Lastwagen, von denen 10% überladen sein könnten, über die Footprint Messstelle fahren. Um die überladenen Fahrzeuge identifizieren zu können, sind detaillierte Fahrzeugdaten notwendig. Zu diesem Zweck wurden von ausgewählten, vorbeifahrenden Lastwagen statische und dynamische Messungen vorgenommen und die Resultate mit den schweizerischen Richtlinien verglichen. Die Daten zeigen, dass die Bestimmung des Umweltfussabdruckes eines Lastwagens nicht einfach ist. Fahrzeuge, die gemäss den Kriterien der Leistungsabhängigen Schwerverkehrsabgabe (LSVA) nach dem Motorentyp, als umweltfreundlich gelten und dadurch weniger Gebühren bezahlen, sind nicht zwingend umweltfreundlich, wenn man die Footprint Kriterien berücksichtigen würde. Die Footprint Auswertung hat gezeigt, dass die Parameter - Abgase, Achslast oder Gesamtgewicht -, die zur Zeit bei der LSVA berücksichtigt werden und deren Reduktion gefördert wird, mehrheitlich in der Nähe oder unterhalb des Grenzwertes liegen. Jedoch liegen andere wichtige Parameter wie Lärm oder Pneudruck oberhalb des akzeptablen Grenzwertes.

Die Lärmbelastung einzelne Fahrzeuge wird im Moment von der LSVA zur Kostenrechnungen nicht berücksichtigt. Lärmmessungen an der Footprint Messstelle haben gezeigt, dass einige Fahrzeuge, welche gemäss LSVA als umweltfreundlich eingestuft werden, einen sehr hohen Lärm verursachen. Eine Reduktion oder Zunahme der Geschwindigkeit hat einen direkten Einfluss auf den Lärmpegel. Bereits bei 1 km/h macht dies ca. 0.15 dB aus. Weiter ist der ermittelte Lärmwert stark von ortspezifischen Faktoren wie Belagstyp und dessen Zustand sowie meteorologischen Daten wie Strassenoberflächentemperatur und Feuchtigkeit abhängig. Es ist deshalb nicht möglich, einen absoluten Grenzwert für die Bezeichnung „umweltfreundliches Fahrzeug“ zu definieren. Zusätzlich sollte man die Tageszeit mitberücksichtigen, da der Verkehrslärm nachts besonders stört. Die grosse gemessene Differenz von 10 dB zwischen dem lautesten und dem leisesten Fahrzeug zeigt ein grosses Potential für Verbesserungen betreffend Lärmreduktion auf. Ein Unterschied von 10 dB ist gleichbedeutend mit einer Verdoppelung bzw. Halbierung der Lautstärke.

Abgase und Partikelausstoss der Fahrzeuge sind von mehreren Faktoren wie Klima, Fahrweise, Belag und Neigung, Fahrzeugtyp, Zustand des Motors und Treibstoff abhängig. Deshalb ist es nicht möglich, die bekannten, typenspezifischen Abgaswerte und den Partikelausstoss der Fahrzeuge in einer bestimmten Fahrsituation mittels der Euro-Emissionsgrenzwerte (EURO 0 bis EORO V) zu beurteilen. Eine Abgasmessung eines an einer Footprint Messstation vorbeifahrenden Fahrzeuges zeigt nicht zwingend die repräsentative Abgasbelastung des Fahrzeuges an. Idealerweise müssen durchschnittliche Emissionswerte (g/km) für verschiedene Kategorien des Schwerverkehrs gefunden werden.

Ein Vergleich zwischen dem Schwerverkehr in der Schweiz und in Grossbritannien hat gezeigt, dass, obwohl dieer Mittelwerte der Achslasten und deras Gesamtgewichte unter der gesetzlichen Limiten liegen, es eine signifikante Anzahl von Fahrzeugen gibt, welche überladen sein könnten. An Werktagen kann dieser Anteil in beiden Ländern über 10% liegen. Für die gleiche Fahrzeugkategorie ergeben sichgelten in Grossbritannien höhere Durchschnittswerte für das Gesamtgewicht als in der Schweiz. Eine Abstimmung der abgestimmte Fahrzeugklassifizierung und der gesetzlichen Anforderungen an das GesamtgGewicht und die Achslasten wären notwendig, um den Fussabdruck der Fahrzeuge miteinander vergleichen zu können. Die Footprint Messstellen in Grossbritannien haben höhere Lärmpegel gemessen, wobei dies teilweise am Unterschied zwischen den verschiedenen Strassenbelägen liegt.

Mittels Footprint Messungen können Histogramme die Verteilung der gemessenen Footprint Parameter aufzeigen. Jeder Parameter sollte vor Ort gemessen und mit den Umweltkriterien verglichen werden. Dies ergibt ein „Rating“ für diese Parameter. Sobald ein Fahrzeug ein individuelles Rating für jeden dieser Parameter erhalten hat, ist die Festlegung für ein Gesamtlabel für das Fahrzeug möglich.

Die Benutzung von solchen Daten können als Anreiz zur Förderung von Fahrzeugtypen mit „geringem“ Umwelfussabdruck benützt werden. Dies entspräche auch dem von der EU beschriebenen Verursacherprinzip, welches im EU Transport White Paper, „Polluter Pays Priciple“ nachzulesen ist.

Résumé

Dans sa phase II, le projet Footprint, a poursuivi le monitorage sur l'autoroute A1 de l'empreinte environnementale des véhicules lourds, définie par la charge dynamique (par mesure Weight In Motion, WIM), le bruit, les vibrations et les émissions de polluants de ces véhicules selon les critères fixés dans le projet européen Eureka Logchain Footprint.

Les mesures WIM ont montré que, les jours de semaine, environ 6000 véhicules lourds passaient sur le site de monitorage, dont environ 10% semblaient être en surchargés. L'identification précise des véhicules surchargés demande toutefois des données détaillées sur les véhicules. Pour ce faire, on a procédé à des mesures statiques et dynamiques sur des véhicules lourds prélevés dans le trafic et leurs résultats ont été comparés avec les critères découlant de la politique suisse en matière de trafic routier. Ces données montrent que la détermination de l'empreinte environnementale des véhicules lourds n'est pas simple. Les véhicules qui, selon les critères de la redevance sur le trafic des poids lourds liée aux prestations RPLP (La redevance sur le trafic des poids lourds liée aux prestations), sont soumis à une taxe moins élevée du fait du type de leur moteur ne sont pas forcément plus favorables à l'environnement si l'on considère leur empreinte environnementale globale. Le monitorage a montré que les valeurs usuellement contrôlées, et dont la réduction est encouragée, tels que les émissions des gaz d'échappement, la charge par essieu et le poids total, sont en majeure partie inférieures ou proche des valeurs limites acceptables. Toutefois les valeurs d'autres paramètres importants, tels que la pression des pneumatiques et le bruit demeurent supérieures aux valeurs limites acceptables

Actuellement la RPLP ne considère pas les émissions de bruit de chaque véhicule comme un critère pour la fixation de la redevance. Les mesures acoustiques effectuées sur le site de monitorage ont toutefois montré que des véhicules qui seraient autrement classés comme respectueux de l'environnement présentaient des émissions de bruit élevées. La réduction ou l'augmentation de la vitesse influence directement les émissions sonores d'environ 0.15 dB par km/h de variation de la vitesse. De plus, le bruit émis par un véhicule dépend significativement de facteurs spécifiques du site de mesure tels que le type et l'état du revêtement ainsi que de paramètres dépendant des conditions météorologiques tels que la température et l'humidité superficielle du revêtement. Il n'est ainsi pas possible de définir en matière de bruit des seuils absolus pour distinguer les véhicules respectueux de l'environnement de ceux qui ne le sont pas. Par ailleurs, l'impact du bruit d'un véhicule doit être considéré en fonction des heures du jour car le bruit est plus dérangeant la nuit. La différence considérable de 10 dB mesurée entre le véhicule le plus bruyant et le véhicule le plus silencieux met en évidence le potentiel d'amélioration possible pour ce qui est de l'impact du bruit. Du point de vue de la perception auditive, une différence de 10 dB correspond à un doublement ou à une réduction de moitié du bruit perçu.

Les émissions de gaz et de particules des véhicules en déplacement sur la route dépendent de la combinaison de nombreux facteurs tels que le climat, le mode de conduite, le type et la pente de la route, le modèle du véhicule, l'état du moteur et le type de carburant. Il n'est donc pas possible d'estimer directement les émissions de polluants d'un véhicule dans une situation réelle à partir des données d'émission indiquées dans son approbation de type (EURO 0 à EURO V). La mesure in situ des émissions gazeuses d'un véhicule routier pour une seule condition d'exploitation du moteur sur une station de monitorage n'est pas exactement représentative de ses émissions. De manière idéale, il faudrait pouvoir disposer des facteurs d'émission moyens (en g/km) pour les différentes classes de véhicules lourds.

La comparaison de l'empreinte environnementale des véhicules lourds en Suisse et en Grande Bretagne a montré que, bien que la valeur médiane de la charge par essieux et du poids total soient inférieures aux valeurs limites correspondantes, un nombre important de véhicules dépassent ces valeurs. Le pourcentage des véhicules en infraction les jours de semaine et Suisse et en Grande Bretagne pourrait dépasser les 10%. La médiane du poids total des véhicules en grande Bretagne est plus élevée que celle des véhicules de classes similaires en Suisse. Une harmonisation de la classification des véhicules et des limites légales pour le poids total et la charge par essieux est indispensable pour permettre une comparaison de l'empreinte environnementale des véhicules lourds sur les sites de monitorage de ces deux pays. Sur le site de monitorage de Grande Bretagne, les niveaux de bruit enregistrés sont plus élevés qu'en Suisse, ce qui peut être partiellement attribué aux types de revêtements routiers différents utilisés en Suisse. Le monitorage des empreintes environnementales a conduit l'établissement d'histogrammes mettant en évidence la distribution des paramètres mesurés. Chaque paramètre est quantifié pour être ensuite comparé aux valeurs limites correspondantes et établir finalement son classement. Un fois ce classement opéré pour chacun des paramètres d'un véhicule, ces différents classements sont réunis afin d'obtenir un indice global de son empreinte avec l'étiquette environnementale correspondante.

Ces données peuvent s'utiliser pour l'établissement de mesures d'incitation pour les véhicules ayant une faible empreinte environnementale et d'une pénalisation de ceux possédant une large empreinte. Cela en accord avec le principe du pollueur payeur établi dans le livre blanc sur la politique des transports de l'Union européenne.

Summary

Phase II of the Footprint project has continued monitoring the environmental footprint of heavy vehicles on the A1 motorway defined as dynamic load (WIM), noise, vibration and pollutant emissions based on criteria set by the European project Eureka Logchain Footprint.

WIM measurements have shown that on weekdays ca. 6000 heavy vehicles pass the footprint site out of which about 10% could potentially be overloaded. In order to accurately identify overloaded vehicles detailed vehicle data is needed. To this end, footprint parameters were measured for freight vehicles selected from the traffic stream statically and dynamically and results were compared to the criteria set up as a result of current Swiss policy. The data shows that identifying the environmental footprint of heavy goods vehicles is not straight forward. Vehicles that based on the Swiss heavy vehicle fee (LSVA) criteria would pay a reduced heavy vehicle fee, due to their engine type, are not necessarily environmentally friendly when the footprint parameters are considered. Footprint monitoring has shown that parameters that are currently controlled and their reduction encouraged such as gaseous emissions, axle loads and gross weight are for the most part below or close to acceptable limits. However other important parameters such as tyre pressure and noise remain to be higher than acceptable limits.

Currently, LSVA does not consider noise emissions of individual vehicles as criteria for the heavy vehicle fee. Noise measurements at the footprint site have shown high noise emissions from vehicles that would otherwise be categorized as environmentally friendly. A reduction or increase of the speed influences directly noise emissions by about 0.15 dB per speed change of 1 km/h. Furthermore, the emitted sound of a vehicle depends significantly on site specific factors such as pavement type and condition as well as on meteorological parameters such as surface temperature and humidity. It is therefore not possible to define absolute thresholds to separate environmentally friendly vehicles from unfriendly ones. In addition the noise impact of a vehicle should be considered in relation to the time of the day as noise is more annoying during the night. The large difference of more than 10 dB between the loudest and the most silent heavy goods vehicle that was measured shows the large potential of possible improvements regarding noise impact. From a perceptional point of view a difference of 10 dB corresponds to a doubling or bisection of the loudness.
Gaseous and particle emissions of vehicles driving on the road depend on a combination of factors including, climate, driving pattern, road type and gradient, vehicle model, engine state and fuel. Therefore, it is not possible to estimate directly the emissions of a heavy vehicle in a certain driving situation from its known type approval emission data (EURO 0 to EURO V). The in-situ measurement of gaseous emissions of individual road vehicles at one single engine operating state in the framework of a Footprint Monitoring Station does not accurately reflect the representative emissions of that vehicle. Ideally, the average emission factors (g/km) for different classes of Heavy Goods Vehicles should be found.

Comparison of footprint of heavy vehicles from Switzerland and the UK has shown that although the median value of axle loads and Gross Vehicle Weights are below the legal limits, there are a significant number of vehicles that surpass this allowable. The number of infringing vehicles on weekdays in Switzerland and the UK could be higher than 10%. The highest median gross weight of vehicles in the UK was higher than Swiss vehicles of similar class. A harmonised vehicle classification and legal limits for gross weight and axle loads is imperative in order to allow comparison of the footprint of heavy vehicles at various sites. The UK sites are generating higher noise levels than the Swiss site which is attributed, in part, to the pavement type.

Footprint monitoring has led to histograms showing the distribution of the measured parameters. Each parameter has to be quantified in situ and compared to environmental limits leading to a rating for that parameter. Once a vehicle is rated for each parameter the individual rating can be added to produce a total footprint index and resulting label.
Such data can be used to create an incentive for vehicle types with a low footprint and a penalty for vehicles with a large footprint. This would be in accord with the polluter pays principle as set out in the EU Transport White Paper.

1 Introduction

1.1 General state of traffic and its monitoring in Switzerland

According to the data published by the Swiss federal office for spatial development (ARE), the external costs of land transport in Switzerland lie between 7.7 and 8.9 billion Swiss Francs which is between 1.8 % and 2.1 % of the gross national product (GNP). Most of this is caused by road transport specifically from accidents, health care costs due to air pollution and climate change [ARE 2007a]. There is legislation in place to reduce the external costs and the Swiss heavy vehicle fee (LSVA) effective since 2001 is in place for this purpose. Monitoring the traffic development and the environmental effect of traffic from 2001 until 2005 shows that the LSVA has been able to accomplish its intended purposes and the efficiency of the traffic has increased [ARE 2007b]. The expected initial side effect that the regional roads would see heavier traffic proved not to be a problem.

In Switzerland 1.68 million people are exposed to road noise over the daytime threshold limit of 60 dB(A) for housing areas according to the Noise abatement ordinance. About 110'000 people are affected by rail noise over this threshold limit during daytime. At nighttime the number rises to 200'000 (Figure 13. 3) [Schlachter 2008]. From the perspective of the people living in the traffic corridors, it is known that noise is considered less annoying on the rail side because it is not continuous as opposed to the continuous noise from road traffic [Miedema 1998]. Due to this fact, in Switzerland a 5 dB bonus is used for rail noise in comparison to road noise. However, the annoyance of noise at night should also be taken into account even though fewer people are exposed to it.

Advances in vehicle design have produced vehicles capable of carrying heavier axle loads, multiple trailers and air suspension. This providing a challenge for the infrastructure manager and designers as infrastructure capacity (road pavements and bridges) should be capable of carrying the additional loads. Currently in Europe the emphasis is on reducing congestion, noise and pollution caused by road traffic. To this end there is a need for a holistic approach to monitoring. Monitoring stations need to take into account the total impact of vehicles on the infrastructure.

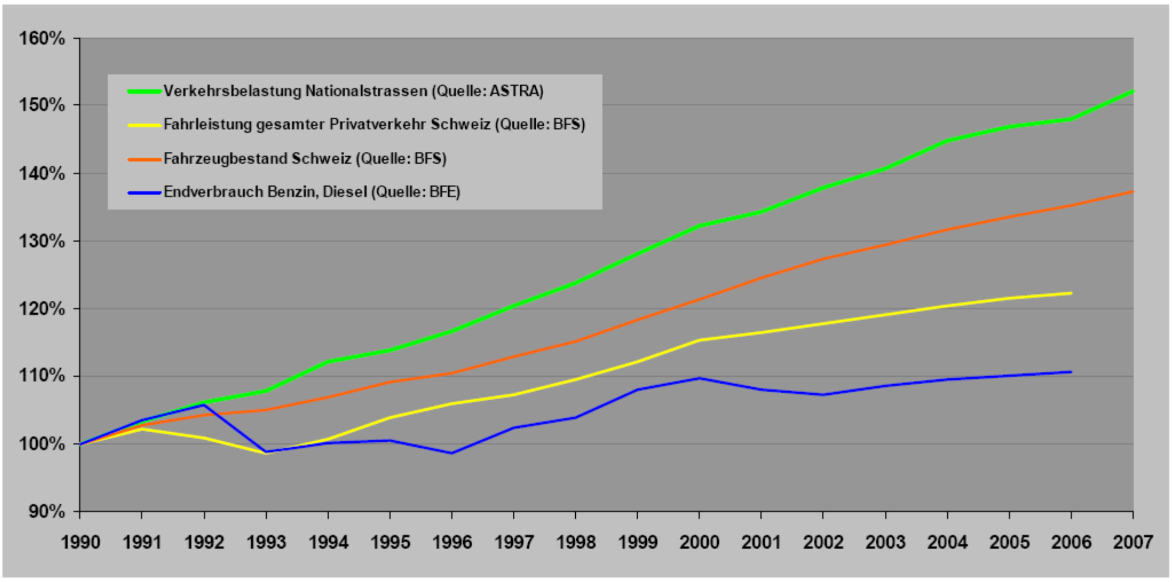


Figure 1. 1 Development of traffic on national roads (green), used kilometres (yellow), number of vehicles (red), Fuel consumption (blue). The year 1990 used as basis for 100%. (ASTRA 2007)

Traffic monitoring by the Swiss Federal Roads Office (ASTRA/FEDRO), Figure 1. 1, shows that in 2007 total traffic has increase more than 50 % in comparison to 1990. This increase in traffic has naturally an effect on the people and infrastructure in the traffic corridors. The heaviest traffic corridors on the road side are between Zürich, Bern and Basel (Figure 1. 2) which is different from the heaviest traffic corridor on the rail side which is between Gotthard and Basel (Figure 1. 3).

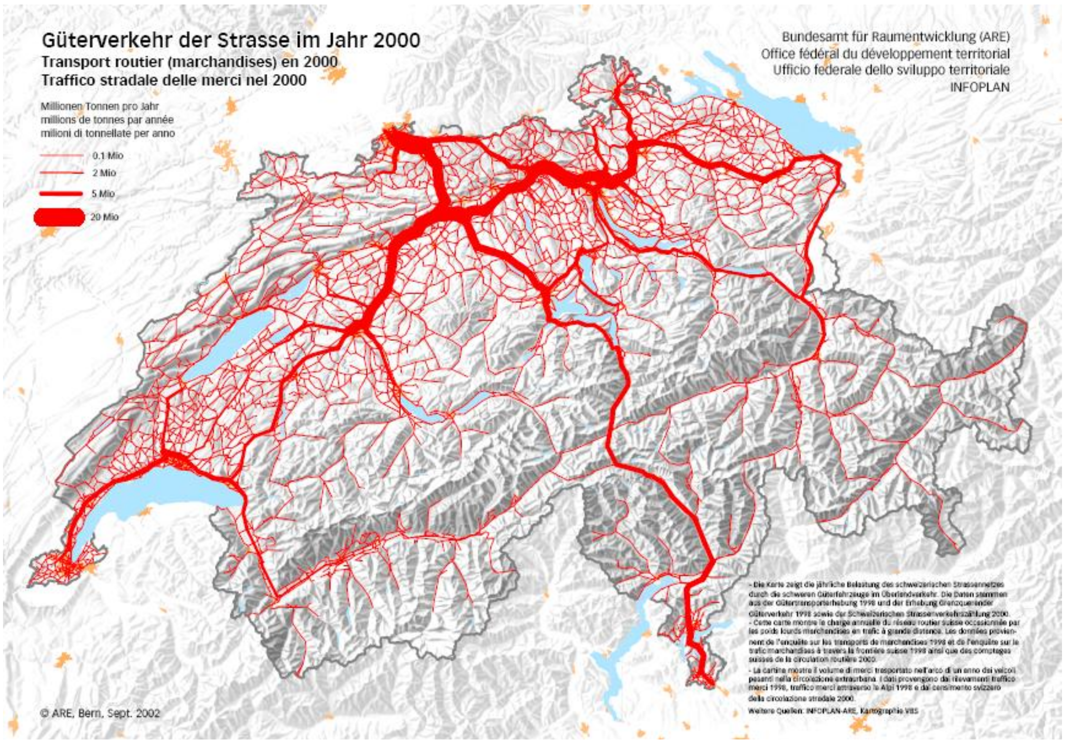


Figure 1. 2 Intensity of road freight in Switzerland (ARE 2002)

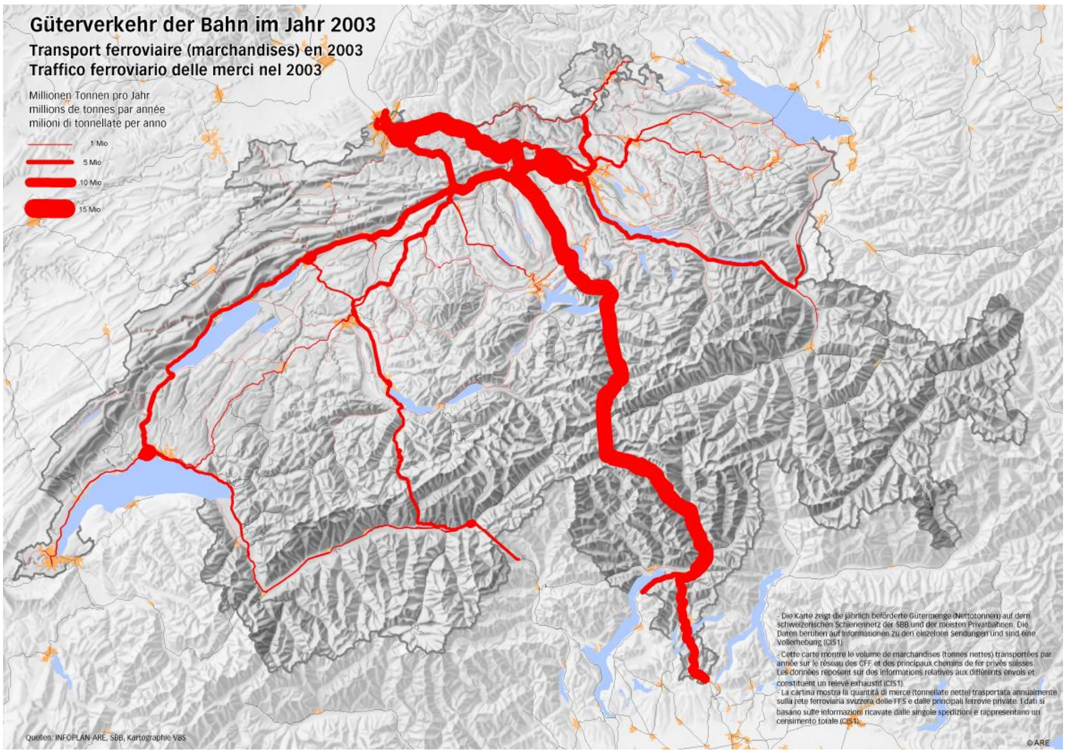


Figure 1. 3 Intensity of rail freight in Switzerland (ARE 2003)

As part of a European cooperative project Eureka Logchain Footprint (www.eureka.be) a monitoring site has been installed on the A1 motorway in Switzerland between Zürich and Bern. Transporting 20 million t per year this site is on the motorway with the heaviest traffic in Switzerland. Up to date (2009) no Footprint monitoring site has been installed on the rail side in Switzerland. However there are sites in Holland, Austria and the Czech Republic.

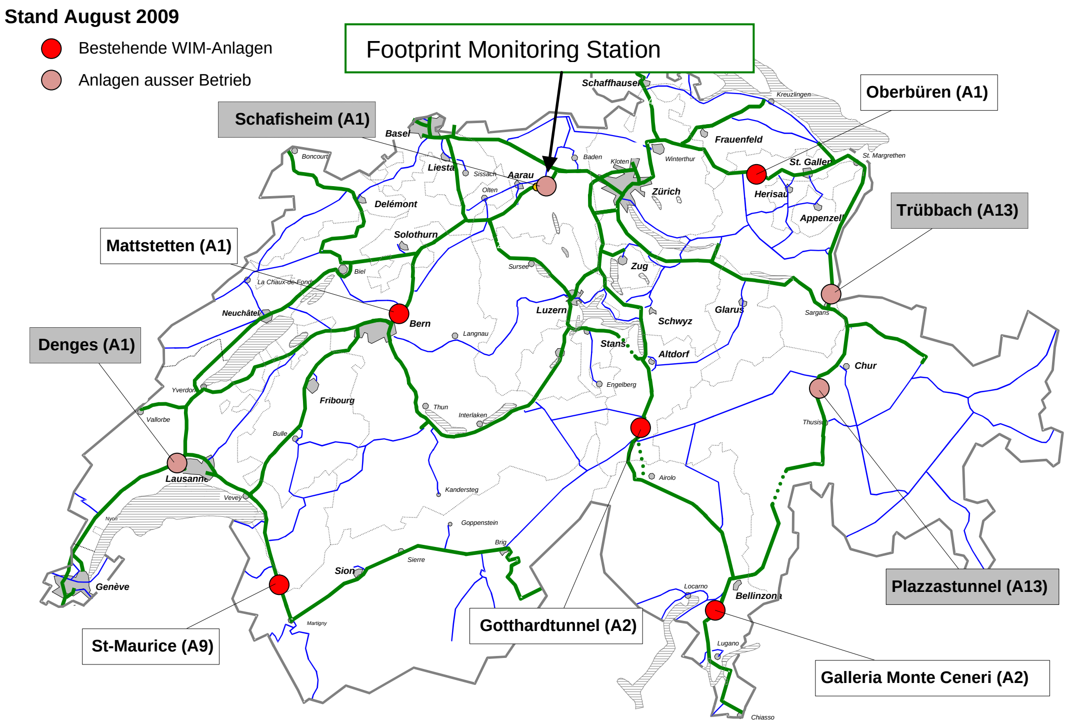


Figure 1. 4 Location of WIM stations in Switzerland in red (ASTRA 2009). Temporarily out of service stations in pink.

Monitoring road traffic is done using Weigh in Motion (WIM) sensors among other methods. Currently there are nine WIM monitoring sites in Switzerland of which five are active in 2009 as shown in Figure 1. 4.

1.2 Eureka Logchain Footprint

1.2.1 Overview

The European cooperative project Eureka Logchain Footprint E!2486, hereafter referred to as Footprint, 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 vibration and gaseous emissions induced by the vehicle. Eureka is a market oriented European cooperative research, and Logchain is an umbrella organization about freight movement currently comprising of 20 projects.

The project Footprint begun in 2001 and was extended to 2008. The European partners have published two reports in order to disseminate the findings of the project. The first report [Mayer 2007] produced guidelines for a footprint monitoring site these results were summarized in the first Swiss footprint report [Poulikakos 2007]. The second report provided information on the impact of road and rail vehicles on the infrastructure and the environment [Mayer 2009]. The executive summary as well as recommendations are listed below.

1.2.2 Excecutive summary

The continuing increase in traffic throughout Europe is creating significant impacts on the infrastructure, environment and resources. From a safety viewpoint, such traffic flows can affect the residual life of structures and dictate when maintenance has to be undertaken whilst the environmental impact is strongly influencing Europe's strategy to reduce environmental impacts from traffic such as greenhouse gas emissions and noise.

In the first project report [Mayer 2007] the partners in the Footprint project described a methodology for measuring and quantifying such impacts for both road and rail modes in a transparent manner. This requires an array of sensors embedded within or alongside the track or pavement at appropriate locations so that vehicles can be monitored in service use. These sensors measure the parameters which characterise the interaction of a vehicle with its infrastructure such as dynamic loading, audible noise and ground borne vibration.

In this second Footprint report, the data from various Footprint measuring systems were analysed to determine the impact on the infrastructure and the environment that characterise these interactions. Data from laboratory tests are also described in order to help characterise suspensions and infrastructures. The data sets are compared with limit values that are prescribed by relevant legislation for both modes.

The concept of an environmentally friendly vehicle is considered and a proposal put forward how to set such limits for road as well as rail vehicles. Such a classification could be used for example to introduce a bonus/malus system of user charging as proposed by the European Commission for reducing noise emissions from the existing rail freight fleet.

Finally the impacts of road and rail traffic are considered from the viewpoint of the operator, infrastructure maintainer and society and the ranking reflects their specific concerns. This kind of information can help to rank strategies which could be used to reduce environmental impact such as noise emissions and through continuing measurement to determine whether such strategies are successful

These recommendations in this report will help to support the initiatives set out in the European Commission's Green Transport package of 8 July 2008. If these recommendations are viewed favourably by Member States, then further work is required to develop and refine these concepts. This work should then be undertaken within a second phase of the Footprint project within the Eureka collaborative framework.

1.2.3 Conclusions and recommendations

R1: *Footprint measurement systems can determine the nature and magnitude of the environmental impacts and how such impacts depend upon vehicle class and flow*

R2: *Footprint measurement systems can detect which vehicles have excessive noise emissions and what may be the origin of this impact whether by vehicle class, speed, type of infrastructure or lack of maintenance of the vehicle or its suspension system*

R3: *Footprint measurement systems can detect which vehicles exert forces in excess of legal limits and can provide information to operators and drivers about the nature of this excessive force such as inappropriate loading, condition of suspension system, wheel quality or tyre pressure*

R4: *The parameters which describe the impact of a vehicle on its surroundings, constitutes its environmental footprint. These are -*

- *gross vehicle mass*
- *axle load*
- *noise*
- *vibration*

- *environmental emissions*

R5: *An environmentally friendly vehicle possesses a small environmental footprint*

R6*: An environmentally friendly vehicle is defined as one whose impacts are significantly less than average for each vehicle class and impact*

R7: *Limits to be set for each environmental impact and vehicle class which can define the degree of environmental friendliness of the vehicle*

R8: *Such limits may be classified as average, environmentally friendly or environmentally harmful*

R9: *The threshold limits to set bonus and malus user charges, if so desired, can be determined by Footprint measuring systems*

R10: *Measurements of vehicles in-service can determine the effectiveness of charging regimes to promote more environmentally friendly vehicles*

R11: *If these recommendations are favourably received then a second phase of Footprint should be undertaken to develop and refine these concepts*

1.2.4 Swiss participation in Eureka Logchain Footprint

Scope

Switzerland was an active member of this project since 2004. The first road Footprint Monitoring Site (FMS) was installed in June 2005 on the A1 motorway between Zürich and Bern in Switzerland. The footprint parameters of dynamic load, noise and vibration are collected and analysed systematically. Swiss participation in this project has been in two phases. The results of the first phase from 2004 to 2007 has been documented in Poulikakos et al 2007, 2008a, 2008b, 2008c, 2008d, Anderegg et al 2005 and 2008, Morgan et al 2008a 2008b and Heutschi 2008. The second phase of the project Footprint began in January 2007. This report documents the results of Phase II of Swiss participation in Footprint as of January 2007.

Goals

Phase II of the footprint project in Switzerland has established seven work groups that address the various topics (Figure 1. 5). The work groups shown below expand on the knowledge gained in Footprint I and fill the gaps that were observed in order to achieve the goals of the project. Specifically, the goals of Footprint II were the following:

- Continue cooperation in the European project Eureka Logchain Footprint
- Continue WIM, SIM, noise, deformation, vibration monitoring from selected samples of traffic on the A1 motorway near Lenzburg.
- Propose options for monitoring of gaseous emissions for single vehicles
- Use FE modelling to evaluate the effect of tyre pavement contact forces on the pavement
- Synchronization of the WIM clock and the FMS clock
- Optimization of data acquisition so that the WIM, Modulas, vibration, temp, deformation data from each vehicle is recorded.
- Improvement of data reduction and data analysis.
- Establish environmentally friendly criteria for the measured parameters
- Evaluation of the various possibilities on how to use the data gained from this project in the operational and legal framework of road tolling and enforcement

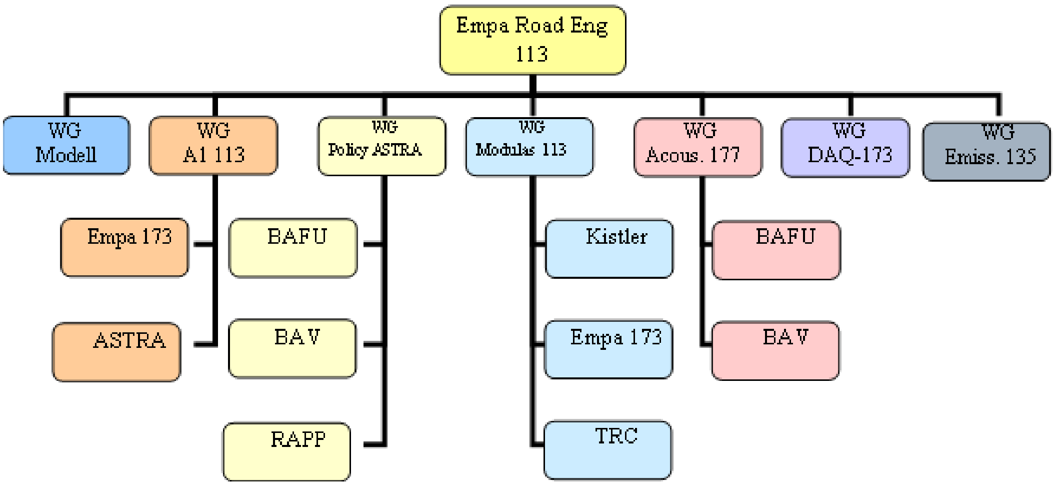


Figure 1. 5 Footprint II Work Groups

2 Footprint Monitoring in Switzerland

2.1 Footprint Monitoring Site (FMS)

The FMS was installed in Switzerland in 2005 on the motorway A1 between Zürich and Bern, direction Bern and at the 82.505 kilometer mark (Figure 1. 4). As shown in Figure 2. 1 Weigh in Motion, noise, vibration, temperature, Stress in Motion (SIM), deformation and humidity are the monitored parameters. Additional information on sensors and site description in given in Poulikakos et al (2007).

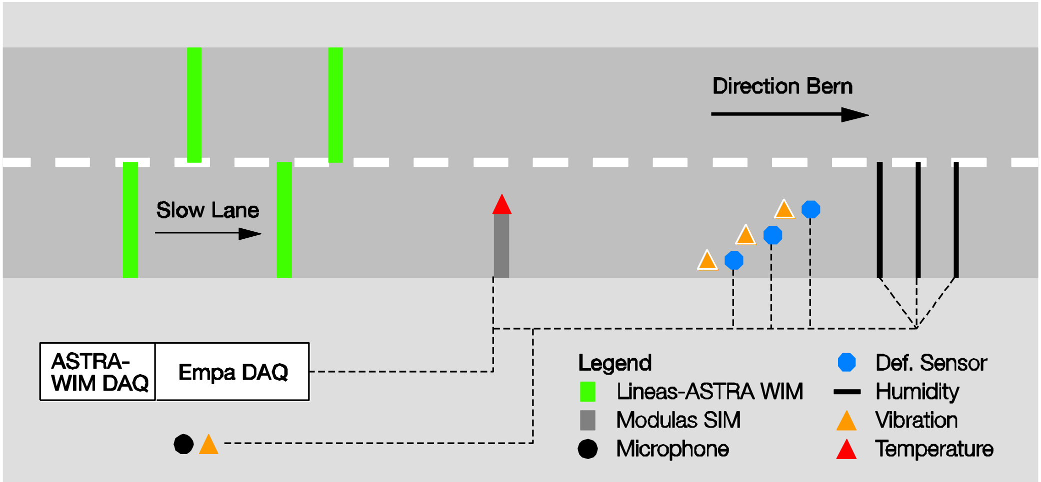


Figure 2. 1 Schema of the Footprint Monitoring Site in Switzerland

2.2 Site inspections

The footprint site was inspected by Empa personnel on 6.07.2007 (Figure 2. 2 and in May 2008 (Figure 2. 3) and the state of the sensors were found acceptable and in working order. The modulas sensor was inspected by Kistler personnel and recommendations have been made for improvement of the sensor. As a result of the inspection it was recommended that the thin grooves made in the pavement for the in pavement vibration sensors had come loose and needed to be refilled.

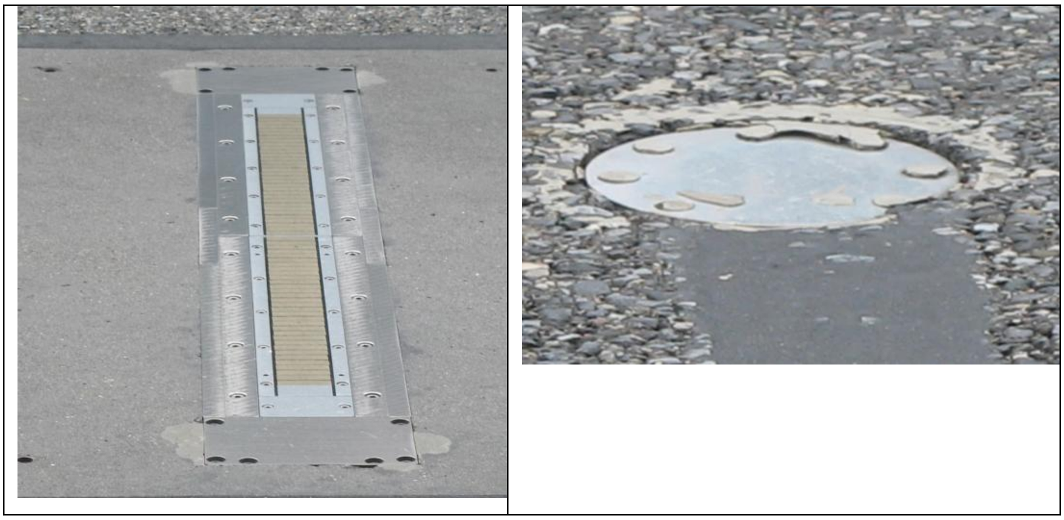


Figure 2. 2 Modulas left and Top of deformation sensors right as inspected on 6.7.2007

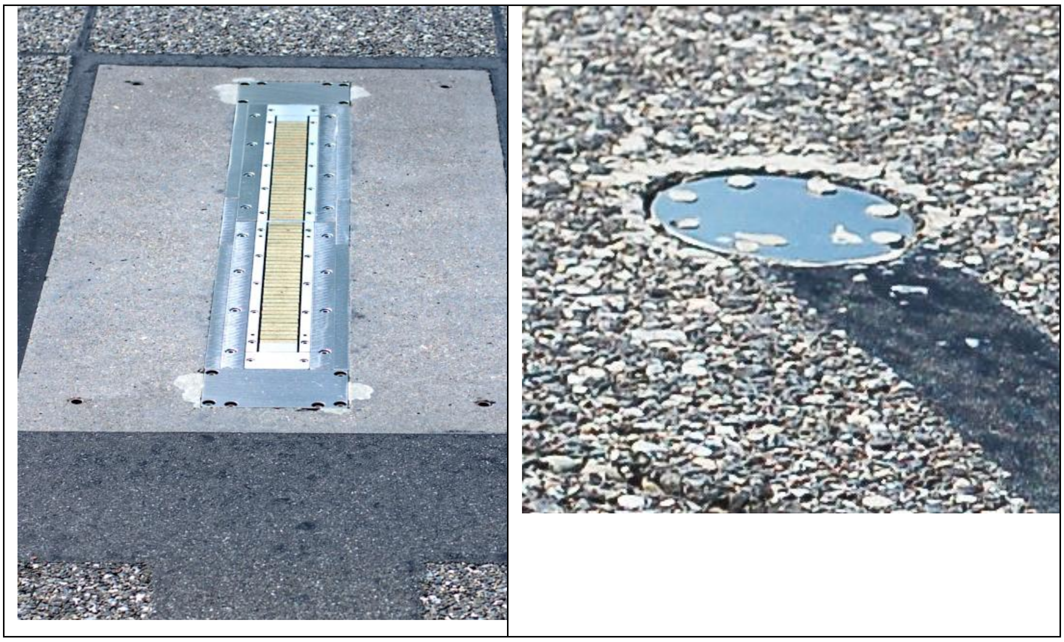


Figure 2. 3 Inspection May 2008

3 Data Collection and Post Processing

3.1 Data collection

3.1.1 General

The data collection system has been operating for 4 years (since 2005) and acquiring data for thousands of vehicles per day, some of the sensors show first effects of failure (Tyre contact Pressure, Deformation), but surprisingly the 3 computers still work generally fine, especially if one takes the cabinet temperatures of 50°C or more on some summer days into account, which are measured at the PC fan during a hot summer day. All the DAQ software was rewritten and minor bugs have been fixed. Over time some of the tyre contact pressure channels have failed. The new software takes the defective channels into account and does not take them into account during the data reduction process. The data of these channels will still be saved but the slow signal decline would compromise the reduction process. It is to be determined, if and how these signals are usable in a later process.

3.1.2 Data collection during measurement campaigns

Due to the enormous amount of data generated each day, the acquisition software for all sensors has been updated in order to have the possibility of measurements campaigns. It is now possible to remotely start a measurement campaign on the A1 site. All the sensor data that is stored on a daily basis is not affected by these campaigns. As shown in Figure 3. 1 only vibration, tyre pressure and dynamic deformation data are affected. A specifically designed Measurement Campaign Daemon checks the configured campaigns, sets the programmed saving limits and restarts the respective DAQ programs. After ending a measurement campaign, the same daemon resets the limits so that no data is stored. The daemon can handle a list of campaigns, where the local editor for these campaigns downloads the latest list from the site and checks new campaigns for reasonability (no time overlap).

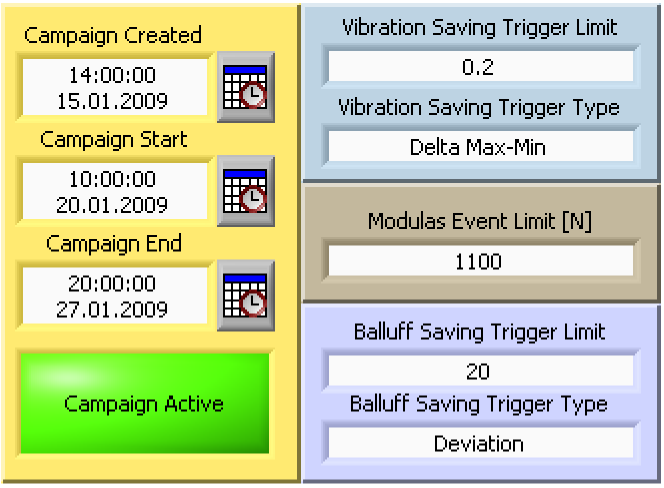


Figure 3. 1 Measurement Campaign

3.2 Unified Post Processing

Until recently, while the data acquisition for all of the sensors (WIM excepted) was unified, and the results stored in a single location, the means by which the results were post-processed varied considerably. For example, the WIM results were typically processed via a series of spreadsheets, while the SIM data, which required more flexible tools, was post-processed using a collection of shell scripts and small programs. While, in each case, the method of post-processing was well suited to the data and was efficient, the various methods did not always interact well with each other leading to difficulties when attempting to compare the data.

In order to rectify this problem, it was decided that as many of the different post-processing functions as possible should be merged into a single, unified program. The following key aims were decided upon:

1. All the data should be organised into a coherent and consistent format.
2. The system must be easily extensible and must be very flexible; able to incorporate changes and new methodologies easily.
3. The system should be well documented and relatively easy for anyone to use or add to.

In order to fulfil these goals, it was decided to create a collection of interoperable MAT-LAB [Matlab 2006] scripts which could handle the recorded footprint data in an object-oriented way. This collection of scripts (named GUS for Grand Unified Scripts) was created and documented. It is currently able to perform simple post-processing and data summary functions for WIM, SIM, vibration and temperature and it is intended that the analysis of the Baluff deformation data will be added to its capabilities in the near future.

Examples of the GUS' output can be seen in chapter 4 and in the papers by Morgan et al [2008], Poulikakos et al. [2008].

4 Weigh in Motion Monitoring

4.1 Overview

The weigh-in-motion (WIM) sensors installed at the FMS continued to produce good results. Due to planned renovation of the road at this site as of August 2009 the sensors are no longer in service. The sensor installation and set-up is essentially unchanged from Footprint I. The sensors were calibrated in fall of 2007 and Summer 2008. The calibration results in 2008 indicate the sensors to comply with the COST 323 accuracy class B+(7) [Kienast 2008].

Data from the Swiss monitoring station confirms the increase in freight transport through Switzerland. Although this increase is an indication of the success of freight transportation through road it also has negative consequences such as capacity problems, increase in pollution due to noise and gaseous and particle emissions and increase of damage to the infrastructure. The current goals of the EU and Switzerland are to promote greener transportation. The aim of the Swiss heavy vehicle fee (LSVA, see chapter 13) and the Eurovignette directive are to internalize external costs of transport such as noise.

The current WIM measurements and total footprint of selected vehicles during the measurement campaign (chapter 10) show that on weekdays there is potentially a significant number of vehicles (ca 10%) that could be overloaded. Further static evaluation is needed as the WIM data does not deliver information on drive axle or type of suspension. As the calibration results showed [Kienast 2008], WIM data corroborated the static data at this site, the WIM sensors could be a useful tool for pre-selection.
Examination of the WIM data from the FMS shows certain trends that are listed below. In general daily weekday traffic is increasing.

4.2 Sensor description

For WIM measurements Lineas® sensors made from silicon-dioxide, SiO_2, and manufactured by Kistler are used. At the FMS site both lanes are covered each containing two rows of three sensors (Figure 2. 1). In addition, the same set up is used for the traffic in the opposite direction (Bern to Zürich).

Quartz based sensors have shown unique qualities as they are electrically and mechanically stable, temperature influences are negligible, show uniform sensitivity over the entire sensor, display a wide measurement range and results are speed independent. The sensors are fully embedded in the pavement with no screws or frames, using a special grout consisting of a two component epoxy and quartz sand allowing decoupling from lateral forces. Lineas sensors can be ground flush if cracks or ruts occur in the pavement. A relatively small intrusion of 55 mm depth x 72 mm width in the pavement is needed. The length of the sensors can be 0.75 m or 1.0 m. At the FMS the sensors are 0.75 m.

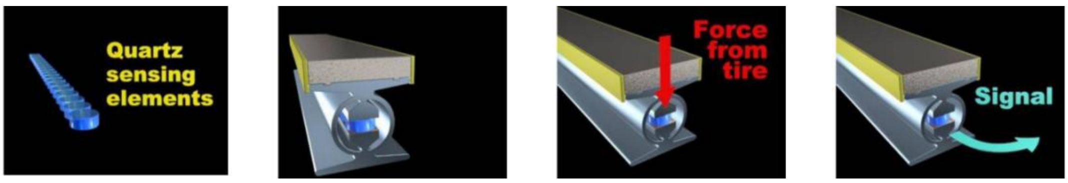


Figure 4. 1 Lineas WIM Sensor (courtesy Kistler instrumente AG)

A wheel rolling over the Lineas 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 (Figure 4. 1). 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 tyre type, tyre quantity or tyre pressure. In the case of dual tyres, the Lineas 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 (AL), gross vehicle weight (GVW), speed, axle distance and vehicle length with very good accuracy at this particular site. On weekdays and on heavier trafficked months the number of heavy vehicles per day is as high as 6500 and as low as 1200 on weekends. The sensors are calibrated once a year normally in the Fall as reported by Mastrangelo (2005, 2006, 2007) and Kienast (2008). The procedure for calibration is based on the COST 323 (1999) and recommendations as defined by the Swiss roads Office [Jegge et.al. 2008, Molinari 2001]. The accuracy class as defined by COST 323 (1999) for the FMS location from 2005 to 2008 is listed in Table 4. 1. As shown the accuracy class in 2008 was B+(7).

Table 4. 1 Summary of calibration results of the WIM sensors at the footprint(1)

Year	**COST 323 accuracy Class**		**No of vehicles used GVW>3.5 t**	**No axles used AL> 2 t**
	before calibration	After calibration		
2005	B+(7)	B(10)	32	77
2006	B+(7)	A(5)	28	71
2007	B(10)	A(5)	30	73
2008	B+(7)	B+(7)	26	64

(1) Sources: [Mastrangelo 2005, 2006, 2007, Kienast 2008]

4.3 Regulations in Switzerland

4.3.1 Vehicle classification

The vehicle classification in Switzerland, the SWISS10 is shown in Figure 4. 2.

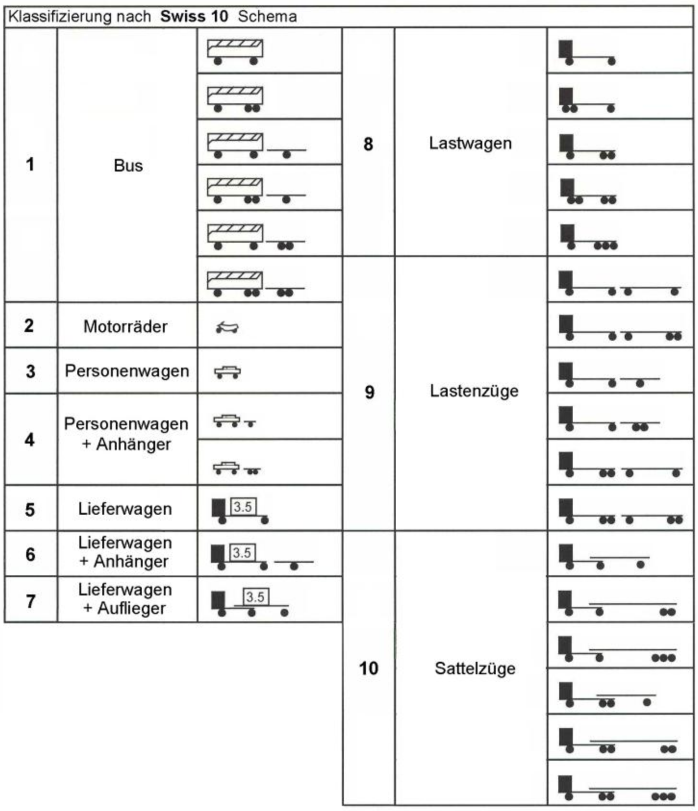


Figure 4. 2 Vehicle Classification. Lastwagen=freight truck, Lastzüge=Freight truck w. trailer, Sattelzüge= Articulated freight truck w. semi trailer.

4.3.2 Allowable loads

The legal limits for axle loads and gross weight in Switzerland are listed in Table 4. 2. As shown they are a function of the axle spacing, single or double axles and suspension system. For example the drive axle is allowed 11.5 t whereas a single non-drive axle is allowed 10 t.

Table 4. 2: Swiss allowable gross vehicle weights (GVW) and axle loads [www.admin.ch/ch/d/sr/741_11/a67.html]

Configuration	Allowable GVW [t]	Special provisions
More than 4 axles	40	44
4 axles	32	
3 axle trolley bus	28	
3 axle	25…26	26 with double axle / air-suspension/ or similar
2 axle	18	
Configuration	Allowable Axle Load [t]	Vehicle in operation before 1.10.1997
Single axle (11.5 t on drive axle)	10…11.5	12
Double axle (<1.00m apart)	11.5	
Double axle (between1.0 and 1.3m apart)	16	
Double axle (between1.3 and 1.80m apart)	18	
Double axle (between1.3 and 1.80m apart w. springs)	19	20
Double axle (>1.8m apart)	20	
Triple axle (<1.3m apart)	21	
Triple axle (Between 1.3m and 1.4m apart)	21	
Triple axle (>1.4m apart)	27	

4.4 WIM Data

4.4.1 Measurement results

Traffic patterns as expected depend on the day of the week, the time of year and time of day. However, from the analysis of the WIM data from 2007, 2008 and 2009 certain patterns have been identified and listed below.

Number of axles per hour as shown in the examples from January 2007 and September 2008 (Figure 4. 4) show a pattern with three peaks at 6:00, 10:00 and 14:00 O'clock, with the highest peak at 6:00.

The allowable axle load in Switzerland, shown in Table 4. 2, for non drive axle is 10 t (11.5 t for drive axle). Figure 4. 5 shows that Swiss class 10 vehicles have the highest number of axles over 10 t. An example of a class 10 vehicle in Figure 4. 3 shows the distribution of axle loads for a typical class 10 vehicle. As seen axle 2 has the highest load in this case which was also a pattern seen in the data analysed.

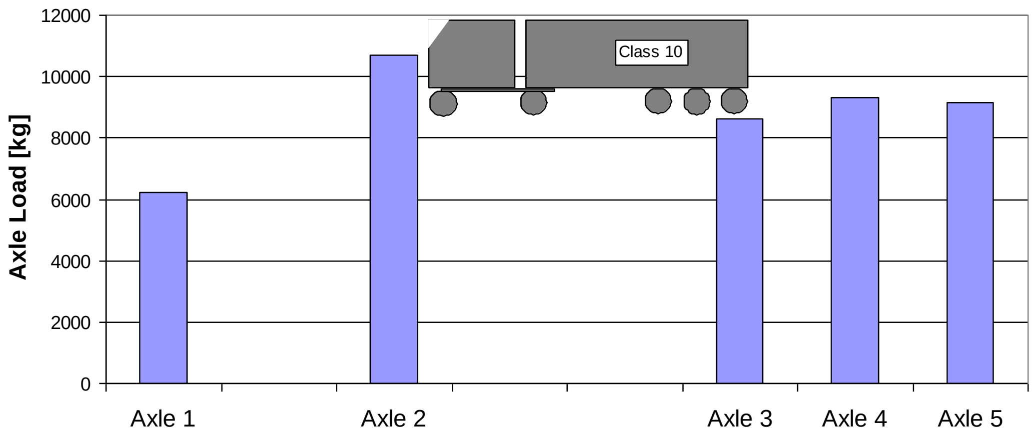


Figure 4. 3 Example of the axle distribution of a typical class 10 vehicle

Figure 4. 6 shows the number of vehicles per day and compares axle loads with allowable of 10 t. The axle loads and distances measured using WIM sensors were compared to criteria in Table 4. 2. The possibly infringing vehicles were all those that could not be automatically classified using the Table and exact vehicle data was required. For the purpose of demonstration, a sample is defined in detail in chapter 10. The data shows that there is an increase in the number of vehicles on weekdays. For example In January 2007 a maximum of ca 5000 vehicles per weekday were recorded whereas in January 2008 this number was increased to 5500 and in September 2008 to 6000. Overall, the number of vehicles on weekdays is ca 6000, Saturdays ca 1500 and Sundays ca 800. A sharp drop (ca 10%) in weekday traffic is seen on Fridays. This is to be expected as heavy vehicles are not allowed on weekends.

However no increase in the minimum number of vehicles was seen as this is during the weekends or the number of infringing vehicles (Figure 4. 7 and Figure 4. 8).

It should be noted as shown in Figure 4. 5 that Swiss10 Class 1 vehicles (buses) also have axles over 10 t.

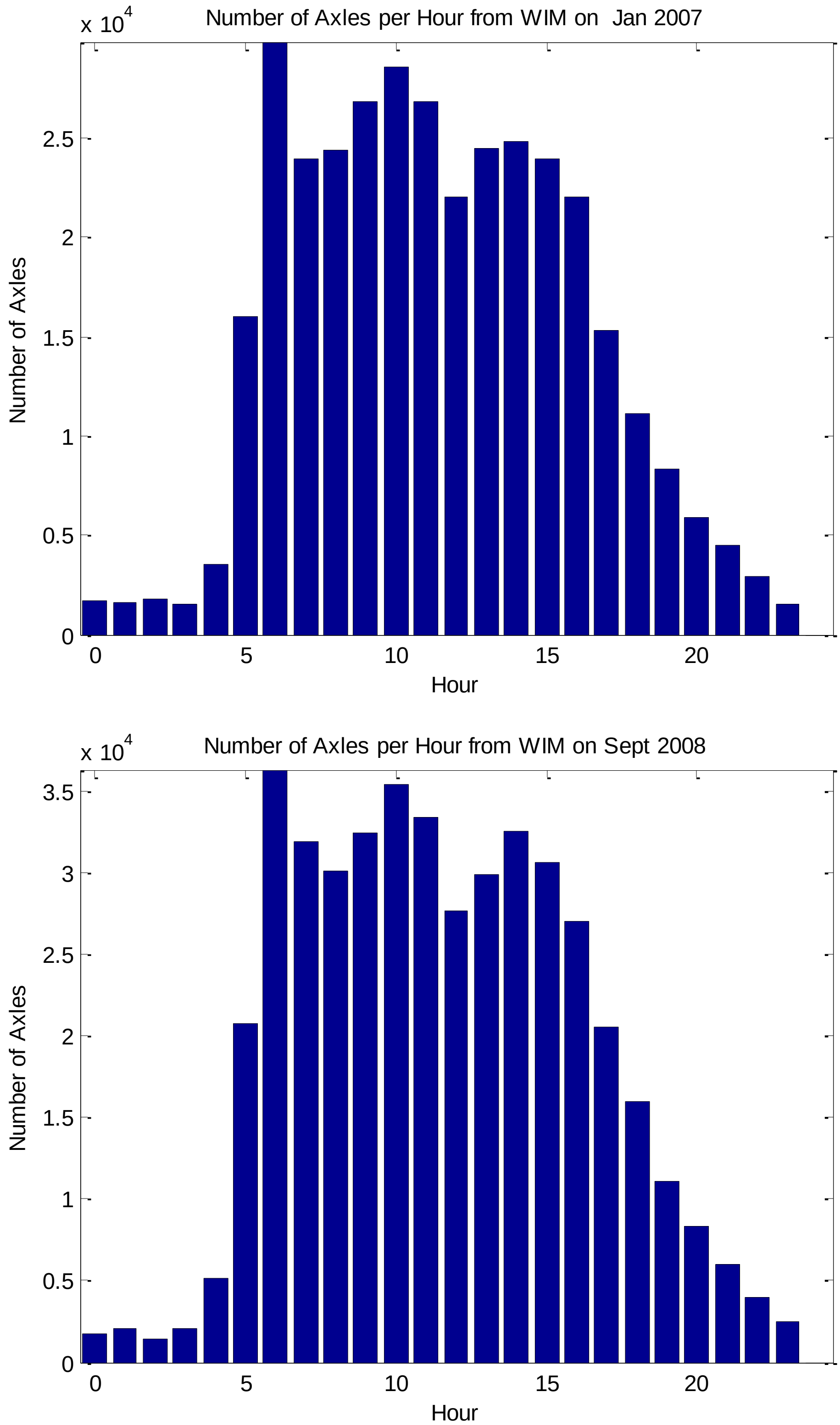


Figure 4. 4 Number of axles per hour from January 2007 and September 2008 shows a peak at 6:00, 10:00 and 14:00.

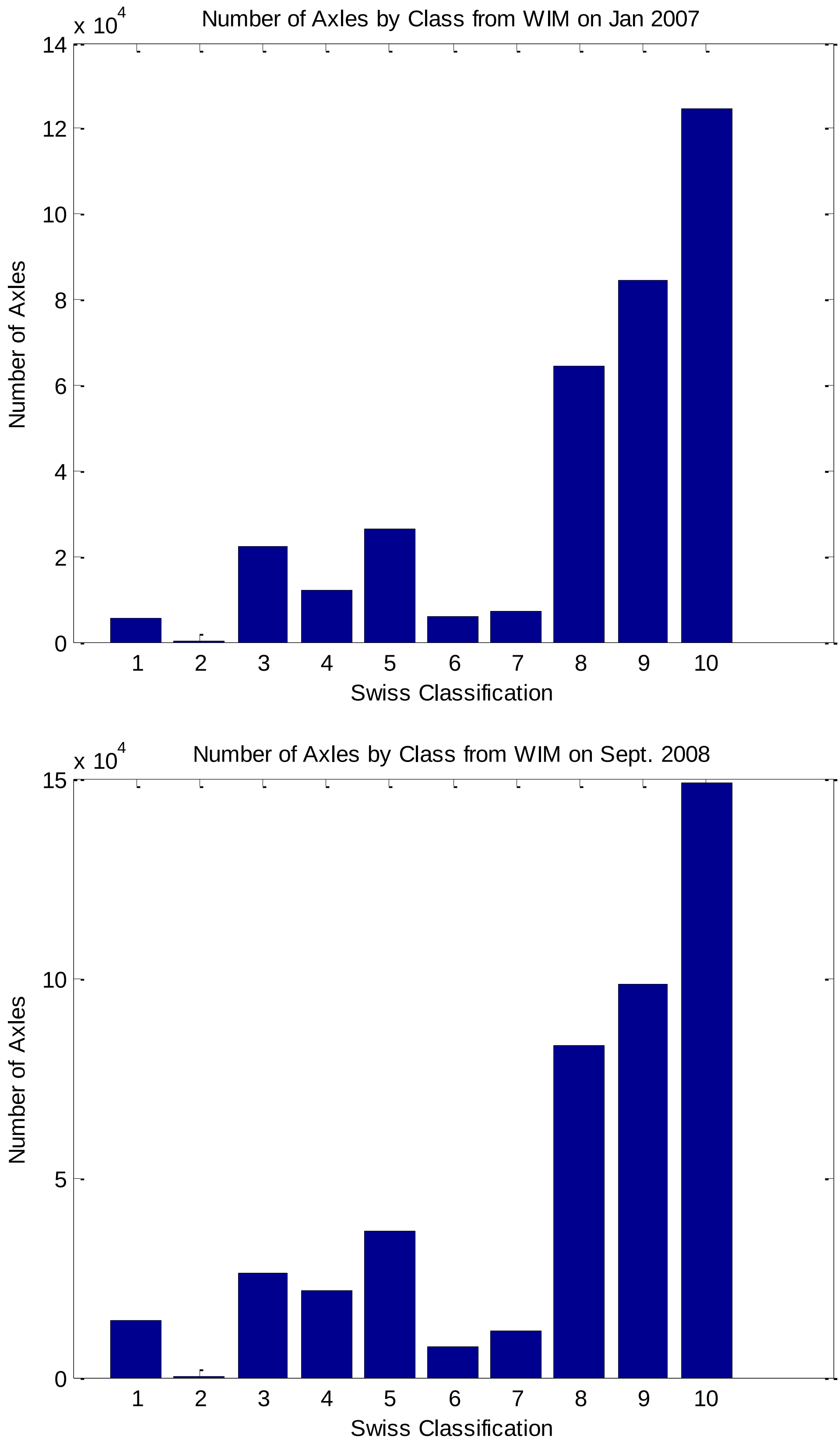
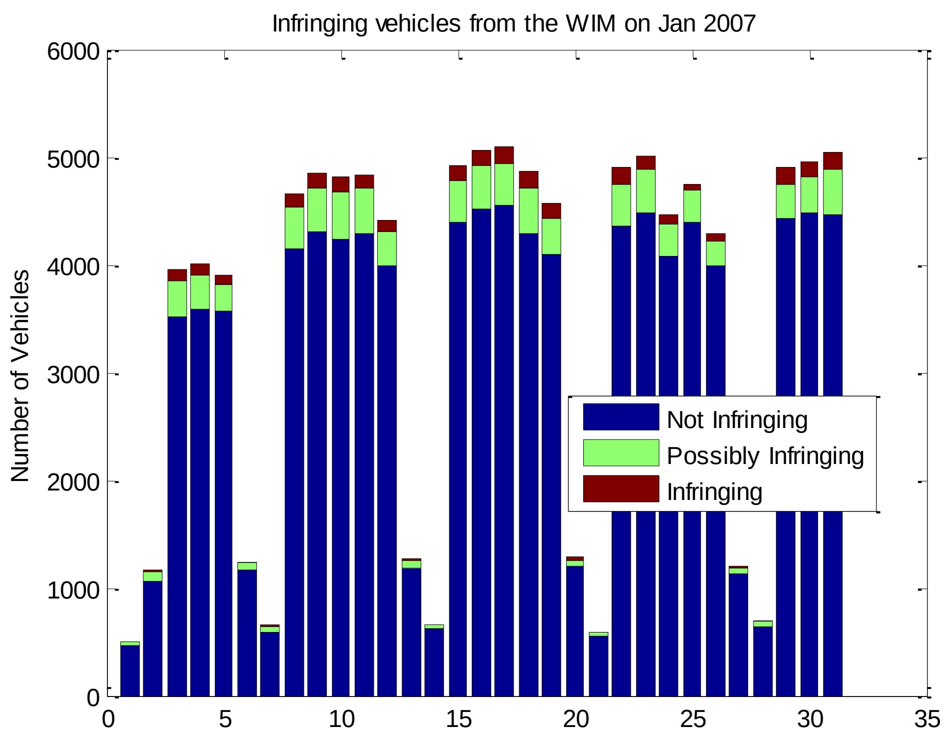


Figure 4. 5 Number of axles by SWISS10 class in January 2007 and September 2008, showing that Class 10 vehicles have the highest number of axles over 10 t.



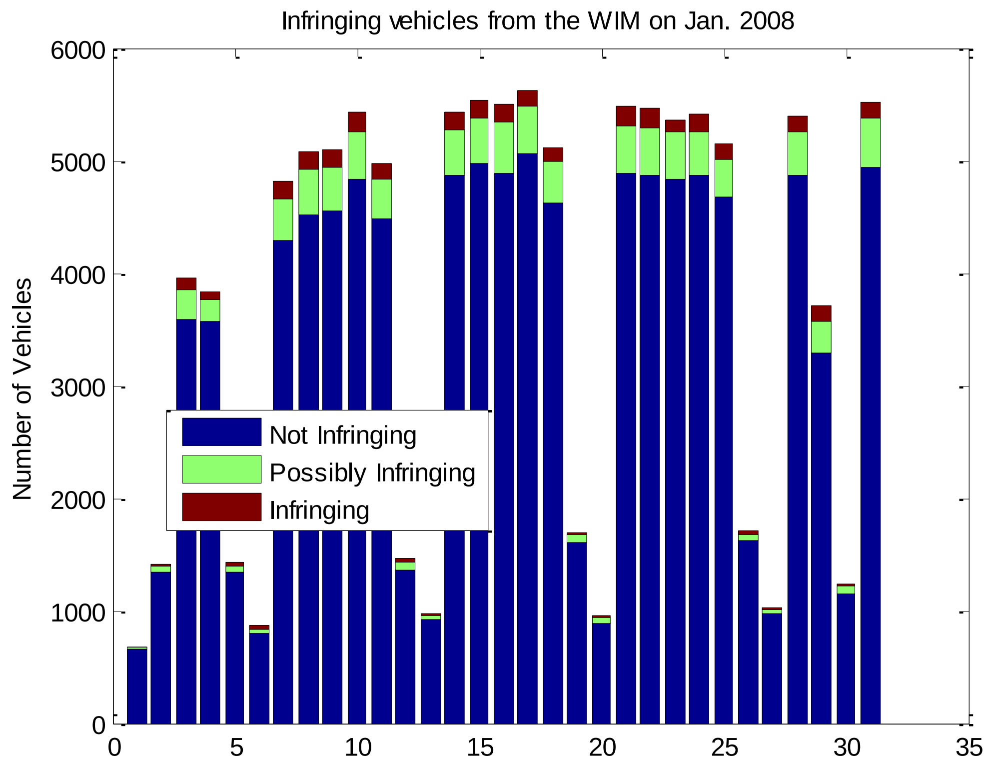


Figure 4. 6 WIM measurements in January 2007 and January 2008 showing that there is an increase in the maximum number of vehicles on weekdays from 5500 in 2007 to ca 6000 in 2008. About 10% of these vehicles could be overloaded

4.4.2 Summary of WIM measurements

Summary of WIM data in Figure 4. 7 and Figure 4. 8 shows maximum, minimum and number of infringing vehicles in the period under investigation. The data shows that an increase in total number of vehicles but not in the possibly infringing vehicles or the minimum number of vehicles which is during weekends. As shown in Figure 4. 7 maximum number of heavy vehicles pick up every year after April. This trend has been observed for 2007, 2008 and 2009. For example the latest data from 2009 shows that in January and April the maximum number of heavy vehicles were 5500 and 5950 respectively. For the rest of the year the higher trend remains until January of the next year where there is a sharp drop. A logarithmic relationship can be used to estimate the trend in traffic as shown in the figure. Figure 4. 8 shows the variation with respect to season. As shown a larger increase from 2007 to 2008 is seen in January than in April or September. Please note that data for August 2009 is only up to August 19th due to de-installation of the WIM sensors for the planned rehabilitation of the pavement.

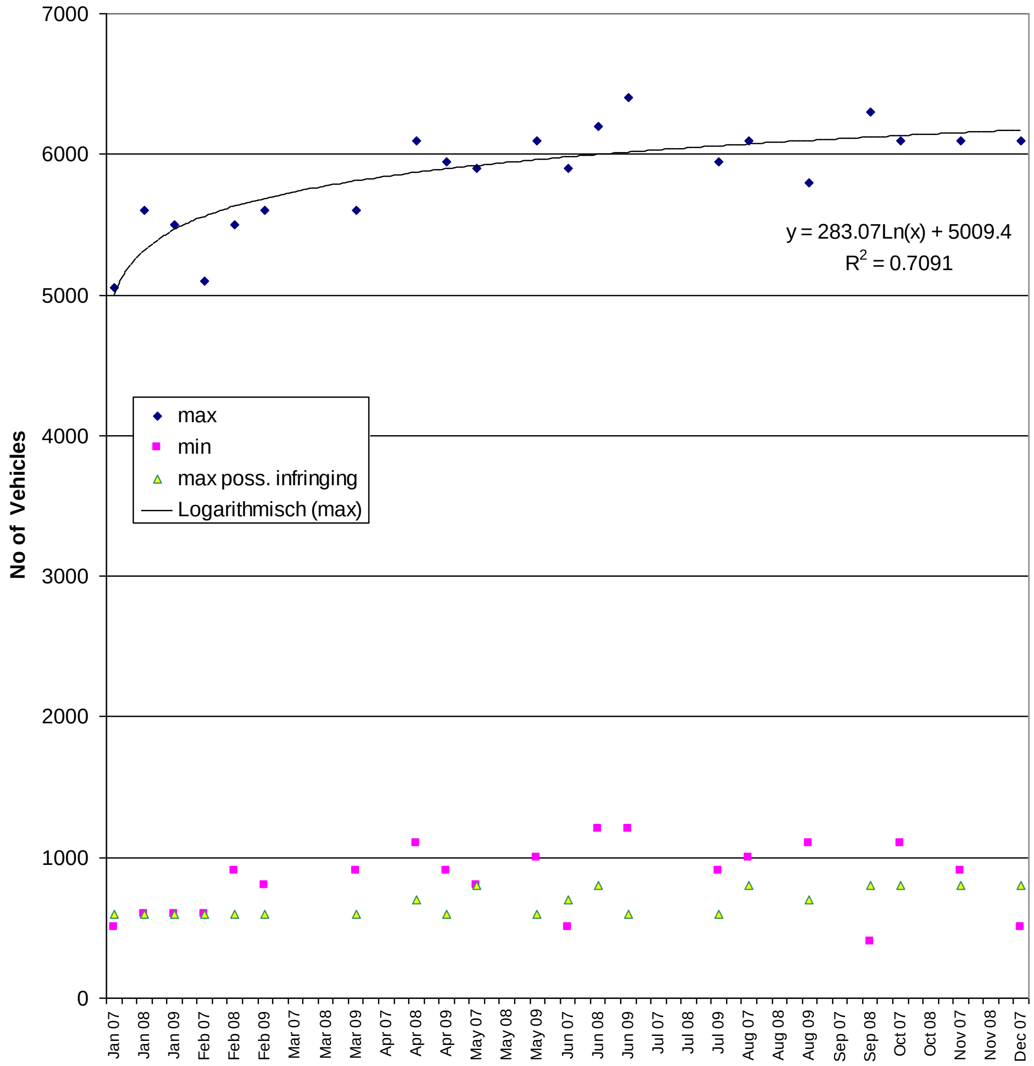


Figure 4. 7 Summary of WIM data showing maximum, minimum and number of infringing vehicles

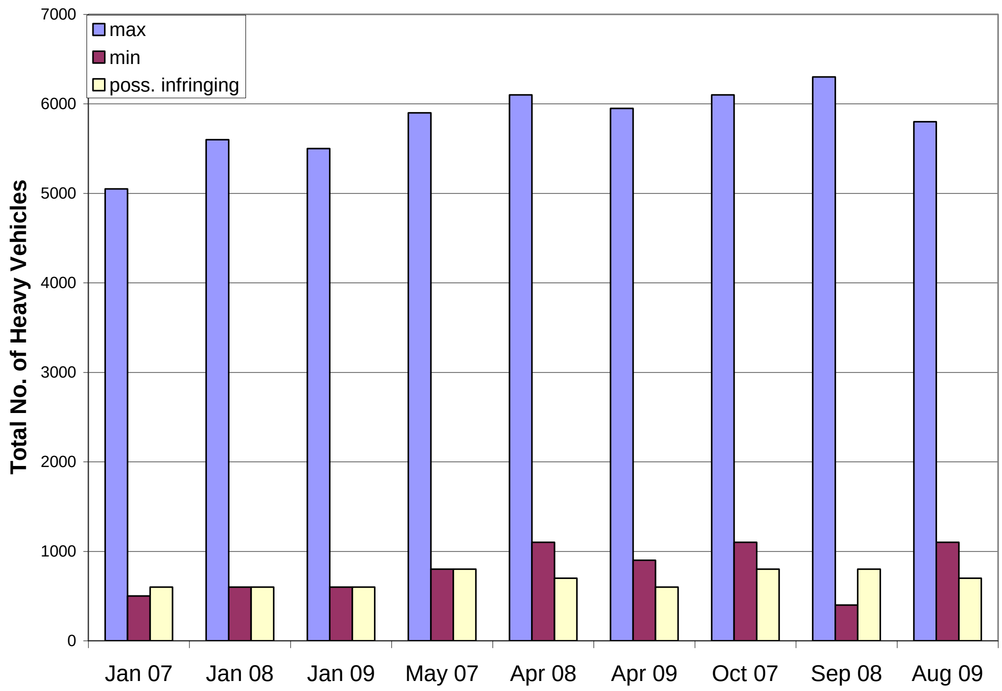


Figure 4. 8 Seasonal comparison of data from 2007, 2008 and 2009

4.4.3 Conclusions

From the measured WIM data the following conclusions can be drawn:

1. Daily data shows that the number of axles peaks at around 6:00, 10:00, 14:00 with the highest peak at 6:00.
2. Number of vehicles on weekdays is ca 6000, Saturdays ca 1500 and Sundays ca 800.
3. A sharp drop in traffic (ca 10%) in weekday traffic on Fridays is seen.
4. Swiss10 Class 1 vehicles (buses) also have axles over 10 t.
5. More axles over 10 t from Swiss10 class 10 vehicles.
6. Number of heavy vehicles per weekday in 2008 is on the rise in comparison to the same period in 2007. The largest increase was in January and February with an increase of ca 600 vehicles per day. However no increase in the minimum number of vehicles was seen as this is during the weekends or the number of infringing vehicles (Figure 4. 7)
7. Axle number 2 is usually the one carrying the most load.
8. Comparison of data from 2007 and 2008 shows an increase in total but not in the possibly infringing vehicles

It can be seen from the sample of results provided that the WIM data can be compared to environmentally friendliness criteria and used for pre selection of infringing vehicles. For example using allowable axle loads, vehicles infringing on this criteria can be selected.

5 Stress in Motion Monitoring

5.1 Overview

Stress in Motion (SIM) monitoring using the Modulas sensor on the A1 [Poulikakos 2007] has shown that the axle load alone is not an indication of the effect of the axle load on the pavement. The tyre pavement contact forces as measured by SIM sensors have a significant effect on the strains produced in the pavement. In addition results have shown that a significant difference in contact force distribution for over/under inflated Tyres can be measured.

5.2 Sensor description

The Modulas SIM sensor (Figure 5. 1) is a piezo quartz sensor array that measures the vertical forces exerted irrespective of the part of the tyre which crosses the device at high and low vehicle speeds. However this type of sensor is not suitable for static loading.
The Modulas is a reusable device, set flush with the road, and measures the vertical contact forces between tyre and pavement during vehicle crossings using 32 independent channels with less than 2% cross-talk and 15 mm spatial resolution (the width of each channel). The SIM sensor is capable of delivering the traditional WIM, parameters such as axle load, speed, and axle distance. At the FMS two Modulas sensors were installed with a total of 64 active channels.

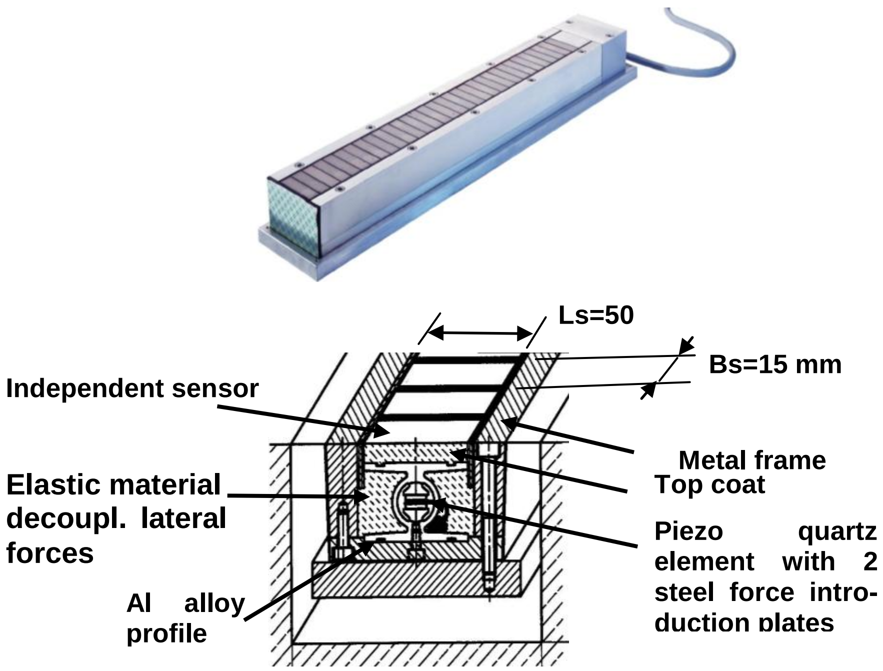
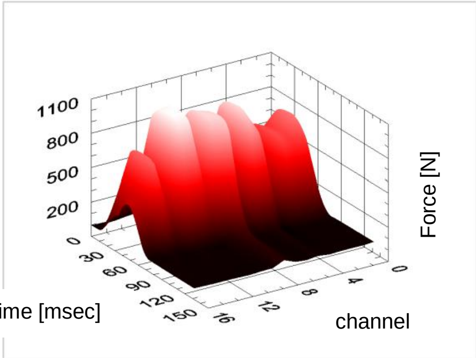
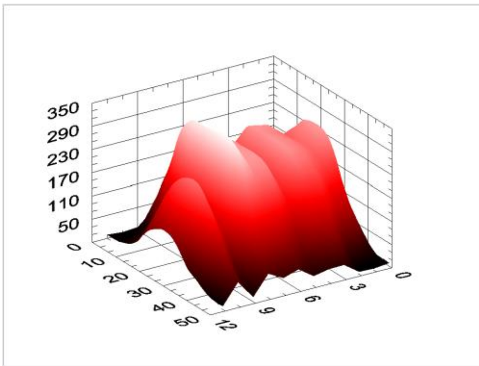
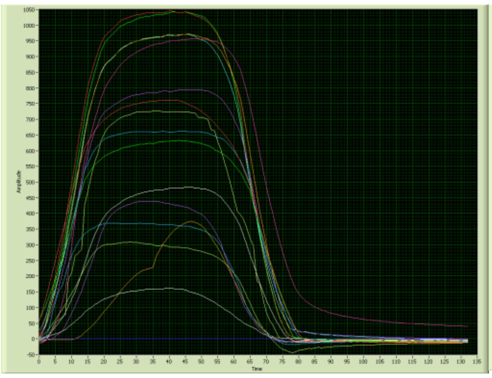
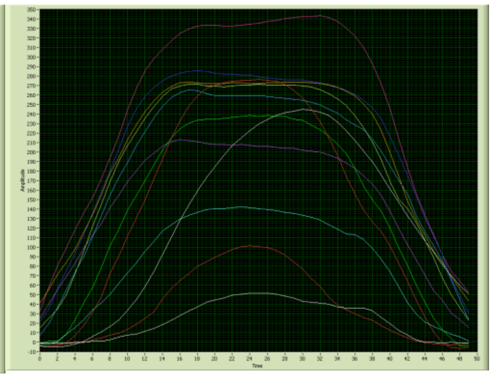


Figure 5. 1 Stress in Motion (SIM) sensor Modulas with 32 channels top; schema of the cross section of the sensor, bottom (courtesy Kistler Instrumente AG)

5.3 Sample of measurement results

The tyre pavement contact forces of a freight vehicle and a passenger vehicle are significantly different as shown in Table 5. 1. In these examples, the maximum force of the passenger vehicle is 340 N whereas that of a heavy vehicle is three times that at 1050 N. More examples are shown for the cases studied in chapter 5.

Table 5. 1 Tyre pavement contact forces (N) for ½ axle example of passenger car and freight vehicle

Case	Freight vehicle	Passenger car
Vehicle time stamp	M_2008_07_15@10_14_13_599.dat	M_2008_07_15@10_14_22_967.dat
3D		
2D		
Max Force [N]	1050	340

5.4 Sensor status

Although the Modulas sensor delivers important information with regard to tyre pavement contact forces the question of durability of these sensors needs to be addressed. Near the end of the Footprint I project (2006), six of the SIM sensor channels were malfunctioning. They displayed errors, thought to be either electrical or interferential in nature, whereby the signal decays very slowly after the truck has passed the sensor. This leads to an overestimation of not only the wheel load but, more importantly, the latch time. The increased latch time causes the sensor to detect passes in which more than one axle is present. These long passes contain significantly more data than the data acquisition system was designed to handle and the SIM sensor's data acquisition has had to be deactivated pending the resolution of this problem.

In spring 2007, the SIM sensor was examined by the manufacturer (Kistler Instrumente AG) and electrical adjustments were made to several of the channels. While this has not resolved the problem entirely, some progress has been made. Several channels do still exhibit the extended latch time however, and the system has been reprogrammed to discard recorded events with very long latch times. This has greatly reduced the amount of data collected.

Due to the large amount of data the Modulas sensor data acquisition has been activated as needed for example during the case studies (Chapter 10).

5.5 Conclusions

Two Modulas stress in motion sensors have been used at the A1 monitoring site since June 2005. The position of the FMS along a curve resulted in the loss of some data due to the fact that the vehicles would drive on the shoulder due to the curve. After 1.5 years at least 6 channels have malfunctioned. The exact number of malfunctioning channels can only be determined in the lab after de-installation. The data acquisition has been adjusted to bypass the failed channels. The measured results show that contact force distribution delivers vital information about the effect of tyres on pavement that cannot be gained by other means. For further development of the sensor higher resolution i.e. smaller channel width is recommended. Higher resolution will avoid the loss of potential peak data. For use on the highway a more robust system is needed. It cannot be expected that a customer will invest a high price in a device that has a very limited service life.

6 Noise Monitoring

6.1 General considerations

Noise emitted by heavy road vehicles depends on site specific factors such as pavement type, pavement age, pavement temperature, pavement condition and possible slope of the road. On the other hand there are vehicle specific factors such as vehicle class (according to the Swiss10 categories), vehicle speed and vehicle mass. Within one vehicle category there is significant variation of the emission of an individual vehicle. This is a consequence of construction details, maintenance and varying age of the vehicles and possible implementations of noise reduction measures. At the occasion of a measurement campaign during September 2005 at the A1 Footprint monitoring site the above mentioned vehicle specific factors were investigated.

6.2 Measurement results

The measurements were performed according to the geometry defined in the ISO standard [EN ISO 11819-1]. For each vehicle the maximum pass-by level was evaluated. Possible interference with sound from neighbour vehicles was corrected by an algorithm developed in Footprint phase I [Mayer 2007] and [Heutschi, 2008].

6.2.1 Statistics for different vehicle categories

In Figure 6. 1 the statistics of all pass-by measurements for each vehicle category is shown. The highest maximum levels are found for Swiss10 category “9”. However the differences between categories “8”, “9” and “10” are small (below 1.5 dB(A)). The variance within a category is about 2 dB(A) for 50% of the vehicles. More detailed information about the level distribution can be found in the histograms in Figure 6. 2 to Figure 6. 4 . The normalization for 80 km/h was done by assuming a linear dependency of the dB value and vehicle speed (0.17 dB per km/h). This first order approximation is valid in a range of about -15/+15 km/h around 80 km/h.

6.2.2 Dependency of vehicle speed

For a given site and vehicle category the most important parameter influencing sound emission is vehicle speed. Figure 6. 5 to Figure 6. 7 show the maximum pass-by levels in different speed classes. The tilted red line in the figures is the expected speed dependency for heavy vehicles according to the Swiss road traffic noise model SonRoad [Heutschi 2004] (see equation below which is valid for speeds between 40 and 120 m/h.); where v is speed in km/h.

$$L_{max} = 10 \log\left(10^{0.1\,(18.5 + 35 \log(v))} + 10^{0.1\left(76.9 + 10 \log\left(1 + \left(\frac{v}{56}\right)^{3.5}\right)\right)} \right)$$

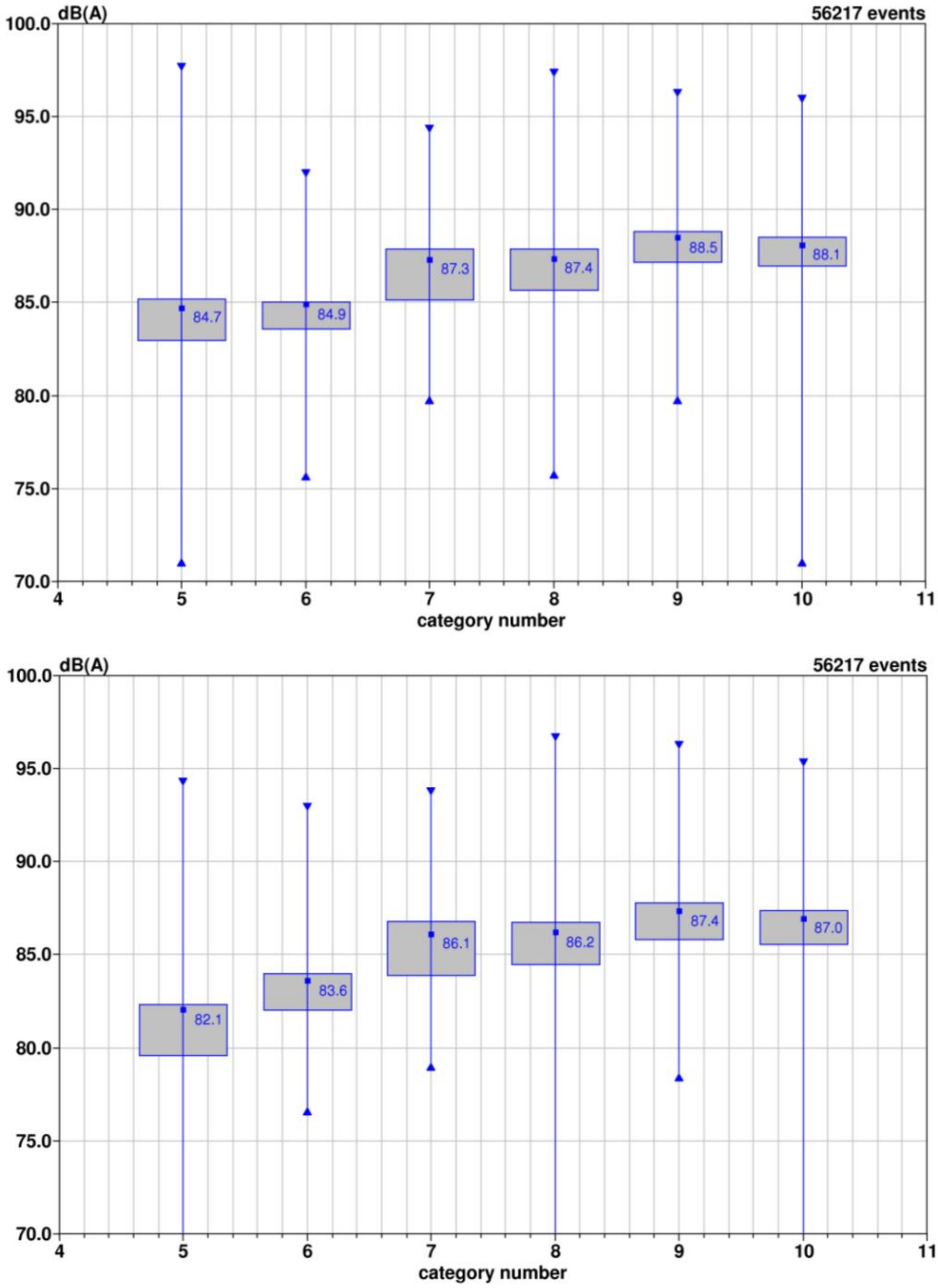


Figure 6. 1: dB(A)-pass-by level statistics of all measurements itemized in Swiss10 categories. The vertical lines bounded by triangles show maximum and minimum values, the grey shaded boxes denote the 50 % span, the labelled squares stand for the energetic mean values. Top: original data, bottom: levels normalized for 80 km/h (see below)

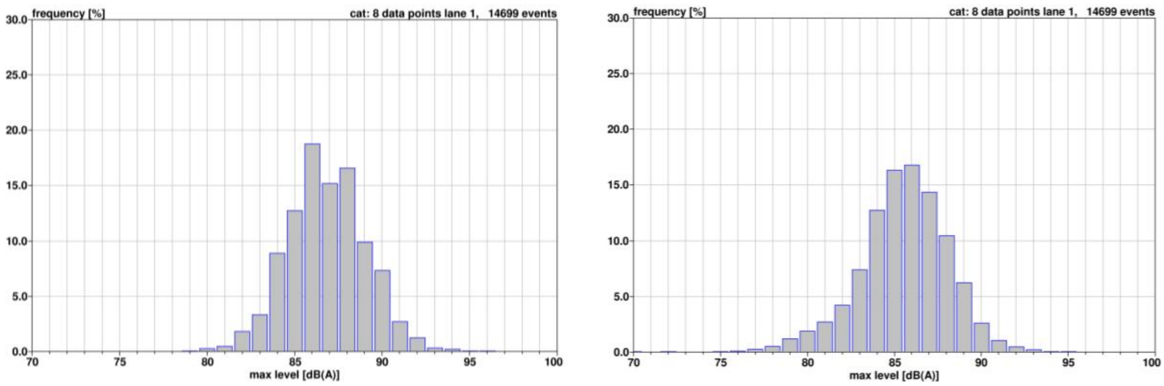


Figure 6. 2: Histogram of all maximum pass-by levels [dB(A)] for category ''8'' vehicles. Left: original data, right: levels normalized for 80 km/h (see below).

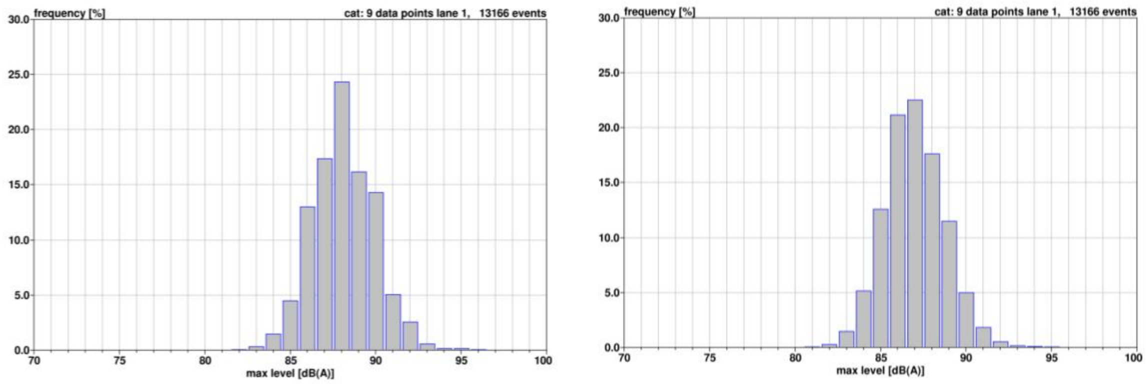


Figure 6. 3: Histogram of all maximum pass-by levels [dB(A)] for category ''9'' vehicles. Left: original data, right: levels normalized for 80 km/h (see below).

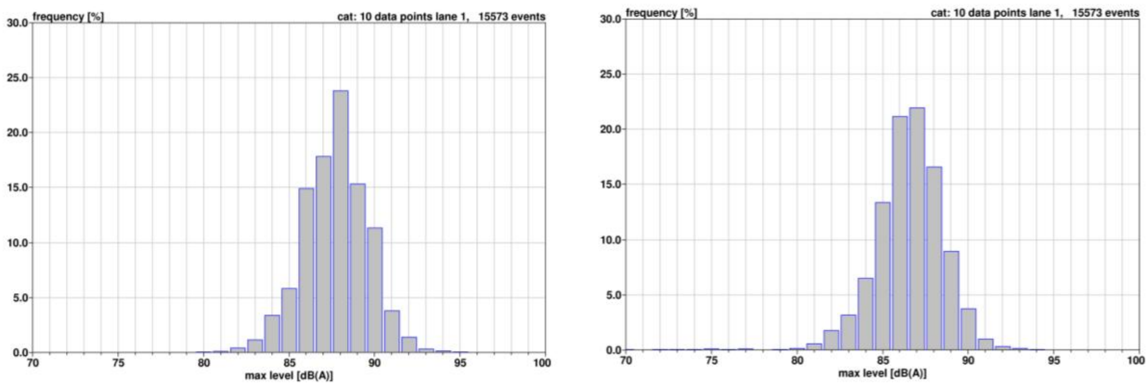


Figure 6. 4: Histogram of all maximum pass-by levels [dB(A)] for category ''10'' vehicles. Left: original data, right: levels normalized for 80 km/h (see below).

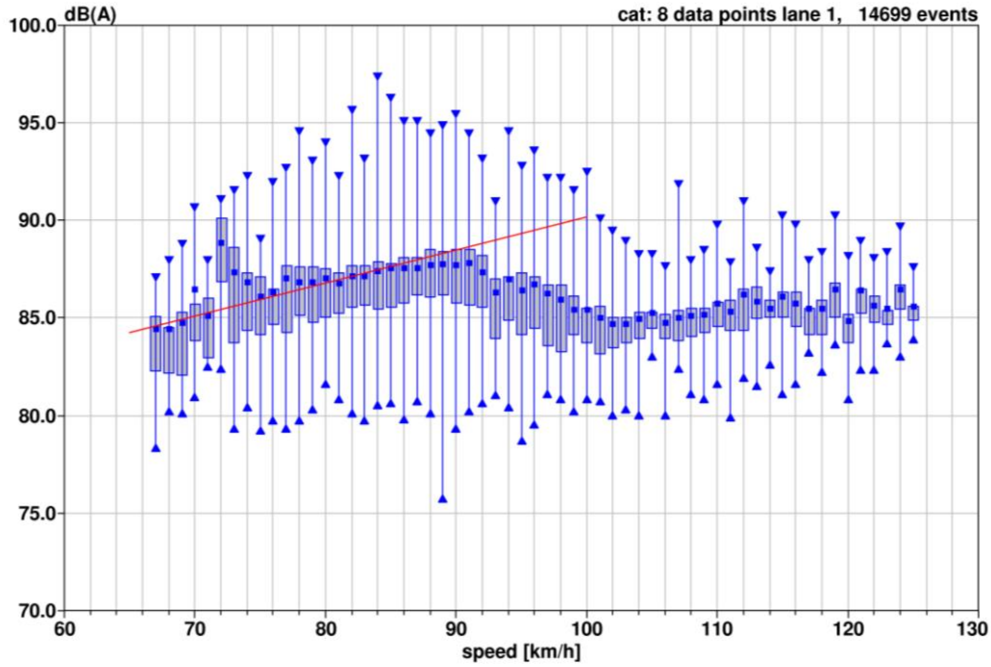


Figure 6. 5: Maximum pass-by levels [dB(A)] for category ''8'' vehicles in different speed classes. The vertical lines bounded by triangles show maximum and minimum values, the grey shaded boxes denote the 50 % span, the squares stand for the energetic mean values. Note that less than 10 % of the evaluated vehicles have speeds above 90 km/h

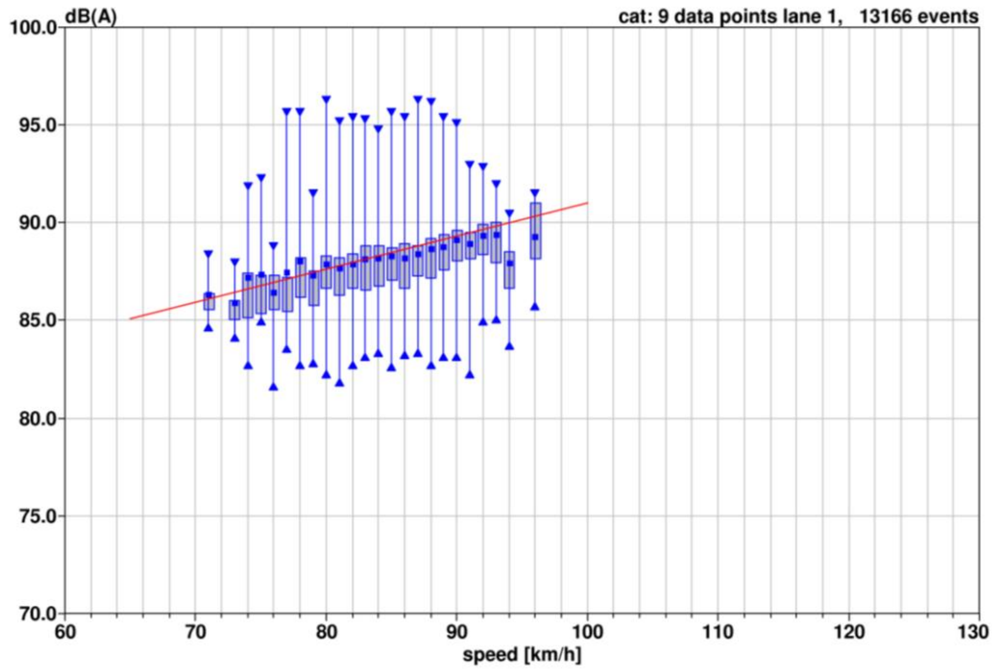


Figure 6. 6: Maximum pass-by levels [dB(A)] for category ''9'' vehicles in different speed classes.

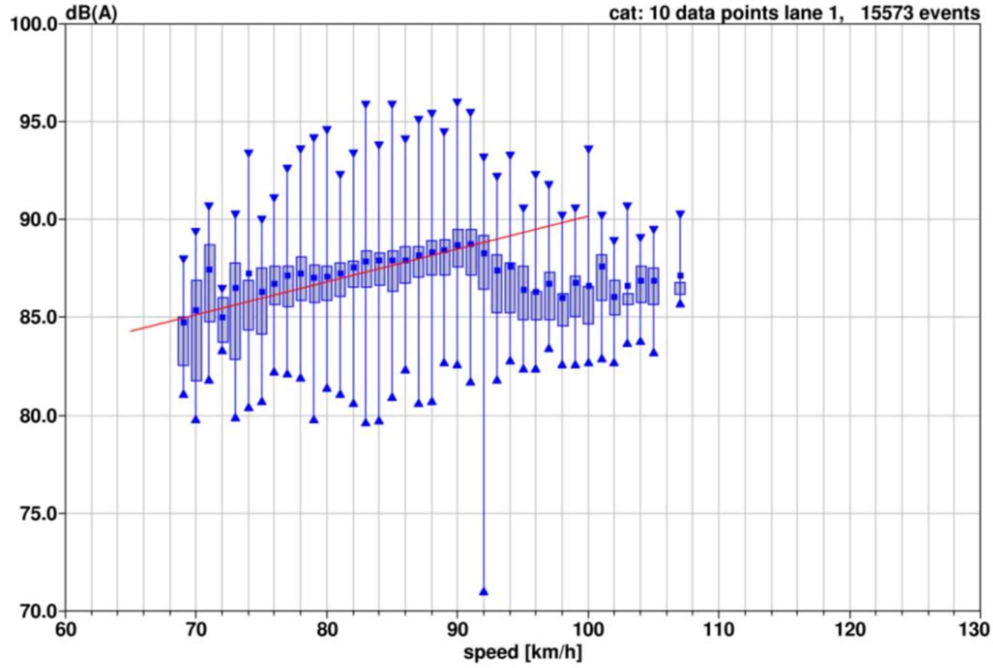


Figure 6. 7: Maximum pass-by levels [dB(A)] for category ''10'' vehicles in different speed classes.

Up to 90 km/h the measured speed dependency coincides with the SonRoad calculation model. Surprisingly enough for category ''8'' and ''10'' vehicles emission seems to decrease for speeds higher than 90 km/h. For speeds higher than about 100 km/h the speed dependency vanishes. The most probable explanation for this behaviour is an error in classification. Vehicles with speeds above 90 km/h are vans and medium heavy vehicles which have lower sound emission. There are almost no category ''9'' vehicles with speeds above 90 km/h. Category ''9'' vehicles are trucks with a trailer. Obviously these can be classified with almost no error.

6.2.3 Dependency of vehicle mass

The influence of vehicle mass was evaluated after normalising the measurements to a reference speed of 80 km/h (assumed speed according to SonRoad, see above). Figure 6. 8 to Figure 6. 10show the measured maximum pass-by levels in different weight classes. The influence of weight on sound emission is relatively small. This is an important aspect when it comes to the question of an optimization of the quotient ton/dB. For category ''8'' vehicles the level increases by 0.12 dB(A) per ton. In category ''9'' emission grows with 0.06 dB per ton. For category ''10'' vehicles the gradient is only 0.03 dB per ton.

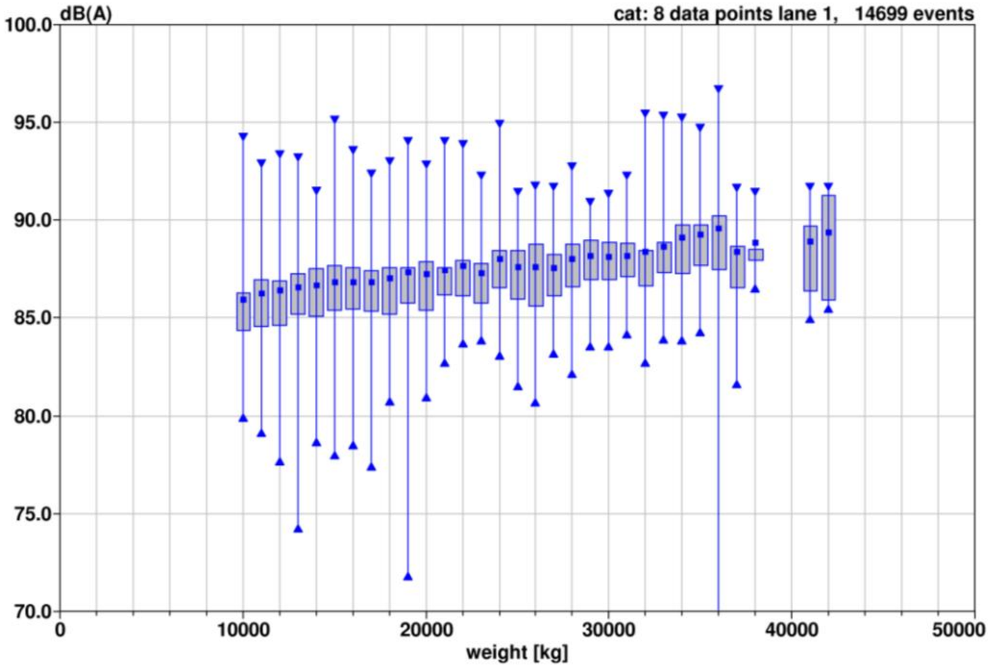


Figure 6. 8: Maximum pass-by levels [dB(A)] for category ''8'' vehicles in different weight classes.

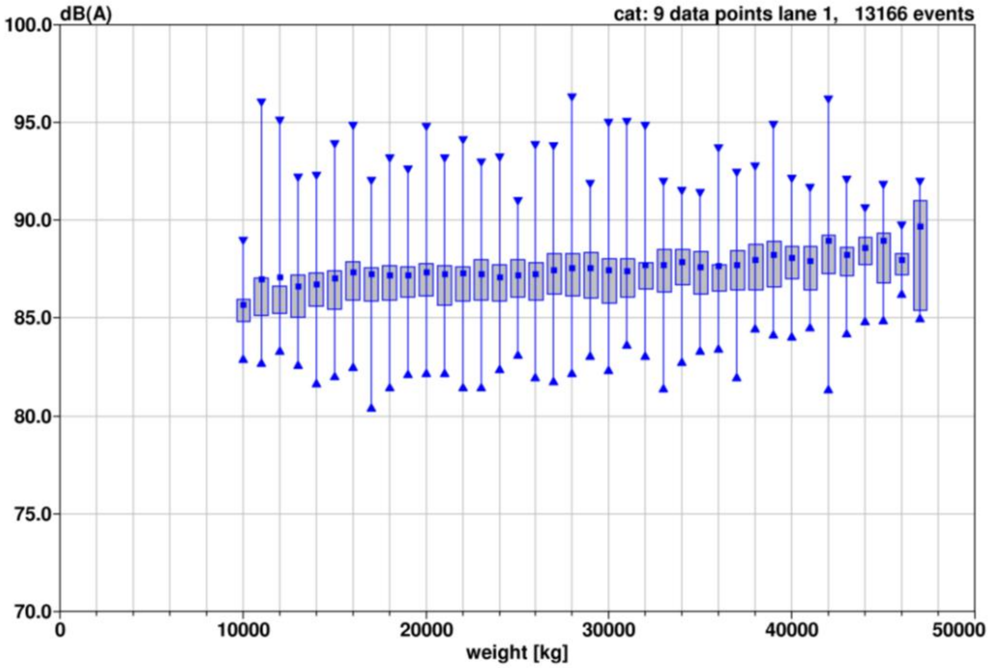


Figure 6. 9: Maximum pass-by levels [dB(A)] for category ''9'' vehicles in different weight classes.

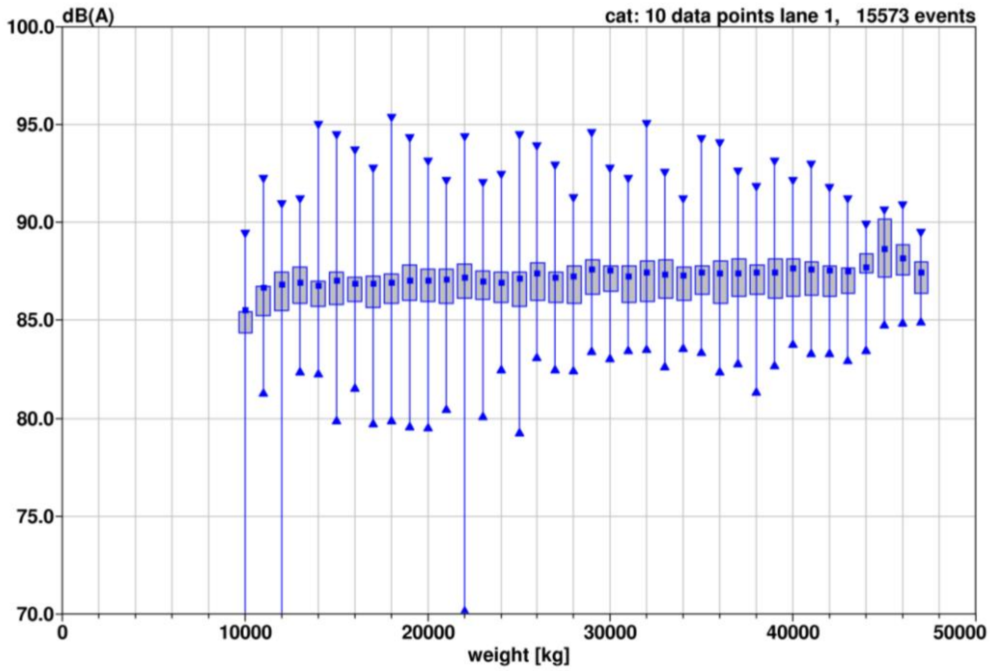


Figure 6. 10: Maximum pass-by levels [dB(A)] for category ''10'' vehicles in different weight classes.

6.3 Conclusions

From comparison with Footprint sites in the U.K. (Chapter 11) it was found that site specific factors have an influence on sound emission of the same order of magnitude as differences between quiet and noisy vehicles. It is therefore important to introduce relative and *not* absolute bonus/malus thresholds (Chapter14). In that sense the median value of all vehicles could be used as a reference for each site. One strategy would be to consider a certain percentage of quietest vehicles as "environmentally friendly" and a certain percentage of loudest vehicles as "environmentally unfriendly". Such a scheme based on the level distribution would account for the fact that the level differences between quiet and loud vehicles is highest for low-noise sites and smallest for loud sites.

Vehicle speed is identified as an important parameter influencing noise emissions. The speed dependency on noise can be calculated with high accuracy. It is proposed to normalize measured sound levels for a reference speed of 80 km/h before comparing them with bonus/malus thresholds. Then the acoustical footprint describes the vehicle and not the driving condition. It would be too easy to get the "environmentally friendly" label just by lowering the speed at the Footprint station.

In order to minimize sound emission for a given amount of goods to be carried, it would be beneficial to use the heaviest vehicles possible which would result in a minimal number of trucks. However such a noise optimization would certainly be disadvantageous regarding damage to the pavement.

7 Pavement Deformation Monitoring

7.1 Deformation measurements with magnetstritive sensors

7.1.1 Sensor performance

As described in the previous Report no.1193 of July 2007 *"Swiss Contribution to Eureka Project Logchain Footprint E!2486"* [Poulikakos 2007] the displacement measurement is based on commercially available magnetostrictive sensors. The schematic of the magnet installation in the different pavement depths and the positioning of the sensors S1, S2 and S3 on the road are given in **Figure 7. 1**: Sensor S1 is positioned at the right edge of the slow lane.

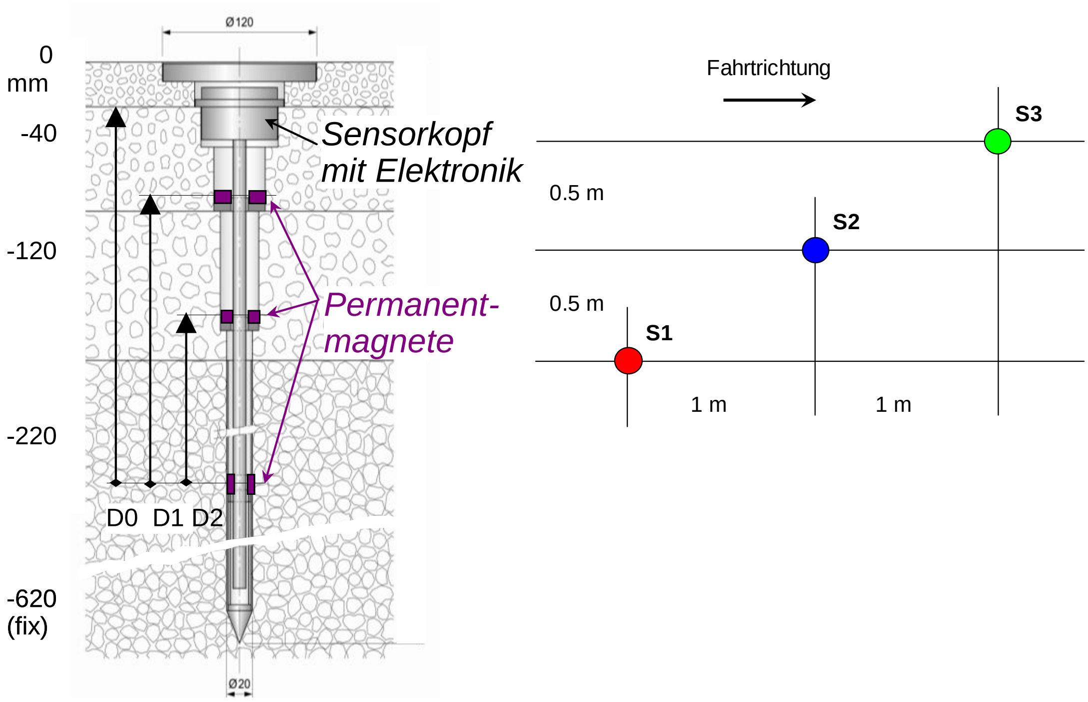


Figure 7. 1 Schematic of the sensor installation and positioning on the road

Since the beginning of the deformation measurements there was no failure detected due to hardware defects of the sensors itself. But since February 2008, two of the three magnets on Sensor S3 failed to produce signals. The temporary lack of data is caused by computer rebooting problems and soft ware updating and testing.

7.1.2 Long term data

Despite some lack of data the long term data indicate the deterioration of the pavement. Two major statements can be made: The maximal vertical plastic pavement deformation over the last three years is in the range of 1 mm (**Figure 7. 2**). And this maximum deformation is seen on sensor S2. That is the vast majority of trucks will pass over this sensor which is installed 0.5 meter from the right edge of the slow lane (**Figure 7. 3**). The shown deformations D0, D1 and D2 are related to the magnet M3 which is placed in the gravel bed of the road and is regarded as a fixed-point.

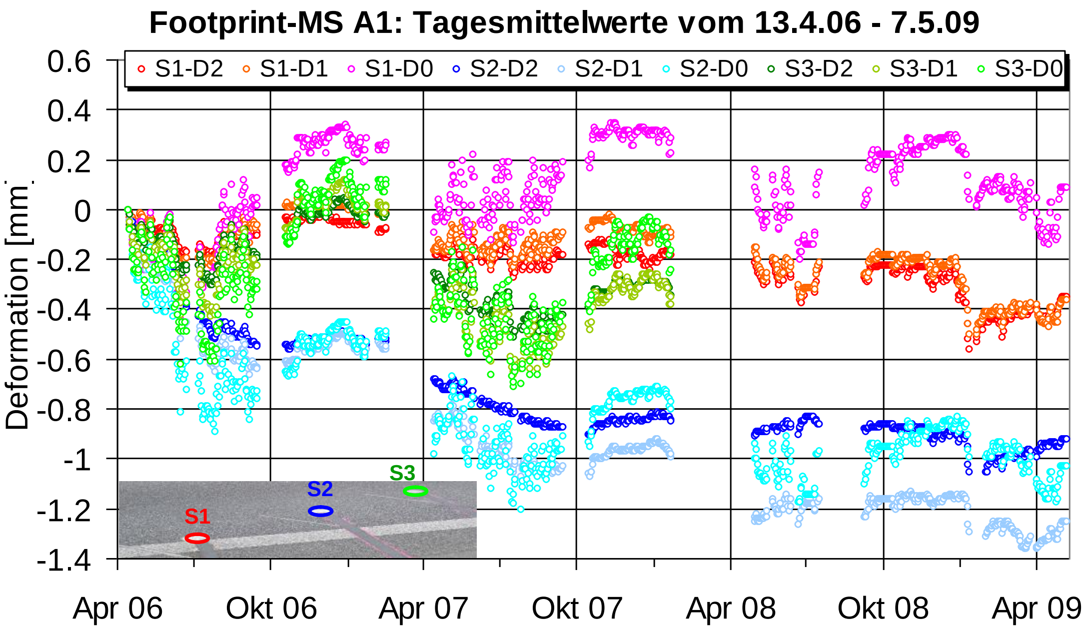


Figure 7. 2 Daily mean values of the measured deformations since April 2006

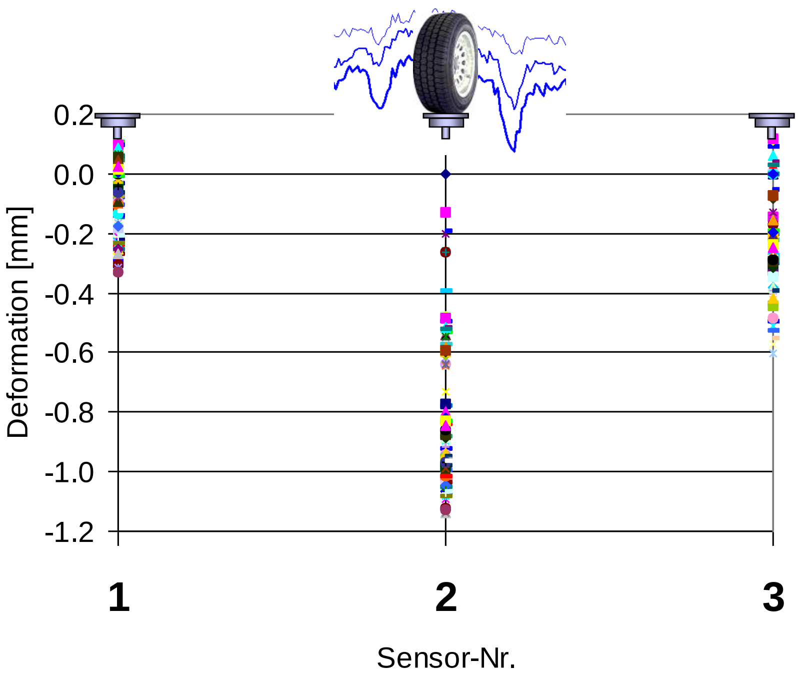


Figure 7. 3 Mean deformations per sensor out of 3 magnets since April 2006

7.2 Conclusions

The magnetostrictive displacement transducers have been in service for four years since June 2005 (continuous measurements since April 2006). The measured vertical pavement deformations during this time are small. In case of further measurements on another site a bigger array of sensors is proposed for more precise information about driving behaviour.

8 Vibration Monitoring

8.1 Overview

Vibration induced by road traffic can cause discomfort of residents living near highways, can affect vibration sensitive processes and might even produce damage in buildings. Vibration levels are affected by the characteristics of the vehicles, driving conditions and factors which are specific for the site (Hajek et al. 2005). The objective of performing vibration measurements at the FMS is to determine what types of vehicles (identified using the information registered by the WIM sensor) produce the highest vibration levels under similar site conditions.

8.2 Measurement results

Traffic vibration guidelines usually define the vibration in terms of the ground velocity, as the sensitivity of humans and the damage of buildings seem to be related only to peak levels and not to the typical frequency contents of the ground borne vibration waves [CALTRANS 1996]. The vibration measuring system at the FMS was designed to continuously measure the ground velocity outside the road using an electromagnetic velocity sensor (geophone) , mounted on the ground using a stake of cruciform section.

When trying to assess human discomfort or building damage due to vibrations, various guidelines 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). 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 0.15 mm/s PPV is the threshold for human perception: below this level humans are not aware that the ground is vibrating. Maximum PPV measured at the FMS for the cases presented in Chapter 10 were compared with this threshold and results are shown in Table 10. 2. For the cases presented, the maximum PPV for each passing vehicle was recorded. Vehicle 24 caused the highest vibration peak measured at the sensor position. The value of 0.041 mm/s PPV was considerably below the threshold of human perception. The results of this sample population corroborated previous measurements that showed the ground borne vibrations at this site are far below the threshold of perception and don't represent and environmental problem [Poulikakos 2007].

8.3 Conclusions

Vibration monitoring at the footprint monitoring site has indicated that the measured values are below limits of perception at this site. However this can change depending on the condition of the road and traffic. Vibration caused by road traffic is of primary concern on bridges.

9 Gaseous and Particle Emissions

9.1 Exhaust gas pollutant emissions from diesel engines

Heavy duty vehicles are normally powered by diesel engines, a small portion of buses and motor-coaches are powered by natural gas engines. Because most heavy vehicles use diesel engines, this section focuses on diesel engine technology.

Diesel engines convert chemical energy to mechanical energy by compression ignition and combustion of a liquid fuel. The fuel is injected with high pressure to the combustion chambers where it mixes with air. In regions where a certain bandwidth of the air-to-fuel ratio is reached, the diffusion-controlled combustion process takes place. Within these combustion zones, the stoichiometry varies: Certain regions face a deficit of air ("rich zones"), other regions face an excess of air ("lean zones"). Due to incomplete combustion and the oxidation of nitrogen at high temperatures, carbon monoxide (CO), unburned hydrocarbons (UHC), particles and oxides of nitrogen (NOx that represents the sum of NO and NO2) are formed. Rich zones lead to high amounts of CO, UHC and particles, lean zones lead to high amounts of NOx. All these emissions (CO, UHC, NOx and particles) are limited in engine emission regulations. The different emissions have different effects:

- CO emissions are poisonous for the blood when high concentrations are present. CO levels from diesel engines are non-critically low and can be relatively easily lowered close to zero using an oxidation catalyst.
- Some hydrocarbons lead to the typical diesel exhaust smell and some are suspected to be carcinogenic (aromatic compounds, polycyclic aromatic hydrocarbons). As for CO, UHC levels from diesel engines are non-critically low and can be relatively easily lowered close to zero using an oxidation catalyst.
- The effect of NOx is critical. NO is less hazardous than NO2. NO2 is a lung irritant and contributes in presence of sunlight and volatile organic compounds strongly to the formation of ozone. Raw emissions from diesel engines consist mainly from NO while some exhaust gas after treatment technologies (e.g. catalyzed particle filters) oxidize NO to NO2. It is likely that NO2 (and not only the sum of NO and NO2 as up to now) will be limited in future legislations.
- Particles are usually divided into solid and volatile particles. Solid particles (soot) consist of agglomerated carbonaceous primary particles that are normally larger compared to the smaller volatile particles. In respect to their difference in size distribution, these two kinds of particles are sometimes called „accumulation mode particles“ and „nucleation mode particles“. The formation of volatile (nucleation mode) particles depends very strongly on their „history“ in the dilution process with ambient air after the exhaust pipe (dilution, cooling, humidity, residence time, and presence of hydrocarbons). Particles from diesel engines have typical diameters between 10 and 400 nm. Unfortunately, these small particles can not be intercepted by the nose but are passed through the bronchia and even to the lung alveolus. The larger particles can cause allergic asthma, the smallest are suspected to pass through to the blood system and particles with condensates are suspected to promote cancer. It can be said that the smaller the particles are, the deeper they affect the human body. In engine emission regulations, particle mass emissions are limited. To measure particle masses, the engine's exhaust gases are diluted with conditioned air and sucked through a filter. The weighing of the filter prior and after the measurement allows the determination of the particle mass. Because concerns about health effects are attributed especially to very small particles and these small particles do significantly contribute to the mass, particle counting methods have been established in the past few years. It is very likely that particle number emission limits for engines will be introduced as soon as new European legislations will be adopted.

Different particle definitions cause often confusions. For ambient air, limits for PM10 exist and are monitored in many sites across Europe. PM10 describes the mass of particles with sizes smaller than 10 μm (10'000 nm). It is not surprising that the PM10 measurements are usually not dominated by the large number of small particles from diesel combustion but by smaller numbers of less problematic larger particles (pollen, road dust re-suspension, abrasion, etc.). Several countries started activities to establish PM2.5 limits (mass of particles with sizes smaller than 2.5 μm) as an additional air quality standard.

9.2 Possibilities to reduce pollutant emissions from diesel engines

To reduce tailpipe pollutant emissions, either the engine's raw emissions created during the combustion process can be lowered or the engine's emissions can be removed using exhaust gas after treatment. These two groups are explained in the subsequent sections.

9.2.1 Raw emission reduction

For good efficiency of the thermodynamic cycle, high combustion temperatures are necessary. Unfortunately, high temperatures cause high NOx because nitrogen that is present in the air is oxidised. In engine development, this fact is known as the "fuel-consumption versus NOx trade-off". One possibility to reduce NOx without too much fuel consumption penalty is exhaust gas recirculation (EGR). To do so, hot exhaust gases are cooled and fed back to the air intake side of the engine. With this measure, the oxygen content in the fresh air is lowered and less NOx is formed during combustion. Unfortunately, the reduction of the available oxygen increases particle, UHC and CO emissions. For all diesel engines but especially for those with EGR, a "NOx versus particles trade-off" exists.

Old engines had relatively simple injection systems that just had the possibility to inject the fuel once per working cycle. More modern injection systems (e.g. common rail) have the possibility to inject up to five times different quantities of fuel per working cycle. This degree of freedom is used to achieve cleaner combustion by better air/fuel mixing and combustion shape forming. It is possible with these new systems to lower the emission levels but the trade-offs described above remain.

9.2.2 Exhaust gas after treatment

CO and UHC

CO and UHC can be relatively easily removed to a large extent using an oxidation catalyst. Such catalysts oxidise CO and UHC using oxygen present in the exhaust gas with precious metals being the catalytic active materials. Oxidation catalysts can also be coated in a way that the oxidation of NO to NO2 is promoted which helps to regenerate particle traps (see later), this obviously also increases NO2 emissions.

NOx

NOx has to be removed if the combustion of the diesel engine is set-up for low-particle but high-NOx emissions. One possibility is NOx storage in a special catalyst. As soon as the catalyst's NOx storage capacity is fully used, it has to be regenerated by a phase of engine operation under rich combustion conditions. This phase leads on the one hand to increased fuel consumption and on the other hand to very high particle emissions so that a particle trap (see later) is absolutely necessary. Because of these two drawbacks, NOx storage technology is not used in the very efficiency-sensitive heavy duty engine market.
The other possibility is called Selective Catalytic Reduction (SCR) where NOx is converted to N_2 and H_2O using ammonia (NH_3). Due to safety and other issues, ammonia is not transported on board of the vehicle but hydrolysed at temperatures above 200 °C in the exhaust system from an aqueous urea ($CO(NH_2)_2$) solution. This solution (32.5% urea, rest water) is available at many fuelling stations across Europe under the market name "AdBlue". SCR technology is used for European heavy duty vehicles since the year 2005.

Particles

Particles can be removed very efficiently using so-called wall-flow particle traps. Best available technology filters remove particles to the level of the ambient air. In wall-flow particle traps, the exhaust gas stream is pressed through a micro-porous ceramic material. This technology has the drawback that a pressure-drop is induced over the filter which increases the engine's fuel consumption. Particle filters regenerate automatically (i.e. the soot is oxidised) when the temperature is high enough. In some applications (e.g. urban buses), the engine power is very low over long periods of time so that the particle filter is not regenerated automatically. Therefore, catalyzed particle filters are often used where the catalyst produces NO_2. NO_2 is able to start the regeneration of the trap at lower temperatures but the NO_2 emissions are obviously also increased (the NO_2 emissions of urban buses using such traps can often be smelled, the smell is similar to chlorine). If less NO_2 has to be emitted, the filter regeneration is guaranteed by the addition of fuel before the trap or by lowering the engine efficiency (which increases the exhaust gas temperature) by late injection or other measures.

There exists also particle after treatment systems with less effectiveness than the wall-flow particle traps. Some manufacturers use a so-called PM-catalyst. In a PM-catalyst, the exhaust gas flows along open catalyzed channels that promote the oxidation of particles. PM-catalysts have the advantage that they add less back-pressure to the engine; they can not plug and do not need a special regeneration strategy.

Figure 9. 1 depicts the efficiency of a wall-flow particle trap and a PM-cat. The measurements were performed on a modern heavy duty diesel engine running at full load at Empa using a Scanning Mobility Particle Sizer (SMPS) spectrometer. It can be seen that a PM-cat is able to reduce about 30% of the particles over the whole size spectrum. The results from the wall-flow trap show the extremely high efficiency of such a system: the particle emissions are reduced to virtually zero over the whole size spectrum.

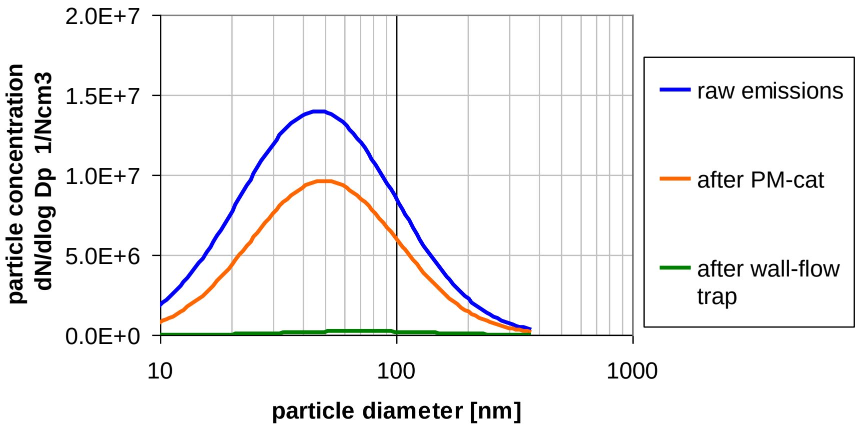


Figure 9. 1 Particle size distributions prior and after a wall-flow trap and a PM-catalyst

9.3 Emission limits

Pollutant emissions of heavy duty engines are limited in most countries worldwide. Currently, three different important legislations with different limits, procedures and reference fuels exist: EC (Europe), EPA (USA) and Japan. There are activities in the UNECE work package 29 (World Forum for Harmonization of Vehicle Regulations) that have the goal to establish worldwide emission standards and procedures in the future. For the European perspective, the current emission legislation is described in the directive 2005/55/EC [DIR 2005]. The emissions are determined on engine test benches, i.e. the engine is directly coupled to a dynamometer and the emissions are measured in steady state operating points and/or in transient cycles. Figure 9. 2 depicts a typical setup.

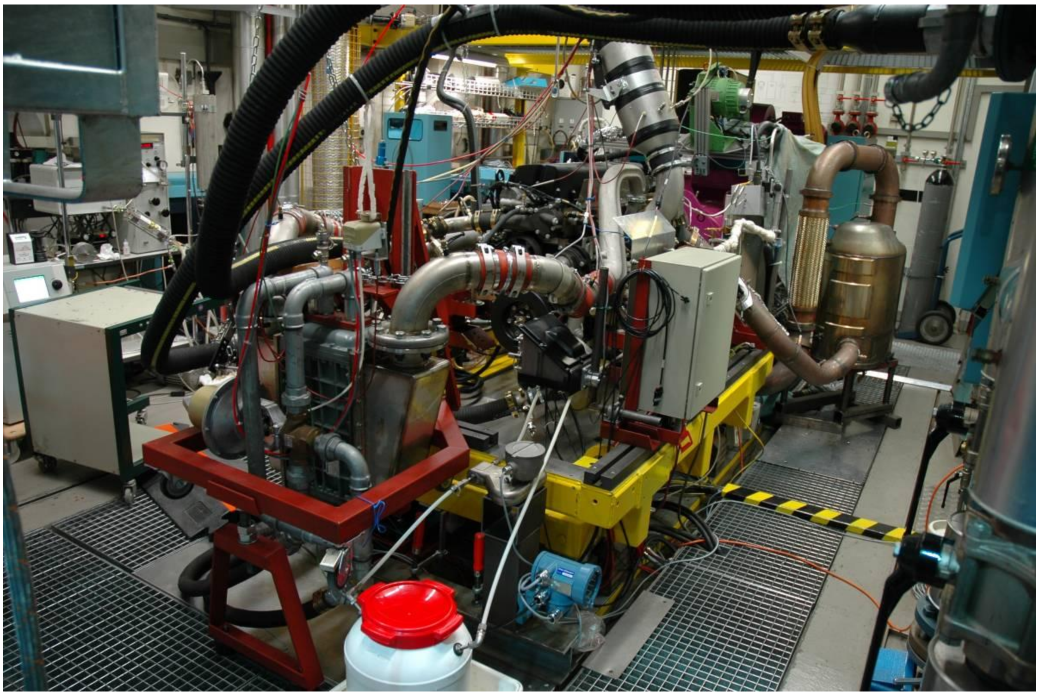


Figure 9. 2: Heavy duty engine on an engine test bench at Empa

For certification tests, the combustion air is conditioned and a reference fuel is used. In the actual European legislation, engines without exhaust gas after treatment systems are driven in a 13-mode test (ESC: European Stationary Cycle). If an engine has an exhaust gas after treatment system. It is additionally driven in a transient cycle (ETC: European Transient Cycle). These cycles are defined relative to the engine's performance: Normalised speed versus normalised torque is unnormalised using engine-specific data (minimum and maximum speed, full load torque). The emissions are determined in a work-specific manner (i.e. in grammes per kilowatt-hour of engine work). Figure 9. 3 depicts the European emission limit values for the stages Euro-I up to Euro-V. It can clearly be seen that the emission limits have been strongly tightened over the last two decades. The European Commission is in the definition phase of the next stage (Euro-VI, most likely coming into force in 2013) and a reduction of 67% particles and 80% Nox relative to Euro-V is likely to be decided.

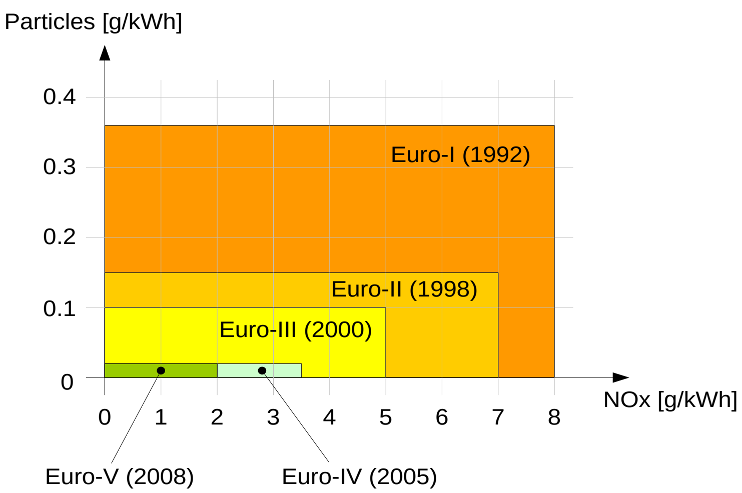


Figure 9. 3: Nox and particle limits for heavy duty engines for the Euro-I to Euro-V stages.

Heavy duty engines up to the Euro-III stage were comparably simple and did not need any exhaust gas after treatment. Some vehicles used particle traps to meet local regulations (e.g. at construction sites in tunnels) or as voluntary measures (e.g. urban buses). The adoption of the Euro-IV and Euro-V emission stages made the use of emission reduction technologies necessary. Some manufacturers followed the path to implement a low-particle/high-Nox combustion strategy and lower the Nox with SCR exhaust gas after treatment. Other manufacturers followed the low-Nox combustion path using EGR and reduced particle emissions with a PM-catalyst. Recently, one manufacturer introduced an engine that does not need a particle or Nox after treatment to meet the Euro-V limits. The engine combines low-particle and low-Nox combustion by high-pressure boosting and high EGR rates using two-stage EGR cooling.

9.4 Pollutant emissions of heavy duty vehicles

Type-approved engines can be installed in different kinds of heavy duty vehicles (bus, tractor-trailer, rigid truck, etc.). The power consumption of the different vehicles varies very much due to differences in vehicle mass, air drag, driving pattern, road slope, load of auxiliaries such as air-conditioning, etc. Therefore, the emission factors in g/km for the different vehicles are not straightforward to calculate, even if the type approval emission data of the engine is known. There exist only two approaches to determine the pollutant emissions of individual heavy duty vehicles:

Put the vehicle on a roller dynamometer, simulate the road load and drive representative cycles.

Drive the vehicle on the street and instrument it with mobile emission analysers.

Both approached are very intensive regarding time and monetary resources. The mobile emission measurement approach has become more important, there are ideas on the European level to implement “Not-To-Exceed” (NTE) pollutant emission limits which could be monitored on selected vehicles using portable emission measurement devices. Some countries perform in-use compliance programs. Heavy duty vehicles that are suspicious for high pollutant emissions are brought into laboratories and put on a roller dynamometer. If the roller dynamometer tests indicate high emissions, the engine is dismounted and put on an engine test bench where the type approval tests are driven. If the engine behaves outside the tolerances, the manufacturer is forced to develop a technical upgrade and apply it to all the engines affected.

There are also attempts to measure emissions of vehicles driving by a measurement site remotely. Unfortunately, these approaches do not give reliable data; mainly because the dilution ratio of the exhaust gases with ambient can not be determined. Additionally, a single-shot measurement does not give any useful information on the overall pollutant emission performance of a vehicle; the emission behaviour is very non-linear.

In order to create systematic data for emission factors (g/km) of heavy duty vehicles on an aggregated level, the environmental agencies of Austria, Germany and Switzerland have established cooperative research activities. The Netherlands and Sweden have also joined the group. A major outcome of this group is the HBEFA (Handbook of Emission Factors for Road Transport) data base (Keller 2004) which was launched 1995 and is frequently updated with emission data of new technologies. This HBEFA methodology was also used for the European FP5 project ARTEMIS (Assessment and Reliability of Transport Emission Models and Inventory Systems).

The basic HBEFA method to estimate emission factors for the different heavy duty vehicles is to dismount in-use engines form vehicles and measure them on test benches. The pollutant emissions of the different vehicles are then modelled using the measured pollutant data which are combined with vehicle and driving pattern parameters. The methodology is described in [2]. The simulation gives systematic emission factors for different categories of the HDV fleet (see Figure 9. 4 and Figure 9. 5) with different loadings for different representative driving cycles at different road gradients. The results are emission factors for more than 30.000 combinations of vehicle categories, driving cycles, road gradients and vehicle loadings. These simulated emission factors are then used as an input for the HBEFA that allows the user a simple simulation of aggregated emission factors for different traffic situations. HBEFA data is normally used for national emission reporting, for sensitivity studies or for local environmental studies.

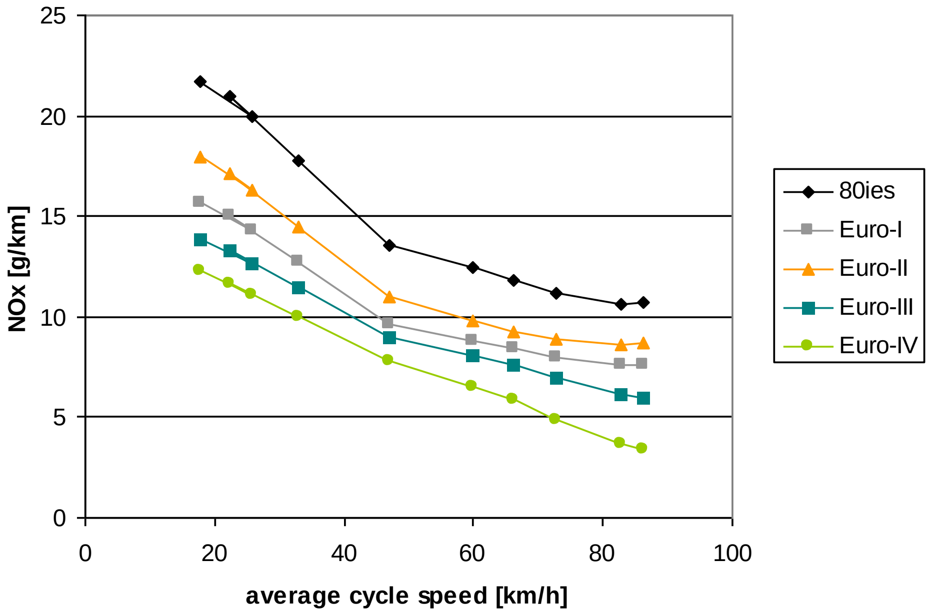
FS	FS-Name	FS	FS-Name	FS	FS-Name
		1413000	RigidTruck gasoline		
1423105	RigidTruck <7,5t 50ies	1423205	RigidTruck 7,5-12t 50ies	1423305	RigidTruck 12-14t 50ies
1423106	RigidTruck <7,5t 60ies	1423206	RigidTruck 7,5-12t 60ies	1423306	RigidTruck 12-14t 60ies
1423107	RigidTruck <7,5t 70ies	1423207	RigidTruck 7,5-12t 70ies	1423307	RigidTruck 12-14t 70ies
1423108	RigidTruck <7,5t 80ies	1423208	RigidTruck 7,5-12t 80ies	1423308	RigidTruck 12-14t 80ies
1423110	RigidTruck <7,5t EURO1	1423210	RigidTruck 7,5-12t EURO1	1423310	RigidTruck 12-14t EURO1
1423120	RigidTruck <7,5t EURO2	1423220	RigidTruck 7,5-12t EURO2	1423320	RigidTruck 12-14t EURO2
1423130	RigidTruck <7,5t EURO3	1423230	RigidTruck 7,5-12t EURO3	1423330	RigidTruck 12-14t EURO3
1423140	RigidTruck <7,5t EURO4	1423240	RigidTruck 7,5-12t EURO4	1423340	RigidTruck 12-14t EURO4
1423150	RigidTruck <7,5t EURO5	1423250	RigidTruck 7,5-12t EURO5	1423350	RigidTruck 12-14t EURO5
1423405	RigidTruck 14-20t 50ies	1423505	RigidTruck 20-26t 50ies	1423605	RigidTruck 26-28t 50ies
1423406	RigidTruck 14-20t 60ies	1423506	RigidTruck 20-26t 60ies	1423606	RigidTruck 26-28t 60ies
1423407	RigidTruck 14-20t 70ies	1423507	RigidTruck 20-26t 70ies	1423607	RigidTruck 26-28t 70ies
1423408	RigidTruck 14-20t 80ies	1423508	RigidTruck 20-26t 80ies	1423608	RigidTruck 26-28t 80ies
1423410	RigidTruck 14-20t EURO1	1423510	RigidTruck 20-26t EURO1	1423610	RigidTruck 26-28t EURO1
1423420	RigidTruck 14-20t EURO2	1423520	RigidTruck 20-26t EURO2	1423620	RigidTruck 26-28t EURO2
1423430	RigidTruck 14-20t EURO3	1423530	RigidTruck 20-26t EURO3	1423630	RigidTruck 26-28t EURO3
1423440	RigidTruck 14-20t EURO4	1423540	RigidTruck 20-26t EURO4	1423640	RigidTruck 26-28t EURO4
1423450	RigidTruck 14-20t EURO5	1423550	RigidTruck 20-26t EURO5	1423650	RigidTruck 26-28t EURO5
1423705	RigidTruck 28-32t 50ies	1423805	RigidTruck >32t 50ies	1425005	TT/AT <7,5t 50ies
1423706	RigidTruck 28-32t 60ies	1423806	RigidTruck >32t 60ies	1425006	TT/AT <7,5t 60ies
1423707	RigidTruck 28-32t 70ies	1423807	RigidTruck >32t 70ies	1425007	TT/AT <7,5t 70ies
1423708	RigidTruck 28-32t 80ies	1423808	RigidTruck >32t 80ies	1425008	TT/AT <7,5t 80ies
1423710	RigidTruck 28-32t EURO1	1423810	RigidTruck >32t EURO1	1425010	TT/AT <7,5t EURO1
1423720	RigidTruck 28-32t EURO2	1423820	RigidTruck >32t EURO2	1425020	TT/AT <7,5t EURO2
1423730	RigidTruck 28-32t EURO3	1423830	RigidTruck >32t EURO3	1425030	TT/AT <7,5t EURO3
1423740	RigidTruck 28-32t EURO4	1423840	RigidTruck >32t EURO4	1425040	TT/AT <7,5t EURO4
1423750	RigidTruck 28-32t EURO5	1423850	RigidTruck >32t EURO5	1425050	TT/AT <7,5t EURO5
1425105	TT/AT <28t 50ies	1425205	TT/AT 28-34t 50ies	1425305	TT/AT >34-40t 50ies
1425106	TT/AT <28t 60ies	1425206	TT/AT 28-34t 60ies	1425306	TT/AT >34-40t 60ies
1425107	TT/AT <28t 70ies	1425207	TT/AT 28-34t 70ies	1425307	TT/AT >34-40t 70ies
1425108	TT/AT <28t 80ies	1425208	TT/AT 28-34t 80ies	1425308	TT/AT >34-40t 80ies
1425110	TT/AT <28t EURO1	1425210	TT/AT 28-34t EURO1	1425310	TT/AT >34-40t EURO1
1425120	TT/AT <28t EURO2	1425220	TT/AT 28-34t EURO2	1425320	TT/AT >34-40t EURO2
1425130	TT/AT <28t EURO3	1425230	TT/AT 28-34t EURO3	1425330	TT/AT >34-40t EURO3
1425140	TT/AT <28t EURO4	1425240	TT/AT 28-34t EURO4	1425340	TT/AT >34-40t EURO4
1425150	TT/AT <28t EURO5	1425250	TT/AT 28-34t EURO5	1425350	TT/AT >34-40t EURO5
1423109	RigidTruck <7,5t DE-East	1423209	RigidTruck 7,5-12t DE-East		
		1425109	TT/AT <28t DE-East	1425209	TT/AT 28-34t DE-East

Figure 9. 4: HBEFA vehicle categories for heavy goods vehicles (from [Keller 2004]).

FS	FS-Name	FS	FS-Name	FS	FS-Name
		626105	Coach <18t Standard 50ies	626205	Coach >18t 3-Axes 50ies
		626106	Coach <18t Standard 60ies	626206	Coach >18t 3-Axes 60ies
		626107	Coach <18t Standard 70ies	626207	Coach >18t 3-Axes 70ies
		626108	Coach <18t Standard 80ies	626208	Coach >18t 3-Axes 80ies
		626110	Coach <18t Standard EURO1	626210	Coach >18t 3-Axes EURO1
		626120	Coach <18t Standard EURO2	626220	Coach >18t 3-Axes EURO2
		626130	Coach <18t Standard EURO3	626230	Coach >18t 3-Axes EURO3
		626140	Coach <18t Standard EURO4	626240	Coach >18t 3-Axes EURO4
		626150	Coach <18t Standard EURO5	626250	Coach >18t 3-Axes EURO5
		626909	Coach <16t DE-East		
727105	Ubus Midi <15t 50ies	727205	Ubus Standard 15-18t 50ies	727305	Ubus Artic. >18t 50ies
727106	Ubus Midi <15t 60ies	727206	Ubus Standard 15-18t 60ies	727306	Ubus Artic. >18t 60ies
727107	Ubus Midi <15t 70ies	727207	Ubus Standard 15-18t 70ies	727307	Ubus Artic. >18t 70ies
727108	Ubus Midi <15t 80ies	727208	Ubus Standard 15-18t 80ies	727308	Ubus Artic. >18t 80ies
727110	Ubus Midi <15t EURO1	727210	Ubus Standard 15-18t EURO1	727310	Ubus Artic. >18t EURO1
727120	Ubus Midi <15t EURO2	727220	Ubus Standard 15-18t EURO2	727320	Ubus Artic. >18t EURO2
727130	Ubus Midi <15t EURO3	727230	Ubus Standard 15-18t EURO3	727330	Ubus Artic. >18t EURO3
727140	Ubus Midi <15t EURO4	727240	Ubus Standard 15-18t EURO4	727340	Ubus Artic. >18t EURO4
727150	Ubus Midi <15t EURO5	727250	Ubus Standard 15-18t EURO5	727350	Ubus Artic. >18t EURO5
		727709	Ubus <20t DE-East	727809	Ubus >20t DE-East

Figure 9. 5: HBEFA vehicle categories for buses (from [Keller 2004]).

The drawback of the HBEFA method is that the available emission factor data is only valid for an average vehicle of the category. Additionally, new engine technologies coming to the market have first to collect mileage before they can dismounted and measured to create new data for the HBEFA. The consequence is that the current version 2.1 of HBEFA (released in 2004) does not include confirmed data on Euro-IV and Euro-V technologies but relies on estimations. An update with confirmed Euro-IV and Euro-V data is likely to be released soon. Figure 9. 6 depicts the emission values provided by HBEFA 2.1 for a tractor-trailer with a mass of 40 tons (categoriy “TT/AT >34-40t” from Figure 9. 4). The emissions are plotted versus the average cycle speed. It is important to notice that these values are not valid for constant-speed driving but for driving cycles. Cycles with slower average speed are typically of urban or rural nature with a lot of dynamics (unsteady driving, stop-and-go) and therefore with a lot of acceleration work. The faster cycles are typically cycles with free-flow traffic and low dynamics but higher rolling- and air drag resistances.



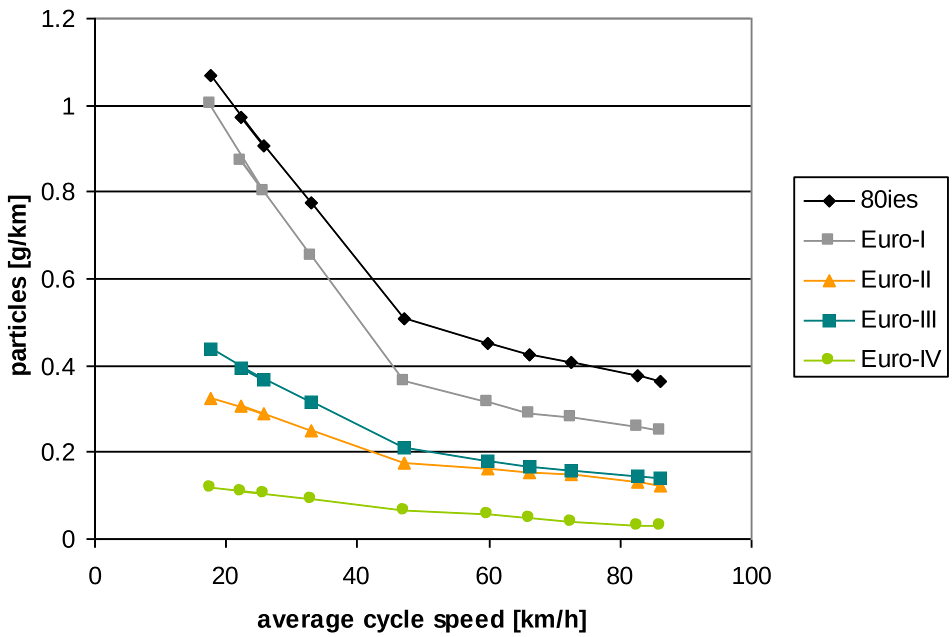


Figure 9. 6 HBEFA emission values (NOx and particles) for a fully loaded tractor-tailer (40 tons).

The emission data of Figure 9. 6 shows for example, that the NOx emissions of the considered Euro-II vehicle is higher than for the Euro-I vehicle. This is surprising because the limit values were tightened (see Figure 9. 3). The reason is that Euro-II engines were equipped with electronic controlled injection systems while Euro-I engines has simple mechanical injection systems. This flexibility was used by the manufacturers to calibrate the engines to the emission goals in the operating points relevant for the emission regulations and to calibrate the engines to low fuel consumption outside these regions. This fact was recognised by the legislation and a “control area” was introduced where the certification official could ask for additional measurements.

9.5 Influence of fuels on pollutant emissions

As long as the fuel properties are within the limits for mineral diesel (European Norm EN590), the emissions are not significantly affected by the existing slight differences between different mineral diesel fuels. As soon as important properties change (e.g. cetane number, ash content, oxygen content, lubricity, vapour pressure, viscosity, density), engine emissions, performance, durability and noise can be changed. However, the following alternative fuels are gaining more importance and should be discussed:

- Fuels synthesised from fossil or biogenic gas (gas-to-liquid GTL, biomass-to-liquid BTL, coal-to-liquid CTL), usually produced with the Fischer-Tropsch process.
- FAME (Fatty Acid Methyl Ester), often called „bio diesel“, made from different vegetable oils. A US standard (ASTM D 6751) exists since 2001; a European standard (EN 14214) exists since 2004.
- Neat vegetable oil. A German pre-standard exists for rapeseed oil fuel (DIN V 51605).
- Recycled waste oil from fossil or biogenic sources.
- The influences of these fuels on the pollutant emissions are summarised in the next sections.

Synthetic diesel (GTL, BTL, CTL)

These fuels are very well suited for diesel combustion. The cetane number is high and the viscosity is close to the viscosity of mineral diesel. The density is about 7% lower compared to mineral diesel; the lower heating values are similar. This leads to slightly higher volumetric fuel consumptions. Synthetic diesel fuels need a lubricity additive. The combustion is cleaner compared to mineral diesel, especially regarding Nox and the number of particles. Synthetic diesel fuel is virtually free of ash which makes it unproblematic for the use with particle traps.

FAME (bio diesel)

FAME fuels have a slightly higher viscosity, an about 5% higher density and more ash than mineral diesel. Their lower heating value is about 12% lower than the one of mineral diesel. This leads to higher volumetric fuel consumptions. FAME fuels degrade sealings and plastics made for normal mineral diesel use; engines have to be equipped with FAME compatible materials if FAME is used. If pure FAME fuel is used, their higher viscosity can cause problems with increased injection pressures (reduced durability of the injection system). The higher ash content can cause problems in vehicles equipped with particle traps. FAME fuels contain oxygen. This leads to increased Nox emissions (about 30% according to Empa experiments).

Neat vegetable oils

These fuels are normally not used in the transport sector. Their properties can vary massively so that no generally valid statement on their performance can be made. If their properties are close to the German pre-standard for vegetable oils, the following effects can be expected. Since the density and the viscosity are much higher compared to mineral diesel, the pressure levels in the injection system can be dramatically affected (measurements at Empa showed an increase of the injection pressure of about 40%). Since vegetable oils contain oxygen, the Nox emissions increase (about 40% according to Empa experiments). Vegetable oils can contain catalyst poisons (sulphur, phosphor) which can lead to a fast catalyst deactivation. Their high ash content can cause problems for engines with particle traps.

Recycled waste oil

For this group, no generally valid statement can be made. On the one hand, waste oil can be refined to a high-quality synthetic diesel- or FAME-like which leads to the properties described above. On the other hand, waste oil can be used with less reconditioning effort and cause large problems. If the waste oil is contaminated with problematic additives, highly problematic emissions can be generated. If the fuel contains for example chlorine (e.g. waste deep-fry oils with salt contamination), dioxin can be generated during the combustion process.

Other factors influencing pollutant emissions

In addition to the engine technology, the vehicle parameters, the driving pattern, the fuel used and the load of auxiliaries, there are a number of other factors influencing the pollutant emissions. Most important are the ambient conditions: temperature, humidity, pressure. The humidity influences mainly Nox: more humidity gives less Nox. The ambient temperature has an influence on several levels: low ambient temperatures cause lower temperature level of the exhaust gas treatment systems and thus a longer warm-up time and less conversion efficiency. High ambient temperatures cause a higher temperature level during combustion and thus more Nox. Higher altitudes (less ambient pressure) cause less air for the combustion (directly and/or because of turbocharger speed limitations) and therefore increased particle emissions.

Another important source of increased pollutant emissions is the malfunctioning of engine or exhaust gas after treatment components. With older technology, only periodic nspecttions were able to detect such faults. The actual emission legislations include also regulations regarding on board diagnosis (i.e. the engine control unit has to detect emission-relevant faults of the systems). Severe faults lead to a power reduction of the engine so that the driver is forced to resolve the problem immediately.

9.6 Conclusions

Area-wide pollutant emissions of in-use heavy duty vehicles can not be measured cost-efficiently. If pollutant emission fluxes on a regional or country level have to be estimated, aggregated systematic emission data as provided by the “Handbook Emission Factors for Road Transport” is necessary. For lowest possible pollutant emissions of individual vehicles it is important that the engine works properly and an allowed fuel is used. This can be ensured with periodic inspections and monitored with national in-use compliance programs.

10 Footprint Case Studies

10.1 Road Vehicles

10.1.1 Introduction

On the 15th of July 2008 using static and dynamic measurements various Footprint parameters were recorded for 46 vehicles from the traffic stream during a measurement campaign as listed in Table 10. 2. The assessed Footprint parameters were gross vehicle weight (GVW), axle load, tyre pressure, engine information, vibration and noise. The vehicles were chosen at random primarily for the purpose of calibration of the weigh in motion (WIM) sensors.

The resulting total footprint from these selected cases is an indication of the environmental friendliness of these vehicles is compared to the LSVA criteria (chapter 13).

10.1.2 Gross weight, axle loads

The WIM sensors at this site record on weekdays ca. 6000 heavy goods vehicles per day and deliver axle load, gross vehicle weight, speed, axle distance, vehicle classification and vehicle length. Yearly calibration of the WIM sensors reported the accuracy class as defined by COST 323 (1999) for this FMS to be B+(7) before and after the calibration in comparison with static measurements. This indicates that in four categories the minimum accuracy was 7% (single axle: B+(7), axle of a group: A(5), group of axles: B+(7), gross weight: A(5)) [Kienast 2008]. Static measurements of the above WIM parameters were made at a temporary static station set up before the FMS. At the static site in addition tyre pressure of the first three axles on the right hand side of the vehicle (when possible) were measured using a manometer.

In order to asses the footprint parameters in terms of environmental friendliness, it is important to set thresholds. For the gross weight and axle load category the limits set by the Swiss government is used [FEDRO 2008]. In Switzerland the maximum allowable gross vehicle weight is 40 t. In addition, 11 categories of allowable axle loads are defined ranging from 10 t to 27 t for group of axles. This wide range is based on axle configuration, axle distance and type of suspension.

The population investigated statically and dynamically in the case studies presented here, (Table 10. 2) had a maximum GVW of 40.15 t and maximum axle load of 12.85 t, both over the limits defined. In one case (2%) the vehicle had a GVW over the limit of 40 t. In 7 cases (15%) the axle load was over 10 t and in four cases (9%) the tyre pressure was above measurable values with the manometer. According to the regulations [FEDRO 2008] the drive axle loads can go up to 11.5 t. However, as shown in Table 10. 4 none of the vehicles had an overloaded drive axle and this higher allowable does not apply to them. Additional regulations apply for groups of axles and further classification is based on distance between the axles. For example vehicle 1 and vehicle 46 have double axle loads of 18.7 with axle distance of 1.4 and 1.34 respectively resulting in allowable of 18 t. Similarly, vehicle 36 has a triple axle load of 21.97 t but is allowed 21 t.

10.1.3 Contact forces and tyre pressure

A sample of the tyre pavement contact forces measured with stress in motion (SIM) sensors and analysed using the finite element vehicle infrastructure interaction model is presented elsewhere [Poulikakos 2008b]. It was shown that for all but the heaviest tyres, the shape of the contact stress distribution that is dependent on the inflation pressure of the tyre had a significant effect on the stresses and strains in the pavement. Grossly over pumped or under pumped vehicles can be detrimental to the pavement. Previous results from the traffic stream have recorded an extreme case with double tyres which had one flat tyre [Poulikakos 2008b]. In most cases the operator is unaware that he might be driving an unsafe and/or environmentally unfriendly vehicle. In some cases tyres can be over pumped in order to save fuel and the effect on the infrastructure is not considered.

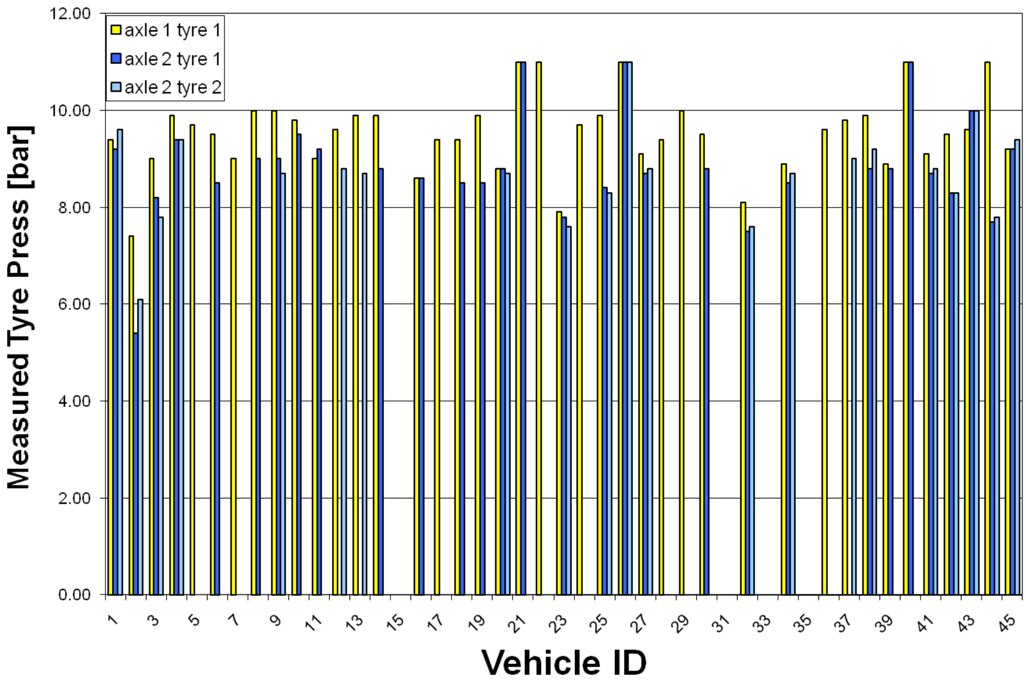


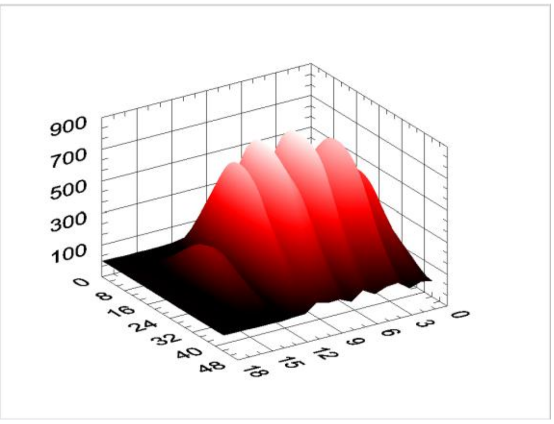
Figure 10. 1 Measured tyre pressure

Due to time limitations, it was possible to measure the inflation pressure of 41 of the 46 cases. The maximum tyre pressure measured while the tyre was warm is listed in Figure 10. 1. Tyre 1 is the outside tyre of double tyres or the single tyre and tyre 2 is the inside tyre of double tyres. The manometer used could record up to 10 bar and the listed values of 11 bar were outside the range that could be recorded. Of the 41 cases four were outside the limit and could be classified as over inflated.

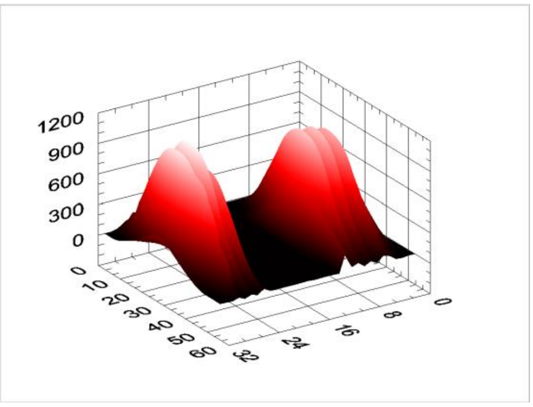
Table 10. 1 Tyre pavement contact forces (N) for ½ axle)

Case	Case 1	Case 2	Case3	Case 4
Vehicle	Vehicle 20	Vehicle 26	Vehicle 22	Vehicle 21
Modulas file	10_05_17_862.dat 10_05_18_147.dat 10_05_18_218.dat	10_29_38_038.dat 10_29_38_281.dat 10_29_38_286.dat 10_29_52_247.dat 10_29_52_299.dat	10_14_13_599.dat 10_14_14_238.dat 10_14_16_136.dat	10_11_12_815.dat 10_11_12_969.dat 10_11_13_231.dat 10_11_13_289.dat 10_11_13_345.dat
Max Axle Load [t]	12.72	7.09	11.96	9.6
Max tyre pressure [bar]	8.8	>10	>10	>10
Max force [N]	825	1150	1050	1050
Speed [km/h]	87	79	89	84

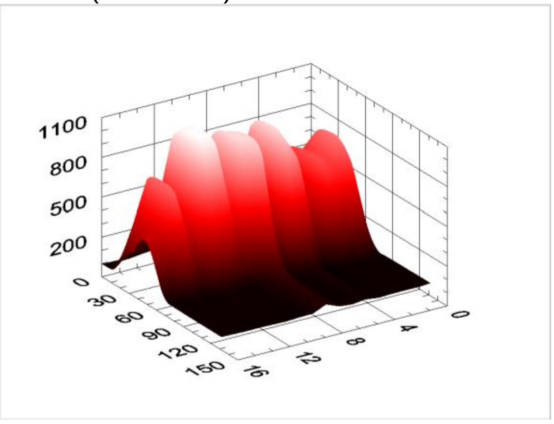
As shown the maximum contact force and shape of the contact force distribution are a function of axle load and tire pressure. Case 1 (Vehicle 20) is an example of a vehicle with high axle loads (AL=12.72 t) but with properly pumped tyres (8.8 bar), resulting in a maximum contact force of 825 N. Whereas case 2 (vehicle 26) and case 4 (vehicle 21) are examples with acceptable axle load (AL= 7.09 and 9.6 t respectively) with over-pumped tyres (>10 bar) resulting in respectively 1150 and 1050 N maximum contact force. Vehicle 22 (Case 4) is an example with high axle loads (AL=11.96 t) but also high tyre pressure (>10 bar). Tyre-pavement contact force distribution as measured by the Modulas sensors is shown in Figure 10. 2.



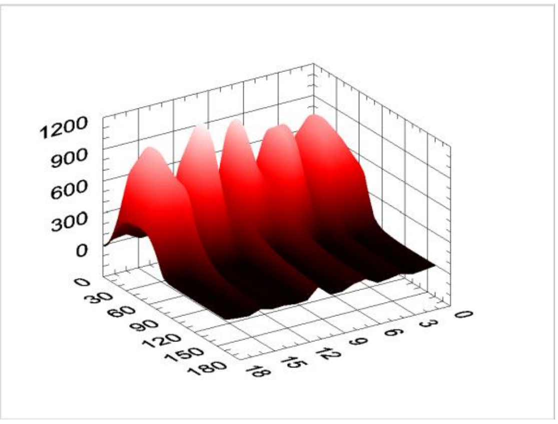
Case 1 (Vehicle 20)



Case 2 (Vehicle 26)



Case 3 (Vehicle 22)



Case 4 (Vehicle 21)

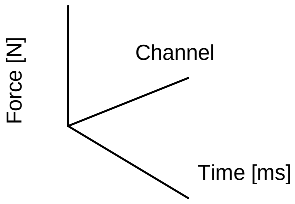


Figure 10. 2 Tyre-pavement contact forces for four cases

10.1.4 Noise

Acoustic emissions of single vehicles were measured with a microphone installed at a certain distance at the border of the road. The measurement geometry for the microphone (distance 7.5 m, height 1.2 m) was chosen according to the international standard ISO 11819-1 ,1997 and as recommended in the Footprint Guidelines [Mayer 2007]. However at the FMS, to avoid shielding by the guard rail, the microphone height was increased to 3 m above road level. From the pass-by of a vehicle the maximum Fast, A weighted sound pressure was determined. The A-filter accounts for the frequency dependent sensitivity of the human ear. By applying a logarithmic scale the results were then displayed as sound pressure levels in decibels [dB(A)]. In the analysis the disturbing effect of possible neighbour vehicles was compensated by an iterative numerical procedure [Heutschi, 2008, Poulikakos et al. 2008a].

The noisiest vehicle from this sample was vehicle no. 20 with 93 dB(A). The most silent vehicle was vehicle no. 23 with a level of 81.8 dB(A). The values shown in Table 10. 2 are the actual measured values and have not been normalized for equal speed (e.g. 80 km/h which is the limit for HGVs). A reduction or increase of the speed influences directly noise emissions by about 0.15 dB per speed change of 1 km/h. It should be noted that the emitted sound of a vehicle depends significantly on site specific factors such as pavement type and condition as well as on meteorological parameters such as surface temperature and humidity. It is therefore not possible to define absolute thresholds to separate environmental friendly vehicles from unfriendly ones. In addition the noise impact of a vehicle should be considered in relation to the time of the day as noise is much more annoying during night time. In order to protect the residents living in this area from health consequences, the Swiss Roads Office is in the process of implementing noise barriers at this location. LSVA does not consider noise emissions as criteria for road pricing. Indeed the big difference of more than 10 dB between the loudest and the most silent vehicle shows the large potential of possible improvements regarding noise impact. From a perceptional point of view a difference of 10 dB corresponds to a doubling or bisection of the loudness. In other words the acoustical energy of vehicle no. 20 is more than 10 times larger than the energy of vehicle no. 23 which means that 10 vehicles no. 23 emit the same portion of noise as one vehicle no. 20.

10.1.5 Vibration

The vibration measuring system at the FMS was designed to continuously measure the ground velocity outside the road using an electromagnetic velocity sensor (geophone) , mounted on the ground using a stake of cruciform section (Chapter 8).

Maximum PPV measured at the FMS were compared with the thresholds as described in Chapter 8. Results are shown in Table 10. 2 and Figure 10. 3. For the cases presented here, the maximum PPV for each passing vehicle was recorded. Vehicle 24 caused the highest vibration peak measured at the sensor position. The value of 0.041 mm/s PPV was considerably below the threshold of human perception. The results of this sample population corroborated previous measurements that showed the ground borne vibrations at this site are far below the threshold of perception and don’t represent and environmental problem [Poulikakos 2007].

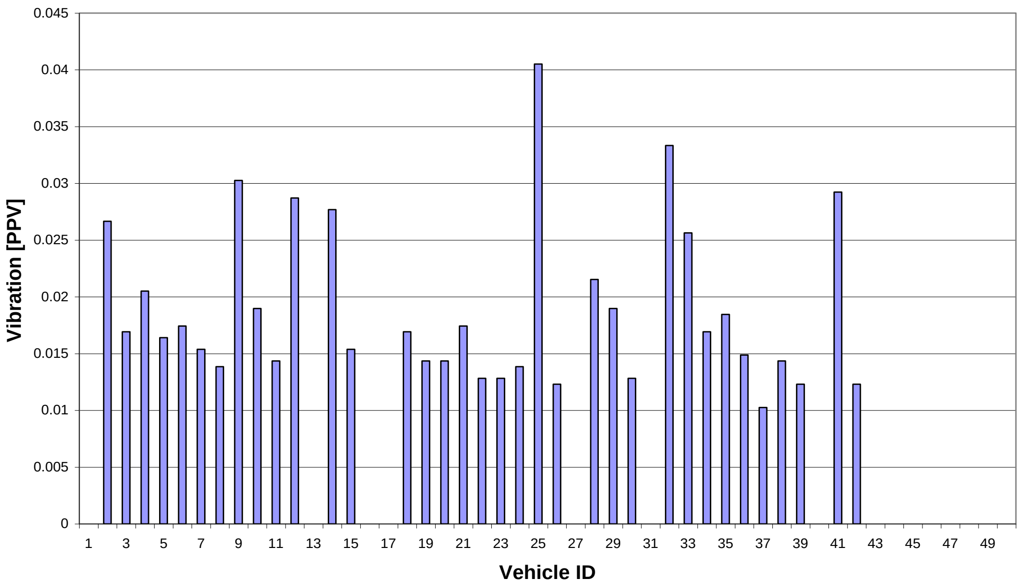


Figure 10. 3 Ground born vibrations in PPV for the vehicles on July 15 2008

10.1.6 Pollutant emissions

Gaseous and particle emissions of vehicles driving on the road depend on a combination of factors including, climate, driving pattern, road type, vehicle model, engine state and fuel. The result is that it is not possible to estimate directly the emissions of a vehicle in a certain driving situation from its known type approval emission data (EURO 0 to EURO V). The in-situ measurement of gaseous emissions of individual road vehicles at one single engine operating state in the framework of a Footprint Monitoring Station does not accurately reflect the representative emissions of that vehicle. Ideally, the average emission factors (g/km) for different classes of HGV should be found. In addition, driving pattern, road gradient and loading should be taken into account (refer Chapter 9).

To estimate realistic emission factors (i.e. regulated emissions in g/km for Particle Matter, NOx, HC and CO) for different engine technologies, different classes of vehicles, different loading and in different driving profiles, several research programs exist. Within a long-time cooperative action coordinated by the Austrian, German and Swiss environmental agencies, a "Handbook of Emission Factors for Road Transport" (HBEFA) has been developed and is updated continuously with new technologies (http://www.hbefa.net). This database contains thousands of emission factors that are based on systematic HGV engine emission measurements in several European laboratories.

For this case study, the vehicle engine information was obtained at the static site as shown in Table 10. 2. The FMS is located on a flat road surface and therefore for the purpose of the calculation a 0 road gradient was used. WIM data and static measurements provided the Gross vehicle weight and speed. An estimation of the emission factors was made using the vehicle class, the engine emission classification, the measured gross vehicle weight and speed by interpolating emission data from the HBEFA. The results in Table 10. 3 show that vehicle 21 with EURO III engine could potentially be the most polluting vehicle in terms of CO, NOx, PM and also the greenhouse gas CO2 (which is proportional to fuel consumption) however in terms of HC vehicle 28 was most polluting. Only 6 vehicles or 13% of this sample had engines older than EURO 3. Statistics kept by the Swiss government from 2001 to 2005 (Figure 13. 2) show that the tendency of the vehicle fleet is generally less polluting. The results presented in Table 10. 3 show that although all EURO3 engines would be treated the same by LSVA, all other parameters kept constant, their pollutant emissions are not equal and depend on the mass and speed of the vehicle. The sample in this study had a relatively high number of EURO V (18) vehicles although EURO IV was first introduced in 1.10.2005 and EURO V in 2008 [ARE 2007b].

Table 10. 2: Recorded Footprint Parameters

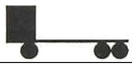
Veh-Nr.	**Swiss 10**	**Gross Weight (3)**	**Max Axle Load (3)**	**Max Tyre Press.**	**Engine**	**Vib.**	**Noise**
	Class	**[t]**	**[t]**	**[bar]**	**Euro Code**	**PPV**	
[mm/s]	dB(A)						
1	8	26.45	11.5	9.6	5	0.027	88.8
2		*	*	7.4	*	0.017	87.5
3		*	*	9	5	0.021	86.2
4	10	33.35	7.85	9.9	5	0.016	86.1
5	8	15.15	9.5	9.7	*	0.017	88.8
6	9	16.7	7	9.5	5	0.015	87.2
7	9	18.15	6.45	9	*	0.014	88.9
8	9	26.55	7.7	10	5	0.030	89.7
9	9	27.45	8.65	10	3	0.019	91.2
10	9	36.5	8.15	9.8	3	0.014	91.7
11	8	*	*	9.2	5	0.029	90.4
12		*	*	9.6	5		*
13	10	17.15	6.2	9.9	3	0.028	*
14	10	13.75	5.35	9.9	3	0.015	90.1
15	10	26.65	10.6	*	*	*	92.2
16	8	13.5	3.95	8.6	3	*	88.3
17	10	13.55	5.6	9.4	5	0.017	87.5
18	10	16.45	5.9	9.4	5	0.014	90.9
19	9	38.75	9.65	9.9	5	0.014	90.7
20	10	38.85	12.85	8.8	5	0.017	93
21	10	39.65	9.6	11	3	0.013	91.6
22	9	40.15	12.05	11	3	0.013	90.9
23	8	7.55	3.85	7.9	4	0.014	81.8
24	10	19.65	6.55	9.7	5	0.041	87.7
25	10	12.3	5.25	9.9	3	0.012	87
26	9	23.7	6.8	11	3	*	90
27	10	13.6	5.2	9.1	5	0.022	88.4
28	10	19.85	6.45	9.4	3	0.019	87.6
29	9	24.3	9.2	10	3	0.013	89.1
30		*	*	9.5	5	*	*
31	8	*	*	*	4	0.033	87.3
32	8	5.25	2.85	8.1	2	0.026	87
33	10	19	5.75	*	3	0.017	86.7
34	9	17.15	6.2	8.9	5	0.018	88.7
35	10	19	7.05	*	3	0.015	86.6
36	10	39.25	11.8	9.6	3	0.010	91.3
37	10	16.95	5.55	9.8	5	0.014	87.9
38	9	20.1	7.25	9.9	5	0.012	89.5
39	8	14.75	8.1	8.9	5	*	86.8
40	8	29.65	9.7	11	0	0.029	*
41	8	12.65	7.15	9.1	5	0.012	88.5
42		*	0	9.5	3	*	*
43	10	21.25	7.8	10	5	*	*
44	*	*	*	11	4	*	*
45	10	26.1	10.2	9.4	*	*	90.5
46	8	26.45	11.5	*	*	*	88.8
Max		40.15	12.85	11	5	0.041	93
Median		22.30	7.51	9.57	3.98	0.019	88.79
Minimum		5.25	0	7.4	0	0.010	81.8
Limit		40	10	11	*Note 2*	0.500	N/A
Nr. over limit		1	7	4	6	0.000	N/A
% over limit		2	15	9	13	0	N/A

*Note 1: * indicates no data or invalid data*
Note 2: Number of vehicles below EURO III
Note 3: Static values for gross weight and axle load shown

Table 10. 3: Further aggregation of gaseous emissions. Blank spaces indicate due to lack of time no data was collected..

Veh-Nr.	Emission	Speed	HC	CO	NOx	PMm	CO2
	Euro Code	[km/h]	[g/km]	[g/km]	[g/km]	[g/km]	[g/km]
1	5	88	0.0129	0.0978	2.353	0.00215	674
2		87					
3	5	79					
4	5	78	0.0145	0.1104	2.827	0.00238	849
5		85					
6	5	84	0.0133	0.0909	2.071	0.00211	587
7		88					
8	5	89	0.0129	0.0980	2.362	0.00215	677
9	3	80	0.2676	1.5517	6.659	0.13114	746
10	3	89	0.2506	1.7224	7.032	0.13854	814
11	5	85	0.0133	0.0866	1.926	0.02067	542
12	5						
13	3	80	0.2839	1.4201	5.925	0.01231	641
14	3	90	0.2735	1.1670	5.410	0.10948	563
15		86					
16	3	87	0.2643	1.1945	5.599	0.10978	607
17	5	84	0.0141	0.0903	1.923	0.02115	544
18	5	86	0.0139	0.0919	2.024	0.02128	578
19	5	77	0.0135	0.1113	2.809	0.00232	819
20	5	87	0.0138	0.1107	2.916	0.00235	874
21	3	84	0.2710	2.5204	7.854	0.16777	959
22	3	89	0.2482	1.8178	7.291	0.14377	852
23	4	77	0.0140	0.0875	3.048	0.02114	499
24	5	85	0.0139	0.0945	2.145	0.02159	618
25	3	88	0.2743	1.1366	5.357	0.10835	554
26	3	79	0.2725	1.4409	6.327	0.12556	696
27	5	83	0.0142	0.0907	1.921	0.02125	543
28	3	73	0.3006	1.5408	6.401	0.13393	701
29	3	84	0.2605	1.4745	6.381	0.12557	716
30	5						
31	4	81	0.0133	0.0927	3.599	0.02122	594
32	2	84	0.3001	0.7830	6.548	0.08329	522
33	3	82	0.2798	1.4620	5.976	0.12389	651
34	5	80	0.0137	0.0936	2.112	0.02155	599
35	3	82	0.2798	1.4601	5.972	0.12380	650
36	3	87	0.2679	2.5263	7.689	0.16587	940
37	5	87	0.0139	0.0924	2.051	0.02133	587
38	5	88	0.0131	0.0930	2.173	0.02112	618
39	5	78	0.0140	0.0930	2.046	0.02168	579
40	0	76					
41	5	89	0.0132	0.0874	1.967	0.02068	555
42	3						
43	5	100	0.0130	0.0939	2.211	0.02116	630
44	4						
45	0						
46							

Table 10. 4: Further aggregation of axle loads

Veh -Nr.	Swiss 10	GVW	AL 1	AL 2	AL 3	AL 4	AL 5	AD 1	AD 2	AD 3	AD 4	Silhouette
		[t]	[t]	[t]	[t]	[t]	[t]	[m]	[m]	[m]	[m]	
1	8	26.45	7.75	11.5	7.2			4.52	1.41			
15	10	26.65	6.5	10.6	4.75	4.8		3.78	5.67	1.38		
36	10	39.25	6.2	11.8	6.9	7.15	7.2	3.59	5.3	1.32	1.28	
45	10	26.1	5.95	9.95	10.2			3.69	8.88			
46	8	26.45	7.75	11.5	7.2			4.49	1.34			

GVW=Gross Vehicle Weight, AL=Axle Load, AD=Axle Distance

10.1.7 Comparison of measured Footprint parameters and LSVA criteria

The results shown in Table 10. 2 indicate that based on measured parameters, vehicles 20, 21 and 22 have a high footprint. Furthermore, statically and dynamically measured footprint parameters for four cases are shown in detail in Table 10. 5, Table 10. 6, Table 10. *7* and Table 10. 8. Also shown is comparison of the footprint with allowable limits when a limit was available. Using footprint parameter for the purpose of environmental labelling is further discussed in Chapter 14. If the limit was surpassed the vehicle received a red label if not a green label. Vehicle 20 (case 1) produced the highest noise and axle load and it was moving over the speed limit, as a result it received in three of six categories a red label. For the purpose of demonstration, the assignment of environmental labelling of vehicle 20 is presented in more detail. In the category gross weigh it measures 39.09 t and 38.85 t dynamically and statically respectively. This value is below the allowable of 40 t in Switzerland therefore it received a green label. However although vehicles can carry 40 t they can declare that they will carry less and therefore qualify for a lower heavy vehicle fee. Therefore, in actuality vehicle data is needed for labelling in this category. In the category axle load it weighed 12.72 t and 12.85 t dynamically and statically respectively which are both above the allowable 11.5 t for drive axle load. In category speed it was going at 87 km/h that was above the allowable of 80 for heavy vehicles. The measured tyre pressure at 8.8 bar for this vehicle was in the normal range at hot tyre state. Further vehicle information is needed in order to assess the allowable tyre pressure. The noise emission for this vehicle was 93 dB(A) at 87 km/h and if normalized for 80 km/h it was reduced to 91.8 dB(A). Comparison of this value for the distribution for category 10 vehicles (Figure 6. 1) shows that this value is beyond the 50% span from the mean of 87 dB(A) and therefore it received a red label. In the gaseous emissions category the engine being EUROV is the best on the market currently and therefore received a green label.

Similarly, Vehicle 26 (case 2) received a red label in two categories. Vehicle 22 (case 3) had the highest gross weight, high axle load and tyre pressure and it was also noisy and received in five categories a red label. Vehicle 21 (case 4) the highest gaseous emissions, had high tyre pressure and high noise level and received in five categories a red label. Following the criteria set by LSVA (Chapter 13), with the same mileage and capacity, vehicle 20 would pay a lower heavy vehicle fee with an engine rating of EURO V even though it had high axle loads damaging the infrastructure and it was the noisiest vehicle affecting the residents in the area.

10.1.8 Conclusions

The environmental footprint of heavy vehicles defined as dynamic load, noise, vibration and pollutant emissions is measured statically and dynamically based on criteria set by the European project Eureka Logchain Footprint. These parameters were measured for freight vehicles selected from the traffic stream and results were compared to the criteria set up as a result of current Swiss policy. The data shows that identifying the environmental footprint of HGVs is not straight forward. Vehicles that based on LSVA would pay a reduced heavy vehicle fee are not necessarily environmentally friendly when the footprint parameters are considered. Parameters that are currently controlled and their reduction encouraged such as gaseous emissions, axle loads and gross weight are for the most part below or close to acceptable limits. However other important parameters such as tyre pressure and noise remain to be higher than acceptable limits.

Table 10. 5 Case 1: Noisiest and Max AL: Vehicle Nr. 20, class 10, 5 axle

Parameter		Measured Amount	Limit	Label
WIM	Gross Vehicle weight	Dyn: 39.09 t Static: 38.85 t	40 t*	
	Axle Load	Dyn:12.72 t Static:12.85 t	10 t	
	Speed	87 km/h	80 km/h	
Tyre Pressure		8.8 bar	-	
Noise		93 (91.8) dB(A)	87 **	
Gaseous Emissions	Engine Type	Euro V	Euro III	

( ) : Noise, normalized for 80 km/h

* : Need information on Declared allowable gross weight

**: Location- and category specific data required

Table 10. 6 Case 2: Max tyre press: Vehicle Nr. 26; Class 9, 5 axle

Parameter		Measured Amount	Limit	Label
WIM	Gross Vehicle weight	Dyn: 22.39 t Static: 23.70 t	40 t*	
	Axle Load	Dyn:7.09 t Static:6.80 t	10 t	
	Speed	79 km/h	80 km/h	
Tyre Pressure		>10 bar	-	
Noise		90 (90.2) dB(A)	87 **	
Gaseous Emissions	Engine Type	Euro III	Euro III	

( ) : Noise, normalized for 80 km/h

* : Need information on Declared allowable gross weight

**: Location- and category specific data required

Table 10. 7 Case 3: highest GVW, Vehicle Nr. 22; Class 9, 5 axle

Parameter		**Measured Amount**	**Limit**	**Label**
WIM	Gross Vehicle weight	Dyn: 39.65 t Static: 40.15 t	40 t*	
	Axle Load	Dyn:11.96 t Static:12.05 t	10 t	
	Speed	89 km/h	80 km/h	
Tyre Pressure		>10 bar	-	
Noise		90.9 (89.4) dB(A)	87 **	
Gaseous Emissions	Engine Type	Euro III	Euro III	

( ) : Noise, normalized for 80 km/h

* : Need information on Declared allowable gross weight

**: Location- and category specific data required

Table 10. 8 Case 4: Highest Gaseous emissions: Vehicle Nr. 21, Class 10, 5 axle

Parameter		Measured Amount	Limit	Label
WIM	Gross Vehicle weight	Dyn: 40.06 t Static: 39.65 t	40 t*	
	Axle Load	Dyn:9.68 t Static:9.06 t	10 t	
	Speed	84 km/h	80 km/h	
Tyre Pressure		>10 bar	-	
Noise		91.6 (90.9) dB(A)	87 **	
Gaseous Emissions	Engine Type	Euro III	Euro III	

( ) : Noise, normalized for 80 km/h

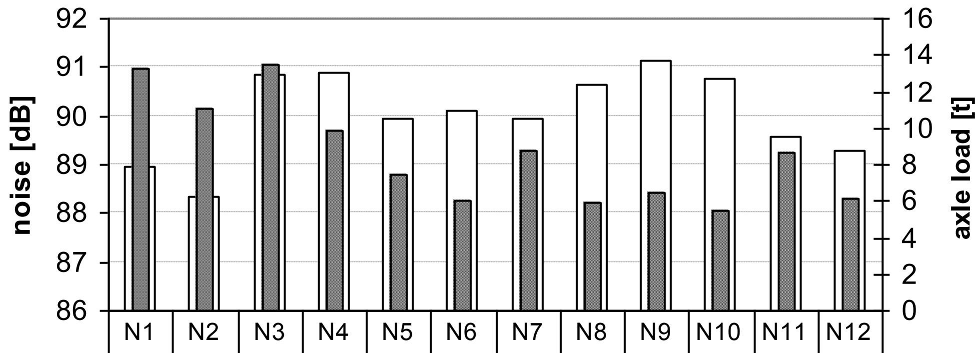
* : Need information on Declared allowable gross weight

**: Location- and category specific data required

10.2 Rail Vehicles

A sample of measured parameters from the rail footprint site is presented for comparison. A simplified FMS was built in ŠKODA VÝZKUM Ltd. In Bolevec, near Pilsen, Czech Republic [Mayer 2009]. Four strain gauge based load sensors were formed from pairs of HBM 6/350LY11 strain gauges, positioned on glass-fibre layer and covered with protective coat against the moisture. These sensors were glued with the HBM adhesive X60 to the bottom of the rail, just measuring the bending stress, induced from passing wheel. The calibration of the sensors was made using a train with known axle load of the engine. A sample of dynamic loads and noise emissions measured at this site during passing of a train with freight wagons is shown in Figure 10. 4. As shown in the figure the maximum noise impact and maximum dynamic load are not always from the same axle.

More information about the environmental footprint of rail vehicles as measured by the rail footprint monitoring sites is published elsewhere [Mayer 2007 and 2009].



	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10	N11	N12
□ noise	89.0	88.3	90.8	90.9	89.9	90.1	90.0	90.6	91.1	90.8	89.6	89.3
■ axle [t]	13.3	11.1	13.4	9.8	7.4	6.0	8.7	6.0	6.4	5.5	8.6	6.2

axle order

Figure 10. 4 Load and noise produced by each passed axle of a passenger train from the FMS in the Czech Republic

11 Comparison of Footprint Parameters from UK and CH Monitoring Sites

11.1 Summary

This chapter reports the results of the road FMS from Switzerland and the UK [Poulikakos 2009]. Individual vehicle data from Weigh-in-Motion (WIM) and noise are compared and discussed. Comparison of the WIM results indicate that a significant number of vehicles surpass the limits set in both countries. Number of overloaded vehicles in Switzerland and the UK could be more than 10% on weekdays. It was shown that the UK sites are generating higher noise levels than the Swiss site. This is attributed in part to the much coarser aggregate embedded in the running course of the pavement to that employed in Switzerland. Such data can be used to create an incentive for vehicle types with a low footprint and a penalty for vehicles with a large footprint. This would be in accord with the polluter pays principle as set out in the EU Transport White Paper [EU 2001].

In order to compare the environmental footprint of vehicles in the UK with those in Switzerland it was imperative to use a harmonized vehicle classification system. As both countries use their own classification systems, a conversion was made to the COST 323 classification as listed in Table 11. 1.

Table 11. 1Swiss and UK vehicle classification and comparison to COST 323

COST Category	Description	Swiss 10 Class	UK Class	note
COST 3	More than 2 axle rigid lorry	8	32 and 33	Swiss class 8 includes 2 axles
COST 4	Tractor with semi-trailer supported by single or tandem axles	10	51,52 and 55	
COST 5	Tractor with semi-trailer supported by tridem axles	10	54 and 56	
COST 6	Lorry with trailer	9	41 – 44	

11.2 Footprint monitoring site in the UK

The UK has three sites located in Plymouth, Sparkford and Tomatin. The Plymouth, Devon site a dual carriageway is on the A374 with a speed limit of 64 km/h. The Sparkford, Somerset site also a dual carriageway is on the A303 with a speed limit of 112 km/h – Whereas the Tomatin, Highland (Scotland) site is a single carriageway on the A9 with a speed limit of 80 km/h. To date, Switzerland has one site located in Lenzburg, between Zürich and Bern. This is a dual carriageway on the motorway A1 with a speed limit of 120 km/h. The Layout for a road FMS on the A303 near Wincanton, UK is shown in Figure 11. 1 and the Swiss site in Figure 2. 1.

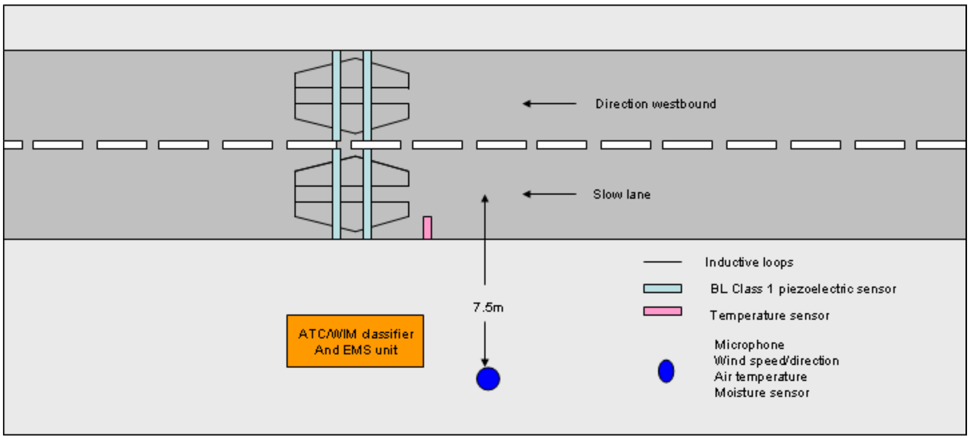


Figure 11. 1 Layout for a road FMS on the A303 near Wincanton, UK

11.3 WIM results

The data presented in this chaoter is focused on heavy vehicles over three tonnes. This data is compared with the allowable values for axle loads and gross weights. Maximum allowable gross weight in the UK is 44 t whereas in Switzerland 40 t is allowed for lorries with trailers. Maximum allowable axle load in the UK and Switzerland is 11.5 t for the drive axle. For axles other than the drive axle, the legal limit depends on number of axles and grouping of axles. In Switzerland additionally type of suspension is considered (refer chapter 4).

Data collected from the three UK sites during September 2008 resulted in 42’832 vehicle records being analysed. Of the four COST 323 categories analysed, the heaviest vehicle identified during this period was from Class 6 which weighed 75.9 t whilst the heaviest axle recorded weighed 19 tonnes, a rear axle on a Class 3 vehicle. Figure 11. 2 shows the extremes of each of the classes analysed along with their mean values. The minimum weights shown in the figure are of a similar level and the median are below the legal limits. However, in all four vehicle classes the maximum weights exceed the legal maximum on UK roads of 44 t by a considerable amount (SI 1998, amendment 2000]. The UK has a maximum legal weight on an individual drive axle of 11.5 t. Examination of the extreme axle loads for Class 4, 5 and 6 shows that this limit is exceeded on a number of different axle configurations as shown in the example for Class 6 (Figure 11. 3). However, it should be noted that the median on all the axles are well within the legal limits.

Data collected from the Swiss site in September 2008 shows that on weekdays a maximum of ca. 6000 and on weekends a maximum of ca. 2000 heavy vehicles pass this site. As shown in Figure 11. 4 more than 10% of the weekday vehicles could be overloaded compared to the legal limits set by the Federal Roads Office [FEDRO 2008] as explained earlier. In order to determine the exact number of overloaded vehicles further aggregation with respect to axle spacing, group of axles and type of suspension is needed. For an example see chapter 10 Furthermore the data shows that although the mean value of Swiss classes 8 (COST 2,3), 9 (COST 6) and 10 (COST 4,5) which are under consideration here are below the legal limit in Switzerland of 40 t there are some that surpass this allowable.

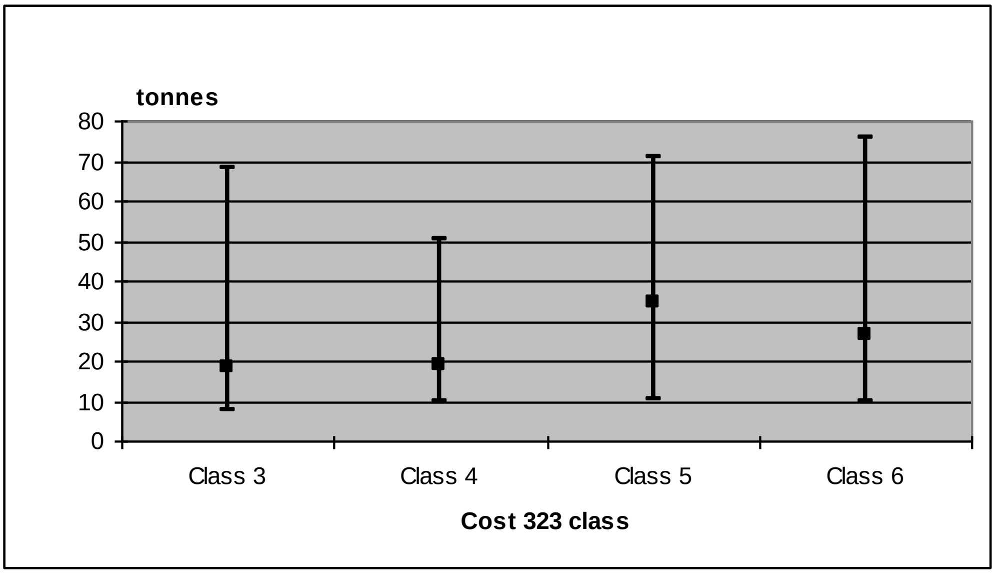


Figure 11. 2 the extremes of each of the classes analysed in the UK along with their mean values

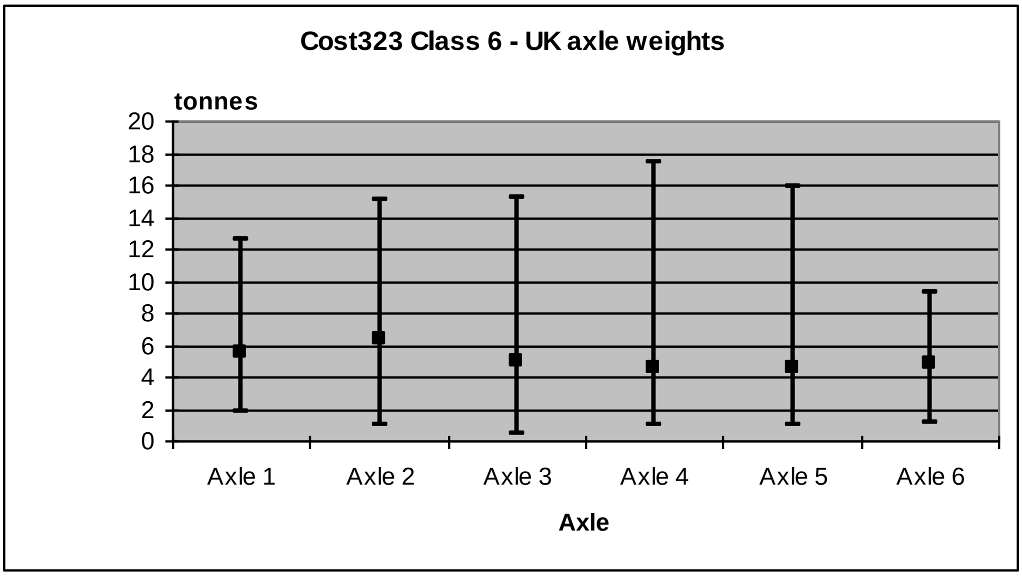


Figure 11. 3 axle loads distribution on class 6 vehicles, UK

Similarly as shown in Figure 11. 4, in the UK a maximum of ca. 1500 vehicles pass by the FMS on weekdays and maximum of ca 500 on weekends out of which more than 10% could be overloaded. However, it should be noted that official statistics [DfT, 2008] obtained from all of the WIM sites operated by the Department for Transport in the UK, quote a maximum of 4% of five axle articulated vehicles are four or more tonnes overweight. This class of vehicle appears to be the biggest offenders of running overweight in the UK.

Comparing the median GVW from Switzerland with that of the UK, the median tonnage of Class 5 vehicles in the UK at 35 t were the highest followed by class 6 at 28 t and class 4 at 20 t, whereas in Switzerland class 9 (COST 6) at 24 t were the highest followed closely by 10 (COST 4,5) . Although the extremes recorded in both countries for class COST 6 were higher.

Figure 4. 5 shows the number of axles over 10 tonnes per class from Switzerland. The data indicates that class 10 (COST 4,5) had the highest number of overloaded axles followed by class 9 (COST 6) and 8 (COST 2,3).

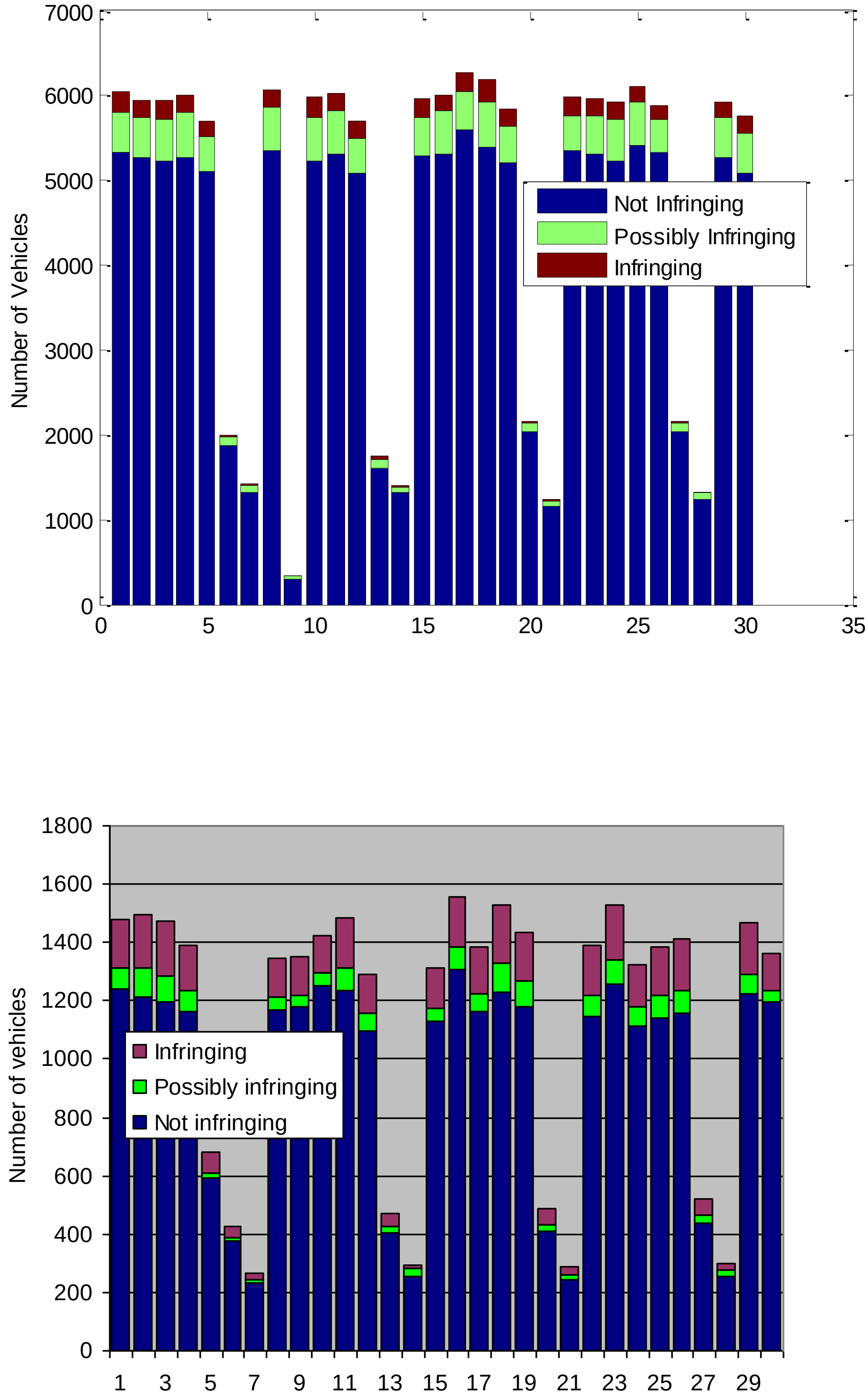


Figure 11. 4 Histogram indicating number of heavy vehicles per day in September 2008, Lenzburg Switzerland top and Plymouth, UK bottom

11.4 Noise results

Noise measurements were carried out using a microphone placed 7.5 m from the centre of the slow lane and 1.2 m above ground, according to the geometry defined in the international organization for standards [ISO 1997]. The microphone signal was weighted with an A-filter to account for the frequency dependent sensitivity of the human ear. Secondly the signal was converted to short time average values with a temporal resolution of 100 ms. By applying a logarithmic scale the results were then displayed as sound pressure levels in decibels (dB(A)). A pass-by event of a vehicle is described by the maximum level Lmax observed in the level time history. To rate level differences from a perceptional point of view it may be observed that an increase of three dB(A) is just audible and an increase of ten dB(A) corresponds to a doubling in loudness.

Noise levels across all three UK sites vary quite widely within each of the vehicle classes as a result of the speed limits at each site. It should be noted that class 6 wasn't examined at two of the sites as the population of this vehicle class was particularly low.

Noise monitoring in the UK has confirmed the fact that there is a direct correlation between speed and noise levels. If one examines COST Class 5 as an example, the noise levels vary from between 89-90 dB(A) at Plymouth (speed limit of 64 km/h) to 96-97 dB(A) at Sparkford (speed limit of 112 km/h). Similar increases can be seen among the other vehicle classes. In all three locations Class 5 vehicles were the noisiest. An example from Sparkford is presented in Figure 11. 5.

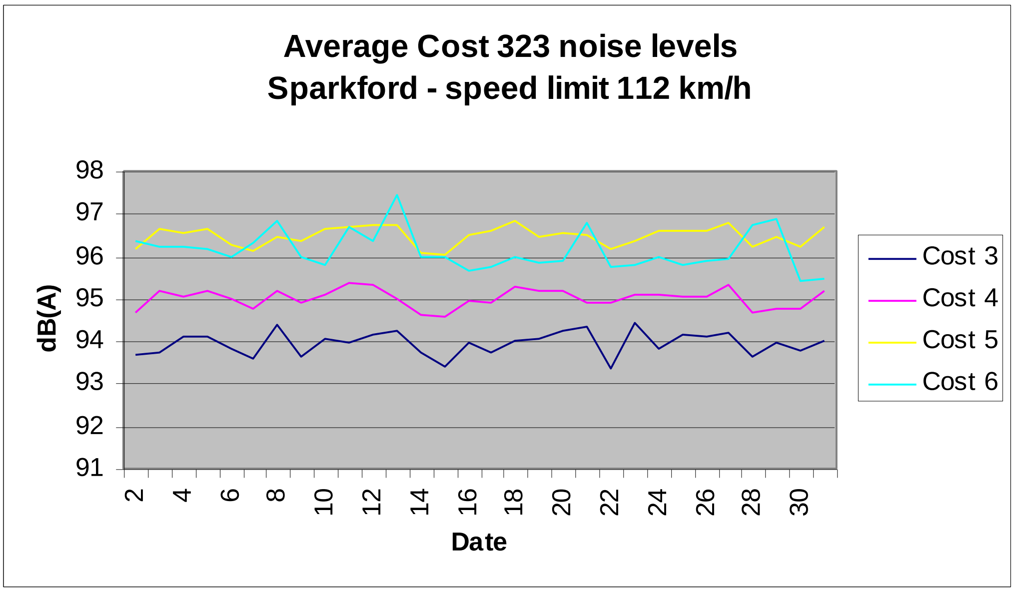


Figure 11. 5 Example of noise monitoring from the UK

For the purpose of comparison the vehicle pass-by levels Lmax measured at the Swiss site were evaluated as a function of speed v [Heutschi, 2008]. A linear regression model developed around 80 km/h yielded the following level-speed dependencies:

COST 323 class 3: Lmax(v) = 78.1 + 0.1108v

COST 323 class 4/5: Lmax(v) = 75.7 + 0.1441v

COST 323 class 6: Lmax(v) = 76.7 + 0.1366v

Table 11. 2 shows the average noise and speed values at the UK sites and for comparison the corresponding noise levels at the Swiss site at Lenzburg. Compared to Plymouth,

the Lenzburg data are about 4 dB(A) lower, for Tomatin the difference is between 5 and 6 dB(A) and for Sparkford the difference is between 6 and 7 dB(A). An important factor to consider is the difference in noise levels being generated between the Swiss and UK sites as a result of tyre noise on the different types of road surfaces. For modern lorries and vehicle speeds above 60 km/h tyre noise is the major contribution to the overall noise level [Heutschi 2004, Sandberg 2002]. All three UK FMS sites are installed in recently laid pavements and are in a good state of repair. However, it should be noted that these sites appear to have a much coarser aggregate embedded in the running course of the pavement to that employed in Switzerland and as a result vehicles in the UK are generating higher noise levels. A second probable reason for the significant deviation is due to differences in the average vehicle fleet. And thirdly there is a significant uncertainty due to the lack of a uniform vehicle classification system. As the Swiss10 classification scheme can not be translated to the COST323 classification in a consistent way.

Table 11. 2 Average noise and speed values at the UK and CH sites

	COST 3		COST 4/5		COST 6	
	level (dB(A))	speed (km/h)	level (dB(A))	speed (km/h)	level (dB(A))	speed (km/h)
Plymouth	88.5	61	88.6	59		
Tomatin	92.5	82	93.6	82		
Sparkford	93.8	88	95.8	92	96.3	94
Lenzburg	84.9	61	84.2	59		
Lenzburg	87.2	82	87.5	82		
Lenzburg	87.9	88	89.0	92	89.5	94

11.5 Conclusion

It was shown that it is possible to measure the noise and dynamic loads of vehicles and to compare this footprint from two countries. Although the median value of axle loads and GVW are below the legal limits, there are a significant number of vehicles that surpass this allowable. The number of infringing vehicles on weekdays in Switzerland and the UK could be higher than 10%. Considering all vehicle classes, the highest median gross weight of vehicles in the UK was higher in comparison to the Swiss vehicles of similar class. A harmonised vehicle classification and legal limits for gross weight and axle loads is imperative in order to allow comparison of the footprint of heavy vehicles at various sites.

It was shown that the UK sites are generating higher noise levels than the Swiss site. This is attributed, in part, to the much coarser aggregate embedded in the running course of the pavement to that employed in Switzerland.

Such data can be used to create an incentive for vehicle types with a low footprint and a penalty for vehicles with a large footprint. This would be in accord with the polluter pays principle as set out in the EU Transport White Paper.

12 Emerging Technologies Relevant to Footprint

12.1 Performance Based Standards (PBS) for heavy vehicles

A PBS system is being developed in Australia to allow four levels of performance standard. These will ensure that the vehicle is matched to the right road network. For example, an 'over-length' quad axle semi-trailer fitted with lift and steering axles running at higher weights could run on general access freight routes providing it met all the Level 1 performance standards.

Other reforms complementary to PBS include the Intelligent Access Program (IAP) for route compliance. This could be used, where there is a demonstrable compliance risk, to ensure heavier payloads do not damage vulnerable infrastructure, such as older bridges.

The end result is more productive, safer and sustainable heavy vehicles on the road network, with the vehicle's performance closely matched to the capacity of the infrastructure. Figure 12. 1 demonstrates the difference between the current mass and dimension regulations and the performance based standards.

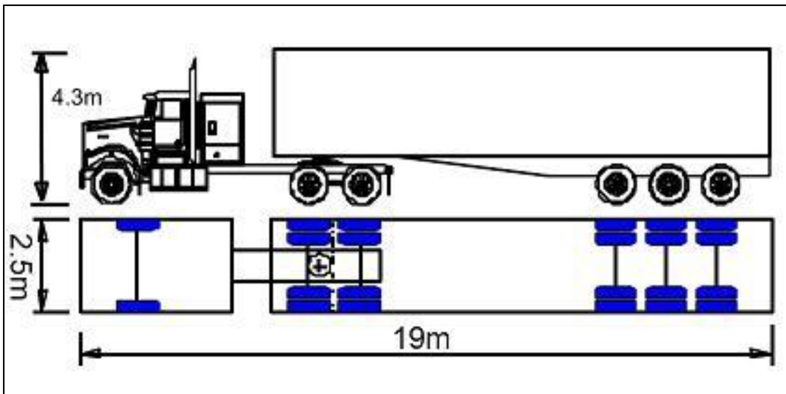
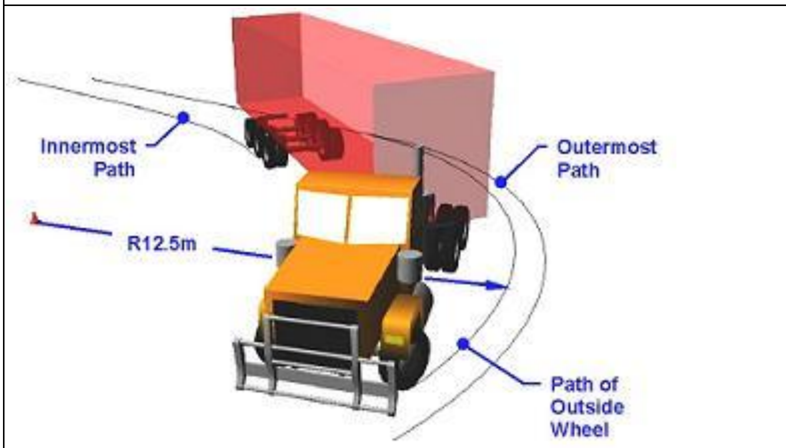
	**CURRENT PRESCRIPTIVE REGULATION** **WHAT THE TRUCK LOOKS LIKE** **(Mass and dimension)**
	**FUTURE PERFORMANCE REGULATION** **WHAT THE TRUCK CAN DO** **(Performance Based Standards)**

Figure 12. 1 performance based standards vs. mass and dimension based regulations [NTC 2009]

12.2 On board tyre pressure monitoring

Footprint monitoring has shown that there are vehicles on Swiss roads with tyres that are under or over inflated. Properly inflated tyres improve fuel economy, reduce braking distance, improve handling and increase tyre life. Underinflated tyres cause overheating and can lead to accidents. It is estimated that approximately ¾ of all automobiles operate with at least one underinflated tyre. Tyre inflation pressure is not monitored systematically by drivers unless vehicle performance is affected. Due to the importance of properly inflated tyres some countries require new vehicle models to have an on board tyre pressure drop monitoring systems (TPMS). TPMSs can be direct or indirect. Direct tyre pressure monitoring systems calculate the pressure drop based on actual pressure measurements through sensors in each tyre. The data is transferred to a receiver located on the dashboard. The driver is informed when a pressure deviation as low as ±0.1 bar is detected. Indirect TPMSs predict tyre pressure drop using vehicle speed measurements. When the tyre pressure decreases, the vehicle's weight reduces the tyre diameter, in turn causing the tyre to rotate at a different rate than when properly inflated. Based on this change in wheel angular speed the inflation pressure is calculated using an algorithm. [Sankaranarayanan, 2007].

12.3 Giga-Liners

Giga-Liners or Mega-Trucks are heavy road vehicles that are 25 m long and can carry 60 tonnes. For the past ten years the mega trucks are on US, Finnish and Swedish roads. Wide access to Swiss roads due to traffic roundabouts or the bridges and tunnels in the alpine region is unlikely. However a limited access of such transport in the foreseeable future due to pressure from the EU is possible. The mega trucks allow transport of a higher load more efficiently and produce less environmental pollutions per tonne of transported goods compared to the current 40 tonne vehicles. On the other hand statistically the higher total weight increases the accident risk and increases road building and renovation costs [Hagenbüchle 2010]. Using a footprint monitoring site can allow monitoring of such trucks and assure compliance with the allowable limits.

12.4 New generation of wide-base tires

The new generation of wide-base tires has wider treads and greater load-carrying capacity than the conventional wide-base tire. In addition, the contact patch is less sensitive to loading and is especially designed to operate at 690kPa inflation pressure at 121km/hr speed for full load of 151kN tandem axle. Al-Qadi et al (2005) have studied the effect of wide based tires in comparison with conventional tires using an FE model. The goal was to quantify pavement damage due to a conventional (385/65R22.5) and a new generation of wide-base (445/50R22.5) tires using three-dimensional (3D) finite element (FE) analysis. Results indicated that the 445/50R22.5 wide-base tire would cause more fatigue damage, approximately the same rutting damage and less surface-initiated top-down cracking than the conventional dual-tire assembly. On the other hand, the conventional 385/65R22.5 wide-base tire, which was introduced more than two decades ago, caused the most damage. In the context of a footprint monitoring site the effect of such tires could be assessed.

13 Policy

13.1 Introduction

According to the data published by the Swiss federal office for spatial development (ARE), the external costs of land transport in Switzerland lie between 7.7 and 8.9 billion Swiss Francs which is between 1.8 % and 2.1 % of the gross national product (GNP). Most of this is caused by road transport specifically from accidents, health care costs due to air pollution and climate change [ARE 2007a]. There is legislation in place to reduce the external costs and the Swiss heavy vehicle fee (LSVA) effective since 2001 is in place for this purpose. Monitoring the traffic development and the environmental effect of traffic from 2001 until 2005 shows that the LSVA has been able to accomplish its intended purposes and the efficiency of the traffic has increased [ARE 2007b]. The expected initial side effect that the regional roads would see heavier traffic proved not to be a problem.

13.2 Road pricing in Switzerland and its consequences

As of January 1st 2001 a new road pricing system (Leistungsabhängige Schwerverkehrsabgabe or LSVA) has been introduced in Switzerland in order to internalize some of the external costs [Suter 2001]. The LSVA is a variable road pricing method that considers some of the external costs of heavy goods vehicles (HGV). It replaced the previous road pricing method that was a flat fee. A detailed presentation of the LSVA can be found elsewhere [Krebs 2004, Suter 2001]. The introduction of the LSVA was in conjunction with the increase in the allowable weight limits for HGV from 28 t to 34 t and then to 40 t in 2005.

The goal of the LSVA that is based on the “user pays principle” was threefold. Firstly, to limit the growth of road heavy goods vehicle traffic, secondly, to transfer freight from road to rail and thirdly to protect the environment.

The LSVA applies to HGV over 3.5 t and is calculated based on three criteria:

- Number of kilometers traveled in Switzerland
- Allowable (declared) gross vehicle weight of the vehicle
- The gaseous emissions of the vehicle based on the vehicle engine type approval record.

At the introduction of the LSVA the price was calculated based on the above at 1.68 Rappen pro tonne and kilometer (Rp/t-km) for trucks that meet EURO I requirements. In 2005 this value was increased to 2.44 and as of 1.1.2008 to 2.70 Rp/t-km. Vehicles with EURO 0 would pay more and with EURO II/III would pay less [Suter 2001].

In order to further encourage vehicles with environmentally friendly engines as of 1.1.09 the three emission categories have been revised (www.ezv.admin.ch):

Category 1 (Euro 0,I,II): 3.07 Rp/t-km (2.00€Ct/t-km)

Category 2 (Euro III) : 2.66 Rp/t-km (1.85€Ct/t-km)

Category 3 (Euro IV+): 2.26 Rp/t-km (1.70€Ct/t-km)

Four examples are presented in Figure 13. 1 As shown the fourth vehicle which is a truck and trailer will pay a lower fee (2.26 Rp/t-km) with a EURO IV+ engine that is cleaner. The fee which is based on the average external costs of HGVs applies to the capacity of the vehicle and not the actual load carried in order to reduce the number of empty vehicles on the roads [Suter 2001].

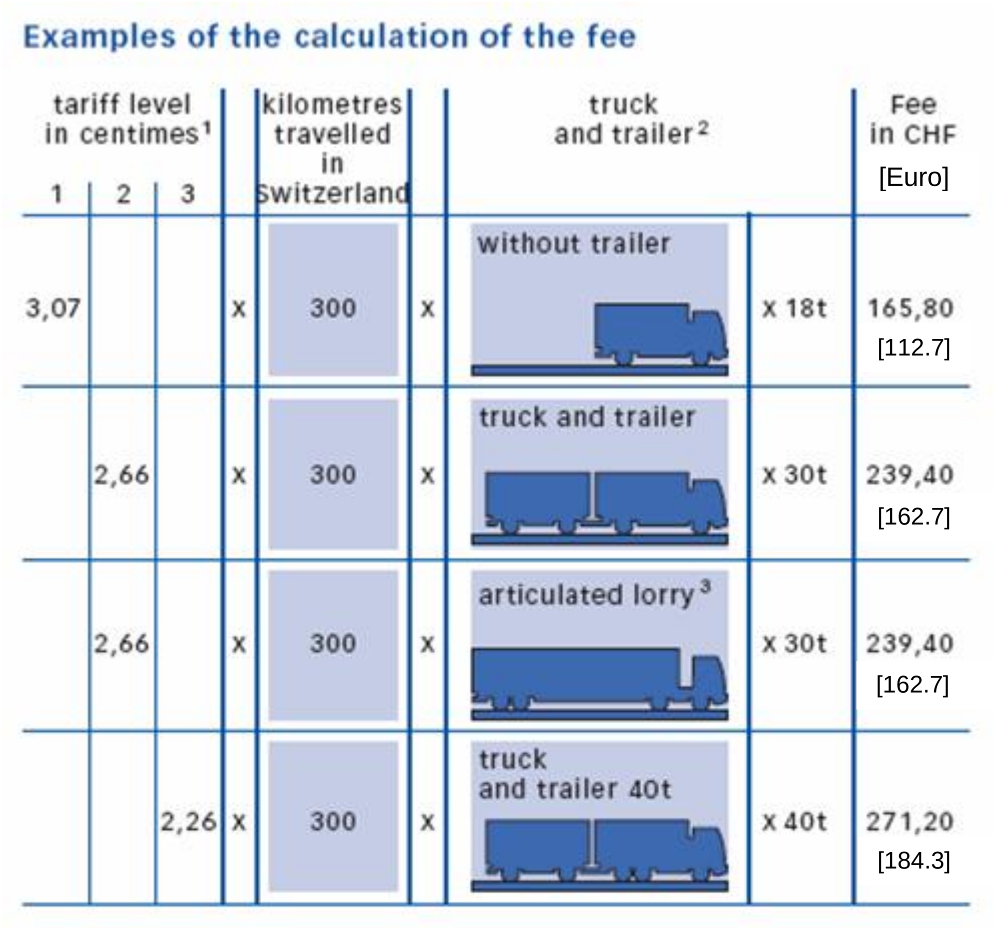


Figure 13. 1 Example of calculation of the Swiss heavy vehicle fee [Balmer 2008]

1/3 of this income is distributed to the cantons and 2/3 to the federal government. The cantons use this income to cover the external costs of transport and the federal government uses the income to finance large transportation projects such as Bahn 2000, the new alp transit tunnel (NEAT) and renovation of the rail transportation in order to reduce noise.

Following Switzerland's example, Austria has introduced a similar road pricing system in 1.1.2004 and Germany a year later that applies to the autobahn network only.

The consequences of this road pricing system are continuously monitored by the federal office for spatial development (ARE). Initial results after the first five years indicate a reduction in the number of HGV and a new trend in the vehicle fleet. At the end of 2005 the number of HGV was 6.5 % less than in 2000.

One of the positive effects of the LSVA has been the reduction in air polluting emissions from HGVs. This is mainly due to reduction in mileage and improvement of average emissions per vehicle. Fleets have been upgraded with vehicles complying with the EURO III norm plus a smaller extent also to EURO IV norm. As shown in Figure 13. 2 in all three categories of inland traffic, import/export and transit traffic the percent of kilometres travelled with EURO III has considerably increased. For example in the transit traffic category the vehicle kilometres with EURO III engines increased from 5% in 2001 to 72% in 2005.

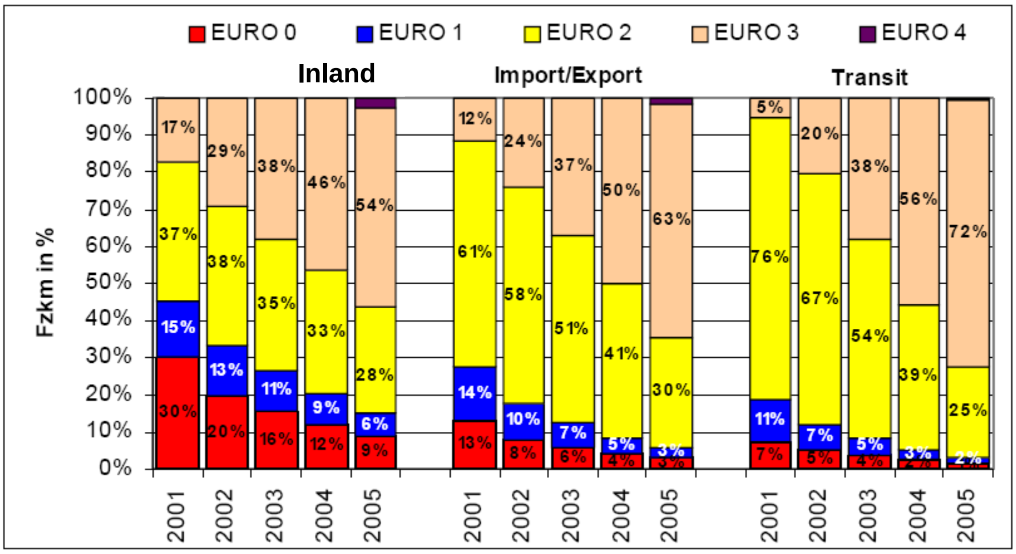


Figure 13. 2 Evolution of travelled kilometres (Fzkm) in % based on EURO norm after the introduction of LSVA [ARE, 2007b]

The Swiss Federal office for the environment has reported that 1 680 000 people in Switzerland are exposed to road noise over the threshold limit for housing areas set at 60 dB(A) for daytime. As shown in Figure 13. 3 this is more than other sources of noise such as rail [Schlachter 2008].
Current projects in Switzerland aim at the remediation of roads, so that the exposure in 2015 for motorways and 2018 for main roads and other roads will be below the impact threshold. According to the law the remediation should primarily be done at the source and on the propagation path (silent road surfaces, operational measures, sound protection barriers etc). If not possible substitution measures are applied (e.g. Sound Proof Windows). After 20 years of remediation 800'000 people have benefited. However, almost 3/4 of the work remains to be done at a total cost of 4 billion Euros.

Daytime Limit > 60 dB(A), Night time limit> 50 dB(A)

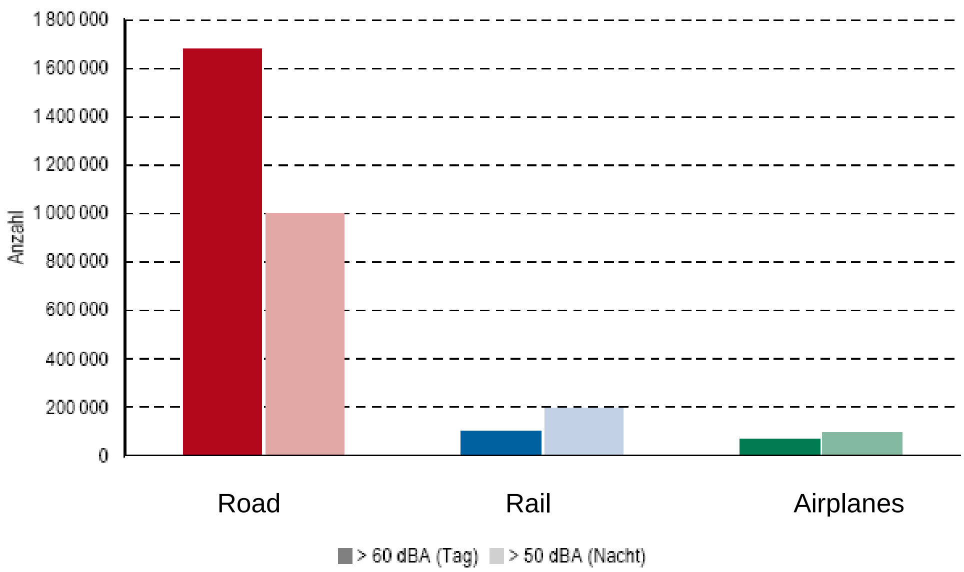


Figure 13. 3 Number of people exposed to noise [Schlachter 2008]

14 Implementation of Footprint Parameters in Road Pricing

14.1 Traditional motivation for road pricing

Road user charges may aim for various objectives. Historically, the main objective was the financing of the construction and operations of road infrastructure. Nowadays road user charges are increasingly used for traffic management or for implementing the polluters pay principle. The Swiss distance-related heavy goods vehicles fee (LSVA) was one of the precursors of this achievement (refer chapter 13).

Road vehicles are grouped into tariff classes. The motivation and justification for grouping vehicles into classes and assigning a certain tariff level varies:

- The tariff scheme can be formed according to the willingness to pay. Those who are economically powerful respectively profit most from transport, shall pay more.
- The tariff scheme can be formed in order to reflect the wear of the road, thus distributing the occurred costs according to the users pay principle.
- The tariff scheme can be formed taking the costs caused to the whole society into account, i.e. including external costs.
- Finally, the tariff scheme can be formed purely for achieving the required steering effect.

Until recently, charges have been collected only at toll stations. The joint operation of lines with cash, credit cards and fully electronic payment mandates a very simple system for vehicle classification. In particular it must be possible that the vehicle can be quickly identified by the person in the toll booth. For this reason the number of axles of the vehicle is the most widely used classification criterion.

Only with the emerging of electronic toll systems that collect the fees in free flow traffic, differentiation with finer classification systems became possible. The vehicle data is stored in electronic on-board equipment and transmitted to the roadside. The available data is quite comprehensive and includes, in addition to vehicle weight limit data, also vehicle dimensions, the emission class and engine type.

Classification is based on the data available in the vehicle documents. The data therefore relates to the vehicle type and make and not to the individual vehicle. The project Footprint II has shown however that the footprint of a vehicle can be very individual and specifically depends on load, speed and tyre pressure.

14.2 Holistic approach to environmental labelling of heavy road vehicles

In order to promote green transport it is necessary to quantify in a fair and transparent manner what entails green transport. Once this quantification is done it can be enforced through a bonus/malus system such as the current bonus for low noise rail vehicles in effect in Switzerland. Without quantification the reduction is limited or not possible.
Currently in Switzerland a differential track access charge is employed where 5-10% of the access charge is reduced as a noise bonus for quieter vehicles [Oertli 2008].

Footprint monitoring stations have made it possible to measure in situ the parameters of dynamic load, noise, and vibration systematically at rail and road sites. This monitoring has led to histograms showing the distribution of the parameters. As shown each parameter has to be quantified in situ and compared to environmental limits leading to a rating for that parameter. Once a vehicle is rated for each parameter the individual parameters can be added to produce a total footprint index. This index in turn can lead to an environmental label as shown in the example of Figure 14. 1. The labels assigned in Chapter 10 to case studies uses this principle for all footprint parameters.

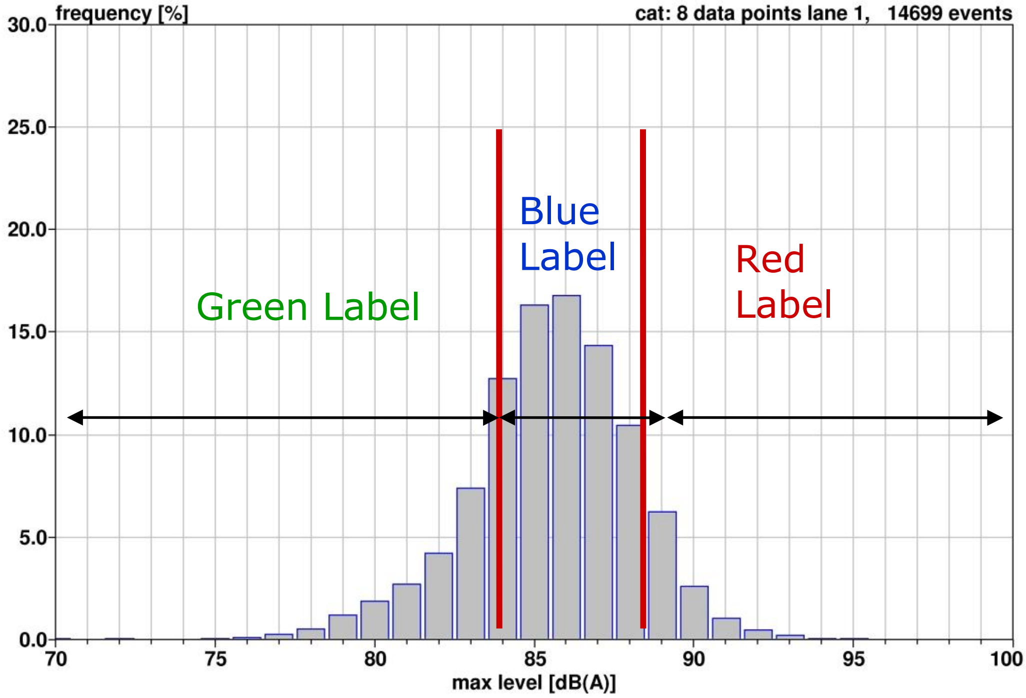


Figure 14. 1 Example of assigning labels for level of noise emissions for Swiss class 8 vehicles.

Such environmental labeling allows the internalization of external costs and produces solutions that support policy.

14.3 Challenges for environmental labelling

Individual footprints for charging are currently not conceivable. Issues of accuracy, verifiability and costs are not answered satisfactorily. However, research results establishing overall dependencies are useful for charging. When the statistical relationship between the vehicle parameters according to the vehicles licence and easily measurable parameters (such as speed) and the induced costs is established, tariffs could be better differentiated than today. This would allow a better mapping of internal and external costs of freight traffic to the right vehicles.

15 Overall Conclusions

The following statements are made based on the experience gained through this project:

- Footprint monitoring has added to the understanding of the evolution in road/vehicle interaction and how this will affect infrastructure design and management.
- The environmental footprint of heavy vehicles defined as dynamic load, noise, vibration and pollutant emissions was measured based on criteria set by the European project Eureka Logchain Footprint. The data shows that on weekdays ca 6000 heavy vehicles over three tonnes pass the footprint site out of which approximately 10% could be overloaded.
- In order to accurately identify overloaded vehicles, detailed vehicle information is needed. To this end, during a measurement campaign the footprint parameters were measured statically and dynamically for freight vehicles selected from the traffic stream and results were compared to the criteria set up as a result of current Swiss policy.
- The data shows that identifying the environmental footprint of HGVs is not straight forward. Vehicles that based on LSVA would pay a reduced fee are not necessarily environmentally friendly when the footprint parameters are considered.
- Parameters that are currently controlled and their reduction encouraged such as gaseous emissions, axle loads and gross weight are for the most part below or close to acceptable limits. However other important parameters such as tyre pressure and noise remain to be higher than acceptable limits.
- Footprint monitoring has led to histograms showing the distribution of the parameters. As shown each parameter has to be quantified in situ and compared to environmental limits leading to a rating for that parameter. Once a vehicle is rated for each parameter the individual rating can be added to produce a total footprint index. This index in turn can lead to an environmental label.
- Vehicles that are not environmentally friendly can also be potentially unsafe.
- The in-situ measurement of gaseous emissions of individual road vehicles at one single engine operating state in the framework of a Footprint Monitoring Station does not accurately reflect the representative emissions of that vehicle. Ideally, the average emission factors (g/km) for different classes of HGV should be found. In addition, driving pattern, road gradient and loading should be taken into account.
- The large difference of more than 10 dB between the loudest and the most silent vehicle shows the large potential for possible improvements regarding noise impact.
- Ground borne vibration caused by heavy vehicles are below threshold of human perception at the footprint monitoring site. However this can change depending on traffic characteristics and pavement condition.
- Using a footprint monitoring site can allow monitoring of 60 tonne mega trucks if they are introduced in the future and assure compliance with the allowable limits.
- Environmental labelling allows the internalization of external costs and produces solutions that support policy.

16 Future Research Needs

Traffic monitoring by the Swiss Federal Roads Office (ASTRA/FEDRO), Figure 1. 1, has shown that in 2007 total traffic has increase more than 50 % in comparison to 1990. This increase in traffic has naturally an effect on the people and infrastructure in the traffic corridors. For a sustainable transportation system there is an urgent need to develop means to reduce the environmental impact of these vehicles.

The European cooperative project Eureka Logchain Footprint E!2468 has developed methods to identify environmentally friendly vehicles for road and rail transport modes. At the same time the Swiss Heavy Vehicle Fee (HVF) or LSVA (the German acronym) has developed a bonus/malus system in order to encourage road vehicles with a small environmental footprint.

Detail examination of vehicles taken from the traffic stream in the Footprint II project has indicated that the parameters encouraged by the LSVA method are indeed at or below environmentally friendly limits whereas the additional parameters defined by the Footprint project are not affected. Footprint II has shown that there are vehicles on the road with very high axle loads but gross vehicle weights that are within limits. There are vehicles with high noise emissions but engines that are up to the latest available technical standards for gaseous emissions.

In August 2009, WIM sensors where built parallel to an LSVA monitoring site on the A1 at Oberbuchsiten. This provides a unique opportunity for evaluation of the following for a sample population:

- Use methods developed in the footprint project to measure the interaction of a vehicle with the infrastructure and the environment
- Provide data about these impacts to operators, infrastructure maintainers and society
- Comparison of Axle loads with allowable limits
- Comparison of Gross weight with declared values using vehicle data
- Using vehicle data to categorize overloaded vehicles based on origin
- Using vehicle data to categorize overloaded vehicles based on vehicle category
- Using vehicle data to categorize noise emissions of vehicles based on origin
- Using vehicle data to categorize noise emissions of vehicles based on vehicle category
- Combine axle load, gross weight, noise emissions and engine data of individual vehicles
- Identify options for reducing the environmental impacts of road and rail modes
- Propose a way of defining environmentally friendly vehicles

This process will allow to combine many of the Footprint parameters with LSVA parameters. Detail analysis of sample data can give clear indication on whether or not the LSVA encouraged environmentally friendly vehicles for a larger sample size than in Fooprint II.

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Appendices

I Eureka proposal to follow up E!2486 Logchain Footprint

I.1 Criteria for environmentally friendly vehicles for road and rail

Background
This Eureka project, which started in 2001, investigated

The relation of the environmental footprint of a vehicle to the lifetime cost of maintaing the infrastructure and the environment

The final workshop of the first phase held at EMPA laboratory, Dubendorf, Switzerland on 26.11.2008 concluded that

- the Footprint project had significantly increased our knowledge of the environmental impact of road and rail vehicles [1,2]
- the environmental impact of transport was a European problem which required a European solution
- evidence suggested that environmentally harmful vehicles may also be unsafe
- with increasing number of vehicles it becomes essential to inform operators that their vehicles may be unsafe
- data collected by Footprint project can be used to set environmental limits
- environmental limits should be based on measurements of vehicles in service as well as laboratory and track testing
- vehicle impacts can be limited through a mixture of regulation and user charging
- the EU green transport package of 8 July 2008 commits Member States to developing more sustainable transport use including the internalisation of external costs
- the Commission proposal of a bonus/malus system which was revenue neutral to reduce the noise from the existing rail vehicle fleet was desirable
- theoretical predictions of the impact of any charging policy can be checked by in service measurements
- *and that the next phase should concentrate on developing criteria for environmentally friendly vehicles*

Goals
For phase 2 the proposed goals are

- to develop equivalent criteria for environmentally friendly road and rail vehicles
- to check the effectiveness of any user charging regime to accelerate the introduction of environmentally friendly vehicles
- to increase the safety of vehicles operating on road or track by making measurements in service and informing the operator

Major tasks
Task I data collection and exchange

- to collect more data from different sites in various countries to broaden the existing data sets
- to check the infrastructure and environmental impacts on secondary roads and tracks
- to develop techniques for determining the dynamic loading as well as the quasi-static loading on structures including bridges
- to facilitate data exchange between infrastructure maintainers
- to refine methods of determining reliability and uncertainty in the data sets
- to develop methods of determining the performance of a vehicle's suspension

Task II data analysis and environmental impact

Data to be analysed to determine trends in

- number and class of vehicles in service
- variation in day/night and summer/winter
- relative importance of type and quality of the infrastructure
- identification of vehicles that may be unsafe
- proportion of vehicles that can be considered environmentally friendly and environmentally harmful
- impacts of any user charging regime

Task III Developing equivalent criteria for environmentally friendly road and rail vehicles

- to assess the analysed data to determine the mean values of the various environmental and infrastructure impacts
- to use statistical analysis to determine possible limits for environmentally friendly and environmentally harmful vehicles
- to determine possible limits for bonus/malus payments of user charging

Task IV Relating impact to user charging

- to consider the appropriate environmental impacts for user charging which should include noise emissions, gross vehicle weight, axle load, vibration and local pollutants
- to relate limit values in task III to cost
- to propose appropriate values for bonus/malus payments

Task V Dissemination

- to discuss with manufacturers, operators and local, national and European authorities
- to organise workshops alongside each project meeting to consider progress
- to present results at conferences and in publications

Proposed time table

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Task/months          0          12          24          36        42

I    data         ----------------------------------------------------

II   analysis               -------------------------------------------

III  criteria                        -----------------------------------

IV   user charging                               ----------------------

V    dissemination          --------------------------------------------
```

Possible partners

UK	SCP, TDC, Datagen, DfT, NRA
CH	EMPA, Kistler, BAV, BAFU, ARE, ASTRA
CZ	SVUM, Skoda, Cdrahe
AT	HBM, OBB, psia, MVUE
NL	Baas, Prorail, DWW
IR	UCD, IRB

Abbreviations

Abbreviation	Meaning
ARE	Swiss Federal Office for Spatial Development
ASTRA	Federal Roads Office (German Acronym)
BAFU	Swiss Federal Office for the Environment
BAV	Federal Office for Transport
DAQ	Data Acquisition
EU	European Union
FEDRO	Federal Roads Office
FMS	Footprint Monitoring Site
Footprint	European Project Eureka Logchain Footprint
GNP	Gross National Product
GUS	Grand Unified Script
HBEFA	Handbook of Emission Factors for Road Transport
HDV	Heavy Duty Vehicles
HGV	Heavy Goods Vehicles
ISO	International Organization for Standards
LSVA	Swiss Heavy Vehicle Fee (Leistungsabhängige Schwerverkehrsabgabe)
NTE	Not to Exceed
PPV	Particle Peak Velocity
SIM	Stress in Motion
SMPS	Scanning Mobility Particle Sizer
SPW	Sound proof windows
TPMS	Tyre Pressure Drop Monitoring Systems
WIM	Weigh in Motion

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Projektabschluss

Schweizerische Eidgenossenschaft
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Confederazione Svizzera
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Eidgenössisches Departement für
Umwelt, Verkehr, Energie und Kommunikation UVEK
Bundesamt für Strassen ASTRA

FORSCHUNG IM STRASSENWESEN DES UVEK — ARAMIS SBT

Formular Nr. 3: Projektabschluss

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Grunddaten

Projekt-Nr.: **ASTRA2006/020**

Projekttitel: Footprint II- Long Term Pavement Performance and Environmental Monitoring on A1

Enddatum: Januar 2010

Texte:

Zusammenfassung der Projektresultate:

Phase II of the Footprint project has continued monitoring heavy vehicles on the A1 motorway. The environmental footprint of heavy vehicles defined as dynamic load, noise, vibration and pollutant emissions is measured based on criteria set by the European project Eureka Logchain Footprint. Measurements of dynamic loads (WIM) have shown that on weekdays ca. 6000 vehicles pass the footprint site out of which about 10% could potentially be overloaded. In order to accurately identify overloaded vehicles detailed vehicle data is needed. To this end, in this phase footprint parameters were measured statically and dynamically for freight vehicles selected from the traffic stream and results were compared to the criteria set up as a result of current Swiss policy. The data shows that identifying the environmental footprint of HGVs is not straight forward. Vehicles that based on LSVA criteria would pay a reduced heavy vehicle fee, due to their engine type, are not necessarily environmentally friendly when the footprint parameters are considered. Footprint monitoring has shown that parameters that are currently controlled and their reduction encouraged such as gaseous emissions, axle loads and gross weight are for the most part below or close to acceptable limits. However other important parameters such as tyre pressure and noise remain to be higher than acceptable limits.

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Zielerreichung:	Footprint monitoring has shown that it is possible to measure in situ dynamic load, noise and vibrations induced by heavy vehicles and to combine this data with the vehicle information such as engine type and allowable weight in order to arrive at the complete indication as to the environmental friendliness of each vehicle.
Folgerungen und Empfehlungen:	It is recommended that in order to reduce the environmental footprint of heavy vehicles a holistic approach should be taken where the reduction of all parameters is encouraged by using a bonus/malus program.
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