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## **Swiss Contribution to Eureka Logchain Footprint E!2486**

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**STRC 03 Conference Paper  
Session Logistics**

**STRC**

**3<sup>rd</sup> Swiss Transport Research Conference**  
Monte Verità / Ascona, March 19-21, 2003

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## Abstract

Because of their high axle mass, freight vehicles have the biggest impact on the infrastructure. The ongoing Eureka Logchain Footprint project aims to reduce this impact through a better understanding of the dynamic interaction, encourage the emergence of more environmentally friendly vehicles and to facilitate conveyance of freight by the route with the lowest environmental impact. Footprint aims to develop objective methods for comparison of environmental friendly road and rail freight transport and to encourage intermodality.

The major phase will be that of enhanced measurements of the dynamic loading; the intention is to extend and upgrade existing measuring stations like weigh in motion (WIM) concept for both road and rail. This will be achieved through the use of an extended and improved sensor array and data capture. In addition audible noise and ground borne vibrations will be measured as these affect persons and buildings adjacent to traffic corridors.

Data from such stations will be analyzed in various ways:

- To assist with improved maintenance procedures
- To aid designs of long life infrastructure
- To supplement the existing data in the COST 323 database
- To provide new inputs to infrastructure cost allocation models
- To provide the basis for a set of environmental indices for vehicles and infrastructure

The use of environmental indices relating to measurable aspects of dynamic interaction is to inform operators, maintainers and EU citizens of the environmental impact of transport. These indices can then be aggregated or thresholds set to define classes of environmentally friendly vehicles and infrastructure. Their uptake could be encouraged by offering a suitable range of benefits thereby promoting the sustainable development of transport.

The project has currently 25 partners from seven European countries (Czech Republic, Hungary, Switzerland, the Netherlands, Belgium and France) with the UK providing leadership.

At EMPA in cooperation with a number of Swiss companies and governmental organizations (Kistler, ASTRA, BAV, BUWAL) algorithms will be developed for analyzing data from a variety of sensors to characterize individual vehicle classes according to their "footprint". Footprint is a unique opportunity to use and compare various innovative devices in parallel and to make a significant contribution to a European collaborative program in which Switzerland's input will be considered in a European consensus, which will be derived on the specification of a "footprint" measuring station.

## **Keywords**

Long Term Pavement Performance Monitoring – European cooperative program – WIM – noise measurements and modeling, EMPA, Eureka, Footprint, intermodality, infrastructure, COST – 3<sup>rd</sup> Swiss Transport Research Conference – STRC 03 – Monte Verità,

## 1. Introduction

The maintenance of road and track increases significantly with increasing axle loads as well as additional freight traffic associated with a single European market. To meet this challenge, a better understanding of the dynamic interaction between freight vehicles and the road is required.

Because of their high axle loads, freight vehicles have the biggest impact on the infrastructure. The ongoing Eureka Logchain Footprint project aims to reduce this impact through a better understanding of the dynamic interaction. Footprint aims to develop objective methods for comparison of environmental friendly road and rail freight transport and to encourage intermodality as well as the emergency of more environmentally friendly vehicles.

The project has currently 25 partners from seven European countries (Czech Republic, Hungary, Switzerland, the Netherlands, Belgium and France) with the UK providing leadership.

At EMPA in cooperation with Kistler Instruments, RTSC, Swiss Road Authority (ASTRA), Swiss Environmental Authority (BUWAL) and Swiss Transportation Authority (BAV), algorithms will be developed for analyzing data from a variety of sensors to characterize individual vehicle classes according to their "footprint".

## 2. Relevance to EU and National Objectives

Various EU objectives have direct relevance to Footprint. Those include the technical specification for interoperability, the uptake of intermodality, methodology for infrastructure charging, reduction of environmental impact (2000 white paper), enhanced safety and the design of the EU rail freight network.

## 3. Objectives of Footprint

Footprint aims to measure the dynamic interaction of vehicle and infrastructure by novel methods, characterize vehicle types in terms of their environmental footprint, determine which types of vehicles cause the greatest damage, identify long term trends in dynamic loading, vibration and noise and to propose incentives which will encourage operators to reduce environmental effect at source. These goals are all relevant to the national objectives of the member countries. Specifically, the objective of the Footprint project is to develop innovative and cost effective methods to identify vehicles by means of their "footprint" as characterized by

- dynamic load
- noise
- vibration
- and gaseous emissions induced by the vehicle.

## **4. Various phases of the project**

The project has six phases. Those are:

- Phase 1-Analysis of existing knowledge
- Phase 2-Modeling
- Phase 3-Measurements of the dynamic interaction and footprint
- Phase 4-Life cycle costing
- Phase 5-Improved methods for managing infrastructure capacity
- Phase 6-Discussions, recommendations and dissemination

EMPA in cooperation with Kistler, RTSC, ASTRA, BUWAL and BAV intend to be involved in all phases of the project. Below are some of the most important contributions to be made.

### **4.1 Modeling**

The contribution of EMPA to this phase is two fold:

1. Track/vehicle interactions: The objective is the computer simulation of track/vehicle interactions as a basis to study damage to infrastructure. The models, which would form the basis of the work, would be developed in cooperation with other European partners and will be used to explore the range of parameters identified in phase 1 and to predict the influence of vehicle, suspension and infrastructure alignment for vehicles to be tested in phase 3.
2. Acoustics: Algorithms will be developed to identify the acoustical emission of single vehicles. The main problem is to estimate and suppress the signals from the neighbor vehicles. The obvious solution of simply evaluating the maximum pass-by levels of axle pairs of in-

terest does not work as there is a systematic error stemming from the emission of the neighbor vehicles. The task is to find an algorithm to estimate and compensate for this effect. The problem will be tackled by conducting computer simulations of the time history of the microphone signal for different configurations of vehicle chains. One crucial point is the uncertainty regarding the directivity of the sources. The simulations and the algorithms found will then be tested for a variety of real measurements of train passages.

## 4.2 Measurement System

Enhanced measurements of the dynamic loading will be used to upgrade existing measuring stations like weigh in motion (WIM) concept for both road and rail in accordance to the recently formed Footprint Specifications for a measurement station. This will be achieved through the use of an extended and improved sensor array and data capture. In addition, audible noise and ground borne vibrations will be measured as these affect persons and buildings adjacent to traffic corridors.

Data from such stations will be analyzed in various ways:

- To assist with improved maintenance procedures
- To aid designs of long life infrastructure
- To supplement the existing data in the COST 323 database
- To provide new inputs to infrastructure cost allocation models
- To provide the basis for a set of environmental indices for vehicles and infrastructure

In 1998 a long-term in-situ measurement system was installed on the Swiss motorway A1 between Zürich and Bern to record the amount and frequency of traffic loads, the numbers and type of vehicles as well as pavement temperatures and vertical deformations within the cross section of the pavement (Figure 1 and Figure 2). The aim of the project is to collect and evaluate relevant data for improving the system properties and service life of roads.

This measurement station will be enhanced in the Footprint project:

- to link the WIM data to temperature and deformation measurements in the pavement.
- to provide valuable WIM input data for the next revision of Swiss Standard
- to provide a Footprint station for the European wide project Eureka Logchain footprint.

- to serve as a validation tool for the development of new magnetostrictive measurement device.
- the test a new WIM system that will measure not only the axle loads but also the pressure distribution under the individual tire.

This measurement station will also be upgraded to include acoustic and vibration measurements in accordance to the Footprint Specifications for a measurement station.

Figure 1: Overview of all measuring points on the test site: Weigh-in-motion (WIM), Deformation (D1...D3, W1) and Temperature Measurement (T)

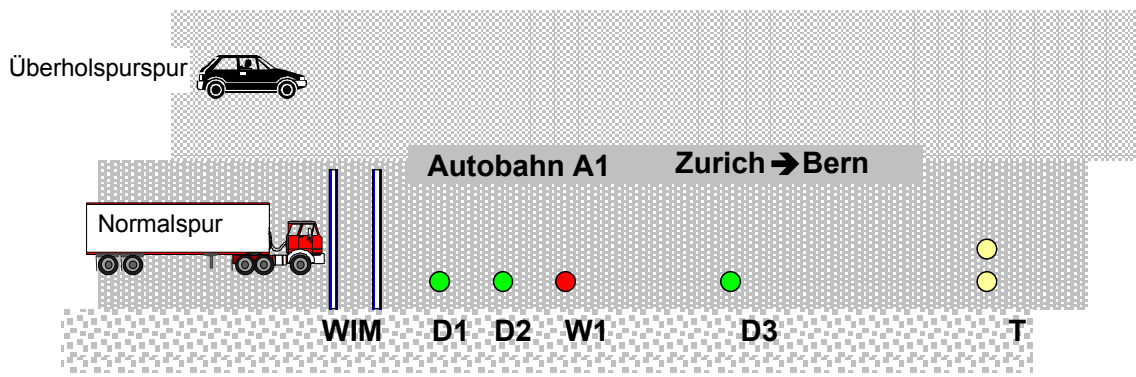
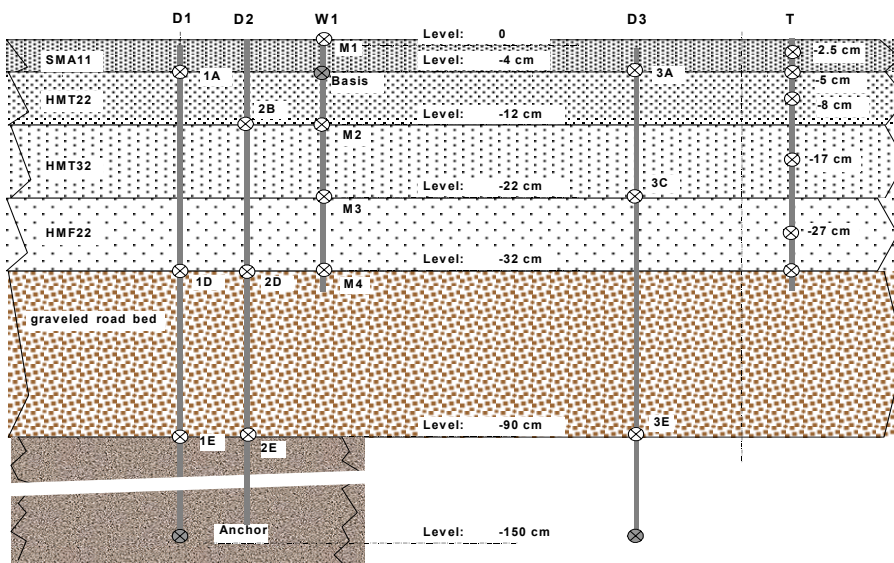


Figure 2: Location of the measuring devices in the individual pavement layers (cross section)

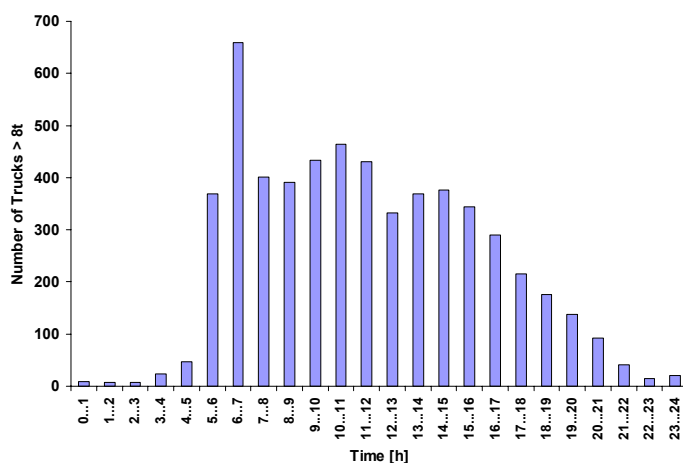


## 4.2.1 WIM Measurements

### Existing WIM

The monitoring of vehicle weight and frequency on the existing A1 site is currently conducted continuously by a WIM (weigh-in-motion) system that consists primarily of two load cells with piezo-electric quartz sensors-LINEAS by the Kistler company . These sensors measure the weight and the axle loads of a passing vehicle. The data is collected by an on-site computer and transferred via modem for evaluation purposes. From the characteristic load/time signal, the vehicle type is determined. In addition, the load equivalency factor with respect to the equivalent single axle load (ESAL) of 8.16 kN is calculated. Data is collected continuously. According to the data evaluation for the year 2000, average number of heavy vehicles per hour was between 230 and 310, extending up to 700 heavy vehicles during rush hour (Figure 3). Over the course of the year, the volume of heavy traffic was equally distributed. However as expected, during holidays (Easter, Christmas) and vacation time (July/August) traffic was significantly lower.

Figure 3 Daily Distribution of Heavy Trucks Averaged Over the Year 2000

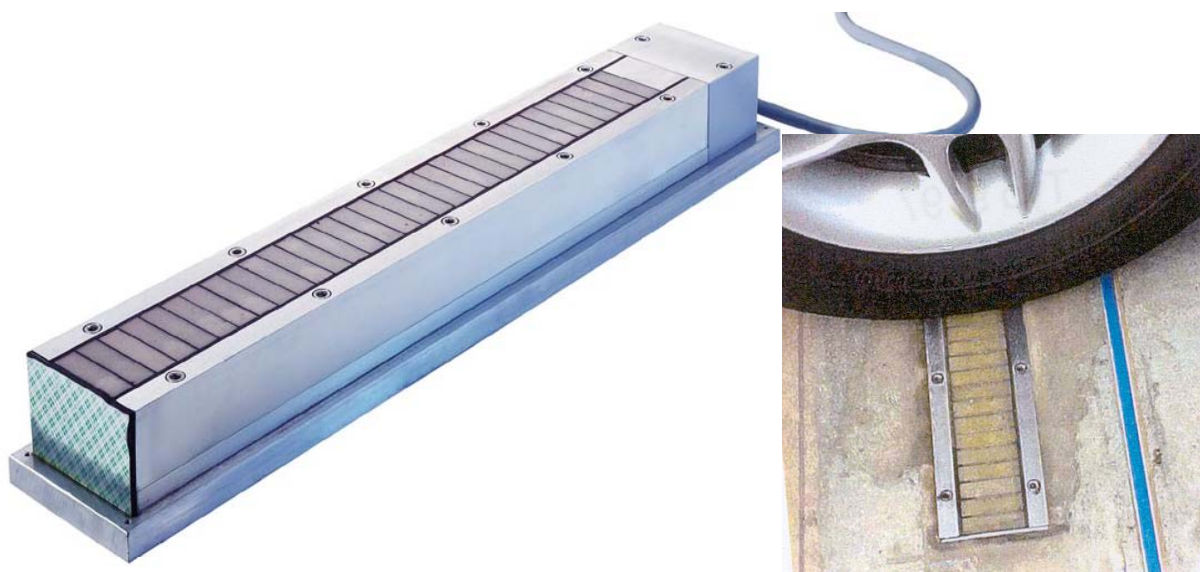


### New WIM

Using new innovative sensors is a major aim of the Footprint project. Up to now pavement deterioration by heavy vehicles is assessed generally as a function of heavy vehicle weight and traffic density data by vehicle classes. The novel design of the Kistler MODULAS sensor

(Figure 4) will add additional information in characterizing the impact of vehicles on pavements. More specifically, the novel measurement methodology takes into account contact pressure distribution of different tire types (single / twin / super single tires). It enables an improved analysis of the factors influencing pavement damage formation and propagation. Tire configuration, dynamic wheel load, force and pressure distribution, width of footprint, wheel path position as well as duration and frequency of crossings will be measured as well. The necessary software will be developed at EMPA.

Figure 4 MODULAS Sensor developed by Kistler Instruments



## Deformation Measurements

The increasing load of highways due to traffic frequencies and traffic loads requires an increasing control of the pavements, which are already exposed to temperature cycling, ice and (salt) water. In addition to the knowledge of the vehicle weight and their frequency, the knowledge of the vertical deformations within the pavement layers is of interest. In order to determine the structural impact of vehicles on the different layers of the pavement by measuring the relative vertical deformations of the pavement at various depths, a measurement system consisting of a number of Differential Deflection Measurement (DDM) devices D1 to D3 was installed. These inductive measurement devices consist of a guide tube holding several LVDTs. The tube is solidly attached against an anchor in a depth of 1.5 m. The different LVDTs are placed in different depths of the pavement. They are clamped on the pavement and measure the relative displacements between their target and the anchor (figure 5). The devices D1 to D3 are based on a system, which was developed in 1980 by CSIR in

South Africa and installed in a re-designed and modified version by a Portuguese firm. Unfortunately, the installation of the system, especially the drilling of the anchor turned out to be rather difficult. The sealing and frost protection of the sensors proved to be an even more critical point: After only one winter, the first sensor D1 had to be replaced. Due to the harsh environmental conditions, which resulted in a deterioration of the whole system, the evaluation of a new measurement device was necessary.

Therefore in December 2001 an additional new measurement device (figure 4) based on the magnetostrictive principle was installed. This measurement device was designed by EMPA and the new sensor system was developed on the basis of the magnetostrictive principle: Magnets m1...m4 fixed to the pavement points M1...M4 (see figure 2) induce in conjunction with an electric pulse in the magnetostrictive material acoustic pulses. Its travel time can be used to determine the position of the magnets. The magnets are attached to the pavement but the sensing element is protected in a hermetic stainless steel enclosure. The magnetostrictive sensor is able to measure simultaneously up to four positions along one measuring axis in different layers of the pavement and contains an additional temperature sensor in the head [Anderegg et al, 2000].

Short-term elastic deformations as well as the long-term plastic deformation of the pavement are of interest. Figure 6 shows two examples of the vertical pavement deformations induced by trucks passing over the sensors at a speed of about 90km/h. The air temperature was about 7°C. Note, the small peaks on top of the right broad pulse which occur from the triple axle and double axle impulses respectively.

Figure 5 Schematic the magnetostrictive measurement device W1 measurement device

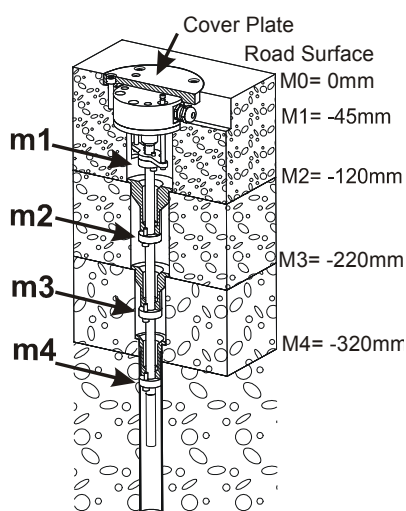


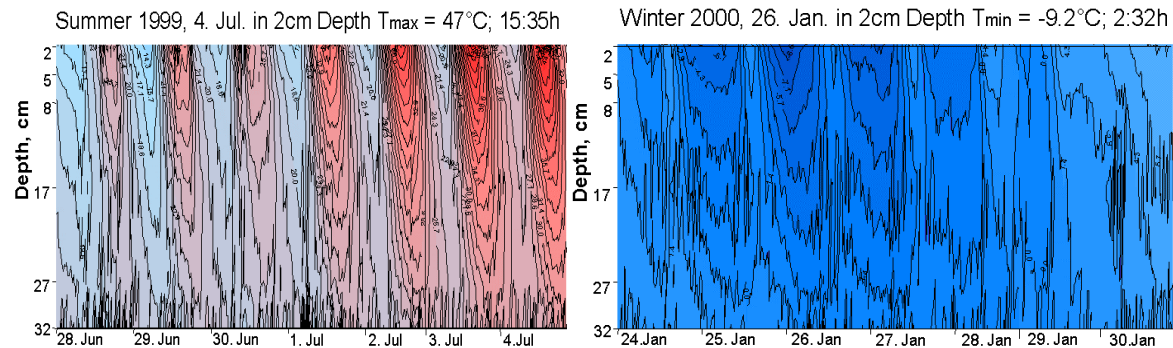
Figure 6 Vertical road deformations due to a passing truck, DDM device D2 in point 2B and 2D on the morning of 5th November 2002



## Temperature Measurements

Due to the fact that the behavior of asphalt materials is highly temperature sensitive, monitoring temperature was seen as an imperative part of this project. Temperature sensors were installed at various depths within the layers of the pavement. Figures 2 and 3 show the position of the sensors and Figure 7 shows the variation of temperature down to a depth of 32 cm using isothermal lines. The left and right figures show summer and winter values respectively. As expected the higher day temperatures appear in the late afternoon still under heavy traffic conditions (Figure 3). As compared to summer, the winter values show less of a variation between day and night between the layers.

Figure 7 Isothermal Lines in the Pavement for the Hottest and Coldest Week in Summer 1999 and Winter 2000 (Distance Between Isothermal Lines 1.4°C)



## Noise Measurements

The noise measurements will be based on existing international standards where possible. In case of trucks the measurement geometry will be chosen according to EN ISO 11819-1 Acoustics located at a distance of 7.5 m and 1.2 m above ground [EN ISO 11819-1, Acoustics]. The basic acoustic quantity to describe the noise emission of single road vehicles is the maximum pass-by level. One problem to be dealt with is the possible disturbance of the acoustic measurement by other vehicles or other noise sources such as airplanes for example. Fortunately the ISO11819-1 standard indicates a method to decide whether or not a measured maximum level is valid or not (6 dB down rule). During the work it has to be examined if the ISO 11819-1 rule is applicable and what is the percentage of measured events that can be evaluated for a given traffic density. For trains the aim is to describe each single vehicle by a noise emission value. It should therefore be possible to detect a noisy vehicle within a quiet train. The corresponding ISO standard on the noise emission measurement of trains [ISO/DIS 3095.2, Railway applications] gives only a procedure for the description of the whole train. The acoustic quantity is the so-called TEL = Transit exposure level which corresponds basically to the acoustical energy of the train passage. There is no guidance on how to split up the measured emission into sub sources. The obvious solution of simply evaluating the maximum pass-by levels of axle pairs of interest does not work as there is a systematic error stemming from the emission of the neighbour vehicles. The task is thus to find an algorithm to estimate and compensate for this effect.

## 5. Environmental Indices

The use of environmental indices relating to measurable aspects of dynamic interaction are useful to inform operators, maintainers and EU citizens of the environmental impact of transport. Footprint aims to develop objective methods for comparison of environmental friendly road and rail freight transport and to encourage intermodality as well as the emergency of more environmentally friendly vehicles.

## 6. Conclusions

Footprint is a unique opportunity to use and compare various innovative devices in parallel and to make a significant contribution to a European collaborative program in which Switzerland's input will be considered in a European consensus, which will be derived on the specification of a "footprint" measuring station.

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