Traffic Measurement Technology
Traffic situations are subject to special monitoring at hot spots to help prevent accidents.  
(photo: Albert Zimmermann/Schindler)
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One of the core objectives of the Federal Roads Office (FEDRO) is to achieve a noticeable improvement in traffic safety and in particular a significant reduction in the number of traffic accidents with serious injuries and deaths. There are various ways of meeting this goal. The Via sicura action programme encompasses roughly 60 measures designed to work towards this goal. A few of these proposed measures are controversial among road users. This certainly also includes more extensive usage of traffic checks. It is a fact that traffic checks are a very effective and thus important measure for preventing traffic accidents. However, checks are subject to repeated public and political criticism.

Measuring devices used to monitor speed, red lights and other physical quantities must exhibit high dependability to achieve credibility. If they were not dependable, they would become an object of criticism themselves and the checks would lose their effect. Police, courts of law and naturally road users, too, must be able to 100% rely on the measured values. Ensuring this is the job of the Federal Institute of Metrology (METAS).

This important task is growing in importance within a constantly changing environment. Technical developments necessitate ongoing adaptations in the areas of inspection, certification, regular verifications and necessary changes in laws. Before a new technology, a new measuring device or a new method can be used, it needs METAS. It is a challenging task to come to terms with advances in technology as well as the changing requirements of police, investigative agencies and of course also the manufacturers. METAS works to keep its eye on the big picture, ensure stability and permanently guarantee the highest possible dependability.

Accordingly, METAS is an important partner to FEDRO in its efforts to increase traffic safety. The great dependability of approved measuring devices and the indisputable competence exhibited by METAS in assessing equipment and measurement results ensure that traffic checks will continue to be an effective tool for reducing traffic accidents.

Dr Rudolf Dieterle
Director FEDRO
Our society relies on dependable measuring instruments and measurement results. They form the necessary basis for activities within our legal, economic and social systems. Just imagine if you couldn’t trust a scale in a grocery store or the quantities printed on packaged goods. What if you couldn’t rely on your speedometer when driving your car or you couldn’t be sure that the measurement was correct and reliable when you were caught by a traffic camera? A situation of this sort would cause lasting disruptions to or even shake the core of our legal and economic system, making life in society much more difficult.

The Federal Institute of Metrology (METAS) is the federal centre of competence for all issues related to measurement, measurement equipment and measurement techniques. Through its activities and its services, METAS ensures that it is possible to perform tests and measurements in Switzerland with the level of accuracy demanded by research, business and society. METAS makes available to business and society a test and measurement infrastructure that is important to all areas of measurements. METAS enables reliable market introduction of measuring instruments and ensures the stability of measurement equipment during its entire lifespan.

Accordingly, METAS must stipulate specific requirements for measurement equipment which is used in the area of safety if fines or interdictions will be issued based on measurements with such equipment. This applies, of course, to speed measurement equipment in particular. The competence for regulations in fields outside of metrology lies with the respective technical authorities. METAS gives them access to its technical competence for the test and measurement support that might be needed. METAS works in close cooperation with various technical authorities in this manner.

We should mention our excellent co-operation with the Federal Roads Office (FEDRO). In the area of applications involving measurement equipment for road traffic, there is a clear division of labour: As the competence centre for road infrastructure and road traffic, FEDRO regulates the usage of measurement equipment and specifies the required accuracy. It bases its efforts on technical, practical and legal frameworks. As the federal competence centre for measurement equipment and measurement techniques, METAS tests measurement equipment and specifies the technical requirements for such equipment and techniques.

At METAS, however, we deal with more than just traffic measurement technology when it comes to road traffic. Our other activities include testing of measuring devices such as weighbridges, profile measuring systems, exhaust gas measuring devices, sound level meters and breathalyzers, along with specification of requirements for these measuring devices, and testing of the technical lighting equipment used in vehicles and illumination measurements in tunnels.

Dr Christian Bock
Director METAS
Measurement Technology in Service of Traffic Safety

Every year traffic accidents on Swiss roads affect about 100,000 persons, and roughly 360 persons are killed (2007: 384; 2008: 357). Pedestrians and in particular children and the elderly as well as cyclists are especially at risk. The most common causes of accidents are driving under the influence of alcohol and driving at excessive or maladjusted speeds. Measures designed to monitor speed serve as a countermeasure. Special checks at critical locations can increase traffic safety. Visible traffic measurement equipment also has a preventive effect. The goal of monitoring is to calm the flow of traffic and ensure less hazardous situations and ultimately less traffic accidents.

Requirements for Speed Measurement Equipment

Heavy traffic on the roads creates major challenges for speed monitoring. Measurements made as part of official checks must be consistent, reliable and precise. An erroneous measurement could result in a driver receiving an unjustified fine or even improperly losing a license. For this reason, the measurement systems must operate correctly at all times as well as being used properly by the police. This is the only way to ensure that measurements can be trusted and will be accepted by the public. Accordingly, speed measurement equipment for traffic monitoring must satisfy demanding requirements:

Measurements accuracy: A measurement made in road traffic cannot be repeated. It must be accurate and dependable the first time. External influences such as temperature, humidity, electromagnetic emissions from mobile telephone systems, high-voltage lines and radio or TV transmitter systems may not interfere with the functioning of the measurement equipment.

Measurements certainty resp. attribution of measured values: A measurement result generated in road traffic must be attributable with 100% accuracy to the measured vehicle and its driver even during heavy traffic and in complex situations.

Measurement stability: The operational reliability of the measurement equipment must be ensured during the entire lifespan of the equipment.

METAS specifies the test and measurement requirements for the various types of measurement equipment so that the conditions stated above are fulfilled. The specifications are intended primarily for manufacturers of the corresponding equipment and for verification laboratories.
**Legal Certainty**

Various countries recognise what is known as the owner prosecution. This means that only the registration plate of the vehicle in question needs to be recorded for prosecution. However, this is not an adequate basis under Swiss law. In Switzerland, the driver must be prosecuted. Each violation of the indicated maximum speed must be recorded in Switzerland in a manner that the measured value can be attributed with no doubt to the driver. Moreover, it must be possible to reconstruct the circumstances afterwards. Therefore, either two independent speed measurement techniques have to be used, or the violation is recorded in conjunction to the measurement, e.g. using a sequence of time stamped images, for which the distance is precisely known, or video recordings.

**Safety Margins**

Every measurement has an intrinsic measurement uncertainty. When speeding violations are prosecuted, safety margins, also known as tolerance allowances, are included in the calculations. This ensures that a lower value than the actual speed of travel is prosecuted in each case. METAS determines the technical requirements for the measurement equipment. The Federal Roads Office (FEDRO) is responsible for usage of measurement equipment by the police and thus also for the safety margins that are actually applied.
Tasks and Activities of the Laboratory for Road Traffic

The staff of the METAS laboratory for road traffic ensure that the measurement equipment used in official traffic checks is accurate and reliable. The experts also test new measurement equipment and measurement techniques. The laboratory possesses a specialised, high-tech measurement infrastructure for this purpose.

Test Equipment and Test Methods
To be able to fulfil its duties, the experts of the laboratory for road traffic are frequently required to perform fundamental studies and develop test methods for new measurement technologies. The difficulty here is that unlike, say, an item to be weighed on a scale, traffic in the normal sense is not available in the laboratory for measurements that can be repeated at will. Traffic changes constantly: Vehicles and speeds vary depending on the time of day and location. Another difficulty is that test methods for speed measurement equipment must also take into account high values for the speed and acceleration that are not available at all during everyday traffic.

To allow testing of measuring devices in the most realistic manner possible even in a laboratory environment, the staff of the laboratory for road traffic have developed complex simulation techniques. This makes it possible to avoid elaborate and expensive measurements in real road traffic. Simulations also have the benefit that different equipment and equipment types can be tested under reproducible, identical conditions, which is not the case with real road traffic situations. The test setups used for these traffic simulation test methods are developed in-house since such systems are not available as commercial products.

Another in-house development is the computer-controlled reference test system operated by METAS on a motorway. This system allows testing of measuring devices under real conditions. The vehicles passing by undergo simultaneous measurements with the device under test as well as a multiple laser light barrier. Through direct comparison of the two measurements, it is possible to assess the quality of a measuring device with extremely high accuracy.

Type Evaluations and Approvals
One of the staff’s main jobs is to perform type evaluations. Before new measurement equipment may be used for official measurements, it must undergo strict, systematic testing. This process determines whether the device type complies with the Swiss legal requirements and is suitable for the intended application.
The main focus of the testing is on the dynamic qualification test: The new measurement equipment is tested in all of the possible critical traffic situations. In particular, the equipment is tested to ascertain it generates correct measurement results even in dense traffic and attributes the results to the proper vehicle. It must also function entirely trouble-free even in the influence area of transmitter systems or railway power networks and when exposed to high and low humidity levels and temperatures. Outside of the specified error limits, not a single erroneous measurement is permitted.

If the measurement equipment fulfils all of the test criteria, METAS issues a certificate of approval. This certificate indicates that the tested device type fulfils all of the requirements and may be used for official measurements.

Orientation towards International Guidelines

METAS carries out its tests in accordance with the recommendations of the International Organisation of Legal Metrology (Organisation Internationale de Métrologie Légale, OIML) to the extent that these recommendations are applicable. This makes it possible to accept test results from recognised agencies outside of Switzerland which perform their testing based on the same guidelines and avoid duplicate testing.

However, for measurement equipment that uses innovative measurement techniques, international guidelines are lacking in many instances. In such cases, the requirements must be determined first and then test methods designed. This entails, under certain circumstances, significant development efforts.

Verifications

Before a device of an approved type model may be used for traffic monitoring, it must undergo initial verification. This ensures that each individual unit of measurement equipment makes accurate measurements from the very start. To guarantee measurement stability over the entire lifespan, METAS and authorised verification laboratories perform re-verifications at regular intervals. During a verification, the device is tested with the aid of the simulation techniques described above under the most realistic usage conditions possible. METAS keeps track of all of the speed measuring devices that are in use. This ensures that only verified devices are used for official measurements.

Speed measurement equipment is verified by the laboratory for road traffic and by specialised verification laboratories, making it possible to perform all of the required verifications in a timely manner. The verification laboratories are authorised and monitored by METAS. They verify measurement equipment in accordance with specifications developed by METAS during the type evaluation for each type of measurement equipment.

Other Activities

Together with other verification laboratories, the laboratory for road traffic ensures that the measurement devices used to determine the performance-related heavy vehicle fee (HVF) are set correctly. The laboratory for road traffic also calibrates all types of tachometers for industry. Moreover, it tests and verifies technical test means used by the cantonal offices for road traffic such as chassis dynamometers, GPS-supported speedometers and tachometers.

For manufacturers of traffic measuring devices that use innovative measurement techniques, the laboratory performs special tests. For example, it can perform comprehensive testing of GPS-supported measurement techniques using simulations in the laboratory. Tests of this sort on roads could only be implemented at a very high cost.

Courts of law often request expert opinions for speed violations or red light contempt. The laboratory for road traffic then attempts to reconstruct the circumstances using photo or video sequences. This is a way of verifying the measured value and attribution to the vehicle after the fact in many cases.

The staff of the laboratory for road traffic participate in interdepartmental working groups creating a legal basis and support the responsible authorities on technical matters. In this manner, METAS contributes to the periodic adaptation of legislation to the latest technical developments.

For the police and other users of traffic measurement equipment, the staff organise technical conferences where practical problems can be discussed and tips on proper usage shared.
How is the Speed of Vehicles Measured?

Doppler Effect

It’s a familiar phenomenon: An ambulance’s siren sounds higher in pitch when the vehicle is approaching than when it is going away. This happens because during the approach of the vehicle, the crests of the sound waves arrive at the observer at shorter intervals than they do when the vehicle is going away. This change in the frequency of waves of all types which occurs when the source and observer are approaching or going away from one another is known as the Doppler effect.

Speed Measurement with Radar

In all radar equipment, speed measurement is based on the Doppler effect (see box). The radar antenna transmits a narrow radar beam at a fixed angle to the orientation of the roadway. If a vehicle enters the radiation field from the antenna, part of the radiation is reflected and received back at the antenna. Due to the vehicle’s motion, the frequency of the radiation changes in proportion to the speed of the vehicle. Accordingly, based on the frequency difference between the transmitted and reflected radiation, the vehicle’s speed can be calculated. Image documentation systems and occasionally film cameras record the measurement data, date, time of day and traffic situation.

The latest generation of radar equipment is capable of also measuring the distance and the angle between the antenna axis and the vehicle motion in addition to the speed. Radar equipment of this type can simultaneously monitor multiple vehicles.
Stationary Supervised Speed Measurement with Radar (1)
The classic form of police speed monitoring involves a stationary measurement with radar equipment. The measurement is performed with the equipment mounted on a tripod or installed in a stationary vehicle. The test personnel supervise the measurement. The duration, frequency and location of such speed checks depend on the accident rate and the risk evaluation by the police. The measurement station can be combined with a traffic stop so the affected drivers can be immediately informed of their incorrect behaviour.

Stationary Autonomous Speed Measurement with Radar (2)
Another commonly used technique involves speed measurements with radar equipment that is operated at a fixed location over a longer period of time. The measurement equipment either uses a fixed installation or it is housed in a transportable measuring booth. This system operates autonomously and with no supervision. The recorded speeding violations are either saved locally or transmitted directly to an evaluation centre.

Speed Measurement with Radar while Moving (3)
Radar equipment can also be used in a moving car (moving radar): The radar equipment measures the speed difference between the police vehicle and the targeted vehicle. A built-in tachograph continuously measures the police vehicle’s own speed simultaneously. The sum of the two values is equal to the speed of the vehicle of interest. This technique is used primarily on motorways.
How is the Speed of Vehicles Measured?

Speed Measurement with Laser

When measuring speed with laser, the delay is measured between individual infrared pulses from the transmitter to the vehicle and back to the receiver. Based on this delay, it is possible to compute the distance between the laser equipment and the vehicle. The distance travelled between two infrared pulses divided by the associated time interval is equal to the vehicle’s speed.

In theory, it would be possible to perform a speed measurement in this manner using just two laser infrared pulses. In practice, however, this would result in errors, for instance, if the intended target point were to change. In order to eliminate erroneous measurements, a larger series of delay measurements is performed and saved as part of a measurement procedure. Using a mathematical operation, the vehicle’s speed is finally computed from the measured values. The measurement data, date, time of day and traffic situation at the time of measurement are recorded using analogue or digital image documentation systems.

Selective Manual Speed Measurement with Laser (4)

In selective manual speed measurements with laser equipment, the test personnel perform the measurement by hand or using a tripod. As was the case with stationary supervised radar measurements, the duration, frequency and location of such speed checks depend on the accident rate and the risk evaluation by the police. This measurement technique is suited above all to speed measurements on motorcycles but also other vehicles over greater distances. The measurement takes one half of a second at most. This means that warning devices possibly used by drivers generally respond too late. The measurement station can be combined with a traffic stop so the affected drivers can be immediately informed of their incorrect behaviour.

Continuous Speed Measurement with Laser (5)

This type of measurement corresponds to the stationary supervised speed measurement with radar, but the measurement principle is based on laser infrared pulses. The measurement distance is equal to around 30 to 50 metres. The technique is commonly used within city limits or around construction areas on motorways.

Speed Measurement with Laser Scanner

Laser scanners have been used for monitoring applications for years, for example, at industrial sites or in museums. They detect and record events and trigger an alarm if necessary. Using appropriate evaluation software, it has become possible to measure speeds using laser scanners. This type of equipment can be used to monitor a larger traffic area. Installations that are stationary, supervised or autonomous, fixed or deployed for only a few days are all possible. Laser scanners can also be combined with red light monitoring. Furthermore, they facilitate front and rear shots of the vehicle of interest from a booth mounted on a mast.

Laser Scanner as a Multifunctional System (6)

Like laser measuring devices, laser scanners are based on the principle of pulse delay measurement. However, with laser scanners the laser beam is additionally displaced at a high speed of rotation in a range of up to 180 degrees. If the pulsed laser beam that is emitted meets an object, it is reflected and recorded by the scanner’s receiver. The time between the transmission of the pulse and the reception of the reflected pulse is directly proportional to the object’s distance from the laser scanner. Based on the sequence of received pulses, the contour of the object and its movement or speed can be computed.
A rotating mirror in the laser scanner deflects the pulsed laser beam so the surroundings are scanned in a fan shape. Using a combination of the latest laser measurement technology and real-time software, it is possible to scan the monitored surroundings in a radius of about 40 metres with great precision. The recorded data are saved for subsequent analysis.

For every object situated in its field of vision, the laser scanner provides precise, uncorrupted information. This includes interactions between different parties involved in the traffic, such as behaviour involving pedestrian priority, right of way and illegal lane changes. The objects are tracked as long as they are in the system’s field of vision. This process has also been extended to allow speculative tracking of objects which are concealed for a brief period of time.

Since the data and the analysis results are transmitted in real time (via cables, Internet or radio and encrypted of course), the information can be used for a variety of purposes such as monitoring traffic flow, traffic surveillance with photos taken in case of violations or for statistical surveys.

Sectional Traffic Monitoring (7)
Selective speed checks will be replaced increasingly in the future by checks of the average speed over a longer distance. In a sectional average speed check of this sort (also known as a section control or speed over distance), every vehicle is photographed at the start and end of the specified road section with a precise timestamp. Based on the time that the vehicle needs to travel the section of road, the average speed can be determined. If the speed is higher than the legal limit, the data are sent to the relevant law enforcement agencies. The vehicle itself is identified through automatic detection of the registration plate. If no violation has occurred, the personal data are deleted immediately.
How is the Speed of Vehicles Measured?

Speed Measurement with Light Barriers
Light barriers can also be used to measure speed. In Switzerland, only laser light barriers have been approved hitherto. At least two parallel, invisible laser light beams are pointed at the roadway so they are reflected and sent back to the measurement equipment. Vehicles passing by interrupt the light beams. These interruptions provide the data needed to compute the speed. Photographic or video equipment is combined with the measurement equipment and is triggered if a vehicle exceeds the specified maximum speed. Sophisticated evaluation logic prevents faulty scan measurements from occurring when critical vehicle configurations are encountered.

Red Light Monitoring and Speed Measurement
If a driver violates the right of way at a traffic light, the potential risk is very much dependent on the driver’s speed. Accordingly, red light monitoring systems are now always integrated with speed measurements.

Monitoring Systems for Speed and Red Lights with Induction Loops (8, 9)
Until a few years ago, induction loops were used exclusively for speed measurements in red light monitoring systems. Multiple sensors are installed underneath the top layer of the roadway with a precisely defined spacing. Detectors register the time that a vehicle needs to pass over these sensors. Based on this time and the spacing between the sensors, the speed can be determined.

Inductive sensors measure the passage of a vehicle based on the change in frequency of a resonant electric circuit. Using these sensors, a red light contempt can be detected and the speed can also be measured. To ensure definitive proof of the violation, two photos are taken as well at a defined time interval or a fixed distance. The first photo serves as proof that the stop line for the red light was violated. The second shows whether and to what extent the driver committing the violation impeded or endangered other parties in the traffic who had the right of way.

Monitoring Systems for Speed and Red Lights with Laser or Radar
Installation of sensors for induction loops requires digging into the road asphalt. Moreover, the asphalt is weakened in an area which is already under significant strain due to the changes in vehicle speed. Accordingly, it is increasingly common nowadays to also combine laser or radar measurement equipment with red light monitoring systems. One approach involves the use of laser scanners. In another approach, the latest radar technology is deployed with frequency-modulated radar sensors which allow lane-sensitive detection. Parallel lanes can be simultaneously monitored in this manner. This is possible only to a limited extent with laser scanners since one vehicle can conceal a parallel lane.
Speed Measurement with Pressure Sensors (10, 11)
Measurement systems with pressure-sensitive piezo-electric sensors are used exclusively for speed measurements on motorways. They are commonly combined with variable traffic sign controllers. In other words, they are used on road sections where different speed limits are applied in phases to control the flow of traffic.

Speed Measurement with Tracking Tachographs (12)
Tachographs are special traffic monitoring systems that are installed in a police vehicle. They consist of a pulse generator, a digital tachometer and a data recorder, and they are sometimes combined with a photo recorder for the traffic situation. Tracking tachographs are used primarily on motorways. They allow the test personnel to target speeders and tailgaters and disqualify them from driving. Tacho-graphs of this sort are not comparable to conventional tachometers or trip recorders. They are very precise and are thus suitable for usage in various areas of traffic monitoring.

Unlike other measurement techniques, the speed of a monitored vehicle is not directly determined with this method. Instead, the tracking tachograph records the police vehicle's own speed. After tracking a vehicle over a specified distance, the average speed can be attributed to the vehicle committing the violation.

In the latest technological generation of such equipment, the police vehicle's own speed is also monitored via GPS and picture information documenting the traffic situation is stored directly on a hard disk. Since a sequence of up to one minute is continuously recorded in a ring memory, the prior history behind a violation against the traffic rules is also available in images. With conventional video recording systems, storage does not begin until after the test personnel detect the start of illegal behaviour.