PLAUSIBILITY OF ROAD WEATHER DATA: METHODS FOR OFFLINE AND ONLINE DETECTION OF ERRONEOEUS MEASUREMENTS

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ABSTRACT

Critical weather conditions in road traffic affect directly road capacity and traffic safety. To adjust those constraints section control systems have to consider environmental data. For sustaining a high level of traffic safety for road users, traffic control algorithms rely on sufficient, precise and fast detection of meteorological data, especially precipitation intensity, visibility and water film thickness. At present, the carriers of traffic management systems often have trouble with malfunctioning road weather sensors and the adjustment of sensor systems.

To improve reliability of those sensor systems under real conditions, a special test site has been installed in “Eching Ost” (near Munich / Germany). The test site provides abundant equipment like cameras, measuring facility and data link and is continuously attended.

In coordination with manufacturers of road weather sensor systems, reference methods have been established to evaluate several environmental parameters. Validation and quality management is a major task of data processing to detect malfunctioning data sources and exclude them from further usage for traffic control. By now a huge data base allows analysis of correlation between measured values by data mining methods to discover benchmark tests and error detection. A prototype software tool has been implemented to apply plausibility checks. Several plausibility checks have been developed, tested and optimized. In the future they can be used e. g. in day-to-day operations. Meteorological coherences (e. g. between fog and relative humidity) can be used to reduce false alarm rates and improve acceptance of traffic control systems.

Keywords: Road Weather Data, Sensor, Plausibility check, Test site, Erroneous measurement detection

1. INTRODUCTION

High traffic loads and traffic congestion lead to an increase in risks of accidents and thus to a worsening of traffic safety. Prognoses state, that passenger and freight traffic load will increase further. Intelligent Telematics Systems can reduce traffic problems and contribute significantly to the reduction in accident numbers, corresponding to the requirements of the European Commission in the "White Paper – European Transport Policy for 2010". Section control systems are one type of telematic system on federal highways. They control traffic using variable message signs (VMS) and thus have an effect on traffic safety and traffic flow relevant parameters (e.g. speed, special attention in the case of potential risk situations). An important objective of section control systems is the increase in traffic safety through a dynamic reaction to current traffic and road weather and road surface conditions. Detecting road weather and road surface conditions and deriving corresponding suggestions for the VMS (warning signals, speed limits) are thus an important feature of section control systems.

Within the framework of section control systems environmental data are input data for situation dependent control. Road users get warned of potentially critical meteorological conditions. For sustaining a high level of traffic safety for road users, traffic control algorithms rely on sufficient, precise and fast detection of meteorological data.

Traffic control based on critical road surface conditions, precipitation and reduced sight are elements of the automatic operation of section control systems. Wet or icy road surface conditions and / or precipitation affect traffic safety negatively in two ways:

Wetness on the road reduces the traction between tyre and road surface. This leads to an extended stopping distance and a reduction of bearable radial forces in cornering. Additionally precipitation and spray may limit driver's sight.

Reduced visibility may be risky for road users. At too great speed under these conditions obstacles will be detected too late. The cognition of critical situations is lagged and then rear-end collision accidents may occur.

These negative effects can be met by displaying adapted speed limits and warning signs on variable message signs (vms).

But environmental data-based control can only have positive effects on traffic safety when the displays of the lane control systems are obeyed by road users. The plausibility of the road weather and road surface condition based VMS states is the basis for the drivers' acceptance. Accurate detection of road weather and road surface conditions in the sphere of section control increases the acceptance/following of the signs and thus supports the reduction in risks of accidents and the rate of accidents aimed at [1].

Therefore the stationary detected environmental data should be of good quality and the actual meteorological conditions should be displayed prompt in the control system.

These are preconditions for a reasonable and effective impact on traffic flow.

In Germany, acquisition and usage of environmental data in lane control systems is fixed in "Merkblatt für die Ausstattung von Verkehrsrechnerzentralen und Unterzentralen" – MARZ [1] and "Technische Lieferbedingungen für Streckenstationen" – TLS [2].

At present, the carriers of traffic management systems often have trouble with malfunctioning road weather sensors and the adjustment of sensor systems.

Atmospheric conditions are because of their inhomogeneous and unsteady characteristics hardly to check in their exact value.

Due to the importance of environmental data acquisition and the expected positive effects in the practice of traffic control a special test site was established.

Before the project "Test site for road weather and road condition monitoring" the quality of systems for environmental monitoring have not been tested comparative.

The quality of sensors was checked sporadically, mostly by section control system carriers.

In day-to-day operations errors in environmental data acquisition were detected not at all or late respectively by random.

The following pictures show an overview.

Fig. 1. Pictures of test site "Eching Ost"

2. TEST SITE "ECHING OST"

To improve reliability of environmental sensor systems under real conditions, in the year 2003 a test site has been installed in "Eching Ost" near Munich / Germany.

The test site project is supported financially as well as organizationally by the Federal Ministry of Transport, Building and Urban Affairs (BMVBS) and the Federal Highway Research Institute (BASt). A working group (AK) of Germany's Road and Transportation Research Association (FGSV) serves as a supervisory board for the project. The actual test site is operated by the South Bavarian Highway Authority (ABDS); the monitoring and evaluation is carried out by the Chair of Traffic Engineering and Control of Technische Universität München.

In the test site, environmental sensor systems of different manufacturers get checked and compared under similar conditions. This way, sensor systems get rated for their ability as detectors in lane control systems. This shall lead to a better understanding and optimization of the systems (hardware and software).

A hand in hand operation of the test site was only possible by the constructive team work with the following manufacturers for environmental sensor systems:

- Adolf Thies GmbH & Co. KG, Göttingen
- G. Lufft Mess- und Regeltechnik GmbH, Fellbach
- GWU-Umwelttechnik GmbH, Erftstadt
- Jenoptik Laser, Optik, Systeme GmbH, Jena
- Ott Messtechnik GmbH & Co.KG, Kempten
- Rosemount Aerospace GmbH, Goodrich Corporation, München
- Sick Maihak GmbH, Analysen- und Prozessmesstechnik, Reute
- Vaisala Traffic, Hamburg

A scheme of the test site is displayed in the following figure.

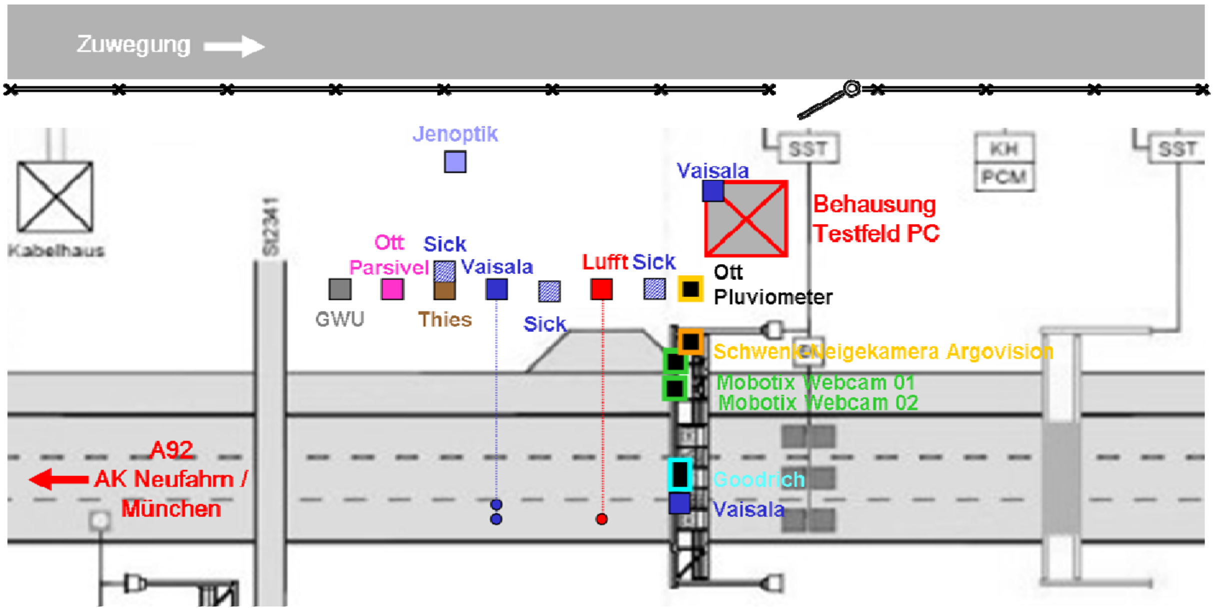

Fig. 2. Schematic of test site "Eching Ost", Motorway A 92 (*State: April 2008*)

The test site provides abundant equipment like cameras, measuring facility and data link and is continuously attended. Regularly updated pictures of two web cams in the test site are available under http://www.vt.bv.tum.de/umfelddaten.

The following environmental data is detected in a 1 minute measuring period:

- Air temperature AT
- Road surface temperature RST
- Precipitation intensity PI
- Relative air humidity RAH
- Direction of wind DW
- Wind speed (average) WSA
- Visibility V
- Wind speed (peak) WSP
- Freezing temperature FT
- Melting point temperature MPT
- Ground temperature in depth 1 TD1
- Ground temperature in depth 2 TD2
- Status of the road surface RSS
- Precipitation type PT
- Water film thickness WFT.

Direct input data for environmental control are precipitation intensity, water film thickness and visibility. These are the most important environmental data, the other data are used for plausibility purposes.

3. OFFLINE EVALUATION – METHODOLOGY AND SCHEME

The sensors in the test site are mainly assessed according to the plausibility of the result delivered and the reaction time. The plausibility of the result is determined:

- relative to each other (continuously)
- fully after observation (random samples)
- fully against reference (random samples).

Therefore "qualitative" comparisons of time-variation curves were made. In coordination with manufacturers of road weather sensor systems, reference methods have been established in order to evaluate several environmental parameters. If available, the measured data gets compared to reference measurements (e. g. sensor Pluviometer for PI, spraying box for WFT and RSS) respectively reference observation (analysis of web

cam pictures for V) additionally. Identified differences get analyzed. Furthermore data acquired by different measuring methods were correlated and analyzed.
When evaluating, specific attention is paid to two aspects:

- A comparison between situations as perceived by the road user and as reproduced by the respective sensors
- Logical and functional dependencies between individual sensors

Different methods are used for checking the different sensors' output with respect to the practical possibilities for use in section control systems. Direct physical reference systems are available for some quantities to be measured such as water film thickness, precipitation intensity, air temperature and relative air humidity. Other parameters, such as the road surface condition or precipitation type are evaluated based on on-the-spot observations and continuous video recordings.
Below, the evaluation methodology for the three utmost important entities, visibility, precipitation intensity and water film thickness, are described.

3.1 Visibility

Observations using the webcams are carried out for checking the visibility distance. The estimated visibility distance is compared with the measurements of the sensors based on reference objects with known distances. For each minute it was recorded, which of the defined objects were or were not visible, respectively. The value for the visibility then was defined as the range between the distance of the object that was just still visible (minimal visibility) and the distance of the object that is just not visible anymore (maximum visibility) (see Figure 3).

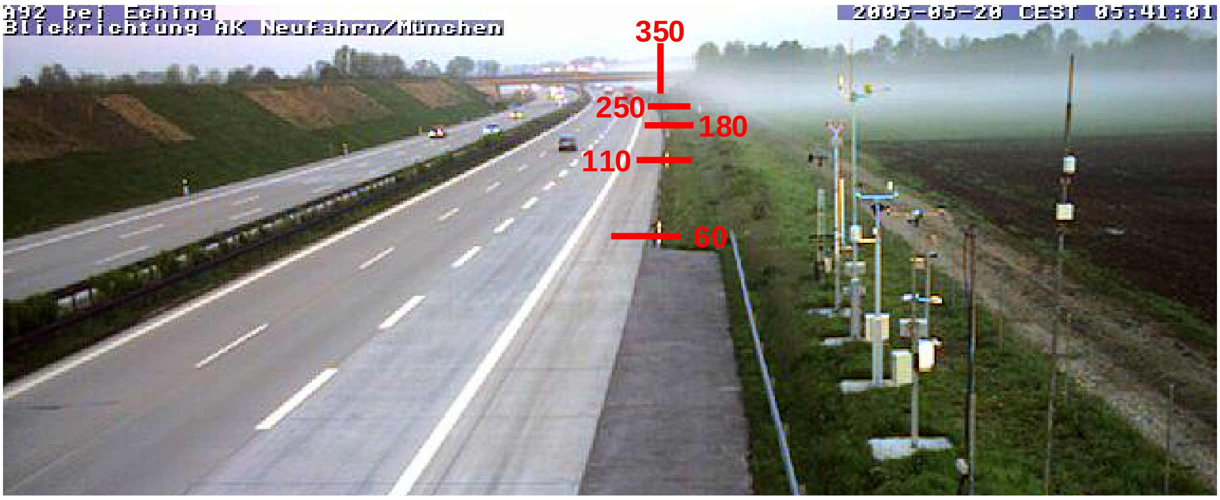

Fig. 3. Distances of objects for visibility measurements

Uncertainties due to subjective perception of the human observer, difference between meteorological and perceived visibility and observation position were taken into account in favour of the sensor.
Over the years, several hundreds of thousands images (one per minute) were collected and stored for evaluation. To save time, rough visibility estimation can be done using the webcam and appropriate automatic image processing algorithms (pre-processing to the manual observed visibility estimation). An algorithm has been developed and tested. It consists of the following steps:

For each Image

1. calculation fo grey values
   (Matrix of grey values)
2. Luminance estimation
   (image usable: yes / no)

IF Image IS usable:

3. Convolution with edge detector
   (Edge-Matrix)
4. Visibility Estimation
   (*Edge Intensity (Sum, Median, Maximum)*
   Visibility in „Pixel-Rows"
   Visibility in Meters

END

Next Image

Listing 1. Visibility etsimation with automatic image processing

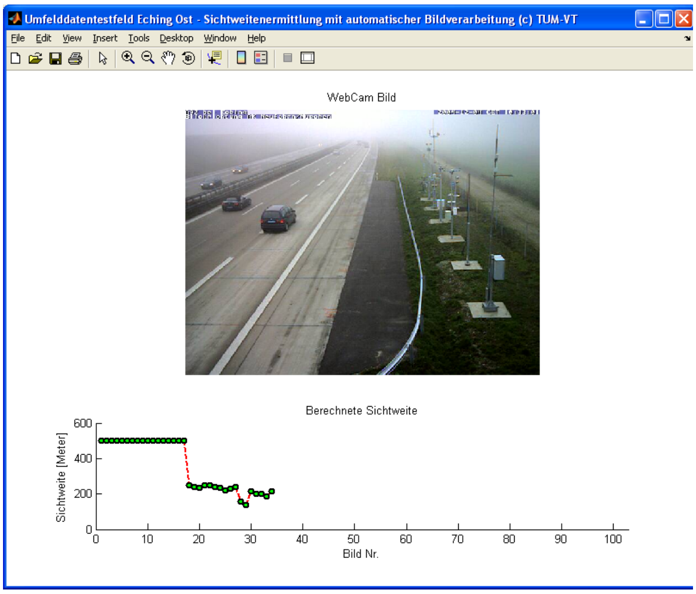

Fig. 4. Graphical Output image and calculated visibility

3.2 Precipitation Intensity

The precipitation intensity is an essential parameter when giving drivers warning of wetness. Usually, warnings are displayed according to predefined precipitation threshold values (see [2] and [4]). For evaluation, daily precipitation sums of the sensors were compared to the daily precipitation sums of a reference system. As a reference, a "Pluviometer" is used. The Pluviometer is the system used by the Deutschen Wetterdienst (DWD), Germany's National Meteorological Service.
The measurements of the Pluviometer were corrected with respect to precipitation type and wind speed. The correction factors were calculated based on empirical results found by Yang et Al [5].

3.3 Water film Thickness

The water film thickness is the thickness of the water layer on the road surface in [mm = litre/m ²].
The sensors' measurements are compared to a known water film thickness that is brought on the sensor by the use of a "spraying box", which is essentially a computer controlled Airbrush spray gun that gives specified amounts of water on the sensor (Fig. 5, description can be found in [6]).

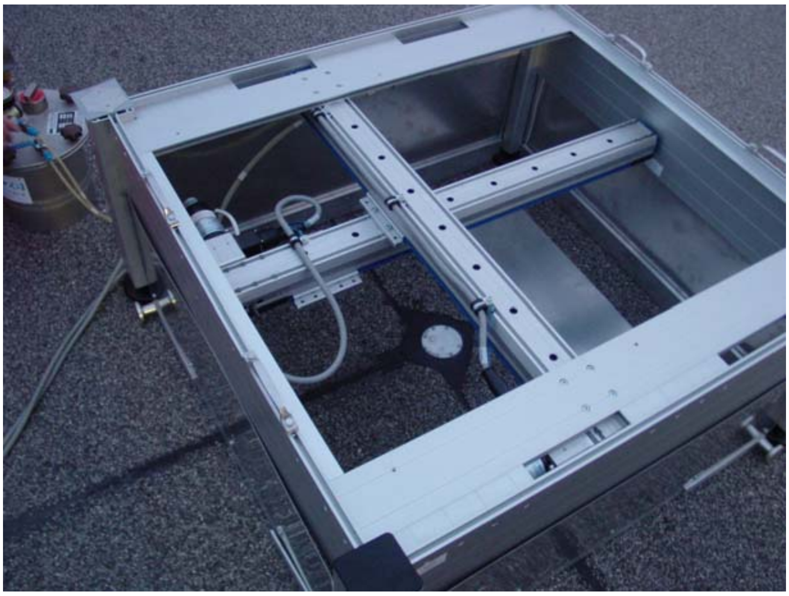

Fig. 5. „spraying box" to use water film thickness measurements

4. AUTOMATIC ONLINE PLAUSIBILITY CHECKS

In Chapter 3 we described methods for sensor evaluation in the test site in order to gain knowledge about specific sensor model performance and consequently improve hardware, firmware and software. This should ensure that only sensors that have the fundamental functionality and accuracy will be built in road weather stations. Nevertheless, experience shows that there is a need for online evaluation and error detection for the sensors in operation.

The conditions and the requirements differ substantial from offline evaluation in the test site:

- Only one unit per parameter per site (no direct comparison possible)
- No reference measurements
- Fast online detection necessary to avoid false alarms and to be able to quickly respond to malfunctioning sensors (maintenance, replacements of units).

To detect erroneous measurements (or better: to estimate the plausibility of measurements), fundamental physical and meteorological temporal and spatial relationships and cross correlations between different parameters are used. The methods for automatic plausibility checks are explained in detail in [7].

4.1 Time Series based (one parameter):

At the first stage, several plausibility checks are applied on each respective measurement time series. Principally, three different kinds of checks are proposed:
Does the actual measurement fall in a plausible range? This is a simple check if a value falls out of the meteorological possible and systems specific range.

$$value_{\min} \le measurement(t) \le value_{\max}$$

Proposed basic provision	
Precipitation Intensity	[0, 20] mm/min
Precipitation Type	{(adapted) WMO Code List}
Road Surface Condition	{(adapted) WMO Code List}
Water film Thickness	[0, 3] mm
Air Temperature	[-30, 60] °C
Humidity	[10, 100] %
Visibility	[10, 2000] m
Luminance	[0, 60000] Lx
Road Surface Temperature	[-30, 80] °C
Salt Concentration	[0, 100] %
Freezing Temperature	[-30, 0] °C
Dew Point Temperature	[-30, 30] °C
Windspeed	[0, 60] m/s
Winddirection	[0, 359] °

Does the time series show the expected *dynamics*? Because of physical and meteorological reasons, road weather and road surface condition parameters change over time. So if the time series stays constant for longer than a given threshold, the time series is marked implausible.

$$measurement(t) = measurement(t-1) = \ldots = measurement(t-n)$$

Proposed basic provision		
Parameter	**Condition**	**Maximal duration with no change in time series**
Precipitation Intensity	> 0 mm/h	5 minutes
Water film Thickness	> 0,03 mm	15 minutes
Air Temperature	-	120 minutes
Humidity	< 100%	120 minutes
Visibility	< 500 Meter	10 minutes
Luminance	-	16 hours
Road Surface Temperature	Road Surface Condition $\neq$ "Snow"	1 hour
Temperature in Depth 1	-	2 hours
Temperature in Depth 3	-	2 hours
Salt Concentration	> 0%	1 hour
Freezing Temperature	< 0 °C	1 hour
Dew Point Temperature	-	1 hour
Windspeed	> 0.5 m/s	30 minutes
Winddirection	-	30 min

Is the *rate of change* not too big? Because of physical and meteorological phenomena, some road weather and road surface parameters can only change at a certain rate. Therefore, if the rate of change is too big, the measurement is marked implausible.

$$|measurement(t) - measurement(t-1)| \leq \Delta r_{\max}$$

Proposed basic provision	
Parameter	**Maximal rate of change (per minute)**
Water film Thickness	+/- 2,0 mm
Air Temperature	+/- 2° C
Humidity	+/- 10 %
Luminance	+/- 30000 Lx
Road Surface Temperature	+/- 7 °C
Temperatur in Depth 1	+/- 0,5 °C
Temperatur in Depth 3	+/- 0,2 °C
Dew Point Temperature	+/- 1 °C)
Windspeed	+/- 15 m/s

4.2 Cross Correlations

Several parameters show cross correlations that can be used for automatic plausibility checks.

First Check	**Second Check**	**Plausible value**	**Implausible value**
Precipitation Type = „Rain“	Air Temperature < AT_{Rain}^{min} (-5 °C)	-	Precipitation Type
Precipitation Type = „None“ AND Precipitation Intensity > 0		-	Precipitation Type, Precipitation Intensity
Road Surface Condition = “dry“ AND Water film Thickness > 0		-	Road Surface Condition, Waterfilm Thickness
Road Surface Condition = „wet“ AND Waterfilm Thickness = 0		-	Road Surface Condition, Waterfilm Thickness
Precipitation Type ≠ „None“ AND Precipitation Intensity = 0	Humidity < $Humidity_{wet}^{min}$ (60%)	Precipitation Intensity	Precipitation Type
Precipitation Type = „None“ AND Precipitation Intensity > 0	Humidity < $Humidity_{wet}^{min}$ (60%)	Precipitation Type	Precipitation Intensity
Precipitation Intensity > 0,5 AND Water film Thickness = 0	ΔT_{Dry} > 3 Minutes AND Humidity < $Humidity_{dry}^{max}$ (60%)	Waterfilm Thickness	Precipitation Intensity
	ΔT_{Wet} > 3 Minutes AND Humidity > $Humidity_{wet}^{min}$ (78%)	Precipitation Intensity	Waterfilm Thickness
Visisbility ≤ $Visisbility^{max}$ (500 Meters)	Precipitation Type = „None“ AND Humidity < $Humidity_{dry}^{max}$ (60%)		Visisbility

Tab. 1. Cross Correlation based Plausibility Checks

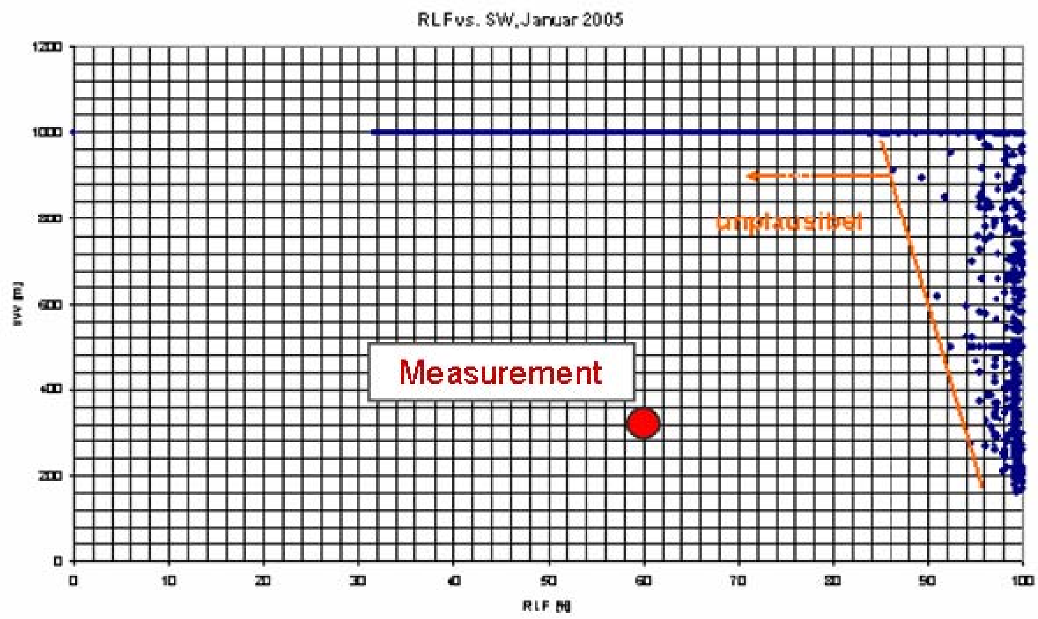

Fig. 6. Cross Correlation between Humidtiy and visibility

4.3 Long Term Cross Site based Plausibility Checks

Long term observations and comparisons between several sites can reveal systematic errors. The results have to be evaluated carefully and with respect to local meteorological and topological characteristics.
The basic assumption is that measurements at a sensor site should show measurements comparable to its two neighbouring stations.
The following parameter can be evaluated in this manner:

- Precipitation Sum
- Average Air Temperature
- Visibility
- Precipitation Type: Number of intervals when „None“„Rain“, „Snow“, „Hail“, „Sleet“ was detected.

If the difference of – relative to the interval looked at – shall not exceed a certain threshold. In Fig. 7. an example is given. Station i+2 seems to be implausible compared to its neighbours and needs to be looked at closer.

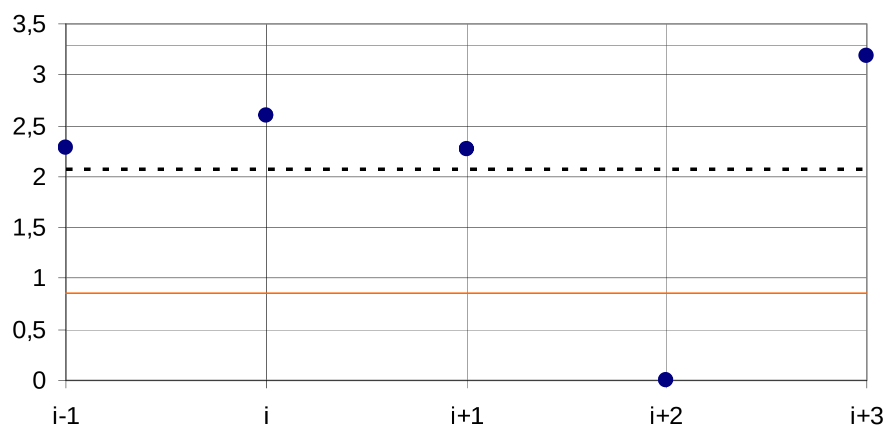

Fig. 7. Example: Longterm Cross Site Plausibility Check for precipitation sum [7]

5. BENEFITS

Based on the above characterized checks for the plausibility of measured environmental data, an evaluations scheme was developed and applied [8]. The sensors were classified as

- "applicable": the sensor responds to situations promptly and represents them well.
- "appropriate with restrictions": the sensor responds to situations and represents them.
- "not appropriate": the sensor responds to situations not promptly and represents them insufficient.

Validation and quality management is a major task of data processing to detect malfunctioning data sources and exclude them from further usage for traffic control. By now a huge data base allows analysis of correlation between measured values by data mining methods to discover benchmark tests and error detection. A prototype software tool has been implemented to apply plausibility checks to the data base. Several plausibility checks have been developed, tested and optimized. In the future they can be used e. g. in day-to-day operations. Meteorological coherences (e. g. between fog and relative humidity) can be used to reduce false alarm rates and improve acceptance of traffic control systems.
These checks were developed and tested:

- plausibility checks for single measurements
- checking logical-physical coherences
- long term plausibility checks.

Detection and usage as well as these plausibility checks will be published as technical bulletin ("Merkblatt für die Erfassung und Nutzung von Umfelddaten in Streckenbeeinflussungsanlagen") by the FGSV [7].
The immediate effects on traffic flow give information about available capacity under critical weather conditions. This can be used as input for stretch control or dynamic travel time prediction algorithms. Results are regularly reported and the proceeding exchange of experiences encouraged improvement of sensor systems.
Also crosslinking to other fields of research like extended floating car data (xFCD) is possible.

6. CONCLUSIONS

Results of the test site [8, 9] show, that not all tested sensors are able to fulfil the high expectations in quality. This is an important result, especially in consideration of fact, that in daily operations environmental data will not get analyzed as intensive as in the test site project. The developed plausibility checks shall help improving data quality.
The sensor systems are checked under real conditions beside the road and not on the laboratory scale, which is a speciality of the test site "Eching Ost". Therefore the sensor systems can get checked under realistic and varying environmental conditions. So far uninvolved manufacturers are welcome to participate in the test site project.
Operating the test site generates benefits for manufacturers. They can match with competitors, so an optimized sensor quality is achieved.
For section control carriers the benefit is knowledge about their sensor systems (systems they already use or plan to purchase). Additional project's benefits are optimized, standardized and economic processes for environmental data acquisition.
This leads to comprehensible and plausible traffic control and an optimized acceptance and hence to an increase in traffic safety.

7. REFERENCES

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