



## **New results for analysing and modelling of weather impact on local traffic flow under the WOLKE project**

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### **ABSTRACT**

The objective of the project WOLKE (Weather related microscopic traffic parameters) was to investigate weather impact on motorized individual traffic. The novelty lies in the integrated modelling-approach which looks at micro-and macroscopic modelling impact and is set to harmonize the effects while utilizing different key values on each level.

The research project focusing the representative pilot areas of Bavarian highway A8 and the City roads of Vienna and was conducted in cooperation with the Bavarian Highway Authority, the University of Stuttgart (UniS), the Austrian Institute of Technology (AIT), and the companies PTV and Ubimet. The paper describes the results of the research work of micKS about the local road weather impact on traffic flow.

Local road weather and detailed traffic flow data at about 30 cross sections with 1 minute samples over a period of 4 Years where analysed. We found, that 15 minutes aggregated data show significant correlations between traffic flow, especially the driving velocity, and certain weather parameters.

The first approach was to describe the parameters of the well known VanAerde fundamental diagram model due to 10 weather classes. Also an alternative fundamental diagram introduced by Ning Wu was used. The parameters free speed and traffic density at maximum capacity of the speed/density diagram where described by using multiple regression analysis.

The second microscopic model approach was describing the driving behaviour by considering the driving dynamics in terms of tire friction, stopping visibility due to the weather situation. The approach results in a simplified microscopic based model, which describe the expected driving speed and capacity reduction due to the road weather parameters intensity and type of precipitation as well as road surface temperature. The parameter of the microscopic model approach where gathered from the acquired traffic and weather data. Both microscopic and macroscopic model show similar results, while the macroscopic approach works with weather classes and the microscopic based model delivers continuous results due to the weather measurement or forecast inputs.

The models could be used for all kinds of highways with up to 4 lanes and provide weather calibrated parameters for the traffic flow models in order to significantly improve forecast of traffic congestions and critical traffic situations caused by weather conditions.

**Keywords:** Road Weather, Traffic flow models, local weather impact on road traffic



## 1 INTRODUCTION

The research project WOLKE (means in English: Weather-related calibration of traffic models for optimized traffic control) was started in January 2011 and ended June 2013. It was a cooperative project between Austria and Germany and was conducted by (AIT) Austrian Institute of Technology in Vienna, UBIMET GmbH in Vienna, PTV AG in Vienna and Karlsruhe, (ZVM/ABDS) The Centre of Traffic Management of the Bavarian Highway Directorate in Munich, University of Stuttgart, Department for Transportation planning and traffic engineering and micKS MSR GmbH in Oberstdorf and was cofounded by the German BMWI and Austrian BMVIT. Besides the modelling of weather related traffic demand modelling and inner-urban pilot sites in Vienna, micKS was responsible for modelling of weather related local traffic flow on highways and inter-urban roads. The modelling approach where also initiated by the author under the framework of an earlier research project [2] "Prediction of Capacity of Road Sections under Hibernial Atmospheric Conditions".

The final aim was, to find a model which is able to describe the impact of all possible weather situations on local traffic flow at all types of inter-urban road sections. The model should be used for traffic control purposes as well as for prediction of traffic situations and travel times for traffic information and route planning purposes. The challenge was to find the relevant influence weather variables which could be quite easy obtained and which are available from weather forecast services.

First of all, archived traffic and road weather data from several cross sections of the Highway A8 Munich – Salzburg where acquired.

## 2 METHODS AND RESULTS

### 2.1 Data Sources used for local road weather impact on traffic flow

Data Sources of the pilot site Bavarian Highway A8 Munich – Salzburg are archived by ZVM, partly under the framework of the IVHS (Intelligent vehicle highway system) and partly under the framework of the German SWIS (Road weather information System on Highways). See map in Figure 1 which shows the locations of the Data Sources along the Highway stretch.

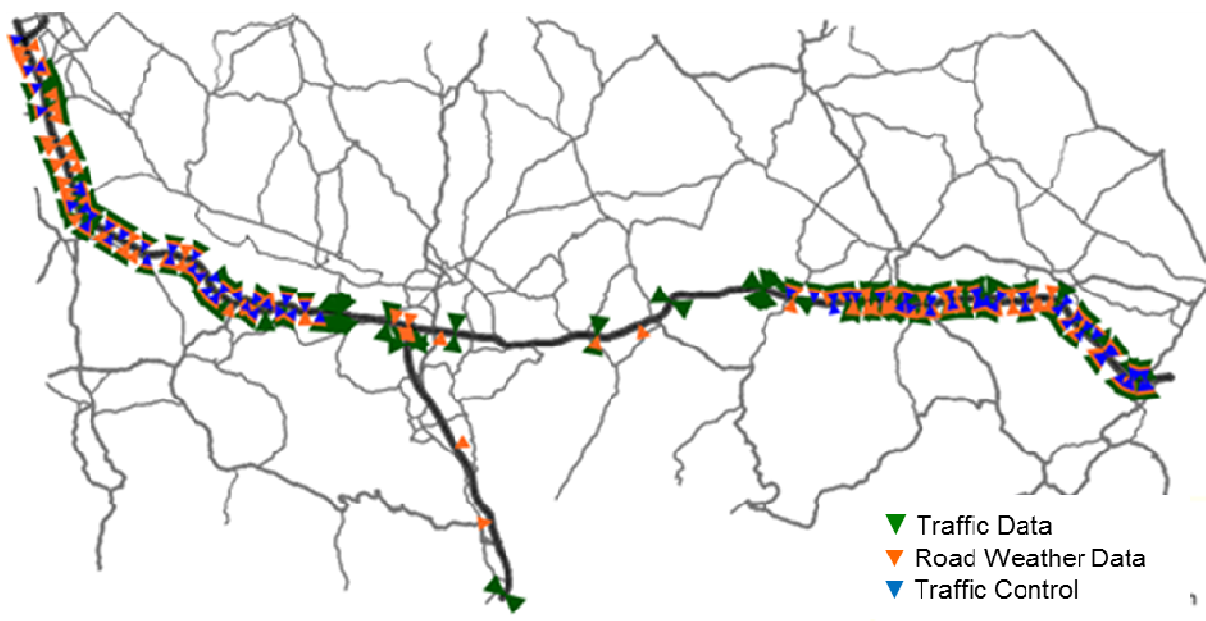


Figure 1: Pilot Site A8 Highway Positions of the Data Sources

Data were available for analysis from January 2008 until March 2012. Traffic data were archived every Minute separate for each lane and direction. Also the road weather data from outstations along the Highway measuring with embedded sensors in the road pavement and with atmospheric weather sensors beside the highway, are available every Minute.

During the analysis it turns out that 15 minute aggregation intervals are best suitable for showing correlations between traffic and road weather data.

Abbr.	Data Type	Unit
LT	Air Temperature	°C
RLF	Relative Humidity	%
TPT	Dewpoint Temperature	°C
RS	Residual Salt concentration	%
FBT	Road Surface Temperature	°C
GT	Freeze Temperature	°C
TT1	Sub Temperature -5cm	°C
TT3	Sub Temperature -30cm	°C
FBZ	Road Surface Condition	Enum
SW	Visibility	m
NI	Intensity of Precipitation	mm/h
NA	Type of Precipitation	Enum

Table 1: Available DataTypes from the Road Weather Sensors

Data Type	Description	Unit
Q_KFZ	Traffic Flow Pass.Cars	veh/h
Q_LKW	Traffic Flow Trucks	veh/h
V_PKW	Average Velocity Pass.Cars	km/h
V_LKW	Average Velocity Trucks	km/h
T	Average Net Time Gap	sec

Table 2: Available DataTypes from the Traffic Sensors

The available Sensor Data from the road weather outstation and from the traffic loops are shown in Table 1 and Table 2.

### 2.3 Finding influencing variables

The diagram in Figure 2 shows an impressive example for a correlation between 15 minute traffic speed and precipitation data of a heavy snowfall event on a certain cross section at a German highway.

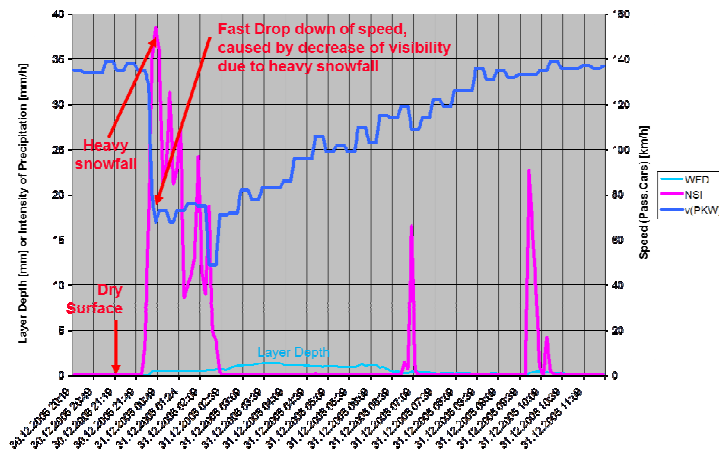


Figure 2: Example of the impact of heavy snowfall on traffic speed with 15 minutes aggregated data: Precipitation, surface layer and car speed.

In order to find relevant influencing weather variables especially on traffic speed, correlation analysis as well as single and multiple regression analysis was performed under different aggregation intervals. We found, that correlation analysis gives the best results when using 15 minutes intervals for a certain cross section. One strong influencing weather variable is precipitation intensity. The influence is also depending on the type of precipitation. Figure 3 shows an example for the correlation of precipitation on traffic speed under rain or snowfall events. One have also to consider that precipitation particularly heavy snowfall not only causes adverse road surface condition but also reduces the visibility, which both lead to a reduction of driving speed and thus to an increase in travel time.

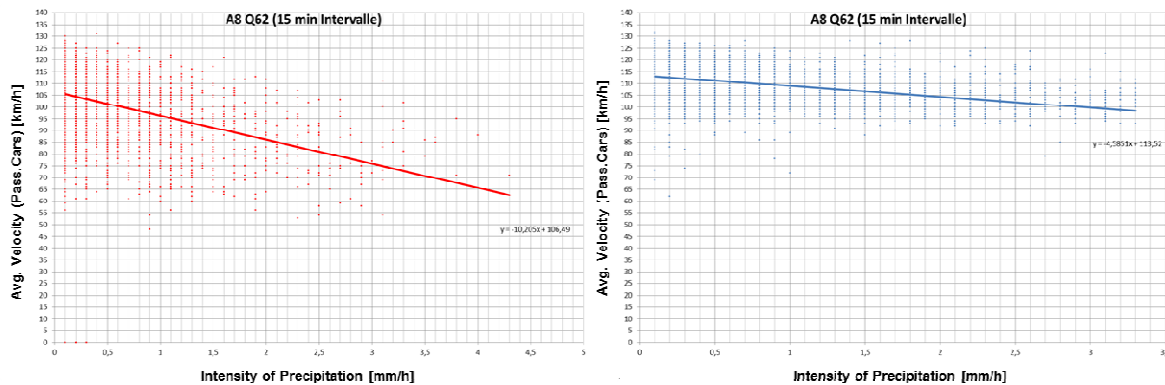


Figure 3: Example for linear correlation between passenger car average velocity and precipitation intensity at snow fall (left diagram) and rain (right diagram) events. At Highway A8 cross section Q62 during period 2008 to 2011.

The major weather variables which could be used to describe significant impact on traffic speed and capacity could be identified as follows:

- Intensity of Precipitation
- Type of precipitation (could be approximated by using Wet Bulb Temperature)
- Wet Bulb Temperature (derived from Air Temperature and Humidity)
- Road Surface Temperature
- Water Layer Thickness (could be approximately derived from precipitation by using a water layer model)

We have also to consider that the impact of weather situations on traffic flow are different for different type of road cross sections. We have identified the following key parameters:

- Number of Lanes
- Curve Radius
- Transversal and Longitudinal Slope
- Stopping Sight Distance (constructive)

## 2.2 Classification of road weather conditions

The goal was to classify weather situations with as much classes as necessary to distinguish between different strength of impact on traffic flow and as less classes as possible in order to minimize the effort to handle.

The road weather classes have been agreed with all participating partners in the project. Table 3 show the defined 10 Weather classes and their criteria's. If type of precipitation is available from present weather sensors or as forecast information it should be taken, otherwise wet bulb temperature has to be taken as approximation.

Class (enum)	Description (enum)	Summary Group Class (enum)	Type of Precipitation (enum)	Intensity of precipitation (mm/h)	Wet Bulb Temperature (°C)	Road Surface Temperature (°C)
1	dry	Dry	no	0	*	*
2	wet road / rain	Wet	rain	< 0,5	≥ 0	> - 2
3	slippery road / rain		rain	< 0,5	≥ 0	≤ - 2
4	wet road / medium rain		rain	≥ 0,5	≥ 0	> - 2
5	slush / snow	Snow/Ice	snow	< 0,5	< 0	> - 2
6	snowy road / snow		snow	< 0,5	< 0	≤ - 2
7	slush / medium snow		snow	≥ 0,5; < 3,5	< 0	> - 2
8	snowy road / medium snow		snow	≥ 0,5; < 3,5	< 0	≤ - 2
9	slush / heavy snow		snow	≥ 3,5	< 0	> - 2
10	snowy road / heavy snow	snow	≥ 3,5	< 0	≤ - 2	

Table 3: Road Weather Classes and their Criterias

We also use a more compact classification with only three classes. The summary classes are:

- Dry (basic class 1)
- Wet (basic classes 2, 3, 4)
- Snow/Ice (basic classes 5 ... 10)

### 2.3 Analysis of free flow speed due to road weather classes

The most important key parameter regarding weather calibration of traffic flow models is the free flow (at low traffic density) car speed at a certain cross section. In order to determine the free flow car speed due to weather class, the distribution function of the 15 min interval average car speed of certain selected cross sections were analysed.

The free flow speed is determined at the 85%-percentile of the distribution function. Also the speed at the 50%-percentile was determined, which could be considered as indicator for the average travel time change due to the weather situation. As an example for a typical cross section, the graphical visualization of the analysis could be examined in Figure 4. One can see that the free flow speed deviates significantly in the different weather classes. As to be expected, the snow/Ice weather class causes the most significant decrease of free flow and average speed and increase of the corresponding travel time but also shows the highest variances.

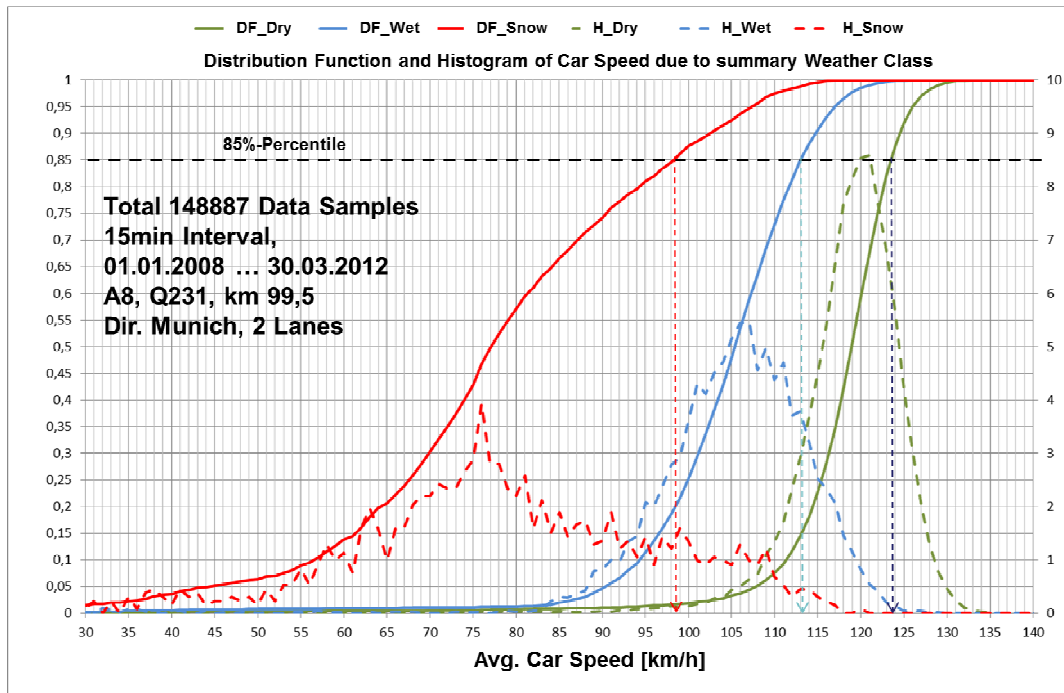


Figure 4: Distribution Function and Histogram of avg. Car Speed (15 min) due to the 3 Weather Class Groups as an example for Cross Section Q231 at A8 during a period of 39 month.

The results of the car speed distribution analysis at some selected cross sections are shown in Table 4.

Cross Section:	Q62			Q83			Q231		
Percentile:	50%	85%	85%	50%	85%	85%	50%	85%	85%
Class:									
Dry	124	126	0%	100	105	0%	119	123	0%
Wet	111	118	-6%	95	100	-5%	105	113	-8%
Snow/ICE	98	112	-11%	81	93	-11%	77	98	-20%

Table 4: Car Speed [km/h] (15 min interval) at 50%- and 85%-percentile at selected cross sections on A8 during a period of 39 month.

## 2.4 Analysis of traffic speed and density relationship due to road weather condition

The analysis of the data samples in the traffic speed/density diagram at different weather situation gives an impression how the weather situation influencing the fundamental diagram.

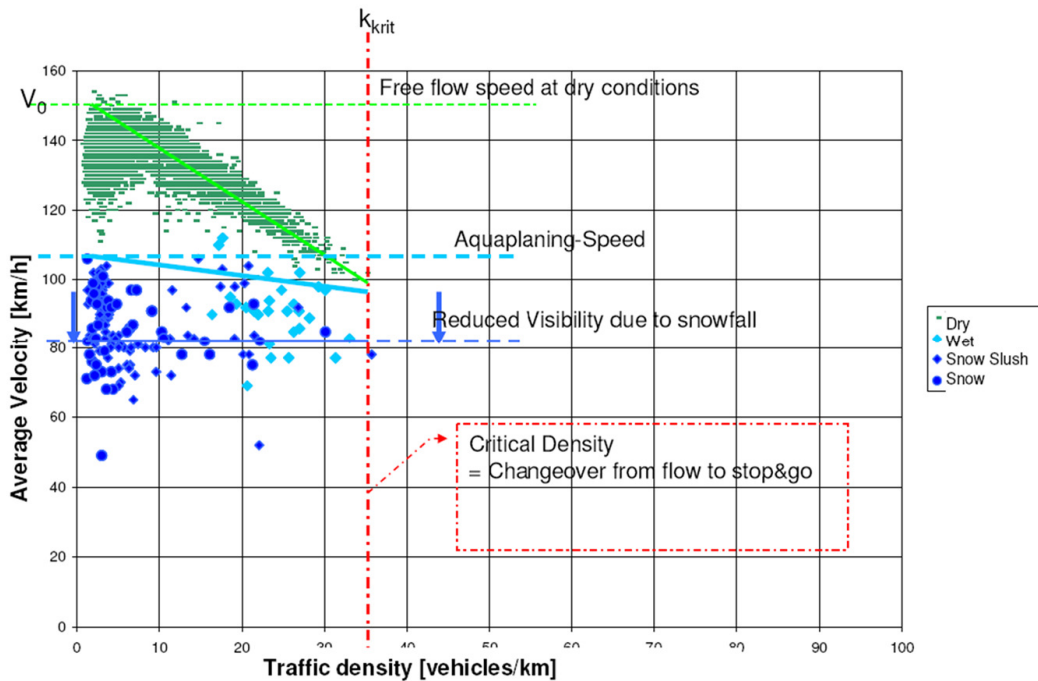


Figure 5: Analysis of Traffic Speed and Density relationship at certain Road Weather Conditions

As Figure 5 shows, the speed/density relation under dry and good weather condition is according to the known fundamental diagram models (green dots). With increasing adversity of the weather condition the free flow speed (at low traffic density) becomes lower and lower. It is obvious that the otherwise typical effect of increasing traffic density on speed becomes less. It could be concluded, that the traffic capacity is more or less not significantly reduced, as long as the road weather condition related free flow speed drops under the so called critical traffic speed. The critical traffic speed/density point is related to the maximum traffic capacity of the road cross section under dry and good weather condition and marks the point where the free flow traffic turns into stop and go because of the capacity overload. In the example cross section showed in Figure 5, the capacity is significantly reduced when the driving speed drops below approx. 98 km/h due to the adversity of the weather condition (mostly when snow, slush and ice happens).

## 3 MODELLING APPROACHES

### 3.1 Weather class calibrated parameters of van Aerde fundamental diagram

The well know traffic model, introduced by van Aerde [4], has the advantage, that the fundamental diagram of a cross section could be described with one single equation (see equation 1) .

$$k(v) = \frac{1}{\Delta x} = \frac{1}{c_1 + \frac{c_2}{v_0 - v} + c_3 \cdot v} \quad (1)$$

Where

$k(v)$  = traffic density as function of traffic speed  $v$

$v_0$  = free flow speed at  $k = 0$

A quite simple approach for calibrating the traffic model by weather condition is to estimate the parameters  $v_0$ ,  $c_1$ ,  $c_2$  and  $c_3$  of the equation, by using multiple regression analysis.



From all 15 minutes interval samples of traffic speed and density, clustered by the road weather classes in the same 15 minute interval, the van Aerde parameters were calculated. Figure 6 shows an example of the resulting fundamental diagrams at the different weather classes at a certain cross section. Also the resulting parameter are stated.

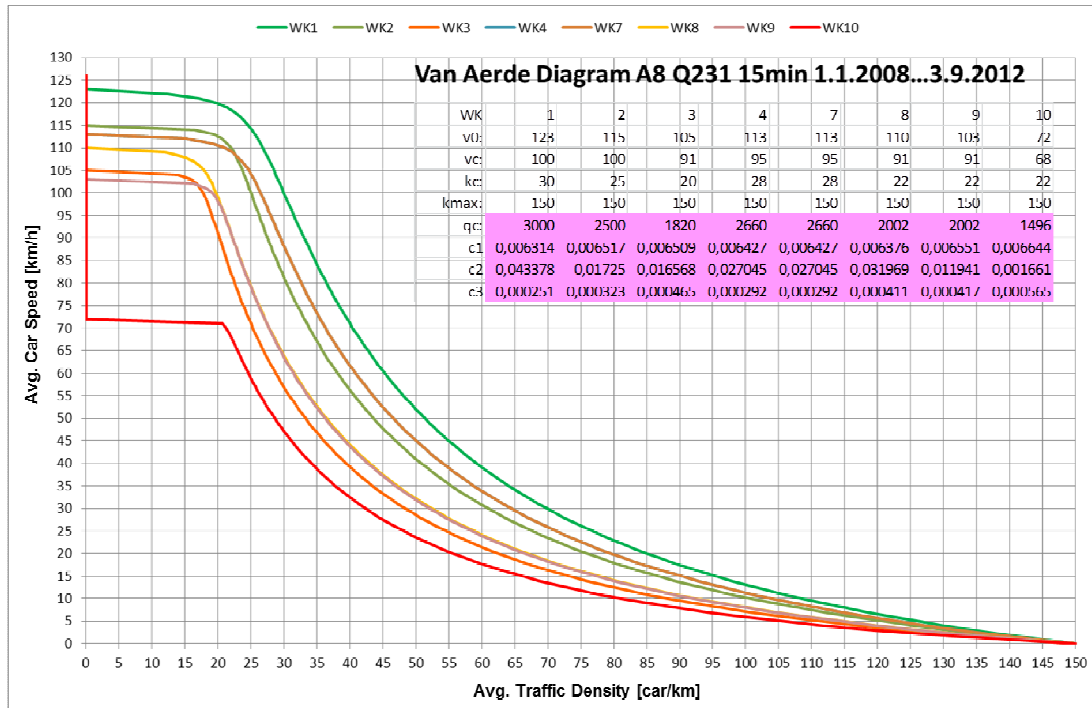


Figure 6: Example of fundamental diagram at a certain cross section. Parameter estimation at the Weather Classes 1...10 (WK1 ... WK10)

This road weather calibrated models could be used for traffic situation forecast at predicted and classified weather conditions.

But strictly speaking, the model is only valid for certain cross sections and the parameter had to be derived from a quite large amount of samples of traffic data and road weather data at the same location over a long period covering enough various weather situations. In addition the variations within the weather classes, although already highly differentiated, are still quite high.

This is the reason why we follow an alternative approach.

### 3.2 Road Weather related traffic flow model using continuous variables

The alternative approach was, to describe the driving behaviour using basic driving dynamic relationships. The model is based on the assumption that an experienced vehicle driver adjusts his speed so that he comes to no critical dynamic driving condition. The key parameters for modelling the driving speed are visibility (visual stopping distance) and tire friction. The structure of the continuous free flow speed model is shown in Figure 7. The visual stopping distance is either a property of the cross section (curve radius etc.) or depending from the actual weather situation. Heavy precipitation, especially snowfall has a significant impact on visibility which could be estimated by a visibility model. We developed a visibility approximation model based on optical extinction (see also [6]). The output of the model versus precipitation intensity is plotted in Figure 8. The visibility reduction due to predicted precipitation intensities could be quite good estimated, but the density of fog (aerosol) is very difficult to be forecasted, therefore visibility reduction due to fog is mostly not reliable predictable.

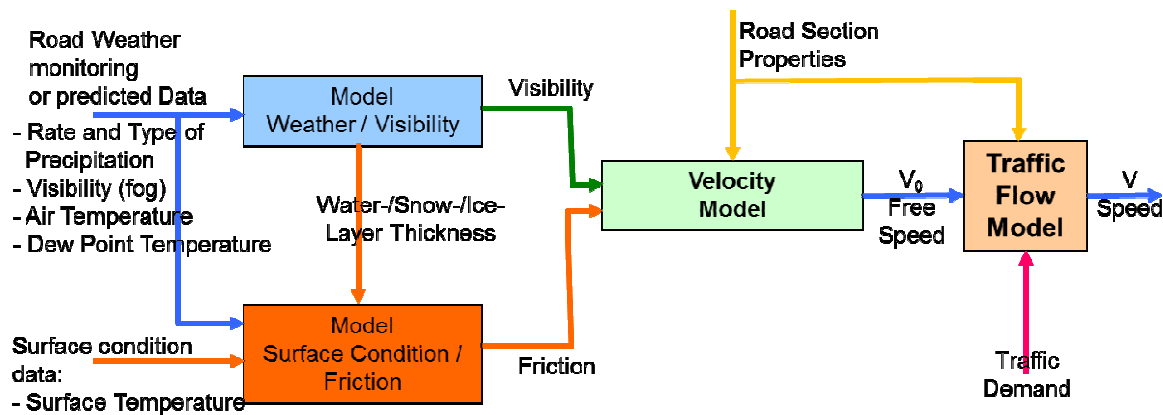


Figure 7: Structure of the continuous weather calibrated traffic flow model

In order to estimate the effective tire friction a layer thickness model was used to evaluate the coverage of the surface due to the atmospheric weather situation and road condition. The following influencing variables are used (actual measured or predicted):

- Intensity [mm/h] and Type [enum] of precipitation
- Air Temperature [°C] and Dewpoint Temperature [°C]
- Road Surface Temperature [°C]

In Figure 8 (left diagram) the output of the empiric friction model under real measured situations is plotted.

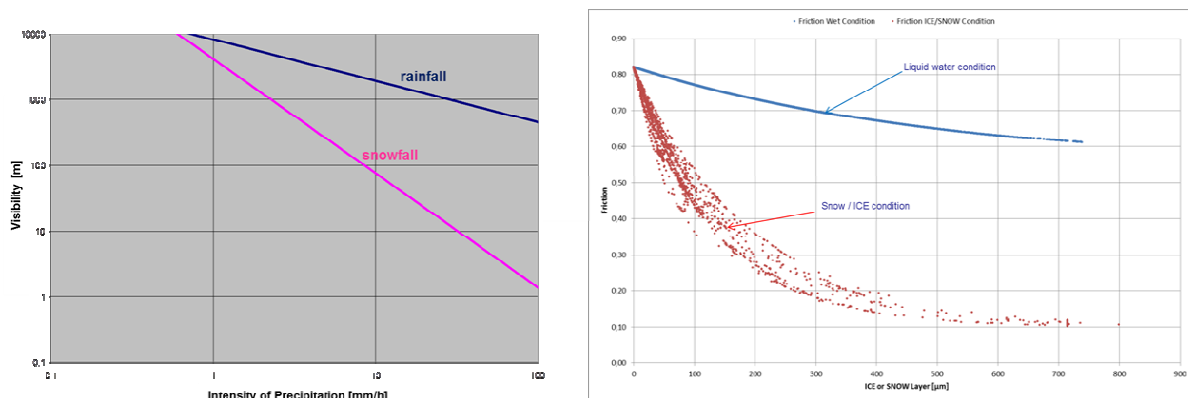


Figure 8: Output of the visibility model versus precipitation (right diagram) and friction model versus water-/snow-/ice-Layer thickness and road surface temperature (left diagram)

Once the effective tire friction and the visible stopping distance were estimated, the adjusted free flow driving speed could be evaluated.

#### 4 PROOF OF THE CONCEPT / TEST OPERATION

During the period of December 2012 until March 2013 a test operation was performed. The pilot server producing traffic flow data forecast due to the weather class derived from the GFS weather forecast in the pilot area.

For the traffic flow data pre-defined fixed free flow speed and traffic capacity values per weather class where used. The fixed values per weather class where derived from the van Aerde parameter estimation from the archived data of typical cross sections.

After the period the acquired real traffic and weather data from the pilot highway stretch where compared with the archived test server outputs and evaluated. In order to proof solely the weather calibration of the traffic model, the uncertainty of the pure weather forecast was compensated.

All 15 min interval samples of road weather and traffic data, measured at the selected location along the pilot stretch, where compared with the pre-defined calibration parameters according to the weather class and with the output of the continuous free flow car speed model introduced in chapter 3.2.



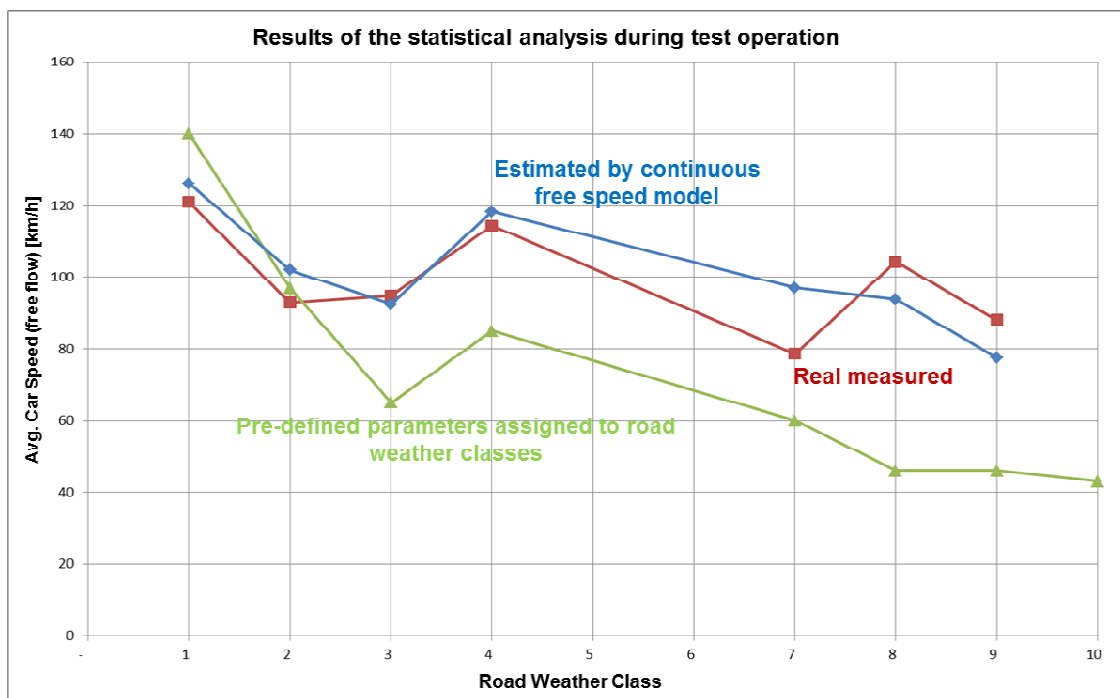


Figure 9: Results of the statistical evaluation of free flow speed in different weather classes during the test period Dec. 2012 to March 2013 at A8, selected cross sections. (Weather classes 5, 6 and 10 do not apply during the test period)

The continuous variable traffic&weather model (3.2) is much better suitable for estimating traffic flow due to road weather situation, than using pre-defined traffic parameters based on weather classes.

## 5 CONCLUSIONS

Although the analysis of the impact of local road weather variables on traffic flow show considerable high variations, due to a lot of uncertainties in measurement and prediction, nevertheless a strong statistical tendency can be encountered. The major influencing road weather variables could be identified.

Even moderate intensities of rain and wetness on the road surface causing a remarkable reduction of driving speed leading to an increase of average travel time. At increasing adversity of the road weather situation the adjusted driving speed decreases more and more and under a certain threshold – depending on the properties of the road section – also the traffic capacity of the road decreases significantly.

The results of the research project leads to the conclusion, that the impact of local road weather conditions on traffic flow had to be considered, in order to provide reliable traffic control, route planning and information.

The model introduced in 3.2 working with continuous weather input variables and basic road section properties, has proven its ability to describe the impact of road weather conditions on traffic flow.

## 6 Acknowledgement

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