QUATRA

Final Report

D 5.1 Analysis report

D 6.1 Final report

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Executive summary

Traffic management systems are using data from different sources for various purposes. In order to validate and confirm the correctness of the data QUATRA has been established. A comprehensive software system has been developed which handles the core functions for traffic data quality checks. This report provides detailed information about the QUATRA system including the conducted field tests.

Within QUATRA two comprehensive quality management tools for quality management of traffic data have been developed for the identification of erroneous data based on statistical estimations and logic based enquiries. The system can be used for analysis of different parameters such as traffic volumes, traffic densities and average vehicle speeds. Furthermore local/global/plausibility indicators have been developed that allow data evaluation and detection of inconsistencies. The erroneous data is flagged and can be analysed in order to differentiate between detector malfunctions and abnormal traffic conditions.

Based on the input from a state-of-the-art analysis relevant criteria and indicators have been defined for definition of the framework of the software tool and the development of statistical models. One tool can be used online to determine the quality of incoming traffic data for freeway control, the second tool is an offline city-service for measuring the quality of urban traffic data for signal control.

As part of the project scope additional concepts and ideas for the QUATRA system have been identified that could be integrated in future follow-up projects. This also covers data imputation for erroneous and missing values based on historical and actual information.

Both algorithms (freeway and urban) have been successfully tested with German and Austrian traffic data supplied by road operators.

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1 Introduction

"ERA-NET ROAD – Coordination and Implementation of Road Research in Europe" was a Coordination Action funded by the 6th Framework Programme of the EC. The partners in ERA-NET ROAD (ENR) were United Kingdom, Finland, Netherlands, Sweden, Germany, Norway, Switzerland, Austria, Poland, Slovenia and Denmark (www.road-era.net). Within the framework of ENR this joint research project was initiated. The funding National Road Administrations (NRA) in this joint research project are Belgium, Switzerland, Germany, Netherlands, Norway and United Kingdom.

Traffic management systems are using traffic data from several different data collection sources for purposes such as visualisation of the current traffic situation, detection of abnormal traffic conditions or traffic control decisions. In order to ensure effective control decisions the reliability and plausibility of traffic data needs to be confirmed and faulty data needs to be detected.

2 Project objective

QUATRA deals with the creation of tools for quality management for traffic data on freeways and in urban road environments. It has two major objectives:

The first objective is to develop procedures and software tools to measure and estimate the quality of incoming online traffic data in e.g. freeway traffic control centres. The incoming data, usually on a minute-to-minute basis is used for freeway control, management and information. For different control or information purposes it is often very important to know, if the underlying traffic data is correct or erroneous. In that case the type of error needs to be identified.

The second objective is to develop a comparable service for urban traffic data for cities and their road authorities. This service has access to the cities' traffic data database and calculates the performance measures and quality indicators on a daily basis. The results can then be accessed by the road operators and authorities.

The quality management for freeways will increase the reliability of automated traffic control under freeway conditions such as guidance and speed harmonization and can be used for generating variable traffic messages. On urban roads it will improve the traffic data quality for example to guarantee a reliable signal coordination and will help to reduce travel times and emissions.

The software has been developed in order to be used for a variety of different existing data collection systems and data formats. The corresponding quality management system provides quality standards for different data collection systems with the objective of homogeneity and high data quality for various telematic requirements and data networks.

2.1 Freeway Tool - Online Assessment

In order to provide high quality data, it is necessary to develop an online system of data verification that uses statistical procedures suitable for checking traditional traffic data in short time periods. This is an important task in order to guarantee the quality of data from different collection systems for specific telematic requirements and the reliability and quality of data transmission systems. Reliable traffic data is vital for traffic guidance, harmonization of speeds and traffic safety.

The statistical model that has been developed especially for the online freeway tool is based on findings of previous research studies that have already been carried out on behalf of the authorities - partly also by the consortium partners. The good suitability of this method for traffic data tests in principle is already proven.

A key objective was to achieve a better statistical reliance of traffic data to optimize the available capacity of the infrastructure. Due to the quality of the data, a wider use of single and combined data is possible with appropriate quality.

In 2012 workshops with Austrian and German road authorities were held to discuss requirements of the authorities and potential solutions that could be developed within QUATRA.

The statistical method uses historical traffic data to predict specific data attributes and is therefore the most appropriate approach for online traffic data checks for road management systems. The proposed method is innovative and superior to previously used approaches.

2.2 Urban Road Tool - Offline Assessment

In contrast to freeways, an urban road network consists of many alternative roads with a high number of intersections. Usually, only main road measurements exist at disperse intersections throughout the network. Those measurements are used for traffic signal control. Faulty measurements lead to a decreasing quality of traffic signal control and to a decrease in service quality such as increased travel times. Therefore a reliable measurement system is the backbone of a balanced urban traffic system.

For urban road authorities it is important to identify faulty detectors quickly and send out maintenance teams for repairs. Up until now only a few cities do have adequate quality management systems for such a task. For the majority of cities comparable systems do not exist. QUATRA identifies faulty detectors offline on a daily basis. Based on the data analysis that is carried out, the cities can execute different actions to solve the problems with faulty detectors.

For the urban road network QUATRA is based on the approach that traffic streams on road section (equipped with detection systems) heading towards comparable directions stay the same during specific times of the day depending on the relevant weekday. Thus, a correlation method compares the daily traffic streams of corresponding detection sites. If the correlation is not within a defined verification interval, one of the two sites is reporting abnormal traffic data (e.g. faulty measurements or abnormal traffic conditions).

3 State-of-the-art Analysis

In order to develop the superior QUATRA tools for traffic data on freeways and in urban road environments an extensive "State-of-the-art analysis" has been carried out (for details refer to the deliverable ENR_Deliverable_State-of-the-art). Main objective is the gathering of knowledge about existing data quality evaluation systems and approaches as well as the collection of research concepts whose contents were partially integrated into the QUATRA system.

Five analysis categories (as follows) included details of technical approaches (based on specific data features), traffic engineering approaches (based on logic combinations of traffic flow fundamentals and neighbouring traffic detection sites), guidelines and standard procedures (setting out specifications for the assurance of the data quality of incoming traffic data), standardised systems and tools (systems that are being developed/used at present) as well as statistical concepts for data evaluation.

Some of the potential concepts that have been identified in the State-of-the-art analysis require certain traffic data aggregation levels that cannot be provided by Austrian and German road operators and authorities. Consequently these could not be integrated into the QUATRA system.

Technical approaches focus on the detection process itself (threshold value tests) and the analysis of certain data attributes as well as the detector communication and the combination of specific attributes. Apart from the technical tests a lot of traffic engineering approaches have been published in the last years that deal with the quality analysis of traffic data. These tests mainly focus on traffic flow theory with the use of the inherent relationships among speed, volume, density and occupancy to assess data validity. Furthermore the principle "conservation of vehicles" is used for assessment. Guidelines, standard procedures and standardised systems provide relevant quality conditions that are used for the definition of the parameters of QUATRA.

As of today automated methods using modern statistical methods based on historical data are not commonly used. Therefore a new statistical approach has been integrated in the QUATRA system. In terms of the statistical approaches screening rules (also called edit rules) are used to determine whether an observation is consistent or not. In order to construct a set of edits one usually starts with hard edits, which hold true for all correctly observed values. This is also the case within this project, whereas dozen of balanced edits are formulated. In this project an additional step is taken. After the hard edits are specified, one generally uses subject-matter knowledge and statistical analyses to add a number of soft edits, which hold true for a high fraction of correctly observed records but not necessarily for all of them (de Waal, 2008). The threshold related to ratio edits (hard or soft edits) have to be determined carefully, so that on the one hand only few values may violate the edit and that on the other hand erroneous values are detected by these edits. To avoid over-editing one should in particular be careful not to specify too many soft edits (de Waal, 2008; Templ and Todorov, 2011). Another problem that is present in traffic data is the missing data problem. Due to malfunction or transmission errors, missing values are introduced. The estimation of the missing cells can even introduce additional bias depending on the method used. Valid estimations and inferences can mostly only be made if the missing data are at least missing at random (Little and Rubin, 1987). Considering a data set, the usual measure used in this context is the Mahalanobis distance, a one-dimensional statistic measuring the distance of a data point from a location with respect to a shape (Maronna et al., 2006; Filzmoser et al., 2008; Hardin and Rocke, 2005).

Due to their importance the State-of-the-art analysis also included the screening of existing guidelines and procedures that have already been developed and analysed during the State-of-the-art analysis. For the purposes of QUATRA selected documents were analysed in terms of quality assurance. These guidelines and procedures focus on basic parameters that represent the quality level of traffic data: accuracy, completeness, validity, timeliness, coverage and accessibility. In the field of traffic data quality management there are already standardised systems and tools in place in various countries. In terms of the analysed guidelines and standard procedures important contents were gathered for the system development and testing procedures.

For the current project the predecessor software LOTRAN-DQ has been taken into account during the software development. Major modifications of the initial quality indicators for freeways and urban roads and the corresponding software have been carried out.

4 Strategy for traffic data assessment

4.1 Strategy development

The QUATRA system is based on the findings of the state-of-the-art analysis where criteria and indicators for the traffic data assessment strategy were defined.

The strategy analysis was carried out during a two stage process. In the first stage the project partners evaluated the results of the literature review for application within the freeways and urban road environment separately. In the second step the interpretations and findings of both project partners were shared and discussed at a round table and a joined approach for definition of quality checks and model development was defined. The suitability of the algorithms and software capabilities could be confirmed which are used for different data system. The aim of the strategy is a method for use in various use cases with an automated procedure that can be controlled and supervised by operators such as in freeway and urban traffic control centres.

The QUATRA system combines a variety of local/global/plausibility indicators with statistical model approaches for the evaluation of freeway and urban traffic data. Some of the technical approaches that are used for the QUATRA algorithms combine and assess different attributes and logic combinations of incoming traffic data and analyse the incoming data in terms of traffic engineering fundamentals. Furthermore the project consortium modified the statistical approach from nast consulting (2008).

The local/global/ plausibility indicators are based on combinations of different values of the traffic data sets as well as the analysis of neighbouring traffic detection sites. Thus the conservation of traffic flow theory is incorporated in the traffic data analysis. Apart from the total number of vehicles balances of single vehicle categories can also be assessed.

The statistical model approach for the freeway and urban road data has been based on the assessment of historical data and prediction of confidence intervals for current road data ranges as well as major anomalies of the data in comparison to standardized statistical parameters. The statistical models are described in detail in chapter 5.2 and 6.1.

4.2 Available traffic data sources

For the development of the freeways assessment tools data from the following test sections were used:

- Austria: sections on S 1 (city freeway in Vienna) and A 12 (rural freeway in Tyrol)
- Germany: sections on A 8, A 9 and A 99 (freeways in the area of Munich)

For the development of the urban assessment tools data from the following test sections were used:

- Austria: City of Vienna
- Germany: City of Bremen

4.3 Detector error messaging and abnormal traffic conditions

In relation to the detection of data anomalies one has to differentiate whether detectors themselves send wrong information due to physical failure, wrong detector installation and calibration or if the data is abnormal compared to historical traffic conditions due to incidents or road works.

Detector error messaging

Regarding physical or data exchange failures detectors automatically submit error values for different variables. The error reporting varies depending on the TLS[a] used at the detection site.

TLS new standard[a]

q=0 && v=255 → detector reports that no vehicle was detected during the interval

q=0 && v=0 → detector reports disruption

(q - traffic volume, v - average vehicle speed)

TLS old standard[a]

q=0 && v=0 → detector reports disruption OR detector reports that no vehicle was detected during the interval

In order to identify detector disruptions time variation curves need to be assessed to gain information about q=0 && v=0 during a longer time period.

Wrong detector installation and calibration

In order to find out erroneous data based on wrong detector installation and calibration the data of neighbouring traffic detection sites can be compared. Under the assumption of conservation of traffic the balances of these detection sites - for example total number of vehicles, single vehicle categories - can be assessed. Once certain thresholds are exceeded the operator or maintenance crew can be informed about potential installation problems. Of course the conservation of flow also needs to cover traffic that exiting and entering the road network via ramps between neighbouring traffic detection sites.

Abnormal traffic conditions

Apart from physical disruptions due to the identified sources above detectors can only identify vehicles that are driving through the specified detection field. Once vehicles are passing by outside of the main detection range only a certain percentage of these vehicles can be registered and the vehicle category is likely to be faulty with a high percentage.

Based on the analysis of time variation curves of historical traffic data typical traffic conditions can be specified according to parameters such as weekday, hour and location. Consequently the current traffic condition under the assumption of normal traffic flow can be predicted and compared with the observed number of vehicles. Once the comparison of predicted and observed numbers of vehicles shows high variations the data record (for example one mite interval) can be flagged as abnormal.

[a] TLS: technical supply conditions used for road stations, used in Austria and Germany

4.4 User Requirements

In 2012 workshops with Austrian and German road authorities were held. Main objective of the workshops with the representatives were discussions of requirements of the authorities and possible solutions that could be solved with QUATRA. In general there are deficiencies in relation to available data especially during use cases were online data is required. These deficiencies mainly arise out of non-technical error sources during the detection process (e.g. wrong installation of sensors).

According to the authorities not only total traffic volumes show erroneous data rather also single vehicle categories. If these category based deficiencies could be identified and reported that would be a clear benefit upon existing approaches.

The following use cases were identified together with the authorities:

- Labelling of erroneous data for traffic statistics: currently traffic statistics are based on offline data that needs to be manually assessed and checked prior to the statistics preparation. The plausibility check is carried out after the traffic data has been collected and saved. An automated labelling done by the QUATRA system provides assistance for the estimation process through flagging the abnormal data entries. These entries can simply be excluded for statistics. The labelling is mainly relevant for 8+1 data detection sites in a first stage according to the authorities (in a second stage also for 2+0 data detection sites)
- Monitoring of operations and sensor availability: data quality is essential for motorway operations. There are systems in place already that identify and record technical failures of sensors and detectors. The evaluation of the transferred content of the traffic data (e.g. accuracy) is not being done at the moment. A single daily check would be sufficient for operations. A possible solution should be able to generate automatic reports of malfunctions and wrong contents because experts („Second Level") are needed for data quality assessment (experts need to go through the data of all installations and sensors manually). Furthermore the expert system should decide by itself if the operator („First Level") should be informed through report generation. It could be found out that the application of the statistical model was much easier to read instead of the interpretation of the global indicators. Further evaluation procedures could be taken into account for future follow-up projects.
- Reconstruction of the traffic situation for traffic control purposes: at present faulty detector data can result in wrong traffic control decisions e.g. on Austrian motorways. An online procedure would be required to analyse the data and create substitute data (mainly traffic volumes and average vehicle speed) in case of error detection. The validated data could then be forwarded to the traffic control algorithms. Furthermore a virtual detection site could be inserted in the user interface that shows the imputed data for a specified section. Within QUATRA a statistical approach has been developed that provides a solution for the data imputation theme. Nevertheless due to limited resources this approach could not be integrated in QUATRA so far. This evaluation procedure has been taken into account for future follow-up projects.

5 Freeway Tool - Online Assessment

5.1 Local/Global/Plausibility indicators

The indicators are based on combinations of different values of the traffic data sets as well as the analysis of neighbouring traffic detection sites and principles of conservation of flow and are as follows:

Local indicators

- Missing data: number or ratio of missing data sets. Normally, each detector should deliver one data set per minute respectively 1.440 data sets per day - otherwise there is a disturbance
- Failure messages from detector: number or ratio of data sets with failure message “255, 255” generated by the detector itself

Global indicators

- Conservation of flow for cars: comparison (ratio) of number of cars at neighbouring measurement cross sections under consideration of inflow and outflow at ramps. The ratio should be 1 - otherwise there is a disturbance
- Conservation of flow for heavy goods vehicles (HGV): comparison (ratio) of number of HGV at neighbouring measurement cross sections under consideration of inflow and outflow at ramps. The ratio should be 1 - otherwise there is a disturbance

Plausibility indicators

The following table provides an overview about the plausibility indicators than have been applied within the freeway tool.

Table 1: Plausibility indicators (1)

Number and comments	Plausibility Check
M1	$QKfz = 0 \Rightarrow (QLkw = 0 \text{ UND } QPkw = 0)$
total traffic must be the sum of individual vehicle categories. If no vehicles total were counted during time period no car or HGV can be registered	
M2	$QKfz - QLkw = 0 \Rightarrow (QPkw = 0 \text{ UND } VPkw = 255)$
if total traffic = total vehicles category 1 there can't be any amount of vehicles for category 2... - furthermore speed of category 2... must be 0	
M3	$QLkw = 0 \Rightarrow VLkw = 255$
if no HGV has been counted average speed must be 0 or code 255	
M4	$QPkw = 0 \Rightarrow VPkw = 255$
if no car has been counted average speed must be 0 or code 255	
M5	$QKfz \geq QLkw$
total traffic must be sum of all vehicles categories	
M6	$QKfz - QLkw > 0 \Rightarrow 0 < VPkw$
if cars have been counted average car speed must increase	
M7	$QKfz > 0 \Rightarrow 0 < VKfz$
if vehicles have been counted average speed must be present	
M8	$QLkw > 0 \Rightarrow 0 < VLkw$
if vehicles have been counted average speed must be present	
M9	$0 < t < T$
detector utilization time must be higher 0 and shorter than time interval	

Source: TRANSVER

Table 2: Plausibility indicators (2)

<table>
<tr><td>M10</td><td>$QKfz = 0 \Rightarrow 0 < Vg,Kfz(t) = Vg,Kfz(t-T)$</td></tr>
<tr><td colspan="2">if no vehicle has been counted during time interval, averaged vehicle time must be higher 0 and same as previous time period</td></tr>
<tr><td>M11</td><td>$VKfz > VGrenz \Rightarrow B < Bgrenz$</td></tr>
<tr><td colspan="2">If average vehicle speed is high during a time interval the detector occupancy rate has to be below a certain treshold (fundamental diagram)</td></tr>
<tr><td>M12</td><td>$QKfz,min \leq QKfz \leq QKfz,max$</td></tr>
<tr><td colspan="2">traffic volumes during a certain time have to be within a certain range - otherwise there is a disturbance</td></tr>
<tr><td>M13</td><td>$QPkw,min \leq QPkw \leq QPkw,max$</td></tr>
<tr><td colspan="2">car volumes during a certain time have to be within a certain range - otherwise there is a disturbance - refer to item 7</td></tr>
<tr><td>M14</td><td>$QLkw,min \leq QLkw \leq QLkw,max$</td></tr>
<tr><td colspan="2">HGV volumes during a certain time have to be within a certain range - otherwise there is a disturbance</td></tr>
<tr><td>M15</td><td>$VKfz,min \leq VKfz \leq VKfz,max$</td></tr>
<tr><td colspan="2">average vehicle speed during a certain time has to be within a certain range - otherwise there is a disturbance</td></tr>
<tr><td>M16</td><td>$VLkw,min \leq VLkw \leq VLkw,max$</td></tr>
<tr><td colspan="2">average HGV speed during a certain time has to be within a certain range - otherwise there is a disturbance</td></tr>
<tr><td>M17</td><td>$VPkw,min \leq VPkw \leq VPkw,max$</td></tr>
<tr><td colspan="2">average car speed during a certain time has to be within a certain range - otherwise there is a disturbance</td></tr>
<tr><td>M18</td><td>$Vg,Kfz,min \leq Vg,Kfz \leq Vg,Kfz,max$</td></tr>
<tr><td colspan="2">smoothed vehicle speed from during a certain time has to be within a certain range - otherwise there is a disturbance</td></tr>
</table>

Source: TRANSVER

Table 3: Plausibility indicators (3)

M19	$B_{min} \le B \le B_{max}$
average car speed during a certain time has to be within a certain range - otherwise there is a disturbance	
M20	$V_{Pkw,links} > V_{Pkw,rechts}$
Germany: average car speed in right freeway lane should be below average car speed in left freeway lane Austria: due to driver behaviour this assumption can not be used for Austrian motorways and urban areas	
M21	$V_{Ausfahrt} < V_{Ausfahrt,grenz}$
average vehicle speed at on-/off ramps during a certain time has to be within a certain range - otherwise there is a disturbance	
M22	$Q_{Lkw,rechts} > Q_{Lkw,links}$
HGV volume in left freeway lane should be below HGV volume in left freeway lane (problem during overtaking manouvres)	

Source: TRANSVER

5.2 Statistical model development

The data analysis with a statistical model represents an additional rule for the assessment of the traffic data based on statistical estimation.

Screening rules, often called *edit rules* are often used to determine whether an observation is consistent or not. An example of an logical (balanced) edit is

$$qKfz = qPkw + qLkw$$

where qKfz, qPkw and qLkw is the number of all vehicles, of cars and of heavy goods vehicles in a given time interval, e.g. measured by detectors on a freeway. The edit above expresses that the amount of trucks and cars should sum up to the total number of vehicles. Such an edit is referred to as a balanced edit[b].

If a ratio of two variables is less (or greater) than a certain threshold, then this edit is referred as ratio edit. For example, vKfz2/vKfz1 > 0.8 which means that the speed the second lane at a freeway should be not less than 20% of the speed of the first lane.

In order to construct a set of edits one usually starts with the hard (or logical) edits, which hold true for all correctly observed values. Balance edits are usually referred as hard edits. Hard edits are specified by subject matter specialists. This is also the case within this project, whereas dozen of balanced edits were formulated. During statistical analyses soft edits are set which hold true for a high fraction of correctly observed records but not necessarily for all of them.

Ratio edits can be either hard edits (hold true for all correctly observed records) or soft edits (hold true for a high fraction of correctly observed records). The threshold related to ratio edits have to be determined carefully, so that on the one hand only few values may violate the edit and that on the other hand erroneous values are detected by these edits. This threshold is either fixed by a subject matter specialist (hard edit) or may vary depending on the input data (soft edit).

To avoid over-editing one should in particular be careful not to specify too many soft edits. In general, users tend to apply more soft edits than necessary to the data (refer to de Waal, 2008 and Templ and Todorov, 2011).

In former projects - but with the following reasons not applied in this project - possible erroneous values were detected by parametric modelling. The number of cars and the length between the cars were considered as a realization of a Poisson distribution. Theoretical properties of the underlying distributions may be used to define malfunctions. In this case, empirical historic data are modelled by a Poisson distribution. From the theoretical properties of this distribution, a threshold was used to define if an value is suspicious.

Although this method can also be applied on subsets of the data, it is a univariate method that does not consider information on covariates. Therefore, the method is of limited use and not considered in this work. Another problem that is present in traffic data is the missing data problem. Due to malfunction or transmission errors, missing values are introduced.

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[b] A non-negative edit is defined as a value not being negative if it passes the edit. For example, the speed of a vehicle cannot be negative

The imputation of missing values is especially important for traffic data, This has especially consequences for statistical methods using the multivariate data information. The naive approach, namely omitting all observations that include at least one missing value, is not attractive because a lot of valuable information might still be contained in these observations. On the other hand, omitting observations may only lead to non-biased estimates when the missing data are missing completely at random.

The estimation of the missing cells can even introduce additional bias depending on the method used. Valid estimations and inferences can mostly only be made if the missing data are at least missing at random. Not only missing values in the data but also values that violate the edits have to be replaced by reasonable substitutes.

In order to create a statistical model approach the data had to be visualised first in order to gain a better insight about possibly hidden data-structures, relationships and errors. Although these results might be well known by specialists every new data set should be first analyzed by explorative methods.

Boxplots of the number of vehicles (variable qKfz) and the mean speed of vehicles (variable vKFZ) aggregated at hours of the day provided useful information and (robust) key statistics: the box contains the inner 50% of the observations the line in the box is the median that splits the sorted data by half. Finally, the so called whiskers lay at the last observation outside $1.5 \cdot IQR$ (interquantile range, which contains the inner 50 % of the ordered observations) measured from the inner box. Values outside the whiskers may be considered as (univariate) outliers. Because of this visual summary statistics of the data - the boxplot, the distribution of the data and possible outliers can be easily seen.

In Figure 1 it can be seen that on a typical rural freeway section during the day between 06:00 and 16:00, the amount of vehicles per minute is constantly high for all two lanes (for the remaining time period between 16:00 and 06:00 there is a constant change in traffic volumes). However, during the night, the mean of the amount of Kfz is close to zero for lane 2, expect some values that are far away from the mean. Apart from the time of the day detector sites near on- and off ramps can also show a different picture due to the lane changing and bypassing manoeuvres.

The data values outside of the whiskers are the ones that are of high interest for the statistical analysis because some of them represent abnormal traffic conditions or detection failure for the particular time during a day.

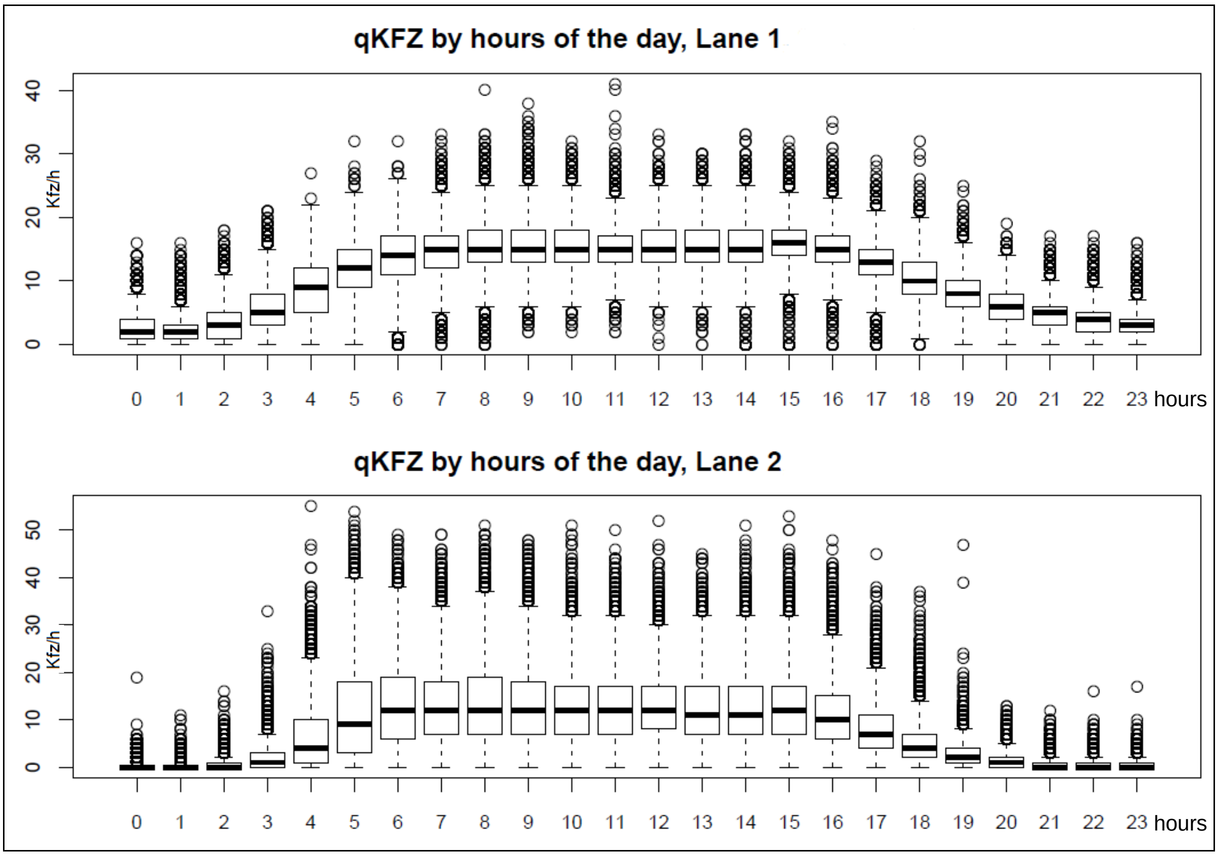


Figure 1: Boxplots of number of KFZ by hours of the day for a typical rural freeway section

Source: nast consulting, Technical University of Vienna

Detection of malfunction and measurement errors in one sector

Data that has been collected or measured generally includes errors due to a variety of reasons. In any case, statistical data editing methods, e.g. checks and corrections, are usually necessary to increase the quality of the available data and to be able to detect malfunctions of measurement units.

First, erroneous values in the data set have to be localized. It is preferable if this problem can be tackled in an automated manner. These localized erroneous values then have to be dealt with. One possibility is to replace faulty measurements by reasonable values using a suitable imputation procedure whenever complete data are needed for further analysis. It is usually not necessary to remove all errors from a data set. Doing automated micro-editing for small errors is often too ambitious and leads to over-editing. However, it is a necessarily to detect systematic errors from measurement units or malfunctions in measurement units because systematic errors do affect results of statistical data analysis.

Of course, a good property of any imputation method is that logical relationships in the data should be preserved. For example, in the case of traffic flow data, the sum of trucks and cars given a specific sector and lane should sum up to the corresponding total number of vehicles also after the imputation process.

The detection of outliers is very important in statistical analysis. Outliers can be considered as atypical observations which deviate from the usual data variability. Since classical statistical models applied to data including outliers can lead to misleading results. In addition to that, measurement errors may also have great influence on aggregates typically published in output tables.

Mahalanobis Distance and Cut-off values

Considering an $n \times p$ data set **X**, the usual measure used in this context is the Mahalanobis distance, a one-dimensional statistic measuring the distance of a data point from a location with respect to a shape. It is defined as

$$d_i = d(\mathbf{x}_i) = \sqrt{(\mathbf{x}_i - \mathbf{t})^T \mathbf{C}^{-1} (\mathbf{x}_i - \mathbf{t})}$$

for an observation **x***i*, $i = 1, \ldots, n$, and the respective location and covariance estimates **t** = **t**(**X**) and **C** = **C**(**X**). Using the arithmetic sample mean as an estimator for the location **t** and the sample covariance matrix as an estimate for **C**, the resulting Mahalanobis distance is not robust since it depends on estimators which are extremely sensitive to outliers. It can easily be shown that the classical Mahalanobis distance can already be corrupted if the data contains only one single outlier.

If robust statistics such as the median as the location estimate **t** and a robust estimate for the shape parameter **C** are used, the resulting distance measure is referred to as the robust Mahalanobis distance. If the data is multivariate normally distributed, the squared Mahalanobis distances based on the classical mean and covariance estimates are approximately χ^2-distributed with p degrees of freedom. To classify the points of a data set as regular points or outliers, a cut-off value has to be specified, which in practice is usually a certain quantile of the respective distribution of the corresponding distances, e.g. the 97.5% quantile of the χ^2_p-distribution. Data points with distances larger than this threshold are then considered as potential outliers.

Assuming that for one sector, detectors are on two or three lanes installed, the two (or three) dimensional joint distribution has to be considered. Herby, no malfunction is detected when

(a) the classical correlation between observations obtained from different lanes is large, and

(b) the percentage of outliers (as identified though the Mahalanobis distance) is small,

(c) a dependency on the day time is given, for example, the ratio (measure first lane / measure second lane) has a typical behaviour which is estimated by based on historical data.

For outlier detection in (b) robust statistical methods have to be applied, since classical methods are themselves influenced by outliers. The exact parameters to define a set of rules based on (c) are estimated from historical data while (a) and (b) can be defined beforehand. The proposed procedures can be applied off- and online.

From the following Figure 2 it can be inferred, for example, that the detection and measurement of traffic volumes per minute and average speeds per minute show abnormal traffic conditions or faulty detection periods. The problem of detecting malfunctions can be viewed as a statistical testing problem. Observations with large multivariate distances from the centre of the data are highlighted in red. Clearly, the observations in red in the lower middle and right part of the plot are such situations since the amount of vehicles during free flow conditions cannot be large while the mean speed is very low. The figure above shows the potential benefit of the application of robust multivariate distances to detect malfunctions and abnormal traffic conditions. While it (and the related estimations) is only based on two-dimensional data (to be able to visually show the concept) the method for detecting outliers for multivariate data greater equal three dimensions is still the same.

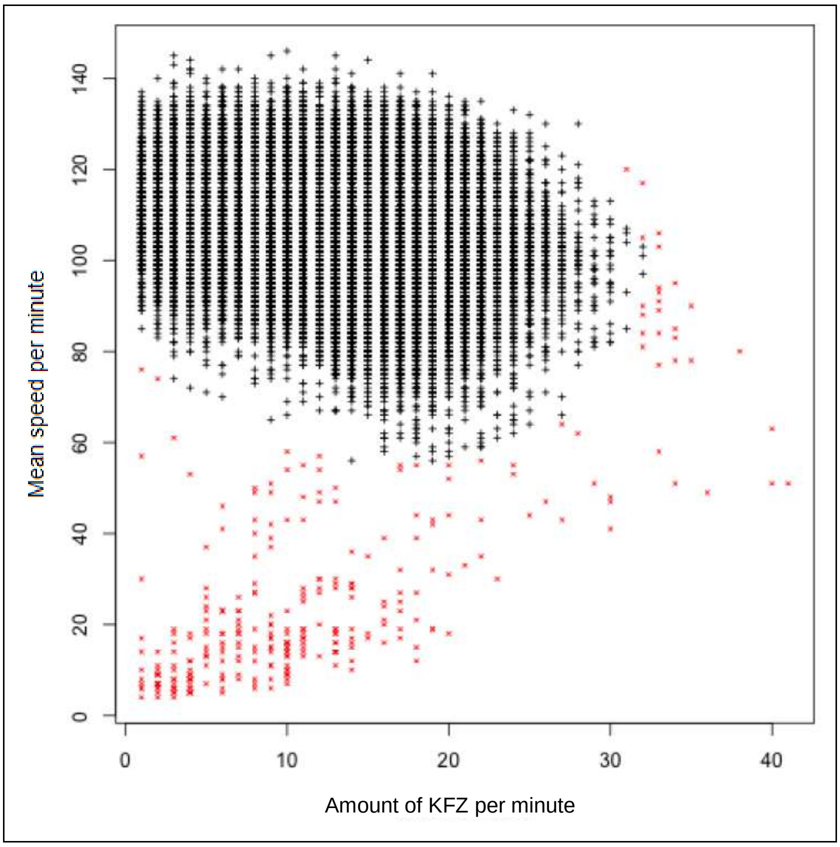


Figure 2: Scatterplot of the amount of vehicles (KFZ) versus the mean speed of vehicles

The colour code red represents observations with large (robust) multivariate distance based on 99.9% tolerance ellipses.

Source: nast consulting, Technical University of Vienna

In Figure 3 can be seen that the techniques mathematically described in the previous section can be generally applied to multivariate data in order to take information on several covariates (e.g. day time, lane number, weekday,...) into account. In this case, spatial dependencies can also be considered which is hardly possible when using multivariate methods based on (robust) distance measures.

Correlation between lanes

If one is interested in the ratios for example of the mean speed of vehicles between lanes at a given sector, one can use again measures based on multivariate distances to detect and identify suspicious ratios/observations. Figure 3 highlights those observations with large (robust) Mahalanobis distances. The observations in red are candidates for erroneous data or abnormal traffic conditions.

Assuming that for one sector, detectors are on two or three lanes installed, the two (or three) dimensional joint distribution is considered. Herby, no malfunction is detected if

(a) the classical correlation between observations obtained from different lanes is large, and

(b) the percentage of outliers is small

A robust estimation for the correlation can be obtained with the MCD algorithm.

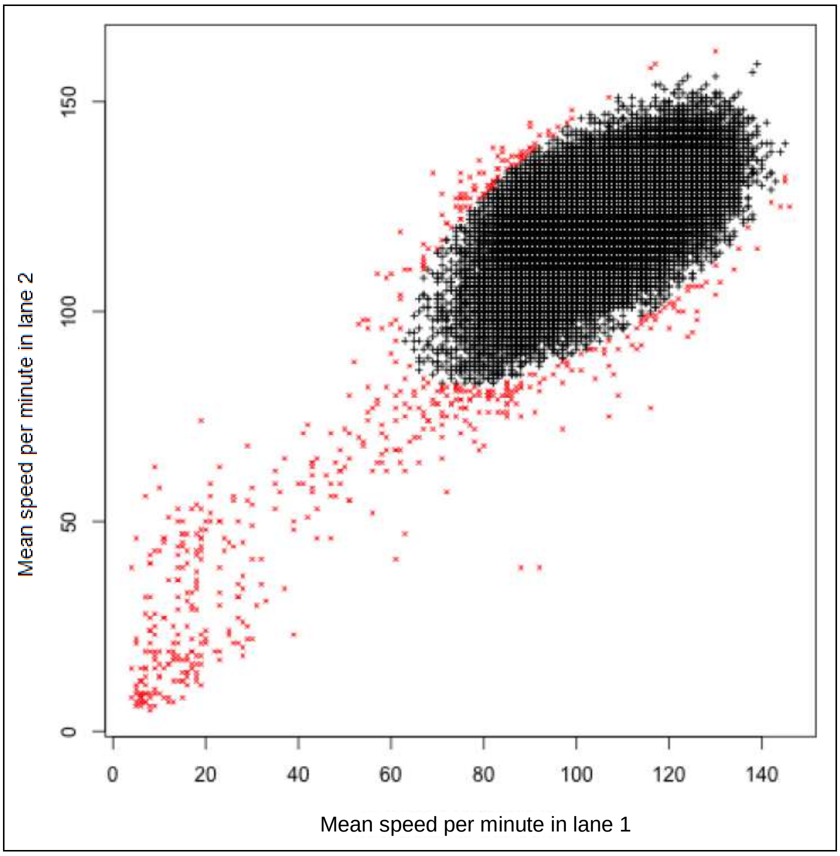


Figure 3: Scatterplot of the mean speed of vehicles (KFZ) in adjacent lanes

The colour code red represents observations with large (robust) multivariate distance based on 99.9% tolerance ellipses.

Source: nast consulting, Technical University of Vienna

Statistical approach

The main idea of the statistical approach is the use of the information of both space and time dependent sectors as well as historical data to formulate a general regression model. In order to decide whether given new measurements (offline or online) of detectors are likely to be faulty, not only prediction intervals given by the model are used but also aggregated information available from historical data.

The first step of model definition was the creation of a pooled dataset containing information from all sectors and lanes under consideration. It is helpful but not necessary to impute missing values for both the dependent variable as well as all independent variables before fitting the regression model.

The coefficients of the model were estimated using historical data. The predicted number of vehicles on a given sector and lane given the model on newly measured data is finally evaluated in order to make a decision if the measured data are likely to be correct.

The idea is to use statistical prediction intervals as well as historical information on the expected number of vehicles on the corresponding lane given day time, month, sector among other characteristics. If both the prediction interval given the model does not contain the observed number of vehicles and the measured number of vehicles is outside the range of the 2.5% and 97.5% quantile of the number of vehicles given historical information the model suspects a detector failure or abnormal traffic condition.

The input data may also depend on the mean travel time between sectors. This time lag may be estimated and included in the model. However given the limited data at hand (no travel times available) this information could not be used for modelling purposes at this stage. Nevertheless the model can be extended in order to apply further variables to detect malfunctions independently of sector properties since these properties are already indirectly used in the underlying regression model.

Another point worth mentioning is that even though traffic count data is modelled an ordinary least square regression (OLS) is used. While it might be beneficial to use a regression based on poisson or negative binomial distribution assumptions the main task is the identification if detectors are working. In addition the OLS approach has some benefits. First of all, OLS-regression is available in virtually any statistical software which is good for later implementation purposes but it is also (considerably) faster than for example using a negative-binomial regression model. This could be useful especially during the online application.

Due to the variability of the variables a data aggregation needs to be carried out since one minute data especially for low-traffic time period can vary quite much. Consequently the data has been aggregated to 5-minute time intervals.

In order to create a profound model a set of independent variables has been created including the specification of a regression procedure such as an ordinary least square regression, poisson-or negative binomial regression procedure or any other robust regression method.

Once the required choices have been made and a suitable model has been found it was required to fit the model to historical data. This results in a set of regression coefficients. A very important limitation with respect to the independent variables that are used in the regression model is that these variables need to be available at the same time interval as the data on number of vehicles that are modelled (especially for an online application). Whenever new data (both on the number of vehicles driving at a specific lane at a given location as well as all the required independent variables have been collected) is available it is possible to plug these new data into the specified model. Then the model predicts the number of vehicles at the given lane and sector as well as the corresponding confidence interval for each predicted value based on historical information.

After this step both the observed and collected values of number of vehicles for a given time interval at a specific lane on a given sector as well as the predicted number of vehicles for the exactly same time, lane and sector are available.

The next task was then to describe the proposed idea to judge whether the observed and measures values significantly different from the expected values in order to identify a high chance of detector failure. The idea is simple and is outlined below.

The main idea is based on two different assumptions – so called statistical indicators. A detector failure or abnormal traffic condition is identified if both assumptions are violated. The assumptions are:

1) the observed (measured) number of vehicles must lie within its corresponding prediction interval given the results of the regression model.
2) the observed (measured) number of vehicles must lie within the range of the 2.5% and 97.5% percentile (normal range) of the distribution of number of vehicles for a given sector, lane, hour and hour of the day based on historical information.

Only if both assumptions are violated a measurement is flagged as possibly faulty. In other words, if the corresponding prediction interval for a newly measured data point does not include the measured number of vehicles and the observed number of vehicles lies outside the normal range based on historical data, there is a strong indication that the detector measuring data for the lane and sector under consideration is at fault and needs to be checked.

Furthermore also standardized residuals have been tested as separate rule for data assessment during the development process. The key idea is that the standardized model-residuals given as difference between observed and predicted values for a given measurement follow a (symmetric) distribution around with mean 0 and standard deviation of 1. If measurements with large standardized residuals are observed the measurement is possibly suspicious and flagged.

In general both proposed procedures are very flexible because the basic model based on historical data can be refitted at any given time. For example the input data used when fitting the model may be changed in a way that more current data (that have been proven to be measured by correctly-working detectors) may be included while old data may be removed. This results in modified regression coefficients that are then used as input parameters for predicting measurements and testing purposes.

Example for traffic data assessment on the German motorway A 8

For the year 2010 one-minute interval data was provided for selected road detection sites along the A 8 motorway in Germany. Extensive work was required for the import and manipulation of the traffic data outside of the proposed software platform of QUATRA. Furthermore different codes and formats are used in German and Austrian data streams - therefore additional work was required for data transformation.

Thus only a few sectors were extracted for model development which feature different numbers of lanes. Furthermore instead of 5 minute intervals for the online application within QUATRA the data was aggregated and tested upon 10-minute intervals.

For testing purposes the following model was applied:

$$qKFZ \sim tNetto + classVA + weekday + vPKW + sectorLane + hour$$

This means that the number of vehicles (*qKFZ*) in a 10-minute interval is explained by a linear combination of the following independent variables along with an intercept:

tNetto: this variable represents the mean net gap between vehicles measured in 1/10 seconds

classVA: indicator of traffic volume which is defined as:

1 - if *qKFZ* >= 1 and *qKFZ* <= 5

2 - if *qKFZ* >= 6 and *qKFZ* <= 10

3 - if *qKFZ* >= 11 and *qKFZ* <= 20

4 - if *qKFZ* >= 21 and *qKFZ* <= 50

5 - if *qKFZ* >= 51 and *qKFZ* <= 100

6 - if *qKFZ* >= 101 and *qKFZ* <= 150

7 - if *qKFZ* >= 151 and *qKFZ* <= 200

8 - if *qKFZ* >= 201

weekday: factor variable specifying weekday of measurement (Monday to Sunday)

vPKW: mean velocity of cars

sectorLane: factor variable specifying all possible combinations of variables SST.Nr (sectors) and DE.Kanal (lanes)

hour: hour of the day

Three different approaches were used for the detection of suspicious measurements and possible detector failures

a) Strategy based on prediction intervals and historical quantiles: In this case possible suspicious measurements are found if the observed value of variable *qKfz* is not within the prediction interval derived in the regression model and the observed value of the number of vehicles does not lie within the 2.5% and 97.5% quantiles of the historical empirical data distribution given a specic sector, lane and hour of the day

b) Strategy based on standardized residuals and historical quantiles: In this case possible suspicious measurements are identified if the absolute values of standardized residuals given of differences between predicted and observed values of the variable *qKfz* are larger than a given threshold and if the observed value of *qKFZ* does not lie within within the 2.5% and 97.5% quantiles of the historical empirical data distribution given a specific sector, lane and hour of the day.

c) Strategy based on robust measures of location and deviance: In this scenario possible measurement errors or suspicious values are highlighted if an outlier is detected based upon median values (as measurements of location) as well as values of the ***Qn***-estimator (as a robust measurement of dispersion) given a specific sector, lane and hour of the day:

$$pnorm(x, me, f * Qn) > 1 - \frac{\alpha}{2}$$

with ***pnorm()*** being the probability function of the normal distribution,

x being an observed value of variable *qKFZ,*

me and ***Qn*** the location and scale estimate for a specific sector, lane and hour of the day based on historical information,

f being a arbitrarily chosen constant and as usual. In the special case a multiplication factor for ***Qn*** was added to gain more flexibility,

α being the significance level.

The test was carried out as follows:

1) the data of the first eight months of 2010 of the section on the motorway A 8 were prepared as input for the first regression model
2) the number of vehicles for each site is predicted given the measured independent variables from all data points available
3) each of the remaining months is treated as newly measured data (September - December)
4) given the model-coefficients obtained in step 2) the number of vehicles for the data-set is predicted
5) a set of measurements and diagnostics is calculated given three different approaches as described above (prediction intervals and historical quantiles, standardized residuals and historical quantiles and robust measures of location and deviance)
6) the data is updated by adding data for an additional month and new prediction intervals are calculated, consequently different estimates for regression coefficients are defined

Based on the results from the calculations for each of the four times that the model has been refitted with additional data, the coefficients of almost all independent variables were significant and also quite stable. The following tables (Table 4 to Table 6) include rates of possibly suspicious values or measurement errors of the three proposed strategies that have been calculated for the months September to December 2011.

Table 4: Share of measurements classified as suspicious and non-suspicious (strategy based on prediction intervals and historical quantiles)

2010	possible suspicious	non-suspicious
Sept.	0.024	0.976
Oct.	0.030	0.970
Nov.	0.019	0.981
Dec.	0.021	0.979

Source: nast consulting, Technical University of Vienna

Table 5: Share of measurements classified as suspicious and non-suspicious (strategy based on standardized residuals and historical quantiles)

2010	possible suspicious	non-suspicious
Sep.	0.011	0.989
Oct.	0.011	0.989
Nov.	0.011	0.989
Dec.	0.011	0.989

Source: nast consulting, Technical University of Vienna

The results from the above tables show that the strategies based on a combination of either standardized model-residuals or prediction intervals together with quantiles of historical data for the dependent variable have classified fewer observations as possibly erroneous data than the results from the third strategy (displayed in the following table) that is solely based on robust measurements of location and scale.

Table 6: Share of measurements classified as suspicious and non-suspicious (strategy based on using robust techniques)

2010	possible suspicious	non-suspicious
Sept.	0.06	0.94
Oct.	0.05	0.95
Nov.	0.05	0.95
Dec.	0.06	0.94

Source: nast consulting, Technical University of Vienna

Furthermore it can be seen on the tables above that the strategy based on standardized residuals in Table 5 leads to the lowest identification rates of possible measurement errors. However, from this information alone it is not possible to state whether any of these methods is superior to another.

In order to select the most appropriate method for QUATRA a comprehensive field testing was carried out. The results of these tests are presented in chapter 8. On a general note it should be stated though that it is indeed quite difficult to compare different strategies since in the data a variable stating observed (and established) measurement errors are missing.

5.3 Conclusions for the freeway tool

Methods for detection of bad detectors from their outputs have been developed based on a superior statistical model approach. Traditional methods are often quite oversimplified, either by looking or modelling univariate information or by using very plain models where only the neighbourhood detector is used to identify malfunctions of detectors.

However, there is much more information included in how detectors behave over time, and that information of one variable is dependent on other covariates. The proposed algorithm performs better than traditional methods and methods used in the past, because historical information on all variables is used that are related with the variable to detect malfunction.

In particular, two methods for the detection of erroneous data were presented. First, robust Mahalanobis distances are used to determine observations that are far away from the main bulk of the data. Secondly, a general regression model is used to identify observations that are unusual far away from their predictions. In combination with a simple second rule based on univariate outlyingness, this gives realistic estimates which observations are suspicious or abnormal. The general model does have - as the name suggests - a broad application area and it is not limited to the currently used data. Data from more than two sectors or more than two lanes can be considered.

To impute missing values or erroneous data points in future follow-up projects, certain models were identified as suitable for further investigations. This would allow much better imputations as traditional methods (like hot-deck, k-nearest neighbour or mean imputation).

The development of a new technology based on mathematical and statistical analysis for automated operation is a substantial improvement in data availability. During the online application QUATRA is evaluating the data automatically during different traffic conditions. The statistical model that has been implemented has also been compared with the results of the local/global/plausibility indicator tests that are also carried out within the QUATRA system. Results of these comparisons are presented in chapter 8.

Once the comparison of predicted and observed numbers of vehicles shows high variations the data record (for example one minute interval) can be flagged as abnormal. In case there are no road works and incidents the detector is likely to report erroneous data. (A future follow-up project could provide an automated matching with the road works database or TMC messages to automatically check if incidents were recorded. If the matching process is successful an automated integration could be started that helps to decide whether the flagged data is accurate or needs to be substituted with estimated data from neighbouring traffic sites or historical traffic data)

The model approach takes dimensional traffic detectors as well as cross-modal key data structures into account and can be calibrated according to the defined quality standards of each client.

The approach is capable for online use and not just the post analysis of historical data that has no impact on the current traffic control. For single detector systems additions or variations are possible. Apart from standardized freeway lane configurations QUATRA can also be applied to special configurations such as road sections with temporary hard shoulder use.

6 Urban Road Tool - Offline Assessment

As described in chapter 2, one of the QUATRA objectives is to develop an urban road tool, having the purpose of quality assessment for traffic data acquired in urban networks.

Within the previous chapter, several possibilities to assess the quality of freeway traffic data have been discussed. Due to certain differences between freeway traffic and urban traffic, it is unfeasible to port the indicators to urban traffic without careful consideration.

On freeways, normally there is equilibrium of vehicles entering and - after passing the dedicated road stretch - leaving it. This closed system allows the identification of malfunctioning detectors on freeways by balancing traffic volumes of consecutive detectors. Freeways are equipped with detectors nearly continuously; even some of the on- and off-ramps are equipped with detection devices.

Contrary to freeway traffic networks the urban traffic networks are open systems, which are equipped comparatively less densely with traffic acquisition infrastructure. There are many roads without traffic data acquisition, which allows (in the context of traffic control systems) vehicles to “disappear” or “appear” due to a huge number of possibilities for vehicles to leave or enter the urban traffic network without being detected. This is why many of the indicators mentioned in chapter 5.1 are not applicable in general. For example, balancing of traffic quantities will only be an appropriate measure at certain road stretches which fulfil the above mentioned requirements.

Statistical data editing methods, e.g. checks and corrections, are necessary to increase the quality of the available data for traffic signal control and traffic management centres in order to provide accurate traffic information in the secondary road network.

Therefore erroneous values in the urban road data need to be localised. It is preferable if this problem can be tackled in an automated manner similar to the freeway data assessment approach. Doing automated micro-editing for small errors is too ambitious as discussed already. From an analysis point of view it is further necessary to detect systematic errors from measurement units or malfunctions in measurement units because systematic errors do affect results of statistical data analysis.

Once the abnormal traffic data is identified the localised data could then be imputed (which is to be covered in a future follow-up project). It is usually not necessary to remove all errors from a data set.

The objective of the following chapters is to develop a comprehensive model to be used to check urban traffic data.

A model, which is able to check the regression and correlation of traffic data derived from consecutive urban detectors, is introduced in chapter 6.1.

Within chapter 6.2, new approaches as well as several indicators used for validating freeway traffic data are checked against their applicability to urban network traffic.

6.1 Statistical model development

Simultaneous to the development of the statistical approach for the freeway data evaluation a corresponding statistical approach has been defined for the urban road data. The data analysis with a statistical model represents an assessment tool the can be used in addition to the local/global/plausibility indicators especially modified for urban road networks.

As stated in the previous chapter regarding the development of the statistical model approach for freeways the detection of outliers is very important in statistical analysis also for urban road environments. Outliers can be considered as atypical observations which deviate from the usual data variability since classical statistical models applied to data including outliers can lead to misleading results. In addition to that, measurement errors also have great influence on aggregates typically published in output tables.

The statistical approach for urban roads needs to consider that there are far more roads in urban traffic networks without traffic data acquisition, which allows (in the context of traffic control systems) vehicles to “disappear” or “appear” without being detected. Consequently the conservation of flow approach can only be applied to a certain extent for urban road networks. Nevertheless the assumption was made during the model development that there is a relatively constant correlation between several detection sites during specific times per day.

The idea of the statistical approach for urban roads is the use of the information of spatial connected detection sites as well as historical data to define pair wise correlations. In order to decide whether given new measurements (offline) of detectors are likely to be faulty verification intervals are defined that allow the assessment of correlations of these sites and the identification of those time periods where the correlation has exceeded the corresponding intervals.

Error detection based on pair wise correlations

In order to detect which traffic site is providing abnormal traffic data pair wise analysis of the correlation of several sites is carried out. In case the correlation results are verified as being within the verification interval the traffic sites are treated providing adequate data. In case the correlation results are verified as being outside of the verification interval both traffic sites are treated providing inadequate data in the first step. In a second step - once all remaining combinations of the sites are calculated - detection sites are identified that have the highest number of mis-matching correlations. The data of all remaining traffic sites is then treated as normal again.

Due to the variability of the variables a data aggregation are carried out since one minute data especially for low-traffic time period can vary quite much. Consequently the data has been aggregated to 5-minute time intervals.

Focused on the data in 5-minute intervals the pair wise correlation are calculated for each potential combination of traffic detection sites based on their spatial connection. The correlations are calculated for each weekday and hour. For example ***n*** correlations for Mondays from 7.00am to 8.00am with ***n*** representing the total number of Mondays in the traffic data set would be calculated.

Next the (α) quantile is being calculated that defines the lower boundary of the verification interval of all correlations. The upper boundary is defined with 1. α can be defined as 1% or 5% for example. A partial test can also be carried out with α instead of $\alpha/2$ due to the fact that a detection site will only have wrong data sets if the current data has a lower correlation than the correlation based on historical data.

The pair wise correlation of each pair of detection sites is validated against the correlation of the corresponding historical values. Consequently the results can be checked against the verification intervals. Each detection site will be issued the total number of correlations that are identified outside of the verification intervals.

Depending on the total number of possible spatial connected detection sites a number of conspicuous combinations per detection sites need to be defined in order to identify the sites potentially providing abnormal data sets. A suitable way is the definition of the percentage β of *p* combinations e.g. 75%.

Those detection sites that show a total of $\beta*(n - 1)$ conspicuous combinations are identified with a high likelihood of abnormal traffic data.

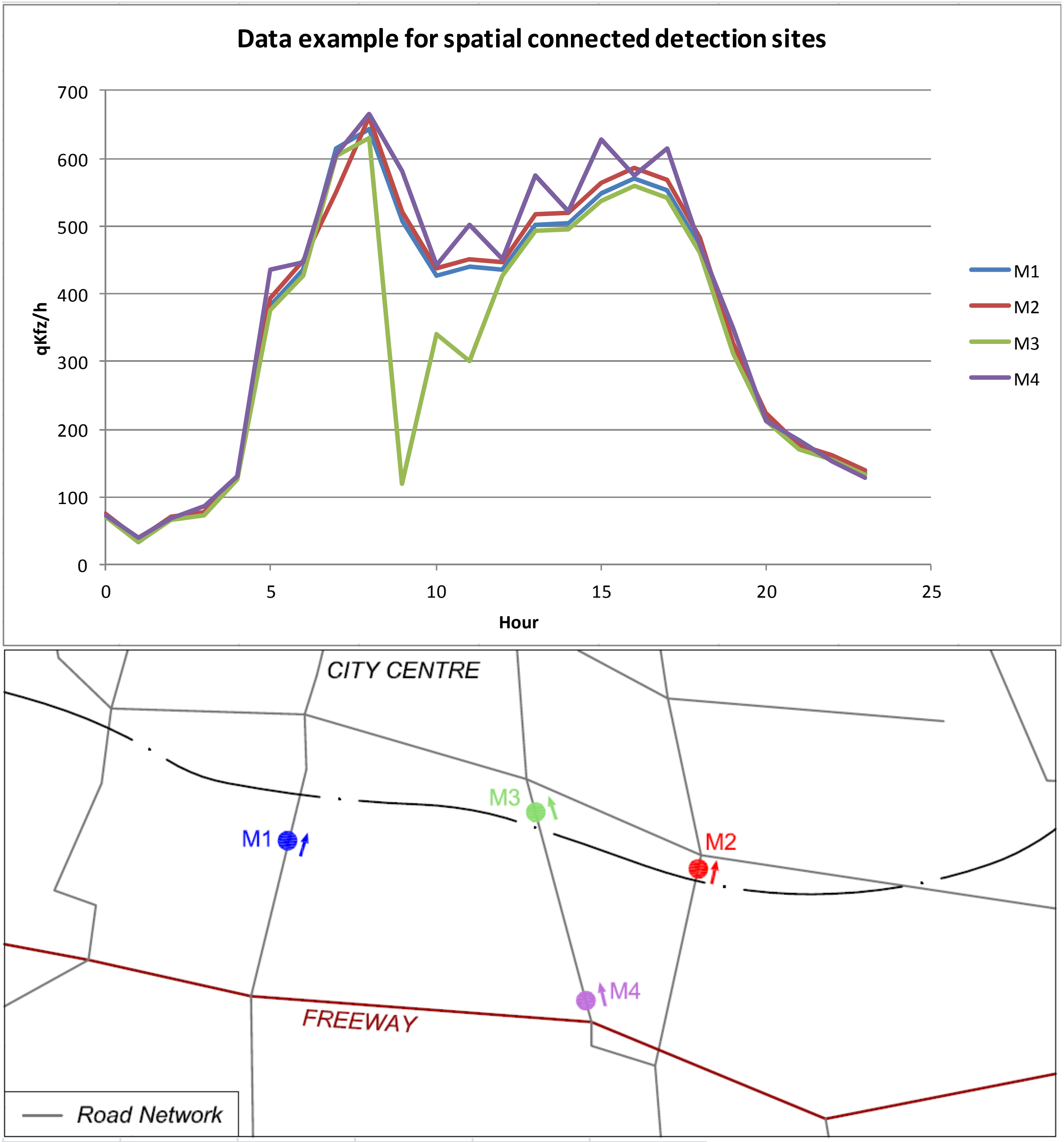
In addition to the defined approach error detection can also be based on multivariate distances. This approach has been discussed within the project team and could be implemented as an additional approach during future follow-up projects.

Practical example with explanation

- ***n*** = 4 spatial connected traffic detection sites (M1, M2, M3 and M4)
- In total there are 6 possible combinations (M1 × M2, M1 × M3, M1 × M4, M2 × M3, M2 × M4, M3 × M4) with each detection site having three options for combinations
- $\beta*(n - 1) = 0,75*3 = 2.25$: detection sites with more than 2 correlation results outside of the corresponding verification interval are treated providing wrong traffic data

Excursion: Application for online use

Based on the defined statistical approach for the offline data evaluation also online data verification can be carried out. Once the data sets have been aggregated to the corresponding offline data interval the pair wise correlations can be calculated for all potential combinations online similar to the offline approach.



pairwise correlation of the spatial connected detection sites					
M1 / M2	M1 / M3	M1 / M4	M2 / M3	M2 / M4	M3 / M4
0,9968	0,9136	0,9932	0,9065	0,9941	0,8876

number of pairwise correlations outside of the verification interval		
M1	1	
M2	1	
M3	3	-> high likelihood providing inaccurate data
M4	1	

Figure 4: Example for a simplified pairwise correlation

Source: nast consulting

6.2 *Evaluation of indicators*

6.2.1 LOTRAN DQ

As stated in chapter 5, LOTRAN DQ is a tool, which has been developed and applied successfully - by now solely in offline freeway applications.

In the following, the well-established indicators used within the QUATRA freeway tool are checked against their applicability to urban traffic use cases (cf. Table 7).

Table 7: Check of the QUATRA freeway indicators against portability for the urban tool

No.	Check	Applicable for Urban Roads	Comments
1	Number or percentage of missing data	Yes	
2	Number or percentage of error messages, specific to each detector	Yes	
3	Number or percentage of data with <u>all entries</u> equal to 0	Yes	It is expected, that in case of no traffic volume the speed is set to n/a.
4	Number or percentage of implausible data-sets	Yes	Is a summary of plausibility checks (cf. Table 8).
5	Balancing of passenger cars (pc) between consecutive detectors	Possibly	Only applicable for stretches with suitable boundary conditions. Possibly without distinction between passenger cars and trucks.
6	Balancing of trucks between consecutive detectors	Possibly	Only applicable for stretches with suitable boundary conditions. Possibly without distinction between passenger cars and trucks.
7	Plausibility Checks	Partly	Criteria derived from MARZ and FGSV working group 3.5.20 (cf. Table 8).

Source: TRANSVER

The plausibility checks in Table 8 are used by the QUATRA freeway tool in order to check the following data:

- Traffic Volume (vehicle (veh)): Qveh [Kfz/h]
- Traffic Volume (trucks): Qtrucks [Kfz/h]
- Traffic Volume (pc): Qpc [Kfz/h]
- Speed (pc): Vpc [km/h]
- Speed (veh): Vveh [km/h]
- Speed (truck): Vtruck [km/h]
- Occupancy: O [%]

The plausibility checks are to be applied to minute-by-minute traffic data of single detectors or cross sections in order to detect implausible data sets.

Within Table 8 the following notations are used:

- Smoothed value: s
- Net time gap: t
- Time interval: T
- Threshold value: Th
- Minimum value: min
- Maximum value: max
- Exit ramp/location: exit
- Entry ramp/location: entry
- Left lane: left
- Right lane: right

Table 8: Plausibility checks of the QUATRA freeway indicators against portability for the urban tool (1)

No.	Plausibility Check [1)]	Applicable for Urban Roads	Comments
m1	Qveh = 0 → (Qtrucks = 0 AND Qpc = 0)	Yes	If vehicles are classified.
m2	Qveh – Qtruck = 0 → (Qpc = 0 AND Vpc = n/a)	Yes	If vehicles are classified, if V is available.
m3	Qtruck = 0 → Vtruck = n/a	Yes	If vehicles are classified, if V is available.
m4	Qpc = 0 → Vpc = n/a	Yes	If vehicles are classified, if V is available
m5	Qveh ≥ Qtruck	Yes	If vehicles are classified
m6	Qveh – Qtruck > 0 → 0 < Vpc	Yes	If vehicles are classified, if V is available.
m7	Qveh > 0 → 0 < Vveh	Yes	If V is available.
m8	Qtruck > 0 → 0 < Vtruck	Yes	If vehicles are classified, if V is available.
m9	0 < t < T	Yes	If t is available.
m10	Qveh = 0 → 0 < Vs,veh(t) = Vs,veh(t-T)	Yes	If smoothing is calculated.
m11	Vveh > VTh → O < OTh	Yes	If V and O are available.
m12	Qveh,min ≤ Qveh ≤ Qveh,max	Yes	
m13	Qpc,min ≤ Qpc ≤ Qpc,max	Yes	If vehicles are classified.
m14	Qtruck,min ≤ Qtruck ≤ Qtruck,max	Yes	If vehicles are classified.
m15	Vveh,min ≤ Vveh ≤ Vveh,max	Yes	If V is available.
m16	Vtruck,min ≤ Vtruck ≤ Vtruck,max	Yes	If vehicles are classified, if V is available.

[1)] Note: The notation "a → b" stands for "is term a correct, then term b must be true", else an error is existent (and NOT: from this it follows that b is correct!)!

Source: TRANSVER

Table 9: Plausibility checks of the QUATRA freeway indicators against portability for the urban tool (2)

No.	Plausibility Check [1)]	Applicable for Urban Roads	Comments
m17	Vpc,min ≤ Vpc ≤ Vpc,max	Yes	If vehicles are classified, if V is available.
m18	Vs,veh,min ≤ Vs,veh ≤ Vs,veh,max	Yes	If smoothing is calculated.
m19	Omin ≤ O ≤ Omax	Yes	If O is available.
m20	Vpc,left lane > Vpc,right lane	No	
m21	Vexit < Vexit,Th	No	
m22	Qtruck,right > Qtruck,left	No	

[1)] Note: The notation "a → b" stands for "is term a correct, then term b must be true", else an error is existent (and NOT: from this it follows that b is correct!)!

Source: TRANSVER

The tables above show that several plausibility checks and indicators have been identified which are suitable to be applied to the urban road tool. A summary of the indicators used within the QUATRA urban road tool can be found in chapter 6.3.

6.2.2 Implausible Vehicle Length

Typical errors of inductive loops are “hanging on” (the measured occupancy is overestimated whilst the acquired traffic volume seems to be plausible) and “pulse breakup”, which is characterized by a short interruption of the registered pulse of a vehicle. An indicator for identifying these errors is vehicle length (BUSCH ET AL., 2006).

The logic to detect these typical errors by checking vehicle lengths is as follows:

- *IF Length > Threshold_max THEN Length = <IMPLAUSIBLE>*

  NB:
  The identified type of error is called “hanging on”

- *IF Length < Threshold_min AND IF Pulse = interrupted THEN Length = <IMPLAUSIBLE>*

  NB:
  The identified type of error is called “Pulse breakup”

A prerequisite for applying these plausibility checks is the availability of vehicle lengths. This information usually is available within single vehicle data-sets. An application is solely possible for inductive loops. The minimum and maximum thresholds need to be determined. Furthermore it is expected, that the functioning of this checks will be influenced by the number of vehicles crossing the detector diagonally. This approach could not be integrated into QUATRA since the required single vehicles detection data cannot be provided by road operators and authorities.

6.2.3 Stagnant Detector

Another common error is called “stagnant detector”: By mistake over a longer period of time the same value is reported by a detector repeatedly.

In order to detect this kind of error, TONNDORF (2002) developed the following logic, which originally has been applied to freeway traffic data:

IF Value x(i) = const for y time intervals THEN Value x(i+y) = <IMPLAUSIBLE>

It is needed to define the length of time (y), which is regarded to be plausible for constant values, which is depending on the kind of data checked. In principle, this plausibility check is applicable to various sets of data. This indicator is also applicable within the freeway model.

6.2.4 Verification of urban traffic data with mobile generated data

The following approach was developed in the course of the QUATRA project. The idea is to check locally acquired traffic data against mobile generated data to identify abnormal traffic conditions such as incidents. Mobile generated information is e. g. Floating Car Data (FCD, e. g. from ADAC or other providers) or data derived from navigation devices (e. g. provided by TomTom).

Mobile information needs to be aggregated over time and space in order to be comparable to the data acquired by the local detectors.

On the one hand the benefit of this approach is that it uses an independent source of information for validation. On the other hand, a sufficient amount of objective mobile generated data has to be available, such that it is not affected by subjective driving behavior of single drivers.

Mobile generated information is not available within the project QUATRA. Therefore this approach could not be integrated into QUATRA but could be used in future follow-up projects.

6.2.5 Verification of urban traffic data with traffic signals

Traffic signals greatly impact urban traffic flow. Based on this relation within the project QUATRA the following indicators were defined:

Depending on the location of the traffic detector in relation to (the stop line in front of) a traffic signal, it can be expected that detectors near the stop line will be occupied by approximately 100 % within a certain period of time. Based on the principles of the creation of waiting queues, in case of two consecutive detectors in front of a stop line it is expected that the mean occupancy of the detector located closer to the stop line is greater than the occupancy of the detector having a greater distance to the stop line. This check depends on the temporal availability of information on occupancy.

Additionally, in comparison speed acquired closer to the stop line is expected to be faster decreasing towards zero – and occupancy growing vice versa. On the other hand, the vehicles in the front of the queue are able to accelerate sooner than the vehicles at the spatial end of a queue. This is why speeds are expected to raise from zero at a sooner point in time than at a detector station with a greater distance to the stop line – and that way is the occupancy expected to behave. This check depends on the temporal availability of information (less than 30 seconds to every second).

This approach was developed for the QUATRA assessment but could not be verified. A precise characterization of the position of every detector (and the relation to other detectors) is a prerequisite for obtaining valuable results. Another important factor is the data acquisition time interval, which shall be lowest possible.

Due to limited funding data from the traffic signals could not be imported within the project QUATRA. Therefore this approach could not be integrated into QUATRA but could be used in future follow-up projects.

6.2.6 Evaluation of travel time-data

A well-established measure to detect speeding vehicles and to acquire information on traffic states is so called "Section Control". Cameras operate as sets of two or more devices installed along a fixed route. They are mostly using an Automatic Number Plate Recognition (ANPR) system to record a vehicle's front number plate at each fixed camera site by using Optical Character Recognition (OCR) on images taken by cameras. As a result the time to travel between these two points can be obtained.

Dedicated measures in order to detect erroneous travel times are to applied to this kind of data. SPANGLER (2009) documented the following errors:

- Number plate is not captured at all (error in system technology)
- Number plate is captured falsely (error in system technology)
- Error in cryptographic technique (error in system technology)
- Number plate is captured repeatedly (error in system technology)
- Spatial variation of acquisition (error in system technology)
- Wrong determination of time stamp (error in system technology)
- Correctly recognized vehicle is not representative for collective (error in traffic engineering)

For each of the mentioned errors, solutions were provided (SPANGLER, 2009). Errors in system technology are mainly to be solved by a careful planning of system set-up. In order to deal with the error in traffic engineering, SPANGLER (2009) proposes a serial filtering technique for travel time data. This approach is defined by an analysis of travel times regarding consecutive vehicles. Implausible high differences in travel times get eliminated.

In spite of showing positive evaluation results (SPANGLER, 2009), the filtering approach will not get implemented to the urban road tool within QUATRA as there are no travel times available for validation. Due to the special characteristics of stretch-wise travel time data vs. locally acquired traffic data, the filtering technique is not qualified for being transferred to other areas of application.

6.3 Conceptual design of the urban road tool

The previous chapters showed that an extensive analysis has been carried out in order to decide which of the indicators are to be applied to the urban road traffic data assessment tool. Finally it was proven that there plenty of indicators were worth to be applied to urban network traffic data. Many of them were derived from the QUATRA freeway tool.

Unlike freeway applications, there is a great dependency on the location of detectors and the availability of traffic data of different kind.

The indicators can be structured in modules as follows:

- Check with data of same type from same detector (STSD)
- Check with data of same type from different detector (STDD)
- Check with data of different type from different detector (DTDD)

The following indicators and checks have been chosen to be incorporated into the QUATRA urban tool.

Table 10: Urban traffic data to be incorporated into the QUATRA urban road tool

Description	**Validated data**			**Module**		
Indicator	Speed	Occupancy	Volume	STSD	STDD	DTDD
Statistical model	X	X	X	X	X	X
LOTRAN DQ (6.2.1)	X	X	X	X	X	
Vehicle Length (6.2.2)		X		X		
Stagnant Detector (6.2.3)	X	X	X	X		
Verification with traffic signals (6.2.5)	X	X			X	

Source: nast consulting and TRANSVER

The following Figure 5 shows the structure of QUATRA urban tool.

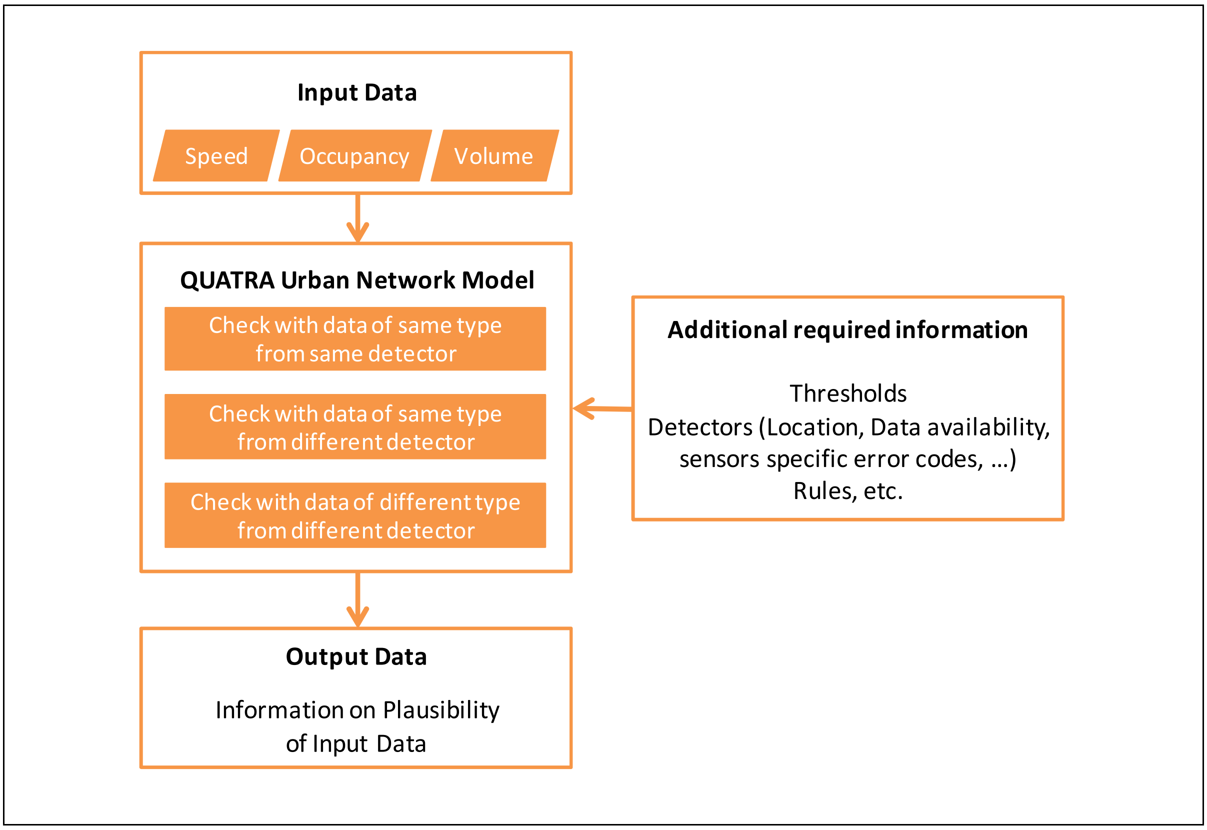


Figure 5: Overview QUATRA Urban road tool

Source: TRANSVER

6.4 Conclusion and outlook

The approach chosen for the development of QUATRA's urban road tool can be summarized as follows:

- Adaption of QUATRA freeway indicators
- Development of novel indicators
- Development of the statistical approach

The indicators and checks chosen to be incorporated into the urban road tool are capable of checking occupancy, speed and volume. Their applicability depends on the availability of traffic data of different kind. Often experiences with their application in practice are already made, but additionally novel approaches have been developed, which could be validated further in future follow-up projects (refer to chapter 6.1).

Chapter 6.2 also contained approaches which were rated to be helpful in order to assess data quality, but they are covering type of data, which are not available within the project QUATRA, e. g. travel time. Rated to be an appropriate means in order to detect malfunctioning detectors is the comparison of locally acquired traffic data with mobile generated data. Several (mostly scientific) approaches have been developed, but they have been implemented into practice seldom by now, as the availability of FCD in particular is still limited. As this source of information was not available within the project QUATRA due to limited funding these approaches have not been incorporated into QUATRA at this stage.

Besides that, the indicators and plausibility checks have to be adapted to the available data within each use case. As the QUATRA objective are detectors used for traffic control purposes, many of the checks and indicators are able to deal with this requirement – although this might be the lower share of detectors used in urban vicinity – compared to those detectors used for traffic signal actuation.

The measures that have been identified in order to maximize the benefits gained from plausibility checks are rated to be needed but were beyond the scope of the project QUATRA and thus only described in brief for future follow-up projects. The preparation of support in order to facilitate and improve the process of decision-making with a benchmarking-concept (like described by Grosanic et al. in 2012 – for details refer to the deliverable ENR_Deliverable_State-of-the-art) would be an optimal further extension of the QUATRA system.

In order to maximize the benefits gained from plausibility checks operators and traffic engineers must be supported in interpreting and reacting to the results of the plausibility checks. Facilitating and improving this decision might become the goals of a benchmarking concept (future follow-up project) for urban traffic data within traffic control systems by comparing a given performance with the known best performance.

Then, possible impacts of failures are to be analyzed, such that the operators and traffic engineers are supported in their day-to-day operations, complementing the help provided e. g. by technical bulletins. Examples of support offered by the proposed benchmarking system are the additional proposal of several standardized reactions to a detected failure as well as assistance for the staff in interpreting the severity of erroneous (urban and freeway) data.

7 Software Development

Main objective of the work package WP4 "Software Development" was the development and implementation of a concept for a software system platform and the corresponding service for data processing and data quality analysis. The two different tools (online-freeway-tool and urban-offline-tool) provide all the information that is required for manual and automated processing and analysis of traffic data.

The platform is able to process data from different streams and formats during online and offline applications. Furthermore corresponding layouts have been set up for operating the manual and automated processing and analysis of the traffic data. As part of the software concept already existing software modules from the software products LOTRAN-DQ (TRANSVER GMBH) have been used, modified and amended to cater for the needs of the QUATRA objectives.

Algorithms and concepts have been developed to create a software platform that is capable for the online application (for example for freeway control centres).

7.1.1 Functionality

Rather than inventing a complete new software tool the functions, data interfaces and visualisation tools of the existing software LOTRAN-DQ have been taken into account for the software tool development of QUATRA. The following functionalities are provided which were based on LOTRAN-DQ and further improved for QUATRA:

- Automatic sequence control that starts the import of data and the calculation of quality indicators at defined times (e. g. each night, each hour or each minute)
- Import of infrastructure data (e. g. number of lanes, ID and location of detectors) as basis for the import of traffic data and the calculation and visualization of quality indicators
- Import of traffic data from a data archive
- Management of parameters for calculation of quality indicators (e. g. thresholds)
- Calculation of quality indicators and statistical indicators for defined intervals (e.g. 1 hour, 1 minute)
- Saving of calculated quality indicators at a data base
- Selection of infrastructure (e.g. stretches, detectors) and period for visualization of quality indicators
- Visualization of infrastructure for freeway sections
- Visualisation of quality indicators and statistical indicators in tables and diagrams
- Configuration of diagrams (e.g. labels, scaling)
- Print of selected tables and diagrams for selected infrastructure
- Export of selected tables (as csv-files) and diagrams (as images) for selected infra-structure
- Help

During several workshops with road authorities in Austria and Germany the following new functionalities have been identified, cost estimated and prioritised[c] as part of the QUATRA software development process. Some of these functionalities have already been implemented in QUATRA while other items could be integrated due to limited funding. The following functionalities could be integrated in future follow-up projects:

- Calculation and Visualization of new quality indicators:
    - New indicator for identification of hanging detectors (delivering the same plausible dataset for a defined period)
    - Logical interconnection of different indicators for plausibility checks
    - Automatic selection of periods without missing data for calculation of “global indicators” (accounting)
    - Automatic interpretation of “global indicators” (accounting)
- Specific calculation parameters for different types of infrastructure (e.g. main road, ramp)
- Online calculation of quality indicators (for traffic state estimation and control purposes)
- Marking of hours with implausible data (that this data will not be used for statistical purposes)
- Interface to bug tracking system to get information about detectors and known errors and to generate tickets if errors have been identified by indicators
- Interface to road works management system to get information about closed lanes etc. (reason for no counting)
- Display of detector information (e.g. type, manufacturer, model)
- Entry of flags and comments (e.g. for detectors with known problems)
- List of indicators that can be filtered and sorted
- Visualization of problems (indicators > thresholds) per detector and interval (coloured matrix)
- Point out changes compared to the last period
- Generation of monthly quality reports for management purposes
- Comparison of detector date with data sources, if available (e.g. toll data, floating car data, mobile phone data)

[c] Not all identified new functionality can be realized in this project

7.1.2 System Architecture

To provide the listed functionalities of the QUATRA system the following components of LOTRAN-DQ are used in order to supply a stable and already tested system:

- LOTRAN-DQ Server
- LOTRAN-DQ Graphical User Interface (Client)
- LOTRAN-DQ Database (for results)

The LOTRAN-DQ server is being started by the automatic sequence control at defined times. It imports the infrastructure data from an infrastructure file (XML-format) by using the infrastructure data interface and the traffic data from a traffic data archive by using the traffic data interface. The LOTRAN-DQ DB interface reads the calculation parameters from the results database. Thereafter the data quality indicators are calculated and written in the results database by using the LOTRAN-DQ DB interface.

The results database provides data to the graphical user interface based upon the selections made for infrastructure, period and indicators. The visualization is provided in tables and diagrams, which can be printed by using the print manager or exported in different formats by using the export manager. The infrastructure visualization uses the infrastructure file and its respective interface. The graphical interface furthermore provides the possibility to set the global calculation parameters in the parameter manager. The help module assists the users with the handling of the software.

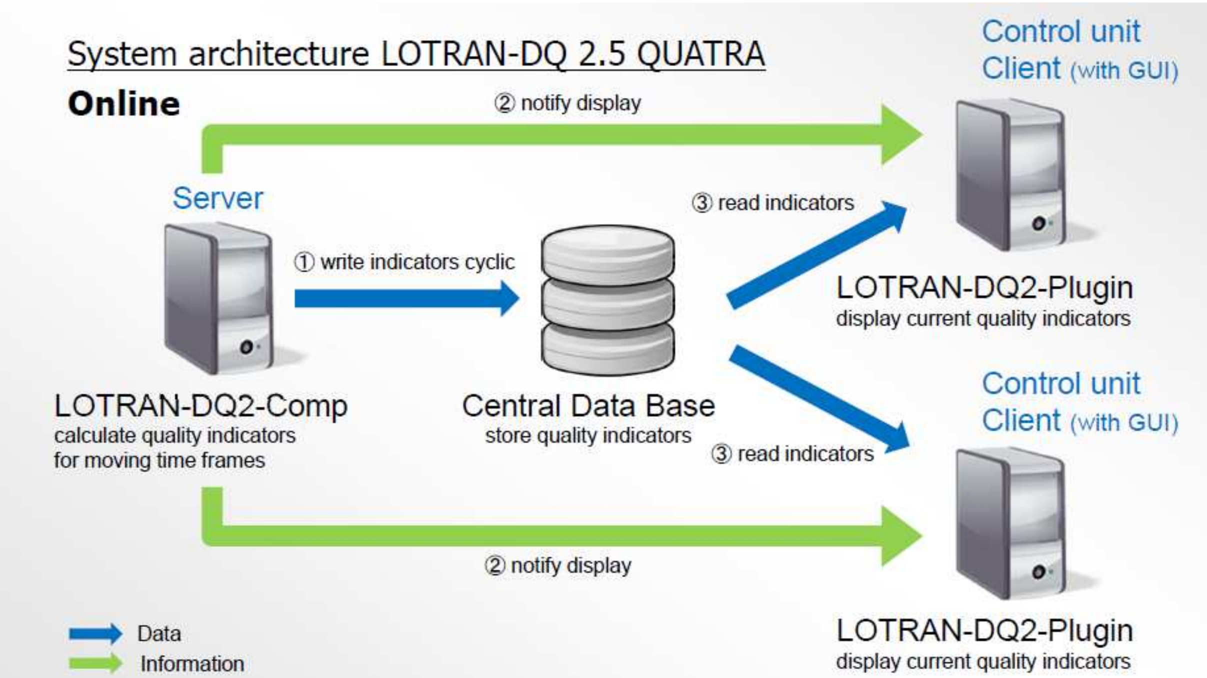


Figure 6: System Architecture QUATRA – online for the freeways tool

Source: TRANSVER

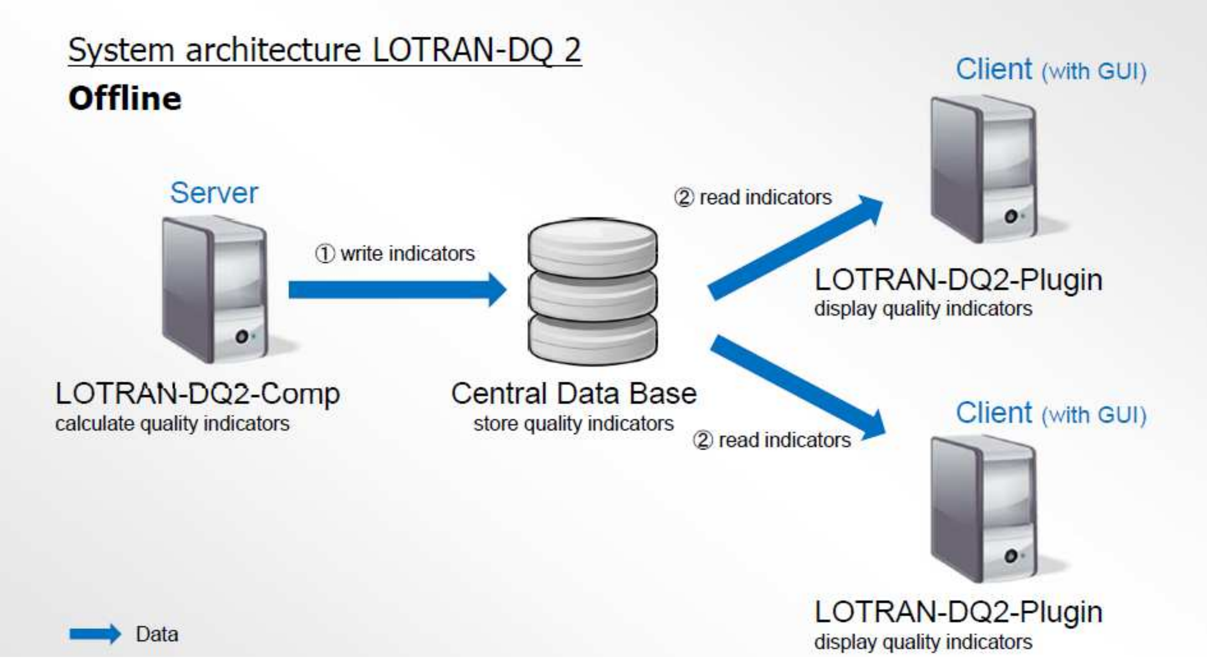


Figure 7: System Architecture QUATRA – offline for the urban roads tool

Source: TRANSVER

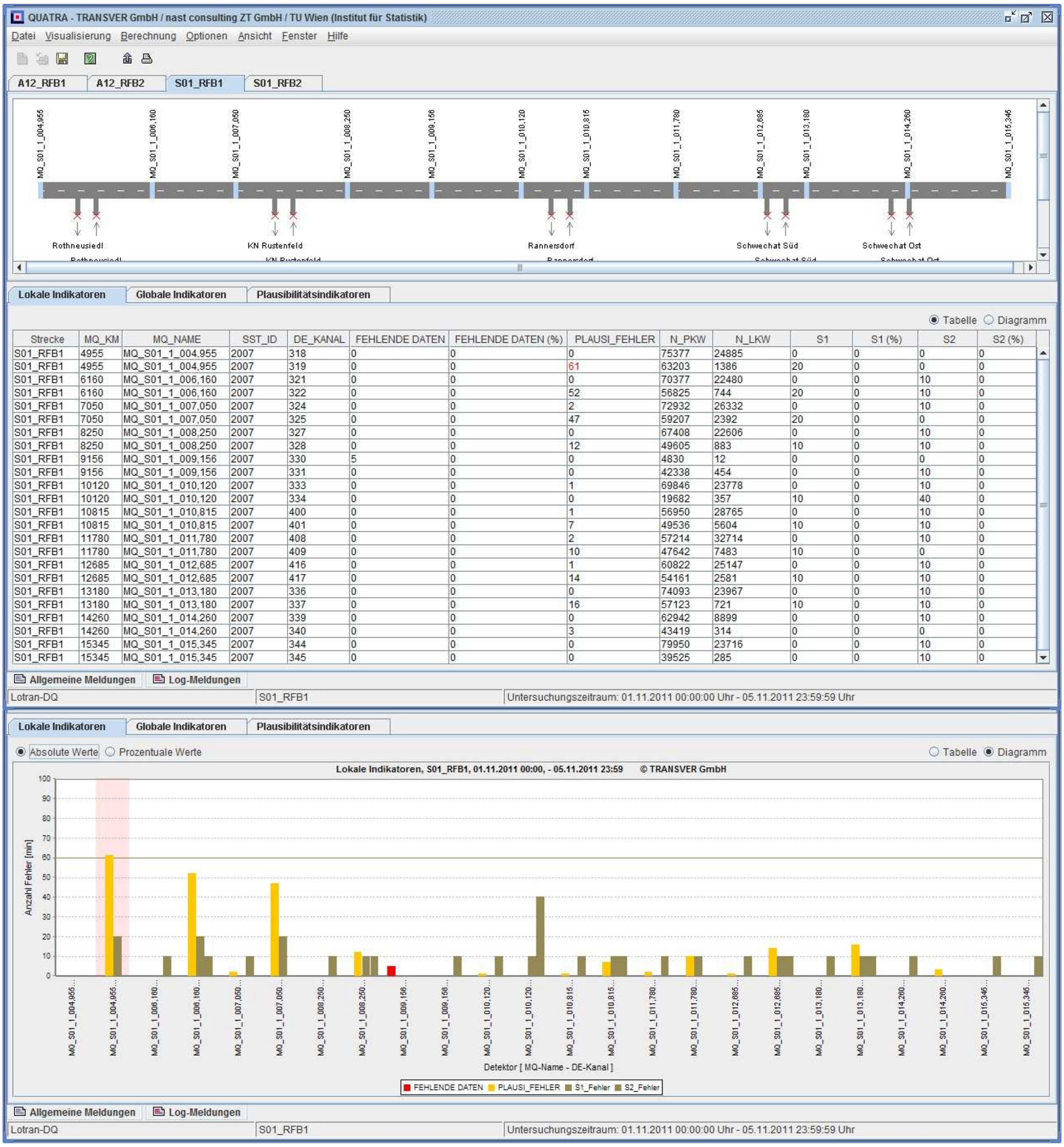
7.1.3 Visualization (Graphical User Interface - GUI)

The visualisation concept consists of one register for each section that provides the following components:

- Visualization of infrastructure (number of lanes, entries and exits, measurement cross sections)
- One register for each of the three types of indicators (local, global, plausibility)
- Provision of a table view in Figure 8 and diagram view in Figure 9

If a data set (at the table) or a detector (at the visualization of the infrastructure) is selected the corresponding detector or data set will be highlighted in blue.

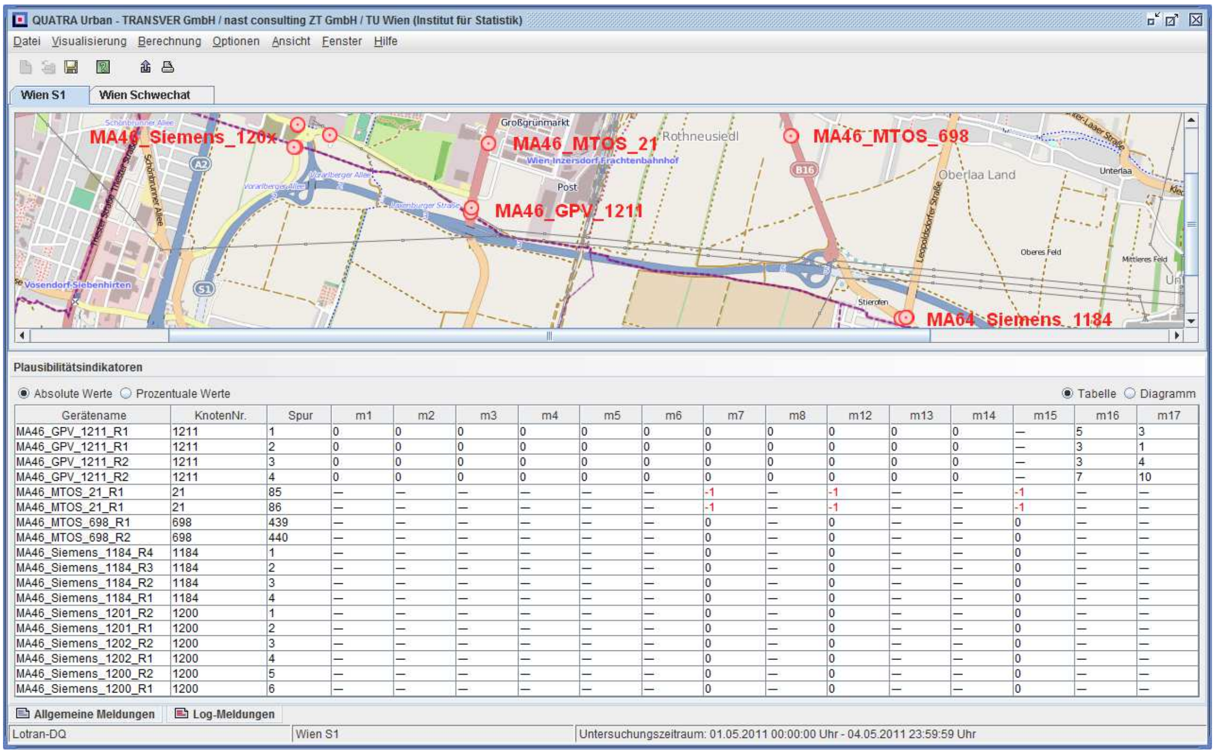
If an indicator value is outside of the visualization thresholds then this value/detector is highlighted in red at the table and diagram. The visualization thresholds can be individually set for each client (while the calculation thresholds are global).



Strecke	MQ_KM	MQ_NAME	SST_ID	DE_KANAL	FEHLENDE DATEN	FEHLENDE DATEN (%)	PLAUSI_FEHLER	N_PKW	N_LKW	S1	S1 (%)	S2	S2 (%)
S01_RFB1	4955	MQ_S01_1_004,955	2007	318	0	0	0	75377	24885	0	0	0	0
S01_RFB1	4955	MQ_S01_1_004,955	2007	319	0	0	61	63203	1386	20	0	0	0
S01_RFB1	6160	MQ_S01_1_006,160	2007	321	0	0	0	70377	22480	0	0	10	0
S01_RFB1	6160	MQ_S01_1_006,160	2007	322	0	0	52	56825	744	20	0	10	0
S01_RFB1	7050	MQ_S01_1_007,050	2007	324	0	0	2	72932	26332	0	0	10	0
S01_RFB1	7050	MQ_S01_1_007,050	2007	325	0	0	47	59207	2392	20	0	0	0
S01_RFB1	8250	MQ_S01_1_008,250	2007	327	0	0	0	67408	22606	0	0	10	0
S01_RFB1	8250	MQ_S01_1_008,250	2007	328	0	0	12	49605	883	10	0	10	0
S01_RFB1	9156	MQ_S01_1_009,156	2007	330	5	0	0	4830	12	0	0	0	0
S01_RFB1	9156	MQ_S01_1_009,156	2007	331	0	0	0	42338	454	0	0	10	0
S01_RFB1	10120	MQ_S01_1_010,120	2007	333	0	0	1	69846	23778	0	0	10	0
S01_RFB1	10120	MQ_S01_1_010,120	2007	334	0	0	0	19682	357	10	0	40	0
S01_RFB1	10815	MQ_S01_1_010,815	2007	400	0	0	1	56950	28765	0	0	10	0
S01_RFB1	10815	MQ_S01_1_010,815	2007	401	0	0	7	49536	5604	10	0	10	0
S01_RFB1	11780	MQ_S01_1_011,780	2007	408	0	0	2	57214	32714	0	0	10	0
S01_RFB1	11780	MQ_S01_1_011,780	2007	409	0	0	10	47642	7483	10	0	0	0
S01_RFB1	12685	MQ_S01_1_012,685	2007	416	0	0	1	60822	25147	0	0	10	0
S01_RFB1	12685	MQ_S01_1_012,685	2007	417	0	0	14	54161	2581	10	0	10	0
S01_RFB1	13180	MQ_S01_1_013,180	2007	336	0	0	0	74093	23967	0	0	10	0
S01_RFB1	13180	MQ_S01_1_013,180	2007	337	0	0	16	57123	721	10	0	10	0
S01_RFB1	14260	MQ_S01_1_014,260	2007	339	0	0	0	62942	8899	0	0	10	0
S01_RFB1	14260	MQ_S01_1_014,260	2007	340	0	0	3	43419	314	0	0	0	0
S01_RFB1	15345	MQ_S01_1_015,345	2007	344	0	0	0	79950	23716	0	0	10	0
S01_RFB1	15345	MQ_S01_1_015,345	2007	345	0	0	0	39525	285	0	0	10	0

Figure 8: GUI – Example of visualization of local indicators including the statistical indicators S1 and S2 for freeways

Source: TRANSVER



Gerätename	KnotenNr.	Spur	m1	m2	m3	m4	m5	m6	m7	m8	m12	m13	m14	m15	m16	m17
MA46_GPV_1211_R1	1211	1	0	0	0	0	0	0	0	0	0	0	0	—	5	3
MA46_GPV_1211_R1	1211	2	0	0	0	0	0	0	0	0	0	0	0	—	3	1
MA46_GPV_1211_R2	1211	3	0	0	0	0	0	0	0	0	0	0	0	—	3	4
MA46_GPV_1211_R2	1211	4	0	0	0	0	0	0	0	0	0	0	0	—	7	10
MA46_MTOS_21_R1	21	85	—	—	—	—	—	—	-1	—	-1	—	—	-1	—	—
MA46_MTOS_21_R1	21	86	—	—	—	—	—	—	-1	—	-1	—	—	-1	—	—
MA46_MTOS_698_R1	698	439	—	—	—	—	—	—	0	—	0	—	—	0	—	—
MA46_MTOS_698_R2	698	440	—	—	—	—	—	—	0	—	0	—	—	0	—	—
MA46_Siemens_1184_R4	1184	1	—	—	—	—	—	—	0	—	0	—	—	0	—	—
MA46_Siemens_1184_R3	1184	2	—	—	—	—	—	—	0	—	0	—	—	0	—	—
MA46_Siemens_1184_R2	1184	3	—	—	—	—	—	—	0	—	0	—	—	0	—	—
MA46_Siemens_1184_R1	1184	4	—	—	—	—	—	—	0	—	0	—	—	0	—	—
MA46_Siemens_1201_R2	1200	1	—	—	—	—	—	—	0	—	0	—	—	0	—	—
MA46_Siemens_1201_R1	1200	2	—	—	—	—	—	—	0	—	0	—	—	0	—	—
MA46_Siemens_1202_R2	1200	3	—	—	—	—	—	—	0	—	0	—	—	0	—	—
MA46_Siemens_1202_R1	1200	4	—	—	—	—	—	—	0	—	0	—	—	0	—	—
MA46_Siemens_1200_R2	1200	5	—	—	—	—	—	—	0	—	0	—	—	0	—	—
MA46_Siemens_1200_R1	1200	6	—	—	—	—	—	—	0	—	0	—	—	0	—	—

Figure 9: GUI – Example of visualization of plausibility indicators for urban roads

Source: TRANSVER

8 Field Trial and Evaluation

Based on the results of the field trial the software parameters of QUATRA have already been modified and can further be changed based on requirements deriving from individual clients. This iterative process ensures a high customer satisfaction of the software product.

8.1 Freeway tool

The statistical model has been tested and evaluated with traffic data from freeways in Austria and Germany. At first the pattern matching was done with historical traffic data from a whole year. Based on the found patterns the statistical indicators were calculated for a test period of one month.

For the evaluation of the statistical model the alerts of the statistical indicators were visualized and compared with the corresponding traffic data (see Figure 10 and Figure 11).

The analysed samples show anomalies in traffic counting (flow) in case an alert of the indicator (high reliability) is recorded.

In the opposite case there is also an alert of the indicators when there is also an anomaly in traffic counting that are identified through operators and data analyses prior to testing the data with the model (high significance).

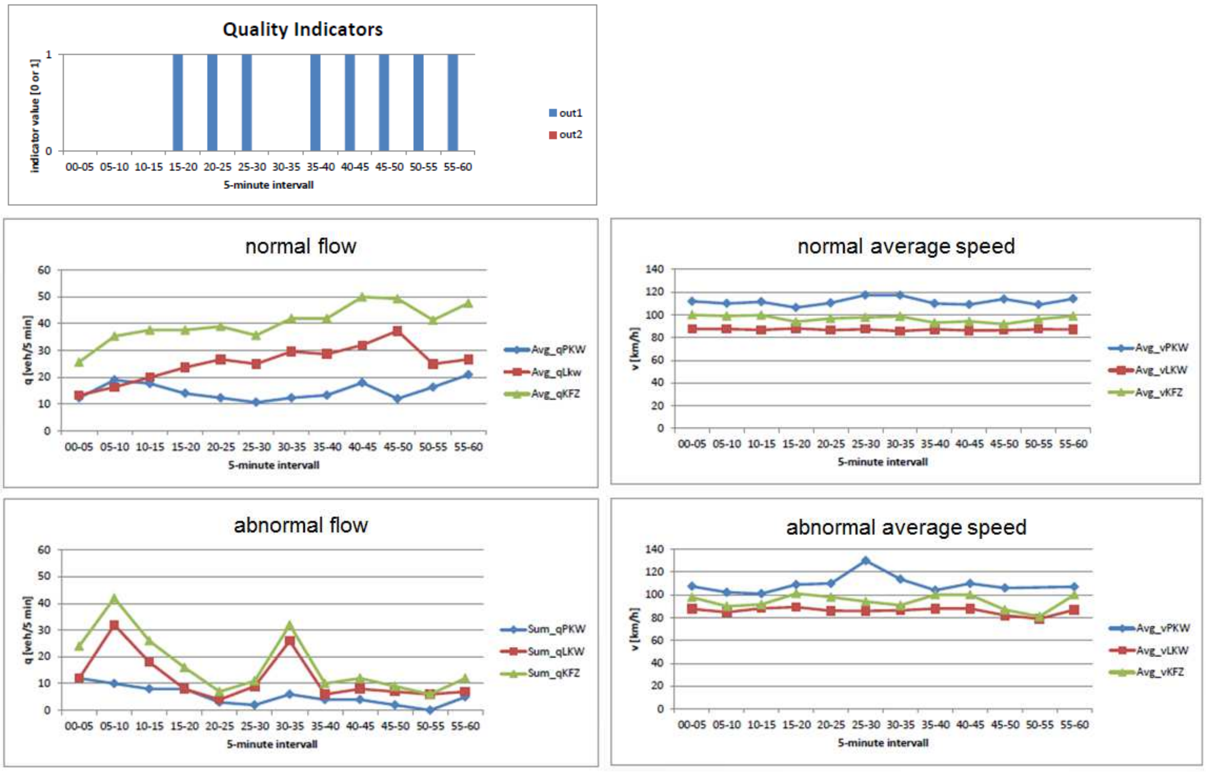


Figure 10: Examples for relevance checks (freeway tool)

(upper row left picture) identification of abnormal condition by statistical indicators out1 (S1) and out2 (S2) (middle row left picture) normal traffic flow data, (middle row right picture) normal average speed data, (lower row left picture) abnormal LKW/KFZ traffic flow data, (lower row right picture) abnormal average PKW speed data

Source: TRANSVER

Although the statistical model has only been trained on the evaluation of KFZ volumes also LKW volumes can be assessed to identify abnormal traffic conditions. Such an example can be seen in the figure above.

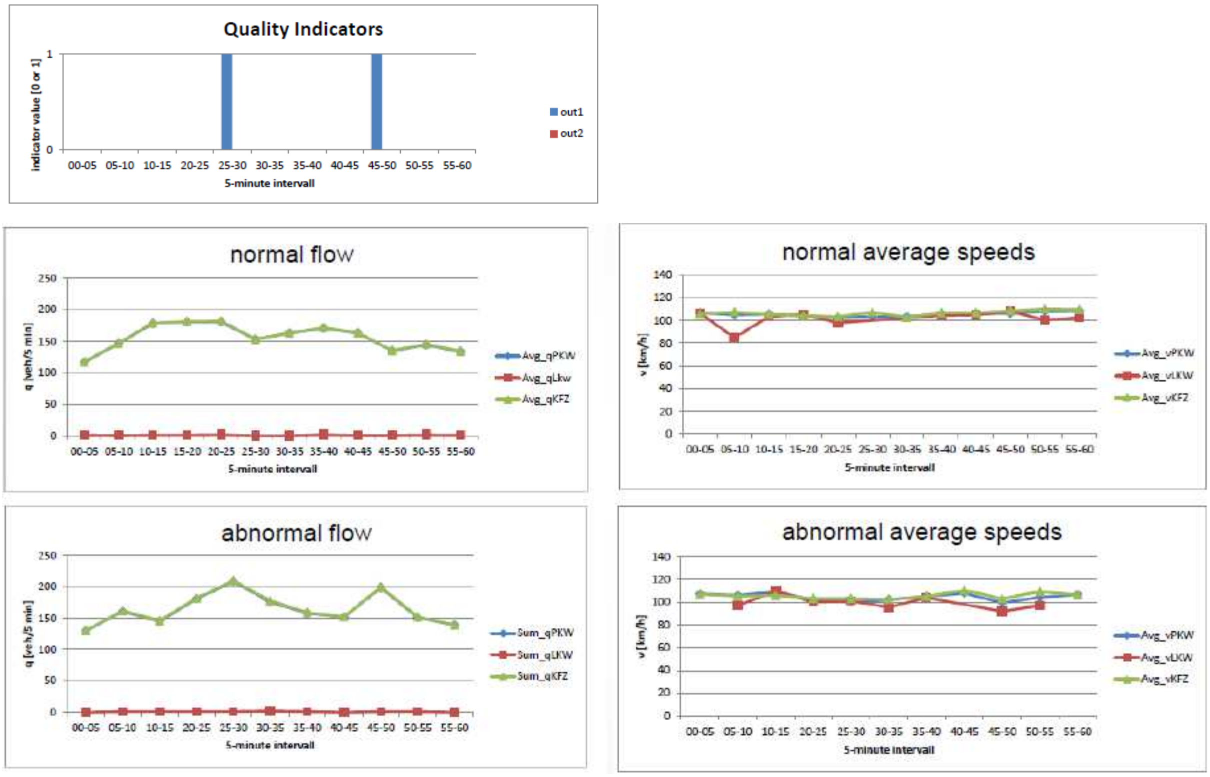


Figure 11: Examples for significance checks (freeway tool)

(upper row left picture) identification of abnormal condition by statistical indicators out1 (S1) and out2 (S2) (middle row left picture) normal traffic flow data, (middle row right picture) normal average speed data, (lower row left picture) abnormal KFZ traffic flow data, (lower row right picture) abnormal average KFZ speed data

Source: TRANSVER

In order to reduce the number of alerts during times with very low traffic (e. g. at night) the triggers can be modified. Because the manual interpretation of the existing Global Indicators (conservation of flow) is sometimes very difficult, the statistical model is optimized for the automatic detection of anomalies in traffic counting. Therefore anomalies of speeds are not yet reliably detected. The detection of abnormal speed measurements can also be improved by re-configuration of the statistical model.

The evaluation has shown that the statistical indicators are suitable for the freeway tool and can be used to identify abnormal traffic data situations. Consequently the reliability of the freeway traffic data can be improved.

8.2 Urban road tool

The statistical model has been evaluated with urban road traffic data from the city of Vienna.

The high frequency of pair wise correlation results outside of the corresponding verification interval (→ check_indicators ≥ 1) lead to a high level of indicator noise. An example can be seen in in **Figure 12**. Consequently the level of suspicious correlations needs to be increased in order to reduce number of false reports.

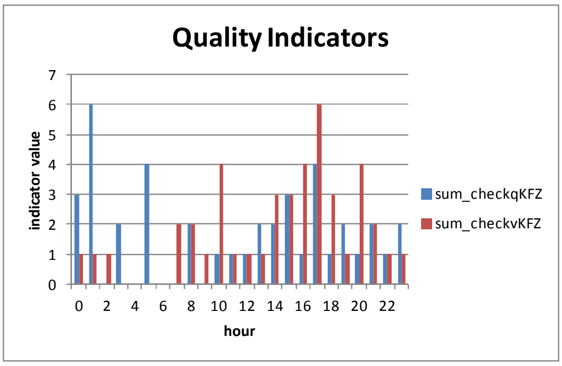


Figure 12: Noise floor of quality indicators (urban road tool)

Source: TRANSVER

By filtering the indicator data and assuming that at least six or more correlation results outside of the corresponding verification interval is an adequate notification for abnormal traffic data in a five minute time interval, it is possible to reduce or even eliminate the noise floor This can be seen in Figure 13.

By analysing the traffic data for the time intervals with at least six or more correlation results outside of the corresponding verification interval numerous examples with abnormal traffic data could be found. An example for such an abnormal traffic condition can also be seen in Figure 13.

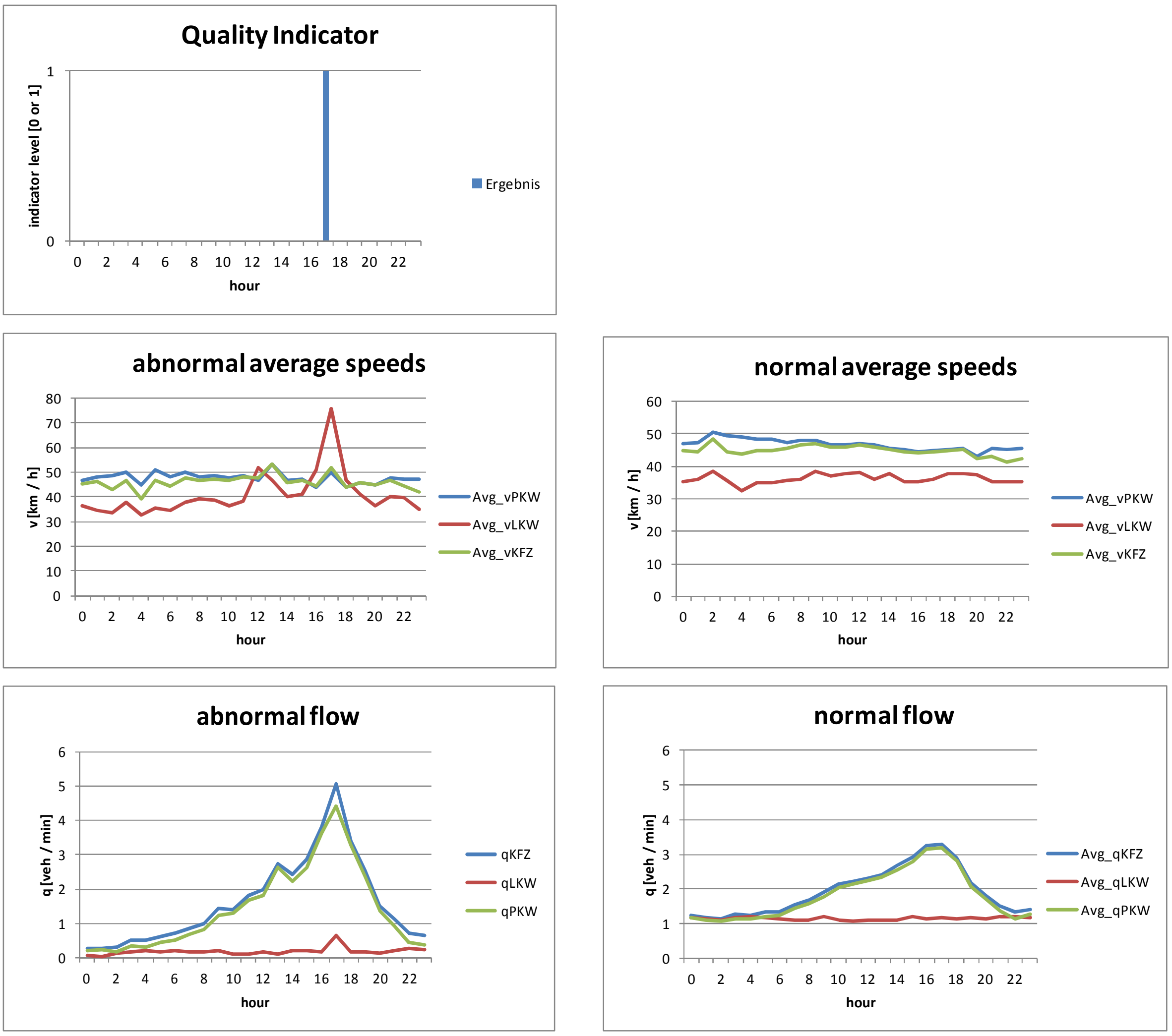


Figure 13: Example for relevance check (urban road tool)

(upper row left picture) identification of abnormal condition by statistical indicator "check" (middle row left picture) abnormal average KFZ speed data, (middle row right picture) normal average speed data, (lower row left picture) abnormal KFZ traffic flow data, (lower row right picture) normal traffic flow data

Source: TRANSVER

An extensive evaluation of the analysis of abnormal traffic data conditions has been carried out. We would like to point out that the data quality of the test sites and provided data periods in Vienna were very high. Neither the statistical model, nor the other urban road tool indicators (including manual data analysis) could find a lot of examples with abnormal traffic data.

The evaluation has shown that the statistical indicators are suitable for the urban road tool and can be used to identify abnormal traffic data situations. Consequently the reliability of the traffic data in urban road networks can be improved.

9 Business Concept

The QUATRA software solution provides various methods for the traffic data analysis and assists during the definition of requirements arising from different detector systems, taking into account different data gathering structures. Consequently the major target group for the QUATRA distribution are road operators, authorities and management companies for road networks worldwide.

The technical and scientific innovations are a comprehensive quality management of data from traditional traffic detection devices as a basis for traffic control, traffic information and traffic management for freeways and for urban networks. The data quality of current and dynamic online data as well as the historical data of the database is automatically checked.

The following contents are significant innovations:

- Comprehensive assessment of large amount traffic data including statistical analysis and numerous plausibility indicators
- Capability of online traffic data evaluation for numerous applications
- Automatic management of data recording
- Data assessment of merged traffic data and various traffic data sources (various interfaces, software can be easily adapted/connected to other systems)
- Professional user interface with clear visualizations of indicators and highlighting of problems

The application of statistical methods makes the provision of different amounts of data with different data quality possible. Due to a data analysis the quality differences can be made comparable and are made available for telematics applications.

The innovative content compared to the current State-of-the-art of data validation is the integration of mathematical and statistical tests for the procedures of evaluation of complex data structures in transport.

Since the system is adaptable for the use of different existing traffic data collection systems a major advantage of the test system is its potential for transnational online and offline applications.

The sales strategy is based on personal contacts with relevant traffic data providers, road authorities and traffic management institutions. Due to preliminary investigations of the consortium partners, the system certainly appears to be feasible for area-wide traffic data acquisition in the freeway network, country roads and urban roads. The distribution and advertisement of QUATRA has already started by existing personal contacts with relevant stakeholders. Both project partners have excellent national and international contacts to secure these markets.

Furthermore information brochures and participations at symposiums will access further representatives of these authorities. Different symposiums will be attended to such as the TRA 2014 (a paper has already been submitted regarding the QUATRA system).

Detailed considerations of multiple options for the potential economic recovery have been discussed between the project partners during the project phase and will be discussed with each potential client.

The business concept is based on providing basic free versions of the QUATRA system to relevant parties.

The revenue will be created out of the corresponding installation and maintenance contracts that need to be negotiated with each single party. Due to the external circumstance of each country having its own data format and configuration most of the work that needs to be carried out prior to the launch of QUATRA is setting up the data interfaces and calibrating the statistical model.

Furthermore quality standards will need to be identified for each client and the different detector systems. These standards will also need to be defined and validated for road sections in accordance with each application system (freeways and urban road environments).

In addition adaptions of existing ITS infrastructure (e.g. traffic control) and consulting services can be expected. A turnover of approximately € 650.000 on the freeway, federal and rural road network in Austria and Germany is to be expected within the first five years. In Germany a total revenue of € 220.000 for the freeway network tool and € 230.000 for the rural road network tool is expected. In Austria a total revenue of € 90.000 for the freeway network tool and € 110.000 for the rural road network tool is expected).

Furthermore in the recent EU countries a turnover of approximately € 350.000 is expected and € 350.000 in the southern and other EU countries.

For the Arabian and Asiatic region approximately a turnover of € 750.000 is expected. In the following years, apart from R&D financed future follow-up projects an on-going expansion is planned in order to extend the range of testing and error sourcing.

10 Conclusions

Traffic data is the basis for most intelligent traffic systems such as line control systems on freeways or adaptive signal control systems in urban areas. The quality of these systems can be only as good as the quality of the traffic data used.

Up to now a daily manual (offline) or even permanent automatic (online) assessment of the data quality was scarcely possible due to the multiplicity of detectors, the large quantity of data and missing reliable quality indicators. The few existing software tools for quality assessment of traffic data provide only basic indicators (e. g. missing data) or difficult to interpret indicators (e. g. ratio of counting from adjacent measurement cross sections) which require a lot of time and expert knowledge for analysis.

The superior traffic data assessment system QUATRA is equipped with new, easy to interpret statistical indicators for quality assessment of traffic data from freeways (online) and urban road networks (offline). The system has been fully developed, successfully tested and implemented in a professional software tool. This software tool enables e.g. operators in traffic management centres to check the data quality on the basis of different graphic visualisations and quality indicators, and if necessary to initiate measures for the improvement of the data quality. Furthermore, the statistical indicators are capable to be used online for automatic quality assessment of incoming traffic data e.g. in traffic control systems.

QUATRA will provide major benefits for road operators and authorities. Individual efforts will mainly be needed for installation and maintenance work (e. g. user specific data interfaces), configuration (e. g. locations of detectors), calibration of the statistical models (e. g. parameter settings), user training, support and maintenance.

During the workshops with road operators a lot of additional requirements and wishes came up (e. g. automatic interpretation of indicators, fusion of indicators, additional visualisations). This could also be integrated in future follow-up project phases. A further idea is to develop a procedure for automatic parameter optimisation and configuration of the statistical model (e. g. to find spatial connected traffic detectors automatically).

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