Quality Management Methods for Real-Time Traffic Information

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Abstract

Quality of real-time traffic messaging is mostly defined in terms of quantitative or technical characteristics that relate almost exclusively to the technical broadcasting and availability of the information. This pays insufficient attention to the traffic messages’ content and conformity with the real situation experienced by drivers. Accuracy of content however is a decisive factor in customer satisfaction and acceptance. In this paper, four different methods for quality management of real-time traffic information are explained and compared in detail: QKZ-Method, QFCD-Method, QBENCH-Method and ASDA/FOTO Travel Time Method.

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1. Introduction

Most drivers are familiar and have experiences, both positive and negative, with radio traffic information messages. Radio is regarded as having been in previous years the only source of up-to-date traffic information. However, modern communication and information technology as well as ever-increasing traffic problems have led to major changes in the traffic information market. Alongside the official and primarily public funded providers, privately owned traffic and mobility services are now established. In addition to handling audio messages delivered by radio, modern vehicles and mobile phones now possess alternative means of processing up-to-date traffic information. The information is first transmitted to the vehicle or smart phone in encoded form via a data channel often referred to as TMC (Traffic Message Channel) or TPEG (Transport Protocol Expert Group) and is then automatically processed for dynamic navigation. The real-time information can also be displayed as a text message, an icon or a color-coded map, which allows drivers the freedom to decide for

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themselves the information’s relevancy and its effect on their choice of route. Irrespective of the type of traffic information used, the actual benefit obtained depends on the information’s quality, which is a decisive factor in determining the economic potential of a traffic information service.

Quality, however, is currently defined predominantly in terms of quantitative or technical characteristics that relate almost exclusively to the broadcasting of the information. Although this ensures minimum standards for the supply of traffic information to the customer in terms of time and space, e.g. field strength, coverage as a proportion of the overall road network etc., it does not pay enough attention to the traffic messages’ content and conformity with the actual situation experienced by the individual. Accuracy of content however is a decisive factor in customer satisfaction and acceptance. Given these problems, this paper presents different methods for determining quality criteria, the aim being to assist independent and objective assessment of real-time traffic information.

In general a total of six typical error types can be defined (see figure 1). Given are a time-space traffic representation (contour plot) and a traffic message, which is valid for a certain period of time and a certain stretch of a freeway. The two most serious errors from the customer's point of view are those of type 1 and 2. Here, the customer receives either no information (1) or incorrect information (2) about congestion. However, the traffic information message may also contain incorrect temporal information (errors 3 and 4), or it may be incorrect in terms of its spatial context (errors 5 and 6). Allocation to error categories allows detailed analysis of the causes of errors and of the associated degradation of quality.

Fig. 1. The six typical error types of traffic information.

2. Quality management methods for real-time traffic information

In the following four different methods for determining the quality of traffic information are described. Two methods are mainly based on stationary measurements (QKZ-method and ASDA/FOTO Travel Time Method), while the two other methods are based on vehicle trajectory (floating car) data.

2.1. QKZ-Method

The basic idea is the superimposition of the reconstructed traffic situation (mostly based on stationary detector data) and the TMC/TPEG-messages. Two indices $QKZ_1$ and $QKZ_2$ are defined to describe quality. This method, which is derived from the area of signal detection theory, offers the possibility of continuously measuring the quality with which traffic information is reported and comparing traffic information services statistically objectively.

The goal is to reconstruct the approximate traffic state experienced by the driver. Empirical traffic data form the basis of this reconstruction. The transitions between different traffic conditions are represented in terms of
their time-space relationship. Based on measurements of speed and/or travel times, means are first calculated for homogeneous sections of the freeway in order to produce a smoothing effect within the data. Next, these measurements are ordered into a matrix according to their spatial and temporal sequence. An adaptive smoothing to calculate the time-space velocity field is used. Finally, the cells of the time/distance matrix are colored. Assessment of the traffic information messages’ objective quality is based on reconstructing the actual traffic situation. The goal is to simulate as realistically as possible the actual situation experienced by the driver. Numerical traffic data, which should, if possible, be gathered independently of the data used to generate the traffic information, form the basis of the actual traffic situation’s reproduction. There are various ways of doing this, e.g. numerical interpolation methods or filtering methods (cp. Kesting). The anisotropic interpolation between the elements or colors allows for an intuitive representation of the actual traffic situation for a selected time on a given section of road.

In the reconstructed representation of the traffic situation with its distance and time axes, it is possible to identify traffic conditions (see Figure 2a). Congestion (E) – defined as driving below 50 km/h – can be represented as a surface. Comparison of the reconstructed actual traffic situation with the message area (A) forms the basis for calculating the quality of the individual process for producing traffic information messages and the overall output. The quality indices for the overall process’ outcome, namely the traffic information message in the vehicle, are derived below.

Fig. 2. (a) Quality indices QKZ₁ and QKZ₂, (b) QKZ₂-QKZ₁ diagram with quality grades.

The congestion event E and the report area A can be unambiguously compared with each other, and the quality of traffic messages can be objectively assessed. The intersection area of E and A is referred to as D. Here the congestion event and the traffic report match exactly in terms of both space and time. Two indices QKZ₁ and QKZ₂ are obtained from the relations of the different areas for event E, the report A and their intersection D.

Quality index one (QKZ₁), the detection rate, describes the degree to which the traffic message concur with the actual congestion event and is calculated from the ratio of the area of the intersection (between the congestion and the message) to the area of the congestion event.

\[ QKZ₁ = \frac{D}{E} \]

Quality index two (QKZ₂), the false alarm rate, describes the proportion of the traffic message that is not relevant to the congestion, i.e. the proportion of the area of the message that lies outside the congestion area. This index is calculated by subtracting the ratio of the intersection to the area of the message from 1.

\[ QKZ₂ = 1 - \left( \frac{D}{A} \right) \]
The two indices are solid means of assessing the quality level of traffic information on the basis of objective data. When quality index one is high and quality index two is low, the quality of reporting is high. The values of quality index one and quality index two can each vary from 0 to 1 or from 0% to 100%. To make the two-dimensional description of quality easier to interpret, categorization from A (very good) to F (poor) in a similar manner to the HCM system can be implemented. To do this, the two indices are entered on a QKZ2-QKZ1 diagram. The proposed quality grades from A to F are likewise entered and an unambiguous classification is obtained for each message (see figure 2b). The quality grades A, B, C, D, E and F appear as concentric ring segments. The quality grading and its extreme values are explained by distinguishing between different cases (see figure 2b). The QKZ-method is implemented in several federal information service platforms, e.g. at ASFINAG in Austria, but also at private service providers such as TOMTOM.

2.2. QFCD-Method

The traffic reality is reconstructed continuously in time and space from a driver perspective using data from probe vehicles (GPS trajectory). The real traffic situation is compared with the relevant, broadcasted TMC/TPEG-traffic information. As traffic information has spatial and temporal extend, it can be added into the time-space diagram. Two quality indices describe the quality and a quality diagram is used to quantify the achieved, measured traffic information quality.

Based on the individual speed of the vehicle, a mean speed per road segment, i.e. TMC segment, is calculated. This generates a time-space segment which for the time t and the road segment x an average speed can be assigned to. This segment is color-coded in the next step, e.g. green for average speeds > 60 km/h („free flow“) and red for average speeds < 60 km/h („congested flow“). It is important to note that by this method only time-space road segments and corresponding traffic information that have been covered by a test car can be evaluated. So, only where a test car has recorded its speed, the quality of the traffic information can be evaluated. If the sample size is sufficient, a continuous time-space speed field could be generated by interpolating between the trajectories of the single test cars (contour map).

The customer’s individual way of driving has impact on the reconstruction of the traffic situation (basis for evaluation) of the traffic information. In case of congestion the driver is not able to choose his speed freely. His driving behaviour is determined by the collective of vehicles. The traffic information, thus, can be evaluated as objective truth. Only driving at extremely low speed in free traffic flow would be critical as from this misinterpretation a traffic congestion could be derived, resulting in a wrong evaluation. This, however, can easily be avoided by well-defined instructions for the test driver such as “go with the flow” and/or “overtake as many vehicles as have overtaken you”.

By means of this method the individual sub processes and their contribution to overall quality can be defined as well as the overall quality of the system. In the following, however, the main focus will be on the overall quality of the system, as the customer only notices this quality in his user device. The traffic messages recorded by the navigation system will be superimposed with the vehicle trajectory-based x-t reconstructed traffic state.

Quality assessment of traffic information is motivated by the comparison of traffic states experienced by the driver with the obtained traffic information at the time and location of a (potential) route decision. Based on this information (or non-information) the driver of the user equipment would have automatically chosen an alternative route. As all relevant indicators are collected in the test vehicle and the comparison depicts the driver/customer perception the QFCD method is called a “microscopic, driver/customer-oriented quality evaluation method”.

The quality of traffic information can be characterized in terms of two quality indices QFCD1 und QFCD2 (see figure 3a) defined by

$$QFCD_1 = \frac{D}{E},$$
$QFCD_2 = 1 - \frac{D}{A},$

where $E$ is the time-space area of congestion in the x-t diagram. $A$ is the x-t area covered with driver-observed traffic messages and $D$ is the intersection of $E$ and $A$. $QFCD_1$ (detection rate) represents the degree of how much the real, experienced congestion event is covered by the traffic message. It is calculated from the ratio of the area of the intersection (between congestion and message) to the area of the congestion event. $QFCD_2$ (false alarm rate) represents the ratio of the non-congestion relevant traffic message, i.e. which area of the message is not covered by the congestion event. It is calculated from the relation between intersection to the area of the message.

Fig. 3. (a) Superimposition of reconstructed real traffic states (from a single vehicle trajectory) and traffic messages. Calculation of quality indices $QFCD_1$ und $QFCD_2$. (b) Quality diagram with an example (mean value (point)). Variation of $QFCD_{1/2}$ and standard result (cross) in the left lower corner of the rectangle.

A statement about one of these indices alone has little meaning without reference to the other index. For example by a shift of threshold values for reporting, it is easy for a provider to increase the sensitivity $QFCD_1$ at the expense of a higher false-alarm rate $QFCD_2$. However, taken as a pair, the two indices provide an objective mean of assessing the quality level of traffic information on a data sample.

Traffic state reconstruction provides a reference representing an imperfect but useful approximation to the ideal of “ground truth”, which would require the true space-time trajectories of all vehicles in the sample. Such a procedure would be much too complex and costly. This is why the method proposed describes a reasonable approach if the samples are taken representatively. Significant results can be achieved by an intelligent field trial design when applying the QFCD method. The number of test cars necessary for the trial can for example be determined by historical traffic messages within the region and a modified Chi-Square test.

Figure 3b shows the so-called QFCD quality diagram. $QFCD_1$ on the vertical axis und $QFCD_2$ on the horizontal axis. Both indices can vary from 0% to 100%. The traffic information quality, corresponding to the “level of service” concept of the Highway Capacity Manual, is separated into three different regions: A (very good), B (satisfactory) and C (sufficient/ inadequate).

2.3. QBENCH-Method

This method was developed with the purpose of estimating the quality of level-of-service oriented, color coded information (cp. Lux). Vehicle trajectories are used to determine the traffic state per road segment. The
real situation is compared with the displayed level-of-service and a loss function is calculated for the entire trip of
a vehicle. The result is one single quality measure.

The QBENCH approach is based on links and their costs as it is the case in routing algorithms. Most routing
algorithms use travel time and expected time of arrival as their criteria, what makes the quality of traffic
information highly important. Let \( t_{ff} \) be the fixed minimum cost (minimum travel time) of each link depending
on road class and speed limit. In case of traffic congestion, the cost of the link is raised. This raise and thus the
traverse time \( t_{rep} \) is given by the real-time traffic information. For each test vehicle, the ideal benefit is recorded
for each link as the difference between minimum travel time \( t_{ff} \) and ground truth speed \( v_{gt} \). QBENCH is the
comparison of the test vehicle's and the provider's benefits:

\[
QBENCH = \frac{\sum_{all} B_{real}}{\sum_{all} B_{ideal}}
\]

Several adjustments have to be made. Considering every exact provider report of freely flowing traffic would
lead to biased results. Therefore, only events with a ground truth or reported speed lower than a congestion
threshold \( t_{ct} \) are taken into account. The ideal benefit is the number of seconds of delay reported by the reference
vehicle scaled by an impact factor \( \varphi \):

\[
B_{ideal} = \begin{cases} 
0, & v_{gt} \leq t_{ct} \\
(\varphi - 1)(t_{gt} - t_{ff}), & v_{gt} > t_{ct} 
\end{cases}
\]

The real benefit applies to the traffic information and is calculated based on a loss function that is different for
over- and understating the congestion:

\[
B_{loss} = \begin{cases} 
(\varphi - 1)(v_{gt} - t_{rep}), & t_{rep} < v_{gt} \\
0, & t_{rep} = v_{gt} \\
t_{rep} - v_{gt}, & t_{rep} > v_{gt} 
\end{cases}
\]

A tolerance area is defined around the ground truth speed, where the loss of benefit is disregarded. To avoid
discontinuities outside the tolerance area, the definitions of the tolerance borders use a traverse time \( t_{lower} \) and
\( t_{upper} \) respectively instead of the ground truth speed \( v_{gt} \):

\[
B_{lower} = B_{ideal} - (\varphi - 1)(v_{gt} - t_{lower})
\]

\[
B_{upper} = B_{ideal} - (t_{upper} - t_{gt})
\]

\[
B_{real} = \begin{cases} 
\frac{B_{ideal}}{B_{lower}} (B_{ideal} - B_{loss}), & t_{rep} < v_{gt} \\
B_{ideal}, & t_{rep} = v_{gt} \\
(B_{ideal} - B_{loss}) + (B_{ideal} - B_{upper}), & t_{rep} > v_{gt} 
\end{cases}
\]
In case of reported free flowing traffic, the real benefit is set to zero. The same quality index might have two different reasons: underestimating congestion, which leads to unexpected raises in travel time or overstating congestion, which eventually causes even higher travel times due to detours. Clearly, the effects depend on road classes. The impact factor $\varphi$ aims at adjusting this by reducing the amount of loss in benefit for specific road classes.

As travel times do not behave linearly, it is advisable to reduce the maximum loss and gain that a single event may generate. This is done by the capped value

$$B_{\text{cap}} = \lambda \times (\varphi - 1) \times \left(\frac{100}{\delta} - 1\right) \times t_{ff},$$

where $\delta$ is the percentage of free flow speed for a segment below which it is considered congested and $\lambda$ is the number of correctly reported congestion necessary to compensate for missing the worst case congestion. Furthermore, $B_{\text{ideal}}$ should be bounded below by a minimum congestion time.

2.4. ASDA/FOTO Travel Time Method

Travel time is one of the most interesting information for drivers. An ASDA/FOTO model and a TMC-/TPEG-information based travel time comparison is the core of this quality method (cp. Rehborn). ASDA/FOTO is based on Kerner's three-phase traffic theory (cp. Kerner 2004, 2009) and automatically reconstructs the real state of traffic congestion by using loop detector data as well as other data sources. In addition, a database tool was realized, which compares the travel times of different traffic service information sources to the real travel times measured by ASDA/FOTO.

Kerner proposed a classification of traffic state on highways into a free flow traffic phase (F) and two traffic phases for congested traffic of lower speed: synchronized flow (S) and wide moving jam (J). Since the two congested traffic phases might be similar in vehicle speed, a spatial-temporal analysis of congested traffic states is important for the consistency of the classification. The ASDA and FOTO models track "synchronized flow" and "wide moving jam" objects in time and space and thus reconstruct congested traffic patterns (see figure 4a). Those models are independent of parameters and also deliver information on traffic states between detectors. Besides stationary detector data, the integration of advanced data sources like floating car data or phone probes is possible. Figure 4b shows some results of ASDA/FOTO models from Northern Bavaria.

In order to define and measure the quality of RDS/TMC messages, those have to be transformed into travel times. This is done under the assumption that the event code has an average speed, e.g. "stationary traffic" with an average speed of 15 km/h. In figure 5a, the red line represents the real travel time ("Ground truth") on a road segment. The "stairs" visualize the travel times based on different types of TMC messages. The quality of RDS/TMC messages is as higher as closer the RDS/TMC curves are to the "Ground Truth" curve. Figure 5b shows the delays of RDS/TMC messages in comparison to real congestion.

3. Comparison

In general, there are two main model categories (see table 1). The first macroscopic model category (QKZ-method and ASDA/FOTO travel time method) is mainly based on stationary detectors. These models can produce results for freeways which have traffic sensors. Once installed and calibrated, they can produce quality estimates for each day, each direction etc. Therefore, you receive statistically robust results but only for (equipped) parts of the network. Both methods are very intuitive and rely on a spatial-temporal reconstruction of the real traffic situation. By superimposing the traffic information one could also see additional types of errors (see figure 1), such as temporal delay of the real-time information or spatial mismatches. One disadvantage of the ASDA/FOTO travel time method is, that it uses an “artificial” travel time comparison, which a driver would not
experience in reality, since it is instantaneously calculated. The major disadvantage of the QKZ-method is, that even small mismatches do count the same than huge spatial-temporal mismatches of reality and message. A problem of both methods is, that usually the input data are already used for generating the messages and thus are not an independent sample of the real situation.

The second microscopic model category (QFCD method and QBENCH method) is based on vehicle trajectory data. This means that one has to drive and record x and t continuously, e.g. via GPS track recording. The reconstruction of the reality thus relies on the driver’s behavior. The driver has to behave “like the typical traffic situation”. In cases of congested traffic this is no big problem since his driving behavior is mainly influenced by the surrounding traffic. In situations of free flow or in phase transitions between traffic states this is much more difficult. But the situations of phase transitions are often the most interesting ones for real-time traffic information customers and also the most difficult ones to model for the service provider generating real-time
traffic information. Usually we only have an independent sample produced with a limited number of vehicles for evaluating the quality of traffic information. Because of the high cost of test driving this sample is typically very small. Thus these models “only” produce a statistically not robust snapshot of the real traffic situations and are highly dependent on the driver behavior. Advantage of these models is that they can be used ubiquitously and produce quality results for the entire road network. The produced output is not as intuitive as for the macroscopic models. For the QFCD method lots of real-time traffic information can not be evaluated and has to be eliminated in a preprocess, because only where we have a trajectory we can calculate the quality index. The QBENCH value itself might be hard to interpret and many different adjustments have to be conducted prior to the calculation.

Table 1. Comparison of QKZ-, QFCD-, QBENCH- and ASDA/FOTO-method

| QM method      | Input data            | Output          | Spatial-temporal coverage                           |
|----------------|-----------------------|-----------------|-----------------------------------------------------|
| QKZ            | Stationary detector   | Quality index   | Long-time, equipped freeway network                 |
| QFCD           | Vehicle trajectory    | Quality index   | Single snapshot of entire road network               |
| QBENCH         | Vehicle trajectory    | Loss function   | Single snapshot of entire road network               |
| ASDA/FOTO      | Stationary detector   | Travel Time comparison | Long-time, equipped network                        |

4. Conclusion and Outlook

Four different methods for quality management of traffic information have been described and compared within this paper. They can be categorized into macroscopic and microscopic models. Each has its strengths and weaknesses.

In the future, models should be developed which can be used for the entire road network but also are statistically representative. The idea could be an independent fleet of vehicles, statistically representative used only for quality checks, but not for the generating process of information. This fleet should allow a continuous and ubiquitous reconstruction of the traffic. Either ASDA/FOTO or the anisotropic interpolation for freeways and additional urban models, like the cell transmission model or UTA (urban traffic analysis) could be used to reconstruct the real traffic situation. A superimposition of the real-time traffic information (either messages or color-coded maps) should be carried out and afterwards a spatial-temporal detection and false alarm rate could be calculated.

Also further quality measures like travel time comparisons, average temporal information delay and average spatial mismatch should be calculated and analyzed since they might help to further improve the overall quality of real-time traffic information.

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