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Time-dependent service quality of network sections

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Abstract

The traffic state in road networks and the corresponding quality of traffic flow is significantly influenced not only by the travel demand but also by road works, accidents or weather conditions. Current guidelines do not yet consider these dynamic effects. In order to overcome these shortcomings, the paper presents the results of a research project which investigates travel times of a complete year for network sections in motorway and urban road networks. Using travel time distributions the research aims at deriving meaningful indicators addressing the reliability of networks and the dynamics of the service quality.
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Time-dependent service quality, reliability, travel time index, travel time measurements

1. Introduction

The traffic state in road networks and the corresponding quality of traffic flow are significantly influenced by the travel demand and the capacity of the road facilities. The demand varies over the time of the day but also over the days of the year. The available capacity fluctuates due to road works, accidents or meteorological conditions. In consequence the travel time needed for a journey depends on the departure time. The current German guidelines do not yet consider these dynamic effects:

- The German Highway Capacity Manual HBS (Handbuch fuer die Bemessung von Strassenverkehrsanlagen, FGSV 2001) like other Highway Capacity Manuals provides a collection of methods for evaluating the Level of Service for single road facilities (road sections, ramps, intersections). Depending on the type of road facility the HBS derives the Level of Service from the volume capacity ratio, the delay time or the traffic density. As reference traffic volume the HBS suggests using the volume of the 30th hour, i.e. that hour of a year with the 30th highest volume.
- The Guideline for Integrated Network Planning RIN (Richtlinien für die integrierte Netzgestaltung, FGSV 2008) evaluates the service quality of a complete journey from origin to destination including access and egress time. For evaluating the service quality in car traffic, travel times obtained during the peak periods on weekdays are used. Delays due to road works or any other incidents are not considered.

In order to overcome this deterministic consideration of the service quality, the presented research project investigates travel times of a complete year for network segments in motorway and urban road networks. By analyzing travel time distributions the research aims at deriving meaningful indicators for the dynamics of the service quality. The main focus lies on indicators measuring the reliability. Subject of the study are not single road facilities but entire network sections between major nodes in a network. A major node is defined as a node where two roads of the same level intersect. Thus a network section covers all road segments and intersections along a route between two neighboring major nodes. The results of the research project shall provide a method for evaluating entire network sections in existing road networks with the objective to prioritize investments for upgrading network sections. For this reason only network sections and time periods without major road works are analyzed.

The paper first discusses indicators for evaluating the service quality in road networks. Then it presents the travel time data available for the study and explains how the data were processed to obtain travel time distributions for an entire year for a large number of network sections. The last part describes a concept for evaluating the service quality with respect to reliability. The presented results are not yet final as the project work is still in progress.

2. Indicators for evaluating the service quality

From the perspective of the traveler various criteria influence the quality of a network section. Important criteria are travel time, reliability, directness, safety, costs and comfort. Both the HBS and the RIN consider the travel time in some way. This paper focuses on indicators that are suitable for quantifying the reliability, i.e. the time-dependent service quality.

The term reliability is defined in various ways. For engineering purposes a common definition for reliability is the following: The ability of an item to perform a required function under stated conditions for a specified period of time (ISO 8402: 1986, 3.18).

If this definition is adopted for road networks then the items considered are the transport facilities along a route in the road network. TU (2008) distinguishes between connectivity reliability (disruption of road links), capacity reliability (blockage of lanes) and travel time reliability. This paper focuses on travel time reliability, so that the required function of a route is an appropriate travel time. In contrast to many technical products, where it is sufficient to differentiate only between two stated conditions (functioning yes/no) the transport facilities provide various conditions within a specified time period, i.e. various travel times. VAN LINT et al. (2008) provide an overview on common indicators for measuring travel time reliability. They classify indicators into statistical indicators (e.g. standard deviation), time index indicators (travel time index), tardy trip indicators (delay resulting from late arrivals) and probabilistic indicators (share of late arrivals). With the objective of analyzing the reliability of entire network sections three approaches are examined in this paper.

2.1. Reliability derived from the dispersion of travel times

The dispersion of travel times describes the bandwidth of the observed travel times. A narrow bandwidth corresponds to a high reliability, a broad bandwidth indicates a low reliability. The dispersion of travel times can be quantified by the following two indicators:

- Standard deviation:
  The standard deviation is a measure of the dispersion of a set of values from its mean. As the standard deviation is growing with an increasing mean the standard deviation of the travel time cannot be used to assess the reliability of network sections of different length. To normalize the standard deviation the standard deviation must be divided by the mean.
- Travel time index:
  The travel time index quantifies the dispersion of the travel time by defining a lower and an upper bound for the travel time. The lower bound corresponds to a target travel time. This target time can be derived from a desired speed or from a percentile of the travel time distribution (e.g. the 15% percentile). The upper bound is defined by a percentile value (e.g. the 99% percentile). The travel time index thus describes the ratio by which the travel time increases compared to the target travel time.

$$TTI = \frac{t_{upper}}{t_{Target}} \tag{1}$$

with

TTI travel time index

t_{upper} upper limit of the travel time

t_{Target} target travel time

The selection of the target travel time has a significant influence on the travel time index. If the target travel time is set as a percentile of the travel time, then the travel time index of a network section is a result of the intrinsic characteristics of the network section. In this case the travel time index describes the operational reliability for a given state of the road network. If the target travel time is derived from a desired speed both the time expenditure as well as the reliability are assessed.

2.2. Reliability derived from the failure probability

In this approach every excess of a target travel time is considered as a failure of the system. This can be quantified by the following indicator:

- Failure probability:
  This indicator describes the share of time intervals with failure over all time intervals. The share of the time interval without failure can also be denoted as punctuality.

$$p_F = \frac{\sum_{i=1}^{I} F\left(t_i, t_{Target}\right)}{I} \quad , F\left(t_i, t_{Target}\right) \begin{cases} 1, \text{if } t_i > t_{Target} \\ 0, \text{if } t_i \leq t_{Target} \end{cases} \tag{2}$$

with

p_F probability of failure [-]

I number of time intervals

t_i travel time of time interval i

t_{Target} target travel time

This indictor requires a desired travel time value as target travel time. Using a percentile of a travel time distribution as target travel time is not appropriate as the failure probability would correspond exactly to the percentile value it is based on.

2.3. Reliability derived from the delay time

The delay time results from the difference between the current travel time and the target travel time. If the current travel time falls below the target travel time the delay time is zero. In contrast to failure probability the delay time also comprehends the severity of the delay. In order to assess the lost time it is related to the vehicle kilometers travelled or to the length of the network section.

- Demand-weighted average delay time:
  The average delay time (seconds per kilometer) of a vehicle results from the ratio of the total delay time of all vehicles to the vehicle kilometers travelled in a given time interval. Calculating this indicator requires information on traffic volume, ideally differentiated into light and heavy vehicles.
- Unweighted average delay time:
  The unweighted average delay time (seconds per kilometer) results from the ratio of the total delay time of all time intervals to the product resulting from the total length by the number of time intervals.

$$t_d = \frac{\sum_{i=1}^{I} MAX\left(t_i - t_{\text{Target}}, 0\right)}{I \cdot l} \tag{3}$$

with

t_d	unweighted average delay time [s/km]
I	number of time intervals
l	length of the considered network section[km]
t_i	travel time of time interval i
t_{Target}	target travel time

Both a percentile value as well as a travel time derived from a desired speed may serve as target travel time. The percentile value selected should lie well below the percentile value of the travel time index.

2.4. Target travel time and target speed

All three approaches described above require a target travel time or a target speed as reference value. The target travel time of a network section can be determined by two fundamentally different approaches:

- Target travel time derived from expected travel time:
  The target time results from the commonly expected travel time for a given state of the road network infrastructure. In order to determine the target travel time, percentiles from the travel time distribution are used. Depending on the application the result one may choose a low percentile value (for instance the 15% percentile for the travel time index) or a higher percentile value (for instance the 50% percentile for the delay time). The reliability resulting from the expected travel time can be considered as an operational reliability. It offers a relative evaluation of the level of service with respect to the existing state of the road network.
- Target travel time derived from a desired planning speed:
  The target travel time is based on a speed considered necessary from a transport planning perspective. This desired speed may depend on the road category or the importance of the places connected by the road. The German RIN guideline specifies ranges for a target speed by road category. The reliability resulting from a desired speed can be considered as planning reliability. It offers an evaluation of the level of service with respect to the desired state of the road network in which the road fulfills the assigned function with an appropriate service quality.

2.5. Weighted and unweighted travel times

Travel time distributions can be derived from weighted or unweighted travel times:

- Weighted travel times: In this case the travel time distribution covers the travel time of individual vehicles, i.e. the travel time is weighted with the demand.
- Unweighted travel times: In this case the travel time distribution is derived from the mean travel time over all vehicles observed in a specific time interval.

Usually the mean of a travel time distribution derived from weighted travel times is higher than the mean from unweighted travel times. The travel time distributions used in this paper result from unweighted travel times.

2.6. Selected indicators

In the presented project three indicators (travel time index, failure probability and unweighted average delay time) were analyzed for an analysis period covering one entire year consisting of 35,040 time intervals of 15 minutes. The results presented in this paper focus on the travel time index and the delay time.

3. Travel times in road networks

3.1. Travel time data

The traffic information supplier ddg (Gesellschaft für Verkehrsdaten, www.ddg.de) provided discrete average vehicle travel time data for each single segment of the entire German motorway network in intervals of 3 minutes for a complete year. A segment encloses the road between two adjacent motorway exits. The approximately 7,000 motorway segments have an average length of 3.6 kilometers. ddg estimates the travel time based on own measurements (overhead stationary detectors, floating car data), traffic messages and a traffic flow model. The data were validated by own measurements via automatic number plate recognition (ANPR) on two motorways. Every measurement covered 7 consecutive days recording almost every vehicle. To eliminate slow vehicles only the 50% fastest vehicles in a time interval were considered in the validation. Figure 1 shows the distribution of the ddg travel times and the observed ANPR travel times for the motorway section between Karlsruhe and Stuttgart (72 km). This result implies a lower dispersion of travel times in the data set provided by ddg compared to the real travel times measured with ANPR. During normal traffic conditions the ddg travel times are longer, i.e. the model assumes a lower free flow speed. In case of severe disturbances the ddg travel times are often shorter than the observed travel times. This shortcoming of the data set must be considered when assessing the results of the data analysis.

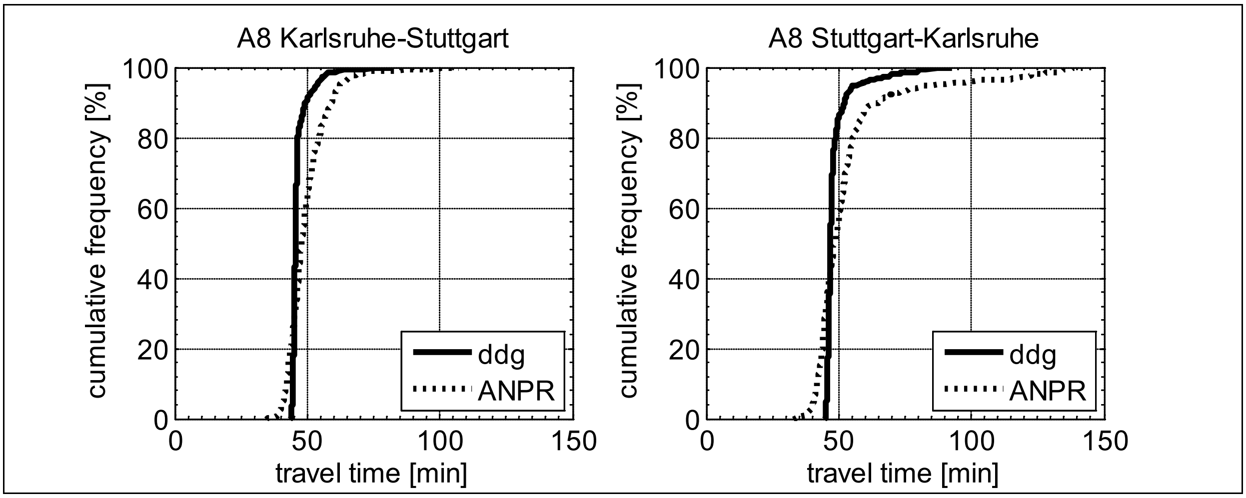


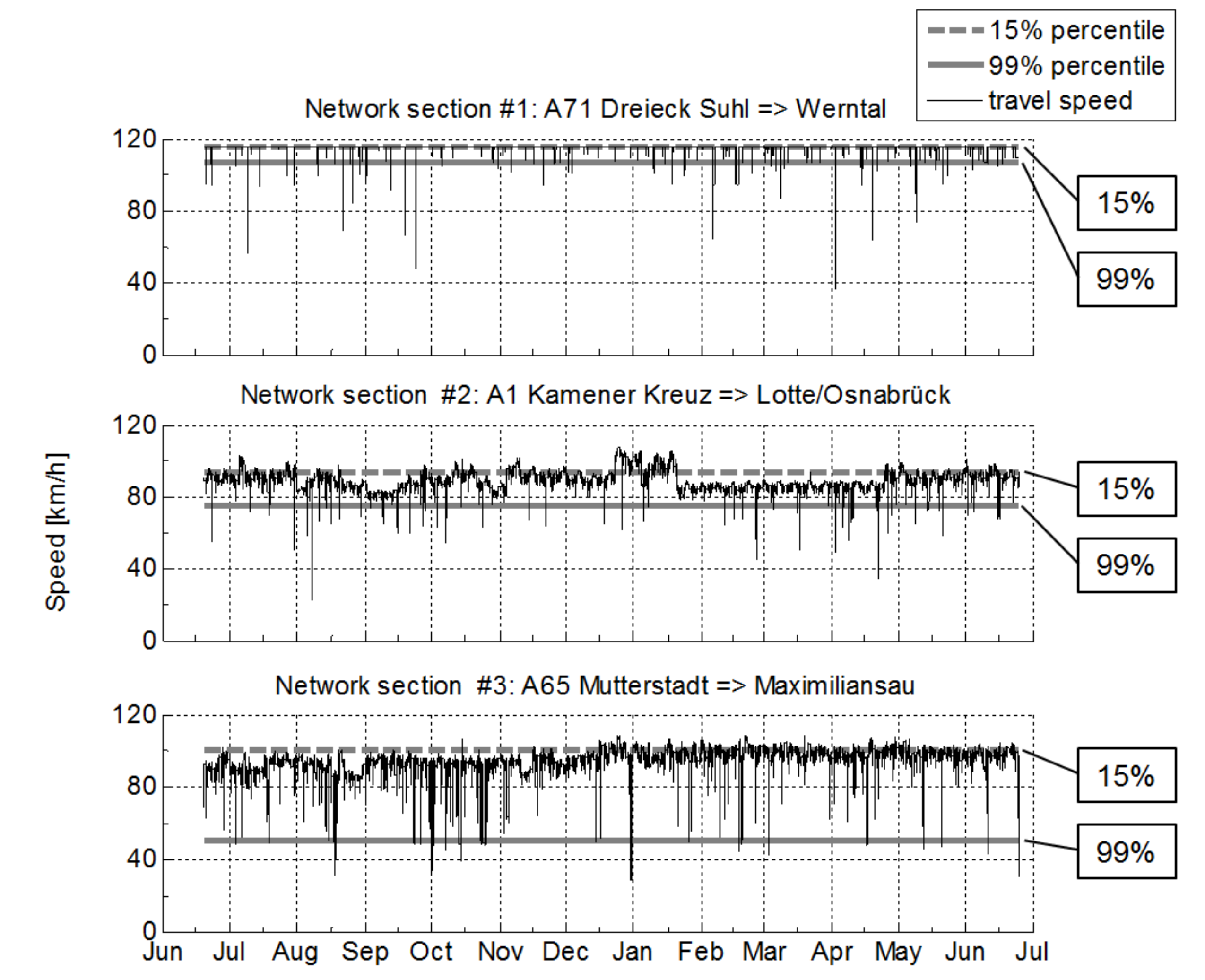
Figure 1: Comparing travel time distributions from ddg and ANPR (Motorway A8 Karlsruhe to Stuttgart).

In addition the DLR (German Aerospace Center, www.dlr.de) provided floating car data (FCD) from taxis for 21 sections of main road network in the German City of Hamburg. These data include the average speed along every section in intervals of 15 minutes for the complete year 2009.

3.2. Travel time distributions for network sections

For generating travel time distributions of network sections travel times are determined assuming one departure every 15 minutes over an entire year. This results in 365 days multiplied by 96 departures = 35,040 travel times for every network section. To compute the travel time of a particular network section the travel times of all road segments belonging to the road section must be concatenated using an algorithm similar to a time-dependent shortest path algorithm. This approach considers the time-dependent traffic state of every segment in time intervals of 3 minutes. For every departure time the algorithm runs through every road segment of the network section. For the first road segment s the algorithm selects the travel speed derived from the travel time in the departure time interval i. With this travel speed the arrival time at the end of the segment is derived. If this point in time lies within the time interval i then the arrival time is used as departure time for the subsequent road segment s+1. If the arrival time exceeds time interval i the distance covered within time interval i is determined. For the remaining distance the travel speed is derived from the travel time in time interval i+1.

The German motorway network consists of approximately 7.000 network segments between two exits. They are aggregated to 772 network sections between major nodes (motorway interchange nodes) covering a directed length of 22.700 km. As the evaluation of the motorway network should not include network sections with major road works, travel time distributions were only computed for 633 network sections. Figure 2 shows the travel speeds of three selected network sections in the German motorway network over the course of one year. The figure displays two percentiles (15% and 99%) for each network section. The ratio of these percentiles determines the travel time index TTI. The higher dispersion of travel times in network section #3 results in a higher TTI.



Network section #	Motorway	Length [km]	$t_{15\%}$ [km/h]	$t_{99\%}$ [km/h]	TTI
1	A71 Dreieck Suhl => Werntal	86.2	115.6	107.2	1.08
2	A1 Kamener Kreuz => Lotte/Osnabrück	79.2	94.1	75.2	1.25
3	A65 Mutterstadt => Maximiliansau	52.6	100.4	50.5	1.99

Figure 2: Travel time distributions and percentiles (15%, 99%) for three network sections in the motorway network.

In the urban network the travel times of the segments were concatenated to 174 network sections between intersections of main roads. Because of the fact that not in every interval a taxi passed every segment there were gaps in the data set which were filled up by a data completion algorithm. The travel times for the network sections were generated by summing up the travel times of the traversed links. In contrast to the motorway network a time-dependent approach is not necessary as the considered network sections in the urban road network are much shorter and travel times do not exceed 15 minutes.

4. Evaluating the service quality

4.1. Methodological approach

In this chapter the observed indicator values are analyzed and used to develop a level of service concept for evaluating the service quality with six levels A to F. The evaluation is based on the assumption that the travel time index decreases with increasing length of the network section. With increasing length the probability to experience multiple severe delays during a trip decreases and better conditions in other parts of the network section can compensate the delay.

Three types of evaluation functions were examined (rational function, exponential function, piecewise linear function with three pieces). For every function type five sets of parameters were determined defining five evaluation functions separating the LOS A/B, B/C, C/D, D/E and E/F. In a first step the parameters were estimated automatically such that an equal number of network sections are allotted to each service level. In a second step the parameters were manually adjusted. This manual parameter adjustment followed two principles:

- The distance between the five evaluation functions should be equal or increase with a lower LOS.
- Assuming that the LOS of the current road network in Germany is above average approximately half of the network sections should be classified as LOS A or B.

The following paragraphs show the resulting evaluation functions after step 2 for the indicators travel time index and delay time. The results focus on the rational function type which was identified most adequate.

4.2. Travel Time Index

Various target values for the target travel time were tested in the study (5%, 10% 15% percentile). With the objective of suppressing excessive speeds the 15% percentile of the travel time is selected. Compared to the target travel time which defines the lower bound of the travel time index the selection of the upper bound percentile has a much higher influence on the result. The difference between the 99.7% percentile and the 99% percentile is higher for all examined network sections than the difference between the 50% percentile and the 5% percentile. For the evaluation of the service quality the upper percentile of 99% is considered to be the most appropriate percentile. On average the 99% percentile represents a network state with a travel time increase of 50% compared to the target travel time. It describes a state which occurs during 90 hours of a year, i.e. one hour every third working day.

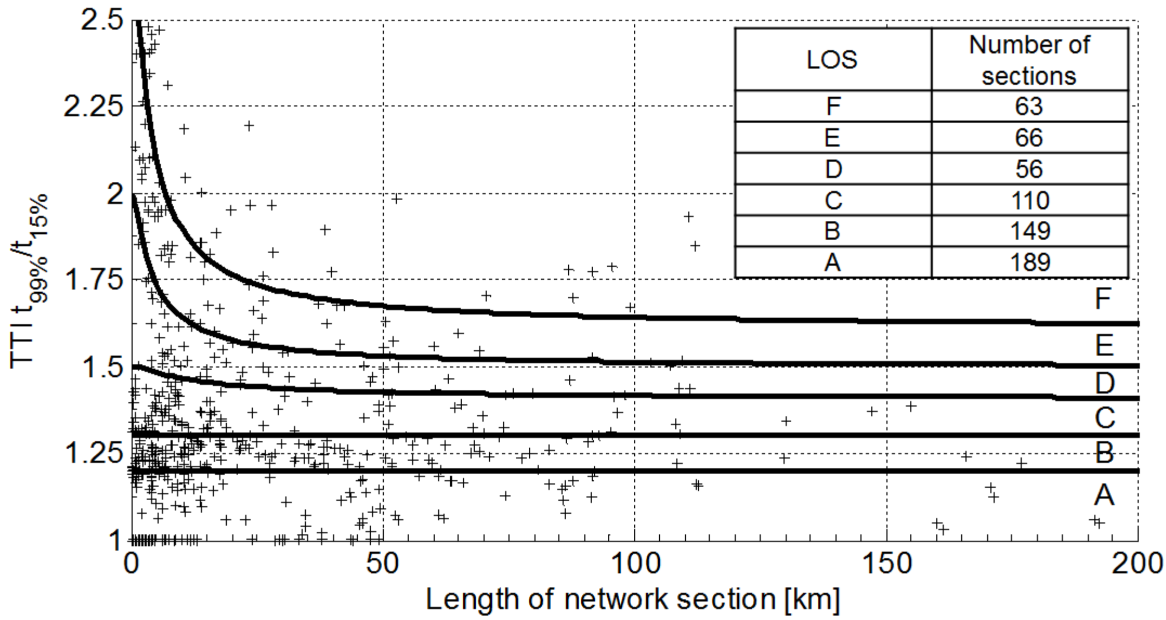
The following form of a rational function (ESTEL, 2008) is used to describe the five evaluation functions for the travel time index:

$$TTI(l) = \left[\left(\frac{A}{l} + B \right)^n + G^n \right]^{\frac{1}{n}} \tag{4}$$

with

TTI	travel time index [-]
l	length of network section [km]
A, B, n	parameter of the evaluation [-]
G	limiting value for $l = 0$ [-]

Figure 3 displays the observed travel time indices of the 633 network sections in the motorway network and the five evaluation functions defining a length dependent LOS A to F. The upper curve indicates that a network section with a length of 100 km has a poor reliability, if the travel time index exceeds a value of 1.65, i.e. if in more than 90 hours of a year the travel time is 65% longer than the free flow travel time (15% percentile).



LOS	Number of sections
F	63
E	66
D	56
C	110
B	149
A	189

Figure 3: Evaluating the travel time index TTI in motorway networks

Figure 4 shows travel time indices and resulting evaluation functions for urban network sections. In this example a constant speed of 40 km/h is used to define a target travel time. BRILON and SCHNABEL (2003) suggested this speed as a reference speed for a LOS A. Because of the numerous disturbances in urban traffic the travel time index for the urban main road network has a higher level than for the motorway network. The dependency on the network section length is recognizable.

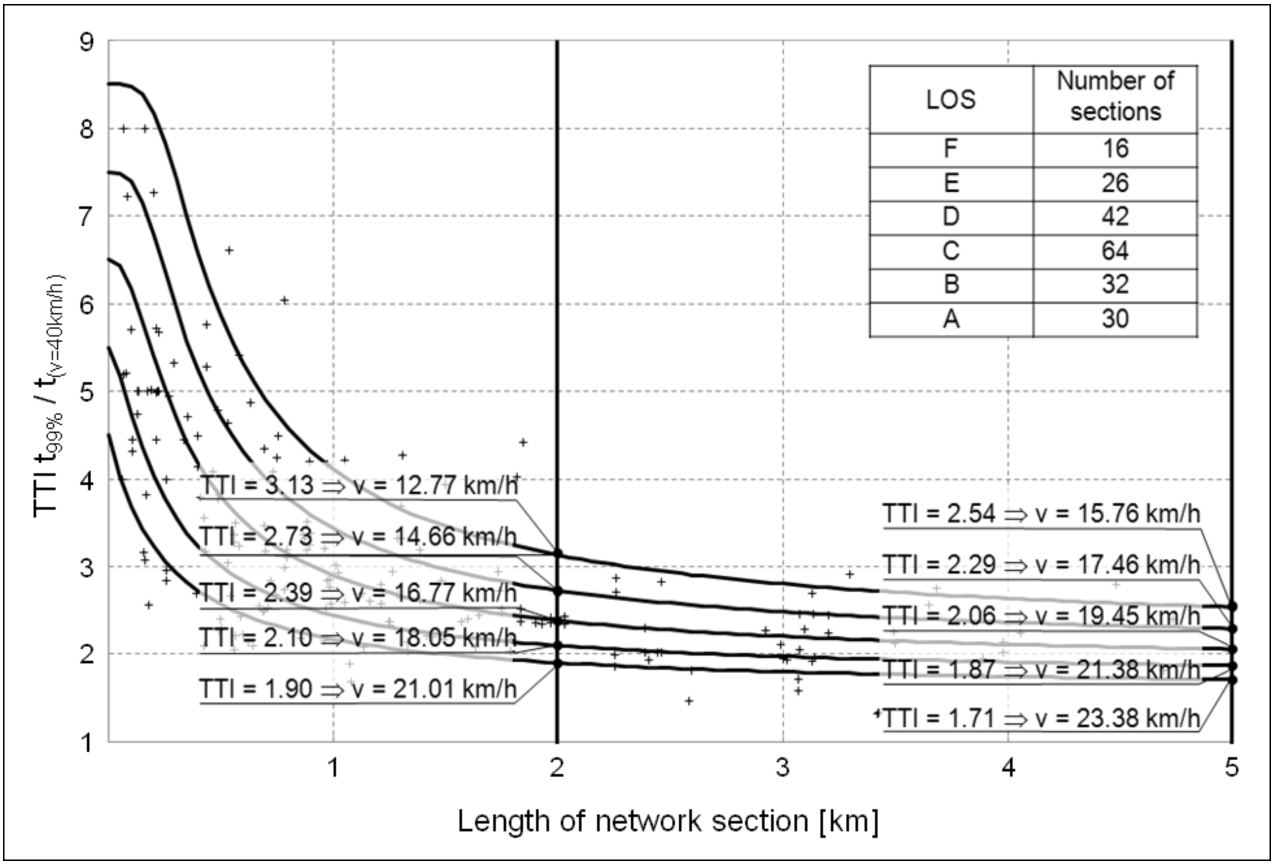


Figure 4: Evaluating the travel time index TTI in urban main road networks

4.3. Delay time

The selected target travel time directly influences the delay times. For a better comparison of the different network sections the target travel time is determined based on a desired planning speed. The desired speed is set to 80 km/h for motorways. Similar to the travel time index, the delay time also decreases with increasing length of the network section. For this reason the same form of function is used for the evaluation of the delay times. Only the parameters are adjusted. Figure 5 displays the resulting evaluation functions for the delay times.

In the urban main road network the desired speed for the delay time analysis is set to 25 km/h. Like the indicator travel time index the delay time in the urban main road network is considerably higher than in the motorway network. It achieves values higher than 60 s/km for short network sections up to 500 m. These high delay times are caused by the traffic lights. With increasing network section lengths the influences from the traffic lights are compensated and the delay times decrease.

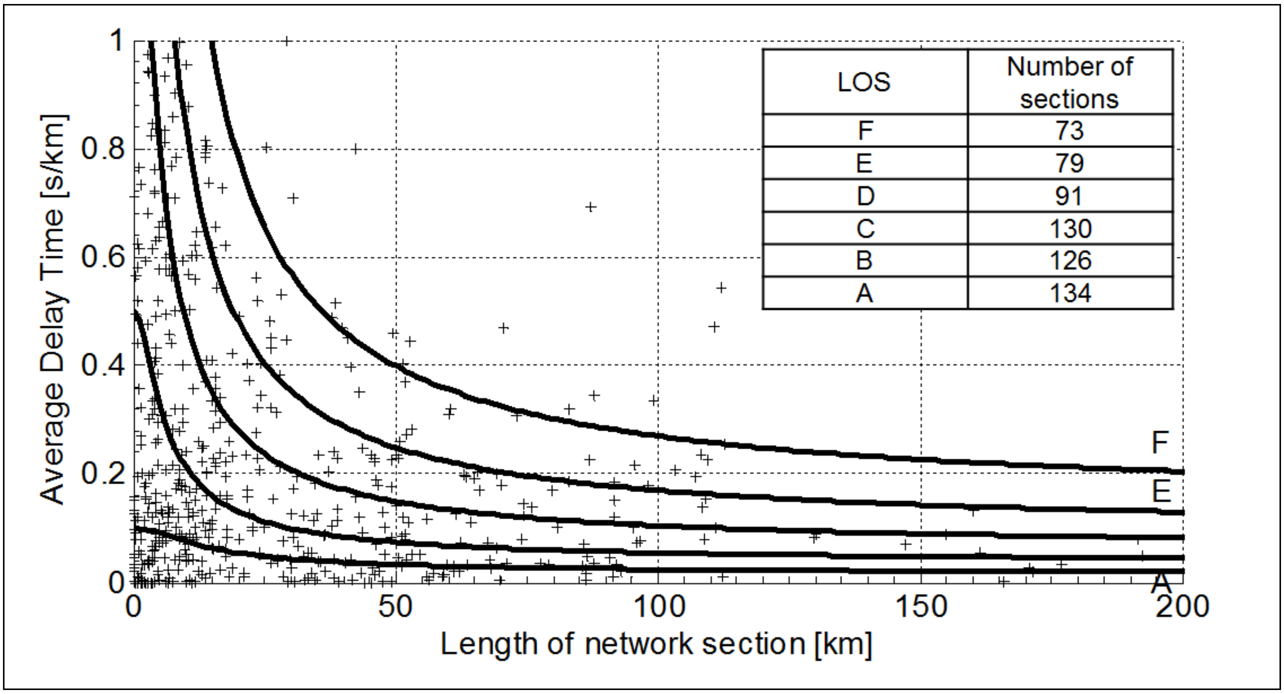


Figure 5: Evaluating the delay time in motorway networks

5. Conclusion

The analysis of the data shows that the travel time index and the delay time provide meaningful indicators for measuring and evaluating the reliability of network sections. For a comprehensive evaluation it is recommendable to evaluate both indicators. While the travel time index describes the dispersion of travel times by comparing two selected points of the travel time distribution the delay time considers the form of the travel time distribution. As both indicators show higher values for short network sections and lower values for long network sections the evaluation function depends on the distance.

The presented results are not yet final as the project work is still in progress. Further analysis of the data will investigate correlations between reliability, road characteristics, traffic demand and functional relevance of the network sections in order to identify parameter values which significantly influence the travel times and their distributions. In addition for applicability issues in the daily engineering practice a simple method for the determination of the service quality will be developed. This method will suggest minimum survey periods required for an evaluation of the reliability.

Currently the availability of accurate travel time data is the main threshold for permanently monitoring and evaluating the reliability of network sections. The data sources available for this research project sounded promising in the beginning but revealed shortcomings in the application. Travel times derived from stationary detectors, a relatively small fleet of floating cars and a traffic flow model failed to reproduce accurate travel times in the case of congestion. Travel times from taxis are a reasonable source for urban areas, although a larger sample would be desirable. In the coming years travel time measurements from floating cars (e.g. TOMTOM), from ANPR systems (e.g. Traffic England, 2010) or from mobile phone data (SCHLAICH et al., 2010) will permit a permanent monitoring of the service quality in road networks. Comparing measured travel time distributions with computed travel times from a Highway Capacity Manual will reveal the additional impact of road works, accidents and weather conditions on the travel time which are currently not included in the capacity analysis.

6. Acknowledgements

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