IMPACTS OF THE SERVICE QUALITY OF SINGLE ROAD FACILITIES ON THE SERVICE QUALITY IN NETWORKS

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ABSTRACT
The paper examines the relationship between the service quality of single road facilities and the service quality of entire journeys in road networks. It reports on a new approach to identify the level of service (LOS_c) of entire journeys and compares the results with the level of service (LOS_s) determined for the single road facilities according to the German Highway Capacity Manual. The concept of a study is presented, where measured journey times and LOS_c of selected od-pairs are associated with LOS_s measurements of the traversed road facilities.

1 INTRODUCTION
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, i.e. a particular network element like a road segment, a ramp, or an intersection. The Level of Service of single road facilities (LOS_s) is derived from the volume capacity ratio, the delay time or the traffic density.

In addition to the HBS the German guidelines provide a complementary Guideline for Integrated Network Planning RIN (Richtlinien für die integrierte Netzgestaltung, FGSV 2005) which is used for categorising road networks and for evaluating the service quality in multi-modal networks. Here the key indicator for measuring the level of service (LOS_c) of an entire journey is the direct speed, i.e. the total journey time from origin to destination divided by the direct distance. The network service quality is determined for a set of relations (od-pairs) described in a hierarchy matrix which contains all relevant relations in the network. This hierarchy matrix derives the importance of a relation based on the Central Place Theory (CPT) proposed by Christaller (1933) from the hierarchy of settlements.

Up to now the two guidelines HBS and RIN are only connected loosely. There is little knowledge how the Level of Service of an entire relation relates to the Level of Service determined for the set of road facilities traversed by this particular relation. A poor Level of Service of a single road facility according to HBS may not necessarily lead to a low Level of Service for the relations passing through this facility. Linking the service quality of relations and single road facilities could supply information about the required Level of Service for a specific road facility.

A current research project examines to what extent the service quality of single road facilities influences the service quality of entire relations and the entire network. To achieve this the project...
analyses a variety of relations by comparing computed Level of Service according to HBS/RIN and observed service quality from journey time measurements. For each examined relation the analysis includes relevant alternative routes which may be used in case of disturbances or for traffic control measures.

The paper will present the fundamental ideas for measuring the service quality for networks as defined in the RIN guideline and it will report on results of the research project, i.e. about the relationship between the service quality of single road facilities based on HBS and the service quality in networks according to RIN.

2 EVALUATION OF SERVICE QUALITY IN ROAD NETWORKS

2.1 Service quality of single road facilities
The German Highway Capacity Manual HBS, published in 2001, provides a set of methods to determine the Level of Service (ranging from A to F) for single road facilities, i.e. a particular element in the network. The HBS considers several types of road facilities, namely freeway segments, grade-separated intersections with ramps, rural roads, signal controlled and yield controlled intersections.

The HBS methods identify for each type of road facility a specific capacity and assign the actual traffic volumes to specific service levels, which promise defined qualities of the traffic flow. The criteria applied for each type of road facility are shown in table 1.

This way it is possible to determine the LOS of single road facilities. However, its broad impact on the entire road network is not taken into account. Until now, there exists no method in the HBS to estimate the impacts of the service quality of a single road facility (e.g. a congested intersection) on the service quality in the network (journey time, direct speed). Likewise the U.S. Highway Capacity Manual HCM (Transportation Research Board, 2000) does not include a method for determining the LOS of an entire journey, only for a sequence of road segments. It only permits to examine intersections, or road segments between intersections. A composite complete assessment of all the single road elements traversed within the course of a journey is not possible.

<table>
<thead>
<tr>
<th>Type of Road Facility</th>
<th>Quality Criterion</th>
</tr>
</thead>
<tbody>
<tr>
<td>freeway segment</td>
<td>capacity ratio</td>
</tr>
<tr>
<td>grade-separated intersection</td>
<td>capacity ratio</td>
</tr>
<tr>
<td>two lane rural road</td>
<td>traffic density</td>
</tr>
<tr>
<td>signal controlled intersection</td>
<td>delay time</td>
</tr>
<tr>
<td>yield controlled intersection</td>
<td>delay time</td>
</tr>
</tbody>
</table>

2.2 Service quality in networks
The RIN guideline provides a method for categorising road networks and for evaluating the service quality. This method comprises five major steps:
1. Development of hierarchy matrices: On the basis of the spatial units of the study area (central places, important transfer locations like airports) hierarchy matrices are developed for different hierarchy levels. Level 1 matrices for example contain long-distance relations which connect metropolitan areas. Level 2 matrices enclose medium-distance relations between towns of medium importance. The hierarchy matrices contain all od-pairs which are of importance for network planning.
2. **Assignment of hierarchy matrices:** In order to determine the importance of each network element the hierarchy matrices are assigned to the network, i.e. for each od-pair defined in the hierarchy matrices an appropriate route is identified. Route assignment considers not only time but also other factors like safety, and bundling of transport flows.

3. **Categorizing the network:** The category of a network element results from the set of routes traversing the element. The route with the highest hierarchy level determines the category of the network element.

4. **Determining and evaluating the service quality:** For each od-pair defined in the hierarchy matrices the service quality is described by a set of indicators (journey time, direct speed, directness, etc). To evaluate the service quality the indicator values are compared with target values. This results in a LOSc value for examined od-pair and each mode of transport (car, public transport, park & ride).

5. **Design of single network elements:** The desired characteristics of single network elements (streets, ramps, intersections) are derived from the category of the network element. The characteristics include the type of intersection control, the type of road cross section and the design speed. For network elements which are used by a high number of od-pair with a poor service quality appropriate design measures should be examined to increase the performance.

![Figure 1: Level 1 hierarchy matrix for Germany](image-url)
The most important indicator for evaluating the service quality of a particular od-pair is the direct speed (= direct distance / journey time). Journey time and the resulting direct speed include not only the in-vehicle time but also access and egress times which can reduce the speed of the entire journey significantly, especially in public transport. It is of advantage to use the indicator direct speed instead of journey time as it implicitly includes the distance. As a journey always comprises low-speed sections (access walk, feeder network) and sections with higher speed (arterial roads, motorways) the distance nevertheless influences the feasible speed. In short-distance trips the impact of the low-speed sections is higher than in long-distance trips. Figure 2 shows the LOS_c for evaluating the direct speed of relations.

![Figure 2: Level of Service LOS_c for evaluating the direct speed of relations](image)

Obviously the LOS_c in road transport can vary depending on the traffic conditions. The RIN guideline suggests to determine the LOS_c for the peak period. Practical applications of the evaluation method, however, face the problem of how to quantify the peak period journey time of entire relations. Three fundamental approaches can be considered:

- Measuring the journey time: The journey time is measured directly by a car drive. This approach provides realistic values, if the measurements are repeated over a longer time period, to make sure that random disturbances (e.g. accidents) do not significantly influence the result. The approach, however, is too expensive for examining all od-pairs of a network and can not be used for the evaluation of future network states.
- Observing the journey time: The journey time is derived from observations of journeys by means of floating car data (FCD) or floating phone data from mobile phones. This approach would provide an ideal data set for continuously monitoring the service quality in the network. Unfortunately at present such data are rarely available.
- Modelling the journey time: The journey time is computed by a macro- or microscopic traffic flow model. In principle this approach is suitable for large networks and for examining future states. The main difficulty of the approach results from the fact that such a model requires reliable information on traffic volumes and route choice.

Up to now applications of the evaluation method used traditional peak hour assignment methods which in some cases were calibrated by measurements of the journey time for selected od-pairs.
3 DATA COLLECTION AND PROCESSING

To examine the impact of the service quality of single road facilities on the quality of network relations both the LOS$_s$ of all facilities traversed by the relation and the overall journey time of this relation need to be analysed. As the service quality varies within the course of a day the analysis must include journeys with different departure times and consider the corresponding traffic volumes on the road.

The research project examines 10 relations each linking a distinct pair of cities with particular regional functions (i.e. cities with major, medium and minor regional relevance). Each relation is connected through a minimum of two alternative routes. For every relation the set of relevant routes is decomposed into single segments which are subjects of a LOS$_s$ analysis according to the HBS methodology.

The required traffic data are surveyed using different measurements in order to provide maximum information on traffic flow conditions over space and time. The following measurements are performed during three hour periods of morning and afternoon peaks:

- Two floating cars equipped with GPS devices travel continuously on the routes of the od-pair. The vehicle positions are recorded every second. This provides time-dependent time-space trajectories along the routes for discrete departure times (microscopic perspective).
- Infrared cameras of an automatic number plate recognition (ANPR) system are positioned at particular locations in the network in order to collect data sets on journey time and travel speed on the different routes for a large number of travellers (macroscopic perspective).
- Traffic volumes are counted at all locations required for determining the LOS$_s$ of single road facilities according to HBS. For this purpose data from permanent and mobile detectors are used.
- Since it has to be considered that the data collected may not cover the entire range of traffic demand particularly for high demand situations, the empiric data is completed by simulated data from a microscopic traffic flow simulation.

Figure 3: Measurement concept
Figure 4 shows the time-space trajectories of one route. The journey time varies depending on the departure time. This results in a time dependent LOS$_C$ for the entire journey which is also shown in Figure 4. Figure 5 displays the corresponding time measurements of all vehicles detected by the ANPR system between two locations. The measured travel times do not directly refer to the journey times in Figure 4 as they cover only the part of the journey between the two measurement locations. They prove, however, that the time-space trajectories represent a vehicle with average travel times.

Figure 4: Time-space trajectories of one route (Seligenstadt - Frankfurt a.M) for different departure times with LOS$_C$ value for the entire journey

Figure 5: Travel time measurements from ANPR systems
The LOS of each single road facility along the route is calculated according to HBS based on traffic volume, traffic density, and delay times. The LOS of each road facility also varies within the course of a day. Figure 6 shows the time-dependent LOS of single road facilities.

Figure 6: Time-space trajectories and time-dependent LOS of single road facilities of one route (Seligenstadt – Frankfurt a. M.) in the morning peak period

4 IMPACTS OF SINGLE ROAD FACILITIES ON COMPLETE JOURNEYS

The data described above form the basis for analysing the relationship between the LOS of single road facilities and the LOS for complete journeys. Different modelling approaches are considered:

- Comparison of LOS of a journey against the weighted mean LOS, which is calculated from the single LOSs of the traversed road facilities weighted by their length.
- Analogous calculation of a weighted mean LOS using not the length but the time as a weighting factor.
- Analogous calculation of a weighted mean LOS using not discrete but continuous LOS values.
- Harmonically standardized capacity ratio LOS

- Comparison of total delay times of a journey with the sum of calculated delay times at single road facilities.

Up to now only the first model, i.e. the weighted LOS, was analysed using the empiric data. The idea of weighing the LOSs of single facilities and to merge them to one characteristic value, which represents the LOS of the complete journey, requires a transformation of the semantic levels (LOSs A – LOSs F) to discrete integer values from 1 to 6. The length of each road facilities is used as a weighting factor. Accordingly the LOS can be formulated as follows:
\[ \text{LOS}_w = \frac{1}{\sum_{i=1}^{n} l_i} \sum_{i=1}^{n} \text{NV}_i \cdot l_i = \frac{1}{\text{L}_{\text{compl}}} \sum_{i=1}^{n} \text{NV}_i \cdot l_i \]

with:
- \( i \) section
- \( l_i \) length of the section \( i \)
- \( \text{NV}_i \) numerical value of the LOS\(_i\) of the traversed road facility at section \( i \)
- \( \text{L}_{\text{compl}} \) total length of route
- \( n \) number of sections

Applying this simple model with real data results in a reasonable correlation of both LOS-indicators as can be seen from Figure 7. This figure shows the measured direct speed and the calculated LOS\(_w\) of four routes for various departure times. As expected the direct speed falls with increasing LOS\(_w\). Examining a particular journey of 20 km direct distance (route Seligenstadt – Frankfurt) a clear linear relationship (\( R^2 = 0.91 \)) between LOS\(_w\) and the LOS\(_c\) according to RIN can be stated (Figure 8).

![Figure 7: Comparison of LOS\(_w\) and direct speed](image)

Supposed that these first results can be proved by further validation, this model allows for the analysis of the impacts of overloaded single facilities on the whole journey. Consequently the efficiency of alternative local measures to improve the overall LOS\(_c\) can be assessed by this method. As an example for such an impact analysis a section of the motorway Seligenstadt – Frankfurt (Figure 6, segment 6-9 between km 6.000 and km 17.000) is considered, which is frequently congested. This section covers two grade-separated interchanges with on- and off-ramps (segment 6 an 8) and two basic freeway segments (segment 7 an 9). For the start time 8:50 both LOS\(_c\) and LOS\(_w\) show a value of D (direct speed = 28 km/h, LOS\(_w\) = 4.4). The linear functional relation derived above now could be used to estimate the impacts and, if costs were available, the
efficiency of alternative local measures which could be implemented in order to improve the service quality of the complete journey. In this context four alternatives are considered:

- Alternative A: Enhancement of the capacity of all segments 6-9 to improve LOS\(_s\) of all four segments from F to D.
- Alternative B: Enhancement of the capacity of the freeway segments (segments 7, 9) to improve LOS\(_s\) from F to D.
- Alternative C: Enhancement of the capacity of all segments 6-9 improve LOS\(_s\) of all four segments from F to E.
- Alternative D: Enhancement of the capacity of the interchanges (segments 6, 8) to improve LOS\(_s\) from F to D.

![Graph showing impact analysis](image)

**Figure 8: Impact analysis**

The impact analysis shows that the highest benefit could be achieved by alternative A, which is the most expensive one. Direct speed would be increased by some 9,3 km/h and would provide a LOS\(_c\) of C according to RIN (Figure 8). Alternative C which improves the LOS\(_s\) F to LOS\(_s\) E for all four segments, however, is less effective (+ 4,6 km/h) than alternative B which only improves the LOS\(_s\) of the freeway segments from F to D (+6,4 km/h.).

The presented findings result from a first data analysis of 4 out of the 10 examined relations. The assumed coherences will be verified and modified in the progressive work.

5 CONCLUSION

The presented study aims at identifying the impact of single road facilities on the network, i.e. the impact on all journeys traversing that particular road facility. Such an analysis can help to locate single road facilities in a network where improvements are most beneficial and thus to rank infrastructure investments. If a single road facility with a low LOS\(_s\) during peak hour was only utilised by journeys with a decent LOS\(_c\) concerning the direct speed improvements are desirable but not urgent. However, if this single road facility was traversed by several od-pairs with a poor LOS\(_c\),
an extension of the particular road facility or modifications in the network should be examined. The presented project is a pilot study to examine the benefits of a planning process which integrates network planning and design of road facilities. The analysis of the field survey data is still under examination, but the first results show, that the methods can help to identify road facilities with a low service quality which at the same time have a high influence on the quality of entire relations.

As mentioned above a major drawback of such a method are the substantial requirements concerning the measurements of journey times for various od-pairs and time intervals. The required technology (licence plate detection, floating car data, floating phone data from mobile phones) are not yet available on a large scale or are still a point of research. With more and continuous data on journey times it would be interesting to examine, if the direct speed of an od-pair leading to a LOS, value F can be defined in a similar way as for single road facilities in the HBS. Here the design volumes for determining the LOS, are defined by the traffic volume which is observed for the 30th busiest hour within a year.

REFERENCES