Journey times from network characteristics and traffic states

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SHORT SUMMARY

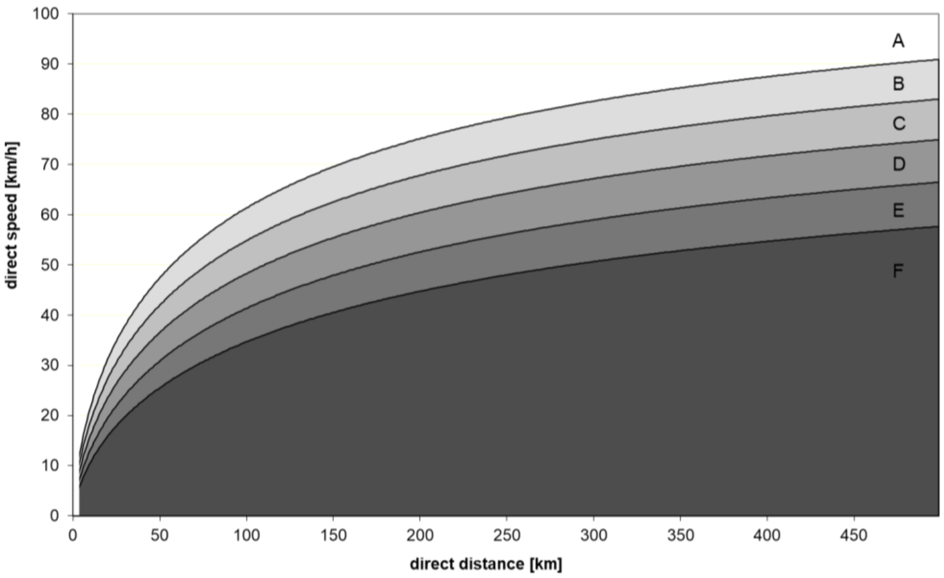
The service quality of a journey depends on the service quality of transport facilities along the route and, in car transport, on the traffic state. Network planning must therefore assess the service quality not only for single transport facilities and network sections, as it is common practice in the Highway Capacity Manuals. Additionally, the service quality of entire journeys should be examined in network planning. This research aims to shows that a certain service quality for journeys can be achieved by meeting certain target speeds on the level of network sections. For this purpose, generic journey times are computed which consider three typical characteristics of a road network and the traffic state: (1) The detour factor depending on the direct distance of the journey. (2) The share of the journey distance travelled on a specific road category. (3) A road category-specific target speed, which also reflects the traffic state.

Keywords: Journey times, Service quality in networks, Transport network modelling

1. INTRODUCTION

Transport networks connect places and thus ensure the accessibility of places. The main task of transport planning is therefore to design the transport network in such a way that movements of people and goods can be carried out with an appropriate service quality. This leads to the question what an appropriate quality is and which requirements result from this for the network design. For this purpose, the German guidelines for integrated networks design GIN (FGSV 2008), provide two types of benchmarks that are used in the planning of transport supply for motor vehicles and public transport:

- Evaluation functions assessing the service quality on the level of an entire journey from origin to destination: The evaluation uses six levels of service (LOS) ranging from A to F. The guidelines provide evaluation functions for time and directness. Time is assessed using the indicator direct speed, which is calculated by dividing journey time and direct distance. Directness is assessed by the indicator detour factor, which is the ratio of journey distance and direct distance. Figure 1 (top) shows the function for evaluating direct speed in car transport. It contains five functions that separate the six service levels.
- Target speeds on the level of network sections: The target speeds specify the requirement for the design of transport facilities and depend on the road category or on the category of public transport. The target speeds do not refer to the design speed, but to the speed during peak hour. Figure 1 (bottom) shows the target speeds for car traffic depending on the road category. A similar table exists in the guidelines for public transport.



Category group		Category		Standard distance range [km]	Target passenger car speeds [km/h]	
MR	Motorways	MR 0/I	Long-distance motorway	40 – 500	100 – 120	
		MR II	Interregional motorway, urban motorway	10 – 70	70 – 90	
RR	Rural roads	RR I	Trunk road	40 – 160	80 – 90	
		RR II	Interregional road	10 – 70	70 – 80	
		RR III	Regional road	5 – 35	60 – 70	
		RR IV	Local road	Up to 15	50 – 60	
		RR V	Access road	–	None	
AR	Arterial roads without adjacent development	AR II	Urban through road, arterial road without adjacent development	–	on the fringe of build-up areas	50 – 60
					within build-up areas	40 – 50
		AR III	Urban through road, arterial road without adjacent development	–	on the fringe of build-up areas	40 – 50
					within build-up areas	30 – 40
UR	Arterial roads with adjacent development	UR III	Urban through road, arterial road within built-up areas	–	20 – 30	
		UR IV	Urban through road, arterial road within built-up areas	–	15 – 25	
SR	roads serving developments	UR IV	Collector road	–	None	
		UR V	Residential road	–	None	

Figure 1: Level of service for direct speed (top) and target speed (bottom) for car transport (FGSV 2008, Figure 15 and Table 13)

The current evaluation functions were developed around 20 years ago using journey time data from the data sources available at the time. In the meantime, transport supply has changed and new data sources (floating car data in car traffic (FCD), nationwide timetable data) have become available. With the objective of updating the evaluation functions a research project collected journey times for 21,500 od-pairs between central places in Germany. They were derived from a network model with speeds obtained from the data provider TomTom. The process of calculating the FCD journey times and to estimate new evaluation functions with these journey times is described in the research report (Friedrich et al. 2023).

This paper aims to shows that a certain service quality for journeys can be achieved by meeting certain target speeds on the level of network sections. For this purpose, an evaluation function for the direct speed is first estimated using od-specific FCD journey times as input. Then the evaluation functions are derived with an alternative method which determines generic journey time. The alternative method shall fulfil two requirements:

- The resulting evaluation function should reproduce the evaluation functions estimated with od-specific FCD journey times.
- The journey times should be determined using a continuous function that reflects three typical characteristics of a road network and the traffic state: (1) The detour factor depending on the direct distance of the journey. (2) The share of the journey distance travelled on a specific road category. (3) A road category-specific target speed, which also reflects the traffic state

The paper focuses on car transport. The same approach has been applied to public transport and will be published in Bawidamann (2025).

2. METHODOLOGY

Evaluation functions from od-specific journey times

In a first step the evaluation functions are estimated with od-specific journey times for 21,500 od-pairs. Starting point is the function type for the evaluation function shown in equation (1) which is taken from the GIN (FGSV 2008). In this function, the direct distance is the variable that determines the direct speed of an service level. The parameters a, b and c of the function are estimated for five evaluation functions, each of which separates two service levels L (A/B, B/C, C/D, D/E, E/F). The evaluation functions are obtained for three traffic states:

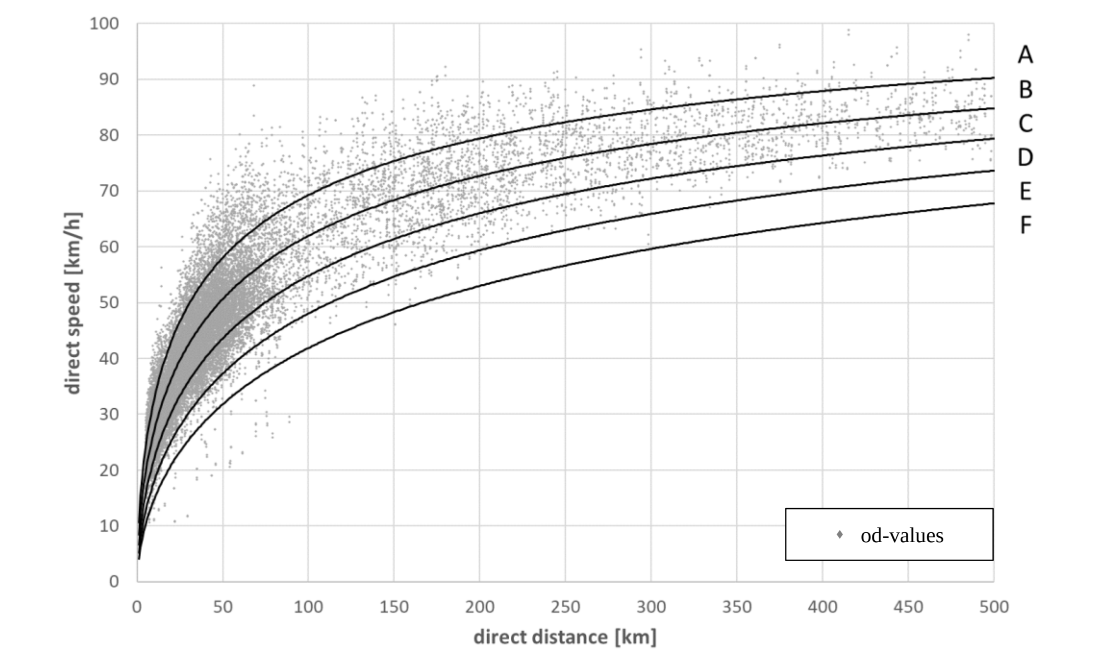
1. Off-peak: For this state, the median of the journey times during off-peak hours is selected as representative journey time.
2. Peak without random disturbances: For this state, the median of the journey times during peak hours is selected as representative journey time (maximum of morning and afternoon peak).
3. Peak with random disturbances: For this state, the 75 %-percentile of the journey times during peak hours is selected as representative journey time (maximum of morning and afternoon peak).

Figure 2 shows the resulting evaluations functions and the corresponding parameters for peak hours without random disturbances.

$$v_{LOS=L}(l^D) = \frac{1}{a_L \cdot (l^D)^{b_L} + c_L} \quad (1)$$

where

L	Index of evaluation function separating two service levels (A/B, B/C, …, E/F)
$v_{LOS=L}$	Direct speed [km/h] of service level L
l^D	Direct distance [km] between origin and destination
a_L, b_L, c_L	Parameter of a service level (see Figure 2)



Parameter	A/B	B/C	C/D	D/E	E/F
a	0,0820	0,1100	0,1430	0,1830	0,2320
b	-0,5970	-0,5970	-0,5970	-0,5970	-0,5970
c	0,0091	0,0091	0,0091	0,0091	0,0091

Figure 2: Evaluation function for direct speed in peak hour without random disturbances

Evaluation functions from od-specific detour factors

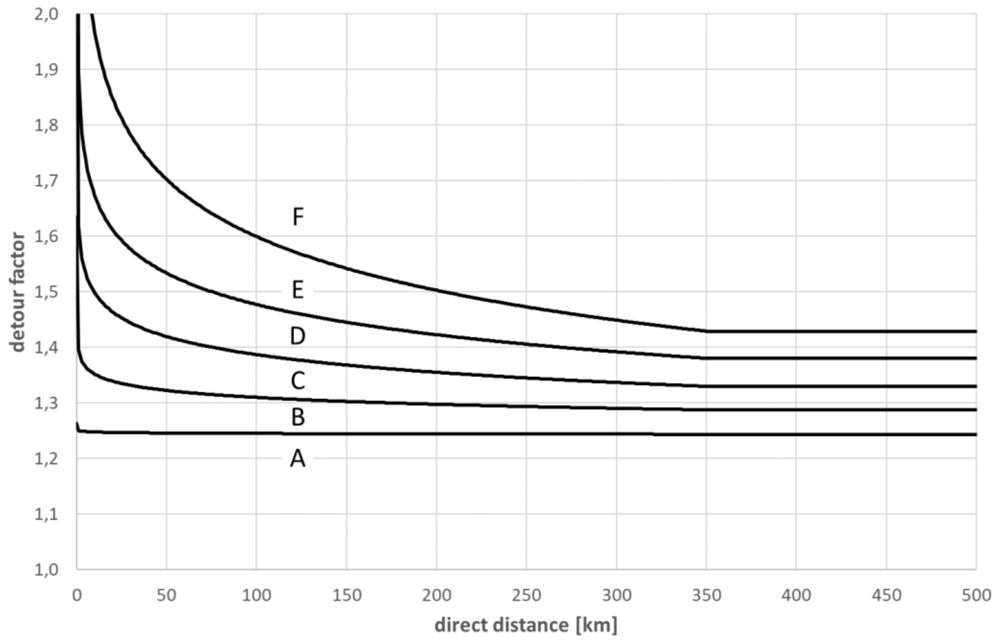
Evaluation functions for the detour factor use equation (2). Figure 3 shows the resulting evaluations functions and the corresponding parameters for the detour factor. Detour factors decrease with distance.

$$f_{LOS=L}^{Detour}(l^D) = \frac{10^{\left(a_L + b_L \cdot log\,10(l^D)\right)}}{l^D} \tag{2}$$

where

$f_{LOS=L}^{Detour}$ Detour factor [-] of service level L

a_L, b_L Parameter of a service level L (see Figure 3)



Parameter	A/B	B/C	C/D	D/E	E/F
a	0,065	0,172	0,282	0,436	0,611
b	1,000	0,970	0,939	0,891	0,835

Figure 3: Evaluation function for the detour factor

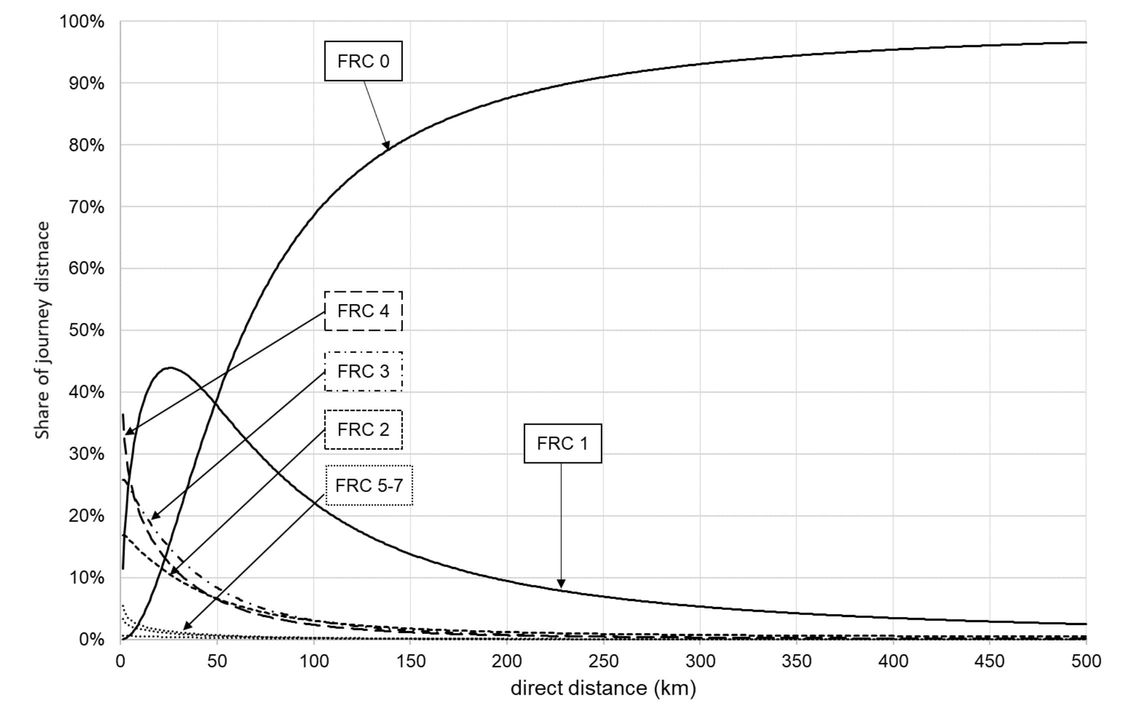
Journey distance by functional road class

For car traffic TomTom distinguishes 8 functional road class (FRC) from 0 (motorway) to 7 (local road of minor importance). The aim of this step is a functional description of the relationship between the direct distance of an od-pair and the resulting share of the journey distance by FRC. For this purpose, the share of each FRC on the journey distance is determined for the examined 21,500 od-pairs. Then od-pairs are divided into 10 km direct distance classes. For each class, the mean value of the length shares of each FRC is determined. These values are used to estimate a gamma function which determines the shares of the journey distance for each FRC. The gamma function is a generalization of the exponential function and therefore enables more flexible function graphs. The estimation determines the parameters a, b and c of the function shown in equation (3) such that the distance squares of the observed and calculated shares are minimized. Figure 4 displays the shares of the journey distances of the FRC over the direct distance.

$$p_{FRC}^{J}(l^D) = \frac{a \cdot ((b^c/\text{Gamma}(c)) \cdot l^{D^{(c-1)}} \cdot e^{-b \cdot l^D}}{\sum_{FRC} a \cdot ((b^c/\text{Gamma}(c)) \cdot l^{D^{(c-1)}} \cdot e^{-b \cdot l^D}} \qquad (3)$$

where

$p_{FRC}^{J}(l^D)$	Function for the share of journey distance of a functional road class FRC depending on the direct distance l^D
$\text{Gamma}(c)$	$\int_0^\infty t^{c-1} \cdot e^{-t} dt$
a, b, c	Parameter by functional road class FRC (see Figure 4)
FRC	Index for functional road class 0-7



Parameter	FRC 0	FRC 1	FRC 2	FRC 3	FRC 4	FRC 5	FRC 6	FRC 7
a	0,007536	1,466503	2,465586	3,754873	6,030028	0,085032	0,574910	1,035283
b	1,082005	1,081948	1,078661	1,083045	1,080636	1,076115	1,077158	1,076651
c	3,221030	1,636638	1,050090	1,056369	0,873686	1,070018	0,824808	0,746160

Figure 4: Share of journey distance by FRC

Evaluation functions from generic journey times

Generic journey times describe the expected journey time for a journey of a given direct distance and a particular traffic state. This journey time considers three typical characteristics of a road network:

- The detour factor depending on the direct distance of the journey.
- The share of the journey distance travelled on a specific functional road class FRC. This share again depends on the direct distance of the journey.
- A road category-specific target speed. This speed also reflects the traffic state.

Equation (4) is used to calculate the generic journey times. To apply equation (4), the following steps are performed:

1. Given is an od-pair with a corresponding direct distance.
2. The direct distance multiplied by the detour factor results in a journey distance. In order to obtain five different evaluation functions for each service L, the detour factor of this service level is applied (see Figure 3).
3. The journey distance is split into one journey distance for each road category using equation (3). The FRC is used as an approximation for the road category.
4. A target car speed is assigned to each road category / FRC. This speed depends on the traffic state (off peak, peak without/with disturbances). The travel time of each FRC is calculated using the target speed and the journey distance of this FRC.

5. The journey time of the od-pair is the sum of the travel times of all road categories, supplemented by an access time. This access time accounts for parking search time and walking time. It ranges between 4 and 9 minutes rising with direct distance.
6. An adjustment factor is introduced in order to achieve a better match between the evaluation functions from od-specific journey times and the evaluation functions from generic journey times. This factor depends on the traffic condition *z* and the service level *L*.

$$t_{LOS=L,z}^{J}(l^{D}) = \sum_{FRC} \left(\frac{l^{D} \cdot f_{LOS=L}^{Detour}(l^{D}) \cdot p_{FRC}^{J}(l^{D}) \cdot f_{LOS=L,z}^{Const}}{v_{FRC,z}^{Target}} \right) + t^{A}(l^{D}) \tag{4}$$

where

$t_{LOS=L,z}^{J}(l^{D})$	Function of the generic journey time [h] of an od-pair depending on direct distance l^{D} in traffic state *z* for level of service *L*
$p_{FRC}^{J}(l^{D})$	Function for the share of journey distance of a functional road class FRC depending on the direct distance l^{D}
$f_{LOS=L}^{Detour}(l^{D})$	Function of detour factor for level of service L
$t^{A}(l^{D})$	Function of access time [h]
$v_{FRC,z}^{Target}$	Target car speed [km/h] on a road of a functional road class FRC in traffic state *z* (Table 1)
$f_{LOS=L,z}^{Const}$	Constant factor for adjusting the journey time depending on traffic state *z* for level of service *L* (Table 2)
z	Index for traffic state (off peak, peak without/with random disturbances)

Parameter estimation for generic journey times

The target speed of each FRC and the adjustment factor for each traffic state *z* and service level *L* are used as parameters to calibrate the generic journey time function of equation (4). These parameters are adjusted in such a way that the curve of the resulting evaluation functions matches the curve of the evaluation functions from the od-specific journey times. This calibration process starts with the target speeds provided in the guideline GIN (FGSV 2008). The target speeds from the GIN are shown in Figure 1 and adapted to functional road classes in Table 1. The GIN states that theses target speeds refer to speeds on network sections in the peak period according to the German Highway Capacity Manual. These speeds also include the necessary waiting times at junctions. The target speeds are then manually adjusted. It turns out that the target speeds on FRC 0 and 1 roads should depend on the direct distance. On longer distances, it is more likely to travel on network sections away from metropolitan areas where somewhat higher speeds are possible, especially during peak periods. For FRC 0 and 1, a linear increase in speed is assumed between the direct distances of 70 km and 120 km. Table 1 lists the resulting target speeds. For a better match of the traffic states “peak period without / with random disturbances”, the adjustment factors are set to values > 1 as shown in Table 2. This is necessary because the spreading of the curves cannot be described solely by the detour factor, as other factors (e.g. disruptions on the route) also influence journey times.

Table 1: Target speeds $v_{FRC,z}^{Target}$ by FRC for three traffic states

Road category	FRC	Direct distance [km]	Target car speeds [km/h]			
			Values from GIN (FGSV 2008) see Figure 1	Off-Peak Period	Peak Period without random disturbances	Peak Period with random disturbances
MR 0/I	0	0 - 70	90 – 110	111	98	85
MR 0/I	0	120 - 500		117	112	93
MR II or RR I	1	0 - 70	80 – 100	90	90	65
MR II or RR I	1	120 - 500		90	90	70
RR II	2	0 - 500	60 – 70	70	70	60
RR III	3	0 - 500	50 – 60	70	70	60
AR II	4	0 - 500	40 – 60	60	50	40
AR III	5	0 - 500	30 – 50	50	40	35
AR III + IV	6	0 - 500	15 – 25	30	30	25
Other	7	0 - 500	-	10	10	10

MR	Motorway Road	0/I	road connecting high order central places
RR	Rural Road	II	road connecting medium order central places
AR	Urban Arterial Road	III	road connecting low order places or urban districts
		IV	road connecting community centres or urban quarters

Table 2: Factor $f_{LOS=L,z}^{Const}$ for adjusting the journey time depending on the traffic states and service level

Service level	Traffic state		
	Off-Peak Period	Peak Period without random disturbances	Peak Period with random disturbances
A/B	1.00	1.01	1.01
B/C	1.00	1.02	1.03
C/D	1.00	1.03	1.05
D/E	1.00	1.04	1.07
E/F	1.00	1.05	1.09

3. RESULTS AND DISCUSSION

Figure 5 compares the evaluation functions from od-specific journey times (in black) and generic travel times (in red) for the three traffic states. Additionally, the figure shows the direct speed values of the 21,500 examined od-pairs. It can be seen that it is possible to explain the evaluation functions from od-specific journey times with generic travel times derived from network characteristics and traffic states.

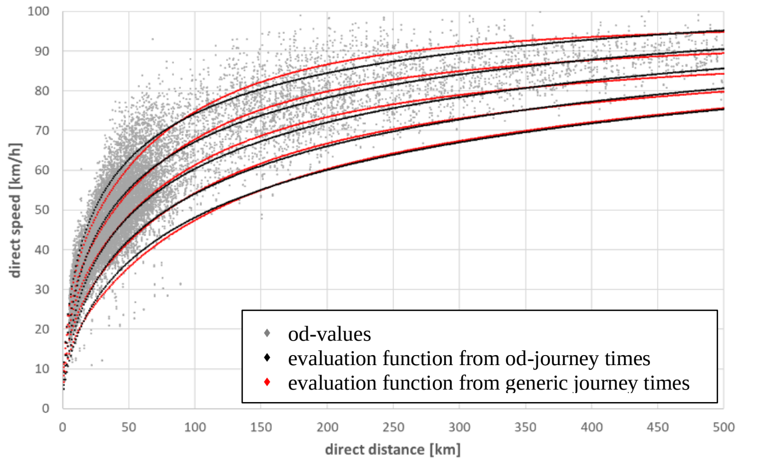
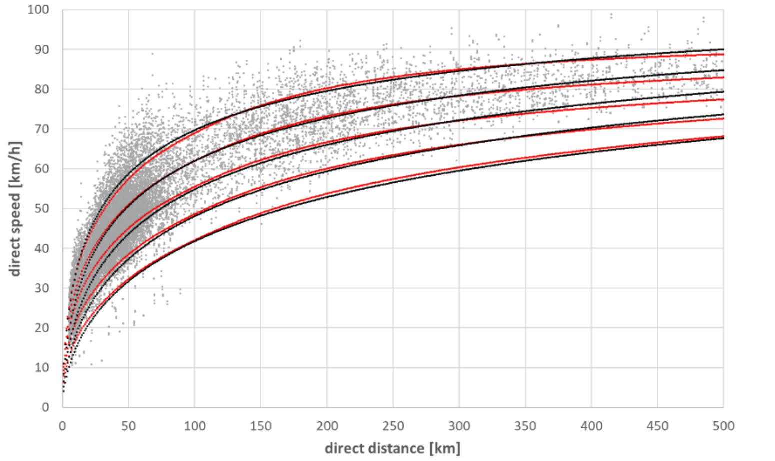
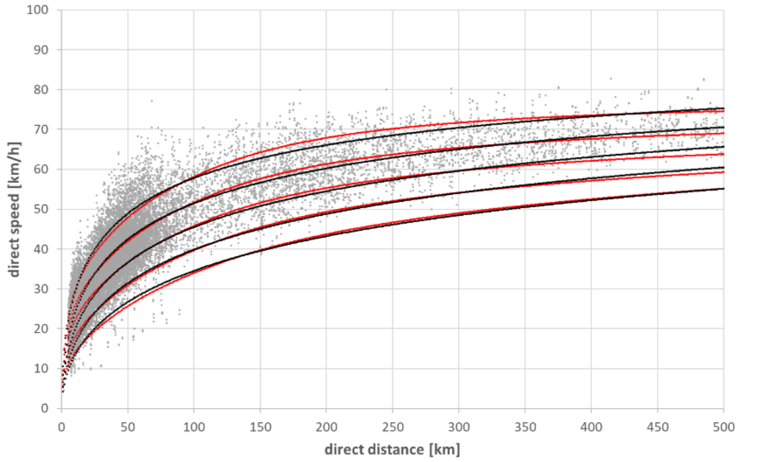
Off-Peak Period	
Peak Period without disturbances	
Peak Period with disturbances	

Figure 5: Comparison of evaluation functions from od-specific journey times (black) and generic travel times (red)

4. CONCLUSIONS

The service quality of a journey depends on the service quality of the transport facilities along the route. In car transport it also depends on the traffic state. Network planning therefore needs to check the service quality not only for single transport facilities and network sections, as it is common practice in the Highway Capacity Manuals. Additionally, the service quality of entire journeys should be examined in network planning. On the level of od-pairs, it is possible to compare service quality between modes (car, public transport), to examine the impact of network density and the resulting detours, and to understand the impacts from shortcomings of single road facilities. Low speeds on a single road facility due to inadequate design or high demand can be acceptable in cases, where the impact on the service quality of a journey can be compensated by other transport facilities along the route with a higher level of service.

This research shows that a certain service quality for journeys can be achieved by meeting certain target speeds on the level of network sections. It confirms the target speeds suggested in the German guidelines (FGSV 2008) and extends the target speeds to three traffic states. The target speeds can also be used to examine impacts of speed limits on certain road categories (motorways, rural roads, urban roads) regarding the service quality of a journey.

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