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Parameters Influencing Lane Flow Distribution on Multilane Freeways in PTV Vissim

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Abstract

In a parameter study, we systematically varied parameter values, and quantified the resulting traffic flow in each individual lane. We modeled two-, three-, and four-lane freeway sections with the microscopic traffic flow simulation tool PTV Vissim. We compared the results with findings from literature. Simulations using car following model Wiedemann 99 fit better to empirical studies than those using Wiedemann 74. Empirically determinable parameters, that have a relevant influence on lane flow distribution are desired speed distributions (mean for heavy-duty vehicles and standard deviation for cars), heavy-duty vehicle share, and the gradient of the section. Additionally, the driving behavior parameters *CC1 (headway time)*, *CC3 (threshold for entering following)*, and *safety distance reduction factor* have an influence. As *CC1* is one of the most relevant parameters for calibrating capacity, *CC3* and the *safety distance reduction factor* remain for lane flow adjustment.

Keywords: PTV Vissim; microscopic traffic flow simulation; lane flow distribution; lane changing parameters; car following parameters; Wiedemann 74; Wiedemann 99; multilane freeway calibration

1. Introduction

Microscopic traffic flow simulations can be used to investigate the impacts of traffic measures or to assess traffic facilities. To achieve reliable results, a simulation must be calibrated based on empirical traffic data. Microscopic traffic flow simulations of multilane freeways are usually calibrated using measured traffic volumes, speeds, or travel times [1, 2, 3, 4]. Traffic flow in individual lanes is not considered specifically. However, microscopic traffic flow simulations are increasingly used for traffic engineering issues that go beyond mere capacity considerations. Examples are emission calculations, effects of autonomous vehicles, or effects of traffic management policies. For such investigations it is not only essential that the empirical capacity is reproduced in the simulation, but the effects at all traffic

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volumes are relevant. A consideration of lane flow distribution in the calibration process can therefore be relevant for some research questions.

The distribution of traffic in the lanes depends on lane selection and changing behavior of the drivers. Drivers *select* a lane either because they want to continue their route or because they want to advance more quickly. After selecting a new lane, drivers perform the actual lane *change*. This results in a certain distribution of vehicles in the available lanes. Most microscopic traffic flow simulation tools do not have a lane selection model, but a lane changing model. The question arises whether a realistic lane flow distribution can be achieved in the simulation and to what extent this lane flow distribution can be influenced by parameter values of the existing driving behavior models. As there is no literature available on this topic, we want to contribute to closing this research gap with the parameter study presented in this paper.

In a literature review we provide insight into empirical lane flow distributions, lane selection and lane changing models. In a parameter study, we identify driving behavior parameters that have an influence on lane flow distribution in PTV Vissim. We investigate lane flow distribution on freeway sections, considering both car following models *Wiedemann 74* and *Wiedemann 99*. The simulations are carried out with PTV Vissim version 2020.00-09. The results should help readers to identify relevant parameters when calibrating a model of a multilane freeway in PTV Vissim.

2. Literature Review

2.1. Empirical Studies on Lane Flow Distribution

There are several empirical studies on lane flow distribution, which deal either with the actual lane flow distribution, or with the factors that influence lane changes. Empirical studies are available for France [5], Germany [6, 7, 8, 9], Great Britain [10], Greece [11], India [12], Italy [13], Netherlands [14], North America [8, 15, 16], and Turkey [17]. Depending on the application and country, these empirical studies can be considered to calibrate lane flow distribution.

Significant differences in lane flow distribution can be observed for different legal requirements. In many European countries, the rule "keep right except to pass" applies. Examples are France, Germany, Great Britain, or Spain. This traffic regulation requires that drivers, if possible, drive in the rightmost lane except for overtaking. It is prohibited to overtake on the right, so faster vehicles must move to the left. The speed distribution of road users in Europe is broader compared to the United States. While heavy-duty vehicles are often limited to a speed of 80 km/h, the speed limit for cars ranges between 100 km/h and 130 km/h in Europe. In Germany there are freeways without speed limit. The engine power and the desired speeds of the car drivers also differ. These factors lead to a speed gradient from the left to the right lane. Accordingly, there can be a speed advantage for drivers when they change lanes to drive closer to their desired speed [6, 18].

Empirical studies show a clear correlation between total traffic volume and relative traffic volume in the lanes. Depending on the traffic volume, uneven lane flow distribution results [5, 8, 9, 10, 13, 14]. Irrespective of the number of lanes, the majority of road users drive in the rightmost lane when traffic volumes are low. In high traffic flow situations, most of the traffic runs in the leftmost lane. For left-hand traffic, the results apply accordingly in reverse. These investigations show that European countries with similar legal requirements also have a similar lane flow distribution.

In contrast to Europe, the United States applies free lane selection. It is allowed to overtake both on the right and the left. Stricter speed limits entail smaller differences in driven speeds between cars and heavy-duty vehicles. As a result, the speed difference for the different lanes is smaller. The lane flow distribution mainly depends on the traffic volume, the time of day, day of the week, and the percentage of heavy-duty vehicles [8, 15, 16].

2.2. Lane Selection and Lane Changing Models

The literature distinguishes between necessary (mandatory) and optional (discretionary) lane changes [6, 19]. A *necessary lane change* is carried out depending on a vehicle's route or due to *Optional lane changes* can be motivated by speed advantages for the drivers, or as part of cooperative driving behavior, for example to assist other road users in merging, diverging, and weaving.

Furthermore, lane selection and lane change should be distinguished. In reality, drivers have an overview of all available lanes and the traffic situation in these lanes. In case of optional lane changes, drivers select a lane in which they can advance best. To model the drivers' decision for a target lane, so-called *lane selection models* are used. *Lane changing models*, on the other hand, replicate the actual execution of the lane change. Time gaps in the target lane and the time gap acceptance of the lane changing driver are decisive for the execution of a lane change [19].

A freely available freeway lane selection algorithm was developed within the project *Next Generation Simulation (NGSIM)* [20]. The developed algorithm models lane selection as a discrete choice problem, and incorporates many attributes of the lanes including, besides others, average density, speed level, time to collision, HOV restrictions, and the proximity of exits and entries. Multiple lane changes are possible to get to the desired lane. The algorithm was validated with empirical data using the commercial microsimulation software tools Aimsun, Paramics, and PTV Vissim, and is currently used as a part of the driving behavior in MITSIMLab and TransModeler.

However, most microscopic traffic flow simulation tools do not consider the overall traffic situation in all lanes in lane changing decisions, i.e. they do not have separate lane selection models, but only lane changing models. Most lane changing models deal with time gaps in neighboring lanes and the drivers' gap acceptance to execute a lane change. Gipps' lane changing model is implemented in Aimsun [18]. The model considers both a driver's route and their desired speed for lane changing decisions. The lane changing model developed by Erdmann [21] for SUMO uses a four-layered hierarchy of motivations (strategic, cooperative, tactical, and lane changes motivated by the keep right rule) for lane changing.

In PTV Vissim, the lane changing model is based on Sparmann's work [6] but contains extensions for improved modeling of tactical driving behavior for necessary lane changes. The lane changing model is based on the idea of interaction states defined in Wiedemann's psycho-physical car following model and distinguishes the three interaction states *uninfluenced*, *potentially influenced*, and *currently influenced*. If a vehicle is potentially or currently influenced by a preceding vehicle, and is therefore slower than its desired speed, the desire for a lane change arises. A vehicle also desires a lane change if one is necessary to reach the next link on its route or to allow another vehicle to execute a lane change (cooperative lane change). Whether a desired lane change is possible is decided in Sparmann's original work by considering the resulting interaction states after the lane change [6]. A vehicle performs a lane change if neither the vehicle ahead nor behind in the overtaking lane is influenced. Both conditions are met if the headway between the vehicles in the target lane is large enough or if the speed differences are low. The headways are primarily dependent on traffic volume and car following behavior. Accordingly, parameters of the car following model also influence lane changing behavior and thus the lane flow distribution.

3. Methodical Approach

We consider optional lane changing behavior on freeway sections in our study. We do not investigate the effects of necessary lane changes near intersections, as lane flow distribution is largely determined by origin-destination demand and the resulting traffic flow on different routes. Therefore, we do not model an existing freeway, as there would be an influence of intersections on lane flow distribution. We built a six kilometer long traffic flow model in PTV Vissim, which reflects a typical European freeway section. We simulate a two-lane, a three-lane, and a four-lane scenario. The vehicle input is increased by 200 veh/h every 15 minutes, starting at 600 veh/h and reaching a maximum of 4400 veh/h (two-lane scenario), 6600 veh/h (three-lane scenario), and 8800 veh/h (four-lane scenario). After reaching this maximum, vehicle input is decreased again by 200 veh/h every 15 minutes down to the initial state. With this approach the entire range of traffic volumes is covered in the simulations. We assumed a heavy-duty traffic share of 10 %, and the sections have no gradient. The lane flow is measured after three, four, and five kilometers.

We conducted a parameter study to determine the influence of car following parameters, lane changing parameters, and speed influencing parameters (desired speed distributions, heavy-duty traffic share, and gradient) on lane flow distribution. All parameter variations are performed separately for cars and for trucks, and for three scenarios (two, three, and four lanes). Based on PTV Vissim's default driving behavior *Right-side rule* (bold values), we simulated three values below, and three values above the default values. We generally chose an increment of 10 % of the initial value (see table 1). For some parameters we have chosen more suitable increments.

PTV Vissim's user manual recommends *Wiedemann 99* for simulations with speeds above 80 km/h with reference to higher following distances at higher speeds [22]. The default parameter values for Wiedemann 74 rather represent urban traffic [22]. Nevertheless, Wiedemann 74 parameter values can be adapted to freeway traffic and therefore we consider both car following models. Parameters that are assigned to both car following models (Wiedemann 74 and Wiedemann 99) are investigated separately for both.

To investigate the impact of desired speeds more closely, we modified the desired speed distributions for cars and trucks. We used the desired speed distributions published by Hoogendorn [23] as initial input. These distributions can be considered as representative for European freeways. The normal distributions have the following parameters for cars (mean $\mu = 120\ km/h$ and standard deviation $\sigma = 14\ km/h$) and for heavy-duty vehicles (mean $\mu = 90\ km/h$ and standard deviation $\sigma = 10\ km/h$). To avoid unrealistically slow and fast vehicles in the simulation, we cut the distributions at 5 % and at 95 %.

Table 1: Examined Parameter Values

	Parameter	W74	W99	Parameter Values (Default Values in Bold)							Increment
Wiedemann 74 Parameters	ax average standstill distance [m]	X		1.40	1.60	1.80	**2.00**	2.20	2.40	2.60	10%
	bx_{add} additive part of safety distance [m]	X		1.40	1.60	1.80	**2.00**	2.20	2.40	2.60	10%
	bx_{mult} multiplicative part of safety distance [m]	X		2.10	2.40	2.70	**3.00**	3.30	3.60	3.90	10%
Wiedemann 99 Parameters	CC0 (standstill distance) [m]		X	1.05	1.20	1.35	**1.50**	1.65	1.80	1.95	10%
	CC1 (headway time) (mean) [s]		X	0.63	0.72	0.81	**0.90**	0.99	1.08	1.17	10%
	σ(CC1) (headway time) (standard deviation) [s]		X	**0.00**	0.05	0.10	0.15	0.20	0.25	0.30	0,05 s
	CC2 (following variation) [m]		X	2.80	3.20	3.60	**4.00**	4.40	4.80	5.20	10%
	CC3 (threshold for entering following) [s]		X	-10.40	-9.60	-8.80	**-8.00**	-7.20	-6.40	-5.60	10%
	CC4 (negative following threshold) [m/s]		X	-0.46	-0.42	-0.39	**-0.35**	-0.32	-0.28	-0.25	10%
	CC5 (positive following threshold) [m/s]		X	0.25	0.28	0.32	**0.35**	0.39	0.42	0.46	10%
	CC6 (speed dependency of oscillation) [1/ms]		X	8.01	9.15	10.30	**11.44**	12.58	13.73	14.87	10%
	CC7 (oscillation acceleration) [m/s^2]		X	0.18	0.20	0.23	**0.25**	0.28	0.30	0.33	10%
	CC8 (standstill acceleration) [m/s^2]		X	2.45	2.80	3.15	**3.50**	3.85	4.20	4.55	10%
	CC9 (acceleration with 80 km/h) [m/s^2]		X	1.05	1.20	1.35	**1.50**	1.65	1.80	1.95	10%
Following Behavior Parameters	increased acceleration [%]	X	X	**100**	150	200	250	300	350	400	50%
	temporary lack of attention - duration [s]/probability [%]	X	X	**0/1.0**	1/1.0	2/1.0	3/1.0	4/1.0	5/1.0	6/1.0	1 s
	temporary lack of attention - duration [s]/probability [%]	X	X	**1/0.0**	1/0.5	1/1.0	1/1.5	1/2.0	1/2.5	1/3.0	0.5%
Lane Changing Parameters	min. headway (front/rear) [m]	X	X	0.35	0.40	0.45	**0.50**	0.55	0.60	0.65	10%
	to slower lane if collision time is above [s]	X	X	7.70	8.80	9.90	**11.00**	12.10	13.20	14.30	10%
	safety distance reduction factor	X	X	0.42	0.48	0.54	**0.60**	0.66	0.72	0.78	10%
	maximum deceleration for cooperative braking [m/s^2]	X	X	-3.90	-3.60	-3.30	**-3.00**	-2.70	-2.40	-2.10	10%
	coop. lane change/max. speed difference [km/h]	X	X	7.56	8.64	9.72	**10.80**	11.88	12.96	14.04	10%
	coop. lane change/max. collision time [s]	X	X	7.00	8.00	9.00	**10.00**	11.00	12.00	13.00	10%
Speed Influencing Parameters	desired speed distribution - car (mean μ) [km/h]	X	X	105	110	115	**120***	125	130	135	5 km/h
	desired speed distribution - truck (mean μ) [km/h]	X	X	75	80	85	**90***	95	100	105	5 km/h
	desired speed distribution - car (standard deviation σ) [km/h]	X	X	9.8	11.2	12.6	**14***	15.4	16.8	18.2	10%
	desired speed distribution - truck (standard deviation σ) [km/h]	X	X	7.0	8.0	9.0	**10***	11.0	12.0	13.0	10%
	gradient [%]	X	X	**0***	1	2	3	4	5	6	1%
	heavy-duty traffic share [%]	X	X	0	5	**10***	15	20	25	30	5%

* default values definied by the authors, values that are not preset in PTV Vissim

The evaluation of the parameter study is structured as follows:

1. *Simulation*: Five simulation runs with different random seeds are evaluated for each parameter value. The evaluation is aggregated to five-minute intervals; excluding a warm-up period of 30 minutes (with 600 veh/h).
2. *Lane flow distribution for all investigated parameters*: We evaluate the relative traffic volume in each lane in five-minute intervals. Each data point is assigned to a traffic volume class (width 200 veh/h). Since the capacity is partially exceeded for some parameters, we exclude classes with less than five data points. For each class and lane, the median of the relative lane flow is determined. The resulting median lane flow distribution is plotted for every parameter, showing the share of vehicles driving in the lanes for each of the seven parameter values.
3. *Deviation in lane flow distribution*: To give an overview of all results, we have summarized the findings in table 2. For each parameter we calculate – separately per lane – the deviation between the maximum and minimum lane flow for each traffic volume class. For each lane, the maximum deviation (Δ [%]), and the traffic volume at which

it occurs, is determined. If the maximum deviation for a parameter is small for all lanes, the parameter does not have a relevant influence on lane flow distribution. We exclude these parameters from further discussion.

4. *Further investigations and discussion for parameters with a high deviation in lane flow distribution*: Parameters that have an impact on lane flow distribution are examined in detail and thus discussed in the results.

4. Results

The lane flow distribution using Wiedemann 74 differs significantly from the results with Wiedemann 99. For all scenarios Wiedemann 99 results in a more even distribution of vehicles in the lanes with increasing traffic volumes. Furthermore, when using Wiedemann 74, the curves intersect (i.e. when the same number of vehicles are driving in the different lanes) at significantly lower traffic volumes than when using Wiedemann 99. In general, we observe that the capacity on three- and four-lane sections is higher in simulations with Wiedemann 99. As we have not calibrated the capacity, this is not exceptional. A comparison with empirical lane flow distributions from literature shows similar distributions for the initial state with Wiedemann 99 [8, 9, 10, 13, 14]. The results for Wiedemann 74 deviate more from the empirical observations. As a first conclusion it can be stated that PTV Vissim can reproduce an empirical lane flow distribution and that Wiedemann 99 is probably more suitable.

Some parameter variations result in a small maximum deviation of the lane flow, and these parameters will therefore not be discussed in more detail. The remaining parameters show notable shifts in lane flow distribution. The evaluation is summarized in table 2, showing for each parameter the maximum deviation in each lane, and the traffic volume at which it occurs. Deviations higher than 5 %, or 10 % are marked in grey.

Table 2: Resulting Maximum Deviation in Lane Flow Distribution

	Parameter	Vehicle Class	2-lane section				3-lane section						4-lane section							
			right lane		left lane		right lane		middle lane		left lane		right lane		middle right lane		middle left lane		left lane	
			Δ [%]	vol. [veh/h]	Δ [%]	vol. [veh/h]	Δ [%]	vol. [veh/h]	Δ [%]	vol. [veh/h]	Δ [%]	vol. [veh/h]	Δ [%]	vol. [veh/h]	Δ [%]	vol. [veh/h]	Δ [%]	vol. [veh/h]	Δ [%]	vol. [veh/h]
Wiedemann 74	bx_{add} additive part of safety distance [m]	car	3.4%	4000	3.4%	4000	2.2%	1000	3.8%	4600	5.7%	4600	1.5%	2400	3.1%	5600	4.1%	5800	7.2%	5600
		truck	2.7%	4200	2.7%	4200	1.0%	4200	2.1%	5800	2.8%	4800	1.1%	5400	1.4%	7200	1.3%	5400	2.4%	6800
	bx_{mult} multiplicative part of safety distance [m]	car	3.3%	4200	3.3%	4200	2.3%	1000	3.5%	4800	4.4%	4800	1.6%	1000	2.8%	5800	3.5%	5800	6.7%	5800
		truck	2.2%	4200	2.2%	4200	2.2%	5800	1.8%	5800	2.6%	5800	1.3%	7400	2.4%	7400	1.6%	5600	2.1%	6000
	safety distance reduction factor [-]	car	5.4%	3600	5.4%	3600	4.2%	5600	3.7%	4000	6.0%	5200	3.0%	7000	3.5%	7000	2.4%	4400	6.2%	7000
		truck	2.8%	4200	2.8%	4200	1.3%	5800	1.6%	5800	2.8%	5800	1.2%	5800	1.4%	5800	1.2%	5200	2.1%	6000
	desired speed distribution (mean μ) [km/h]	car	4.7%	2000	4.7%	2000	4.1%	5000	3.5%	4600	3.4%	3400	4.5%	5400	3.2%	2800	3.9%	5800	4.4%	5800
		truck	9.9%	1000	9.9%	1000	9.7%	2000	4.6%	1000	8.2%	3200	9.5%	2200	4.6%	1200	4.2%	2200	8.4%	4200
	desired speed distribution (standard deviation σ) [km/h]	car	6.6%	600	6.6%	600	5.9%	600	4.3%	2800	8.3%	1600	5.8%	1200	4.5%	3000	3.7%	1200	7.3%	3400
		truck	2.1%	3600	2.1%	3600	2.4%	1200	1.5%	3800	2.0%	4800	1.9%	800	1.9%	1000	1.7%	5400	1.9%	5800
	gradient [%]	all	19.5%	3200	19.5%	3200	15.3%	4600	4.9%	800	17.5%	4600	13.2%	7400	6.7%	7200	5.8%	7400	14.5%	7200
	heavy-duty traffic share [%]	all	11.7%	1000	11.7%	1000	10.8%	1400	5.8%	800	12.4%	2400	10.3%	1000	5.4%	3400	5.4%	1600	12.8%	4200
Wiedemann 99	CC1 (headway time) (mean) [s]	car	5.9%	1000	5.9%	1000	7.5%	2200	3.6%	600	7.5%	3600	7.0%	2000	4.8%	6000	4.3%	3000	8.8%	6400
		truck	2.0%	1600	2.0%	1600	2.0%	4800	1.1%	1600	2.0%	4800	2.3%	7200	1.3%	1400	1.6%	7000	2.2%	7000
	σ(CC1) (headway time) (standard deviation) [s]	car	1.9%	4000	1.9%	4000	1.7%	5800	1.0%	1000	2.3%	5400	2.2%	8200	1.9%	7400	1.2%	800	2.7%	7400
		truck	1.0%	2400	1.0%	2400	1.2%	5200	1.0%	1800	1.2%	4800	1.2%	8200	0.8%	8200	0.9%	8200	1.5%	8200
	CC3 (threshold for entering following) [s]	car	4.6%	1000	4.6%	1000	5.3%	2600	3.3%	800	5.2%	2400	5.9%	1800	3.4%	1000	3.6%	2800	4.6%	6400
		truck	0.8%	3000	0.8%	3000	1.3%	5000	0.7%	3200	1.2%	5600	1.5%	8200	0.9%	7200	0.6%	6400	1.9%	8200
	to slower lane if collision time is above [s]	car	3.7%	400	3.7%	400	4.1%	5000	0.9%	4200	4.2%	5200	3.9%	7000	2.7%	7000	2.0%	7200	5.9%	7000
		truck	0.7%	4400	0.7%	4400	1.0%	5600	0.6%	4800	0.8%	5600	1.7%	8200	0.8%	7400	1.0%	8200	1.2%	7400
	safety distance reduction factor [-]	car	5.4%	4000	5.4%	4000	4.5%	5800	2.5%	1000	4.4%	5800	4.3%	7200	2.7%	7200	2.8%	7200	4.8%	7200
		truck	0.9%	3400	0.9%	3400	0.9%	6000	0.9%	1400	1.1%	2800	1.7%	8200	1.1%	8200	0.7%	2200	1.8%	8200
	desired speed distribution (mean μ) [km/h]	car	4.6%	4000	4.6%	4000	6.8%	5600	3.3%	2400	3.9%	5600	6.8%	7200	3.1%	2400	3.6%	7200	4.2%	7000
		truck	6.8%	1000	6.8%	1000	7.7%	2000	5.2%	1200	3.7%	2000	6.8%	2200	5.0%	1200	2.9%	6800	3.9%	7000
	desired speed distribution (standard deviation σ) [km/h]	car	5.1%	1600	5.1%	1600	4.8%	1200	3.9%	600	5.7%	3800	4.8%	1400	3.4%	5000	2.6%	1800	5.3%	5800
		truck	1.8%	800	1.8%	800	1.7%	600	2.9%	600	1.1%	2800	2.0%	1000	1.5%	1000	1.1%	800	1.8%	7400
	gradient [%]	all	8.5%	4000	8.5%	4000	11.6%	1600	6.3%	600	9.2%	2200	10.9%	2800	6.4%	3400	6.5%	2400	11.9%	4400
	heavy-duty traffic share [%]	all	9.2%	1800	9.2%	1800	10.9%	1800	4.8%	1000	9.2%	4000	8.8%	1600	4.9%	6600	4.5%	2400	10.1%	6400

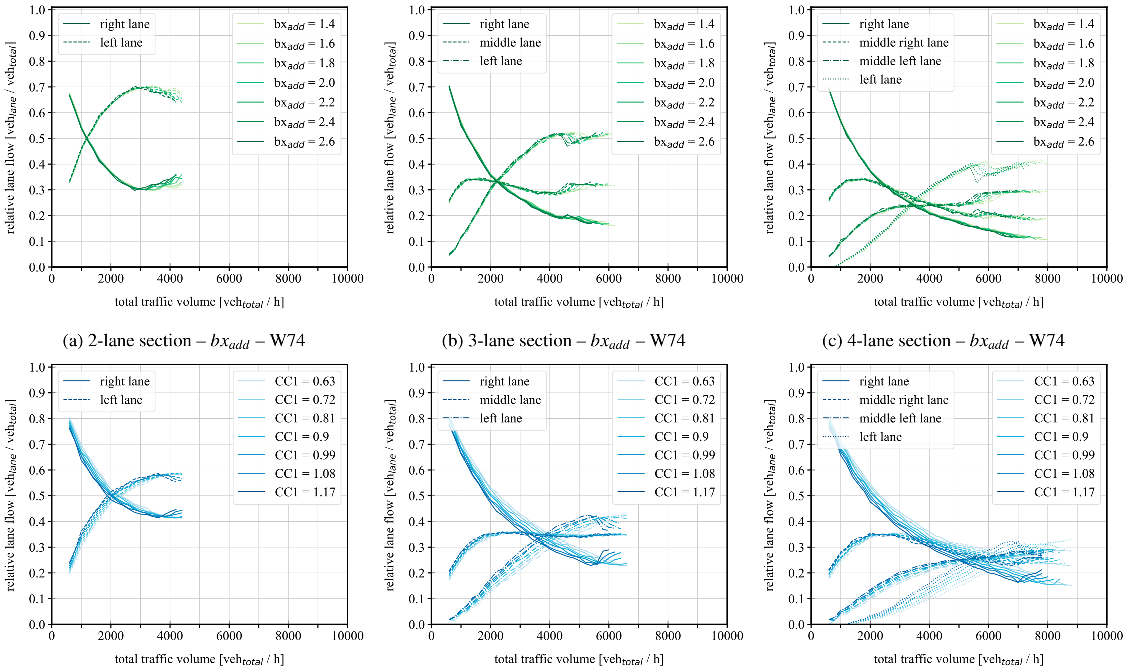
Deviations above 5 % are marked in light grey, and deviation above 10 % in dark grey.

The **headway time (CC1)** is one of the most relevant parameters in the Wiedemann 99 car following model to calibrate capacity. With increasing CC1, the headway between the vehicles widens, and thus the capacity decreases. CC1 value is drawn from a distribution for each vehicle, parameterized by the mean and the standard deviation of CC1. Figure 1 shows the results for CC1 variations. By increasing the mean of CC1, the share of vehicles in the right lane decreases. This effect grows with increasing traffic volumes. The middle lane for three-lane sections, and the middle right lane for four-lane sections show only little change. However, if the standard deviation of CC1 is increased without changing the mean value, there is almost no change in the lane flow distribution.

For Wiedemann 74 the headway between vehicles is calculated based on the parameters **additive part of safety distance** (bx_{add}), and **multiplicative part of safety distance** (bx_{mult}). Compared to the mean of CC1, bx_{add} shifts the mean time gap. bx_{mult} causes a spreading of the distribution, similar to the standard deviation of CC1. Both parameters have almost no influence on lane flow distribution, which is surprising since CC1 has a significant influence. As for CC1, an influence on the capacity can be observed. Figure 1 shows the results for bx_{add} variations.

The modification of the **threshold for entering following (CC3)** for Wiedemann 99 leads to similar changes as for CC1, because CC3 also affects the perception threshold. The higher CC3 is set, the more vehicles drive in the left lane. However, unlike CC1, CC3 does not affect capacity, but mainly lane flow distribution. The influence of CC3 decreases with increasing traffic volume.

These changes refer to passenger cars. If the same parameters are changed for trucks, there is hardly any shift. This is mainly because we examined only 10 % heavy traffic share.



(a) 2-lane section – bx_{add} – W74 (b) 3-lane section – bx_{add} – W74 (c) 4-lane section – bx_{add} – W74

(d) 2-lane section - CC1 - W99 (e) 3-lane section - CC1 - W99 (f) 4-lane section - CC1 - W99

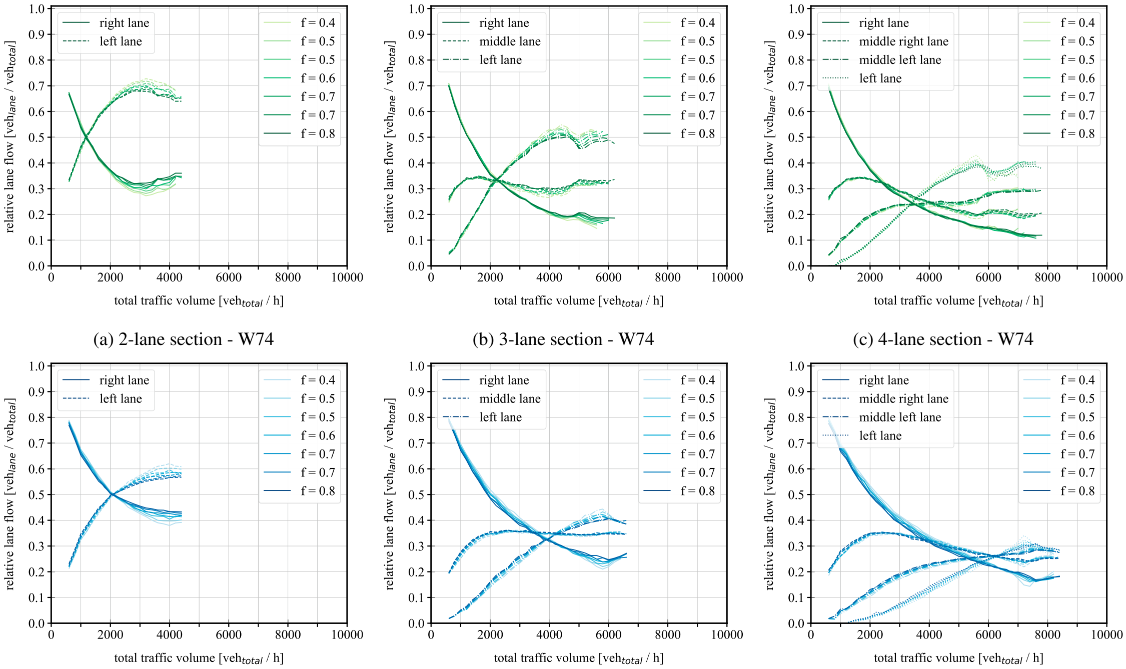
Fig. 1: Results for Parameter *CC1* (mean) and bx_{add} Variation (Cars) – Wiedemann 74 and Wiedemann 99

The **safety distance reduction factor** multiplied by the *original safety distance* describes the headway in the neighboring lane that a vehicle needs at a minimum to perform a lane change. By reducing this factor, smaller gaps can be used for lane changes, and traffic flow in the left lane increases (see figure 2). The effect intensifies with increasing traffic volumes. More frequent lane changes could also have a negative impact on capacity at high traffic volumes. Varying the safety distance reduction factor for trucks has almost no influence, as trucks have fewer overtaking desires.

If the keep right rule applies, a vehicle changes back **to a slower lane if collision time is above** a certain threshold. A higher factor means that fewer vehicles change lanes to the right after overtaking. As the number of small time gaps in the right lane increases with increasing traffic volume, more and more vehicles remain in the left lanes. For simulations with Wiedemann 99, the evaluation shows a shift in traffic flow from the right to the left lane. Changing the parameter value for trucks has no influence. For simulations with Wiedemann 74, this parameter shows almost no effect on lane flow distribution.

Speed influencing parameters have a strong influence on lane flow. However, these parameters are often known or measurable in reality, and are not further calibrated.

If the **mean of the desired speed distribution** for cars is increased, there is a shift from the rightmost to the left lanes with increasing traffic volumes. If the average speed of heavy-duty traffic is reduced, there is also a shift to the



(a) 2-lane section - W74
(b) 3-lane section - W74
(c) 4-lane section - W74
(d) 2-lane section - W99
(e) 3-lane section - W99
(f) 4-lane section - W99

Fig. 2: Results for Parameter *Safety Distance Reduction Factor* Variation (Cars) – Wiedemann 74 and Wiedemann 99

left lanes. The maximum deviation in lane flow distribution is higher in simulations with Wiedemann 74 than with Wiedemann 99. If the **standard deviation of the desired speed distribution** for cars increases, the range between slow and fast cars grows. Overtaking desires become more frequent, and traffic shifts from the right and middle lanes to the left lane(s). The influence is again more significant for Wiedemann 74.

With increasing **gradient**, the vehicles are distributed more evenly over the lanes for all traffic volumes. Compared to level sections, more vehicles drive in the left lane when traffic volume is low, and more vehicles drive in the right lane when traffic volume is high. This is comparable to reducing the average speed of heavy-duty traffic. With increasing gradient, capacity decreases.

In PTV Vissim, a higher **share of heavy-duty vehicles** results in higher usage of the left lane(s). Since heavy-duty vehicles have lower speeds, cars overtake more frequently when heavy-duty traffic share is high. However, with a higher share, this effect becomes smaller, as the number of cars decreases, and there are fewer overtaking desires.

5. Conclusion

In our parameter study, we varied car following, lane changing, and speed influencing parameters in PTV Vissim, and analyzed their impact on lane flow distribution. Wiedemann's parameters CC1 and CC3 are relevant as they determine the headway at which a vehicle activates a lane change desire. Although CC1 has an influence when using Wiedemann 99, the parameters bx_{add} and bx_{mult} have no influence on the lane flow distribution when using Wiedemann 74. We assume that the computation of the safety distance is implemented differently for both car following models. This should be further investigated. Since a free lane change is motivated by a speed difference to the vehicle ahead, all parameters influencing the speed have a strong impact on lane flow distribution. The lane flow distribution in simulations with Wiedemann 99 comes close to empirical findings from the literature. We recommend Wiedemann 99 car following model for questions related to lane flow distribution.

CC1 is one of the most relevant parameters for the calibration of freeway capacity. Since CC1 also has a strong influence on lane flow distribution, this aspect should be taken into account during calibration. For this purpose, empirical data of each lane of the investigated freeway should be used. If no measured data are available, the literature provides empirical lane flow distributions for different countries and legal regulations. The gradient and the heavy-duty traffic share must be adjusted in a traffic flow model according to local conditions. A change in the desired speed distributions influences the lane flow distribution, and can have an effect on capacity. We recommend to determine desired speed distributions empirically, and separately for cars and trucks, as there are important local differences. The remaining parameters to adjust the lane flow distribution in PTV Vissim are: CC3, and safety distance reduction factor. CC3 has similar impacts than CC1, however CC3 has barely any effect on capacity. The safety distance reduction factor influences both the lane flow distribution and the capacity. Since the effects of individual parameters are correlated, a multidimensional sensitivity study should be conducted.

Since software version 2020, PTV Vissim offers the possibility to adjust the driving behavior separately for each lane. Especially the lane flow in the middle lane(s) can hardly be influenced by the parameters presented here. The lane specific behavior could allow more detailed adjustments.

The presented work does not provide calibrated parameter values. Rather, we would like to point out that the lane flow distribution can change significantly if individual parameters are changed. The findings should be consulted when simulations of freeways are calibrated.

References

[1] Toledo, T., M. E. Ben-Akiva, D. Darda, M. Jha, and H. N. Koutsopoulos (2004) "Calibration of Microscopic Traffic Simulation Models with Aggregate Data" *Transportation Research Record: Journal of the Transportation Research Board* **Vol. 1876** No. 1: 10–19, http://dx.doi.org/10.3141/1876-02.

[2] Fellendorf, M. and P. Vortisch (2007) "Validation of the Microscopic Traffic Flow Model VISSIM in Different Real-World Situations".

[3] Dong, J., N. Hawkins, A. Houchin, N. Shafieirad, and C. Lu (2015) "Vissim Calibration for Urban Freeways: Final Report" *Institute for Transportation, Iowa State University*.

[4] Leyn, U. and P. Vortisch (2015) "Calibrating VISSIM for the German Highway Capacity Manual" *Transportation Research Record: Journal of the Transportation Research Board* **Vol. 2483** No. 1: 74–79, http://dx.doi.org/10.3141/2483-09.

[5] Duret, A., S. Ahn, and C. Buisson (2012) "Lane flow distribution on a three-lane freeway: General features and the effects of traffic controls" *Transportation Research Part C: Emerging Technologies* **Vol. 24**: 157–167, http://dx.doi.org/10.1016/j.trc.2012.02.009.

[6] Sparmann, U. (1978) "Spurwechselvorgänge auf zweispurigen BAB-Richtungsfahrbahnen" *Forschung Straßenbau und Straßenverkehrstechnik* **Heft 263**.

[7] Leutzbach, W. and F. Busch (1984) "Spurwechselvorgänge auf dreispurigen BAB-Richtungsfahrbahnen" *Institut für Verkehrswesen, Universität Karlsruhe*.

[8] Wu, N. (2005) "Impact of traffic regulation on lane flow - distribution and capacity of motorways" *Fifth international conference of transportation professionals, Xian, China*.

[9] Geistefeldt, J. (2007) "Verkehrsablauf und Verkehrssicherheit auf Autobahnen mit vierstreifigen Richtungsfahrbahnen" *Heft 30/2007, Lehrstuhl für Verkehrswesen, Ruhr-Universität Bochum*.

[10] Yousif, S., J. Al-Obaedi, and R. Henson (2013) "Drivers' lane utilization for United Kingdom motorways" *Journal of Transportation Engineering* **Vol. 139** No. 5: 441–447, http://dx.doi.org/10.1061/(ASCE)TE.1943-5436.0000531.

[11] Golias, J. and D. Tsamboulas (1995) "Macrolevel estimation of highway lane usage" *Journal of Transportation Engineering* **121** No. 1: 40–49.

[12] Chatterjee, S., S. Chakraborty, and S. K. Roy (2016) "An investigation of lane flow distribution on multi-lane highways under mixed traffic condition".

[13] Pompigna, A. and F. Rupi (2017) "Lane-distribution models and related effects on the capacity for a three-lane freeway section: case study in Italy" *Journal of Transportation Engineering, Part A: Systems* **Vol. 143** No. 10, http://dx.doi.org/10.1061/JTEPBS.0000080.

[14] Beentjes, R. M. (2012) "Performance of rush-hour lanes and plus lanes: a study to behavioral factors and design factors" *Master Thesis, Delft University of Technology*.

[15] Lee, J. and B. Park (2011) "Determining lane use distributions using basic freeway segment density measures" *Journal of Transportation Engineering* **Vol. 138** No. 2: 210–217, http://dx.doi.org/10.1061/(ASCE)TE.1943-5436.0000313.

[16] Sasahara, F., L. Elefteriadou, and S. Dong (2019) "Lane-by-Lane Analysis Framework for Conducting Highway Capacity Analyses at Freeway Segments" *Transportation Research Record*, http://dx.doi.org/10.1177/0361198119840609.

[17] Gunay, B. (2004) "An investigation of lane utilisation on Turkish highways" *Transport* **Vol. 157** No. 1: 43–49, http://dx.doi.org/10.1680/tran.157.1.43.36467.

[18] Gipps, P. G. (1986) "A model for the structure of lane-changing decisions" *Transportation Research Board*.

[19] Ramanujam, V. (2007) "Lane Changing Models for Arterial Traffic" *Master Thesis, Massachusetts Institute of Technology*.

[20] FHWA (2006) "NGSIM - Freeway Lane Selection Algorithm".

[21] Erdmann, J. (2015) "SUMO's Lane-Changing Model" *Modeling Mobility with Open Data (M. Behrisch and M. Weber, eds.), Springer International Publishing*: 105–123, http://dx.doi.org/10.1007/978-3-319-15024-6_7.

[22] PTV Group (2020) "PTV Vissim and PTV Viswalk Help".

[23] Hoogendoorn, S., Vehicle-Type and Lane–Specific Free Speed Distributions on Motorways. *Transportation Research Record*, 2005.