Layout of 2+1-routes in Germany - New findings

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This paper includes altogether 10 pages. One page includes the title page and another one the abstract with 190 words. The body of paper with 4,559 words including the references, 1 table and 9 figures (= 10 x 250 = 2,500 words) is presented on 8 pages. The total count of words is 7,059.

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ABSTRACT

The aim of the presented dissertation (Irzik, 2009) was to determine an optimal length for two-lane sections within 2+1-routes in dependence on various parameters. A correlation between traffic volume and share of incomplete dissolving processes has been used in order to define the necessary length of a two-lane section. A maximum length – depending on traffic volume and share of heavy goods vehicles – is also suggested. This restriction shall prevent that the length of a two-lane section and with it the length of the one-lane section of the opposite direction will increase excessively. Otherwise negative effects on platooning would have to be expected. Finally a minimum length according to traffic safety is recommended for two-lane sections within 2+1-routes. This recommendation is based on the relation between the share of vehicles changing from the passing to the right lane on the last 200 m of a two-lane section related to the total number of all passing processes and the number of observed conflicts while lane changing on the last 200 m. The overall result of the presented dissertation is a simplified method for determining the optimal length of two-lane sections within 2+1-routes.

1. INTRODUCTION

A 2+1-route is characterised by a single carriageway three-lane cross section. It consists of two-lane sections with a passing lane and one-lane sections before (= feeder sections), behind and besides each passing section (see figure 1). While the traffic flow in a passing section has the possibility to pass slow vehicles, the traffic flow in the opposite direction is not allowed to pass. At the same time vehicle platoons are arising in one-lane sections. Therefore, the passing lanes have to alternate in each direction along the whole 2+1-route. If vehicle platoons are not dissolved at the end of the passing sections, the level of service impairs and negative impacts on traffic safety will have to be expected.

In recent years a number of research projects dealt with traffic safety of and investigations into traffic flow on 2+1-routes (i.e. Weber, Löhe 2003; Brannolte, Baselau, Dong 2004; Gattis, Bhave, Duncan, 2006). Nevertheless up to now there have been no comprehensive findings concerning passing process and dissolving of platoons in dependence on marginal conditions relating to design and operation others than model based considerations. Therefore the prime aim of the presented dissertation (Irzik, 2009) was to develop a procedure in order to determine the optimal length of passing sections on 2+1-routes on the basis of empirical studies. The solution to a conflict of objective hereby formed a special problem: On the one hand passing sections must be long enough for all entering platoons to be dissolved at its end. On the other hand they must not be too long since this would have an adverse effect on the length of the opposing one-lane section and thus on platooning. Apart from determining the dimension of passing sections based on platoon dissolving, aspects of traffic safety were also included in the investigation. The research project "Passing process on 2+1-routes" (Friedrich, Dammann, Irzik, 2005) commissioned by the Federal Highway Research Institute constitutes the basis of the presented dissertation (Irzik, 2009).

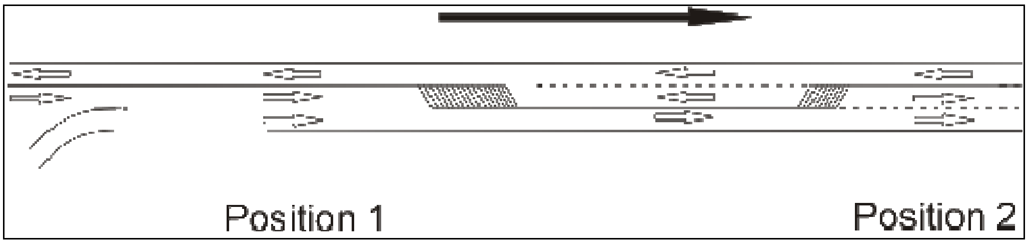


FIGURE 1 Schematic representation of operational form of 2+1-routes (Priemer, 2004)

2. METHODOLOGY

The summary of current scientific knowledge concerning this topic formed the initial step. After a description of the choice of investigated sections, the relevant parameters of traffic flow and passing process as well as platooning and dissolving of platoons were introduced. Following the description of the developed and applied investigation methodology for the empirical investigations, the procedure of the analysis of empirically obtained data as well as the used methods/techniques was listed. As a rule the obtained results were represented statistically, and if possible compared to results of previous studies. At first the speed and passing process (here especially the beginning and the end of passing) and platooning ahead of as well as within 2+1-routes were analysed. Finally different approaches to the determination of the length of passing sections required for dissolving platoons on 2+1-routes were tested.

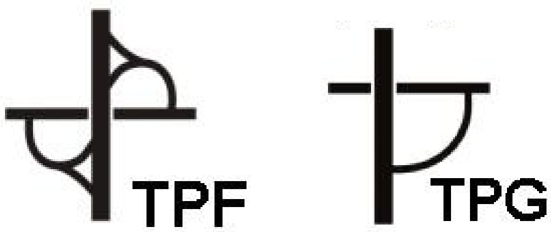
3. ANALYSIS OF LITERATURE

All studies dealing with traffic safety on 2+1-routes during the past few years show that 2+1-routes are characterised by a higher traffic safety, expressed in terms of accident cost rate, in comparison to other single carriageway cross sections outside built-up areas. However, due to the comparatively high speed level the average accident severity is slightly higher in comparison to narrower two-lane rural roads.

Weber, Löhe (2003) couldn’t conformed safety concerns regarding the opening of 2+1-routes for mixed traffic. But it must be kept in mind that Weber, Löhe observed small numbers of agricultural vehicles respectively a marginal share of bicycle traffic on these roads and resulting low accident figures only. Furthermore especially the simulation results obtained in the development of a design procedure for the up-date of the German Highway Capacity Manual (HBS, FGSV, 2001) proved an explicit negative influence of slow moving traffic on the quality of traffic flow (see Baselau, 2006, Brannolte, Baselau, Dong, 2004).

The work of Weber, Löhe (2003) contains a hint at a minimum length of passing sections for reasons of safety. In their study, Weber, Löhe (2003) recommend a minimum length of 1,000 m for passing lanes within 2+1-routes with mixed traffic. The accident analysis within the frame of their investigation showed a disproportionally high number of accidents on sections shorter than 1,000 m compared to sections with lengths exceeding 1,000 m.

Weber, Löhe (2003) also found out that an adapted alignment in combination with partially grade separated junctions (see figure 2) does not only have a positive influence on a homogeneous speed level but also on a lower accident cost rate. Palm, Schmidt (1999) already stated that – like for accidents on sections between junctions – the accident rate and accident cost rate for accidents at junctions are lower on 2+1 routes than on single carriageway two-lane cross sections. This can most likely be explained by the fact that the number of at-grade junctions on 2+1-routes is smaller than on two-lane rural road cross sections. The 2+1-route on the Federal Road B10 near Landau investigated by Kölle (1999) contained one partially grade separated and one partially at-grade junction (see figure 2). Despite a speed limit of 70 km/h in the junction area of the partially at-grade junction the accident cost rate for this junction area is more than twice that of the partially grade separated junction. As considering an almost equal accident rate, this result points at a substantially higher accident severity in the partially at-grade junction. This was due to the high speeds within the junction area, which were observed in defiance of the speed limit. Hence the predominant number of accidents at the partially at-grade junction occurred in the junction area of the major road B10. At the partially grade separated junction, however, only few accidents had to be registered. These were mainly damage only accidents that were caused by lane changes in the merging area with lane additions. Main accident locations were the at-grade parts of these partially grade separated junctions at the minor road. Kölle formed so called "composite systems" in order to determine the influence of junctions on the adjoining sections. A composite system consisted e.g. of the junction itself and 500 m of the adjoining sections. Therefore composite system no. 1 includes the partially at-grade junction, and no. 2 the partially at-grade junction. The comparison between these both systems showed that for the latter, the accident cost rate of system no. 2 amounts to only about a fifth of the accident cost rate determined for the system no. 1. Kölle's investigation included two further junctions, a partially grade separated junction and an at-grade junction, on a 2+1 route (B49). The accident cost rate at this partially grade separated junction was slightly higher than at the partially at-grade junction on the B10. But it was only half of the rate of the at-grade junction along the same 2+1 route. At the partially grade separated junction on the B49 there were also only few accidents caused by entering or exiting vehicles. Like the partially grade separated junction on the B10, that one on the B49 is characterised by a high level of safety as compared to other partially grade separated junctions investigated by Kölle.



TPF: partially grade separated
TPG: partially at-grade

FIGURE 2 Selected junction types according to the new guidelines for the design of rural roads (RAL) currently being developed (FGSV, 2007)

In terms of the existing findings regarding passing process and dissolving of platoons it had to be assessed that they were lacking adequate empirical verification. So the procedure developed by Roos (1989) is based on theoretical considerations. For this reason there were still uncertainties in the determination of optimal section lengths in dependence of traffic parameters. Therefore it seemed urgently necessary to broaden the knowledge about passing process and dissolving of platoons. It was found out that different definitions of platoons from literature exist. In this investigation a vehicle was assigned to a platoon if the gross time gap to the vehicle ahead or the platoon leader was below 3 s (following Roos and Brannolte, Baselau, Dong). In this case the platoon leader's speed must not exceed 90 km/h. Further is agreed that the platoon leader himself does not belong to the platoon. As a supplementary condition within this investigation it was agreed that compared to Roos und Brannolte, Baselau, Dong the vehicle must pass the platoon leader in the passing section. Otherwise it was assumed that vehicles which do not pass the platoon leader have already reached their desired speed in the feeder section and are therefore not obstructed in their movement. Because of the chosen investigation methods, the afore mentioned studies could not comply with this condition.

4. CHOICE OF TWO-LANE SECTIONS

As known from previous studies, the traffic situation especially on rural roads is influenced by a large number of factors. These could be related to traffic itself, road design or operation and could lead to some extent correlation. For this reason it is often impossible to quantify the influence of individual factors respectively any selected factors. In order to still get a result, as many potential influence factors as possible should be kept constant. Therefore in this investigation only 2+1 routes were considered

1. which are operated as a road for motor vehicles only,

2. which have a speed limit of 100 km/h,
3. where there are only partially grade separated junctions,
4. which have a slight gradient (±2 %), and
5. where the curviness is low,

because these parameters can be considered as being characteristic for 2+1 routes in Germany.

Eleven of the 15 investigated sections listed in table 1 start with a lane addition (see figure 3), the other four with an uncritical transition (see figure 4.). Those eleven sections with a lane addition cover a wide spectrum of section lengths between approx. 800 m to 1,700 m. The four sections starting with an uncritical transition vary between approx. 900 m to 1,400 m. Seven investigated passing sections are located at the beginning of the 2+1 route, i.e. at position 1 (see figure 1). Consequently the seven relating feeder sections are located outside the actual 2+1 route. Therefore they are part of a "normal" two-lane cross section. In contrast the remaining eight investigated passing sections (position 2 or higher) as well as their feeder sections are within the 2+1 routes. Each of these feeder section is also an opposite direction lane of another passing section.

Figure 3 Start of the two-lane passing section with lane addition at partially grade separated junction

Figure 4 Start of the two-lane section with an uncritical transition

TABLE 1 Investigated sections

investigated section	BP = bypass dt = direction towards	Federal State	Road No.	adt [veh/24]	HGV-share [%]	Position	Transition	Length [m]	L_{feeder} [m]
1	BP Jever, dt Wittmund	NI	B 210	13.000	8	1	lane add.	1.474	2.200
2	BP Jever, dt Wittmund	NI	B 210	13.000	8	2	lane add.	1.208	1.500
3	BP Jever, dt Wilhelmshaven	NI	B 210	13.000	8	2	lane add.	1.498	1.100
4	Kirchhain / Cölbe, dt Marburg	HE	B 62	13.000	8	1	lane add.	1.092	2.000
5	Kirchhain / Cölbe, dt Marburg	HE	B 62	13.000	8	2	lane add.	1.687	1.400
6	Kirchhain / Cölbe, dt Kirchhain	HE	B 62	13.000	8	1	lane add.	1.706	500
7	Paderb. / Schlangen, dt Horn-Bad Meinberg	NW	B 1	17.000	10	3	lane add.	828	1.800
8	Paderborn / Schlangen, dt Paderborn	NW	B 1	17.000	10	1	lane add.	1.403	3.500
9	Paderborn / Schlangen, dt Paderborn	NW	B 1	17.000	10	3	lane add.	1.195	1.400
10	Niederbiel / Leun, dt Limburg an der Lahn	HE	B 49	19.000	11	1	lane add.	895	2.600
11	BP Straubing, dt Landau an der Isar	BY	B 20	20.000	16	1	lane add.	1.296	1.200
12	Niederbiel / Leun, dt Limburg an der Lahn	HE	B 49	19.000	11	2	uncritical	929	1.200
13	BP Straubing, dt Landau an der Isar	BY	B 20	20.000	16	4	uncritical	1.146	1.400
14	BP Dachau, dt Dachau	BY	B 471	16.000	10	1	uncritical	1.258	1.500
15	BP Dachau, dt Fürstenfeldbruck	BY	B 471	16.000	10	2	uncritical	1.353	1.600

5. DETERMINATION OF OPTIMAL LENGTHS OF PASSING SECTIONS

In the scope of this study several approaches towards determination of required passing section lengths were examined. It is obviously that the length of the passing process depends amongst other things on the platoon length building up in the feeder section. Figure 5 shows the number of observed platoon lengths. From literature the 85 % percentile platoon length – with regard to an interval (see figure 6) – is seen as the decisive parameter for the dimensioning of the passing sections. But in the analysis of platooning it was found that this parameter cannot be determined logically and/or with a sufficiently accurate congruence on the basis of the data collected in the frame of the investigation.

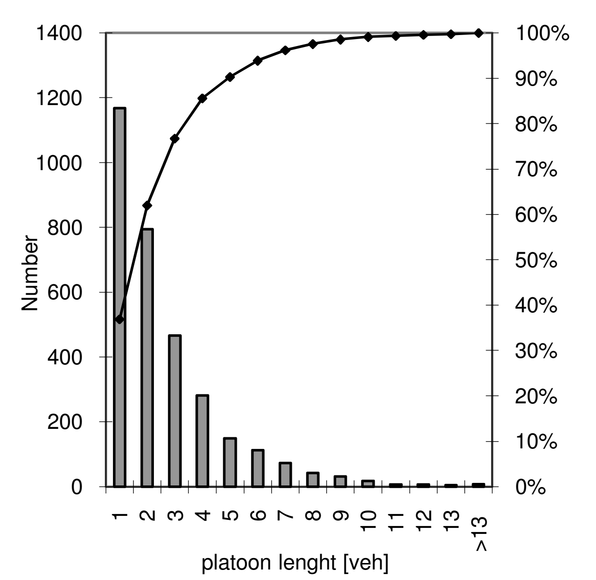


Figure 5 Number of observed platoon lengths (n=3.163)

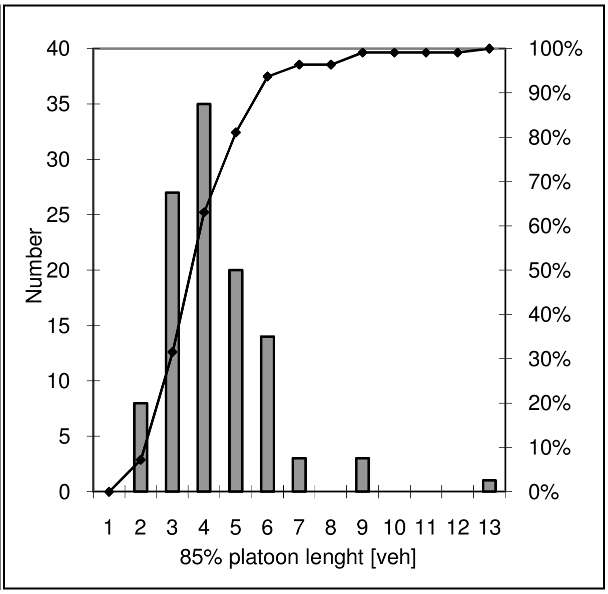


Figure 6 Number of 85 % platoon length (n=111)

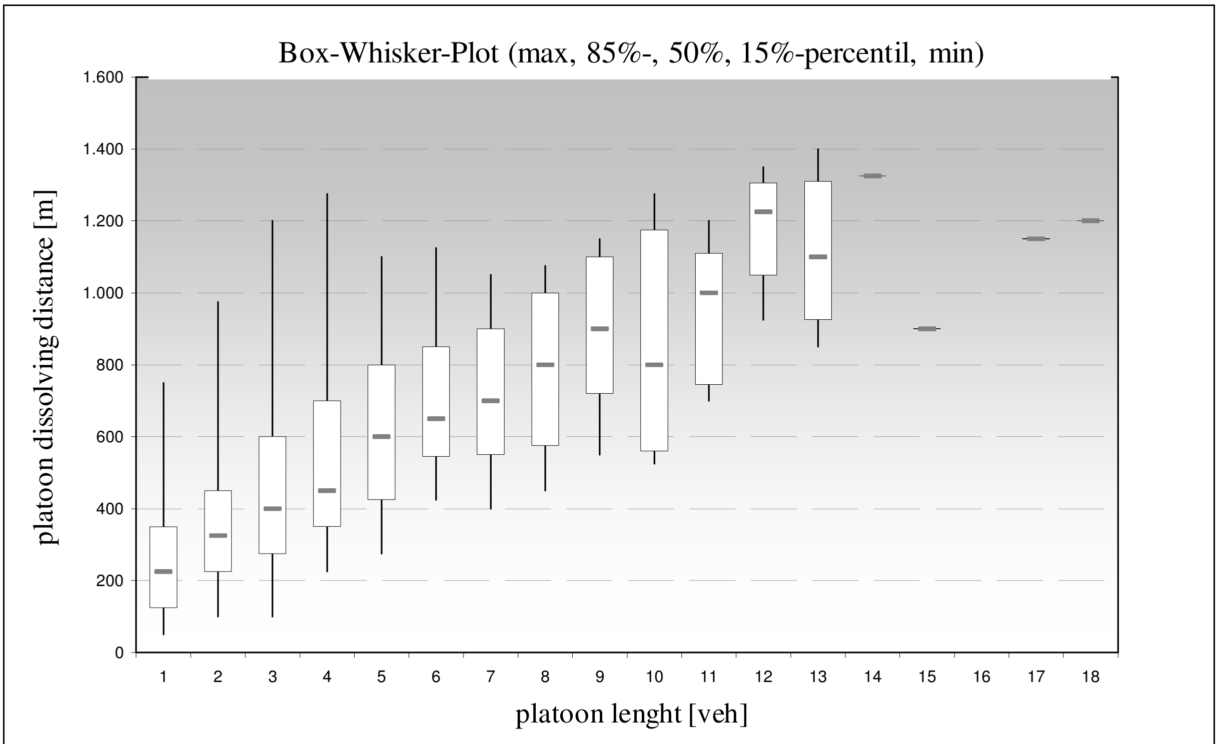


Figure 7 Platoon dissolving distance in dependency of the platoon length (Box-Whisker-Plots) (n=1.384)

However, a procedure for the determination of the section length on the basis of empirically monitored platoon dissolving distances (see figure 7) also shows some weak points. Such a procedure also developed in the scope of this study, based in general on the theoretical deliberations of Roos (1989). It has the decisive disadvantage of not taking into account the platoons that were not dissolved. Furthermore in this procedure it is necessary to consider influence factors which result from the design/lay-out of the transition at the beginning, the (absolute) position or the length of the passing sections as well as the traffic volume, the share of HGVs and probably a prohibition of overtaking for HGVs. All these factors make this procedure much more difficult.Detached from Roos procedure a different approach was pursued, which, in addition, is much easier to handle. In this approach the rate of platoons that were not dissolved are taken as a level of service in the determination of the passing section length.

In the analysis of platoon dissolving there were some platoons on individual investigation sections that could not be dissolved fully on the current lengths of these sections. Based on the total quantity of platoons during the investigation period, the rate of not dissolved platoons can be obtained. This rate is especially dependant on the traffic volume but also on the section length. So, if a level for the rate of not dissolved platoons is pre-set, the required section length can be determined in dependency of traffic volume based on this correlation.

Influencing factors arising from the length or position of the overtaking sections are implied in this procedure. Since all but one section, where platoons were not fully dissolved, were only found on investigated sections with a lane addition, there is no need to explicitly provide for the way the platoon leader needs for merging in form of a supplement to the length a platoon needs for dissolving. From the insights obtained into the platoon leaders' lane changing behaviour it appears admissible to adapt the required section lengths for the dissolving process in case of a beginning with an uncritical transition by a reduction. This is because on sections with lane addition the platoon leaders generally merged after 125 m, while on those investigated sections that begin with an uncritical transition the first vehicle to pass the platoon leader merged at the latest after 50 m in 85% of all cases. So the reduction can be 75 m.

No hints regarding e.g. a maximum platoon share which should be avoided according to aspects of safety can be gained from a comparison of parameters of platooning and the safety relevant parameters "crossing ghost island at the critical transition" respectively "sum of (weighted) conflicts on the last 200 m of a pssing section". With regards to the determination of an optimal length of passing sections, the results received in the analysis of platooning on feeder sections within 2+1 routes were used. It appeared that starting from a platoon share of 34.5 % (according to the definition used within the frame of this investigation) platoons with at least 7 vehicles in any platoon must be expected. It was shown that 15 % of all platoons of 7 vehicles required more than 900 m before they were dissolved. However, 95 % of the 1,384 platoons where the dissolving process was observed until the end needed less than 900 m to dissolve. Furthermore the frequency distribution of the 85 %-platoon lengths revealed that considering peculiarities of individual feeder sections a maximum 85 % platoon length of 7 vehicles can be assumed. As a result both aspects together are proposed to avoid platoons longer than 7 vehicles respectively the relevant share of platoons by restricting the length of the feeder section and correspondingly the length of the passing section in the opposite direction. Since a correlation between the share of platoons, the traffic volume, HGV-share and the length of the feeder section could be proved, this specification serves to determine a maximum length of a passing section. Due to the discovered effects an increasing HGV-rate leads to a decreasing maximum length (see figure 8). This means that several shorter sections should be preferred to fewer longer sections for higher HGV-rates. In principle this coincides with the recommendations regarding an optimum length contained in the RAS-Q 96 (FGSV, 1996) derived from the results of the project group "Intermediate cross sections" (Brannolte et. al., 1992).

6. RECOMMENDATIONS

6.1 General

Apart from recommendations for the determination of the optimal passing section length within a 2+1-route gained from this investigation, hints will be provided for cross section design and choice of junction type which are partially based on findings from previous studies but which have also been derived from available investigations in the frame of the dissertation.

6.2 Determination of the Optimal Length of a Passing Section

There are a number of marginal conditions that need to be observed in the application of the procedure developed within in the frame of this study because the investigated sections were specifically chosen with a good comparability of the passing sections regarding the determination of the required passing section lengths in mind. Due to the choice of the investigation sections influences of the pre-set constant design and operational characteristics could not be examined.

The new approach for the determination of the optimal length of an overtaking section is – strictly speaking – only applicable to 2+1-routes which fulfil the characteristics listed under number 4. As an additional marginal condition it must be considered that passing was prohibited for HGVs on investigation sections with a higher traffic volume and simultaneous higher HGV-rate. Traffic volumes between 400 vehicles per hour and direction and lengths below 800 m were excluded from the investigation and are also not within the application area for

2+1-routes as defined by the RAS-Q 96 (FGSV, 1996). A traffic volume of 1,300 vehicles per hour and direction must be considered as upper limit.

With a practicable procedure for the determination of the optimal passing section length in mind, the specification of a quality standard for the number of not dissolved platoons is suggested. In figure 8 the admissible respectively recommended passing section lengths are depicted depending on

- traffic volume,
- position within the 2+1-route (Pos.),
- HGV-rate and
- share of not dissolved platoons .

In order to limit the lengths of passing sections with regards to platooning in the one-lane sections of the opposite direction, a platoon share of 34.5 % according to the platoon definition applied in this study is recommended as "to be avoided" (see number 5). For such a platoon share, platoon lengths of more than 7 vehicles must be expected. The investigation did, however, show that platoons of such a length are quite rare but often characterised by extremely long platoon dissolving distances as compared to the total of observed platoons. For this reason it seams to be admissible to limit the length of passing sections according to the chosen criteria in order to avoid oversizing.

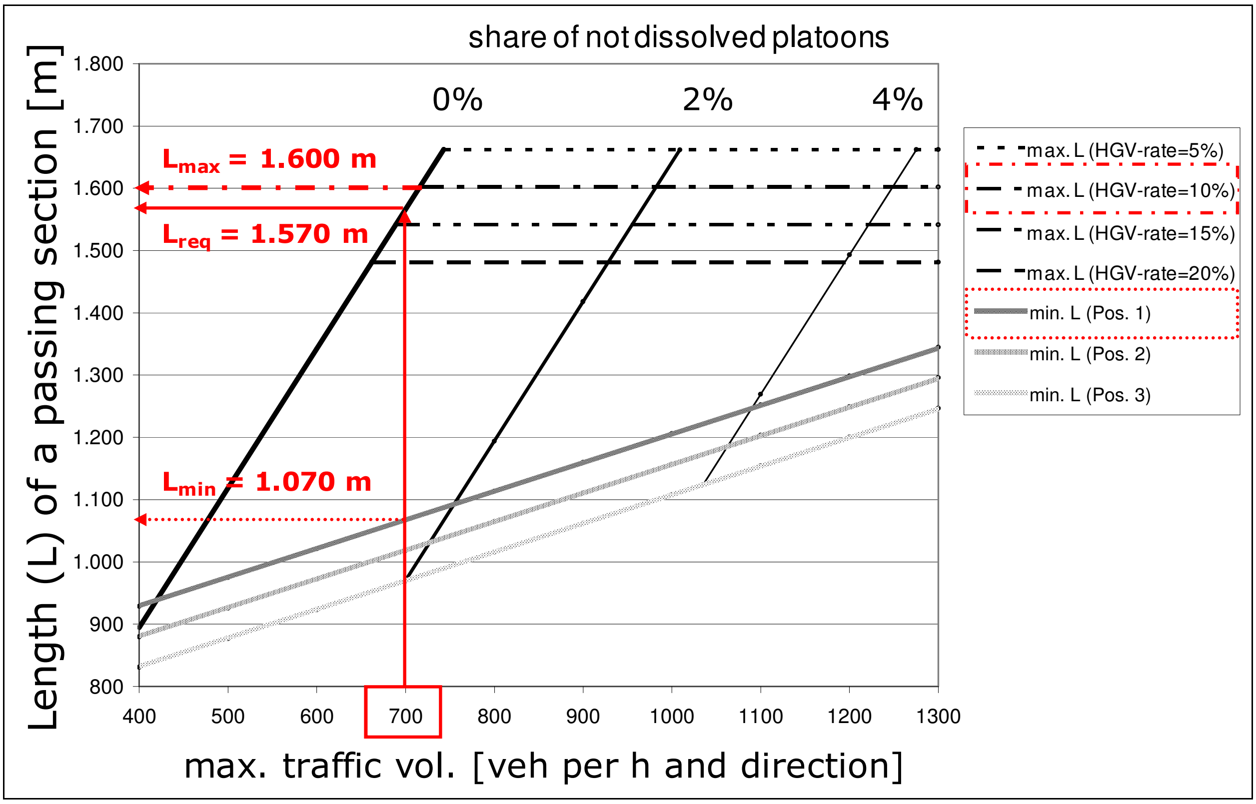


Figure 8 Determination of lengths of passing sections which begin with a lane addition at partially grade separated junctions

A rate of 32.5 % of vehicles, changing from the passing to the right lane at the end of a passing section, is seen to be critical and therefore must "be avoided" in the determination of the minimal length of passing sections derived from safety considerations. This specification is motivated by the fact that even though only for rates above 45 % an increasing number of (weighted) conflicts per vehicle had to be observed the range between 20 % and 45 % was not covered by the investigation. At a rate of lane changes at the end of 32.5 % a (weighted) number of 0.036 conflicts within 30 minutes per vehicle must be expected theoretically. This limit is considered to be admissible because in approx. one third of the 21 observed 30 minute intervals less (weighted) conflicts within 30 minutes per vehicle occurred.

For sections beginning with an uncritical transition a reduction of about 75 m of the required section length for complete platoon dissolving determined according to figure 8 appears to be admissible due to the results obtained in the analysis of platoon leaders and the resulting differences with regards to the start of platoon dissolving (see number 5). In these sections, also the maximum length of a passing section can be 200 m longer because only the ghost islands located at the transition areas must be added to the length of a passing section to reach the length of the one-lane section of the opposite direction. For sections that begin with a lane addition at a partially grade separated junction the junction area has to be considered in contrast to the comparatively short ghost island at an uncritical transition. This area was calculated with approx. 200 m.

Figure 8 shows as an example the determination of the required length (L_{req}) for a passing section under consideration of the maximum length (L_{max}) and the recommended minimum length (L_{min}) for passing sections at position 1 with a maximum traffic volume of 700 vehicles per hour and direction and a share of HGV of 10 %.

6.3 Cross Section Design

Within their study in 1999 Palm, Schmidt evaluated various lane and carriageway widths according to traffic safety by, inter alia, comparing various accident parameters. It became obvious that a lane width of 3.50 m with a 0.50 m shoulder should be preferred for safety reasons. However, to enable a passing of road maintenance or broken down vehicles on single lane sections within 2+1-routes without impairing the opposing traffic, a width of minimum 5.25 m should be provided. This would leave a 15 cm safety margin according to the legal vehicle width of 2.55 m as per the StVZO §32. The new German Guidelines for the Design of Rural Roads (RAL) (FGSV, 2007), currently being developed, therefore suggest to install a shoulder of 0.75 m next to the 3.50 m wide lane on the one side and a 1.00 m wide median on the other side (see figure 9). The wider median can additionally serve as a distinguishing criterion between the different design classes according to RAL (catchword "self explaining roads"). Findings relating to the optimal design of this median can be expected from a current research project.

The investigation by Weber, Löhe (2003) showed that even though on all routes included in their investigation the existing widths of the verges in the single lane sections were below the 2.50 m stipulated in the guidelines, this was not reflected in the accident occurrence. So it should be possible to narrow the verge width to only 1.50 m. However, if the section is located on a dam where there are crash barriers at the roadside (e.g. to prevent dropping off the road) the verge width should be at least 1.80 m to enable the installation of steel crash barriers with the impact range W4 (=1.30 m) (1.80 m = 1.30 m + 0.50 m distance from road edge to crash barrier).

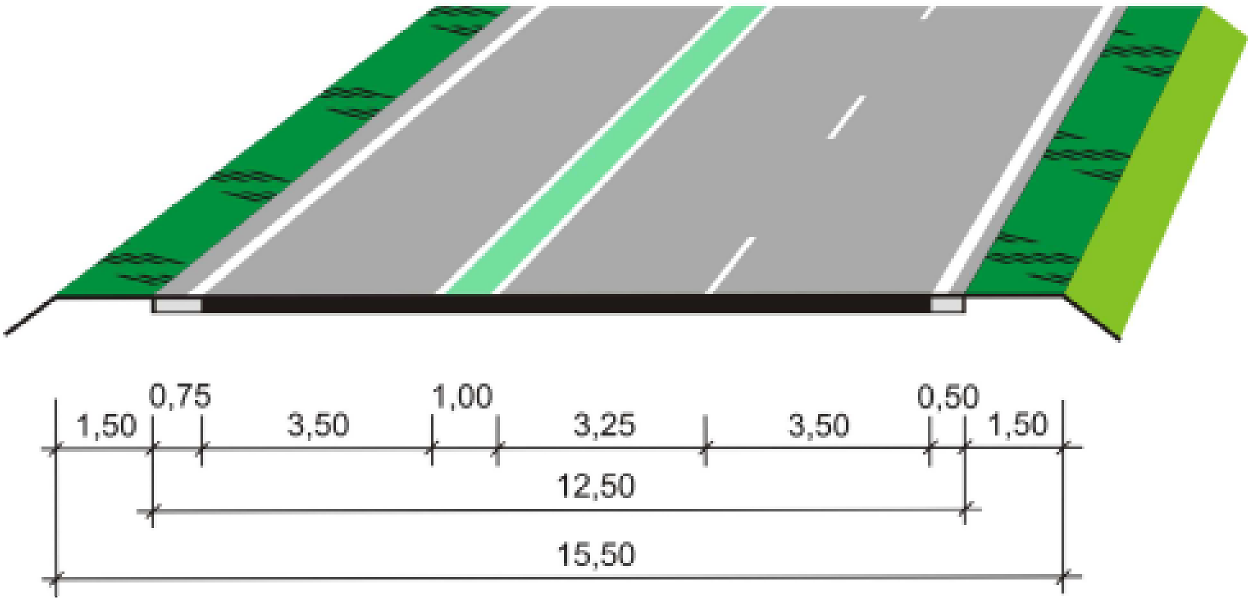


Figure 9 RQ 15,5 according to new guidelines for the design of rural roads currently being developed (RAL, FGSV, 2007)

6.4 Junctions

Since among the routes investigated by Weber, Löhe (2003) those with a relatively straight alignment and partially grade separated junctions displayed the most favourable accident cost rates and an even speed level, a high design standard should be intended for 2+1-routes wherever possible. It can be deduced from this demand that, if possible, uncritical transitions should be positioned in such a way that there will be a lane addition in junction areas for the entering traffic. There were no noteworthy disruptions of traffic flow and traffic safety observed by Weber, Löhe for this junction layout.

Work performed by Kölle (1999) supports the construction of partially grade separated junctions along 2+1-routes recommended by Weber, Löhe. Kölle recommends implementation of partially grade separated junctions wherever high travel speeds should be achieved for simulaneous short junctions distances and high junction volume. Since 2+1-routes in general belong to road category LS I (see FGSV, 2007) high travel speeds should be guaranteed. Simultaneously high junction volumes prevail on 2+1-routes.

The raised concerns that those "high" speeds will be "carried" from the links into the partially grade separated junction cannot be supported by the analyses of speed behaviour which were carried out within the frame of this investigation. First there must be stated that traffic reaches the (partially grade separated) junction only following a one-lane section, not following a passing section. For one-lane sections (inside and outside 2+1-routes) the results showed that excessive speeds had to be observed in only a minor number of cases and the legal speed limit was only violated in a range similar to that one to be found on "ordinary" two-lane rural road cross sections.

Furthermore the results derived from the investigation by Kölle (see number 3) showed that partially grade separated junctions on 2+1-routes hold a much higher safety level compared to the safety level of other junction types on 2+1-routes but also compared to other partially grade separated junctions on two-lane rural roads.

7. CONCLUSION

As a major contribution to the advancement of knowledge a practical procedure for the determination of the optimal length of a passing section on 2+1-routes could be developed within the frame of the dissertation presented in this paper. In contrast to the procedure for a determination of a necessary length with regards to the dissolving of platoons as known from literature (see Roos, 1989), it also contains recommendations concerning a minimum length derived from safety considerations as well as an upper limit in order to avoid excessive platooning in the opposite direction. The newly developed procedure is not based on theoretical deliberations but on comprehensive empirical studies as well as correlation and regression analyses. Together with the procedure for the assessment of traffic quality on roads with 2+1-layout developed by Brannolte, Baselau, Dong (2004) respectively Baselau (2006), traffic planners have two helpful instruments for planning 2+1-routes. While the procedure developed within the dissertation that forms the basis of this paper serves to determine the section lengths in the (pre-) planning stage, the other procedure by Brannolte, Baselau, Dong respectively Baselau can be used to assess the level of service on 2+1-routes.

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