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Accident Analysis & Prevention
Volume 203, August 2024, 107643

Safety effects of bypass lanes at unsignalized three-leg junctions

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Received 5 January 2024, Revised 3 May 2024, Accepted 16 May 2024, Available online 22 May 2024, Version of Record 22 May 2024.

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Highlights

- Bypass lanes are a low-cost alternative to left-turn lanes at yield-controlled T-junctions.
- Previous studies indicate that bypass lanes reduce accidents.
- Bypass lanes are often installed at high-accident junctions.
- When controlling for bias, bypass lanes increase accidents.

Abstract

Bypass lanes are a low-cost measure to increase capacity at unsignalized T-junctions without left-turn lanes that allow through-traffic to pass left-turning vehicles on the right. There is very limited knowledge about the safety effects of bypass lanes. We found six previous studies that could be summarized by means of *meta*-analysis, and the results show an average accident reduction of 10 percent. However, the results from previous studies are inconsistent and may be biased. Therefore, the present study has estimated safety effects of by-pass lanes in Norway, based on a sample of 2,227T-junctions (incl. 94 with bypass-lanes) for which relevant data was available for a period of up to 10years. We developed accident prediction models and conducted before-after analyses. The accident prediction models show that junctions with bypass lanes have 82 percent more accidents than junctions without bypass lanes, when controlling for endogeneity. Endogeneity occurs when the implementation of a measure is conditional on the frequency of crashes, as has been the case with bypass lanes. The before-after analysis shows that average accident numbers decrease after the installation of bypass lanes. However, when controlling for regression-to-the-mean (RTM), average accident numbers increase. RTM means that accident numbers would have been likely to decrease even without any measure because they had been exceptionally high in the before period. The control for potential biases in our study is likely to contribute to the discrepancy between results from our study and previous studies, most of which have not controlled for the same potential biases. We conclude therefore that bypass lanes, although favorable for capacity, are likely to be unfavorable for safety when compared to other unsignalized T-junctions without left-turn lanes. Unfavorable safety effects may partly be due to site specific conditions, such as road alignment and sight conditions, that contribute to rear-end collision risk or inappropriate driver behavior. However, this does not necessarily mean that bypass lanes never should be used. For example, at junctions where a bypass lane may solve capacity problems, and where site-specific conditions are favorable, bypass lanes may still be an acceptable solution.

Previous

Next

Keywords

Bypass lane; Junction; Accident prediction model; Before-after study; Empirical Bayes method; Endogeneity

1. Introduction

Designing junctions that are both safe and avoid delays is an important problem for highway agencies. At T-junctions on low-volume rural roads, left-turn lanes are often installed to increase capacity (Dissanayake and Esfandabadi, 2015, Indiana DOT, 2018). Bypass lanes are a low-cost alternative to left-turn lanes at unsignalized T-junctions (Bugg, 2012; Fitzpatrick et al., 2002), which are used in Australia, Denmark, Finland, Norway, the United States, and perhaps other countries. A bypass lane is basically a through lane that is widened to almost twice the standard lane width. When left-turning vehicles are waiting for their turn beside the center line, through traffic may use the rightmost part of the bypass lane to pass those vehicles. Between the main lane and the rightmost part of the bypass lane, a lane line may be marked, but this varies between countries; in Norway, bypass lanes do not have such a lane line. Compared to left-turn lanes, bypass lanes require less space and less maintenance, which makes them cheaper, while they may provide similar benefits to capacity (Fitzpatrick et al., 2002; Esfandabadi, 2014).

The standard design of a bypass lane at three-leg junctions in Norway is shown in Fig. 1. Two thirds of the bypass lane should be before the point where vehicles are turning left. The bypass lane (from curb to center lane) should be 3.0–3.5 m wider than a normal lane.

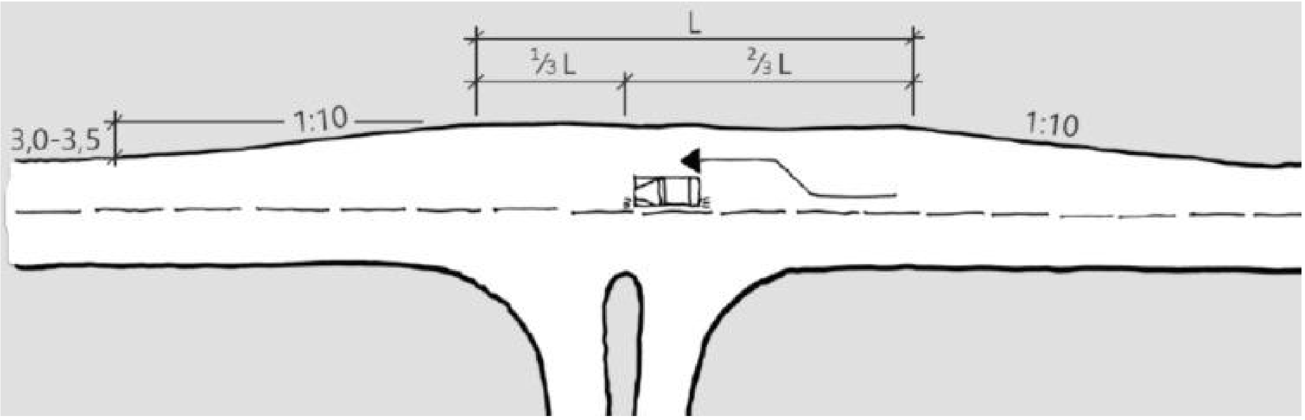

Fig. 1. Design of bypass lanes at three-leg junctions in Norway (Statens vegvesen, 2023).

Very little is known about the safety effects of this design. The objective of this paper is to evaluate the safety effects of bypass lanes at three-leg junctions. In addition to summarizing results from previous studies, we developed accident prediction models and conducted before-after analyses. As we will show in the following section, previous studies yield highly mixed and uncertain results, and most results may be biased. Therefore, we will use different methodological approaches on the same dataset (and subsets of this dataset). This approach can generally be expected to yield more robust results than results from one single method. Additionally, we will address the most common biases, namely regression-to-the-mean in before-after studies, and endogeneity in the accident prediction models. These biases and how they are addressed in this study, is explained in the following sections.

2. Safety effects in previous studies

A search for relevant studies was made on Google Scholar. Various search terms were used to identify papers about bypass lanes. In addition to “bypass lane” we included “auxiliary lane”, “flyby lane”, “passing lane”, and “passing blister” in our search. We also used possible terms in Scandinavian languages, German, and Dutch. Terminology is not standardized, but the term bypass lane appears to be the most common. However, all search terms are also used for other measures. In addition to a search term for bypass lanes, we included one of the following in all searches: accident, crash, injury, fatality, and risk. The search was not restricted in time, region, or language. We were most interested in quantified effects that can be summarized in *meta*-analysis, we focused on studies that have reported accident numbers or a quantitative estimate of effect, as well as some measure of uncertainty (e.g. confidence interval or standard deviation of the estimate of effect). The most common reasons for excluding studies were that studies were not about bypass lanes according to our definition, that they did not investigate safety effects, or that they did not report enough information for inclusion in *meta*-analysis. We ended up with six studies that could be included in a *meta*-analysis. Table 1 shows the results from each individual study as well as the summary effect based on *meta*-analysis.

Table 1. Previous studies of bypass lanes at junctions.

Study	Study design	Percentage change of accident numbers	95% confidence interval (%)
Dissanayake and Esfandabadi, 2015 (USA)	Before-after	−50	(−80; +24)
Giæver & Holt, 1994 (Norway)	Before-after	−30	(−53; +3)
Peltola & Mesimäki, 2019 (Finland)	Cross-sectional	−18	(−30; −5)
Preston & Schoenecker, 1999 (USA)	Before-after	−5	(−22; +15)
Kulmala, 1995 (Finland)	Cross-sectional	+5	(−29; +50)
Kulmala, 1992 (Finland)	Before-after with control for RTM	+24	(−43; +170)
All studies, summary effect from *meta*-analysis	**Random-effects model**	**−10**	**(−22; +4)**

The summary estimate from *meta*-analysis indicates an accident reduction of 10 percent which is not statistically significant. The summary estimate of effect is based on a random-effects model of *meta*-analysis. This model accounts for the fact that estimates of effect may vary systematically between studies. For a technical description of *meta*-analysis, see Elvik (2018).

However, the results from the individual studies are not only highly heterogeneous and uncertain, which is accounted for in *meta*-analysis. Most results may additionally be biased: Results from before-after studies can potentially be affected by regression-to-the-mean (RTM). RTM may occur in before-after studies when there were exceptionally many accidents in the before period. In such cases accident numbers will most likely decrease in the after period even without any effective measure, and the results from the study may therefore be overly optimistic (Elvik, 2008). Among the before-after studies in Table 1, only one has controlled for RTM. A potential bias in cross sectional studies is endogeneity: If a measure is mainly implemented at high-crash locations, these locations may still have more accidents than other locations, even if the measure is effective in reducing accident numbers. However, when endogeneity is not explicitly controlled for, results from cross sectional studies may be unduly unfavorable. Among the cross-sectional studies in Table 1, none has accounted for endogeneity.

Studies that could not be included in *meta*-analysis because they did not provide sufficient information, do not help to shed light on the results in Table 1 because they are also very heterogeneous. One of them found a reduction of injury accidents by 11 percent and an increase of fatal accidents by 130 percent (Ermer et al., 1991, USA). Another study found a 15 percent decrease of accident numbers (Rajamäki, 2008, Finland). A third study found varying and uncertain effects on accident severity (Preston & Schoenecker, 1999, USA).

Regarding the effect of bypass lanes on specific accident types, there are also contradictory findings. Rear-end collisions were found to increase in one study (Ermer, 1991), and in Australia, concerns about rear-end collisions have led to very restrictive criteria for implementing bypass lanes (Austroads, 2023). Another study found no effect of bypass lanes on rear-end collisions (Peltola & Mesimäki, 2019). In contrast to these findings, bypass lanes are assumed to *resolve* rear-end collision problems according to Kostyniuk & Massie (1994). Another potential problem with bypass lanes is that they may not always be used as intended; for example, some drivers use them like ordinary passing lanes (Dissanayake and Esfandabadi, 2015, McCoy and Hoppe, 1986).

In summary, results from previous empirical studies are heterogeneous, uncertain, and inconclusive regarding the safety effects of bypass lanes. The present study addresses the most important potential biases in most previous studies and aims to clarify the relationships between bypass lanes and accidents.

3. Data and analyses

We investigated the effects of bypass lanes on accidents with two different approaches, one based on accident prediction models and the other on before-after analyses. For both approaches, data were collected for 2227 yield-controlled three-leg junctions on two-lane roads. All junctions have a speed limit of 40–80 km/t on the major road, and none of them is channelized, has a median on the major road, or speed cameras. Traffic volume was mostly an AADT between 1,000 and 15,000 on the major road. Traffic volume on the minor road was known for only 190 junctions. A bypass lane existed at 94 junctions at the end of the period covered by the data. These are all bypass lanes in Norway that could be identified in the National road data base.

Data for each junction covered a period of up to ten years (2010–2019); however, data was not available for all junctions in all years, and years with major changes (e.g. if left-turn lanes were installed) were excluded. Data were available for a total of 20,194 junction-years. The data were provided by the Norwegian Public Roads Administration (NPRA), mainly based on the National road data base. Information about the existence and installation years of passing lanes was collected manually by the NPRA.

Table 2 shows the number of accidents distributed by junction-years. The mean number of accidents per junction per year was 0.014242, with a variance of 0.015131. The distribution of accidents between junctions per year was almost entirely random. Only 5.9 percent of the total variance was systematic, i.e. constituted an overdispersion compared to the purely random variation of the Poisson distribution. Additionally, the p-value of the Chi-square test is statistically significant for the Poisson, but not for the negative binomial distribution. These results indicate that it will be more adequate to develop the accident prediction models as negative binomial model, rather than Poisson models.

Table 2. Distribution of accidents between junctions included in the study.

Number of accidents per junction	Number of junction-years	Expected by Poisson distribution[a]	Expected by negative binomial distribution
0	19,876	19,867	19,876
1	265	283	266

Number of accidents per junction	Number of junction-years	Expected by Poisson distribution[a]	Expected by negative binomial distribution
2	11	2	10
Total	20,152		
Chi-square test		X^2=41.212; df=2; p<0.000	X^2=0.103; df=2; p=0.9494

a

Random variation: 94.1 %, systematic variation: 5.9 %.

Fig. 2 shows an overview of the analyses that are described in the following sections. First, we developed accident prediction models, including one that controls for endogeneity (model 4) and one that is used as safety performance function in the EB analysis in chapter 5. The before-after analyses include a simple analysis without comparison group, and an Empirical Bayes analysis.

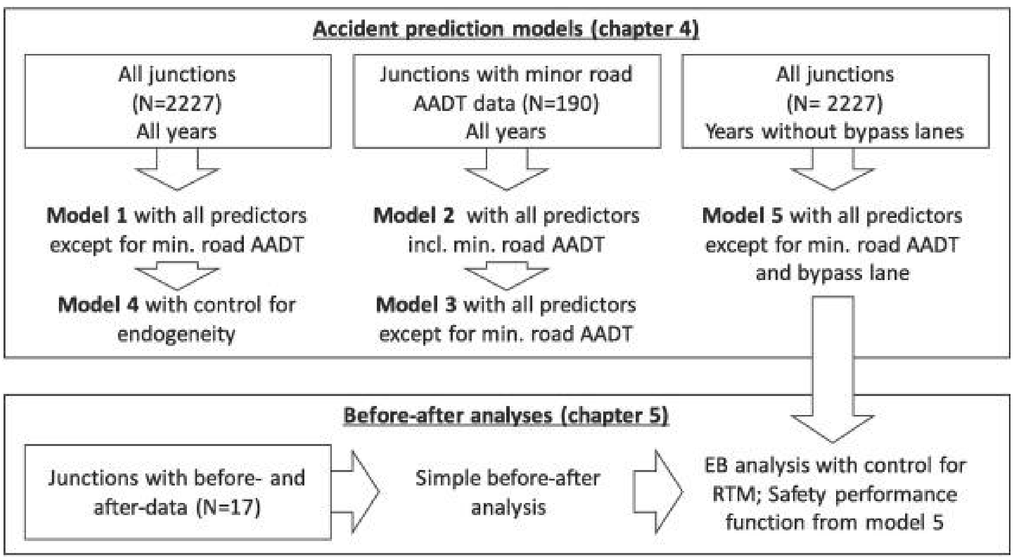

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Fig. 2. Overview of analyses and models in the present study.

4. Accident prediction models

Accident prediction models were developed first for all junctions and then only for those junctions for which data on minor road volumes were available (Table 3). The empirical distribution of accidents per junction per year (Table 2) fits the negative binomial distribution almost perfectly. When developing accident prediction models, negative binomial regression was applied. Model 1 is based on 287 accidents, and models 2 and 3 are based on 75 accidents.

Table 3. Accident prediction models 1–3 for three-leg junctions in Norway (statistically significant coefficients in bold).

	Model 1: All junctions (N=20152)		Model 2: Junctions with minor volume data (N=1828)		Model 3: As model 2, without minor volume predictor (N=1828)	
	Coeff. (sd)	**p**	**Coeff. (sd)**	**p**	**Coeff. (sd)**	**p**
Bypass lane	**0.882** (0.194)	0.000	**0.708** (0.312)	0.023	0.353 (0.297)	0.235
Ln($AADT_{major\ road}$)	**1.159** (0.098)	0.000	**0.775** (0.213)	0.000	**1.049** (0.193)	0.000
Ln($AADT_{minor\ road}$)			**0.607** (0.166)	0.000		
Share of heavy vehicles (%)	**−0.034** (0.016)	0.034	0.036 (0.032)	0.265	−0.006 (0.032)	0.846
Speed limit 40 km/h	−0.607 (0.533)	0.255	−1.182 (0.747)	0.114	−0.831 (0.744)	0.264
Speed limit 50 km/h	**−0.548** (0.180)	0.002	**−0.774** (0.321)	0.016	−0.572 (0.315)	0.069
Speed limit 60 km/h	**−0.454** (0.179)	0.011	−0.593 (0.330)	0.072	−0.484 (0.330)	0.143
Speed limit 70 km/h	**−0.727** (0.231)	0.002	**−0.878** (0.421)	0.037	**−0.925** (0.427)	0.031
Speed limit 80 km/h	(Ref.)		(Ref.)		(Ref.)	
2019	**−1.017** (0.302)	0.001	**−1.961** (0.761)	0.010	**−1.967** (0.76)	0.010
2018	**−0.791** (0.281)	0.005	**−1.258** (0.573)	0.028	**−1.252** (0.573)	0.029
2017	**−0.597** (0.265)	0.024	−0.748 (0.470)	0.112	−0.721 (0.470)	0.125
2016	**−0.548** (0.262)	0.037	−0.705 (0.470)	0.134	−0.716 (0.470)	0.127
2015	−0.367 (0.251)	0.144	−0.382 (0.436)	0.381	−0.406 (0.435)	0.351
2014	−0.209 (0.241)	0.386	−0.863 (0.495)	0.081	−0.852 (0.494)	0.085
2013	−0.507 (0.262)	0.053	−0.827 (0.495)	0.095	−0.850 (0.494)	0.086
2012	−0.049 (0.233)	0.834	−0.478 (0.435)	0.272	−0.454 (0.434)	0.295
2011	−0.099 (0.238)	0.677	−0.112 (0.401)	0.779	−0.106 (0.401)	0.790
2010	(Ref.)		(Ref.)		(Ref.)	
Channelization on minor road	**0.538** (0.155)	0.001	−0.483 (0.268)	0.071	−0.210 (0.256)	0.411
Constant term	−12.878 (0.864)	0.000	−13.26 (1.911)	0.000	−10.972 (1.707)	0.000
Overdispersion parameter	1.176 (0.684)		0.000 (0.002)		0.000 (0.002)	
Elvik-index	0.728		1		1	

Given the low number of accidents per junction, these models may be affected by the low mean value problems discussed by Lord (2006). A low mean value leads to instability in the overdispersion parameter of negative binomial regression models and thus makes it difficult to assess how well these models fit the data or determine if an overfitted model has been developed. These points are discussed further below.

Model 1 is based on all junctions, including those without volume data for the minor road. Model 2 includes only junctions with volume data for all three legs. Model 3 includes the same set of junctions but omitted the variable for volume on the minor road. Models 2 and 3 were developed to investigate if there are systematic differences between junctions with and without minor road volume data. This might be the case if, for example, minor road volume information is more often available at junctions with a higher geometric standard. Such differences might introduce bias.

In the datasets for model 2 and 3, only 1.2 percent of the variation in the number of accidents is systematic. The standard error of the overdispersion parameter in these models was considerably larger than the best estimate of the parameter. There is a non-negligible probability that the overdispersion parameter is negative, which implies an overfitted model. An overfitted model explains part of the random variation in the number of accidents in addition to the systematic variation. Coefficients in models 2 and 3 may therefore be partly spurious. Model 1 is not overfitted. It explains about 73 percent of the systematic variation in the number of accidents according to the Elvik-index of goodness-of-fit (Fridstrøm et al., 1995).

The coefficient for traffic volume on the main road (the volume predictor in all models is the natural logarithm of the Annual average daily traffic, AADT) in model 1 has a value of more than 1, suggesting that the number of accidents increases more than proportionally with volume. The value of the coefficient for traffic volume in model 1 is likely to have an omitted variable bias. This is confirmed by model 2, in which a predictor for minor road volume is added, and in which the coefficient drops from 1.159 to 0.775. The coefficient for minor road volume is 0.607. In model 3, minor road volume was omitted and the coefficient for traffic volume on the major road again has a value above 1 (1.049).

The coefficient for bypass lane is positive in all models. This indicates that junctions with bypass lanes have more accidents on average than junctions without bypass lanes. According to model 1, bypass lanes increase the number of accidents by 142 percent with a 95%-confidence interval from +65 to +253 percent. Only in model 3, the coefficients for bypass lanes is not statistically significant. Moreover, one cannot conclude that building bypass lanes increases the number of accidents because the results may be affected by endogeneity. This implies that bypass lanes may have been implemented at junctions that had a higher expected number of accidents than other junctions, and junctions with bypass lanes may still have more accidents than others, even if the bypass lanes had an accident reducing effect.

To test for endogeneity, a logistic regression was run to identify variables predicting the presence of a bypass lane (Kim & Washington, 2006; Table 4). The dependent variable is the existence of a bypass lane in the following year. A previous accident is a strong predictor, with an odds ratio of 5.143. This supports the hypothesis that the results from the accident prediction models in Table 3 are affected by endogeneity (Table 5).

Table 4. Logistic regression model for testing endogeneity: existence of bypass lane in the following year as dependent variable.

	Junctions without bypass lane in current year (N=17 420)		
	OR	**Std. Err.**	**P>z**
Accident	**5.143**	1.596	0.000
Ln(AADT)	**2.697**	0.442	0.000
Share of heavy vehicles (%)	**1.108**	0.017	0.000
Speed limit 40km/h	**0.640**	0.664	0.667
Speed limit 50km/h	**0.215**	0.082	0.000
Speed limit 60km/h	**0.833**	0.213	0.474
Speed limit 70km/h	**1.833**	0.499	0.026
Speed limit 80km/h	(reference)		
2019	(reference)		
2018	**0.130**	0.081	0.001
2017	**0.170**	0.093	0.001
2016	**0.308**	0.136	0.008
2015	**0.479**	0.181	0.052
2014	**0.622**	0.219	0.176
2013	**0.687**	0.237	0.275
2012	**0.756**	0.252	0.402
2011	**0.999**	0.317	0.998
2010	(reference)		
Channelization on minor road	**2.162**	0.506	0.001
Constant term	**0.000001**	1.52E-06	0.000

Table 5. Outcome model (model 4) with control for endogeneity: accidents as dependent variable.

	Junctions without bypass lane in current year (N=17 420)		
	Coeff.	**Std. Err.**	**P>z**
Bypass lane	**0.598**	0.223	0.007
Ln($AADT_{major\ road}$)	**1.259**	0.106	0.000
Speed limit 40km/h	(Reference)		
Speed limit 50km/h	**−0.047**	0.573	0.934
Speed limit 60km/h	**0.025**	0.576	0.965

	Junctions without bypass lane in current year (N=17 420)		
	Coeff.	**Std. Err.**	**P>z**
Speed limit 70km/h	**−0.251**	0.598	0.675
Speed limit 80km/h	**0.478**	0.581	0.411
Channelization on minor road	**0.657**	0.1680	0.000
Constant term	**−15.016**	1.055	0.000
R	**1.584**	0.478	0.000

To control for endogeneity, a two-stage analysis was performed based on the instrumental variable approach described by Katrakazas et al. (2021). The analysis was performed in R (ivtools; Sjolander & Martinussen, 2019). According to this approach, two models are estimated: one model for exposure (in this case, the existence of a bypass lane), and one model for the outcome (accidents). In the exposure model, the existence of a bypass lane is predicted by:

- Ln(AADT) for the previous year
- Presence of bypass lane in the same junction in previous years (none of the bypass lanes were removed during the study period)
- Average number of accidents in previous years
- Channelization on minor road (dummy)
- Speed limit of previous year (set of dummy variables).

As data from previous years was used to predict the probability of a bypass lane for a given year, the first year of data (year 0) for all junctions was excluded. The data included up to 10years per junction, hence the number of years included in “previous years” varied from 1 to 9.

The outcome model includes the estimated probability of a junction having a bypass lane, that is calculated in the exposure model, as a predictor variable to control for endogeneity. Other predictor variables are the same as in the models described above (Table 3). However, both exposure and outcome model are quasi-Poisson models.

In the outcome model (model 4), the coefficient for bypass lane remains positive. This suggests that the predicted number of accidents at junctions with a bypass lane is about 82 percent higher than at junctions without a bypass lane, when variables listed in Table 3 and endogeneity are controlled for. The 95%-confidence interval ranges from +17 to +182 percent.

5. Before-after analyses

Before-after analyses of the effects on accidents of implementing bypass lanes were possible for those junctions where a bypass lane was implemented between 2010 and 2019. The year of installation is omitted from analysis to avoid that the construction period affects the results and because data was only available for a whole year at a time. Table 6 shows the numbers of junctions and accidents that could be included in the before-after study, as well as the numbers of accidents at these junctions in the before and after period. Predicted numbers of accidents were calculated for each junction in the before- and after period with accident prediction model nr. 5 (Table 7). Expected accident numbers are explained below (empirical Bayes analysis).

Table 6. Numbers of junctions included in the before-after analysis with observed, predicted, and expected accident numbers.

	Before	**After**
N of junctions	17	17
N of junctions * years	86	63
Observed N of accidents	11	5
Accidents per mill. vehicles (major road)	23.7	16.4
Predicted N of accidents	1.918	0.984
Expected N of accidents		1.244

Table 7. Accident prediction model (model 5) for three-leg junctions without bypass lanes in Norway (N=19298; statistically significant coefficients in bold).

	Coeff. (sd)	**p**
Ln(AADT$_{major\ road}$)	**1.261** (0.109)	0,000
Share of heavy vehicles (%)	−0.034 (0.019)	0,069
Speed limit 40km/h	−0.779 (0.621)	0,209
Speed limit 50km/h	**−0.636** (0.207)	0,002
Speed limit 60km/h	**−0.561** (0.207)	0,007
Speed limit 70km/h	**−1.008** (0.304)	0,001
Speed limit 80km/h	(ref.)	
2019	**−1.054** (0.334)	0,002
2018	**−0.978** (0.325)	0,003
2017	**−0.569** (0.286)	0,047
2016	**−0.604** (0.291)	0,038
2015	−0.342 (0.270)	0,205
2014	−0.397 (0.276)	0,150
2013	**−0.574** (0.291)	0,048

	Coeff. (sd)	p
2012	−0.129 (0.258)	0,617
2011	−0.307 (0.273)	0,262
2010	(ref.)	
Channelization on minor road	**0.642** (0.179)	0,000
Constant term	−13638 (0.864)	
Model for overdisp. par.		
Ln($AADT_{major\ road}$)	−1.263 (0.534)	0,018
Constant term	11.864 (4.523)	0,009

The number of accidents per mill. Vehicles in the before period (23.7) is over three times as high as at all junctions without bypass lanes that are included in accident modeling (6.9). Thus, it is likely that there will be a large regression-to-the-mean effect in these data.

Compared to junctions that had no bypass lanes during the whole study period, the junctions that were included in the before-after analyses, had higher volumes. The average AADT on the main road was 4975 for junctions included in the before-after analyses in the before-period, while the AADT in 2010 was 3580 at junctions that never had bypass lanes, and 6034 for all junctions that had bypass lanes in at least one year of the study period.

5.1. Simple before-after analysis

Since the bypass lanes were installed at different times at all junctions, it was not possible conduct a common before-after analysis with comparison group. Therefore, we conducted a simple before-after analysis without comparison group. The results show that the number of accidents per mill. vehicles on the major road has decreased by 31 percent (from 23.7 to 16.4; Table 6), with a p-value of 0.82, as calculated with the estimation procedure described by Hauer (2008).

However, because of the large expected RTM effect, the result is likely to be biased in favor of bypass lanes. It may also be affected by general changes in accident risk, which has decreased considerably in Norway over the last decades (Elvik & Høye, 2023).

When observed accident numbers in the before- and after period are compared to predicted accident numbers in the before and after period (Table 6) to control for changes in volumes and general trends over time, accidents have decreased by 11 percent (p=0.49). This result may still be affected by changes in traffic patterns or road conditions over time; however, none of the junctions had major changes that would be expected to affect accident numbers such as signalization or larger reconstruction projects. The result may also be affected by RTM, which is addressed in the Empirical bayes analysis in the next section.

5.2. Empirical Bayes analysis

To control for regression-to-the-mean, the change of the number of accidents from the before- to the after-period has been estimated with the empirical Bayes (EB) method (Hauer et al., 2002).

As a first step, the EB estimate of the expected number of accidents in the after-period was calculated for each junction as a function of:

- The predicted accident numbers in the before and after periods, which is calculated for each junction with accident prediction model 5 (Table 7); this model is based on the same junctions as model 1 (Table 3), however, junctions with bypass lanes and the predictor for bypass lanes are omitted from the model,
- The observed accident numbers in the before period, and
- Weights that are based on the overdispersion parameter of accident prediction model 5.

The expected number of accidents is higher than the predicted number of accidents because of the high observed number of accidents in the before period. This upwards adjustment is the part of the EB analyses that reduces the potential bias by RTM: By comparing the observed number if accidents in the after period to the expected, rather than the predicted number of accidents, one takes into account that the number of accidents in the before period may have been exceptionally high. The sum of these expected accident numbers at all junctions is 1.24 (Table 6). The observed number of accidents in the after-period was 5 (Table 6). The ratio of these numbers is 5/1.24=4.020, suggesting a fourfold increase in the number of accidents after installation of bypass lanes However, this result may be biased.

In the second step, an unbiased EB-estimate of effect for all junctions has been calculated:

$$\text{EB - estimate (unbiased)} = \frac{O_a/E_a}{1+Var(E_a)/E_a^2} \tag{1}$$

where O_a and E_a are the observed and expected numbers of accidents in the after period, respectively. The result is 3.63, i.e. an increase of the number of accidents by 263 percent. Based on the standard deviation of the unbiased EB-estimate, calculated as described by Hauer (1997), the 95-percent confidence interval ranges from −100 percent to 658 percent. In other words, the estimated increase in the number of accidents is extremely uncertain, which is due to the small number of accidents in the after period.

6. Summary and discussion

Do we know more about the effects on safety of bypass lanes at junctions than we did before the study presented in this paper was made? If knowledge grows by means of successful replication of studies, the answer is no. Most previous studies found that bypass lanes reduce the number of accidents, and the summary effect based on six studies is an accident reduction by 10 percent. However, the result is non-significant, the results from the individual studies are mixed and for the most part highly uncertain, and most studies are before-after studies without control for regression-to-the mean, or case control studies without control for endogeneity.

The present study has used two different approaches to shed light on the effects of bypass lanes at T-junctions on rural two-lane roads in Norway.

First, we developed accident prediction models for 2227 unsignalized T-junctions on rural two-lane roads in Norway. These show that junctions with bypass lanes on average have 142 percent more accidents than otherwise comparable junctions without bypass lanes. However, bypass lanes are often installed at junctions with exceptionally high accident numbers. Therefore, the results are likely to be affected by endogeneity. With statistical control for endogeneity, the difference between junctions with and without bypass lanes is smaller, but junctions with bypass lanes still have more accidents (+82 percent) than those without.

Second, we conducted a before-after study that is based on a 17T-junctions where bypass lanes were installed during the study period. When volumes and general trends are taken into account, accident numbers decreased by 11 percent from the before to the after period. However, because of high accident numbers in the before period, the results are likely to be affected by regression-to-the-mean. When regression-to-the-mean is statistically controlled for with the empirical Bayes method, the results show that accidents increase on average by 263 percent. Because of the small number of accidents in the after period, this estimate is extremely uncertain. However, an increase of the number of accidents is reasonable, given the small decrease without control for regression-to-the-mean and the high number of accidents in the before situation, which indicates a large regression-to-the-mean effect.

The results from both approaches, the accident prediction models and before-after analysis, are consistent in indicating that bypass lanes increase accident numbers. This is inconsistent with findings from previous studies. However, none of the previous studies has controlled for endogeneity or regression-to-the-mean. Especially results from before-after studies, most of which found accident reductions, are therefore likely to be biased in favor of bypass lanes. A cross sectional study from Finland found that junctions with bypass lanes have fewer accidents on average than junctions without. There may, however, be other criteria for installing bypass lanes in Finland than in Norway.

Studies that have investigated effects on specific accident types or on driver behavior indicate that bypass lanes may increase rear-end collisions, and that they may be used inappropriately. Such effects may be related to site specific conditions, such as alignment and sight conditions, and they may explain the inconsistent and likely unfavorable effects of bypass lanes.

Since bypass lanes can be effective in reducing intersection capacity problems, it would be useful to investigate how such local conditions affect the safety effects and if there are conditions were no unfavorable safety effects must be expected.

7. Conclusions

The following main conclusions can be drawn:

1. Based on six previous studies, bypass lanes at three-leg junctions reduce accidents on average by 10 percent (95%-confidence interval [−22; +4]). However, most studies are before-after studies that have not controlled for regression-to-the-mean, and the results may therefore by biased in favor of bypass lanes.

2. In Norway, bypass lanes are often installed at junctions with exceptionally high accident numbers. Results from empirical studies are therefore likely to be affected by endogeneity (cross-sectional studies) and regression-to-the-mean (before-after studies).

3. We conducted cross-sectional analyses with control for endogeneity and a before-after analysis with control for regression-to-the-mean. Both approaches show that bypass lanes increase accident numbers. In the cross-sectional analysis with control for endogeneity, junctions with bypass lanes have 82 percent more accidents (95%-confidence interval [+17; +182]) than junctions without.

4. Potential safety problems with bypass lanes include misuse (e.g. using them as passing lanes) and rear-end collisions. However, such problems are often related to site specific conditions, such as alignment and sight conditions.

5. Differences between results from the present study and previous studies are likely to be due to a lack of control for potential biases in the previous studies.

6. Investigating how local conditions affect the safety effects of bypass lanes would be useful.

CRediT authorship contribution statement

Alena Katharina Høye: Writing – review & editing, Writing – original draft, Visualization, Supervision, Project administration, Methodology, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Ingeborg Storesund Hesjevoll:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Conceptualization. **Rune Elvik:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgement

This research was funded by the Norwegian Public Roads Administration, grant number 4949, to Alena Katharina Høye.

Recommended articles

Data availability

Data will be made available on request.

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