Channelisation

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Please note: The studies included in this synopsis were selected from those identified by a systematic literature search of specific databases (see supporting document). The main criterion for inclusion of studies in this synopsis and the DSS was that each study provides *a quantitative effect estimate*, preferably on the number or severity of crashes or otherwise on road user behaviour that is known to be related to the occurrence or severity of a crash. Therefore, key studies providing qualitative information might not be included in this synopsis.

1 Summary

Soteropoulos A., Stadlbauer, S., March 2017

1.1 COLOUR CODE: GREEN

In general, channelisation of junctions seems to reduce accident frequency. Differences between the effectiveness of different types of channelisation of junctions like left-turn lanes or right-turn lanes are difficult to quantify.

1.2 KEYWORDS

channelisation; channelization; left-turn; right turn; segregation; traffic islands; markings; side road: passing lane; improve sight; driving patterns; right-of-way; intersection; junction

1.3 ABSTRACT

From the studies on the effect of channelisation of junctions on road safety, it seems that channelisation of junctions reduces accident frequency: most studies reported reductions in accident frequency that were statistically significant. Although some negative effects were presented in some studies, these were not statistically significant. Since the results regarding specific outcomes are diverse, differences between the effectiveness of left-turn lanes and of right-turn lanes or between T-arms and crossroads are difficult to quantify. Research was mainly carried out in North America as well as in China and Australia. The transferability may be questioned because of potential regional characteristics.

1.4 BACKGROUND

1.4.1 What is channelisation?

Channelisation of junctions is a physical measure of road safety to improve safety at intersections by traffic flow separation, sight improvement and the simplification of driving patterns and right-of-way rules (Elvik et al. 2009). Channelisation can be carried out in two different ways: traffic streams can be segregated in a physical way by the use of curbed traffic islands or channelisation is induced by road markings. Furthermore, there are different types of channelisation. Probably the most frequent one is the left-turn channelisation, where an exclusive left-turn lane is provided. Due to that segregated lane, the left-turning vehicles are enabled to quickly clear the intersection approach (Gowri & Sivanandan 2008). Additionally, right-turn channelisation is a common treatment at intersections that is used for free-flow or nearly free-flow right-turn movements (Potts et al. 2013). Alternatively, passing lanes can be a form of channelisation. These lanes are provided for vehicles going straight, so that they can pass vehicles waiting for a left-turn. Hence, they are used as an alternative to left-turn lanes (Elvik et al. 2009). Moreover, the installation of center two-way left-turn lanes (Persaud et al. 2007) and left-turn waiting areas (Jiang et al. 2016) – areas which are located beyond the stop bar and considered as the extension of an exclusive left-turn lane – are possible.

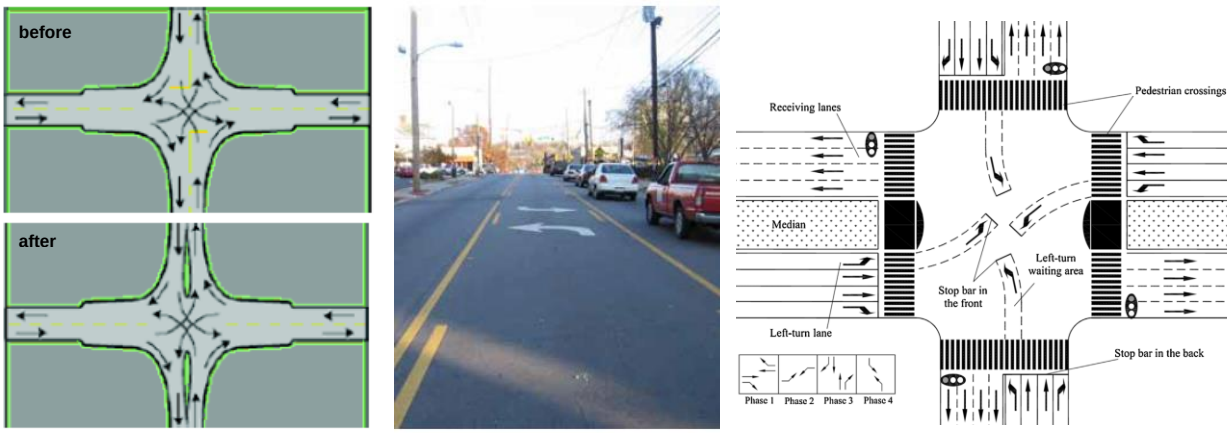

Figure 1. Junction channelisation before and after the installation of traffic islands on the main road – left (Yannis et al. 2011), center two-way left-turn lanes – middle (Persaud et al. 2007) and left-turn waiting areas – right (Jiang et al. 2016)

1.4.2 How does channelisation affect road safety?

Channelisation provides separated lanes for different traffic flows. When – for instance – an exclusive left-turn lane is present, only the left-turning vehicles are delayed in waiting for an acceptable gap. If such a lane is not provided, these vehicles have to wait in the same area as through traffic in the same direction, which then also incurs at least some delay. At the same time vehicles going left and waiting for a gap in the oncoming traffic are exposed to a higher risk of being struck by a vehicle approaching from behind. Trying to avoid this risk might also induce drivers to accept insufficiently long gaps in the oncoming traffic, potentially increasing crash risk (Zhou et al. 2010).

These factors concern right-turn lanes too. Even if vehicles going right have right-of-way, crossing pedestrians or bicyclists may cause the vehicle to stop at the intersection. If there is no separated right-turn lane this also causes delay for vehicles going straight. For pedestrians, right-turn lanes can reduce the pedestrian crossing distance of major streets even though it makes it necessary to cross two roadways if they are physically segregated. Additionally, a channelising island can serve as a refuge area for pedestrians or cyclists, especially when it is raised by curbs. It allows vulnerable road users to cross the street in two stages (Potts et al. 2013).

1.4.3 Which safety outcomes are affected by channelisation?

In the international literature, the effect of channelisation on road safety has been mostly measured on one basic outcome, namely accident frequency (number of crashes occurred). One study focused on the amount of more dangerous intersections and one on driver behaviour.

1.4.4 How is the effect of channelisation studied?

International literature indicated that the effect of channelisation on road safety is often examined by conducting before-after designs. These (quasi-)experimental methods are very suitable for measuring crash occurrence. Some (quasi-)experiments using repeated measures (when improved intersections were compared to unimproved) were used investigating the effects of channelisation, whereas one quasi-experiment focused on the effects of left-turn waiting areas using digital cameras. One study developed crash reduction factors using a survey and a literature review and one used a negative binomial model including data of 347 intersections investigating safety effects

of exclusive left-turn lanes. Moreover, one study used a driving simulation recording kinematic measures.

The studies identified focused on junctions on urban roads as well as junctions on rural roads. Most research has been done in the United States but studies from Australia, Canada, China and a meta-analysis from Norway were found as well.

1.5 OVERVIEW RESULTS

There were 11 studies coded for channelisation measures. Among those, one was a meta-analysis including studies focusing on the crash occurrence before and after the installation of left-turn or right-turn lanes and road side channelisation.

1.5.1 Main results

As mentioned above, there are different types of channelisation. Hence, different measures have to be evaluated separately. For example, there were studies only focusing on the implementation of left-turn lanes while other strictly focussed on left-turn waiting areas or right-turn lanes.

The meta-analysis reports significant positive effects for left- and right-turn lanes at crossroads (percent change of accident frequency of -27% and -19% respectively), whereas T-arms were not influenced in a significant positive way. Furthermore, side road channelisation has no significant effects on road safety.

The main findings of the remaining 10 original studies are:

- There are many results indicating a significant positive effect of left-turn lanes. In addition, there are many statistically non-significant positive effects but also some showing negative effects.
- Left-turn waiting areas also have significant positive effects on road safety. However, again there are non-significant positive as well as negative results.
- For right-turn channelisation most of the results presented showed significant positive effects.
- Especially center two-way left-turn lanes mainly lead to significant positive effects.
- The studies focused on a lot of different outcome variations. For instance, the road network, crash type or injury severity might differ from design to design. Hence, it is very difficult to summarise the effect of channelisation in one paragraph. Furthermore, the different types of channelisation have to be considered.

1.5.2 Transferability

Overall, since 10 studies as well as a meta-analysis were found, the topic has been deeply studied. Results were primarily found for motor vehicle crashes. Even though there was one meta-analysis including studies from Europe, research was mainly carried out in North America as well as in China and Australia. The transferability may be questioned because of potential regional characteristics.

1.6 NOTES ON ANALYSIS METHODS

In general, the coded studies are of sufficient quality and are methodologically sound. However, some of the studies used only small samples for investigation.

2 Scientific overview

2.1 LITERATURE REVIEW

2.1.1 Analysis of study designs and methods

Overall ten high quality studies and one meta-analysis on channelisation were selected and coded. Out of them, seven studies as well as the meta-analysis focused on accident frequency. Furthermore, one study used the percentage of more dangerous or safer intersections, one study the maximum yaw, lateral acceleration and driving errors and one study the driving performance as outcome.
Studies on accident frequency mostly deployed (quasi-)experimental methods. Mostly before-after designs (Høye 2013; Newstead & Corben 2001; Osama et al. 2016; Persaud et al. 2007; Rimiler et al. 2003; Srinivasan et al. 2014) but also repeated measures (Classen et al. 2009) and the traffic-conflict technique within a quasi-experimental study (Jiang et al. 2016) were used. One study (Agent et al. 1996) developed crash reduction factors using a survey and a literature review and another study (Ivan et al. 2009) used a negative binomial model. Moreover, one study (Shechtman et al. 2007) used a driving simulation recording kinematic measures.

The studies identified focused on junctions on urban roads as well as junctions on rural roads. Most research has been done in the United States but also studies from Australia, Canada, China and a meta-analysis from Norway including studies from Sweden, Finland, Norway and the United States were found.

Table 1 illustrates an overview of the main features of coded studies (sample, method, outcome and results).

Table 1 Description of coded studies

Author, Year, Country	Sample, method/design and analysis		Reference group	Additional information on analysis
Agent et al., 1996; United States	Development of accident reduction factors using a survey of numerous US states and a review of literature	accident reduction factors associated with specific safety improvements	-	only presentation of accident reduction factors
Classen et al., 2009, United States	Repeated measures experimental design including 8 intersections and 71 healthy drivers subjoined to young and old drivers	Experiment with repeated measures examining the driving performance	unimproved intersections in same road network	Focus on urban (residential) and signalised intersections
Høye, A., 2013, Norway	Meta-analysis including 8 studies using a before-after design	Meta-analysis with random effects and fixed effects	-	Meta-analysis includes studies from Norway, Sweden, United States and Finland
Ivan et al., 2009, United States	Repeated measures, quasi-experimental design including 3 to 21 unsignalised intersections in Connecticut, USA	Negative binomial model percentage of dangerous intersections	Intersections without left-turn lane	Focus on urban and rural roads, T-arms and crossroads and 2 and 4 lanes, significantly safer and significantly more dangerous intersections investigated
Jiang et al., 2016, China	Quasi-experimental study investigating the effects of left-turn waiting areas at 8 signalised intersections in China	Quasi-experiment focusing on post-encroachment-time and occurrence of conflicts by the use of digital cameras	Intersections without left-turn waiting area	Focus on signalised intersections in an urban road network
Newstead & Corben; 2001, Australia	Observational, quasi-experimental, before-after analysis of 559 different sites	before-after analysis of crash occurrence	untreated intersections	hazardous sites throughout Victoria
Osama et al., 2016, Canada	Quasi-experimental crash modification functions for 12 signalised intersections with one or more left-turn lanes installed	Before-after analysis, non-linear intervention full-Bayes model	untreated intersections	Focus on signalised crossroads
Persaud et al., 2007, United States	Quasi-experimental design investigating crash data of 144 sites in 4 different states in the USA	Before-after analysis, empirical Bayes design	untreated sites	Focus on urban and rural roads
Rimiller et al., 2003, United States	Quasi-experimental design investigating the effects of left-turn lane treatment at 15 intersections in Connecticut (USA)	Before-after analysis	untreated sites	Focus on urban roads
Shechtman et al., 2007, United States	Evaluation of intersection design on driving performance on urban, suburban and residential street networks including 39 participants	Driving simulation recording kinematic measures	untreated intersections	Focus on urban and suburban road and kinematic measures
Srinivasan et al., 2014; United States	Quasi-experimental design regarding signal installation with and without left-turn lanes at 117 intersections in North Caroline (USA)	Before-after analysis, empirical Bayes	untreated intersections	Focus on 3- and 3-legged intersections in rural and suburban road network (2 lanes)

2.1.2 Study results

For channelisation in general (without any specifications) Newstead & Corben (2001) present an accident reduction of more than 36% which represents a statistically significant positive estimate on

road safety. Agent et al. (1996) investigating accident reduction factors associated with specific safety improvements detected a crash reduction of 25%, however no test for statistical significance was presented.

Regarding left-turn channelisation, there were significant positive estimates for T-arms as well as for crossroads. Since many studies focused on different outcomes (different crash types, different crash severities etc.) a summary of the results would not be really representative.
In her meta-analysis Høye (2013) presented a significant crash reduction of 27% after the implementation of left-turn lanes at crossroads, however, for T-arms the reduction was not significant. In addition, Osama et al. (2016) found the left-turn treatment to be more effective for severe than for non-severe collisions. Moreover, the results showed that the treatment effectiveness decreased over time for the post-treatment years for both severe and non-severe collisions.
Persaud et al. (2007) conducted a before-after analysis and investigated the effects of the installation of center two-way left-turn lanes. Using crash data of 144 sites in 4 different states of the US, they found that the installation of center two-way left-turn lanes is more effective at rural intersections than at urban intersections. The difference was highly significant, except for Illinois. For urban installations, the safety effect was negligible, suggesting that potential sites in this environment should be very carefully selected and that further research might be necessary to identify circumstances most favourable for urban installations.

Srinivasan et al. (2014) compared the effects of left-turn channelisation at T-arms and crossroads. The latter experienced a larger and significant reduction in total crashes. Furthermore, left-turn channelisation at T-arms and crossroads (individual and combined) had positive effects for injury and fatal crashes as well as for rear-end accidents. Overall, injury, fatal and rear end crashes benefited the most from channelisation in the form of left-turn lanes. Compared to left-turn channelisation at T-arms, left-turn channelisation at crossroads experienced a larger reduction in frontal impact crashes. At crossroads, a larger increase in rear-end crashes when left-turn lanes were not implemented but a smaller reduction in rear-end crashes when at least one left-turn lane was added were also observed. However, frontal impacts were not reduced by the addition of the left turn lanes.
Furthermore, results of Agent et al. (1996) show a crash reduction due to left-turn lanes at intersections (with or without signal). When it comes to left- or right-turn related accidents this reduction is even higher. However, it should be noted that no test for statistical significance and only the accident reduction factors (without methodical detail) are presented.
In addition, Newstead & Corben (2001) indicate that left-turn lanes had a non-significant accident reduction of more than 21%. Also Rimiller et al. (2003) indicate a crash reduction due to the installation of left-turn lanes, however the estimates were statistically non-significant. The installation of left-turn lanes at unsignalised intersections experienced a greater crash reduction than at intersections with traffic signals and the installation of left-turn lanes at T-arms experienced a greater safety benefit than at crossroads. Furthermore left-turn lanes also performed better on main roads with two lanes than on sites with four lanes. It is unclear whether these differences should be explained by the specific site features or by the entering volumes of traffic. Regarding crash severity solely incapacitating and property damage only crashes experienced a crash reduction after left-turn lanes were installed.
Ivan et al. (2009) used a quasi-experimental design with repeated measures investigating the effects of the installation of left-turn lanes on the percent change of more dangerous and safer intersections. Focusing on same-direction crashes (turning-same direction, sideswipe-same direction, rear-end) the percentage of more dangerous intersections decreases with left-turn lanes for all intersection types except for urban two-lane crossroads. For all intersection types, with the exception of urban four-lane crossroads, the percentage of safer intersections increases. When it comes to fatal and injury crashes the installation of left-turn lanes leads to less dangerous intersections, except for urban two-lane crossroads and urban four-lane T-arms. At the same time

the amount of safer intersections increases for rural two-lane T-arms and urban four-lane crossroads. However, the sample size was rather small for some intersection types. Details concerning the significance of results were only presented for single intersections; hence no significant conclusion can be made.

Regarding right-turn channelisation, in her meta-analysis Høye (2013) presented a significant crash reduction of 19% after the implementation of right-turn lanes at crossroads, however for T-arms the reduction was not significant. Moreover, Agent et al. (1996) presented an accident reduction of 25% for all crashes and 50% for right-turn related crashes when right-turn lanes were installed. However, results were not statistically significant. In addition, Newstead & Corben (2001) presented a non-significant crash reduction of almost 20% after right-turn lanes were installed. Details on intersection types were not mentioned. Furthermore Classen et al. (2009) suggest that right-turn channelisation and an acceleration lane might benefit both younger and older drivers, even though there was an interaction effect detected and the result is non-significant. No estimate was presented in this study. Shechtman et al. (2007) used a driving simulation investigating the effects of different infrastructure related measures. Manoeuvre 2 was the only right turn in the simulated drive. The road conditions in the improved intersection (right-turn channelisation and an acceleration lane at the intersection) showed decreases in maximum yaw and maximum lateral acceleration which means an improvement of the lateral control for both young and old drivers in a significant way. Also driving errors were reduced significantly. Considering age differences, it was found out that the maximum yaw and maximum lateral acceleration were greater for the younger drivers. With a larger sample the estimates might become statistically significant.

When it comes to the effect of both left-turn and right-turn lanes, Høye (2013) showed a statistically significant crash reduction of 45% at crossroads. Results for T-arms were not significant. Also effects for side road channelisation were investigated, but these were not significant.

Jiang et al. (2016) – focusing on left-turn waiting areas – indicate that the number of conflicts generally decreases at intersections with such areas. The difference between improved and unimproved intersections is statistically significant regarding conflicts between left-turning and the opposing through vehicles (66%). The estimates presented indicate that the number of conflicts is much smaller at improved intersections. A great advantage of left-turn waiting areas are the stop bars in the front of them. Since there is a clearance zone, conflicts between the left-turning vehicle and the opposing through traffic are reduced. Merging conflicts and other crashes were negatively influenced by left-turn waiting areas but not in a significant way. At the same time rear-end accidents were reduced and diverging crashes showed no differences (both non-significant).

2.1.3 Description of analysis carried out

Vote-count analysis

Considering the number of studies with the relevant estimates is was decided that a vote-count analysis could be conducted. Table 2 gives an overview of the results of the analysis. Results show that channelisation has positive effects on accident frequency. For every single category, except for side road channelisation, channelisation leads to significant improvements. Even though a few estimates presented show a negative effect of channelisation on road safety, they were non-significant. There could not be any differences between the effectiveness of left-turn lanes and right-turn lanes nor between T-arms and crossroads detected.

Table 2 Results of the vote-count analysis

	Total number of effects tested	Result (number of effects)*				Result (% of effects)	
		↗	-	↘		↗	↘
Accident Frequency	**38**	**-**	**20**	**8**		**0%**	**100%**
Channelisation (not specified)	2	-	1	1		0%	100%
Left-turn channelisation	22	-	18	4		0%	100%
Right-turn channelisation	5	-	4	1		0%	100%
Left- and right-turn channelisation	2	-	1	1		0%	100%
Side road channelisation	2	-	2	-		-	-
Left-turn waiting area	5	-	4	1		0	100%

*Significant effects on road safety are coded as: positive (↘), negative (↗) or non-significant (–)

As presented above, it can be summarised that channelisation has an overall positive effect on road safety. The only inconclusive results were non-significant, hence, for channelisation, a green colour code was chosen.

2.2 CONCLUSION

Studies on the effect of channelisation on road safety identified in the international literature focused mainly on accident frequency. In a few studies driving behaviour or the amount of more dangerous or safer intersections were used as an outcome variable.

Regarding channelisation, in general, studies on accident frequency mostly show a reduction of crash occurrence. Those effects were often statistically significant. Even if there were also a few negative effects presented in some studies, they were not statistically significant.
Since results regarding specific outcomes are different in some cases, neither any differences between the effectiveness of left-turn lanes and right-turn lanes nor between T-arms and crossroads can be summarised.

Conducting a vote-count analysis the overall positive effect of channelisation on road safety can be emphasized. Since the only inconclusive results were non-significant a green colour code can be assigned to the measure.

3 Supporting document

3.1 METHODOLOGY

3.1.1 Literature Search strategy

The Literature search was conducted in November and December 2016. It was carried out in four databases with similar search strategies. The following databases were browsed through during the literature search: 'Scopus', 'Science Direct', 'TRID' and 'Taylor and Francis Online'. Detailed search terms, as well as their linkage with logical operators and combined queries are shown in the following tables. The study scope did not exclude countries or source types like "Journal" or "Project". In some of the searches remaining studies were limited to subject areas (e.g. "Engineering"). Out of the overall 381 potentially eligible studies, after screening the abstracts of these 381 studies, from 26 the full-text was obtained, but only 1 study was coded and included in the synopsis. Other already known or during the literature search occasionally (e.g. via Google) found studies as well as studies found in the literature search for other topics and including effects for channelisation were added as additional studies (9). The reference lists of the studies were only partly checked.

Table 3 Literature search strategy, database: Scopus

search no.	search terms / operators / combined queries	hits
#1	(TITLE-ABS-KEY ("channelisation" OR "channelization" OR "measure" OR "safety") AND TITLE-ABS-KEY ("intersection" OR "junction")) AND PUBYEAR > 1989	**15,633**
#2	(TITLE-ABS-KEY ("channelisation" OR "channelization" OR "measure") AND TITLE-ABS-KEY ("intersection" OR "junction")) AND PUBYEAR > 1989	**9,597**
#3	TITLE-ABS-KEY ("channelisation" OR "channelization" AND "measure" OR "treatment" OR "countermeasure" OR "separation" OR "lane") AND TITLE-ABS-KEY ("intersection" OR "junction") AND PUBYEAR > 1989	**42**

Table 4 Literature search strategy, database: ScienceDirect

search no.	search terms / operators / combined queries	hits
#1	pub-date > 1989 and ("channelisation" OR "channelization") and ("junction" OR "intersection")	**409**
#2	pub-date > 1989 and ("channelisation" OR "channelization" AND "measure" OR "effect") and ("junction" OR "intersection" AND "safety")	**97**

Table 5 Literature search strategy, database: TRID

search no.	search terms / operators / combined queries	hits
#1	"channelisation" OR "channelization" AND "junction" OR "intersection	**9,252**
#2	"channelisation" OR "channelization" AND "junction" OR "intersection AND "treatment" (in: Pedestrians and Bicyclists, Safety and Human Factors, Transportation (General))	**181**

Table 6 Literature search strategy, database: Taylor & Francis Online

search no.	search terms / operators / combined queries	hits
#1	Search Everything (channelization OR channelisation) AND Abstract (junction OR intersection) and Keywords (traffic OR transportation)	**61**

Table 7 Results Literature Search

Database	Hits
Scopus (remaining papers after several limitations/exclusions)	42
Science Direct	97
TRID	181
Taylor & Francis Online	61
Total number of studies to screen title/ abstract	**381**

The final 11 studies included in the synopsis indicate that the topic has been investigated to a great extent. The prioritising criteria for coding were the following, however all studies codable and suitable for the topic were coded.

- Prioritising Step A (e.g. meta-analysis first)
- Prioritising Step B (most recent studies)
- Prioritising Step C (Journals over conferences and reports)
- Prioritising Step D (Prestigious journals over other journals and conference papers)

One meta-analysis was found.

3.1.2 Exploratory analysis of results

Table 8 presents an overview of the main outcomes of the coded studies.

Table 8 Main outcomes of coded studies on channelisation

Author, Year, Country	Exposure variable	Outcome variable / Outcome type	Effects		Main outcome - description
Agent et al., 1996; United States	Channelisation at Intersection - General	Crash count / All	_	percent accident reduction=25%	Non-significant reduction of total crash occurrence due to channelisation at intersection in general
	Left Turn Lane - with Signal	Crash count / All	_	percent accident reduction=25%	Non-significant reduction of total crash occurrence due to adding a left turn lane with signal
	Left Turn Lane - with Signal	Crash count / Left Turn Related	_	percent accident reduction=45%	Non-significant reduction of left turn related crash occurrence due to adding a left turn lane with signal
	Left Turn Lane - without Signal	Crash count / All	_	percent accident reduction=35%	Non-significant reduction of total crash occurrence due to adding a left turn lane without signal
	Left Turn Lane - without Signal	Crash count / Left Turn Related	_	percent accident reduction=50%	Non-significant reduction of left turn related crash occurrence due to adding a left turn lane without signal

Author, Year, Country	Exposure variable	Outcome variable / Outcome type	Effects		Main outcome - description
	Right Turn Lane	Crash count / All	–	percent accident reduction=25%	Non-significant reduction of total crash occurrence due to adding a right turn lane without signal
	Right Turn Lane	Crash count / Right Turn Related	–	percent accident reduction=50%	Non-significant reduction of right turn related crash occurrence due to adding a right turn lane without signal
Classen et al., 2009; United States	Right turn with channelisation and acceleration lane	Driving performance	–	-	Benefits for both older and younger drivers although there was an interaction effect detected
Høye, 2013, Norway	Implementation of left-turn lane	Crash count / Crossroad	↘	Percent change=-27%, 95% CI	Significant positive effect of left-turn lane at crossroads on road safety
	Implementation of left-turn lane	Crash count / T-arm	–	Percent change=-11%	Non-significant positive effect of left-turn lane at T-arms on road safety
	Implementation of right-turn lane	Crash count / Crossroad	↘	Percent change=-19%	Significant positive effect of right-turn lane at crossroads on road safety
	Implementation of right-turn lane	Crash count / T-arm	–	Percent change=-22%	Non-significant positive effect of right-turn lane at T-arms on road safety
	Implementation of left-turn lane and right-turn lane	Crash count / Crossroad	↘	Percent change=-45%	Significant positive effect of left-turn lane and right-turn lane at crossroads on road safety
	Implementation of left-turn lane and right-turn lane	Crash count / T-arm	–	Percent change=-8%	Non-significant positive effect of left-turn lane and right-turn lane at T-arms on road safety
	Implementation of side road channelisation	Crash count	–	Percent change=-28%	Non-significant positive effect of side road channelisation
	Implementation of side road channelisation	Crash count	–	Percent change=11%	Non-significant negative effect of side road channelisation
Ivan et al., 2009, United States	Installation of left-turn lane	Percent of more dangerous intersections / Same direction crashes	–	Percent change=-8%	Left-turn lanes lead to a reduction of dangerous rural 2-lane T-arms
	Installation of left-turn lane	Percent of more dangerous intersections/ Same direction crashes	–	Percent change=-6%	Left-turn lanes lead to a reduction of dangerous rural 2-lane crossroads
	Installation of left-turn lane	Percent of more dangerous intersections/ Same direction crashes	–	Percent change=-5%	Left-turn lanes lead to a reduction of dangerous urban 2-lane T-arms

Author, Year, Country	Exposure variable	Outcome variable / Outcome type	Effects		Main outcome - description
	Installation of left-turn lane	Percent of more dangerous intersections / Same direction crashes	_	Percent change=7%	Left-turn lanes lead to an increase of dangerous urban 2-lane crossroads
	Installation of left-turn lane	Percent of more dangerous intersections / Same direction crashes	_	Percent change=-20%	Left-turn lanes lead to a reduction of dangerous urban 4-lane T-arms
	Installation of left-turn lane	Percent of more dangerous intersections / Same direction crashes	_	Percent change=-23%	Left-turn lanes lead to a reduction of dangerous urban 4-lane crossroads
	Installation of left-turn lane	Percent of safer intersections / Same direction crashes	_	Percent change=3%	Left-turn lanes lead to an increase of safe rural 2-lane T-arms
	Installation of left-turn lane	Percent of safer intersections / Same direction crashes	_	Percent change=98%	Left-turn lanes lead to an increase of safe rural 2-lane crossroads
	Installation of left-turn lane	Percent of safer intersections / Same direction crashes	_	Percent change=33%	Left-turn lanes lead to an increase of safe urban 2-lane T-arms
	Installation of left-turn lane	Percent of safer intersections / Same direction crashes	_	Percent change=7%	Left-turn lanes lead to an increase of safe urban 2-lane crossroads
	Installation of left-turn lane	Percent of safer intersections / Same direction crashes	_	Percent change=27%	Left-turn lanes lead to an increase of safe urban 4-lane T-arms
	Installation of left-turn lane	Percent of safer intersections / Same direction crashes	_	Percent change=-7%	Left-turn lanes lead to a reduction of safe urban 4-lane crossroads
	Installation of left-turn lane	Percent of more dangerous intersections / fatal and injury	_	Percent change=-12%	Left-turn lanes lead to a reduction of dangerous rural 2-lane T-arms
	Installation of left-turn lane	Percent of more dangerous intersections / fatal and injury	_	Percent change=-10%	Left-turn lanes lead to a reduction of dangerous rural 2-lane crossroads
	Installation of left-turn lane	Percent of more dangerous intersections / fatal and injury	_	Percent change=11%	Left-turn lanes lead to an increase of dangerous urban 2-lane crossroads
	Installation of left-turn lane	Percent of more dangerous intersections / fatal and injury	_	Percent change=5%	Left-turn lanes lead to an increase of dangerous urban 4-lane T-arms

Author, Year, Country	Exposure variable	Outcome variable / Outcome type	Effects		Main outcome - description
	Installation of left-turn lane	Percent of more dangerous intersections / fatal and injury	–	Percent change=-13%	Left-turn lanes lead to a reduction of dangerous urban 4-lane crossroads
	Installation of left-turn lane	Percent of safer intersections / fatal and injury	–	Percent change=4%	Left-turn lanes lead to an increase of safe rural 2-lane T-arms
	Installation of left-turn lane	Percent of safer intersections / fatal and injury	–	Percent change=-2%	Left-turn lanes lead to a reduction of safe rural 2-lane crossroads
	Installation of left-turn lane	Percent of safer intersections / fatal and injury	–	Percent change=-16%	Left-turn lanes lead to a reduction of safe urban 2-lane crossroads
	Installation of left-turn lane	Percent of safer intersections / fatal and injury	–	Percent change=-4%	Left-turn lanes lead to a reduction of safe urban 4-lane T-arms
	Installation of left-turn lane	Percent of safer intersections / fatal and injury	–	Percent change=3%	Left-turn lanes lead to an increase of safe urban 4-lane crossroads
Jiang et al., 2016, China	Implementation of left-turn waiting area	Crash count / Left-turn and opposite through	↘	Relative difference=-66.66%, p<0.001	Significant positive effect of left-turn waiting area on conflicts between left-turning vehicle and vehicle going through intersection
	Implementation of left-turn waiting area	Crash count / Merging	–	Relative difference=16666%, p=0.35	Non-significant negative effect of left-turn waiting area on merging conflicts
	Implementation of left-turn waiting area	Crash count / Rear-end	–	Relative difference=-23.81%, p=0.267	Non-significant positive effect of left-turn waiting area on rear-end conflicts
	Implementation of left-turn waiting area	Crash count / Diverging	–	Relative difference=0	No effect between intersections with and without left-turn waiting area
	Implementation of left-turn waiting area	Crash count / Others	–	Relative difference=100%, p=0.759	Non-significant negative effect of left-turn waiting areas on other crashes
Newstead & Corben, 2001, Australia	Channelisation (no further information presented)	Crash count / All	↘	Percent accident reduction=36,37%, p=0.0075	Significant positive effect of channelisation on road safety
	Left-turn lane (no further information presented)	Crash count / All	–	Percent accident reduction=21.26%, p=0.3949	Non-significant positive effect of left-turn lane on road safety
	Right-turn lane (no further information presented)	Crash count / All	–	Percent accident reduction=19.64%, p=0.2305	Non-significant positive effect of right-turn lane on road safety
Osama et al., 2016, Canada	Installation of one or more left-turn lanes	Crash count / Fatal & Injury	↘	percent accident reduction=27.3%	Significant reduction of fatal and injury crashes after installation of one or more left-turn lanes at crossroad

Author, Year, Country	Exposure variable	Outcome variable / Outcome type	Effects		Main outcome - description
	Installation of one or more left-turn lanes	Crash count / Property damage only	–	percent accident reduction=3.6%	Non-significant reduction of property damage only crashes after installation of one or more left-turn lanes at crossroad
	Installation of one or more left-turn lanes	Crash count / All	↘	percent accident reduction=15.9%	Significant reduction of total crashes after installation of one or more left-turn lanes at crossroad
Persaud et al., 2007, United States	Installation of centre two-way left-turn lanes	Crash count / All	↘	percent accident reduction=29.1%	Significant positive effect of installation of centre two-way left-turn lanes on all crashes on rural roads in Arkansas, California, Illinois and North Carolina
	Installation of centre two-way left-turn lanes	Crash count / Injury	↘	percent accident reduction=19.1%	Significant positive effect of installation of centre two-way left-turn lanes on injury crashes on rural roads in Arkansas, California, Illinois and North Carolina
	Installation of centre two-way left-turn lanes	Crash count / Rear-end	↘	percent accident reduction=36.2%	Significant positive effect of installation of centre two-way left-turn lanes on rear-end crashes on rural roads in Arkansas, California, Illinois and North Carolina
	Installation of centre two-way left-turn lanes	Crash count / All	↘	percent accident reduction=51.2%	Significant positive effect of installation of centre two-way left-turn lanes on all crashes on rural roads in Arkansas
	Installation of centre two-way left-turn lanes	Crash count / All	–	percent accident reduction=3.8%	Non-significant positive effect of installation of centre two-way left-turn lanes on all crashes on urban roads in Arkansas
	Installation of centre two-way left-turn lanes	Crash count / All	↘	percent accident reduction=50.8%	Significant positive effect of installation of centre two-way left-turn lanes on all crashes on rural roads in California
	Installation of centre two-way left-turn lanes	Crash count / All	–	percent accident reduction=-2.8%	Non-significant negative effect of installation of centre two-way left-turn lanes on all crashes on urban roads in California
	Installation of centre two-way left-turn lanes	Crash count / All	–	percent accident reduction=16.7%	Non-significant positive effect of installation of centre two-way left-turn lanes on all crashes on rural roads in Illinois
	Installation of centre two-way left-turn lanes	Crash count / All	–	percent accident reduction=9.4%	Non-significant positive effect of installation of centre two-way left-turn lanes on all crashes on urban roads in Illinois
	Installation of centre two-way left-turn lanes	Crash count / All	↘	percent accident reduction=27.3%	Significant positive effect of installation of centre two-way left-turn lanes on all crashes on rural roads in North Carolina

Author, Year, Country	Exposure variable	Outcome variable / Outcome type	Effects		Main outcome - description
	Installation of centre two-way left-turn lanes	Crash count / All	–	percent accident reduction=-5%	Non-significant negative effect of installation of centre two-way left-turn lanes on all crashes on urban roads in North Carolina
Rimiller et al., 2003, United States	Installation of left-turn lane	Crash count / same direction	–	percent accident reduction=61%	Non-significant positive effect of left-turn lanes on same direction crashes at intersections with no signal
	Installation of left-turn lane	Crash count / intersecting direction with one vehicle making left turn	–	percent accident reduction=25%	Non-significant positive effect of left-turn lanes on intersecting direction crashes with one vehicle making left turn at intersections with no signal
	Installation of left-turn lane	Crash count / intersecting direction with no vehicle making left turn	–	percent accident reduction=45%	Non-significant positive effect of left-turn lanes on intersecting direction crashes with no vehicle making left turn at intersections with no signal
	Installation of left-turn lane	Crash count / opposite direction	–	percent accident reduction=60%	Non-significant positive effect of left-turn lanes on opposite direction crashes at intersections with no signal
	Installation of left-turn lane	Crash count / Other	–	percent accident reduction=-11%	Non-significant negative effect of left-turn lanes on other crashes at intersections with no signal
	Installation of left-turn lane	Crash count / All	–	percent accident reduction=58%	Non-significant positive effect of left-turn lanes on all crashes at intersections with no signal
	Installation of left-turn lane	Crash count / same direction	–	percent accident reduction=-16%	Non-significant negative effect of left-turn lanes on same direction crashes at signalised intersections
	Installation of left-turn lane	Crash count / intersecting direction with one vehicle making left turn	–	percent accident reduction=-21.2%	Non-significant negative effect of left-turn lanes on intersecting direction crashes with one vehicle making left turn at signalised intersections
	Installation of left-turn lane	Crash count / intersecting direction with no vehicle making left turn	–	percent accident reduction=18%	Non-significant positive effect of left-turn lanes on intersecting direction crashes with no vehicle making left turn at signalised intersections
	Installation of left-turn lane	Crash count / opposite direction	–	percent accident reduction=34%	Non-significant positive effect of left-turn lanes on opposite direction crashes at signalised intersections
	Installation of left-turn lane	Crash count / Other	–	percent accident reduction=21%	Non-significant positive effect of left-turn lanes on other crashes at signalised intersections
	Installation of left-turn lane	Crash count / All	–	percent accident reduction=17%	Non-significant positive effect of left-turn lanes on all crashes at signalised intersections

Author, Year, Country	Exposure variable	Outcome variable / Outcome type	Effects		Main outcome - description
	Installation of left-turn lane	Crash count / same direction	–	percent accident reduction=44%	Non-significant positive effect of left-turn lanes on same direction crashes at T-arms
	Installation of left-turn lane	Crash count / intersecting direction with one vehicle making left turn	–	percent accident reduction=12%	Non-significant positive effect of left-turn lanes on intersecting direction crashes with one vehicle making left turn at T-arms
	Installation of left-turn lane	Crash count / intersecting direction with no vehicle making left turn	–	percent accident reduction=43%	Non-significant positive effect of left-turn lanes on intersecting direction crashes with no vehicle making left turn at T-arms
	Installation of left-turn lane	Crash count / opposite direction	–	percent accident reduction=51%	Non-significant positive effect of left-turn lanes on opposite direction crashes at T-arms
	Installation of left-turn lane	Crash count / Other	–	percent accident reduction=-17%	Non-significant negative effect of left-turn lanes on other crashes at T-arms
	Installation of left-turn lane	Crash count / All	–	percent accident reduction=52%	Non-significant positive effect of left-turn lanes on all crashes at T-arms
	Installation of left-turn lane	Crash count / same direction	–	percent accident reduction=-13%	Non-significant negative effect of left-turn lanes on same direction crashes at crossroads
	Installation of left-turn lane	Crash count / intersecting direction with one vehicle making left turn	–	percent accident reduction=-18%	Non-significant negative effect of left-turn lanes on intersecting direction crashes with one vehicle making left turn at crossroads
	Installation of left-turn lane	Crash count / intersecting direction with no vehicle making left turn	–	percent accident reduction=16%	Non-significant positive effect of left-turn lanes on intersecting direction crashes with no vehicle making left turn at crossroads
	Installation of left-turn lane	Crash count / opposite direction	–	percent accident reduction=37%	Non-significant positive effect of left-turn lanes on opposite direction crashes at crossroads
	Installation of left-turn lane	Crash count / Other	–	percent accident reduction=28%	Non-significant positive effect of left-turn lanes on other crashes at crossroads
	Installation of left-turn lane	Crash count / All	–	percent accident reduction=17%	Non-significant positive effect of left-turn lanes on all crashes at crossroads
	Installation of left-turn lane	Crash count / same direction	–	percent accident reduction=39%	Non-significant positive effect of left-turn lanes on same direction crashes at 2-lane intersection

Author, Year, Country	Exposure variable	Outcome variable / Outcome type	Effects		Main outcome - description
	Installation of left-turn lane	Crash count / intersecting direction with one vehicle making left turn	–	percent accident reduction=27%	Non-significant positive effect of left-turn lanes on intersecting direction crashes with one vehicle making left turn at 2-lane intersection
	Installation of left-turn lane	Crash count / intersecting direction with no vehicle making left turn	–	percent accident reduction=32%	Non-significant positive effect of left-turn lanes on intersecting direction crashes with no vehicle making left turn at 2-lane intersection
	Installation of left-turn lane	Crash count / opposite direction	–	percent accident reduction=57%	Non-significant positive effect of left-turn lanes on opposite direction crashes at 2-lane intersection
	Installation of left-turn lane	Crash count / Other	–	percent accident reduction=-17%	Non-significant negative effect of left-turn lanes on other crashes at 2-lane intersection
	Installation of left-turn lane	Crash count / All	–	percent accident reduction=38%	Non-significant positive effect of left-turn lanes on all crashes at 2-lane intersection
	Installation of left-turn lane	Crash count / same direction	–	percent accident reduction=-16%	Non-significant negative effect of left-turn lanes on same direction crashes at 4-lane intersection
	Installation of left-turn lane	Crash count / intersecting direction with one vehicle making left turn	–	percent accident reduction=-34%	Non-significant negative effect of left-turn lanes on intersecting direction crashes with one vehicle making left turn at 4-lane intersection
	Installation of left-turn lane	Crash count / intersecting direction with no vehicle making left turn	–	percent accident reduction=47%	Non-significant positive effect of left-turn lanes on intersecting direction crashes with no vehicle making left turn at 4-lane intersections
	Installation of left-turn lane	Crash count / opposite direction	–	percent accident reduction=31%	Non-significant positive effect of left-turn lanes on opposite direction crashes at 4-lane intersection
	Installation of left-turn lane	Crash count / Other	–	percent accident reduction=34%	Non-significant positive effect of left-turn lanes on other crashes at 4-lane intersection
	Installation of left-turn lane	Crash count / All	–	percent accident reduction=25%	Non-significant positive effect of left-turn lanes on all crashes at 4-lane intersection
	Installation of left-turn lane	Crash count / Fatal	–	Relative difference=-0.3%	Non-significant negative effect of left-turn lanes on fatal crashes
	Installation of left-turn lane	Crash count / incapacitating	–	Relative difference=3.6%	Non-significant positive effect of left-turn lanes on incapacitating crashes

Author, Year, Country	Exposure variable	Outcome variable / Outcome type	Effects		Main outcome - description
	Installation of left-turn lane	Crash count / non-incapacitating	–	Relative difference=-1.4%	Non-significant negative effect of left-turn lanes on non-incapacitating crashes
	Installation of left-turn lane	Crash count / reported but readily non-visible injury	–	Relative difference=-2.2%	Non-significant negative effect of left-turn lanes on reported but readily non-visible injury crashes
	Installation of left-turn lane	Crash count / property damage only	–	Relative difference=0.1%	Non-significant positive effect of left-turn lanes on property damage only crashes
Shechtman et al., 2007, United States	Right-turn channelisation with acceleration lane	Maximum yaw (radians/sec)	↘	F test=27.63, p<0.01	Significant positive effect of right-turn channelisation with acceleration lane on maximum yaw
	Right-turn channelisation with acceleration lane	Maximum lateral acceleration (g)	↘	F test=8.92, p<0.01	Significant positive effect of right-turn channelisation with acceleration lane on maximum lateral acceleration
	Right-turn channelisation	Driving errors	↘	r=96, p=0.01	Significant positive effect of right-turn channelisation with acceleration lane on driving errors
Srinivasan et al., 2014, United States	Implementation of left-turn lane	Crash count / All, 3-legged intersection	↘	CMF=0.748, SE=0.095	Significant positive effect of left-turn lane on all crashes at 3-legged intersections
	Implementation of left-turn lane	Crash count / All, 4-legged intersection	–	CMF=0.924, SE=0.07	Non-significant positive effect of left-turn lane on all crashes at 4-legged intersections
	Implementation of left-turn lane	Crash count / All, 3- and 4-legged intersection	–	CMF=0.876, SE=0.066	Non-significant positive effect of left-turn lane on all crashes at 3-legged and 4-legged intersections
	Implementation of left-turn lane	Crash count / Injury and fatal, 3-legged intersection	↘	CMF=0.566, SE=0.113	Significant positive effect of left-turn lane on injury and fatal crashes at 3-legged intersections
	Implementation of left-turn lane	Crash count / Injury and fatal, 4-legged intersection	↘	CMF=0.799, SE=0.089	Significant positive effect of left-turn lane on injury and fatal crashes at 4-legged intersections
	Implementation of left-turn lane	Crash count / Injury and fatal, 3- and 4-legged intersection	↘	CMF=0.744, SE=0.071	Significant positive effect of left-turn lane on injury and fatal crashes at 3-legged intersections and 4-legged intersections
	Implementation of left-turn lane	Crash count / Rear-end, 3-legged intersection	↘	CMF=0.412, SE=0.079	Significant positive effect of left-turn lane on rear-end crashes at 3-legged intersections
	Implementation of left-turn lane	Crash count / Rear-end, 4-legged intersection	↘	CMF=0.555, SE=0.079	Significant positive effect of left-turn lane on rear-end crashes at 4-legged intersections
	Implementation of left-turn lane	Crash count / Rear-end, 3- and 4-legged intersection	↘	CMF=0.494, SE=0.059	Significant positive effect of left-turn lane on rear-end crashes at 3-legged intersections and 4-legged intersections

Author, Year, Country	Exposure variable	Outcome variable / Outcome type	Effects		Main outcome - description
	Implementation of left-turn lane	Crash count / Frontal impact type 1, 3-legged intersection	–	CMF=1.02, SE=0.23	Non-significant negative effect of left-turn lane on frontal impact type 1 crashes (left turn same roadway, left turn different roadway, angle) at 3-legged intersections
	Implementation of left-turn lane	Crash count / Frontal impact type 1, 4-legged intersection	–	CMF=0.879, SE=0.101	Non-significant positive effect of left-turn lane on frontal impact type 1 crashes (left turn same roadway, left turn different roadway, angle) at 4-legged intersections
	Implementation of left-turn lane	Crash count / Frontal impact type 1, 3- and 4-legged intersection	–	CMF=0.916, SE=0.101	Non-significant positive effect of left-turn lane on frontal impact type 1 crashes (left turn same roadway, left turn different roadway, angle) at 3-legged intersections and 4-legged intersections
	Implementation of left-turn lane	Crash count / Frontal impact type 2, 3-legged intersection	–	CMF=1.086, SE=0.225	Non-significant negative effect of left-turn lane on frontal impact type 2 crashes (left turn same roadway, left turn different roadway, angle, right turn same roadway, right turn different roadway, sideswipe opposite direction, head-on) at 3-legged intersections
	Implementation of left-turn lane	Crash count / Frontal impact type 2, 4-legged intersection	–	CMF=1.016, SE=0.108	Non-significant negative effect of left-turn lane on frontal impact type 2 crashes (left turn same roadway, left turn different roadway, angle, right turn same roadway, right turn different roadway, sideswipe opposite direction, head-on) at 4-legged intersections
	Implementation of left-turn lane	Crash count / Frontal impact type 2, 3- and 4-legged intersection	–	CMF=1.046, SE=0.107	Non-significant negative effect of left-turn lane on frontal impact type 2 crashes (left turn same roadway, left turn different roadway, angle, right turn same roadway, right turn different roadway, sideswipe opposite direction, head-on) at 3-legged intersections and 4-legged intersections

*Significant effects on road safety are coded as: positive (↘), negative (↗) or non-significant (–)

3.2 FULL LIST OF STUDIES

3.2.1 Meta-analyses

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