Traffic signal installation

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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.

Summary

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1.1 COLOUR CODE: LIGHT GREEN

On the basis of both study and effect numbers, it can be argued that traffic signal installation measures have a mostly positive effect on road safety. Results show that the examined measure does efficiently change road safety levels in most cases.

1.2 KEYWORDS

Traffic signals, signal installation; junction treatments

1.3 ABSTRACT

Traffic signal installation is a measure regarding the implementation of a pedestrian signal phase or improved traffic signal timing, and belong to the group of junction treatments. Six high quality studies, including two meta-analyses, were coded. Most studies show significant road safety benefits. Traffic signal installation was found to reduce total collisions by 29% in the first meta-analysis and the implementation of left-turn phase was found to reduce turning or crossing crashes by 15%. Overall, crash occurrence and severity are mitigated, although one specific crash type appears more frequent: rear-end crashes. On a basis of both study and effect numbers, it is evident that traffic signal installation measures have a mostly positive impact on road safety. Only rear-end crashes increased after the installation. The positive effects do outnumber the negative ones by a considerable margin, and many outcomes are statistically significant. The results seem generally transferable with caution.

1.4 BACKGROUND

1.4.1 Definition of traffic signal installation measures

In order to facilitate transport, road signals are often utilised at junctions, especially in areas of high traffic volumes or with subpar visibility. This essentially entails changing the traffic conditions of the junction. Junctions that are not signalised or those that operate with traffic signs are reconfigured after relevant calculations, most frequently at a network level. Relevant traffic signal equipment is installed and connected, appropriate to the junction that is treated. For instance, there are specialised pedestrian traffic lights providing countdown timers or separate arrangements for certain directions of movement (amber flashing lights that have yielding functions etc.). The whole process is monitored after the implementation and usually timing calibrations and reconfigurations follow, to ensure the network functions optimally. Red light cameras are also utilised, to monitor illegal and violating behaviour in their respective junctions.

In general, traffic signal installation measures are considered and implemented because they utilise existing infrastructure with limited hardware changes and similarly little time is required for their realisation. The consequences of their installation should be studied at network level as they will affect other junctions and road segments nearby.

1.4.2 How do traffic signal installation measures affect road safety?

Traffic signal installation measures are intended to optimise the use of the junction space, allowing all road user groups to access the junction and cross towards their intended destinations. They aim to solve issues of priority control, especially in areas where two roads of comparable size meet, or in areas with limited visibility which could lead to crashes when drivers are not careful and large delays when they are. This is often achieved via the provision of a separate direction phase (for instance signalised left-turn implementation), which ensures safe access for the direction that is segregated. Of particular interest is the benefit to more vulnerable road users; pedestrians and cyclists can have dedicated phases to serve their directions more safely. Essentially, traffic signals aim to reduce crashes and conflicts as a first priority, and junction delays as a second. Red light cameras act as a deterrent, monitoring violating drivers.

1.4.3 How is the effect of traffic signal installation measures studied?

Traffic signals have been utilised for decades, and their effects are extensively studied and documented, though there have been varying approaches and sampling frames. A common practice for installation treatments is to identify a singular junction or network as a study area. Afterwards before-after measure approaches are implemented to capture the effect of traffic signal installation measures in influencing road safety levels, comparing the same areas with and without the presence of the measure. The parameters used for the estimates of benefits are crash numbers or conflict rates, which offer direct insights on road safety levels, and also injury comparison to determine whether crashes have lesser consequences (injury mitigation).

1.5 OVERVIEW OF RESULTS

The effects of traffic signal installation measures on road safety appear to be mostly positive. There are several positive outcomes from the examined studies, some of them concerning crash and conflict reduction. The two meta-analyses that were examined (and which in turn include several other original studies) report a reduction of total collisions by 29% when traffic lights are installed and a reduction of turning or road crossing crashes by 15% when a left turn phase is implemented. The rest of the studies support those outcomes, which show overall crash reduction due to traffic signal installation, apart from the case of rear-end crashes.

1.6 TRANSFERABILITY

Coded studies are based on data from Canada, Israel, Norway, Turkey and the United States; two of the studies are meta-analyses and therefore they encompass more countries and international data in their datasets. While this can be generally considered a good sample of countries, there is still room for representation of other areas of the globe, and a respective gap of knowledge, especially concerning less motorised regions. Most studies examined their respective study areas uniformly, investigating all crash types and road users as grouped. There are, however, instances of differentiation between rural and urban areas and crash types (crossing or turning into a road, left-turn and rear-end crashes).

1.7 NOTES ON ANALYSIS METHODS

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While the methodology applied for capturing the impact of traffic signal installation measures is similar (before-after measure application approaches), the outputs are interpreted in various manners: Crash comparison is either provided directly (absolute or percentile difference), or in a more complex form (CMF or model coefficients). Outcomes are subjected to significance testing to determine the level of statistical significance of each parameter on road safety levels. There is some room for investigating different road user categories and/or other geographical regions. All aforementioned factors make the findings for traffic signal installation measures transferable with caution.

2. Scientific overview

2.1 ANALYSIS OF STUDY DESIGNS AND METHODS

After appropriate use of various search tools and databases, six (6) high quality studies were selected and coded for the measure of traffic signal installation, two of which were meta-analyses encompassing several other relevant studies from the literature. The studies utilised before-and-after designs and investigated several parameters. Those parameters included direct variables, like crash number comparisons (Elvik et al., 2015a, Gitelman et al., 2001, Persaud et al., 2005 and Sacchi et al., 2016) or comparisons between the odds of injury severity categories (Celik and Oktay, 2014). The meta-analysis studying the effect of left-turn phase implementation also investigated crash number variations (Elvik et al., 2015b).

The aforementioned parameters of crashes or injured users provide a very direct method of investigating effects on road safety, which has both the advantage of being direct and comprehensible but also the drawback of being quite simplistic, often ignoring network particularities which are best captured via crash rates distributed by network geometry (for instance taking into account vehicle-kilometres). These data would be more complex and harder to obtain and calculate, however.

In order to examine the relationship between the various effects of traffic signal installation, the studies either deployed significance testing (for example t-testing, or p-value calculations, or standard error provision) or at least conducted basic descriptive statistical analyses.

2.2 LITERATURE REVIEW

The studies examined reported mostly positive results regarding outcomes of variables for road safety. The results of the meta-analyses are of particular importance. The first meta-analysis (Elvik et al., 2015a) regarded traffic signal installation treatments via the examination of four original studies concerning several different accident types. Traffic signal installation was found to reduce total collisions by 29%, collisions with crossing vehicles by 74%, left-turn collisions by 60% while rear-end accidents were increased by 45%. As explained previously, the increase of rear-end accidents can be explained to a certain degree due to traffic signal installation.

The second meta-analysis (Elvik et al., 2015b) concerned the implementation of left-turn phases, and investigated six original studies. Injury crashes caused by turning or crossing into a road were reported to be reduced by 15%, while all crashes were reported to have a similar reduction when turning left (14%). Other cases were not found to be statistically or quantitatively significant.

Similarly, red-light camera systems investigated by Persaud et al. (2005) had an impact of reducing all right-angle crashes by 24.6%, which amounted to 15.7% when examining injury only crashes. On the other hand, rear-end crashes were found to have increased once again (14.9% in total, 24% for injury only accidents).

On a similar note, Gitelman et al. (2001) found several significant reductions in injury crashes on urban and mixed areas (urban & rural), ranging from 20% to 21%. The odds ratio of injury crashes occurring varies, per the sample studied, from 0.697 to 0.792. Similarly, Celik and Oktay (2014) compared the odds ratio of different injury categories. Traffic light installation mitigated crashes overall, making a crash about 4 times more likely to be injurious than fatal.

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Finally, Sacchi et al. (2016) investigated several sites and injury categories for traffic signal installation. They employed CMF calculations to complement direct crash comparisons; crashes with injuries or fatalities were found to be reduced by a CMF of 0.782 while overall crashes were reduced by a CMF of 0.840.

Number	Author(s); Year; Country;	Sampling frame for signal installation studies	Method for signal installation investigation	Outcome indicator	Main Result
1	Elvik, R., Høye, A.; 2015; Norway [meta-analysis]	Summary of effects that can be expected from traffic signal installation from previous research.	Crash comparison [Random effects meta-analysis]	Crash comparison [Percentage difference]	The total number of accidents is reduced by 29 % after installing traffic signals, many additional results.
2	Elvik, R., Høye, A.; 2015; Norway [meta-analysis]	Summary of effects that can be expected for implementation of specific measures related to left turn phasefrom previous research.	Crash comparison [Random effects meta-analysis]	Crash comparison [Percentage difference]	Both a protected left-turn phase and a protected-permissive left-turn phase have no effect when all crashes are considered. Both measures reduce person damage injuries in crashes that occur when turning left by 14-15%.
3	Celik, A. K., & Oktay, E.; 2014; Turkey	A retrospective cross-sectional study is conducted analysing 11,771 traffic accidents reported by the police in two provinces of Turkey.	Comparison between injury type categories [Multinomial logit model]	Injury category comparison [Odds ratio - Slope]	The estimation results showed that some traffic control devices are not sufficiently able to decrease fatal injuries.
4	Gitelman, V., Hakkert, A. S., Doveh, E., & Cohen, A.; 2001; Israel	Data on road infrastructure and some 400 interurban and some 500 urban projects were recorded in the database from which more than 30 examples of treatment types evolved.	Crash comparison [Before - after analyses]	Injury crashes comparison [Odds ratio - Percentage difference]	Significant injurious crash reductions were observed (20-21%).
5	Persaud, B., Council, F., Lyon, C., Eccles, K., & Griffith, M.; 2005; United States	Study methodology included collection of background information and specification of statistical methodology. Afterwards 132 sites with red light cameras in the US were examined.	Crash comparison [Empirical Bayes and before - after analyses]	Crash comparison [Percentage difference]	Results showed a significant decrease in right-angle crashes but a significant increase in rear-end crashes.
6	Sacchi, E., Sayed, T., & El-Basyouny, K.; 2016; Canada	The countermeasure analysed was the installation of traffic signals at unsignalised urban/suburban intersections in British Columbia	Crash comparison [Full Bayes and before - after analyses]	Crash comparison (annual and predicted) [Absolute & Percentage difference, CMF]	Results showed that traffic signal treatments led to reductions of collision frequency. These reductions were more marked for severe than non-severe crashes.

Table 1: Description of coded studies

2.2.1 Limitations

A few limitations can arguably be found in the current literature for the effects of traffic signal installation on road safety. Firstly, there is room for the inclusion of more countries in the sample, especially from developing countries. Secondly, parameters that are more thorough or different in scope could be examined as well, such as braking distance, headways and reaction time from traffic signal installation.

An overview of the main features of the coded studies (sample, method, outcome and results) is illustrated in Table 1.

2.3 RESULTS FOR TRAFFIC SIGNAL INSTALLATION

The effects of traffic signal installation can be summarised as follows:

2 studies (meta-analyses) with significant reductions on all road crashes, except rear-end crashes where they report significant crash increases
1 study with significant reductions on right angle crashes and significant increases for rear-end crashes (via installation of red light cameras)
2 studies with significant crash reductions amongst several types of accidents (injury only, damage only, all severities, urban areas)
1 study with significant injury category reductions (injury mitigation)

The quantitative results of the coded studies with their general effects on road safety are summarised in Table 2, which is presented in the supporting document.

After the results were reviewed together, the following points were observed:

a) There is an adequate number of studies, however;
b) Those studies have not used the same methods for analysis but somewhat different ones
c) There are only a few similar indicators but at times expressed differently
d) The sampling frames were quite different, and there was some lack of statistical verification
e) Two meta-analyses are already included in the studies examined

2.4 DESCRIPTION OF ANALYSIS CARRIED OUT

2.4.1 Review type analysis

After considering the previous points it was decided that a meta-analysis could not be carried out; therefore the review type analysis was selected. The effect of the traffic signal installation measures is given via qualitative analysis.

When aiming for a more strategic overview, the results reported from the selected studies provide a mostly positive picture of the general average effects of the measure. The only negative outcomes were reported for rear-end crashes, a finding which stands to reason given the barring enforcement of traffic signals (red lights) which forces vehicles to stop. This means that some drivers do not anticipate vehicles in front of them braking, either due to the act itself or because they were familiar with the road before the signal installation and were caught by surprise, thus increasing rear-end crashes.

2.4.2 Overall estimate for road safety

On a basis of both study and effect numbers, it can be argued that traffic signal installation measures have a mostly positive effect on road safety. The positive effects outnumber the negative ones by a considerable margin, and many outcomes are statistically significant. There are two meta-analyses included in the group of studies taken into consideration, which encompass the benefit of several other studies; their results also show significant benefits on a road safety basis. Overall, crash occurrence and severity are mitigated, and only a specific crash type is more frequent (rear-end crashes), owing to the nature of the treatments. In short, results consistently show that the examined measure does efficiently change road safety levels in most cases.

2.5 CONCLUSION

The review-type qualitative analysis carried out showed that traffic signal installation measures have a mostly positive impact on road safety, with regard to crash occurrence and injury. There are a considerable number of positive effects with sufficient statistical verification to consider this measure beneficial and thus suggest it for field implementation.

3. Supporting document

3.1 SUPPORTING QUANTITATIVE TABLE

Below follows Table 2, including all quantitative effects from the coded studies for the measure of traffic signal installation.

Number	Author(s); Year; Country	Measure Exposure	Outcome indicator	Quantitative Estimate	Effect on road safety
1	Elvik, R., Høye, A.; 2015; Norway [meta-analysis]	Installation of traffic signals	Crash comparison [Percentage difference]	Accident collisions - Total: Percent change = -29.00%, CI [95%] = (-41.00%, -14.00%)	↑
				Accident collisions - With crossing vehicle: Percent change = -74.00%, CI [95%] = (-77.00%, -71.00%)	↑
				Accident collisions - Left-turn: Percent change = -60.00%, CI [95%] = (-65.00%, -54.00%)	↑
				Accident collisions - Rear-end: Percent change = 45.00%, CI [95%] = (24.00%, 70.00%)	↓
2	Elvik, R., Høye, A.; 2015; Norway [meta-analysis]	Implementation of left-turn phase	Crash comparison [Percentage difference]	Accident collisions - Total: Accident severities - All All accident types Percent change = 0.00%, CI [95%] = (-9.00%, 9.00%)	-
				Accident collisions - Total: Accident severities - Injury Accidents by turning or crossing into a road Percent change = -15.00%, CI [95%] = (-19.00%, -12.00%)	↑
				Accident collisions - Total: Accident severities - All Accidents by turning or crossing into a road Percent change = 3.00%, CI [95%] = (-1.00%, 8.00%)	-
				Accident collisions - Total: Accident severities - All Accidents when turning left Percent change = -14.00%, CI [95%] = (-21.00%, -5.00%)	↑
				Accident collisions - Total: Accident severities - All Accidents - rear end Percent change = 8.00%, CI [95%] = (0.00%, 15.00%)	-
3	Celik, A. K., & Oktay, E.; 2014; Turkey	Installation of traffic signals	Injury category comparison [Odds ratio]	Injury/Fatality Odds ratio: OR = 4.030, t-test = 3.05, p = 0.05, CI [95%] = (1.650, 9.870)	↑
			Injury category comparison [Slope]	No Injury/Fatality Slope: b = 5.670, t-test = 3.80, p = 0.05, CI [95%] = (2.320, 13.900)	↑
4	Gitelman, V., Hakkert, A. S., Doveh, E., & Cohen, A.; 2001; Israel	Installation of traffic signals	Injury crashes comparison [Percentage difference]	Injury crashes, All areas Percent change = -20.00%	↑
				Injury crashes, Urban areas Percent change = -21.00%	↑
			Injury crashes comparison [Odds ratio]	Injury crashes, Urban areas [With reference group] OR = 0.7920, CI [95%] = (0.6080, 1.0330)	↑

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Number	Author(s); Year; Country	Measure Exposure	Outcome indicator	Quantitative Estimate	Effect on road safety
				Injury crashes, Urban areas [Without reference group] OR = 0.6950, CI [95%] = (0.5750, 0.8400)	↑
5	Persaud, B., Council, F., Lyon, C., Eccles, K., & Griffith, M.; 2005; United States	Installation of Red Light Camera systems	Crash comparison [Percentage difference]	Accident severities - All Accidents - Right angle Percent change = -24.60%, s.e. = 2.900	↑
				Accident severities - Injury Accidents - Right angle Percent change = -15.70%, s.e. = 5.900	↑
				Accident severities - All Accidents - Rear-end Percent change = 14.90%, s.e. = 3.000	↓
				Accident severities - Injury Accidents - Rear-end Percent change = 24.00%, s.e. = 11.600	↓
6	Sacchi, E., Sayed, T., & El-Basyouny, K.; 2016; Canada	Installation of traffic signals	Crash comparison [Relative difference]	Accident sites - All Accident severities - Fatal plus Injury Relative difference of Annual average collision frequency = -0.4200	-
				Accident sites - All Accident severities - Damage only Relative difference of Annual average collision frequency = 3.3300	-
				Accident sites - Treatment only Accident severities - Fatal plus Injury Relative difference of Annual average collision frequency = 0.5500	-
				Accident sites - Treatment only Accident severities - Damage only Relative difference of Annual average collision frequency = 1.4200	-
			Crash comparison [CMF]	Accident sites - All Accident severities - All CMF [before - after] = 0.8400, p<0.05	↑
				Accident sites - All Accident severities - Fatal plus Injury CMF [before - after] = 0.7820, p<0.05	↑
				Accident sites - All Accident severities - Damage only CMF [before - after] = 0.8980, p<0.05	-
			Predicted Crash comparison [Percentage difference]	Accident sites - All Accident severities - All Prediction difference = 16.00	↑
				Accident sites - All Accident severities - Fatal plus Injury Prediction difference = 21.80	↑
				Accident sites - All Accident severities - Damage only Prediction difference = 10.20	↑

↑	denotes positive road safety effects	-	denotes unclear or marginal road safety effects
↓	denotes negative road safety effects	* denotes that no statistical analysis was conducted for the significance of the effects	

Table 2: Quantitative results of coded studies and impacts on road safety.

3.2 METHODOLOGY

3.2.1 Literature search strategy

In this chapter the literature search that was carried out will be presented for the measure of traffic signal installation that was examined in this synopsis. The results are summarised in relevant tables. Several databases were examined in an attempt to locate all relevant scientific publications. As with the standards specified for the SafetyCube project, journal or conference papers published after 1990 were prioritised over reports.

3.3 IDENTIFYING RELEVANT STUDIES FOR IMPROVING TRAFFIC SIGNAL TIMING

Database: Scopus **Date:** 20th of December 2016

search no.	search terms / operators / combined queries	hits
#1	"road" AND "safety"	
#2	AND ("traffic signal" OR "traffic light")	1073
#3	AND ("install*" OR "implem*")	206
	All years	215

Database: TRID (trid.trb.org) **Date:** 20th of December 2016

search no.	search terms / operators / combined queries	hits
#1	Traffic signal installation	767
	All years	1185

Database: Science Direct **Date:** 20th of December 2016

search no.	search terms / operators / combined queries	hits
#1	"road" AND "safety" AND " traffic signal" OR "traffic light"	22285
#2	AND ("install*" OR "implem*"), Filter: "safety"	283

<u>Limitations/Exclusions:</u>
Search field: TITLE-ABS-KEY
Published: 1990 to current
Document Type: "Review" and "Article"
Language: "English"
Source Type: "Journal"
Only Transport Journals were considered
Subject Area: "Engineering"

3.4 RESULTS OF LITERATURE SEARCH

Database	Hits
Scopus (remaining papers after several limitations/exclusions)	215
TRID	1185
Science Direct	283
Total number of studies to screen title/abstract	1683

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3.5 SCREENING

Total number of studies to screen title/ abstract	1683
-De-duplication	0
-exclusion criteria A (not related to the topic/not relevant risk factor)	1549
-exclusion criteria B (part of meta-analysis)	0
Remaining studies	134
Not clear (full-text is needed)	134
Studies to obtain full-texts	134

3.6 ELIGIBILITY

Total number of studies to screen full-text	134
Full-text could be obtained	89
Reference list examined Y/N	Yes (+0 papers)
Eligible papers prioritized	6

3.7 PRIORITISING CODING

- Prioritising Step A (accidents over other performance indicators)
- Prioritising Step B (Journals over conferences and reports)
- Prioritising Step C (journal quality)
- Prioritising Step D (more recent studies)

3.8 LIST OF CODED STUDIES FOR TRAFFIC SIGNAL INSTALLATION

1. Elvik, R., Høye, A. (2015a). The handbook of road safety measures, online version (Traffic signal installation)
2. Elvik, R., Høye, A. (2015b). The handbook of road safety measures, online version (implementation of left-turn phase)
3. Celik, A. K., & Oktay, E. (2014). A multinomial logit analysis of risk factors influencing road traffic injury severities in the Erzurum and Kars Provinces of Turkey. Accident Analysis & Prevention, 72, 66-77.
4. Gitelman, V., Hakkert, A. S., Doveh, E., & Cohen, A. (2001, September). A study of safety effects of road infrastructure improvements under Israeli conditions. In Proceedings of International Conference Traffic Safety on Three Continents, Moscow, Russia (CD-ROM).
5. Persaud, B., Council, F., Lyon, C., Eccles, K., & Griffith, M. (2005). Multijurisdictional safety evaluation of red light cameras. Transportation Research Record: Journal of the Transportation Research Board, (1922), 29-37.
6. Sacchi, E., Sayed, T., & El-Basyouny, K. (2016). A full Bayes before-after study accounting for temporal and spatial effects: evaluating the safety impact of new signal installations. Accident Analysis & Prevention, 94, 52-58.

3.9 LIST OF STUDIES INCLUDED IN THE META-ANALYSIS (1) ELVIK, R., HØYE, A. (2015A)

1. Harkey, D. (2008). Accident modification factors for traffic engineering and ITS improvements (Vol. 617). Transportation Research Board.

2. Jensen, S. U., & ApS, T. (2010). Safety Effects of Intersection Signalization: a Before-After Study. In Transportation Research Board 89th Annual Meeting Compendium of Papers, Washington, DC.
3. McGee, H. W. (2003). Crash experience warrant for traffic signals (No. 491). Transportation Research Board.
4. Camden, A., Buliung, R., Rothman, L., Macarthur, C., & Howard, A. (2011). The impact of pedestrian countdown signals on pedestrian–motor vehicle collisions: a quasi-experimental study. Injury prevention, injuryprev-2011.

3.10 LIST OF STUDIES INCLUDED IN THE META-ANALYSIS (2) ELVIK, R., HØYE, A. (2015B)

1. Chen, L., Chen, C., Ewing, R., McKnight, C. E., Srinivasan, R., & Roe, M. (2013). Safety countermeasures and crash reduction in New York City—Experience and lessons learned. Accident Analysis & Prevention, 50, 312-322.
2. Harkey, D. (2008). Accident modification factors for traffic engineering and ITS improvements (Vol. 617). Transportation Research Board.
3. Hauer, E. (1991). Should stop yield? Matters of method in safety research. ITE journal, 61(9), 25-31.
4. Lyon, C., Haq, A., Persaud, B., & Kodama, S. (2005). Safety performance functions for signalized intersections in large urban areas: Development and application to evaluation of left-turn priority treatment. Transportation Research Record: Journal of the Transportation Research Board, (1908), 165-171.
5. Srinivasan, R., Council, F., Lyon, C., Gross, F., Lefler, N., & Persaud, B. (2008). Safety effectiveness of selected treatments at urban signalized intersections. Transportation Research Record: Journal of the Transportation Research Board, (2056), 70-76.
6. Srinivasan, R., Lyon, C., Persaud, B., Baek, J., Gross, F., Smith, S., & Sundstrom, C. (2012). Crash modification factors for changes to left-turn phasing. Transportation Research Record: Journal of the Transportation Research Board, (2279), 108-117.