Road Safety on Rural Roads

Handbook of accident prediction models, accident modification factors and user manual for calculation tools

November 2018

Trafitec
Transformervej 18
2860 Søborg
www.trafitec.dk

List of Contents

1. Introduction

This handbook introduces useful tools and methods for calculating the expected number of accidents and injuries when planning or redesigning existing roads and junctions in rural areas. The handbook is aimed at professionals working with road safety in road administrations and consultancy.

The handbook is based on the report *Uheldsmodeller, sikkerhedsfaktorer og værktøjer for landevejsnettet* [1], which describes road safety on rural roads and develops accident prediction models and accident modification factors that show how road safety is affected by changes of road design and traffic management.

Below is a brief introduction of the handbook contents.

Chapter 2
To estimate accidents and injuries on a specific road network, the network must be divided into junctions and links. Definitions of junctions and links in rural areas can be found in chapter 2.

Chapter 3
The number of accidents and injuries at junctions and on links can be estimated by the use of accident prediction models. An accident prediction model is a mathematical expression, used to describe how the number of accidents and injuries depends on different variables e.g. traffic volume. Chapter 3 describes Accident Prediction Models (APMs) for signalised junctions, roundabouts, priority junctions and links in rural areas.

Chapter 4
When estimating accidents and injuries for links and junctions where the design differs from the designs described in Chapter 3, accident modification factors (AMFs) are used. AMFs describe how design, geometry and traffic management changes safety. The use of AMFs is described in Chapter 4.

Chapter 5
Chapter 5 describes how APMs can be used to predict the road safety impact when redesigning existing junctions and links as well as in the planning of new roads or junctions. The chapter includes two examples of how to use the APMs and AMFs.

Chapter 6
Two calculations tools which make it easy to estimate the number of accidents and injuries at junctions and on links have been developed. Chapter 6 includes a brief manual to the calculation tools. The calculations tools can be downloaded free of charge from the website of the Danish Road Directorate or Trafitec.

2. Division of the road network

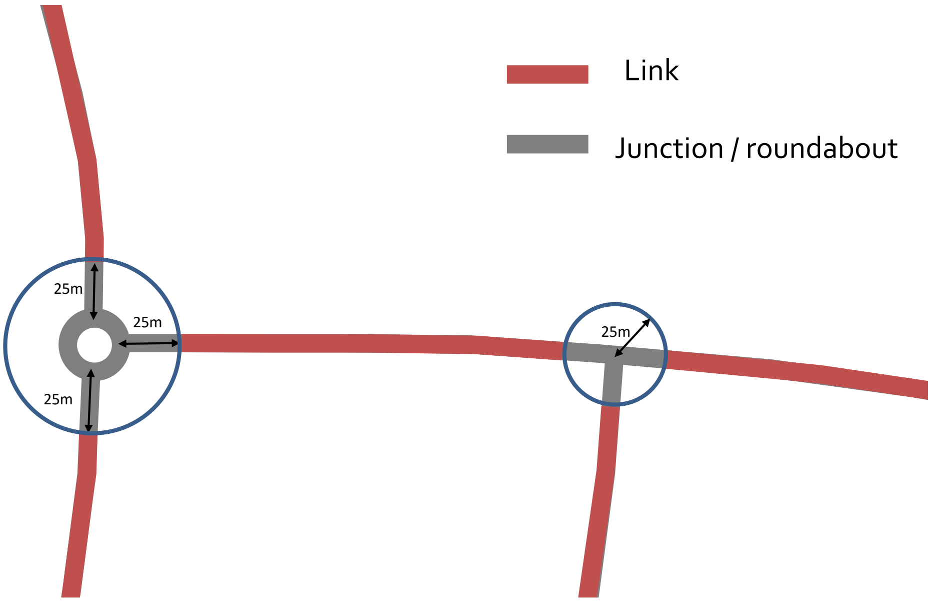
To estimate the number of accidents and injuries of a network the network has to be divided into junctions and links. Often it is only necessary to divide a small part of the road network, or perhaps just to estimate the number of accidents and injuries for one link or one junction.

All roads in rural areas except motorways can be included. However, junctions at interchanges between motorways and rural roads can be included.

The Accident Prediction Models (APMs) described in this handbook applies for the three most common junction types; *signalised junctions, priority junctions* and *roundabouts*. Furthermore, APMs for the most common link type; *links with dual-way traffic* are included.

2.1 Definition of junction and link

A division of the road network into junctions and links are clear. The figure below shows a link between two junctions, one roundabout and one 3-armed junction.



Definition of junction/roundabout and link. A junction goes from the center point, i.e. where the roads intersect, and 25 m out of each arm. The link is the road between the two junctions.

As illustrated on the figure above a **junction** is not defined as a single point, but goes from the center point, i.e. where the roads intersect, and 25 m out of each arm of the junction.

Since the APM only applies for rural areas, the center point of the junction must be placed in rural area, while one or more of the arms may be partly situated in town zone.

A **link** is often defined as the road between two junctions, but there may also be other "end points" for a link than junctions. It may be that a link ends at a town sign (transition between rural and urban area) or perhaps another type of link e.g. a merge area. Examples of "end points" are described in section 2.5.

Below follows a description of each junction and link type, for which the accident prediction models (APMs) described in this handbook are developed.

2.2 Signalised junction

The APMs applies for signalised junctions in rural areas, where the following conditions exist:

- 3- or 4-arm junctions
- Dual-way or one-way traffic on arms

If a junction has one ore more shunts, these are to be considered as right turn lanes.

2.3 Roundabout

APMs applies for roundabouts in rural areas with:

- 2, 3, 4, 5 or 6 arms
- Dual-way or one-way traffic on arms

If a roundabout has one or more shunts, these are considered as entry lanes.

2.4 Priority junctions

The APMs applies for priority junction in rural areas, where the following conditions exist:

- 3-arm junction or 4-arm junction (not signalised)
- Give way ▽, stop  or yield to vehicles from the right
- Dual-way or one-way traffic on arms

If a junction have one or more shunts these are to be considered as right turn lanes on the primary road.

2.5 Other junction types

Due to a limited amount of data no APMs have been developed for railway crossings, staggered junctions as well as other atypical junctions.

A *staggered junction* is two priority junctions with a distance of 50 m or less between the center points of the junctions. If the distance between center points is less than 15 m, the two junctions are considered as one 4-arm junction, and thus the APMs for 4-arm junctions can be used. If the distance between the center points is *more* than 15 m, the staggered junction is considered as two individual 3-arm junctions, i.e. the relevant APMs and AMFs are to be used for the individual junction.

Examples of other junction types can be seen in [1].

2.6 Links

APMs only applies for the most common link type in rural areas, where the following conditions exist:

- Dual-way traffic
- No signalised junctions, no roundabouts and no railway crossings as well as no priority junctions with traffic islands and/or turn lanes
- Asphalt paved carriageway
- A total width of carriageway ≥ 5,5 meter
- Annual Average Daily Traffic (AADT) ≥ 500

Access roads/minor priority junctions along the link are accepted as long as there are no turn lanes and no traffic islands and as long as there are no traffic counts (AADT) for the secondary road (access road/side road).

Along a link there might be parking bays as well as rest areas. These are included in a link (and in APMs for links) even if the rest area has its own ID. Larger parking areas e.g. lots for carpooling are not included in a link. APMs for parking areas have not been developed.

A link is often defined as the road between two junctions (junction, roundabout or railway crossing), but the start or end of a link may also be at a town sign (transition between rural and urban area), at road ends, or where the link change to another link type (e.g. merge area or road with one-way traffic).

If the design of the link changes significantly (e.g. regarding the central reserve, road lighting or the width of the carriageway changes more than 2 m), it might be a good idea to divide the link into two or more links. However, most of the major changes in roads cross sections occur at junctions and roundabouts as well as at town signs, where the division of a link into two or more links is irrelevant.

Examples of end-points for links are given below:

The end-point is a junction/roundabout
A junction is not only defined as a center point. The end-point of a link at a junction is defined as 25 m from the center point of the junction (at junctions, roundabouts and railway crossings, see section 2.1).

The end-point is a junction/roundabout with a shunt
A shunt is considered as a part of a roundabout or a junction. Therefore, accidents on shunts are included in the developed APMs for roundabouts and junctions. The end-point of a link is still defined as 25 m from the center point of the junction or roundabout. The presence of a shunt does not affect the definition of links.

Dead end link
A link can begin or end at ferry terminals, harbors or at properties (farmhouses). At ferry terminals – parking areas and lanes for waiting cars are *not* to be considered as a part of the link.

The link ends at another type of link
The end of a link might be where a merge area or road with one-way traffic starts.

A *road with one-way traffic* in rural areas is often a ramp at a grade separated junction. A road with one-way traffic will usually go from a junction (25 m from the center point of the junction) to a nose at an entrance merge area or an exit diverge area.

An *entrance merge area* is defined to start at the beginning of the nose and end 200 m after the end of the taper. An exit diverge area is defined to begin 200 m before the start of the taper and end at the end of the nose.

2.7 Other link types

Because of a limited amount of data *no* APMs have been developed for entrance merge areas, exit diverge areas and roads with one-way traffic.

For calculation of accidents and injuries on merge and diverge areas in rural areas, it is recommended to use the APM for links (Dual-way traffic), where each access road (entrance ramp) is registered as a side road (see AMF for side roads).

For calculation of accidents and injuries on roads with one-way traffic in rural areas, see *Trafiksikkerhed på motorveje* [2].

3. Accident prediction models

In this chapter follows a description of Accident Prediction Models (APMs) for junctions and links in rural areas. APMs are based on police recorded accidents in Denmark in the years 2011-2016 and primarily junctions and links on the primary road network has been included.

The APMs describes the relation between accident density and traffic volume for a specific type of link or junction. APMs for 3- and 4-arm signalised and priority junctions, 4-arm roundabouts and links with dual-way traffic has been developed.

For each of the six types of junctions and links S*afety Performance Functions* (SPFs) has been developed. A SPF is a design specific accident prediction model and is only valid for a variant of a junction or link type, e.g. 4-arm roundabouts of a specified design and traffic management. If the design of the link or junction differs from the design that applies for the SPF, *Accident Modification Factors* (AMFs) are used. AMFs describe how design, geometry and traffic management changes road safety. The use of AMFs is described in Chapter 4.

Below follows a description of *safety performance functions* for signalised junctions, roundabouts, priority junctions as well as links with dual-way traffic.

3.1 Signalised junctions

Safety Performance Functions (SPFs) for signalised junctions have the following function expression:

$$\mathrm{UHT} = \mathrm{a} \cdot \mathrm{N}_{\mathrm{pri}}^{\mathrm{p}_1} \cdot \mathrm{N}_{\mathrm{sek}}^{\mathrm{p}_2}$$

where

UHT	is the density of accidents or injuries per junction per year.
a, p_1 and p_2	are estimated constants.
N_{pri} and N_{sek}	is Annual Average Daily Traffic (AADT) on primary and secondary road of the junction. Traffic on any shunts must be included in N_{pri} and N_{sek}.

Parameter values (a, p_1 and p_2) for SPFs for 3-arm and 4-arm signalised junctions can be seen in Appendix 1.

SPFs apply for 3-arm and 4-arm signalised junction with the following conditions:

3-arm signalised junction

- AADT for all incoming vehicles is 3,000 – 40,000
- Median islands (physical island in the middle) or central reserve in all arms of the junction
- 2 left turn lanes
- 1 right turn lane
- No separation islands (between turn lanes and lanes for straight ahead driving) and no shunts
- No bicycle facilities
- Lighting of junction and arms
- No turning prohibition
- Speed limit of 70 kph
- No turn arrows (neither right nor left)
- Dual-way traffic in all arms of the junction

4-arm signalised junction

- AADT for all incoming vehicles is 3,000 – 40,000
- Median islands or central reserve in all arms of the junction
- 4 left turn lanes
- 2 right turn lanes
- No separation islands and no shunts
- No bicycle facilities
- Lighting of junction and arms
- No turning prohibition
- Speed limit of 70 kph
- No turn arrows (neither right nor left)
- Dual-way traffic in all arms of the junction

If the junction design differs from the SPF, e.g. if one or more of the arms have one-way traffic or some kind of bicycle facility, accident modification factors (AMFs) must be applied – see Chapter 4.

3.2 Roundabouts

Safety Performance Functions (SPFs) for roundabouts have the following function expression:

$$\mathrm{UHT} = \mathrm{a} \cdot \left(\mathrm{N_{pri}} + \mathrm{N_{sek}}\right)^{\mathrm{p_1}}$$

where

UHT	is the density of accidents or injuries per roundabout per year.
a and p_1	are estimated constants.
N_{pri} and N_{sek}	are the number of incoming vehicles (AADT) on all arms of the roundabout. Traffic on shunts must be included in $N_{pri} + N_{sek}$.

Parameter values (a and p_1) for SPFs for roundabouts are given in Appendix 1. SPFs are valid for 4-arm roundabouts with the following conditions:

- AADT for all incoming vehicles is 500 – 25,000
- 1 circulating lane
- 4 arms
- A total of 4 entry lanes
- 80 km/t speed limit
- Central island diameter of 30 meters
- Central island height of 0.0-1.9 meter
- Width of truck apron next to central island is 2.0 meters
- Width of circulatory carriageway is 6.5 meters
- Triangular or trumpet shaped splitter islands on all arms
- No shunts
- No bicycle facilities
- No pedestrian crossings
- Lighting of roundabout and arms
- Dual-way traffic on all arms of the roundabout

If the design differs from the above, e.g. in cases of roundabouts with more than 4 arms or with cycle lanes, accident modification factors (AMFs) must be applied – see Chapter 4.

3.3 Priority junctions

Safety Performance Functions (SPFs) for priority junctions have the following function expression:

$$UHT = a \cdot N_{pri}^{p_1} \cdot N_{sek}^{p_2}$$

where

UHT	is the density of accidents or injuries per junction per year.
a, p_1 and p_2	are estimated constants.
N_{pri} and N_{sek}	is Annual Average Daily Traffic (AADT) on primary (main) and secondary (minor) road of the junction. Traffic on any shunts must be included in N_{pri} and N_{sek}.

Parameter values (a, p_1 and p_2) for SPFs for priority junctions are given in Appendix 1.

SPFs are valid for 3-arm junctions and 4-arm junctions with the following conditions:

- AADT for all incoming vehicles is 500 – 25,000
- 80 kph speed limit on the primary road
- No median islands (ghost or physical island in the middle) on the primary road
- No median islands on the secondary road
- No turn lanes, neither left nor right turn lanes
- No bicycle facilities
- No pedestrian crossings
- No lighting of junction or arms
- No separation islands and no shunts
- Obligation to give way (give way sign and marked yield line)
- No turning prohibition
- Dual-way traffic in all arms of the junction

If the design differs from the above, e.g. if the junction has road lighting or there is obligation to stop (stop sign and marked stop line), accident modification factors (AMFs) must be applied – see Chapter 4.

3.4 Links

Safety Performance Functions (SPFs) for links with dual-way traffic have the following function expression:

$$\mathrm{UHT} = \mathrm{a} \cdot \mathrm{N}^{\mathrm{p}}$$

where

UHT	is the density of accidents or injuries per km per year.
a and p	are estimated constants.
N	is annual average daily traffic (AADT) on the link.

Parameter values (a and p) for SPFs for links are given in Appendix 1.

By multiplying L (length of link in km) on the right side of the function expression for accident density becomes U (number of accidents or injuries per year) on the link ($\mathrm{U} = \mathrm{a} \cdot \mathrm{N}^{\mathrm{p}} \cdot \mathrm{L}$).

SPFs are valid for links with the following conditions:

- AADT between 500 and 32,000
- 2 traffic lanes, each with a width of 3.5 m
- 80 kph speed limit
- No central reserve
- Nearside hard shoulder width of 0.5 m
- Width of shoulders (unpaved) of 2 m
- No sidewalk
- No road lighting
- Maximum gradient of 2 %
- 10 degrees curvature per km
- Cycling allowed
- No side roads

If the link design differs from the above, e.g. road lighting is present or another speed limit than 80 kph, accident modification factors (AMFs) must be applied – see Chapter 4.

3.5 Modelling uncertainty

Assessments of uncertainty of the estimated numbers of accidents are given in [1], where among others dispersion parameter, standard deviation etc. for estimated constants for each SPF are given. The level of statistical uncertainty for estimated number of accidents are usually modest because the developed SPFs typically explain a very large extent of the systematic variation in the number of accidents. The level of uncertainty for estimated number of accidents are usually 10-30 %, so the real level can be 10-30 % higher or lower than the estimated.

3.6 Accident costs

The estimated number of accidents and injuries can be converted to accident costs by the use of economical unit prices for accidents and injuries. The unit prices for the current 2018 edition of the calculation tools are set to 2017 price level:

- 29,492,829 DKK per killed
- 4,654,307 DKK per severe injury
- 608,667 DKK per slight injury
- 740,934 DKK in property damage per reported accident

Reported accidents includes injury accidents and property-damage-only with police report (PDO w/report). Property-damage-only accidents without police report

(PDO no report) are not valued and thus not included in the calculation of accident costs.

For estimation of accident costs is referred to the calculation tools (Chapter 6), that automatically estimate accident costs, so that the economic consequences of different alternatives easily can be assessed.

4. Accident modification factors

As described in Chapter 3, Safety Performance Functions (SPFs) only apply for a specific design and traffic management of respectively links and junctions. If the design of a link or junction differs from the specific design or traffic management, the expected number of accidents can be estimated by using *accident modification factors* (AMFs).

The use of AMFs makes it possible to account for changes in design, geometry and traffic management, and thereby describe the effects of different road technical measures on road safety. The use of SPFs in combination with AMFs makes it possible to estimate expected numbers of accidents and injuries for junctions and links of alternative designs.

This chapter describes the AMFs that are used in relation to the SPFs. The AMFs are listed in the table below:

AMF / Type of design	3-arm signalised junction	4-arm signalised junction	4-arm rounda-bout	3-arm priority junction	4-arm priority junction	Link
One-way traffic	X	X		X	X	
Number of turn lanes	X	X		X	X	
Left turn arrows	X	X				
Bicycle facility	X	X	X	X	X	
Speed limit	X	X	X	X	X	X
Number of entry lanes			X			
Splitter/median island on arm			X	X	X	
Central island diameter			X			
Central island height			X			
Width of truck apron			X			
Width of circulatory carriageway			X			
Road/junction lighting			X	X	X	X
Type of priority				X	X	
Curvature						X
Gradient						X
Central reserve						X
Width of travel lane						X
Width of nearside hard shoulder						X
Width of shoulder						X
Cycling prohibited						X
Side roads						X

If the design of a junction or link differs from the one that apply to the safety performance function, accident modification factors are used.

It has not been possible to set up AMFs for e.g. safety barriers, curve marking, overtaking prohibition, rumble strips, design of safety zone, visibility splay at junctions, right turn arrows and type of signal-control. This is due to the fact that the safety effect for these measures are either too uncertain or that data for links and junctions that are used in the SPFs are insufficient.

In the Road Directorate's Road Safety Handbook from 2014 *"Trafiksikkerhed"* [3] that describe the safety effects of road safety measures, safety effects of several of the above-mentioned measures are described. However, those safety effects can't be used in relation to the SPFs because the presence of these measures on links and at junctions, which the SPFs are based upon, are unknown. Nevertheless, the Road Safety Handbook may provide ideas of measures that can affect road safety, beyond the AMFs presented in the following.

Accident Modification Factors (AMFs) are presented briefly without specifying which studies and considerations are behind the values. A more detailed presentation of how AMFs are set up can be found in the background report [1].

4.1 Use of accident modification factors

An Accident Modification Factor (AMF) is multiplied on the result from a SPF and thereby changing the expected number of accidents and injuries. For junctions the expression would look like this:

$$\mathrm{UHT} = \mathrm{a} \cdot \mathrm{N}_{\mathrm{pri}}^{\mathrm{p}_1} \cdot \mathrm{N}_{\mathrm{sek}}^{\mathrm{p}_2} \cdot \mathrm{AMF}_1 \cdot \mathrm{AMF}_2 \dots ,$$

Where AMF_i is an accident modification factor.

With the use of *many* AMFs, there must be reservations that there may be synergies between the design elements included in the AMFs. This means that the final results may be slightly misleading.

By the use of an abnormal or unreal combination of AMFs, e.g. a 100 kph speed limit on a very curved link with many side roads per km, the results of the estimated number of expected accidents and injuries may be very misleading.

4.2 Signalised junctions

4.2.1 One-way traffic

One-way traffic may be present at one or more arms of signalised junctions. Junctions at interchanges with motorways usually have one-way traffic in one or more arms of the signalised junction.

SPFs for signalised junctions are based on junctions with dual-way traffic in all arms of the junction. The following AMFs can be used on signalised junctions with one or more arms with one-way traffic:

AMF for one-way traffic	One-way traffic in one or more arms	
	Yes	No
Injury accidents and injuries	0.60	1.00
PDO accidents w/report	0.75	1.00
PDO accidents no report	0.90	1.00

AMFs for one-way traffic at 3-arm and 4-arm signalised junctions in rural areas.

4.2.2 Number of turn lanes

Turn lanes are lanes exclusively for left or right turning vehicles. Combined lanes for e.g. vehicles turning right or going straight through are not considered as a turn lane.

SPFs for 3-arm signalised junctions are based on junctions with 1 right turn lane and two left turn lanes. The following AMF's can be used for turn lanes at **3-arm signalised junctions**:

AMF for turn lanes	Number of turn lanes				
	0	1	2	3	≥4
Accidents and injuries – 3-arm junctions	1.15	1.10	1.05	1.00	0.95

AMFs for turn lanes at 3-arm signalised junctions in rural areas.

SPFs for 4-arm signalised junctions are based on junctions with 2 right turn lanes and 4 left turn lanes. The following AMFs can be used for turn lanes at **4-arm signalised junctions**:

AMF for turn lanes	Number of turn lanes								
	0	1	2	3	4	5	6	7	≥8
Accidents and injuries – 4-arm junctions	1.30	1.25	1.20	1.15	1.10	1.05	1.00	0.95	0.90

AMFs for turn lanes at 4-arm signalised junctions in rural areas.

4.2.3 Left turn arrows

Left turn arrows can be with 1-arrow (protected/permissive left turn) or 3-arrow (protected left turn). SPF for signalised junctions are based on junctions *without* left turn arrows. The following AMF's can be used for left turn arrows at signalised junctions:

AMF for left turn arrows	Left turn arrows		
	None	1-arrow	3-arrows
Accidents and injuries – 3-arm junctions	1.00	1.00	0.55
Accidents and injuries – 4-arm junctions	1.00	1.00	0.80

AMFs for left turn arrows at signalised junctions in rural areas.

AMFs for left turn arrows are based on a Danish study that shows clear results of protected left turn in rural areas. AMFs for left turn arrows are changed compared to [1].

Left turn arrows may only be used at junctions with at least one left turn lane. Any effects of separation islands at protected left turn are included in the AMFs above.

4.2.4 Bicycle facility

A bicycle facility can be a one-way or dual-way cycle path (or track) or a cycle lane or a wide (≥0.8 m) nearside hard shoulder.

SPFs for signalised junctions are based on junctions *without* bicycle facilities. The following AMFs can be used for bicycle facilities at 3-arm and 4-arm signalised junctions:

AMFs for bicycle facility	Bicycle facility			
	None	Wide nearside hard shoulder or cycle lane	One-way cycle paths	Dual-way cycle paths
Accidents and injuries	1.00	1.10	1.00	1.10

AMFs for bicycle facilities at signalised junctions in rural areas.

4.2.5 Speed limit

Speed limit at 3-arm and 4-arm signalised junctions is the average speed limit on the arms about 100 m from the center point of the junction. Both Danish and foreign studies show that speed limit at signalised junctions is of great importance for the road safety at these junctions.

SPFs for signalised junctions are based on junctions with a speed limit on 70 kph. The following AMFs can be used for speed limits at signalised junctions:

AMF for average speed limit on arms	Speed limit (kph)				
	50	60	70	80	90
Injury accidents	0.82	0.92	1.00	1.05	1.07
PDO accidents (w/report and no report)	0.83	0.92	1.00	1.04	1.07
Killed	0.57	0.78	1.00	1.14	1.21
Severe injuries	0.65	0.83	1.00	1.10	1.16
Slight injuries	0.84	0.93	1.00	1.04	1.06
All injuries	0.74	0.88	1.00	1.07	1.11

AMFs for the average speed limit on arms at 3-arm and 4-arm signalised junctions in rural areas.

All injuries include killed, severe- and slight injuries. The AMFs listed in the table above for *All injuries* are not included in the calculation tool.

4.3 Roundabouts

4.3.1 Number of entry lanes

Entry lanes are lanes used by motor vehicles when entering a roundabout. Single lane roundabouts usually have one entry lane per arm. Multilane roundabouts often have two entry lanes per arm.

SPFs for roundabouts are based on 4-arm single lane roundabouts with one entry lane per arm, i.e. a total of 4 entry lanes.

The following AMFs can be used for entry lanes at roundabouts:

AMF for entry lanes	Number of entry lanes							
	2	3	4	5	6	7	8	9
Injury accidents and injuries	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
PDO accidents (w/report and no report)	0.54	0.77	1.00	1.23	1.46	1.69	1.92	2.15

AMFs for entry lanes at roundabouts in rural areas. A shunt (with one travel lane) must be considered as one entry lane.

4.3.2 Splitter island on arm

The arms of the roundabouts might be designed with or without splitter islands. The splitter island can be designed with a triangular shape, a parallel shape or a trumpet shape.

SPFs for roundabouts are based on roundabouts with triangular or trumpet shaped splitter island in all arms. The following AMFs can be used for splitter islands on arms of the roundabout:

AMF for type of splitter island on arms	Type of splitter island on arms		
	None / mixed	Parallel	Triangular/Trumpet
Injury accidents and injuries	1.00	1.20	1.00
PDO accidents (w/report and no report)	1.00	1.15	1.00

AMFs for type of splitter island on arms at roundabouts in rural areas.

4.3.3 Central island diameter

The central island diameter is usually around 30 m for single lane roundabouts and around 45 m for multilane roundabouts. In rural areas there are only few roundabouts with central island diameters of more than 60 m. Every time the central island diameter increases with 2 m the length of adjacent links towards the roundabout is reduced with 1 m. Safety studies of conversion of junctions to roundabouts show that central island diameters of 20-40 m including possible truck aprons provides the best safety effects.

SPFs for roundabouts are based on roundabouts with a central island diameter of 30 m (truck apron not included). The following AMFs are used for central island diameter of roundabouts:

AMF for central island diameter	Central island diameter (meters)						
	≤10	20	30	40	50	60	≥70
Accidents and injuries	0.77	0.88	1.00	1.14	1.30	1.49	1.70

AMFs for central island diameter of roundabouts in rural areas.

4.3.4 Central island height

Central island height is measured as the height difference between the circulatory carriageway and the top of the central island (items that are so high and wide that road users may hide behind it). Examples of items may be landscaping, planting, mounds, sculptures, etc. When the height of a central island is 2 m or higher, a passenger car may *hide* behind it on the opposite side of the central island.

SPFs for roundabouts are based on roundabouts with a central island height of 0.0-1.9 m. The following AMFs can be used for roundabouts’ central island height:

AMF for central island height	Central island height (meters)	
	0.0-1.9	2.0-10.0
Accidents and injuries – single lane roundabouts	1.00	0.78
Accidents and injuries – multilane roundabouts	1.00	1.00

AMFs for roundabouts’ central island height in rural areas.

4.3.5 Width of truck apron

The width of the truck apron, which is the area between the circulatory carriage-way and the central island, is often 1-3 m at single lane roundabouts in rural areas. Studies show that the width of truck apron affects the accident rate by up to 20 % at single lane roundabouts, with the best safety effects for widths of about 2 m.

SPFs for roundabouts are based on roundabouts with a 2 m wide truck apron. The following AMFs can be used for width of truck apron at roundabouts:

AMF for width of truck apron	Width of truck apron (meters)				
	0	0.5-1.4	1.5-2.4	2.5-3.4	3.5-7.0
Accidents and injuries – Single lane roundabouts	1.20	1.10	1.00	1.05	1.05
Accidents and injuries – Multilane roundabouts	1.00	1.00	1.00	1.00	1.00

AMFs for width of truck apron at roundabouts in rural areas.

4.3.6 Width of circulatory carriageway

The circulatory carriageway width is usually 6-8 m at single lane roundabouts in rural areas. SPFs for roundabouts are based on roundabouts with a circulatory carriageway width of 6.5 m. The following AMFs can be used for circulatory carriageway width at roundabouts:

AMF for width of circulatory carriageway	Width of circulatory carriageway (meters)				
	3.5-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-10.5
Accidents and injuries – Single lane roundabouts	1.20	1.10	1.00	1.05	1.05
Accidents and injuries – Multilane roundabouts	1.00	1.00	1.00	1.00	1.00

AMFs for width of circulatory carriageway at roundabouts in rural areas.

4.3.7 Bicycle facility

Bicycle facilities at roundabouts can be cycle lanes or cycle tracks or cycle paths. Cycle tracks and cycle paths can be designed so motorists must yield to circulating cyclists or vice versa so circulating cyclists must yield to entering or exiting motorists. It is also possible that cycling is prohibited in a roundabout, which often is the case at roundabouts with separated cycle paths leading the cyclists through a tunnel under one or more arms of the roundabout. 29 % of injuries at roundabouts in rural areas occurs among pedestrians, cyclists and moped riders.

SPFs for roundabouts are based on roundabouts with cycling allowed but *without* any bicycle facility. The following AMFs can be used for bicycle facilities at roundabouts:

AMF for bicycle facility	Type of bicycle facility				
	None	Cycling prohibited	Cycle lane	Cycle track, motorist must yield	Cycle path, cyclist must yield
Accidents and injuries	1.00	0.90	1.25	1.00	0.80

AMFs for bicycle facility at roundabouts in rural areas.

4.3.8 Junction lighting

Roundabouts almost always have junction lighting. SPFs for roundabouts are based on roundabouts with junction lighting. The following AMFs can be used for junction lighting at roundabouts:

AMF for junction lighting	Junction lighting	
	Yes, junction lighting	No, no junction lighting
Injury accidents	1.00	2.25
PDO accidents (w/report and no report)	1.00	1.75
Killed	1.00	3.50
Severe injuries	1.00	2.50
Slight injuries	1.00	2.00
All injuries	1.00	2.35

AMFs for junction lighting at roundabouts in rural areas.

AMFs listed in the table above for *All injuries* are not used in the calculation tool.

4.3.9 Speed limit

The speed limit on arms about 100 m from the center points of the roundabout do not seem to affect road safety at roundabouts. SPFs for roundabouts are based on a speed limit on 80 kph on all arms of the roundabout. The AMF is set at 1.00 for all levels of speed limit on arms at roundabouts in rural areas.

4.4 Priority junctions

4.4.1 Type of priority

There are three different types of priorities: Obligation to give way (give way sign and marked yield line), obligation to stop (stop sign and marked stop line) and yield to vehicles from the right (no signs and no markings).

SPFs for priority junctions are based on junctions with obligation to give way. The following AMFs are used for the three different kinds of priority:

AMF for type of priority	Type of priority		
	Yield to vehicles from the right	Obligation to give way	Obligation to stop
Injury accidents and injuries – 3-arm junctions	1.04	1.00	0.75
PDO accidents (w/report and no report) – 3-arm junctions	0.92	1.00	0.75
Injury accidents and injuries – 4-arm junctions	1.04	1.00	0.65
PDO accidents (w/report and no report) – 4-arm junctions	0.92	1.00	0.65

AMFs for type of priority at 3- and 4-arm priority junctions in rural areas.

4.4.2 One-way traffic

Priority junctions may have one or more arms with one-way traffic e.g. at interchanges.

SPFs for priority junctions are based on junctions *without* arms with one-way traffic. AMFs for arms with one-way traffic at priority junctions are the same as used for signalised junctions:

AMF for one-way traffic	One-way traffic in one or more arms	
	Yes	No
Injury accidents and injuries	0.60	1.00
PDO accidents w/report	0.75	1.00
PDO accidents no report	0.90	1.00

AMFs for one-way traffic at 3-arm and 4-arm priority junctions in rural areas.

4.4.3 Turn lane on primary road

The presence of turn lanes on the primary (main) road will almost always mean that there are median islands (ghost or physical islands in the middle of the road) on the primary road.

SPFs for priority junctions are based on junctions *without* turn lanes on the primary (main) road. The following AMFs can be used for turn lanes on the primary road at **3-arm priority junctions**:

AMF for turn lane	Number of turn lanes on primary (main) road		
	0	1	2
All accidents and injuries – 3-arm junctions	1.00	0.85	0.75

AMFs for turn lanes on the primary road at 3-arm priority junctions in rural areas.

The following AMFs can be used for turn lanes on the primary road at **4-arm priority junctions**:

AMF for turn lanes	Number of turn lanes on primary (main) road				
	0	1	2	3	4
All accidents and injuries – 4-arm junction	1.00	0.90	0.80	0.70	0.60

AMFs for turn lanes on the primary road at 4-arm priority junctions in rural areas.

4.4.4 Median island on secondary road

Median islands on secondary (minor) roads at priority junctions will often be kerb separated, i.e. physical islands not ghost islands. SPF for 3- and 4-arm priority junctions are based on junctions *without* median islands on the secondary road. The following AMFs can be used for priority junctions with median islands on the secondary (minor) road:

AMF for median islands on secondary (minor) road	Number of median islands on secondary road	
	0	1-2
All accidents and injuries – 3-arm junction without median islands on primary road	1.00	1.15
All accidents and injuries – 3-arm junction with median islands on primary road	1.00	1.00
All accidents and injuries – 4-arm junction without median islands on primary road	1.00	1.05
All accidents and injuries – 4-arm junction with median islands on primary road	1.00	0.85

AMFs for median islands on secondary (minor) roads at 3- and 4-arm priority junctions in rural areas.

4.4.5 Bicycle facility

Bicycle facility can be a single- or dual-way cycle path (or track), wide (≥0.8 m) nearside hard shoulder or cycle lane.

SPFs for 3- and 4-arm priority junctions are based on junctions *without* bicycle facilities. AMFs for bicycle facilities are the same for priority junctions and signalised junctions:

AMFs for bicycle facility	Bicycle facility			
	None	Wide nearside hard shoulder or cycle lane	One-way cycle paths	Dual-way cycle paths
Accidents and injuries	1.00	1.10	1.00	1.10

AMFs for bicycle facilities at priority junctions in rural areas.

4.4.6 Junction lighting

Junction lighting at priority junctions seems to improve road safety.

SPFs for priority junctions are based on junctions *without* lighting. The following AMFs are used for junction lighting at priority junctions:

AMF for junction lighting	Junction lighting	
	Yes, lighting	No, no lighting
Injury accidents	0.91	1.00
PDO accidents (w/report and no report)	0.96	1.00
Killed	0.82	1.00
Severe injuries	0.90	1.00
Slight injuries	0.93	1.00
All injuries	0.91	1.00

AMFs for junction lighting at 3- and 4-arm priority junctions in rural areas.

All injuries include killed, severe- and slight injuries. The AMF listed in the table above for *All injuries* are not included in the calculation tool.

4.4.7 Speed limit

Speed limit at 3- and 4-arm priority junctions is calculated as the average speed limit on the two arms of the primary (main) road at a distance of about 100 m from the center point of the junction. It is assumed that speed limit on secondary (minor) roads is irrelevant to the road safety of priority junctions, which seems reasonable with good pre-warning of the junction on the secondary roads.

SPFs for priority junctions are based on junctions with 80 kph speed limit on the primary road. The following AMFs are used for speed limits at priority junctions:

AMF for speed limit on primary (main) road	Speed limit kph				
	50	60	70	80	90
Injury accidents	0.74	0.84	0.93	1.00	1.04
PDO accidents (w/report and no report)	0.75	0.85	0.93	1.00	1.04
Killed	0.42	0.61	0.81	1.00	1.12
Severe injuries	0.52	0.69	0.85	1.00	1.09
Slight injuries	0.77	0.86	0.94	1.00	1.03
All injuries	0.64	0.77	0.89	1.00	1.06

AMFs for speed limits on primary road at 3-or 4- arm priority junctions in rural areas.

AMFs for *All injuries* listed in the table above are not used in the calculation tool.

4.5 Link

4.5.1 Curvature
Curvature (bendiness) describes the links' horizontal alignment. Curvature is the number of degrees the link curves per km.

SPFs are based on links with a curvature of 10 degrees per km. The following AMFs are used for curvature on links:

AMF for curvature	Curvature (degrees per km)							
	0	10	20	30	40	60	90	120 -
Accidents and injuries	1.10	1.00	1.03	1.06	1.09	1.16	1.27	1.40

AMFs for curvature on links in rural areas.

4.5.2 Gradients
Gradient define the grade of slopes of the vertical alignment.

SPFs for links are based on links with a gradient of maximum 2 %. The following AMFs are used for gradients on links:

AMF for maximum gradients	Maximum gradients (%)									
	0	1	2	3	4	5	6	7	8	9 -
Injury accidents and injuries	0.96	0.98	1.00	1.05	1.10	1.16	1.22	1.28	1.34	1.41
PDO accidents (w/report and no report)	0.98	0.99	1.00	1.02	1.04	1.06	1.08	1.10	1.13	1.15

AMFs for maximum gradient on links in rural areas.

4.5.3 Central reserve
Central reserves on links leads to fewer accidents and far fewer injuries.

SPFs for links are based on links without central reserves. The following AMFs can be used for central reserve on links:

AMF for central reserve	Central reserve		
	None	Partly (>50 %)	Yes (100 %)
Injury accidents and injuries	1.00	0.90	0.75
PDO accidents (w/report and no report)	1.00	0.97	0.95

AMF for central reserve on links in rural areas.

4.5.4 Width of travel lane
The width of travel lanes affects road safety.

SPFs for links are based on two travel lanes with a width of 3.5 m each. The following AMFs are used for width of travel lanes on links:

AMF for width of travel lane	Width of travel lane (meters)						
	2.75	3.00	3.25	3.50	3.75	4.00	4.25-6.75
Accidents and injuries	1.18	1.12	1.06	1.00	0.94	1.00	1.06

AMF for width of travel lanes on links in rural areas.

4.5.5 Width of nearside hard shoulder

The width of the nearside hard shoulder affect road safety.

SPFs for links are based on nearside hard shoulders with a width of 0.5 m. The following AMFs are used for different width of nearside hard shoulders on links:

AMF width of nearside hard shoulder	Width of nearside hard shoulder (meters)					
	0.0	0.3	0.5	1.0	1.5	2.0-3.5
Accidents and injuries	1.12	1.02	1.00	0.95	0.90	0.81

AMF for width of nearside hard shoulders on links in rural areas

4.5.6 Width of shoulder

Width of shoulders (unpaved) only has a minor impact on road safety.

SPFs for links are based on links with 2 m wide shoulders in each side of the road. The following AMFs are used for the width of shoulders on links;

AMF for width of shoulder	Width of shoulder (meters)						
	0.0	0.5	1.0	1.5	2.0	2.5	3.0 -
Injury accidents and injuries	1.00	1.00	1.00	1.00	1.00	1.00	1.00
PDO accidents (w/report and no report)	1.12	1.09	1.06	1.03	1.00	0.98	0.96

AMFs for width of shoulders (unpaved) on links in rural areas.

4.5.7 Cycling prohibited

Prohibition of cycling reduces the number of accidents and injuries on a link.

SPFs for links are based on links where cycling is allowed. The following AMFs are used for links where cycling is prohibited.

AMF for cycling prohibited	Cycling prohibited	
	Yes, cycling prohibited	No, cycling is allowed
Accidents and injuries	0.85	1.00

AMFs for links with cycling prohibited in rural areas.

4.5.8 Road lighting

Road lighting along links results in a large decrease in accidents and injuries in darkness.

SPFs for links are based on links without road lighting. For links with road lighting the following AMFs have been set up:

AMF for road lighting	Road lighting	
	Yes, road lighting	No, no road lighting
Injury accidents	0.91	1.00
PDO accidents (w/report and no report)	0.96	1.00
Killed	0.82	1.00
Severe injuries	0.90	1.00
Slight injuries	0.93	1.00
All injuries	0.91	1.00

AMFs for road lighting on links in rural areas.

All injuries include killed, severe- and slight injuries. The AMF for *all injuries*, listed in the table above are not used in the calculation tool.

4.5.9 Side roads

Side roads are access roads (drive ways to/from properties) and minor roads that are defined in vejman.dk and can be found in cvf.vd.dk (Danish road databases). No AADT must be available for side roads. The junction between the link and the side road must not have traffic islands and not have turn lanes. SPFs for links are based on 0 side roads per km. The following AMFs are used for links with side roads:

AMF for side roads	Number of side roads per km					
	0	1	2	3	4	5 -
Accidents and injuries	1.00	1.08	1.16	1.24	1.32	1.40

AMFs for side roads on links in rural areas.

4.5.10 Speed limit

The speed limit is set to the value that applies for the longest part of the link. The importance of speed limit on road safety is well documented. SPFs for links are based on links with a speed limit of 80 kph. The following AMFs are used for speed limit on links:

AMF for speed limit	Speed limit kph					
	50	60	70	80	90	100
Injury accidents	0.74	0.84	0.93	1.00	1.04	1.06
PDO accidents (w/report and no report)	0.75	0.85	0.93	1.00	1.04	1.06
Killed	0.42	0.61	0.81	1.00	1.12	1.19
Severe injuries	0.52	0.69	0.85	1.00	1.09	1.14
Slight injuries	0.77	0.86	0.94	1.00	1.03	1.05
All injuries	0.62	0.76	0.89	1.00	1.07	1.10

AMFs for speed limit on links in rural areas.

AMFs for *all injuries* listed in the table above are not used in the calculation tool.

5. Use of accident prediction models and accident modification factors

In this chapter is found a brief description of how Accident Prediction Models (APMs) and Accident Modification Factors (AMFs) can be used to predict the road safety impact when redesigning existing junctions and links as well as in planning of new junctions and links.

At the end of the chapter two examples of calculation of how to use APMs and AMFs in practice are presented. The two examples are based on calculations made manually. Alternatively, calculations can easily be done by using the developed calculation tools (see chapter 6).

5.1 Redesigning of existing junctions and links

By using APMs and AMFs the expected road safety effect of redesigning existing junctions or links can be estimated. The use of APMs and AMFs for preliminary assessment has the following two advantages:

- The estimated changes in accidents, injuries and costs are not affected by the random variation in accidents. Hence, it is unnecessary to account for the regression to the mean.

- An estimated accident change caused by e.g. converting a priority junction to a roundabout will be more exact, because the actual design of both the priority junction and the roundabout is considered.

In preliminary assessment of an expected safety effect, the number of accidents recorded in the existing junction or on the existing link are not used.

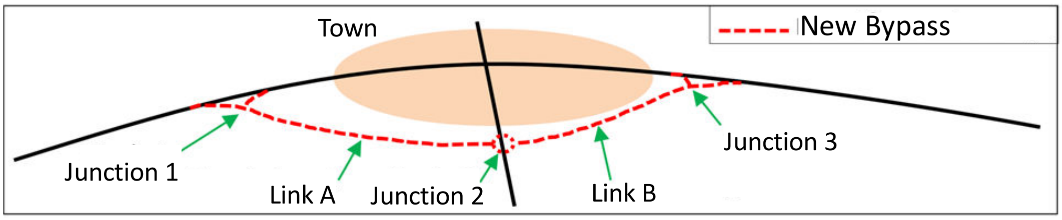
Thus, the method described is an additional method compared to the other methods of preliminary assessments presented in the Road Directorate's Handbook *Trafiksikkerhedsberegninger og ulykkesbekæmpelse* [4].

By using the calculation tools (see Chapter 6), the road safety impact of several different redesigns or reconstructions can easily be estimated. Enabling one to find a safe and cost-efficient solution.

5.2 Construction of links and junctions

When constructing new roads or junctions, the choice of design is among others based on information about the expected number of accidents, injuries and accident costs. However, other considerations than road safety are also considered. The use of this method with SPFs and AMFs provides – at the moment – the most accurate estimation of expected accidents and injuries for new roads and junctions, and is far better than any other method in previous handbooks.

The choice of junction and link design could e.g. be in relation to a new bypass road, including construction of three new junctions and two new links.



Construction of a new bypass road with three junctions and two links.

The number of accidents and injuries on the coming bypass road will depend on the design of junctions and links that are being constructed as well as the distribution of traffic between the old road and the proposed bypass road.

By using SPFs and AMFs the expected number of accidents and injuries can be estimated for links and junctions of various designs and traffic management. Also, the expected impact on road safety in relation to traffic volume can be calculated.

By using the calculation tools (see Chapter 6) the number of accidents and injuries for a new road network of different alternative designs can easily be estimated.

5.3 Black spot identification

The accident prediction models in Appendix A, has not been developed for black spot identification. The purpose of black spot identification is to identify existing links and junctions, where the recorded number of accidents is higher than expected. Black spot identification should instead be based on APMs (a-p-values) estimated by the Danish Road Directorate, at present time based on accidents from the years 2012-2016.

5.4 Example 1 – New construction

Example 1 – NEW CONSTRUCTION

In connection with expansion of a business area, **a new 3-arm signalised junction** is being established. The 3-arm junction connects the business area to a main road by a new access road. Two alternative designs of the 3-arm junction are drafted:

1. Only turn lanes on the main (primary) road
2. Turn lanes in all arms of the junction, protected left turn on the primary road and 1-arrow right turn on the access (secondary) road.

Two questions are asked:

1. How many more accidents and injuries will happen at the site, where the new signalised junction is established?
2. How does the junction design (two alternatives) influence accident costs?

In order to answer the two questions, the following are estimated:
- Accidents, injuries and accident costs per year on the 50 m of the main road, which is replaced by the new 3-arm signalised junction.
- Accidents, injuries and accidents costs per year for each of the two alternative designs of the new 3-arm signalised junction.

The main road has an AADT of 18,000 and a link length of 50 m. First the SPF for links in appendix 1 is used. The preliminary number of injuries per year for the main road is calculated to:

$= a \cdot N^{p} \cdot L$
$= 0.000041252 \cdot 18{,}000^{0,8138} \cdot 0.05$
= 0.0060 injury accidents per year (SPF)

As the design of the link differs from the SPF, AMFs must be used. The following AMFs are used:

- Curvature = 0, AMF = 1.10
- Gradient = 0, AMF = 0.96
- 4 travel lanes each with a width of 3.50 m, AMF = 1.00
- Central reserve along the whole link, AMF = 0.75
- 0.5 meters wide nearside hard shoulders, AMF = 1.00
- 2.0 meters wide shoulders, AMF = 1.00
- Road lighting, AMF = 0.91
- Pedestrians and cycling prohibited, AMF = 0.85
- No side roads, AMF = 1.00
- 70 kph speed limit, AMF = 0.93

The final number of injury accidents per year on the main road is calculated to:

$= a \cdot N^{p} \cdot L \cdot AMF_1 \cdot AMF_2 \cdot \ldots \cdot AMF_{10}$
$= 0.000041252 \cdot 18{,}000^{0{,}8138} \cdot 0.05 \cdot 1.10 \cdot 0.96 \cdot 1.00 \cdot 0.75 \cdot 1.00 \cdot 1.00 \cdot 0.91 \cdot 0.85 \cdot 1.00 \cdot 0.93$
= 0.0034 injury accidents per year

In the same way the final number of PDO accidents w/report and PDO accidents no reports on the main road is estimated to respectively 0.0066 and 0.0103. The total expected number of accidents then is 0.0034 + 0.0066 + 0.0103 = 0.0203 per year. The final expected number of killed, severe and slight injuries per year on the main road is estimated to 0.0004, 0.0018 and 0.0026 respectively. The total number of expected injuries is then 0.0004 + 0.0018 + 0.0026 = 0.0048 per year.

The accident costs for the main road are calculated on the basis of unit prices specified in section 3.5 and the final number of injury and PDO accidents w/report as well as killed, severe and slight injuries. Accident costs on the main road per year is:

= killed · 29,492,829 DKK + severe injuries · 4,654,307 DKK + slight injuries · 608,667 DKK + injury and PDO accidents w/report · 740,934 DKK.
= 0.0004 · 29,492,829 + 0.0018 · 4,654,307 + 0.0026 · 608,667 + 0.0100 · 740,934 DKK
= 29,167 DKK.

The new 3-arm signalised junction is expected to have an AADT of 19,500 on the main (primary) road and 5,000 on the access (secondary) road. By using the SPFs for 3-arm signalised junctions given in Appendix 1, the preliminary number of injury accidents for the junction per year can be estimated:

$= a \cdot N_{pri}^{p_1} \cdot N_{sek}^{p_2}$
$= 0.000002870 \cdot 19{,}500^{0.7749} \cdot 2{,}500^{0.3732}$
= 0.1123 injury accidents per year (SPF)

The AMFs for the two alternative 3-arm signalised junctions are not the same. *Alternative 1* has:

- Dual-way traffic, AMF = 1.00
- 2 turn lanes, AMF = 1.05
- No left turn arrows, AMF = 1.00
- No bicycle facility, AMF =1.00
- 70 kph speed limit, AMF = 1.00

The final number of injury accidents per year for *Alternative 1* is calculated as:
$= a \cdot N_{pri}^{p_1} \cdot N_{sek}^{p_2} \cdot AMF_1 \cdot AMF_2 \cdot \ldots \cdot AMF_5$
$= 0.000002870 \cdot 19{,}500^{0.7749} \cdot 2{,}500^{0.3732} \cdot 1.00 \cdot 1.05 \cdot 1.00 \cdot 1.00 \cdot 1.00$
= 0.1179 injury accidents per year

Similarly, the final number of PDO accidents w/report and PDO accidents no report per year for *Alternative 1* is estimated to 0.5895 and 0.3734 respectively. The total number of expected accidents is then 0.1179 + 0.5895 + 0.3734 = 1.0808 per year. The final number of killed, severe and slight injuries per year is estimated to 0.0065, 0.0590 and 0.0655 respectively. The total number of expected injuries is 0.0065 + 0.0590 + 0.0655 = 0.1310 per year. The accident costs are 1,030,312 DKK per year.

In Alternative 2 two AMFs are different:

- 4 turn lanes, AMF = 0.95
- Protected left turn, AMF = 0.55

The final number of injury accidents per year for *Alternative 2* is calculated to:

$= a \cdot N_{pri}^{p_1} \cdot N_{sek}^{p_2} \cdot AMF_1 \cdot AMF_2 \cdot \ldots \cdot AMF_5$
$= 0.000002870 \cdot 19{,}500^{0.7749} \cdot 2{,}500^{0.3732} \cdot 1.00 \cdot 0.95 \cdot 0.55 \cdot 1.00 \cdot 1.00$
= <u>0.0587 injury accidents per year</u>

Similarly, the final number of PDO accidents w/report and POD accidents no report per year for *Alternative 2* is estimated to 0.2934 and 0.1858 respectively. The final number of killed, severe and slight injuries per year is estimated to 0.0033, 0.0293 and 0.0326 respectively. The total number of expected injuries is 0.0033 + 0.0293 + 0.0326 = 0.0652 per year. The accident costs are 514,423 DKK per year.

All together the results are:

Results	Accident/year	Injuries/year	Accidents costs/year
Main road – 50 m long link	0.0203	0.0048	29,167 DKK.
3-arm signalised junction Alternative 1	1.0808	0.1310	1,030,312 DKK.
3-arm signalised junction Alternative 2	0.5379	0.0652	514,423 DKK.

The answers of the two questions are:

1. The new junction will lead to about 0.52-1.06 more accidents per year and about 0.06-0.13 more injuries per year.
2. Accident costs for Alternative 1 is about 516,000 DKK higher per year than that of Alternative 2.

5.5 Example 2 – Conversion of existing junction

Example 2 – CONVERSION OF EXISTING JUNCTION

A 4-arm priority junction with many accidents is to be converted to a single lane roundabout with 4 arms. Two questions are asked:

1. Will the conversion prevent accidents and injuries, and if so, how many per year?
2. How are accidents costs affected? (Is the conversion cost effective?)

To answer the two questions, the expected number of accidents and injuries per year as well as accident costs per year are estimated for the existing 4-arm priority junction and the future 4-arm roundabout. This means that recorded accidents are not used in this preliminary assessment.

The priority junction has an AADT on 8,000 on the primary (main) road and 2,000 on the secondary (minor) road. The following AMFs are used for the existing junction:

- Obligation to give way on the secondary road, AMF = 1.00
- Dual-way traffic on all arms, AMF = 1.00
- Median islands as well as two left turn lanes on the primary road, AMF = 0.80
- No median islands on the secondary road, AMF = 1.00
- Dual-way cycle path along the primary road, AMF = 1.10
- No road lighting, AMF = 1.00
- 80 kph speed limit, AMF = 1.00

Using the SPF for 4-arm priority junctions (see Appendix 1) and the above mentioned AMF's the number of injury accidents per year for the 4-arm priority junction can be estimated to:

$= a \cdot N_{pri}^{p_1} \cdot N_{sek}^{p_2} \cdot AMF_1 \cdot AMF_2 \cdot \ldots \cdot AMF_7$
$= 0.000421465 \cdot 8{,}000^{0.2957} \cdot 2{,}000^{0.3929} \cdot 1.00 \cdot 1.00 \cdot 0.80 \cdot 1.00 \cdot 1.10 \cdot 1.00 \cdot 1.00$
= <u>0.1048 injury accidents per year</u>

In the same way the number of PDO accidents with and without reports for the priority junction can be estimated to 0.1905 and 0.0514 respectively. Thus, giving a total of 0.3467 expected accidents per year. The number of killed, severe and slight injuries are estimated to respectively 0.0038, 0.0610 and 0.0686 giving a total of 0.1334 expected injuries per year. Accidents costs are 656,538 DKK per year.

The roundabout is expected to have the same AADT as the priority junction, that is an AADT of 10,000 incoming vehicles. The roundabout is designed with:

- Four entry lanes, AMF = 1.00
- Triangular shaped splitter islands, AMF = 1.00

- Central island diameter of 30 m, AMF = 1.00
- Central island height of 3 m, AMF = 0.78
- Truck apron of 2 m, AMF = 1.00
- Circulatory carriageway of 6 m, AMF = 1.00
- Cycle path at the roundabout, where cyclists have to yield to motorists entering or leaving the roundabout, AMF = 0.80
- Junction lighting at the roundabout, AMF = 1.00

By using the SPFs for roundabouts and the above mentioned AMFs the number of injury accidents per year for the roundabout can be estimated to:

$= a \cdot (N_{pri} + N_{sek})^{p_1} \cdot AMF_1 \cdot AMF_2 \cdot \ldots \cdot AMF_8$
$= 0.000002132 \cdot 10{,}000^{1.0924} \cdot 1.00 \cdot 1.00 \cdot 1.00 \cdot 0.78 \cdot 1.00 \cdot 1.00 \cdot 0.80 \cdot 1.00$
= <u>0.0312 injury accidents per year</u>

In the same way the number of PDO accidents w/report and PDO accidents with no reports for the roundabout can be estimated to 0.1225 and 0.0852 respectively. Thus, the total number of expected accidents is 0.0312 + 0.1225 + 0.0852 = 0.2389 per year. The number of killed, severe and slight injuries per year is estimated to 0.0012, 0.0218 and 0.0134. This gives a total number of expected injuries of 0.0364 per year. Accident costs are 258,893 DKK per year.

The roundabout has – in terms of accidents – a wider range than the priority junction. This means that the links on both the primary and secondary road will be 40 m shorter. Thus, expected accidents and injuries for a 40 m link on the primary road and 40 m on the secondary road must be added to the results for the priority junction in order to provide comparable results. The design of both primary and secondary road is the same and have the same design as the SPF for links with dual-way traffic i.e. all AMFs for the two 40 m links are 1.00.

The estimated number of injury accidents per year on 40 m primary road is:

$= a \cdot N^p \cdot L \cdot AMF_1 \cdot AMF_2 \cdot \ldots \cdot AMF_{10}$
$= 0.000041252 \cdot 8{,}000^{0.8138} \cdot 0.04$
= <u>0.0025 injury accidents per year</u>

Similarly, the number of PDO accidents w/report and PDO accidents no report per year on the 40 m primary road is estimated to 0.0034 and 0.0042 respectively. Thus, the total number of expected accidents is 0.0025 + 0.0034 + 0.0042 = 0.0101 per year. The estimated number of killed, severe and slight injuries is 0.0004, 0.0014 and 0.0015 respectively. The total number of expected injuries then is 0.0004 + 0.0014 + 0.0015 = 0.0033 per year. Accidents cost are 23,598 DKK per year.

The estimated number of injury accidents per year on 40 m secondary road is:

$= a \cdot N^p \cdot L \cdot AMF_1 \cdot AMF_2 \cdot \ldots \cdot AMF_{10}$
$= 0.000041252 \cdot 2{,}000^{0.8138} \cdot 0.04$
= <u>0.0008 injury accidents per year</u>

Similarly, the number of PDO accidents w/report and PDO accidents no report per year on the 40 m secondary road is estimated to 0.0011 and 0.0008 respectively. Thus, the total number of expected accidents is 0.0008 + 0.0011 + 0.0008 = 0.0027 per year. The number of killed, severe and slight injuries is estimated to 0.0001, 0.0004 and 0.0004 respectively. The total number of expected injuries then is 0.0001 + 0.0004 + 0.0004 = 0.0009 per year. Accidents costs are 6,462 DKK per year.

All together the results are:

Results		Accident /year	Injuries/year	Accident costs/year
Priority junction	Junction	0.3467	0.1334	656,538 DKK.
	40 meters primary road	0.0101	0.0033	23,598 DKK.
	40 meters secondary road	0.0027	0.0009	6,462 DKK.
	A total of	0.3595	0.1376	686,598 DKK.
Roundabout		0.2389	0.0364	258,893 DKK.

The answers of the two questions are:

1. The conversion will prevent about 0.12 accidents and 0.10 injuries per year.
2. Accident costs will be reduced by about 428,000 DKK per year.

6. Calculation tool user manual

As illustrated in Example 1 and 2 in Chapter 5, the estimations of accidents and injuries can be done manually “by hand”. Alternatively, estimations can easily be done by using calculation tools (Excel spreadsheet), where the APMs (accident prediction models) and AMFs (Accident modification factors) are incorporated.

Two calculation tools have been developed; one for links and one for junctions. This chapter includes a brief user manual for the calculation tools, which can be downloaded free of charge from websites of the Danish Road Directorate and Trafitec.

Both calculation tools consist of four Excel sheets:

1) Input data
2) Used data
3) Calculation sheet
4) Results 2011-2016

6.1 The sheet ”Input data”

Junctions

The calculation tool for *junctions* in rural areas estimates accidents and injuries based on the “input data” listed below:

- Junction type (signalised junction, priority junction or roundabout)
- Number of arms (Junctions: 3 or 4 arms, Roundabouts: 2, 3, 4, 5 or 6 arms)
- Annual Average Daily Traffic (AADT) for each arm

AADT in the range between 1 and 40,000 may be entered. This means that it is possible to enter AADT values outside the SPFs valid range. However, it should be noted that using data not valid for the SPFs might produce unreliable results.

In addition to the three basic data mentioned above (junction type, number of arms and AADT), also data about e.g. Junction-ID, road names, mile markers, etc. can be entered. Some data can be put in by selecting via “drop-down” menus.

In the “Input data” sheet also data used to calculate AMFs can be entered. These data are organised by the three junction types; signalised junctions, roundabouts and priority junctions. If no data in relation to calculation of AMFs is entered it is assumed that the design and regulation of the junction or roundabout are the same as the one that applies for the SPF.

Input data for calculation of AMFs accepted by the calculation tool for junctions are given in the table below.

Type	Column	Accepted values
Signalised junction	One-way traffic	2 choices
	Turn lanes (incl. shunts)	0 ≤ number ≤ 16 (integer)
	Left turn arrows *	3 choices
	Bicycle facility *	4 choices
	Average speed limit *	40 ≤ speed limit kph ≤ 110 (decimal digit)
Roundabout	Type of roundabout	2 choices
	Entry lanes (incl. shunts) *	2 ≤ number ≤ 20 (digital)
	Splitter islands on arms	4 choices
	Central island diameter	5 ≤ diameter meters ≤ 175 (decimal digit)
	Central island height	2 choices
	Width of truck apron	0 ≤ width meters ≤ 20 (decimal digit)
	Width of circulatory carriageway	2 ≤ width meters ≤ 20 (decimal digit)
	Bicycle facility *	5 choices
	Junction lighting	2 choices
Priority junction	Type of priority	3 choices
	One-way traffic	2 choices
	Turn lanes on primary road (incl. shunts)	0 ≤ number ≤ 4 (integer)
	Median islands on secondary road *	2 choices
	Bicycle facility *	4 choices
	Junction lighting	2 choices
	Speed limit on primary road *	40 ≤ speed limit kph ≤ 110 (decimal digit)

Junction data for calculating of AMFs and values accepted by the calculation tool.
** = See note for junction data below.*

Notes in relation to junction data:

- ***Left turn arrows (signalised junction):*** A left turn lane is required for the presence of 1 or 3 left turn arrows.

- ***Bicycle facility (signalised junctions or priority junctions):*** There may be different bicycle facilities on the arms of the junction. If one or more arms have dual-way cycle paths "dual-way cycle path" is selected. If there are *no* dual-way cycle path but one-way cycle path on one or more arms "one-way cycle path" is selected. If there is *no* cycle paths on *any* of arms of the junction but a wide nearside hard shoulder or cycle lane on one or more arms then "hard shoulder or cycle lane" is selected. If there are no bicycle facilities on any of the arms "None" should be selected.

- ***Average speed limit (signalised junction):*** The average speed limit on all arms about 100 m from the center point of the junction.

- ***Median islands on secondary road (priority junction):*** It is assumed that there are median islands on the primary road, when turn lanes are present on the primary road.

- ***Speed limit on primary road (priority junction):*** The average speed limit on the two arms on the primary road about 100 m from the center point of the junction.

- ***Entry lanes incl. shunts (roundabout)***: If the number of entry lanes is not entered, the calculation tool assumes that the number of entry lanes is equal to the number of arms at single lane roundabouts, while the number of entry lanes is twice the number of arms at multilane roundabouts.

Links

The calculation tool for *links* in rural areas estimates accidents and injuries based on the following "Input data":

- Length of the link
- Annual average daily traffic (AADT) on the link

AADT in the range between 1 and 40,000 may be entered. Please be aware of values that are not in the range of the individual SPF. It should be noted that use of data – AADT as well as other data – that are not valid for the SPFs may result in unreliable results.

In addition to the two basic data mentioned above (link length and AADT), also data of e.g. road names, mile markers, etc. can be entered, see screenshot below. The link length is calculated when data of FROM mile marker and TO mile marker is entered, but the link length may also be entered directly in the column "Length" in km by overwriting the 0-value. Several of the parameters as e.g. speed limit can be selected via a "drop-down" menu.

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	LINK-ID	Link							Data for calculation of accident modification factors (AMFs)				
2													
3													
4		Road name	FROM (mile marker)		TO (mile marker)		Length	Annual Average	Curvature	Maximum gradient	Central reserve	Width of travel lane	Width of nearside hard shoulder
5		Road number	KM	M	KM	M	km	Daily Traffic (AADT)	Degrees curving	% - gradient	Yes/Partly/No	Meters	Meters
12	1	Highway 66	1	125	2	521	1.396	5,012	42	1	No	3.5	0.5
13	2	Uplands Road	4	654	6	103	1.449	3,069	26	2	No	3.5	1.25
14	3	Hill Highway	2	359	3	874	1.515	8,520	8	4	Partly	3.75	0.5
15							0.000						

Input data | Used data | Calculation | Results 2011-2016

Screenshot from the calculation tool for ***links*** *in the sheet "Input data".*

Data used to calculate accident modification factors (AMFs) for links can be entered in the sheet ”Input data”. That is e.g. data concerning the width of nearside hard shoulders, speed limit and road lighting. If *no* data in relation to calculation of AMFs is entered, it is assumed that the design of the link is the same as the one that applies for the SPF.

In cases where a link has data, which is not accepted by the calculation tool, e.g. a travel lane width of 2.5 m, one has to enter another value that is accepted by the calculation tool, even though it means that the result will be less reliable. If the travel lane width is 2.5 m the entered value should be closest to the correct value, i.e. 2.75 m.

	Column	Accepted values
Link (dual-way traffic)	Curvature *	0 ≤ degrees ≤ 1000 (decimal digit)
	Maximum gradient	0 ≤ gradient % ≤ 20 (decimal digit)
	Central reserve *	3 choice
	Width of travel lane *	2.75 ≤ width meters ≤ 7.00 (decimal digit)
	Width of nearside hard shoulder *	0 ≤ width meters ≤ 4 (decimal digit)
	Width of shoulder *	0 ≤ width meters ≤ 20 (decimal digit)
	Road lighting *	2 choices
	Cycling prohibited	2 choices
	Side roads *	0 ≤ Number of side roads ≤ 20 (integer)
	Speed limit	6 choices

Data of links for calculation of AMFs and values that is accepted by the calculation tool.
** = See note for link data below.*

Notes in relation to data of links:

- ***Curvature:*** One must enter how many degrees the link curves from one end to the other (continuously adding). The calculation tool converts the entered number of degrees to a number of degrees per km.

- ***Central reserve:*** A link with a central reserve has a central reserve along the whole link. If a link has a central reserve along 50-99 % of the link length it is considered as partly central reserve.

- ***Width of travel lane, nearside hard shoulder and shoulder:*** It is the average width of one through going travel lane that must be entered. It is the average width of one nearside hard shoulder and one shoulder that must be entered.

- ***Road lighting:*** Enter “Yes” if there is road lighting along more than 50 % of the link length.

- ***Side roads:*** The number of defined side roads (incl. drive ways) – or supposed to be defined – on the link in vejman.dk (Danish road database). No AADT must be available for side roads. The junction between the link and the side road must not have traffic islands nor turn lanes. The calculation tool converts the entered number of side roads to a number of side roads per km.

6.2 The sheet ”Used data”

The sheet ”Used data” shows data that the calculation tool uses to estimate the number of accidents and injuries, see screenshot below. Only when required data are entered in the sheet “Input data” – and these are accepted by the tool – the entered data are shown in the sheet “Used data”. In the calculation tool for junctions, data of the selected junction type are shown in the sheet “Used data”.

It is not possible to enter data in the sheet “Used data”.

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	**LINK-ID**	**Link**							**Data for calculating of accident modification factors (AMFs)**				
2													
3													
4		Road name	FROM (mile marker)		TO (mile marker)		Length	Annual Average	Accepted link	Length	Annual Average	Curvature	Maximum gradient
5		Road number	KM	M	KM	M	km	Daily Traffic (AADT)	Yes/no	km	Daily Traffic (AADT)	Degree of curve per km	% - gradient
6	1	Highway 66	1	125	2	521	1.396	5,012	Yes	1.396	5,012	30	1.0
7	2	Uplands Road	4	654	6	103	1.449	3,069	Yes	1.449	3,069	18	2.0
8	3	Hill Highway	2	359	3	874	1.515	8,520	Yes	1.515	8,520	5	4.0
9									No				

Input data | **Used data** | Calculation | Results 2011-2016

*Screenshot from the calculation tool for **links**, the sheet “Used data”.*

6.3 The sheet ”Calculation”

The sheet ”Calculation” shows the calculated AMFs that are used by the calculation tool, see screenshot on next page. The following abbreviations are used in the sheet:

- **ACC** is the number of accidents
- **INJ** is the number of injuries
- **INJ ACC** is the number of injury accidents
- **PDO ACC** is the number Property-Damage-Only accidents

At the far right of the sheet are the results of estimated accidents and injuries based on the relevant SPFs. That is, the number of accidents and injuries per year in the period 2011-2016, when no AMFs has been included in the calculations.

It is not possible to enter data in the sheet “Calculation”.

LINK-ID	Link							Accident Modification Factors (AMFs)					
	Road name	FROM (mile marker)		TO (mile marker)		Length	Annual Average	Curvature	Maximum gradient		Central reserve		Width of travel lane
	Road number	KM	M	KM	M	km	Daily Traffic (AADT)	ACC and INJ	INJ ACC and INJ	PDO ACC	INJ ACC and INJ	PDO ACC	ACC and INJ
1	Highway 66	1	125	2	521	1.396	5,012	1.06	0.98	0.99	1.00	1.00	1.00
2	Uplands Road	4	654	6	103	1.449	3,069	1.02	1.00	1.00	1.00	1.00	1.00
3	Hill Highway	2	359	3	874	1.515	8,520	1.05	1.10	1.04	0.90	0.97	0.94

Input data | Used data | Calculation | Results 2011-2016

*Screenshot from the calculation tool for **links**, the sheet "Calculation".*

6.4 The sheet "Results 2011-2016"

The sheet "Results 2011-2016" shows the estimated expected number of accidents and injuries per year when AMF's have been used, see screenshot below. In addition, the estimated accidents costs in 2017-prices are shown.

It is not possible to enter data in the sheet "Result 2011-2016".

LINK-ID	Link							Expected number of accidents and injuries per year in the period 2011-2016 Per link - not per km								Accident costs
	Road name	FROM (mile marker)		TO (mile marker)		Length	Annual Average		PDO accidents	PDO accidents						Per year
	Road number	KM	M	KM	M	km	Daily Traffic (AADT)	Injury accidents	w/report	no report	All accidents	Killed	Severe injuries	Slight injuries	All injuries	DKK (2017-prices)
1	Highway 66	1	125	2	521	1.396	5,012	0.0615	0.0850	0.0891	0.2355	0.0092	0.0347	0.0345	0.0785	563,290
2	Uplands Road	4	654	6	103	1.449	3,069	0.0390	0.0527	0.0474	0.1391	0.0061	0.0217	0.0198	0.0476	360,098
3	Hill Highway	2	359	3	874	1.515	8,520	0.0964	0.1359	0.1679	0.4003	0.0139	0.0553	0.0604	0.1296	875,966

Input data | Used data | Calculation | Results 2011-2016

*Screenshot from the calculation tool for **links**, the sheet "Results 2011-2016".*

References

[1] *Uheldsmodeller, sikkerhedsfaktorer og værktøjer for landevejsnettet. Kryds og strækninger i det åbne land. (Accident prediction models, accident modification factors and calculation tools for rural road network. Junctions and links in rural areas.)* Trafitec, October 2017.

[2] *Trafiksikkerhed på motorveje. Uheldsmodeller, sikkerhedsfaktorer og vejledning til IT-værktøj. (Road safety on motorways. Accident prediction models, accident modification factors and guide to calculation tools.)* Trafitec, August 2015.

[3] *Håndbog, Trafiksikkerhed. Effekter af vejtekniske virkemidler. 2. udgave. (Road Safety Handbook. Effects of road safety measures. Second edition.)* Rapport nr. 507, Vejdirektoratet, 2014.

[4] *Håndbog, Trafiksikkerhedsberegninger og ulykkesbekæmpelse. (Accident calculations and Accident Prevention Handbook.)* Vejdirektoratet, August 2015.

Appendix 1. Estimated a- and p-values

The estimated constants (a- and p-values) for the Safety Performance Functions (SPFs) are shown in the tables below. The calculated number of accidents and injuries per year is valid for the period 2011-2016. *All accidents* include injury accidents, PDO accidents w/report and PDO accidents with no report. *All injuries* include killed as well as severe and slight injuries

3-arm signalised junction		**a**	**p1**	**p2**
Used models	Injury accidents	0.000002870	0.7749	0.3732
	PDO accidents w/report	0.000014350	0.7749	0.3732
	PDO accidents no report	0.000009089	0.7749	0.3732
	Killed	0.000000159	0.7749	0.3732
	Severe injuries	0.000001435	0.7749	0.3732
	Slight injuries	0.000001594	0.7749	0.3732
Models not used	All accidents	0.000026308	0.7749	0.3732
	Injury accidents and PDO w/report	0.000017220	0.7749	0.3732
	All injuries	0.000003188	0.7749	0.3732

4-arm signalised junction		**a**	**p1**	**p2**
Used models	Injury accidents	0.000582216	0.4078	0.2069
	PDO accidents w/report	0.002579539	0.4078	0.2069
	PDO accidents no report	0.000832892	0.4078	0.2069
	Killed	0.000016173	0.4078	0.2069
	Severe injuries	0.000371971	0.4078	0.2069
	Slight injuries	0.000347712	0.4078	0.2069
Models not used	All accidents	0.003994647	0.4078	0.2069
	Injury accidents and PDO w/report	0.003161755	0.4078	0.2069
	All injuries	0.000735856	0.4078	0.2069

4-arm roundabout		**a**	**p1**
Used models	Injury accidents	0.000002132	1.0924
	PDO accidents w/report	0.000026700	0.9666
	PDO accidents no report	0.000018578	0.9666
	Killed	0.000000083	1.0924
	Severe injuries	0.000001495	1.0924
	Slight injuries	0.000000914	1.0924
Models not used	All accidents	0.000048995	0.9732
	Injury accidents and PDO w/report	0.000097344	0.8209
	All injuries	0.000002492	1.0924

Tables continues on the next page ...

3-arm priority junction		**a**	**p1**	**p2**
Used models	Injury accidents	0.000007283	0.6952	0.4186
	PDO accidents w/report	0.000011542	0.7246	0.4661
	PDO accidents no report	0.000002074	0.9263	0.3320
	Killed	0.000000558	0.6578	0.4892
	Severe injuries	0.000004634	0.6578	0.4892
	Slight injuries	0.000010884	0.6155	0.3850
Models not used	All accidents	0.000017685	0.7826	0.4105
	Injury accidents and PDO w/report	0.000017884	0.7240	0.4453
	All injuries	0.000015117	0.6298	0.4508

4-arm priority junction		**a**	**p1**	**p2**
Used models	Injury accidents	0.000421465	0.2957	0.3929
	PDO accidents w/report	0.000766300	0.2957	0.3929
	PDO accidents no report	0.000206901	0.2957	0.3929
	Killed	0.000015326	0.2957	0.3929
	Severe injuries	0.000245216	0.2957	0.3929
	Slight injuries	0.000275868	0.2957	0.3929
Models not used	All accidents	0.001394666	0.2957	0.3929
	Injury accidents and PDO w/report	0.001187765	0.2957	0.3929
	All injuries	0.000536410	0.2957	0.3929

Link		**a**	**p**
Used models	Injury accidents	0.000041252	0.8138
	PDO accidents w/report	0.000045875	0.8381
	PDO accidents no report	0.000003431	1.1480
	Killed	0.000011878	0.7373
	Severe injuries	0.000018486	0.8410
	Slight injuries	0.000004008	1.0197
Models not used	All accidents	0.000043359	0.9652
	Injury accidents and PDO w/report	0.000079100	0.8387
	All injuries	0.000017291	0.9453