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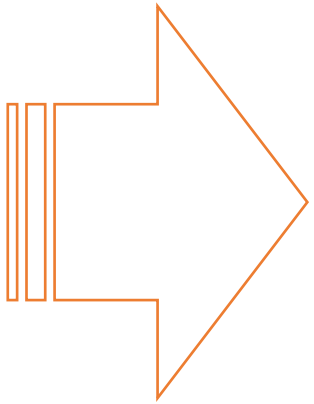
Human tolerance and speed management – design parameters for a Safe System

Strategic actions guided by human tolerance levels

Dr Johan Strandroth

Crash Type		Impact speed
	head on	70 km/h
	side-impact	50 km/h
	side impact with tree	30 km/h
	pedestrian	30 km/h



Source: Transport Accident Commission

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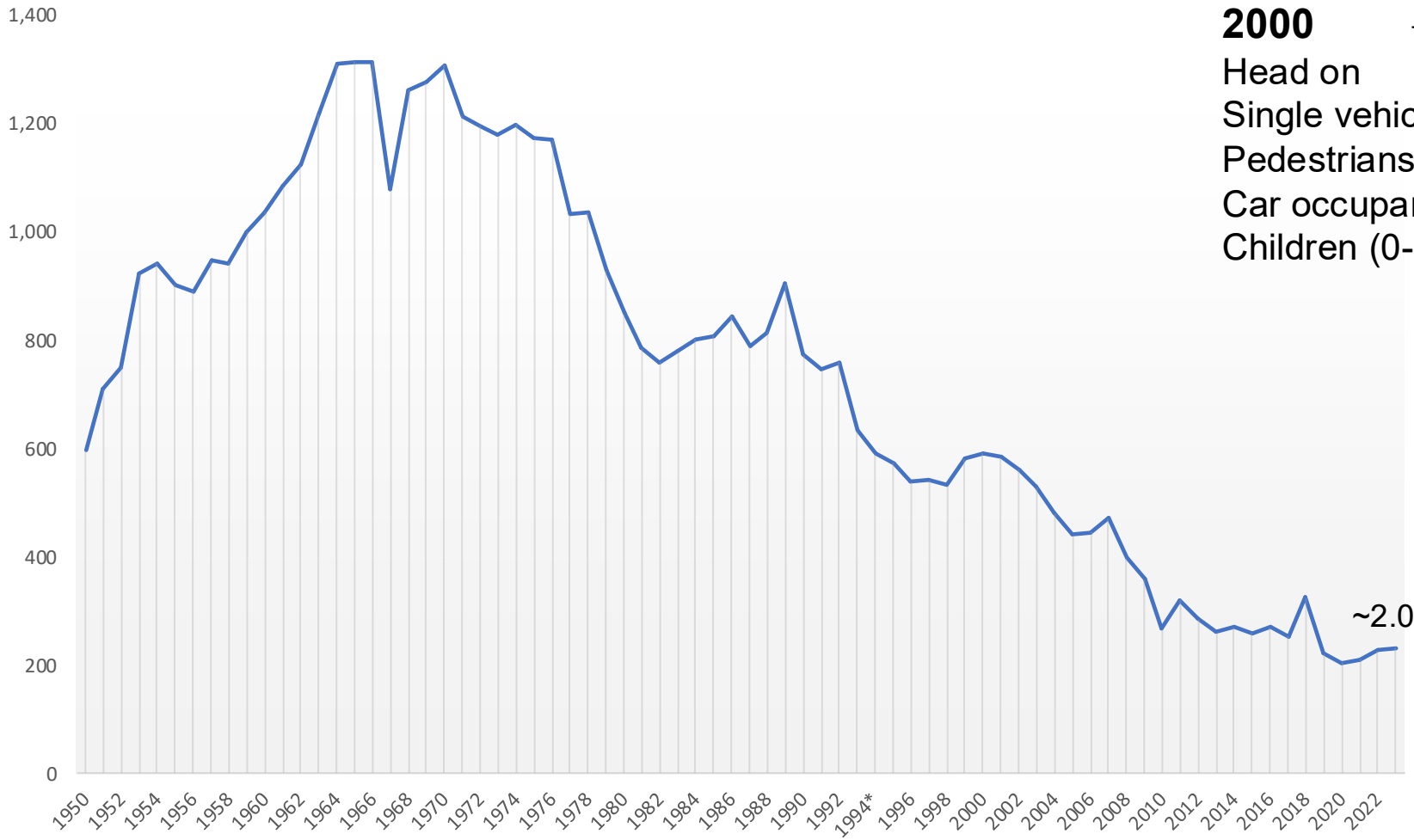
Successful implementation of Safe System Principles



2000	→	**2020**
Head on		-50%
Single vehicle		-60%
Pedestrians		-55%
Car occupants		-67%
Children (0-14)		-70%

~2.0 fatalities per 100,000 pop

Source: Swedish Transport Agency

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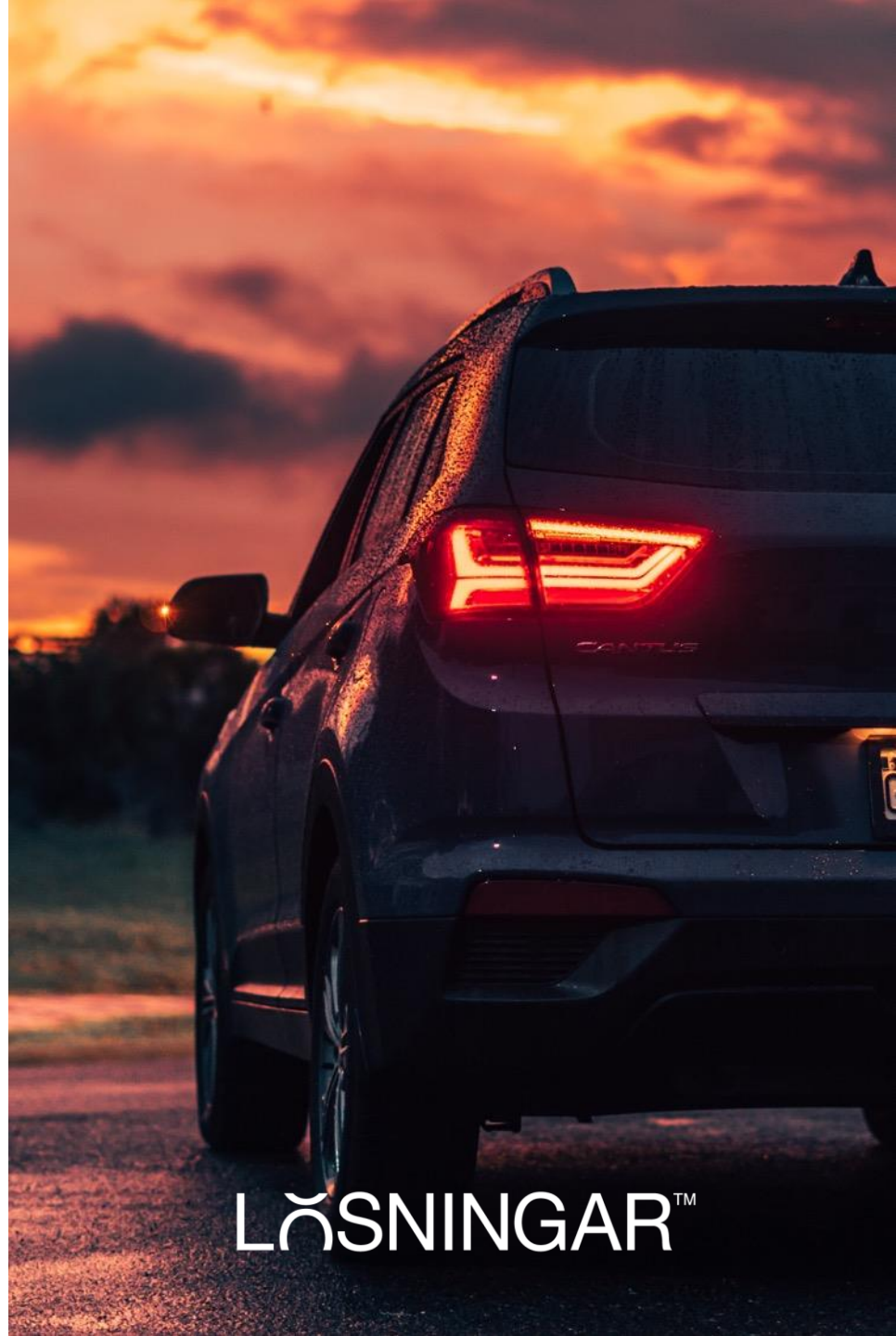
2030 passenger vehicle

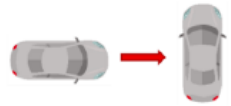
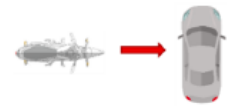
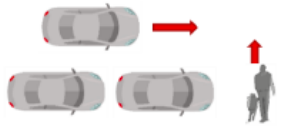
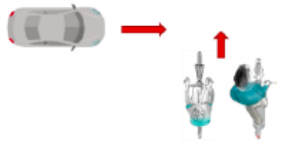
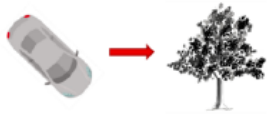
AEB Bicyclist
AEB Head-On
AEB Intersection
AEB Pedestrian
AEB Rear End
Alcohol Interlocks
Electronic Stability Control
Emergency Lane Keeping
ISA Limiting
E-Call
Lane Keep Assist
Seatbelt Reminders



Utilizing human crash tolerance as key design factor

Crash Type		Impact speed
	head on	70 km/h
	side-impact	50 km/h
	side impact with tree	30 km/h
	pedestrian	30 km/h

Source: Transport Accident Commission

	Maximum acceptable impact speed (km/h)	Maximum safe travelling speed with optimal sight and road friction (km/h)
	dV 15	110
	60	80
	30	50
	40	40
	60	60
	40	40
	0	5-7
	20	40
	30	60
	60	80

Rizzi, M. et al. (2023). Proposed Speed Limits for the 2030 motor vehicle. Proceedings of ESV.

Network Safety Plan

Safe System End States, Part 1 Rural Roads and Intersections

VICTORIA State Government | Department of Transport and Planning

Technical Content →

Allan, M., Hunter, C., Strandroth, J., Corben, B. Developing a rural Network Safety Plan for Victoria. Extended abstract in proceedings of the 2024 Australasian Road Safety Conference, Hobart, Tasmania.

Example of rural road stereotype

Road Stereotype:

M3 - Moderate movement of people and/or goods

Systemic crash types:

Head-on, Single, Rear-end

Before:

Speed limit of 100 km/h with minimal infrastructure

Allan, M., Hunter, C., Strandroth, J., Corben, B. Developing a rural Network Safety Plan for Victoria. Extended abstract in proceedings of the 2024 Australasian Road Safety Conference, Hobart, Tasmania.

Mismatch between best practice and real life

Crash test 32 km/h

Real life crash ~70 km/h

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Developing rural road stereotypes – Midblock

Rural Road Stereotype and Modal Priorities M3	Identified Systemic Crash Types and Risks	Safe System End-state Requirements: Speed and Infrastructure Elements	Explanatory comments	Head-on Collisions	ROR	Wild/domestic animal Collisions	Rear end crashes
M&P Definition: Moderate movement of people and/or goods on routes connecting municipalities or provides primary access to municipal-level places.	Head-on collisions	Maximum speed limit of 80 km/h	Consistent with M3 status, mid-range mobility is provided by a strong reliance on vehicle safety technology and targeted investment in safe infrastructure. Head-on impact speeds above 60 km/h are beyond the Safe System Boundary Conditions for preventing deaths and MAIS3+ injuries. AEB will be capable of shedding 20 km/h in head-on collisions prior to impact.				
Prioritise: General traffic, freight and buses.	RoR - rollovers or collisions with roadside trees or poles	Mid- and/or passenger-side-barriers only at locations of elevated risk (for mid-barriers, refer to Note 2).	ELK (Emergency Lane Keep) is more sensitive and intrusive than LDW/LKA, indicating that no additional manoeuvring width is required to prevent lane departures into the roadside or across the centre line. At locations of elevated risk (refer to Note 4), where vehicle safety technology, such as ELK, LKA, ESC and AEB, functions sub-optimally, additional infrastructure measures, such as mid-barriers and/or provision for lateral manoeuvring, may be needed to offset this effect.				
	Collisions with wildlife or domestic animals	Continuous ATLM centre, lane and edge line markings (refer to Note 5).	Alert drivers to lane departures and needed to support the effective functioning of lane keep assist (LKA) (references)				
	Rear end crashes	Continuous sealed passenger-side shoulders, 0.5 m to 1.0 m widths (refer to Note 3)	At locations with severely restricted space outside the traffic lane, and/or constantly changing alignment, vehicle safety technology, such as ELK, LKA, ESC and AEB, functions sub-optimally. Additional infrastructure measures are needed to offset this effect.				
		Good standard of vertical and horizontal alignment and lane-widths (refer to note 7)	Required to ensure vehicle technologies, such as LKA and AEB, can operate optimally at high speeds.				

Example of rural road stereotype

Road Stereotype:

M3 - Moderate movement of people and/or goods

Systemic crash types:

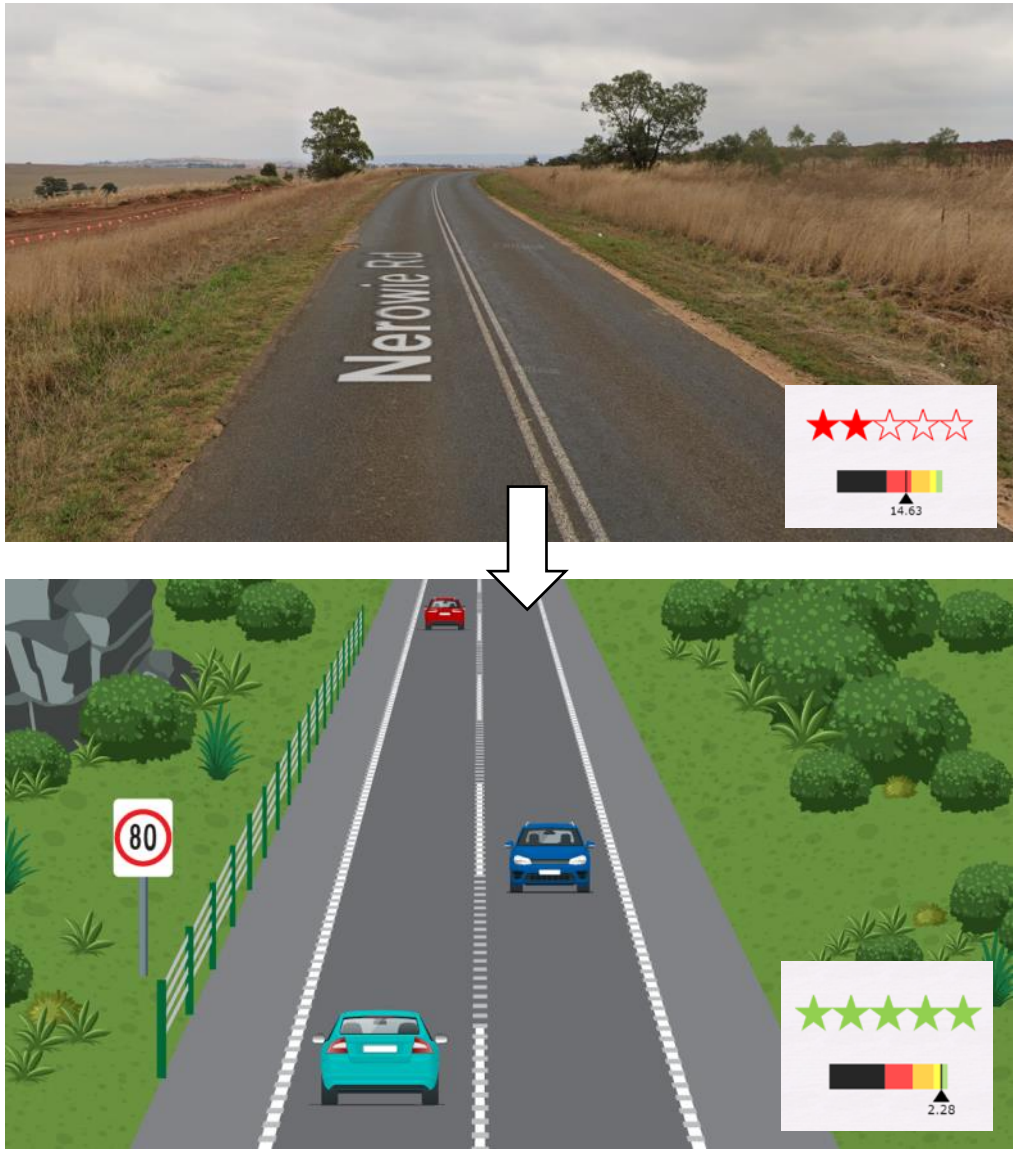
Head-on, Single, Rear-end

Before:

Speed limit of 100 km/h with minimal infrastructure

After:

- 80 km/h speed limit
- Supporting infrastructure including targeted roadside barriers, sealed shoulders and delineation improvements



Allan, M., Hunter, C., Strandroth, J., Corben, B. Developing a rural Network Safety Plan for Victoria. Extended abstract in proceedings of the 2024 Australasian Road Safety Conference, Hobart, Tasmania.

Developing rural road stereotypes – Intersections

Rural Road Stereotype and Modal Priorities	Systemic Crash Types and Risks	Intersecting Road Classification	Maximum Speed Limit on Major Leg	Safe System End-state Requirements: Speed and Infrastructure Elements	Explanatory comments
M1					
M&P Definition: Mass movement of people and/or goods on routes with a state or national-level movement function or provides primary access to state-level places. **Prioritise**: General traffic, freight and buses.	Intersections: side-impacts	M1	110 100	Grade-separation Roundabout (not on 110 km/h M1 roads)	Grade-separation eliminates major conflict points (though some residual risk remains, such as involving heavy vehicles, motorcyclists, rear-end and side-swipe impacts) and roundabouts safely dissipate energy in vehicle-to-vehicle crashes.
		M2	110 100	Grade-separation Roundabout (not on 110 km/h M1 roads)	Grade-separation eliminates major conflict points (though some residual risk remains, such as involving heavy vehicles, motorcyclists, rear-end and side-swipe impacts) and roundabouts safely dissipate energy in vehicle-to-vehicle crashes.
		M3	110 100 110	Grade-separation Roundabout (not on 110 km/h M1 roads) LILO - Left-in/Left-out only (for low volume/low function M3 roads, see note 2)	Grade-separation eliminates major conflict points (though some residual risk remains, such as involving heavy vehicles, motorcyclists, rear-end and side-swipe impacts) and roundabouts safely dissipate energy in vehicle-to-vehicle crashes. LILO acceleration lanes should be designed to limit maximum side Impact Speed to 70 km/h and shallow angles, allowing energy at impact to be safely dissipated. LILO is not likely to be appropriate for many M3 roads, especially where volumes are substantial and/or function is strategically important. For a 100 km/h major road, side-road traffic needs to be able to accelerate to at least 30 km/h before joining the major traffic stream.
		M4, M5	110 100 110 110	Grade-separation (see Note 1). Roundabout LILO - Left-in/Left-out only Closure/traffic re-routing	LILO limits Impact Speeds to 70 km/h and shallow angles, allowing energy at impact to be safely dissipated, and closures and grade-separation eliminate major conflict points (though, in the case of grade-separation, some residual risk remains, such as involving heavy vehicles, motorcyclists, rear-end and side-swipe impacts).

Allan, M., Hunter, C., Strandroth, J., Corben, B. Developing a rural Network Safety Plan for Victoria. Extended abstract in proceedings of the 2024 Australasian Road Safety Conference, Hobart, Tasmania.

Safe System end-states for rural intersections versus various intersecting combinations of M1-M5

<table>
<tr><th>Movement Category</th><th>M1</th><th>M2</th><th>M3</th><th>M4</th><th>M5</th></tr>
<tr><td>M1</td><td rowspan="2">Grade-separation
Roundabout</td><td></td><td rowspan="2"></td><td rowspan="3"></td><td rowspan="5"></td></tr>
<tr><td>M2</td><td>Grade-separation
Roundabout
Left-in/Left-out only (for low volume/low function M3 roads)</td></tr>
<tr><td>M3</td><td>Grade-separation
Roundabout
Left-in/Left-out only</td><td>Grade-separation
Roundabout
Left-in/Left-out only</td><td>Roundabout
60 km/h platforms
60 km/h speed limit
Left-in/Left-out only</td></tr>
<tr><td>M4</td><td colspan="2" rowspan="2">Grade-separation
Roundabout
Left-in/Left-out only
Closure/traffic re-routing</td><td colspan="2">Roundabout
60 km/h platforms
Left-in/Left-out only
Closure/traffic re-routing
60 km/h speed limit</td></tr>
<tr><td>M5</td><td>Roundabout
60 km/h platforms
Left-in/Left-out only
Closure/traffic re-routing
60 km/h speed limit</td><td>Roundabout
60 km/h platforms
Left-in/Left-out only
Closure/traffic re-routing
60 km/h speed limit</td></tr>
</table>

Allan, M., Hunter, C., Strandroth, J., Corben, B. Developing a rural Network Safety Plan for Victoria. Extended abstract in proceedings of the 2024 Australasian Road Safety Conference, Hobart, Tasmania.

Example of rural road stereotype

Road Stereotype:

M1 Highway and M5 Labuan Road intersection

Systemic crash type:

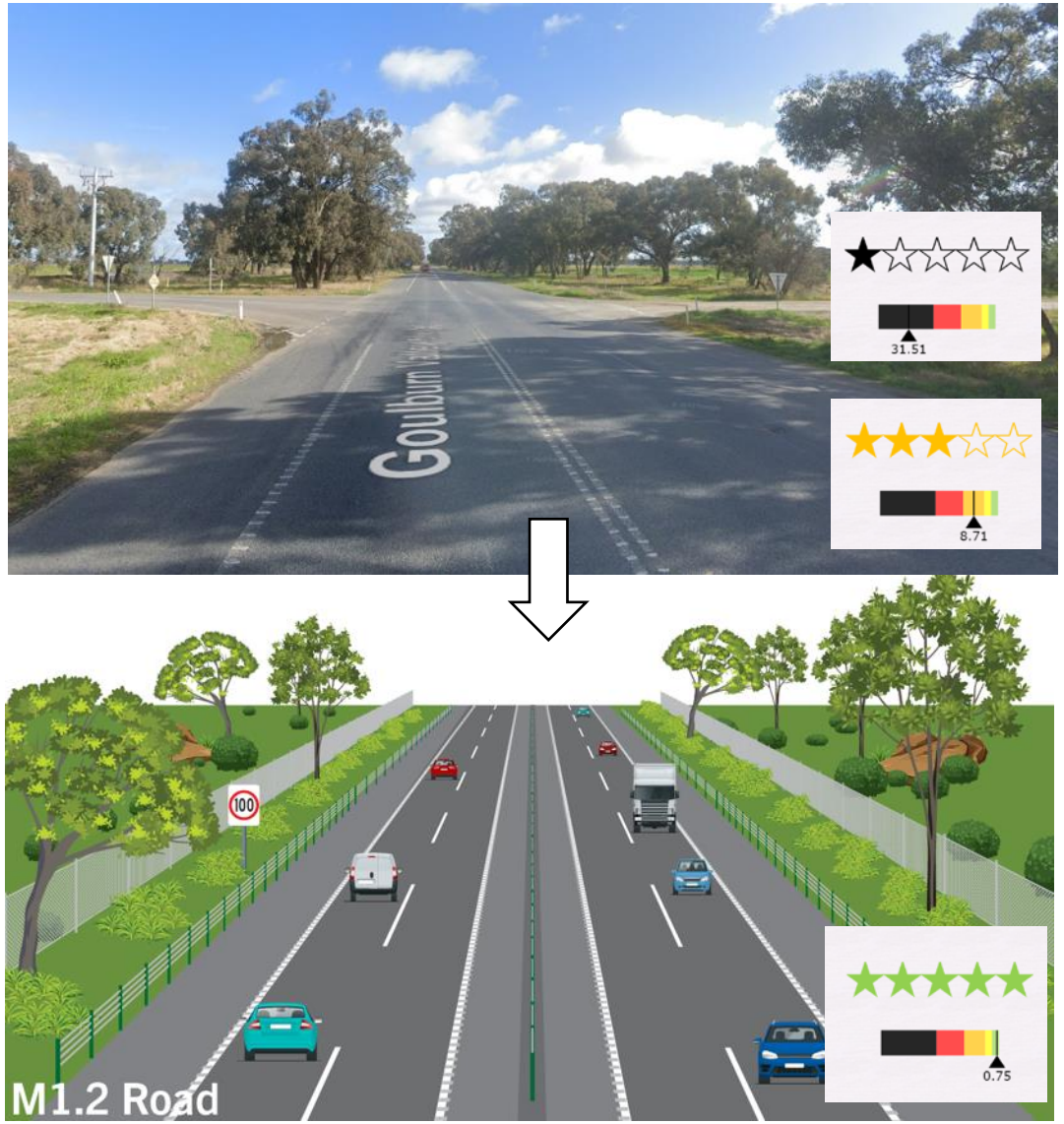
Right turn across path, Crossing, Rear-end, Head-on

Before:

- Speed limit of 100 km/h without Safe System infrastructure and with poor delineation
- At-grade uncontrolled 4-leg intersection

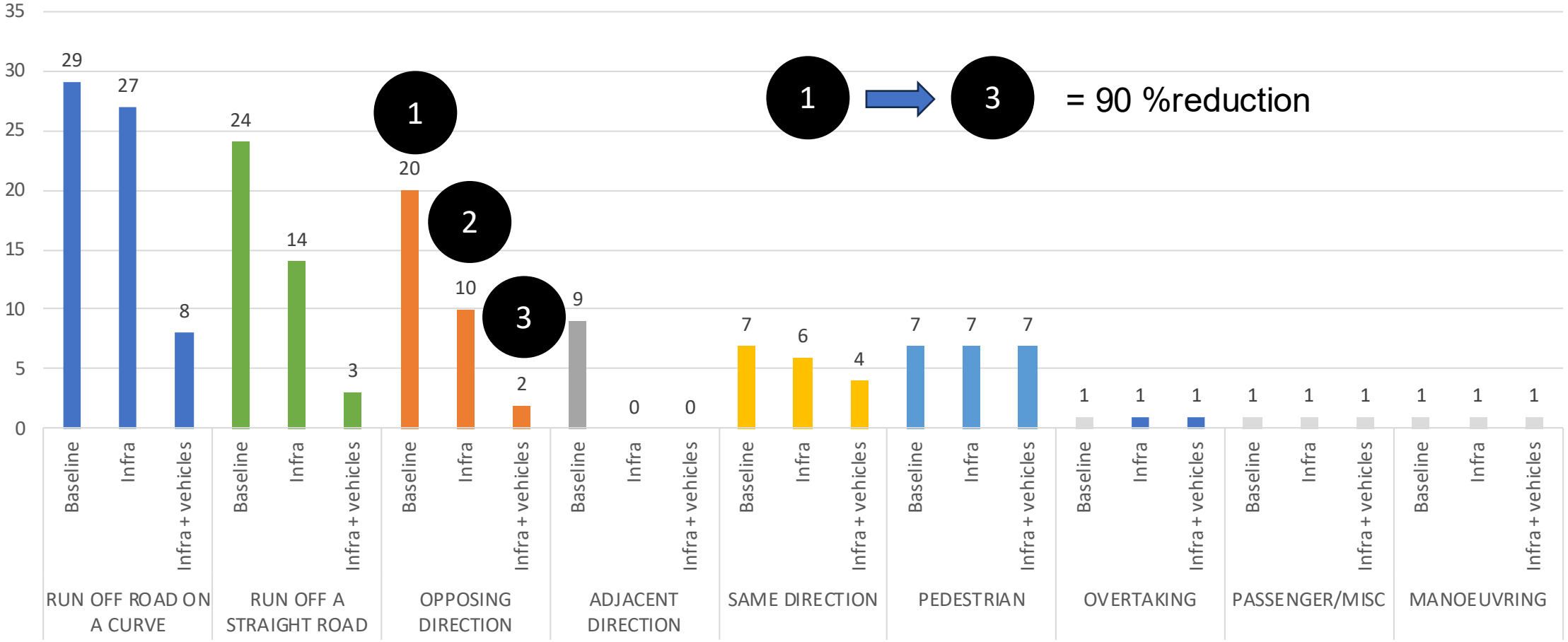
After:

- Median barrier on Murray Valley Highway (prevents vehicle crossing centreline)
- Left in/left out or closure of Labuan Road, with safe U-turn facilities (or roundabout) downstream



Allan, M., Hunter, C., Strandroth, J., Corben, B. Developing a rural Network Safety Plan for Victoria. Extended abstract in proceedings of the 2024 Australasian Road Safety Conference, Hobart, Tasmania.

Validation of Safe System End States



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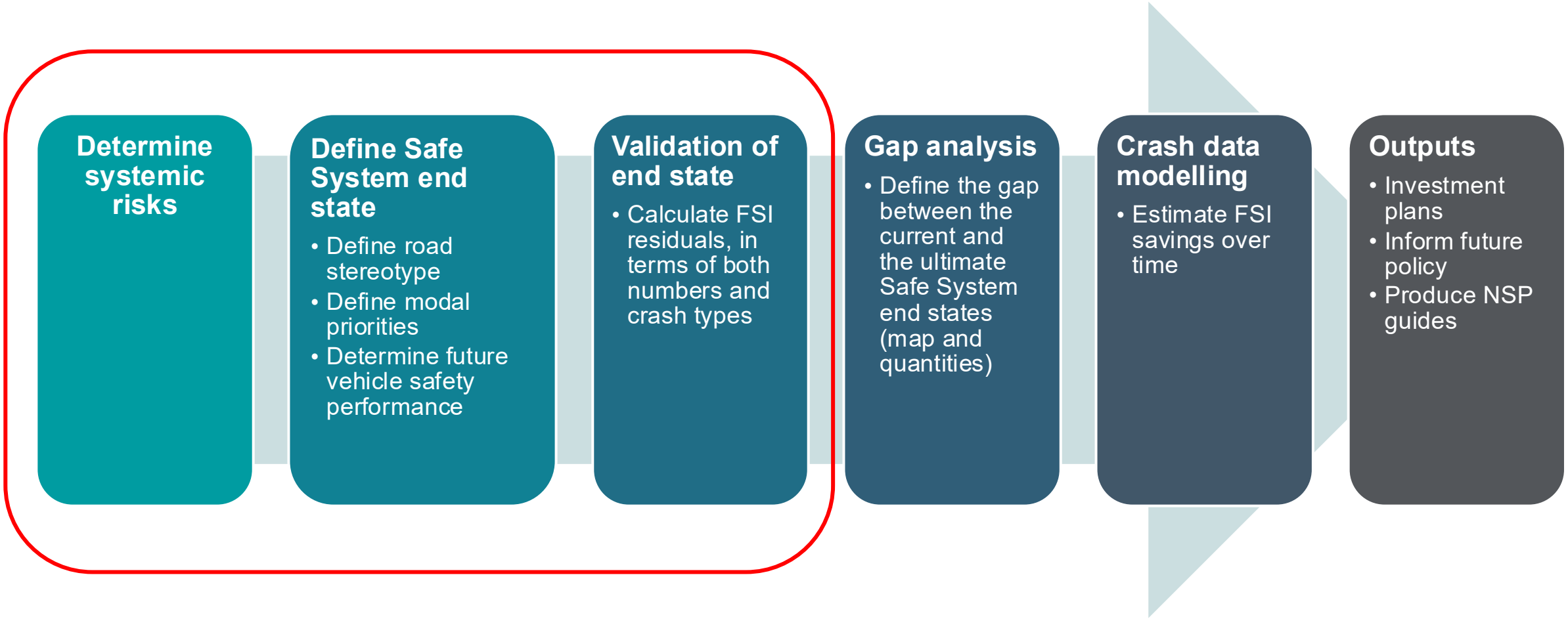
NSP Development Methodology



Example

Description: Moderate movement of people and/or goods on routes connecting municipalities or primary access to Municipal level places.

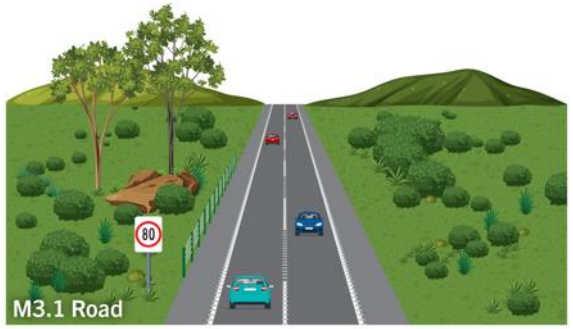
Principles behind Investment: Moderate Infrastructure improvements and speed reductions to support future vehicles. Less movement priority requiring less investment. Minimise likelihood of collisions along whole route and provide targeted barrier protection in higher risk locations.

Policy requirements:

M3 roads must have:

- Audio Tactile Line Marking
- Line marking for delineation
- Sealed Shoulder of minimum 1m on the passenger side to allow recovery for errant vehicle with ESC and lane keep technology
- Where volumes are greater than 3000vpd targeted barrier in high-risk locations is required

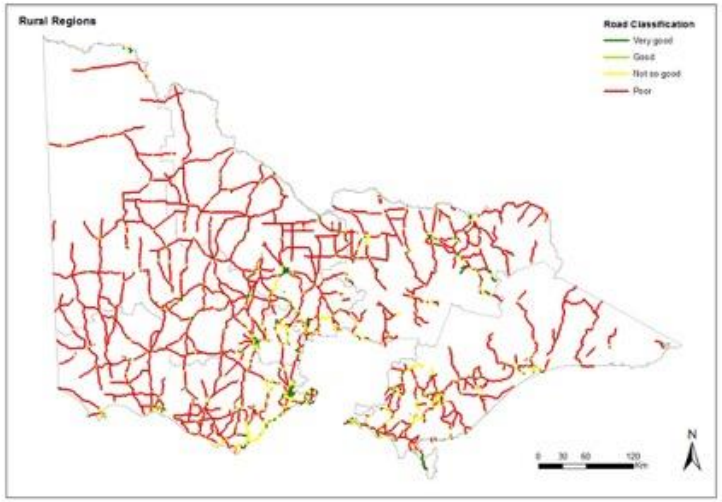
Example Cross Section:



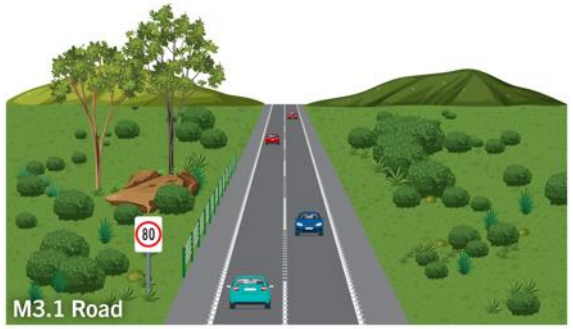
Gap-analysis and investment plans (remediation)

Policy (new development)

Rural arterials



	Road length
Acceptable	1,500 km
Not acceptable	13,200 km



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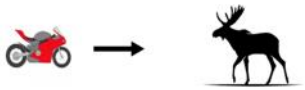
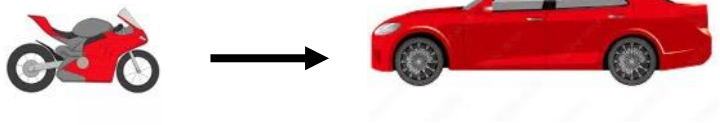
From injury risk functions to system design for PTW (DRAFT)

1

Configuration	% of all fatalities
	24%
 Object X	17%
	8%
	8%
	7%
	5%
Total	**70%**

2

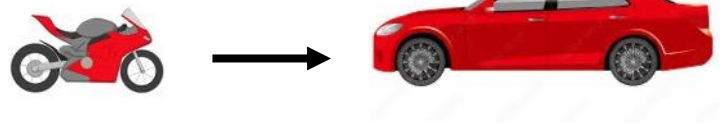


- 10% risk of fatality at around 90 km/h relative speed (Terranova et al. 2023)
- 10% risk of MAIS 3+ and fatal at around 50 km/h relative speed (Complettano et al. 2025; Lübbe et al. 2022)

3

- AEB reduce speed 20 km/h = maximum relative speed 100 km/h?

4



Safe travel speed = 50 km/h
(35 km/h for MAIS 3+ and fatal)

5

Rural road

- Max travel speed 50 km/h
- No heavy vehicles in opposite direction
- Clear zones or MPS

Source: Research Project for the Swedish Transport Administration – 'Design Principles for a Safe System for Powered Two-Wheelers'

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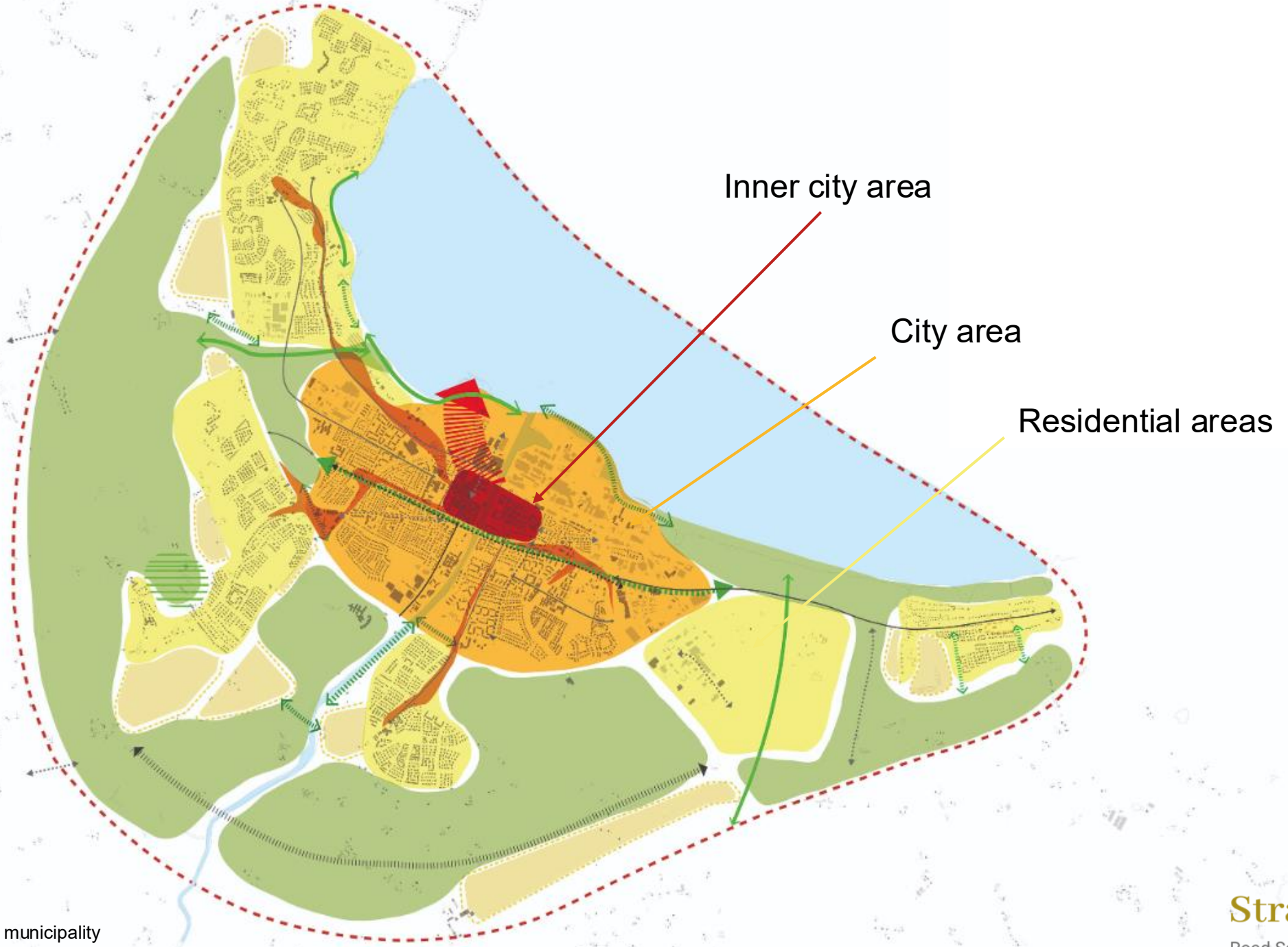
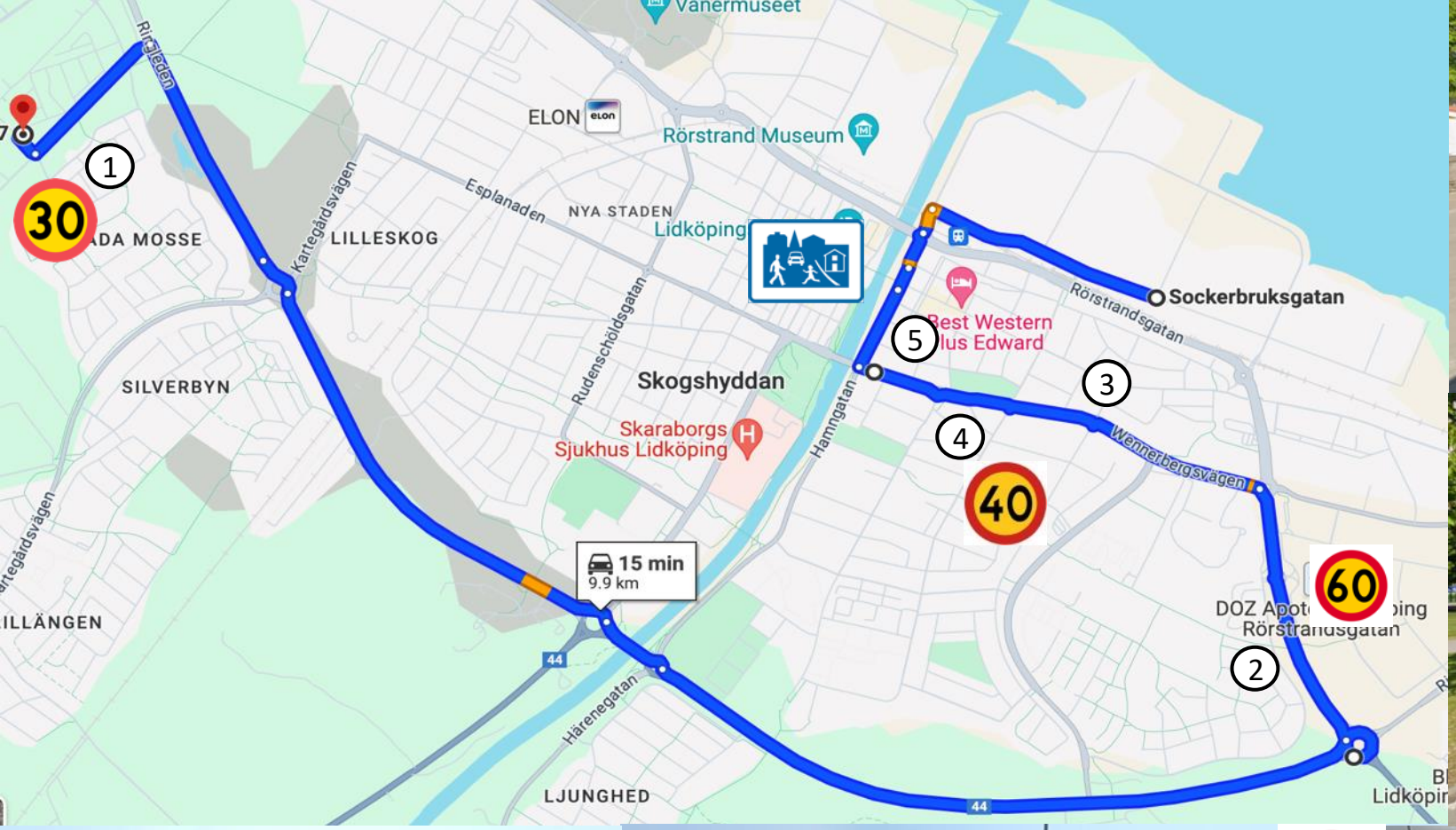
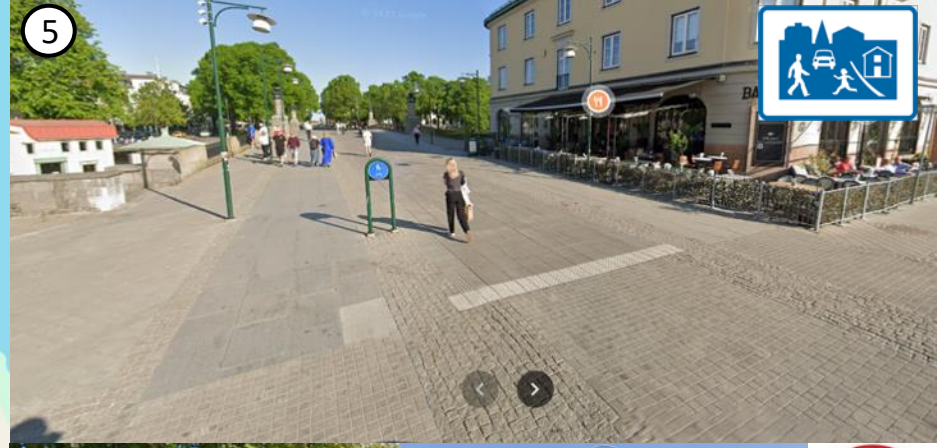
Lidköping, a case study



Source: Lidkoping municipality


Vänermuseet
ELON
Rörstrand Museum
NYA STADEN
Lidköping
LILLESKOG
Esplanaden
Kartegårdsvägen
Rudenschöldsgatan
Skogshyddan
SILVERBYN
Skaraborgs Sjukhus Lidköping
Hamngatan
Rörstrandsgatan
Sockerbruksgatan
Wennerbergsvägen
15 min
9.9 km
Härenegatan
LJUNGHED
DOZ Apot
Rörstrandsgatan
1
2
3
4
5
30
40
60
44

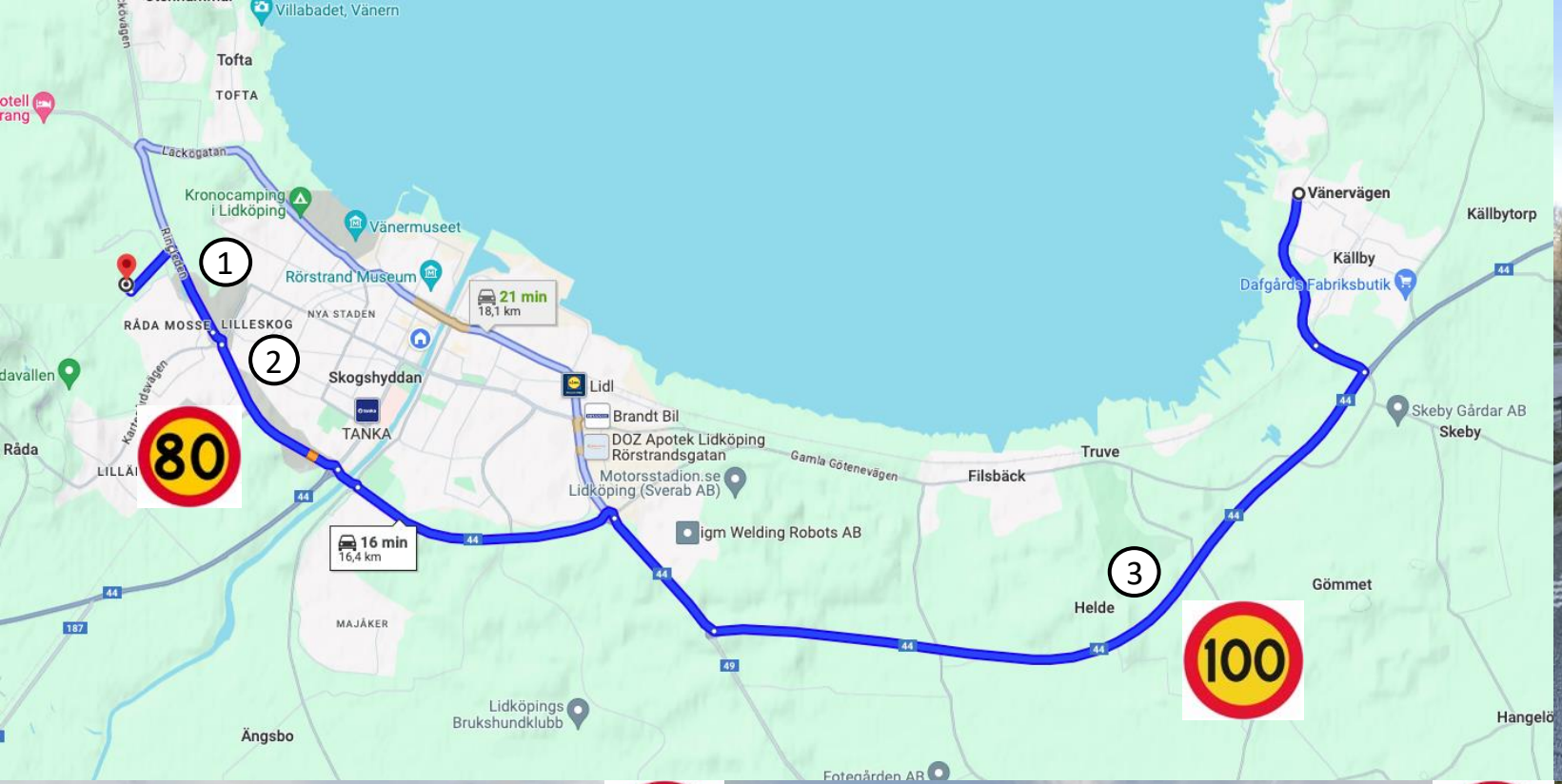

5


4
40
Wennerbergsvägen


1
30


2
60
Rörstrandsgatan


3
40


Villabadet, Vänern
Tofta
TOFTA
Kronocamping i Lidköping
Vänermuseet
Rörstrand Museum
21 min
18,1 km
RÅDA MOSSE
LILLESKOG
NYA STADEN
Skogshyddan
TANKA
Råda
LILLÄ
80
16 min
16,4 km
MAJÅKER
Ängsbo
Lidköpings Brukshundklubb
Lidl
Brandt Bil
DOZ Apotek Lidköping Rörstrandsgatan
Motorsstadion.se Lidköping (Sverab AB)
igm Welding Robots AB
Gamla Götenevägen
Filsbäck
Truve
Vänervägen
Källbytorp
Källby
Dafgårds Fabriksbutik
Skeby Gårdar AB
Skeby
Helde
Gömmet
100
Hangelö
Fotegården AB
1
2
3


110
E6


1
80
Ringleden


2
80


3
100
100
44

Thanks!

Dr Johan Strandroth
johan@strandroth.com