Simulation of individual injury risk with an agent-based transport model

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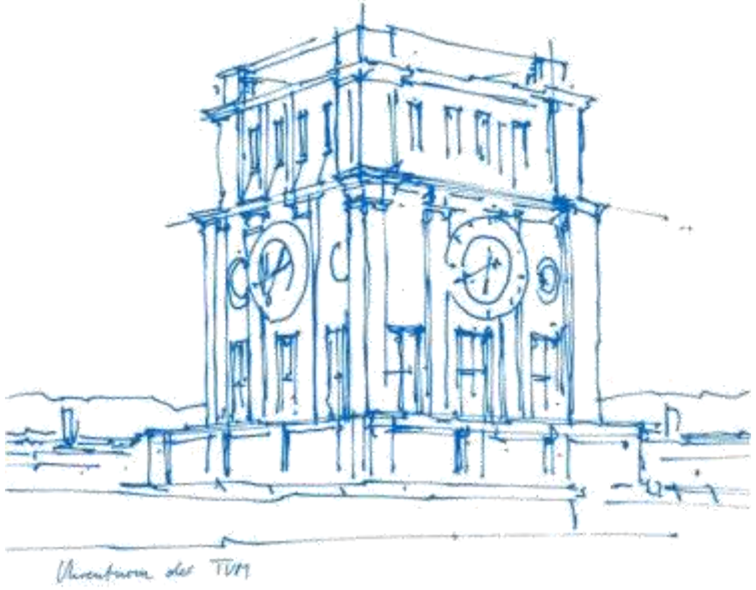


Introduction

Traffic exposure is the main predictor of crash frequency

$$y = AADT^{a} \cdot L^{b} \cdot e^{\beta \cdot X}$$

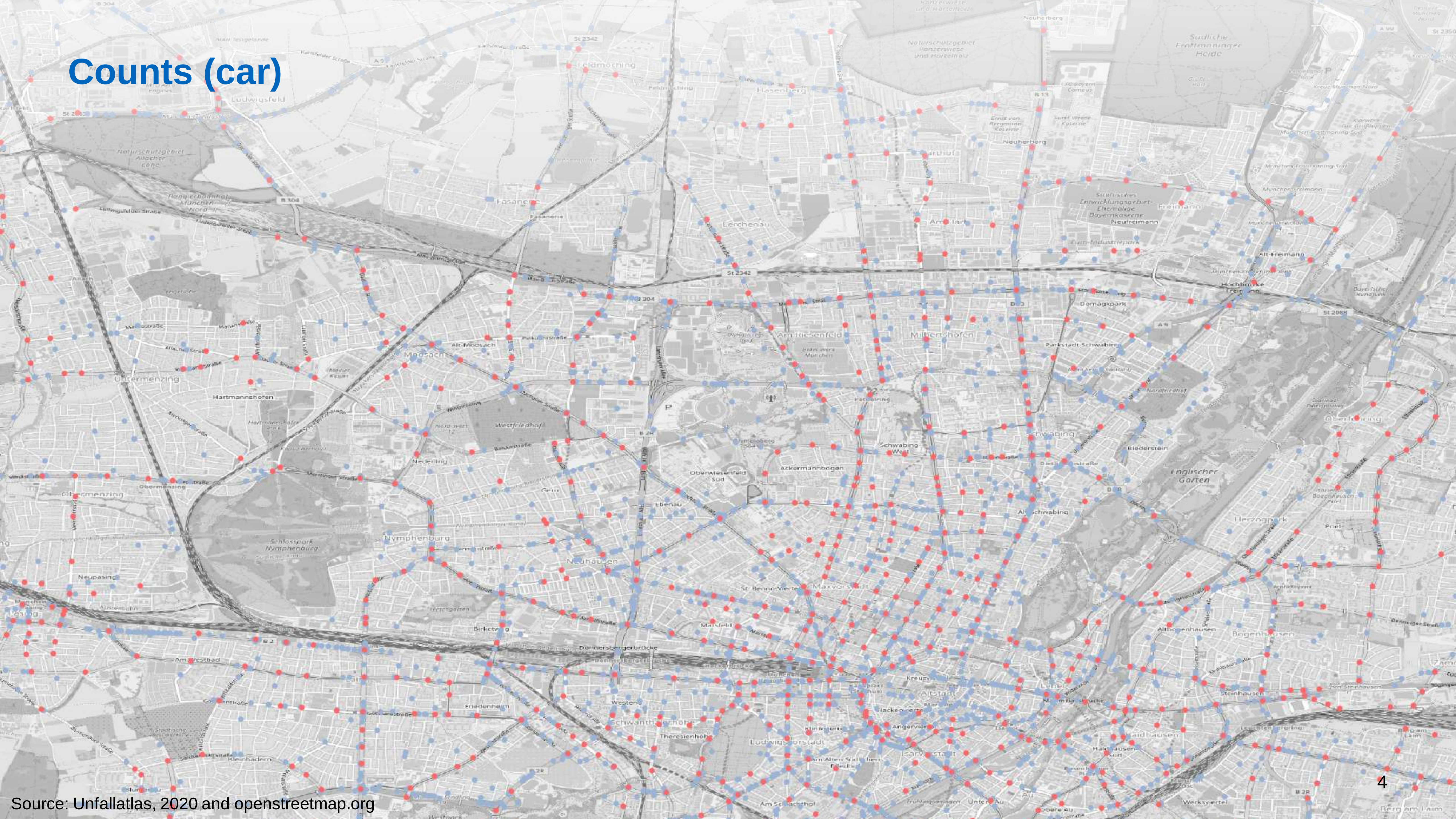
Where:

- y is the number of crashes
- $AADT$ is the traffic volume
- L is the road length
- X are other variables
- a, b, and β are parameters

Crashes

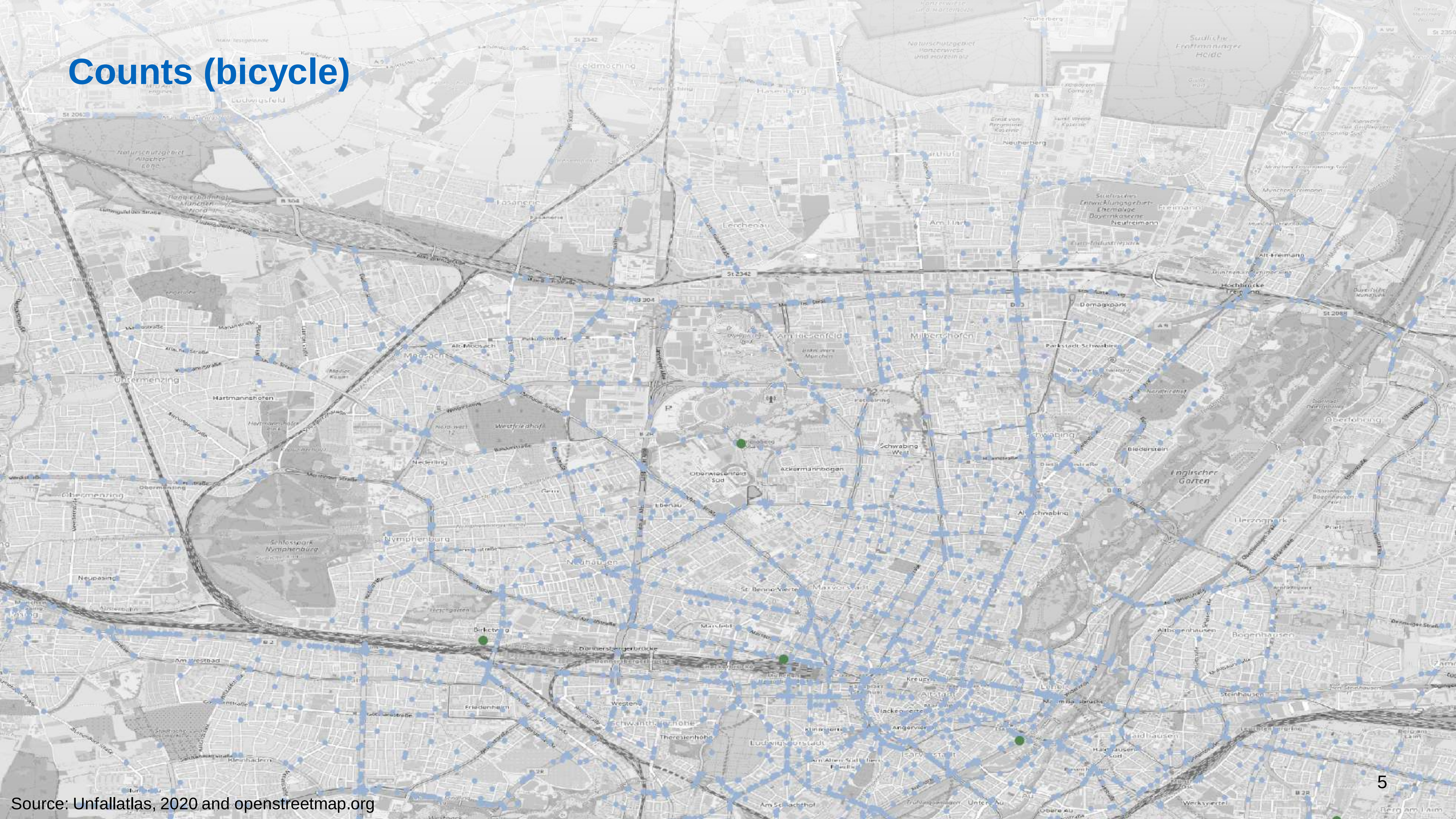
Source: Unfallatlas, 2020 and openstreetmap.org

Counts (car)



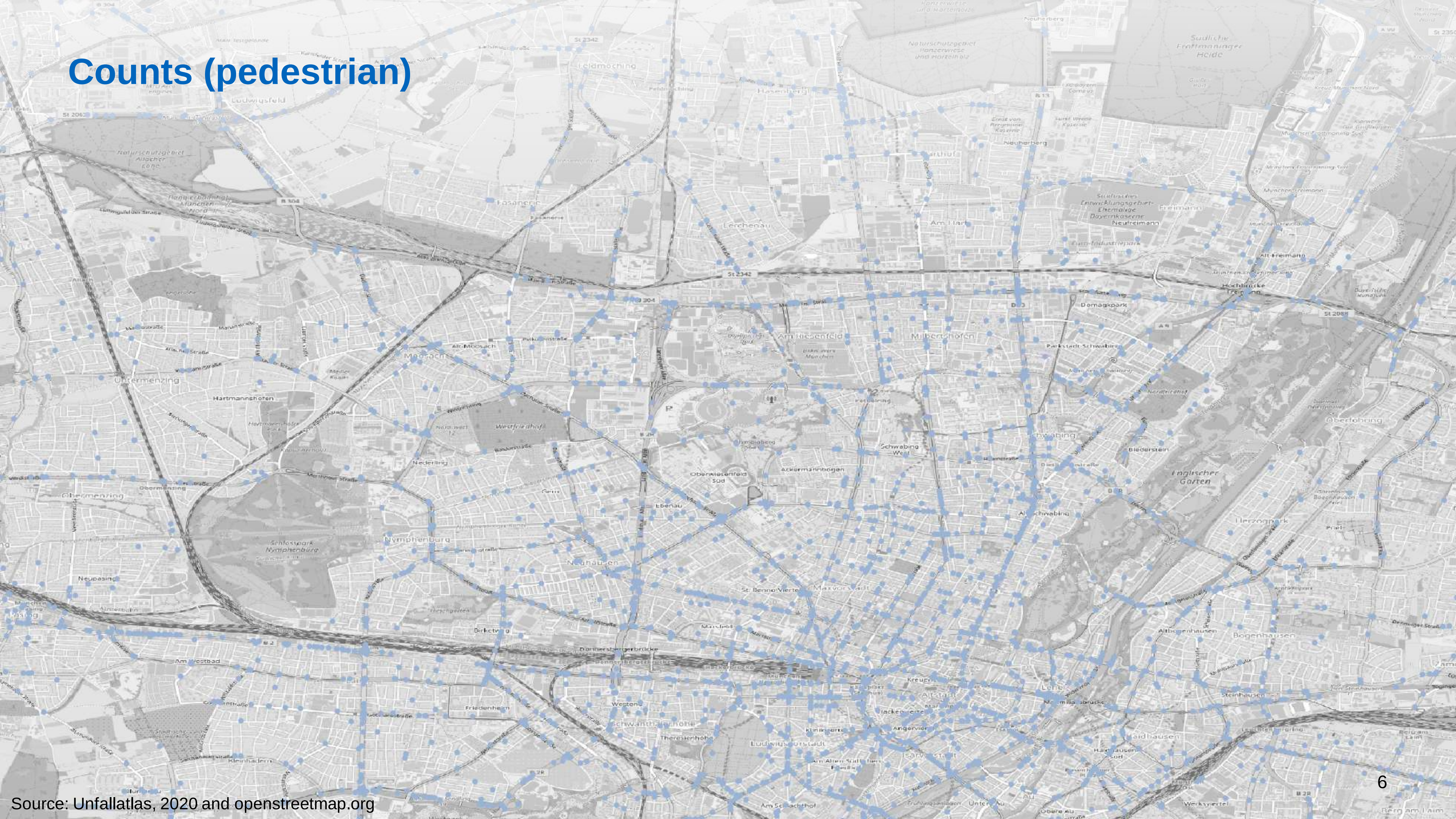
Source: Unfallatlas, 2020 and openstreetmap.org

Counts (bicycle)



Source: Unfallatlas, 2020 and openstreetmap.org

Counts (pedestrian)



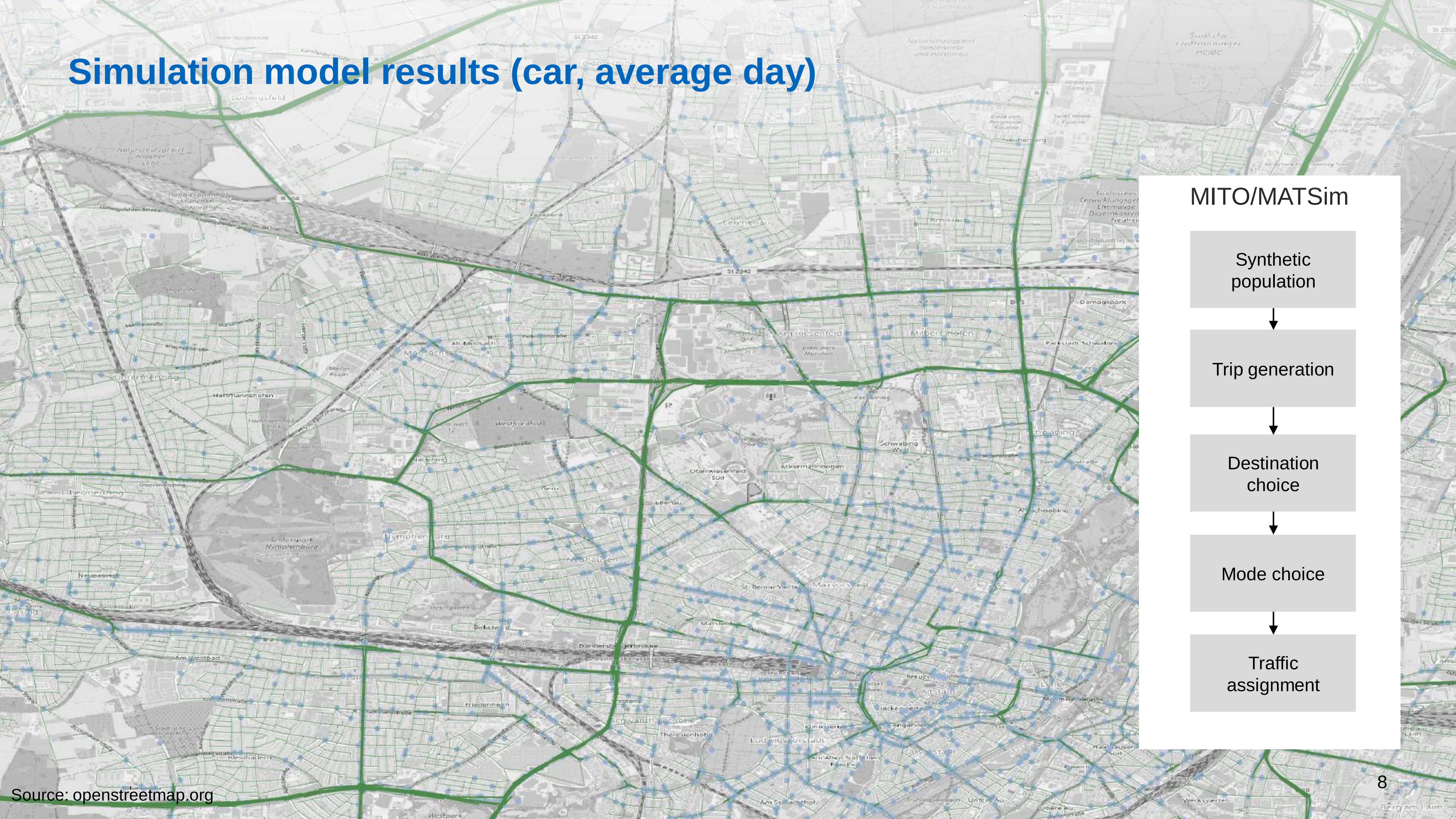
Source: Unfallatlas, 2020 and openstreetmap.org

Introduction

Existing road safety models:

- Calculate number of crashes of links
- Apply models commonly on a subset of roads (primarily on main roads)
- Apply models mainly for car mode
- Useful for finding out where the crash occurs, but cannot answer the question who is exposed to the risk of being killed or injured

Simulation model results (car, average day)



MITO/MATSim

Synthetic population → Trip generation → Destination choice → Mode choice → Traffic assignment

Source: openstreetmap.org

Introduction

In this study, a road safety model is developed:

- Calculate **number of casualties on links**
- Apply **to the entire network** (including cyclist roads and minor roads for pedestrian)
- Apply models **for car-occupants, cyclists and pedestrians**
- Built in **an agent-based environment**

→ Can assess the crash injury risk of individual trips and individual agents.

How we model individual injury risks in MATSim

Inputs	Model steps	Outcome variables
Crash prediction models Simulated traffic volumes	1. Annual link crash frequency	$Crash_{l,s,m}$
Crash time of day distribution	2. Crash frequency at a certain time of day	$Crash_{l,s,m,h} = \frac{Crash_{l,s,m}}{365} * Weight_h$
Casualties per accident	3. Convert crashes into number of ***casualties***	$Casualty_{l,h,s,m} = Crash_{l,s,m,h} * Casualty\ Ratio_{s,m}$
Link exposure	4. Injury risk on each link	$R_{l,h,s,m} = \frac{Casualty_{l,h,s,m}}{Volume_{l,h,m} * Length_l}$
Simulated routes by agent	5. Injury risk of each trip/agent	$R_i = \sum_{l=1}^{links} \sum_{h=0}^{24} R_{l,h,s,m} * P_{l,h}$

l = link
s = severity
m = mode
h = hour

Step 1: Annual Crash frequency

Data: UnfallAtlas 2016 - 2018

Statistic models: Zero-Inflated Poisson (ZIP)

Dependent variables: annual number of crash of link l by ***severity*** by ***case (mode)***

Case	Truck/PT	Car	Bike	Pedestrian	Victim
Case 1	√	√			Car-occupant
Case 2	√	√	√		Cyclist
Case 3			√		Cyclist
Case 4	√	√	√	√	Pedestrian

Estimation results (Step 1: non-zero model coefficients)

Variable	Case 1 Car-occupant		Case 2 Cyclist		Case 3 Cyclist only		Case 4 Pedestrian	
	Light	Severe	Light	Severe	Light	Severe	Light	Severe
Intercept	-2.68***	-1.87***	-4.14***	-3.13***	-2.29***	-1.94***	-3.50***	-2.73***
Traffic conditions								
Motor traffic volumes in 1,000	0.04***	1.72***	0.18***	0.23*	-	-	0.05*	-
x motorway	base	-	-	-	-	-	-	-
x primary road	0.10***	-	-	-	-	-	-	-
x secondary road	0.09***	-	-	-	-	-	-	-
x tertiary road	0.88***	-	-	-	-	-	-	-
x residential or minor road	4.13***	-	-	-	-	-	-	-
Bike flows in 1,000	-	-	4.91***	6.32***	4.74***	5.74***	-	-
Pedestrian flows in 1,000	-	-	-	-	-	-	2.68***	2.80***
Roadway function								
is motorway	base	base	-	-	-	-	-	-
is primary road	-0.30***	-0.33.	-	-	-	-	-	-
is secondary road	-0.13***	-0.33.	1.03***	1.05**	-	-	-	-
is tertiary road	-1.24***	-	0.90***	0.65.	-0.46***	-	0.51***	-0.37.
is residential road	-2.33***	-1.61***	1.55***	1.14**	0.19*	0.56**	-	-
Roadway geometry								
log(link length)	0.36***	0.14***	-	-	-	-	-	-
Number of intersections	0.06***	-	-	-	-	-	-	-
Efron's pseudo R2	25.6%	17.6%	13.9%	2.3%	7.59%	1.6%	10.0%	4.0%
McFadden's pseudo R2	23.9%	22.7%	13.1%	9.3%	11.1%	8.1%	16.6%	15.2%

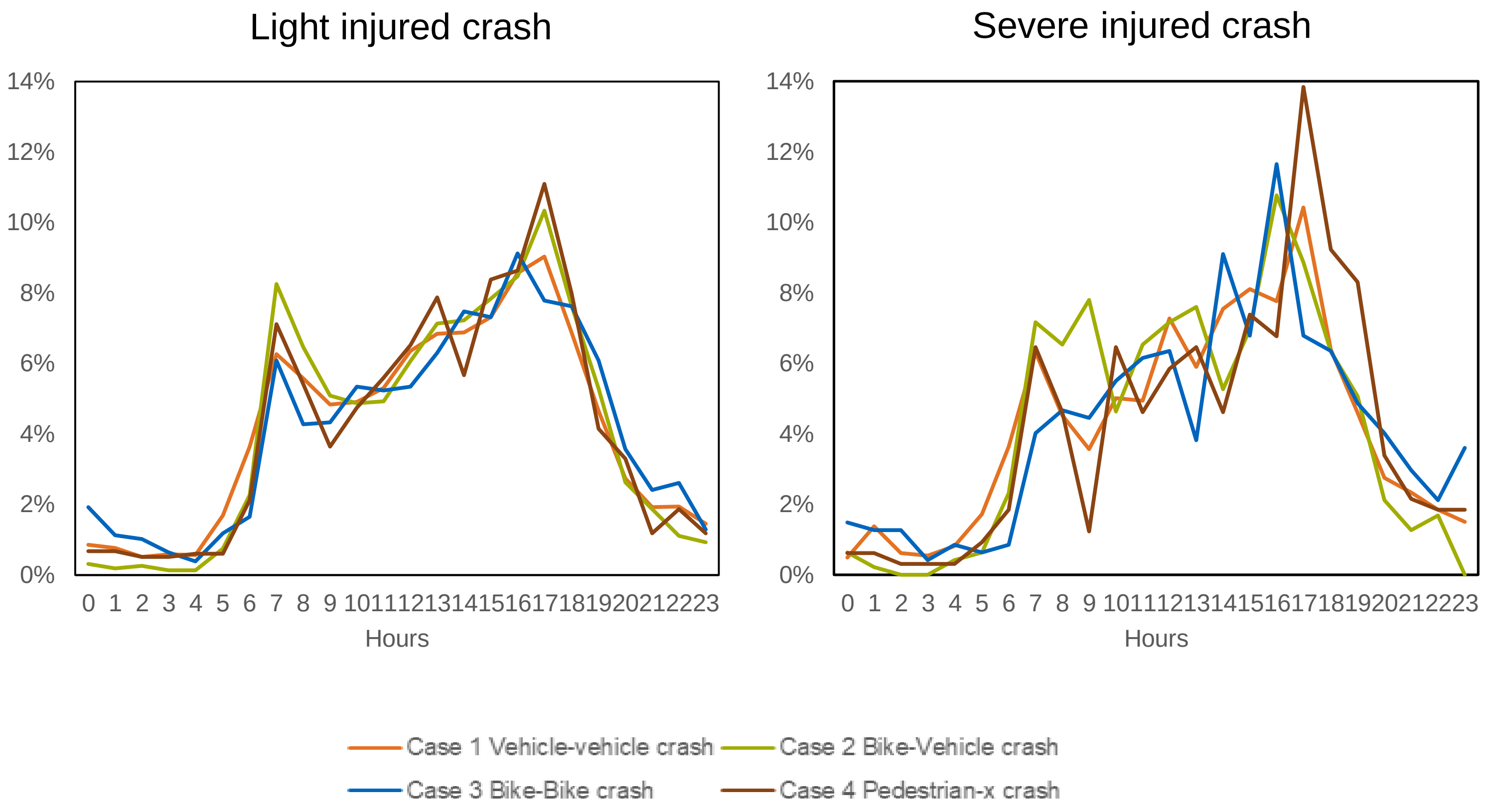
Note:
Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1
Not significant variables were not estimated in the final model (-)

Estimation results (Step 2: Count model coefficients)

Variable	Case 1 Car-occupant Light	Case 1 Car-occupant Severe	Case 2 Cyclist Light	Case 2 Cyclist Severe	Case 3 Cyclist only Light	Case 3 Cyclist only Severe	Case 4 Pedestrian Light	Case 4 Pedestrian Severe
Intercept	-1.61***	-6.81***	-3.24***	-5.81***	-4.88***	-7.06***	-4.37***	-5.99***
Traffic conditions								
Motor traffic volume in 1,000	0.01***	0.01***	0.01***	0.01$^{.}$	0.01***	0.01$^{.}$	0.01***	0.01$^{.}$
x motorway	base	-	-	-	-	-	-	-
x primary road	-	-	-	-	-	-	-	-
x secondary road	0.04***	-	-	-	-	-	-	-
x tertiary road	0.11***	-	-	-	-	-	-	-
x residential or minor road	0.18***	-	-	-	-	-	-	-
Bike flows in 1,000	-	-	0.08***	0.08***	0.10***	0.10***	-	-
Pedestrian flows in 1,000	-	-	-	-	-	-	0.10***	0.11***
Roadway function								
is motorway	base	base	-	-	-	-	-	-
is primary road	-0.30***	-0.14**	base	base	base	base	base	base
is secondary road	-0.68***	-0.14**	-0.12*	-0.21*	-	-	-	-
is tertiary road	-1.28***	-0.78***	-0.12*	-	0.32***	-	-	-0.22$^{.}$
is residential road	-2.21***	-0.93***	-0.11°	-0.43***	-	-0.22*	-0.24***	-0.77***
Roadway geometry								
log(link length)	0.35***	0.81***	0.38***	0.45***	0.51***	0.62***	0.46***	0.54***
Number of intersections	0.03***	-	0.03***	0.04***	0.01***	-	-	-
Efron's pseudo R2	25.6%	17.6%	13.9%	2.3%	7.59%	1.6%	10.0%	4.0%
McFadden's pseudo R2	23.9%	22.7%	13.1%	9.3%	11.1%	8.1%	16.6%	15.2%

Note:
Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1
Not significant variables were not estimated in the final model (-)

Step 2: Crash distribution over time of day



Step 3: Convert into casualties

Average number of casualties by severity for different travel modes extracted from UK STATS19

	Light accident			Severe accident					
	Light injured			Light injured			Killed or severely injured		
	Car	Cyclist	Pedestrian	Car	Cyclist	Pedestrian	Car	Cyclist	Pedestrian
Case 1	1.23	0.00	0.00	0.29	0.00	0.00	1.01	0.00	0.00
Case 2	0.01	0.99	0.00	0.01	0.01	0.00	0.01	0.99	0.00
Case 3	0.00	1.05	0.00	0.00	0.00	0.00	0.00	1.00	0.00
Case 4	0.02	0.01	1.03	0.01	0.00	0.05	0.02	0.01	1.00

Case 1: vehicle-vehicle accident
Case 2: bike-vehicle accident
Case 3: bike-bike accident
Case 4: pedestrian-x accident

Application

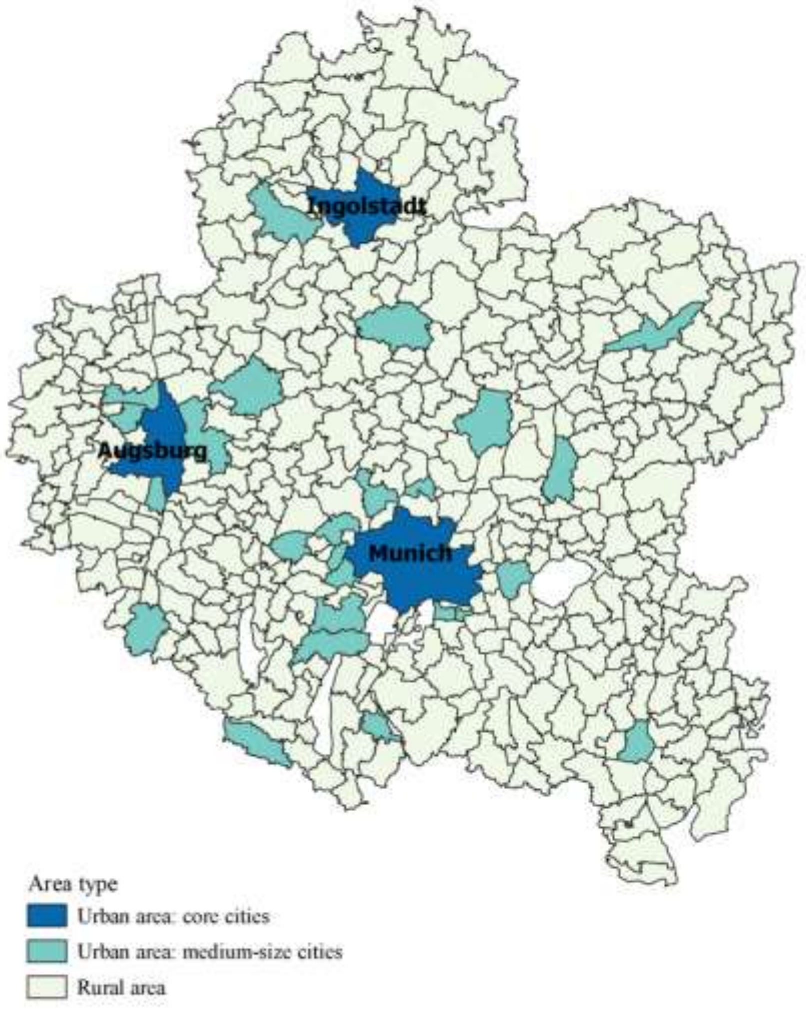
8 million synthetic trips generated from in-house agent-based land use and transport model (SILO and MITO):

… 44% car trips

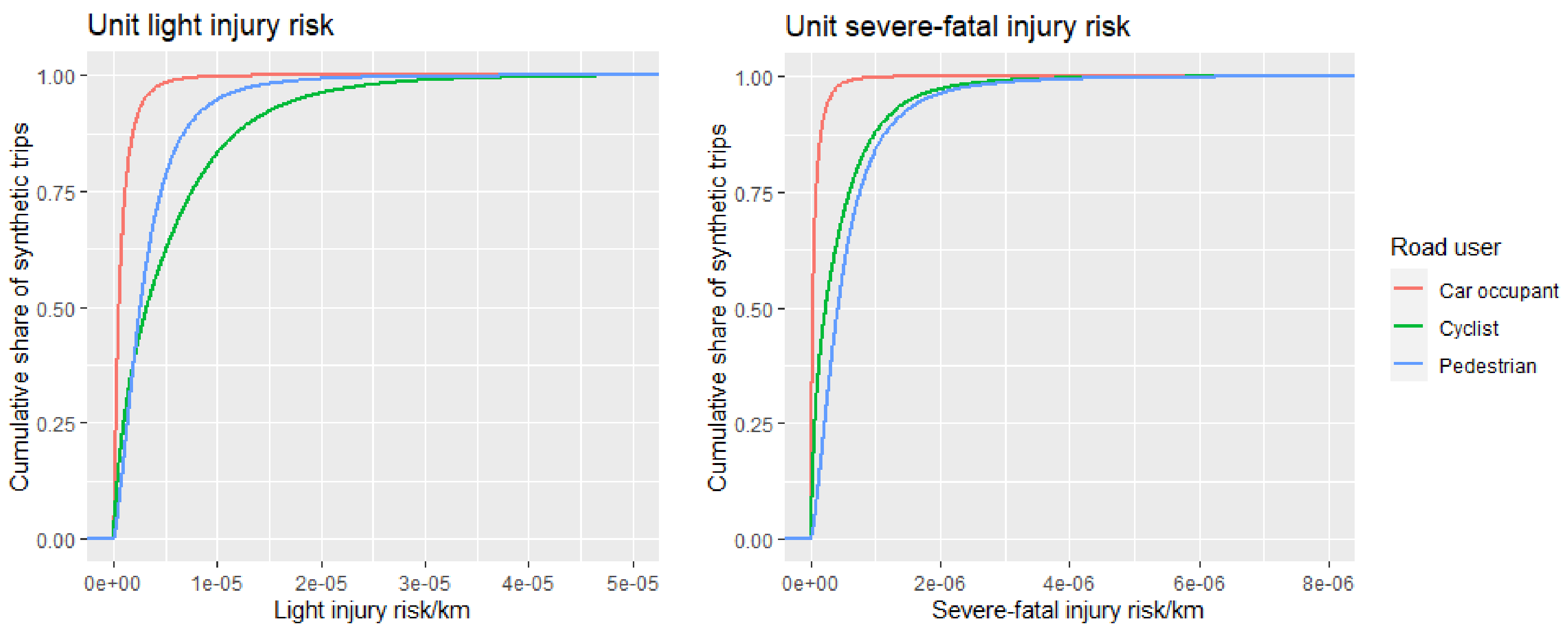
… 13% cycling trips

… 18% pedestrian trips.

MATSim ran with a subsample of 5% of all trips for trip assignment

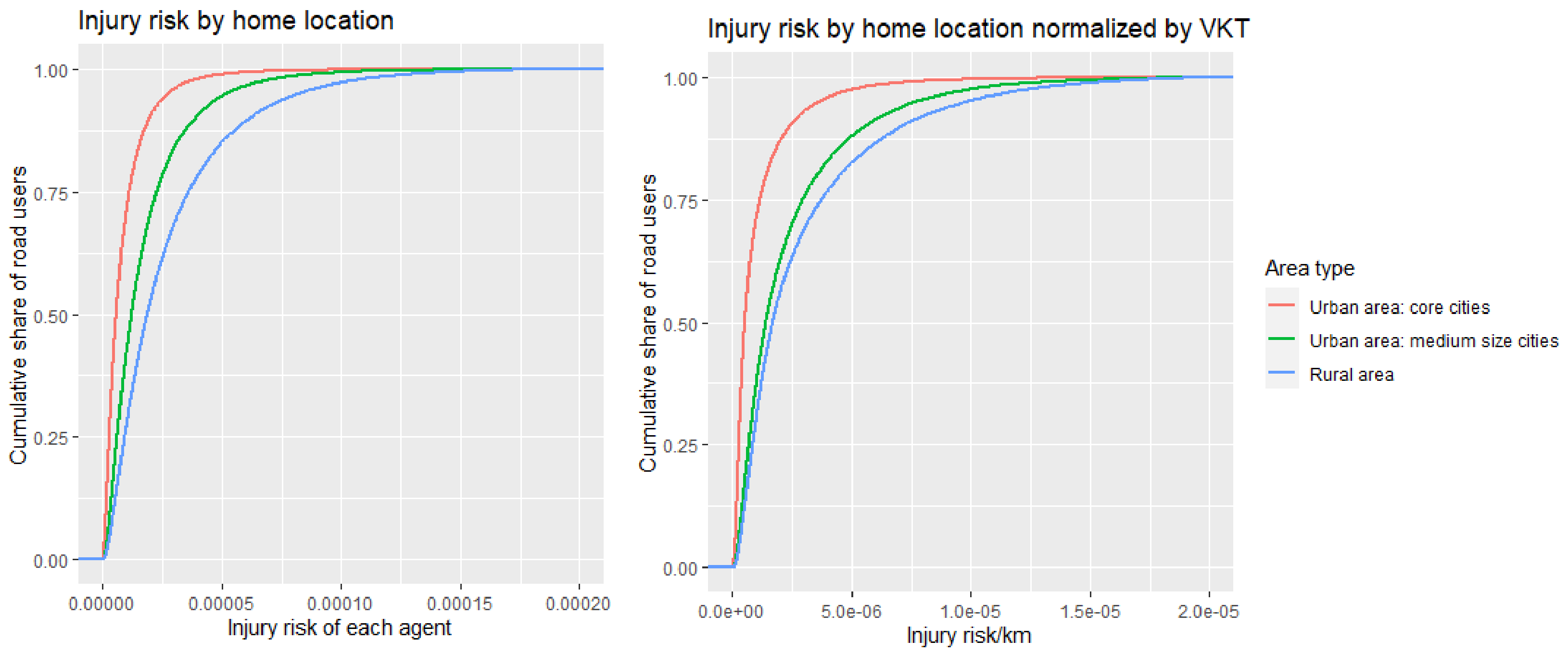


Who are the most vulnerable road users?

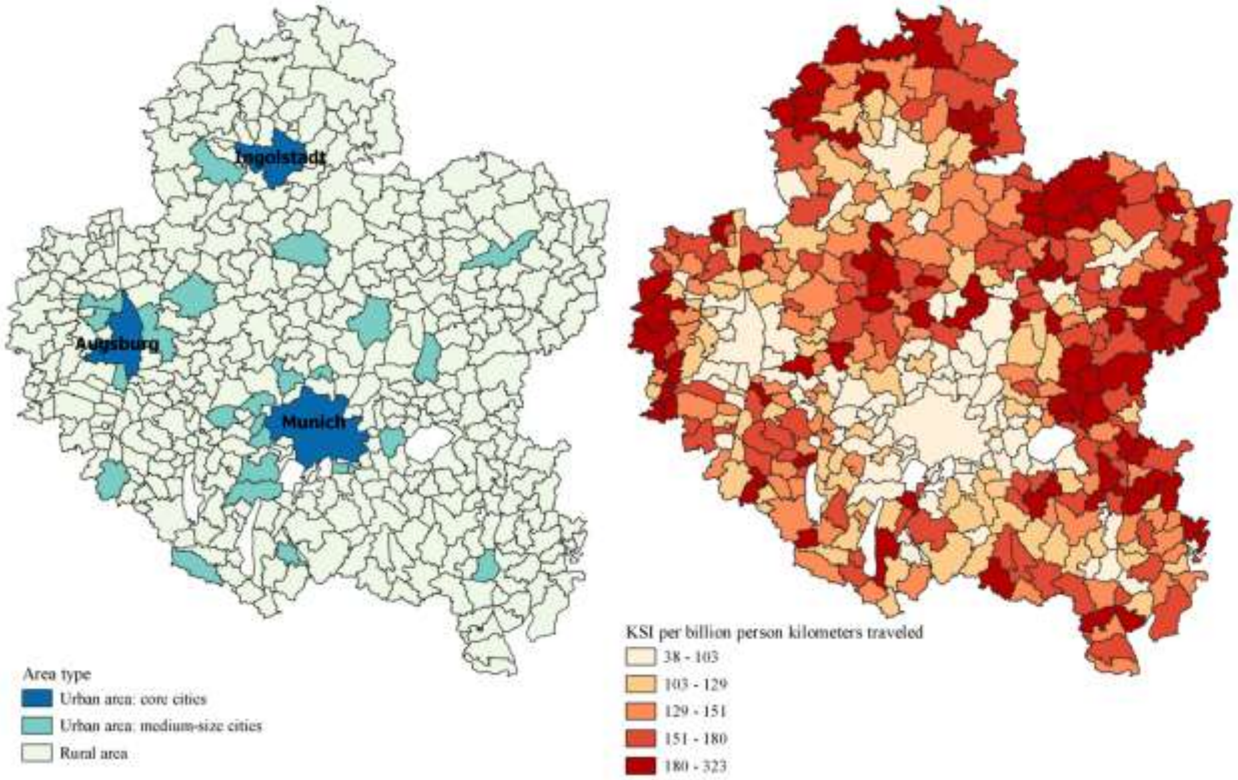


Road safety inequity?

Distribution of **severe injuries risk** of by the **area type of home location**



Road safety inequity?



Left: classification of area types for the Munich region

Right: KSI risk per billion person kilometers traveled of each municipality

Conclusions

- Large-scale risk assessment (every road, every trip and every crash)
- Explore the individual risks of using the roads
- Road safety from a transport planning perspective
- Make forecasts into the future, considering potential changes of mode choice decisions or of distance travelled by users
- Depends on transport model quality
- Road network described with few geometric attributes

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