WHAT INTERACTIONS ARE HAPPENING IN MUNICH’S BICYCLE LANES?
(AND THE ROLE OF FACILITY DESIGN AND HUMAN BEHAVIOR)

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Prof. Dr. Kelly Clifton
BICYCLE LANES

Bicycle Lane Along Sidewalk

On-Street Bicycle Lane
COMPARING TWO LANE TYPES

Which type of bicycle lane is better?
COMPARING TWO LANE TYPES

Bicycle Lane
Along Sidewalk

On-Street
Bicycle Lane

Which type of bicycle lane best meets the goals it was designed to achieve?
COMPARING TWO LANE TYPES

Which type of bicycle lane best meets the goals it was designed to achieve?

- Safety
- Mobility
- Access
How can we evaluate if these goals are achieved?

Which type of bicycle lane best meets the goals it was designed to achieve?
How can we evaluate if these goals are achieved?

**TYPICAL RESEARCH APPROACHES**

**QUALITATIVE**
- Interviews
- Travel Diaries
- Ethnography

**QUANTITATIVE**
- Historic Safety Data
- Count-Based Observation
- Instrumented Bicycles
- Surveys
“...it is **not possible to pre-program the interaction** between public life and space in detail, but targeted studies can provide a basic understanding of what works and what does not, and thus suggest qualified solutions.”

INTERACTIONS & REACTIONS ARE KEY

Assumptions:
Interactions are a natural and unavoidable. BUT, the aim is that interactions do not require the impacted person to adjust their behavior to negotiate the interaction.
Assumptions:
Interactions resulting in some form of lateral reaction or yielding action are indicators that something isn’t working well with the design of the facilities or how they are being used.
INTERACTIONS & REACTIONS ARE KEY

Assumptions:
No negative intent is assumed on the part of the person or object who instigates the interaction. The infrastructure or other conditions may be responsible for incorrect behavior.
NEW MIXED-METHOD APPROACH

Methods Applied:
- Direct, Unobtrusive Observation
- Grounded Theory-Driven Coding
- Binary Logistic Regression

Unit of Analysis:
Interactions
(Involving at least 1 bicyclist and 1 other person or stationary object)

Design Review:
- Interaction Frequency
- Interaction Characteristics
- Interaction Severity

Which type of bicycle lane best meets the goals it was designed to achieve?

Methods Applied:
- Direct, Unobtrusive Observation
- Grounded Theory-Driven Coding
- Binary Logistic Regression

Unit of Analysis:
Interactions
(Involving at least 1 bicyclist and 1 other person or stationary object)
NEW MIXED-METHOD APPROACH

Avoids Reliance on Reported Behavior:
“...it is not unusual for persons to say they are doing one thing but in reality they are doing something else.” (Corbin & Strauss 2015)

Focuses on Observed Behavior:
“...direct observation provides much more accurate results about behavior than do reports of behavior.” (Bernard 2018)

Applies Grounded Theory:
Data is gathered using both inductive and deductive logic, with an openness to document and analyze both expected and unexpected interactions.
METHODOLOGY: Understand the Scene

DOCUMENT EXISTING CONDITIONS

- BICYCLE TRANSPORT GOALS
- DESIGN STANDARDS & TRAFFIC RULES
- SITE-SPECIFIC CONTEXT
METHODOLOGY: Understand the Scene

DOCUMENT EXISTING CONDITIONS

- **BICYCLE TRANSPORT GOALS**: local to national policy goals (and performance measures)
- **DESIGN STANDARDS & TRAFFIC RULES**: standards, guidelines, and rules applicable to the case study site
- **SITE-SPECIFIC CONTEXT**: presence and location of facilities and fixed objects at the case study site
METHODOLOGY: Observe Behavior & Use

DOCUMENT EXISTING CONDITIONS

BICYCLE TRANSPORT GOALS

DESIGN STANDARDS & TRAFFIC RULES

SITE-SPECIFIC CONTEXT

OBSERVE INTERACTIONS

ITERATIVE CODING PROCESS

Define Variables

Discover Dependent Variables

Analyze Interactions

Identify Interactions

Discover Insights into Interactions

OBSERVE INTERACTIONS

DOCUMENT EXISTING CONDITIONS

BICYCLE TRANSPORT GOALS

DESIGN STANDARDS & TRAFFIC RULES

SITE-SPECIFIC CONTEXT

Iterative Coding Process

Define Variables

Discover Dependent Variables

Analyze Interactions

Identify Interactions

Discover Insights into Interactions

Iterative Coding Process

Iterative Coding Process

Iterative Coding Process

Iterative Coding Process

Iterative Coding Process

Iterative Coding Process
What types of interactions are bicyclists involved in while using streets with different types of bicycle facilities?

**METHODOLOGY: Observe Behavior & Use**

**DOCUMENT EXISTING CONDITIONS**

- BICYCLE TRANSPORT GOALS
- DESIGN STANDARDS & TRAFFIC RULES
- SITE-SPECIFIC CONTEXT

**OBSERVE INTERACTIONS**

**ITERATIVE CODING PROCESS**

1. Define Variables
2. Discover Dependent Variables
3. Identify Interactions
4. Analyze Interactions
5. Discover Insights into Interactions
**METHODOLOGY: Observe Behavior & Use**

**DOCUMENT EXISTING CONDITIONS**
- BICYCLE TRANSPORT GOALS
- DESIGN STANDARDS & TRAFFIC RULES
- SITE-SPECIFIC CONTEXT

**OBSERVE INTERACTIONS**

**ITERATIVE CODING PROCESS**
- Define Variables
- Discover Dependent Variables
- Analyze Interactions
- Identify Interactions
- Discover Insights into Interactions

...what instigated it?
...where did it occur?
...who and what was involved?
...what were participants doing?
**METHODOLOGY: Define “Interaction”**

**Interaction Definition:** “a negotiation of movement between a Stimulus and Reactor, involving a bicyclist and another person using any mode of transportation or a stationary object.” (Silva et al. 2020)

- **Stimulus:** The person or object whose action or presence instigates the interaction.
- **Reactor:** The person who reacts (or not) to the action or presence of the stimulus.
METHODOLOGY: Define “Interaction”

Stimulus
Participant

Incorrect
Lane Use

Reactors
Participant

Lateral
Reaction

METHODOLOGY: Define “Interaction”
METHODOLOGY: Evaluate Functionality

DOCUMENT EXISTING CONDITIONS

- BICYCLE TRANSPORT GOALS
- DESIGN STANDARDS & TRAFFIC RULES
- SITE-SPECIFIC CONTEXT

OBSERVE INTERACTIONS

ITERATIVE CODING PROCESS

- Define Variables
- Discover Dependent Variables
- Discover Insights into Interactions
- Analyze Interactions
- Identify Interactions

EVALUATE IMPACT OF INTERACTIONS

PERFORMANCE MEASURE REVIEW

- Safety
- Mobility
- Access

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METHODOLOGY: Evaluate Functionality

Which type of bicycle lane best meets the goals it was designed to achieve?

- Safety
- Mobility
- Access

Based on the Analysis
METHODOLOGY: Analyze Interactions

Stimulus

Reactor

Stimulus Action

Reaction to Stimulus

IMPACT OF INTERACTION
METHODOLOGY: Analyze Interactions

Dependent Variable =

“Reaction to Stimulus”

0 = No Reaction 😊

1 = Lateral Reaction or Yielding 😞
**METHODOLOGY: Analyze Interactions**

Reaction to Stimulus =

\[
\text{constant} \times \\
\text{Spatial Variables} \times \\
\text{Temporal Variables} \times \\
\text{Behavioral Variables} \times \\
\text{Participant Characteristic Variables}
\]
METHODOLOGY: Discover Problem-Areas

- **DOCUMENT EXISTING CONDITIONS**
  - BICYCLE TRANSPORT GOALS
  - DESIGN STANDARDS & TRAFFIC RULES
  - SITE-SPECIFIC CONTEXT

- **RECOMMEND MITIGATION MEASURES**

- **EVALUATE IMPACT OF INTERACTIONS**
  - PERFORMANCE MEASURE REVIEW
    - Safety
    - Mobility
    - Access

- **OBSERVE INTERACTIONS**

- **ITERATIVE CODING PROCESS**
  - Define Variables
  - Discover Dependent Variables
  - Identify Interactions
  - Analyze Interactions
  - Discover Insights into Interactions

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COMPARATIVE CASE STUDY

One-Day Study of Two Streets Segments

Bicycle Lane Along Sidewalk

On-Street Bicycle Lane

Munich, Germany
COMPARATIVE CASE STUDY

One-Day Study of Two Streets Segments

Site: Augustenstraße
1208 Interactions Observed
From 07:48 to 20:16 (Duration: 12hrs 28min)
1.6 Interactions per Minute

Site: Arcisstraße
280 Interactions Observed
From 08:15 to 20:01 (Duration: 11hrs 46min)
0.4 Interactions per Minute
COMPARATIVE CASE STUDY

Findings for:
1-on-1 Interactions

Site: Augustenstraße
582 1-on-1 Interactions Observed
(48% of Interactions at Site)
0.8 Interactions per Minute

Site: Arcisstraße
210 1-on-1 Interactions Observed
(75% of Interactions at Site)
0.3 Interactions per Minute
COMPARATIVE CASE STUDY

Reaction to Stimulus =

\[ \text{constant} \times \]

Spatial Variables \( \times \)

Temporal Variables \( \times \)

Behavioral Variables \( \times \)

Participant Characteristic Variables
## COMPARATIVE CASE STUDY: Results

<table>
<thead>
<tr>
<th>Group</th>
<th>Variable</th>
<th>Values</th>
<th>β</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Spatial Variables</strong></td>
<td><strong>Case Study Bicycle Lane</strong></td>
<td>(0=Along Sidewalk; 1=On-Street)</td>
<td>.662</td>
<td>.078</td>
</tr>
<tr>
<td></td>
<td>Bicycle Lane Present</td>
<td>(0=No; 1=Yes)</td>
<td>.695</td>
<td>.231</td>
</tr>
<tr>
<td></td>
<td>Bicycle Lane Buffer Present</td>
<td>(0=No; 1=Yes)</td>
<td>-.849</td>
<td>.067</td>
</tr>
<tr>
<td></td>
<td>Driveway Present</td>
<td>(0=No; 1=Yes)</td>
<td>-.479</td>
<td>.237</td>
</tr>
<tr>
<td></td>
<td>Landscape Strip Present</td>
<td>(0=No; 1=Yes)</td>
<td>-.489</td>
<td>.177</td>
</tr>
<tr>
<td></td>
<td>Dumpster Present</td>
<td>(0=No; 1=Yes)</td>
<td>.642</td>
<td>.486</td>
</tr>
<tr>
<td><strong>Temporal Variables</strong></td>
<td><strong>Time of Day</strong></td>
<td>(0=AM or PM Peak; 1=10:00-16:00)</td>
<td>.511</td>
<td>.033</td>
</tr>
<tr>
<td></td>
<td>No. Interactions/Study Lane/5-min (continuous)</td>
<td></td>
<td>.032</td>
<td>.081</td>
</tr>
<tr>
<td><strong>Behavioral Variables</strong></td>
<td><strong>Stimulus’ Reaction to Reactor</strong></td>
<td>(0=No Reaction; 1=Lateral Reaction or Yielding)</td>
<td>.372</td>
<td>.174</td>
</tr>
<tr>
<td></td>
<td>Stimulus Distracted</td>
<td>(0=No; 1=Yes)</td>
<td>1.048</td>
<td>.032</td>
</tr>
<tr>
<td></td>
<td>Stimulus’ Lane Use</td>
<td>(1=Correct Lane Use)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(2=Allowed Use of the Roadway)</td>
<td>-3.743</td>
<td>.000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(3=Reactive Incorrect Lane Use)</td>
<td>-5.187</td>
<td>.000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(4=Incorrect Lane Use)</td>
<td>-3.970</td>
<td>.000</td>
</tr>
<tr>
<td></td>
<td>Reactor’s Lane Use</td>
<td>(1=Correct Lane Use)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(2=Allowed Use of the Roadway)</td>
<td>1.078</td>
<td>.019</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(3=Reactive Incorrect Lane Use)</td>
<td>5.298</td>
<td>.000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(4=Incorrect Lane Use)</td>
<td>18.683</td>
<td>.998</td>
</tr>
<tr>
<td><strong>Participant Variables</strong></td>
<td><strong>Stimulus Has Object</strong></td>
<td>(0=No; 1=Yes)</td>
<td>.973</td>
<td>.272</td>
</tr>
<tr>
<td></td>
<td><strong>Stimulus is At Work</strong></td>
<td>(0=No; 1=Yes)</td>
<td>.547</td>
<td>.237</td>
</tr>
<tr>
<td></td>
<td><strong>Reactor is At Work</strong></td>
<td>(0=No; 1=Yes)</td>
<td>-.683</td>
<td>.428</td>
</tr>
<tr>
<td></td>
<td><strong>Stimulus’ Mode</strong></td>
<td>(0=Bicyclist or Pedestrian; 1=Driver or Stationary Object)</td>
<td>2.761</td>
<td>.000</td>
</tr>
<tr>
<td></td>
<td><strong>Reactor’s Mode</strong></td>
<td>(1=Bicyclist)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(2=Pedestrian)</td>
<td>-1.228</td>
<td>.000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(3=Vehicle Driver)</td>
<td>-2.174</td>
<td>.001</td>
</tr>
</tbody>
</table>
COMPARATIVE CASE STUDY: Results

More Associated w/ No Reaction

More Associated w/ Lateral Reactions & Yielding

Spatial Variables

- Bicycle Lane Buffer Present
- Landscape Strip Present
- Driveway Present
- Dumpster Present
- Time between 10:00-16:00
- No. Interactions/Site/5-min

Temporal Variables

- Stimulus - Reacts to Interaction
- Stimulus - is Distracted

Behavioral Variables

- Stimulus - Correct Lane Use (constant)
- Stimulus - Reactive Incorrect Lane Use
- Reactor - Correct Lane Use (constant)
- Reactor - Allowed Lane Use
- Reactor - Incorrect Lane Use (omitted from graph)
- Reactor - Reactive Incorrect Lane Use
- Stimulus - Has Object
- Stimulus - is at Work

Participant Characteristics

- Reactor - is a Bicyclist (constant)
- Reactor - is a Pedestrian
- Reactor - is a Driver
- Stimulus - is a Driver or Stationary Object

Key

- Significant
- Non-Significant

No Reaction Some Reaction
RESULTS: Spatial Variables

More Associated w/ No Reaction:

- Bicycle Lane Buffer Present
  \[ \beta = -0.849 \quad \text{sig.} = .067 \]
- Landscape Strip Present
  \[ \beta = -0.489 \quad \text{sig.} = .177 \]
- Driveway Present
  \[ \beta = -0.479 \quad \text{sig.} = .237 \]

More Associated w/ Lateral Reactions & Yielding:

- On-Street Bicycle Lanes
  \[ \beta = 0.662 \quad \text{sig.} = .078 \]
- Bicycle Lane Present
  \[ \beta = 0.695 \quad \text{sig.} = .231 \]
- Dumpster Present
  \[ \beta = 0.642 \quad \text{sig.} = .486 \]
**RESULTS: Spatial Variables**

**Key Finding:**
Interactions occurring along street segments with on-street bicycle lane are more likely to result in lateral reactions or yielding behavior, than those occurring on streets with bicycle lanes built-up along the sidewalk.

On-Street Bicycle Lanes

\[ \beta = 0.662 \quad \text{sig.} = .078 \]
RESULTS: Spatial Variables

Bicycle Lane  😊  Along Sidewalk

FINDINGS FOR:
1-on-1 INTERACTIONS

On-Street Bicycle Lane  😞
RESULTS: Spatial Variables

Findings for: 1-on-1 Interactions

<table>
<thead>
<tr>
<th>Bicycle Lane Type</th>
<th>Reaction Type</th>
<th>% Within Bicycle Lane Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>On-Street</td>
<td>Lateral Reaction or Yielding</td>
<td>62%</td>
</tr>
<tr>
<td></td>
<td>No Reaction</td>
<td>38%</td>
</tr>
<tr>
<td>Along Sidewalk</td>
<td>Lateral Reaction or Yielding</td>
<td>77%</td>
</tr>
<tr>
<td></td>
<td>No Reaction</td>
<td>23%</td>
</tr>
</tbody>
</table>

Key:
- Green: No Reaction
- Purple: Lateral Reaction or Yielding
RESULTS: Spatial Variables

**Findings for: 1-on-1 Interactions**

<table>
<thead>
<tr>
<th>Bicycle Lane Type</th>
<th>Reaction Type</th>
<th>% of Total Interactions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Along Sidewalk</td>
<td>Lateral Reaction or Yielding</td>
<td>57%</td>
</tr>
<tr>
<td></td>
<td>No Reaction</td>
<td>16%</td>
</tr>
<tr>
<td>On-Street</td>
<td>Lateral Reaction or Yielding</td>
<td>16%</td>
</tr>
<tr>
<td></td>
<td>No Reaction</td>
<td>10%</td>
</tr>
</tbody>
</table>

- **Bicycle Lane Along Sidewalk**
- **On-Street Bicycle Lane**
RESULTS: Spatial Variables

Bicycle Lane
Along Sidewalk

Findings for:
1-on-1 Interactions

More Associated w/ No Reaction

More Associated w/ Lateral Reactions & Yielding

On-Street Bicycle Lanes

$\beta = 0.662$  sig. = .078

KEY

<table>
<thead>
<tr>
<th>No Reaction</th>
<th>Some Reaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Significant</td>
<td>Non-Significant</td>
</tr>
</tbody>
</table>

On-Street Bicycle Lanes
RESULTS: Spatial Variables

**Key Finding:**
Where there are facilities providing extra space between travel lanes, interactions are less likely to result in reactions.

- **Bicycle Lane Buffer Present**
  \[ \beta = -0.849 \quad \text{sig.} = .067 \]

- **Landscape Strip Present**
  \[ \beta = -0.489 \quad \text{sig.} = .177 \]
RESULTS: Spatial Variables

**FINDINGS FOR:**
1-on-1 INTERACTIONS

Bicycle Lane Buffer Present

No Bicycle Lane Buffer
RESULTS: Spatial Variables

**Findings for:** 1-on-1 Interactions

<table>
<thead>
<tr>
<th>Reaction</th>
<th>Bicycle Lane Buffer Present</th>
<th>No Bicycle Lane Buffer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lateral Reaction or Yielding</td>
<td>68%</td>
<td>80%</td>
</tr>
<tr>
<td>No Reaction</td>
<td>32%</td>
<td>20%</td>
</tr>
</tbody>
</table>

**KEY**
- No Reaction
- Lateral Reaction or Yielding
RESULTS: Spatial Variables

**Findings for: 1-on-1 Interactions**

- **Bicycle Lane Buffer Present**
  - Lateral Reaction or Yielding: 36%
  - No Reaction: 17%

- **No Bicycle Lane Buffer**
  - Lateral Reaction or Yielding: 38%
  - No Reaction: 10%

**Key**
- Green: No Reaction
- Purple: Lateral Reaction or Yielding
RESULTS: Spatial Variables

**Findings for:**
1-on-1 Interactions

More Associated with:

- No Reaction
  - Bicycle Lane Buffer Present
    \[ \beta = -0.849 \quad \text{sig.} = 0.067 \]
  - Landscape Strip Present
    \[ \beta = -0.489 \quad \text{sig.} = 0.177 \]

More Associated with:

- Lateral Reactions & Yielding

---

**Key:***

- Significant
- Non-Significant
RESULTS: Temporal Variables

<table>
<thead>
<tr>
<th>Time from 10:00 to 16:00</th>
</tr>
</thead>
<tbody>
<tr>
<td>β = 0.511 sig. = .033</td>
</tr>
</tbody>
</table>

More Associated w/ Lateral Reactions & Yielding

No. Interactions / Site / 5-min

β = 0.032 sig. = .081

More Associated w/ No Reaction

KEY

<table>
<thead>
<tr>
<th>Significant</th>
<th>Some Reaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-Significant</td>
<td></td>
</tr>
</tbody>
</table>

No Reaction Some Reaction

Significant

Non-Significant
RESULTS: Temporal Variables

Key Finding:
Interactions are more likely to result in lateral reactions or yielding behavior when they occur between 10:00 and 16:00.

Time from 10:00 to 16:00
$\beta = 0.511$  sig. = .033
RESULTS: Temporal Variables

FINDINGS FOR:
1-on-1 Interactions

**Time of Day x Reaction Type**

<table>
<thead>
<tr>
<th>% Within Time of Day</th>
<th>AM or PM Peak</th>
<th>Between 10:00 and 16:00</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Reaction</td>
<td>31%</td>
<td>20%</td>
</tr>
<tr>
<td>Lateral Reaction or Yielding</td>
<td>69%</td>
<td>81%</td>
</tr>
</tbody>
</table>

**Time of Day x Reaction Type**

<table>
<thead>
<tr>
<th>% of Total Interactions</th>
<th>AM or PM Peak</th>
<th>Between 10:00 and 16:00</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Reaction</td>
<td>45%</td>
<td>7%</td>
</tr>
<tr>
<td>Lateral Reaction or Yielding</td>
<td>20%</td>
<td>28%</td>
</tr>
</tbody>
</table>
RESULTS: Behavioral Variables

More Associated w/ No Reaction

- Stimulus - Allowed Lane Use
  $\beta = -3.743$  $\text{sig.} = .000$

- Stimulus - Reactive Incorrect Lane Use
  $\beta = -5.187$  $\text{sig.} = .000$

- Stimulus - Incorrect Lane Use
  $\beta = -3.970$  $\text{sig.} = .000$

More Associated w/ Lateral Reactions & Yielding

- Stimulus - Reacts to Reactor
  $\beta = 0.372$  $\text{sig.} = .174$

- Stimulus - is Distracted
  $\beta = 1.048$  $\text{sig.} = .032$

- Reactor - Allowed Lane Use
  $\beta = 1.078$  $\text{sig.} = .019$

- Reactor - Reactive Incorrect Lane Use
  $\beta = 5.298$  $\text{sig.} = .000$
RESULTS: Behavioral Variables

Key Findings:

The Reactor Participant is **most likely** to react when the Stimulus Participant is legally using their designated travel lane.

The Reactor Participant is **least likely** to react when the Stimulus Participant reactively moves to a travel lane they are not designated to use.
RESULTS: Behavioral Variables

**Findings for:**
1-on-1 Interactions

**Stimulus Lane Use x Reaction Type**

<table>
<thead>
<tr>
<th>% within Stimulus Lane Use</th>
<th>Correct Lane Use</th>
<th>Allowed Lane Use</th>
<th>Reactive Incorrect Use</th>
<th>Incorrect Lane Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>99%</td>
<td>18%</td>
<td>63%</td>
<td>41%</td>
<td></td>
</tr>
</tbody>
</table>

**Stimulus Lane Use x Reaction Type**

<table>
<thead>
<tr>
<th>% of Total Interactions</th>
<th>Correct Lane Use</th>
<th>Allowed Lane Use</th>
<th>Reactive Incorrect Use</th>
<th>Incorrect Lane Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>24%</td>
<td>6%</td>
<td>6%</td>
<td>15%</td>
<td></td>
</tr>
</tbody>
</table>

**Key**
- No Reaction
- Lateral Reaction or Yielding
RESULTS: Participant Variables

More Associated w/ No Reaction

- Reactor - is at Work
  $\beta = -0.683$  $\text{sig.} = .428$

- Reactor - is a Pedestrian
  $\beta = -0.489$  $\text{sig.} = .177$

- Reactor - is a Driver
  $\beta = -0.479$  $\text{sig.} = .237$

More Associated w/ Lateral Reactions & Yielding

- Stimulus - Has an Object
  $\beta = 0.662$  $\text{sig.} = .078$

- Stimulus - is at Work
  $\beta = 1.048$  $\text{sig.} = .032$

- Stimulus - is a Vehicle Driver or Stationary Object
  $\beta = 0.642$  $\text{sig.} = .486$

Key:
- Significant
- Non-Significant

Legend:
- No Reaction
- Some Reaction
Key Findings:
Bicyclists are the most likely to react to interactions.
Vehicle Drivers are the least likely to react to interactions.
Vehicle Drivers and Stationary Objects are the most likely to instigate a reaction.
RESULTS: Participant Variables

Stimulus Participant

**STIMULUS MODE x REACTION TYPE**

% within Stimulus Mode

<table>
<thead>
<tr>
<th>Stimulus Mode</th>
<th>Reaction Type</th>
<th>0%</th>
<th>20%</th>
<th>40%</th>
<th>60%</th>
<th>80%</th>
<th>100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stationary</td>
<td>Object</td>
<td>45%</td>
<td>20%</td>
<td>6%</td>
<td>11%</td>
<td>45%</td>
<td>100%</td>
</tr>
<tr>
<td>Object</td>
<td>Vehicle</td>
<td>55%</td>
<td>89%</td>
<td>94%</td>
<td>6%</td>
<td>89%</td>
<td>100%</td>
</tr>
<tr>
<td>Vehicle</td>
<td>Driver</td>
<td>20%</td>
<td>55%</td>
<td>39%</td>
<td>45%</td>
<td>61%</td>
<td>100%</td>
</tr>
</tbody>
</table>

Reactor Participant

**REACTOR MODE x REACTION TYPE**

% within Reactor Mode

<table>
<thead>
<tr>
<th>Reactor Mode</th>
<th>Reaction Type</th>
<th>0%</th>
<th>20%</th>
<th>40%</th>
<th>60%</th>
<th>80%</th>
<th>100%</th>
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</thead>
<tbody>
<tr>
<td>Vehicle</td>
<td>Object</td>
<td>80%</td>
<td>45%</td>
<td>61%</td>
<td>39%</td>
<td>55%</td>
<td>20%</td>
</tr>
<tr>
<td>Object</td>
<td>Bicyclist</td>
<td>20%</td>
<td>55%</td>
<td>39%</td>
<td>45%</td>
<td>61%</td>
<td>100%</td>
</tr>
<tr>
<td>Bicyclist</td>
<td>Pedestrian</td>
<td>20%</td>
<td>55%</td>
<td>39%</td>
<td>45%</td>
<td>61%</td>
<td>100%</td>
</tr>
</tbody>
</table>
RESULTS: Participant Variables

Stimulus Participant

**STIMULUS MODE x REACTION TYPE**

% OF TOTAL INTERACTIONS

- **STATIONARY OBJECT**
  - No Reaction: 23%
  - Lateral Reaction or Yielding: 27%
- **VEHICLE DRIVER**
  - No Reaction: 30%
  - Lateral Reaction or Yielding: 0.3%
- **PEDESTRIAN**
  - No Reaction: 12%
  - Lateral Reaction or Yielding: 4%
- **BICYCLIST**
  - No Reaction: 4%
  - Lateral Reaction or Yielding: 4%

Reactor Participant

**REACTOR MODE x REACTION TYPE**

% OF TOTAL INTERACTIONS

- **VEHICLE DRIVER**
  - No Reaction: 16%
  - Lateral Reaction or Yielding: 63%
- **PEDESTRIAN**
  - No Reaction: 9%
  - Lateral Reaction or Yielding: 7%
- **BICYCLIST**
  - No Reaction: 2%
  - Lateral Reaction or Yielding: 3%

KEY

- Green: No Reaction
- Purple: Lateral Reaction or Yielding
# RESULTS: Behavioral Variables

## FINDINGS FOR:
**1-on-1 INTERACTIONS**

<table>
<thead>
<tr>
<th>More Associated w/</th>
<th>More Associated w/</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Reaction</td>
<td>Lateral Reactions &amp; Yielding</td>
</tr>
</tbody>
</table>

### Key Findings:

**Stimulus - is a Vehicle Driver or Stationary Object**

- \( \beta = 0.642 \)  
- \( \text{sig.} = .486 \)

**Reactor - is a Driver**

- \( \beta = -0.479 \)  
- \( \text{sig.} = .237 \)

**Reactor - is a Pedestrian**

- \( \beta = -0.489 \)  
- \( \text{sig.} = .177 \)

**Stimulus - is a Bicyclist or Pedestrian**

- \( \beta = \text{reference} \)  
- \( \text{sig.} = .000 \)

**Stimulus - is a Bicyclist**

- \( \beta = \text{reference} \)  
- \( \text{sig.} = .000 \)

**Vehicle Drivers and Stationary Objects are the most likely to instigate a reaction.**

**Vehicle Drivers are the least likely to react to interactions.**

**Bicyclists are the most likely to react to interactions.**
COMPARATIVE CASE STUDY: Results

More Associated w/ No Reaction

- Bicycle Lane Buffer Present
- Landscape Strip Present
- Driveway Present

More Associated w/ Lateral Reactions & Yielding

- On-Street Bicycle Lanes
- Bicycle Lane Present

Spatial Variables

Temporal Variables

Behavioral Variables

- Stimulus - Correct Lane Use (constant)
- Reactor - Correct Lane Use (constant)
- Reactor - Allowed Lane Use
- Reactor - Incorrect Lane Use (omitted from graph)

Participant Characteristics

- Reactor - is at Work
- Reactor - is a Bicyclist (constant)
- Reactor - is a Pedestrian
- Reactor - is a Driver

Stimulus - Reactive Incorrect Lane Use

Stimulus - Reactive

Stimulus - Has Object

Stimulus - is at Work

Key

- Significant
- Non-Significant

- No Reaction
- Some Reaction
RESEARCH APPROACH

With all this new data, do we know if we are achieving goals?

Which type of bicycle lane best meets the **goals** it was designed to achieve?

- Safety
- Mobility
- Access
## EVALUATION: Spatial Variables

<table>
<thead>
<tr>
<th>Variable</th>
<th>Safety</th>
<th>Mobility</th>
<th>Access</th>
</tr>
</thead>
<tbody>
<tr>
<td>On-Street Bicycle Lane</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bicycle Lane Present</td>
<td>(-)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BL Buffer Present</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Landscape Strip Present</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
</tr>
<tr>
<td>Driveway Present</td>
<td>(-)</td>
<td></td>
<td>(+)</td>
</tr>
<tr>
<td>Dumpster Present</td>
<td>(-)</td>
<td>(-)</td>
<td></td>
</tr>
</tbody>
</table>
EVALUATION: Design, Use and Users

- **On-Street Bicycle Lanes:**
  Fewer interactions, mostly 1-on-1 interactions, but higher statistical likelihood for interactions resulting in reactions.

- **Bicycle Lane Buffers and Landscape Strips:**
  Extra space is good for safety, mobility, and access!

- **Time of Day:**
  Street designs perhaps better accommodate “no reaction” interactions during commute times, but functionality reduces during the day when the street use is more diverse.

- **Legal Lane Use:**
  A person who is simply using their travel lane can be a stimulus of a lateral reaction in another person legally using their lane. This should not be happening so much...

- **Transport Mode:**
  Bicyclists are reacting the most, indicating an issue with objective/subjective safety and/or that the roadway design is not providing enough capacity for different mode users.
“The main challenge to investigating the functionality of bicycle facilities along street segments is that *urban street are not only transportation facilities, they are public spaces.*”

**RESEARCH OUTLOOK**

- **Evaluation of Case Study Sites:**
  This method and findings can be used to evaluate the existing bicycle lanes and generate design standards and traffic regulations to avoid undesirable/unsafe interactions.

- **Inform Existing and Future Research on Bicyclists’ Interactions:**
  Future research can investigate how road users perceive the discovered interactions to identify those with the greatest impact on subjective safety.

- **Inform Understanding of User Behavior in Other Contexts:**
  The grounded theory-driven observational method can be used to investigate interactions/behaviors on other types of infrastructures and public spaces.

- **Provide Insights into Impacts of Emerging Micro-mobility:**
  Exploratory studies using this method can be used to help us understand how e-scooter user behaviors; how they use the roadway and how they interact with other mode users.
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cat.silva@tum.de

Thanks!

All photographics and graphics contained in this document were taken or made by Cat Silva.